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edited by
Barry F. Beck
Georgia Southwestern College
Americus, Georgia 31709
U.S.A.

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Edited by
Barry F. Beck
Department of Geology
Georgia Southwestern College
Americus, Georgia, 31709, U.S.A.

EDITOR'S REMARKS

At the onset of this task of editing the Proceedings of the Eighth International Congress of Speleology, it was necessary to establish some priorities. The organizing committee generally agreed that a pre-published volume was much more useful than a more detailed account of the Congress which might be delayed three or four years waiting for all the contributors to respond. Further, it was agreed that cost was to be kept to a minimum while meeting our pre-publication deadline. The editor felt that languages other than English ought to be represented where possible to make the new scientific advances herein available to the largest audience possible. Finally, I found that the resources were not available to rewrite or redraft any contributions.

The preparation of the manuscript for photoreduction required retyping all papers to a common format on oversized paper. The typing was done by Terry Looney, Pat Morgan, Mattie Walton, Liz Smith, and Sally Shell. A special thanks goes to Peggy Palmer who typed a number of manuscripts in French, which none of the other typists were familiar with, and who volunteered her valuable services to the Congress gratis.

The layout of the illustrations was the work of Camille DeShazo, Lola Carlisle, and Erik Beck. Printing was done by Gammage Print Shop, Americus, Georgia.

The preparation of the final version was done as carefully as possible within the constraints of time and budget. I realize that numerous typographical errors occur in this volume. When you realize that each reduced page herein represents seven to eight original manuscript pages, the number of typing errors is more acceptable. Of course, final responsibility for all errors rests with the editor.

I would like to thank all the people who worked on these volumes for their dedicated and conscientious efforts. Special recognition must go to Terry Looney, Pat Morgan, and Camille DeShazo who accepted their jobs not as part-time work, but as professional responsibilities and who worked accordingly.

For scientific knowledge to be acceptable it must be both timely and widely accessible. By prepublishing these volumes in multiple languages I hope my staff and I have met both these criteria.

Barry F. Beck, Editor
Geology Department
Georgia Southwestern College
Americus, Georgia, 31709, U.S.A.

ORDERING INFORMATION

Additional copies of this two volume set will be available from the N.S.S., Cave Avenue, Huntsville, Alabama, 35810, U.S.A., at a cost of $48.00 per set, postpaid (surface mail). We would appreciate it if all participants would bring this to the attention of their University or Geological Survey library.

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Equilibrium Versus Events in Blind Valley Enlargement

J. N. Jennings, Bao Haosheng and A. P. Spate
The Australian National University, Canberra, Australia

Abstract

The hypothesis that blind valleys will match sinking stream erosive power was tested with a small assemblage at Yarrangobilly, New South Wales. Only a 40% statistical explanation of while blind valley volume in terms of streamsink basin area was obtained; even for this certain anomalous and extreme cases had to be excluded. The volume depends also on age of underground capture and its timing is irregular because of the contradictory operation of erosive power, antagonistic to capture till it occurs, thereafter promoting incision at the sinking point.

Résumé

L'hypothèse que les vallées aveugles alleront avec la puissance de dégradation des fleuves engouffrés est mis a l'épreuve avec un petit assemblage à Yarrangobilly, New South Wales. Seulement une explication statistique de 40% s'établit que le volume entier de la vallée aveugle est en accord avec l'aire de drainage au dela de la perte; même pour ceci des cas anomales et extrêmes doivent être exclus. Le volume depends aussi de l'âge de l'engouffrement et son règlement est irregulier à cause de l'effet contradictoire de la puissance de dégradation, contraire à la capture jusqu'elle est achevée, ensuite avancant l'incision à la perte.

In recent decades, geometric relationships established between morphometric characteristics of river basins and between them and river behaviour have been interpreted as dynamic equilibria. The same theme has been carried into karst geomorphology, and the idea has developed that karst landforms evolve in a manner akin to the modelling of fluvial relief. Streamsinks and blind valleys have been investigated along these lines (Williams, 1966; White & White, 1979). Consistent with this work is the hypothesis that dynamic equilibrium will be achieved between the size of a blind valley and the energy of the sinking stream which has produced it. At Yarrangobilly Caves in New South Wales the incision which has taken place since certain streams went underground can be identified and this hypothesis can be tested here.

This karst is a meridional strike belt, about 9 km by 1 km, of Silurian limestone, chemically pure, mechanically strong and of low primary permeability, with a strong dip to the west. The limestone forms a strath terrace between a ridge of underlying volcanics to the east and one of overlying impermeable clastic sediments to the west (Figure 1). The Yarrangobilly River occupies a V-valley or gorge, about 30 m deep where it encounters the limestone and over 150 m deep where it leave it at the southern end. This lies mainly along the western margin of the limestone with only a narrow strip of limestone on the west bank or none at all.

There are seventeen blind valleys in the sense that a perennial or intermittent stream channel ends against a threshold and goes underground. None is large but the range in size is considerable; some are simply dolines with a stream running into them. They are mainly found where streams run off the volcanics to the east onto the limestone strath. Only one is found to the west of the gorge where the limestone is narrow. The situation is more complex at the northern end of the strike belt where the Yarrangobilly River crosses the strike belt down dip and the outcrop is broken.

Estimates of the volumes of these blind valleys have been made from either contoured maps in a few larger cases or survey traverses and cross-sections for the majority. There may be errors as great as 20% in these estimates but a case has been made for regarding their use in the present context as valid (Jennings, Bao & Spate, 1980).

It is necessary to enquire whether the drainage basins truncated by underground capture have themselves maintained quilibria such as characterise normal fluvial systems. Long-term discharge data are not available so only morphometric relationships can be tested. Application of Strahler ordering gives the usual results from standard morphometry (Jennings, Bao & Spate, 1980). The regression of total stream lengths (L in km) against basin area (A in km^2) in these truncated catchments takes a form typical of normal systems.

$$L = 2.24\ A^{1.13} \qquad P = 0.001 \qquad r^2 = 0.95$$

The closed river basins from the Appalachians studied by White & White (1979) do not correspond completely in definition to the Yarrangobilly ones, some being composite in nature; nevertheless they yield a basically similar regression.

$$L = 2.29\ A^{0.85} \qquad r^2 = 0.88$$

Amongst other factors, stream erosion depends on discharge and velocity, long term measures of which are not available for the blind valley streams. Basin area has been selected as a surrogate for stream discharge; close relationships have been established elsewhere between that area on the one hand and mean annual flood and mean annual runoff on the other. Schumm's relief ratio is a convenient basis for comparison of gradients between catchments. Since withdrawal of material into caves at streamsinks will also affect blind valley size, underground hydraulic gradients were calculated on the basis of altitudes of the streamsinks and their connecting springs and the straightline distances between them.

Surveying of the blind valleys for this enquiry brought to the fore complexities, the existence of which was known but the significance not appreciated. One complexity is that the point of sinking has shifted in some cases and another is that terraces and breaks of slope reveal separate phases of incision which have succeeded one another in the formation of the blind valley. Figure 2 is a sketch map of a blind valley affected in both ways. Two blind valley volumes were calculated therefore:

(1) present incision related to the present position of the streamsink and/or the last phase of incision,
(2) total incision defined by the saddle beyond which there is an overall downward gradient in the abandoned dry valley continuing from the streamsink.

Logarithmic plots of blind valley volumes for both present and total incision against both basin relief ratio and underground hydraulic gradient show a wide scatter in all cases with no prospect of significant regression. There is, however, no great range in these two gradients in this set of catchments and any effects they may have will be readily obscured by other factors.

There is a considerably greater range in basin area above streamsink. Even so when blind valley volume for present incision is plotted against it, again on a log-log basis (Figure 3a), the scatter remains as great and there is no significant relationship between the two.

The implication of these results is taken to be that the times when the different streams started to excavate these volumes of rock have varied so much as to prevent the dynamic factors controlling erosion from expressing themselves in the morphology in the manner hypothesised. Events have taken the upper hand and equiligrium not achieved.

However, the periods of time for the whole formation of the blind valleys may have varied less than the ages of the final events registered in the landforms. The more time there has been for the influence of the overall relief and geological structure to operate the more it could even out other effects. Figure 3b is a log-log plot of the total volume of the blind valleys against the stream basin area and it gives better indication of a linear relationship. Moreover the four instances which depart most from this tendency are special cases which warrant exclusion from the set.

(a) Northernmost Blind Valley (NBV) is hardly more than tangential to the short northern boundary of the limestone, a disposition different from that of the majority of the blind valleys. Moreoever there is a likelihood that this may be a semi-blind valley where surface flow follows round the margin of the limestone on occasion.
(b) Wombat Creek (WC) is also distinctively located structurally, with much of its headwater area being on limestone; its lower valley runs along the contact of the limestone with the overlying impervious clastics.
(c) Mill Creek (MC) has cut a gorge across the limestone and its streamsink close to the Yarrangobilly River

has been triggered by a geologically recent rockfall, even though there is a little incision associated with its underground route through the bedrock.

(d) Rules Creek (RC) has also cut a gorge across the limestone. It has terrace remnants witnessing a longer, more complex history than Mill Creek's but its blind valley volume is small because of a recent cut through a former higher threshold.

If these four cases are excluded, the remaining set of 13 blind valleys have a common structural arrangement with non-karst rocks in the headwaters and limestone in the lower basin. For these a significant regression can be obtained.

$$V = 46724\ A^{1.36} \qquad r^2 = 0.40 \qquad P = 0.025$$

where V = blind valley volum in m^3 and A = basin area above streamsink in km^2. Thus there is a tendency for a stream sinking underground here to produce a blind valley of a size matching its erosive power.

Nevertheless this tendency is largely obscured by the variable timing of the underground captures. The streams have not had equal opportunities to achieve dynamic equilibrium since their drainage system was dislocated in this way. Details of geological structure are likely to have contributed to this but also the dynamic factors involved operate in contradictory fashion. Thus the bigger the stream is the more it will prevent or delay complete underground capture, although from the moment this happens the same factor will foster a larger blind valley. At Yarrangobilly this is evident when the stream is related to its opportunity for capture. Two ratios were calculated as measures of this for all streams which encounter the limestone:

(1) $$\frac{\text{length of present and/or former streamcourse over limestone}}{\text{whole length of streamcourse}}$$

(2) $$\frac{\text{straight line length across limestone}}{\text{basin length}}$$

The lower these ratios are the less the opportunity there is for a stream to form a blind valley.

The Yarrangobilly River itselv, which crosses the limestone over three reaches, has low values; it only loses parts of its flow underground, most strikingly at the Natural Bridge, where however high flows follow the meander bend bypassed by the baseflow.

Two tributaries with low ratios, Brownleys Back Creek and Traverse Creek, flow across their limestone reaches. The latter does so only in flood flow but it has not formed even a semi-blind valley. It was given its name by speleologists because it alone crosses the full width of the limestone strath on the surface.

Of the blind valleys, the lowest values are those of the Northernmost Blind Valley creek, Mill Creek and Rules Creek, thus helping to explain why these blind valleys are anomalous. The last two are the largest streams to have blind valleys and their size enabled them to evade underground capture till late and to cut gorges across the strath.

The factor of gradient, which failed to find expression in the analysis of the blind valley volumes, also operates contradictorily. Thus, although steep gradient is properly expected to enhance blind valley growth once capture occurs, it also promotes runoff and restrains engulfment of streams. Of six right bank tributaries in the Yarrangobilly gorge, only one has a blind valley. Of the other five, two have low limestone total course ratios which are unfavourable to engulfment. Of the other three which are not explicable on that count, two have high basin relief ratios, which explain their behaviour. At the other end of the scale, low gradients are also not conducive to underground capture and this factor contributes to the failure of the Yarrangobilly River to sink completely along its long course over the limestone; meander spur cutoffs offer the best opportunity here.

These several factors greatly vary the timing of captures so that only modest indications of dynamic equilibrium can be identified at Yarrangobilly. A capture represents an intervention in a fluvial system which is likely to derange morphometric relationships. Howard (1971) introduced capture simulation into computer modelling of surface river networks and improved morphometric prediction compared with the use of completely random walk models. Perhaps a larger population of blind valleys may provide a basis for more positive conclusions than Yarrangobilly does for the kind of study presented here.

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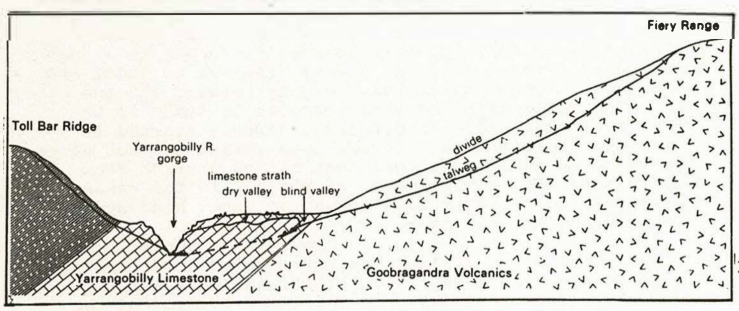

Figure 1. Schematic section across the Yarrangobilly River valley, N.S.W. V.E = 3X.

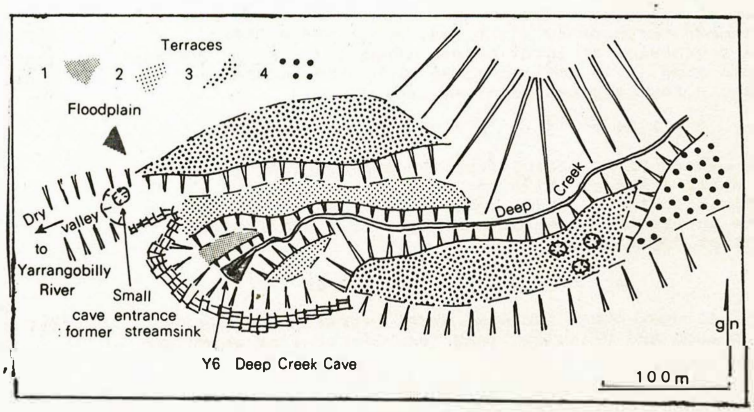

Figure 2. Shifting streamsink and phasing of incision, Deep Creek, Yarrangobilly.

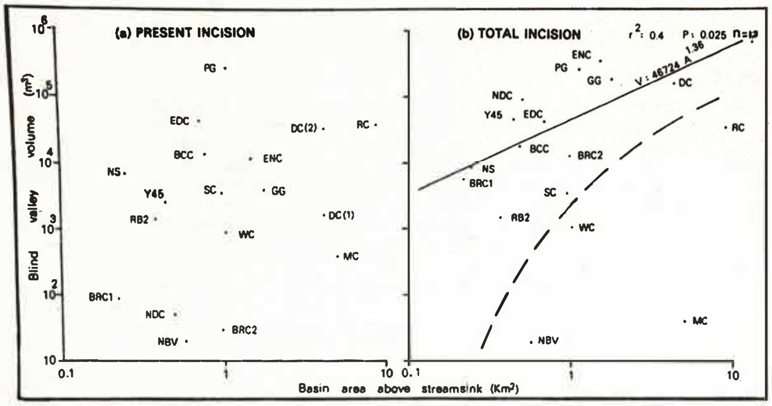

Figure 3. Scatter plots and regression of blind valley volume against basin area above streamsink, Deep Creek, Yarrangobilly.

The Community Structure of Arthropods Associated with Bat Guano and Bat Carcasses in Tumbling Creek Cave, Missouri

Barbara J. Martin
334 Sunnyside Ave., Apt. #1, Ottawa, Ontario, KIS/OSI, Canada

Abstract

The community structure of arthropods associated with bat guano and bat carcasses is examined in Tumbling Creek Cave, southern Missouri.

Bat guano is the most abundant food resource in the cave. Sixty-seven species of arthropod were collected during a year's sampling. There was a high degree of local patchiness of distribution. There was no discernible seasonality at the community level of total number of species, total density or total biomass. There was a successional sequence of arthropods associated with the decomposition of guano and carrion.

Dominance was high both in terms of number and biomass at all times and sites. Mites predominated on the guano piles in terms of number of species and relative abundance. A few species were consistently dominant: within the guano - the fungivorous mite, Polyaspis sp., and the pseduoscorpion, Hesperochernes occidentalis; on both fresh guano and fresh carrion - the predatory mite, Erynetes sp.; and at areas away from high concentrations of guano - the fly, Bradysia sp., and the collembolan group, Arrhopalites spp. The flies and the Collembola appear to be excluded from high concentrations of guano (i.e. guano piles) through predation.

The decomposition of carrion in the cave differed from that of epigean carrion in three main respects: The prominence of Collembola and the absence of Hymenoptera, the prominence of fungi, and the great prolongation of decomposition in the cave.

Résumé

La structure de la faune d'arthropodes associée avec le guano et les carcasses de chiroptéres dans la grotte de Tumbling Creek, au sud du Missouri, a été examinée.

Le guano de chiroptéres est la source la plus abondante de nourriture dans la grotte. Soixante-sept espéces d'arthropodes ont été recueillies durant une année d'échantillonnage. La distribution des animaux était trés variable sur les distances courtes. Il n'y avait aucune évidence des changements de saison au niveau de nombre total d'espéces, de densité totale, ou de biomass totale. Il y avait une succession d'arthropodes associée avec la dédomposition de guano et de carcasses.

La dominance était élevée en termes de nombres et de biomasse, partout et indépendemment du moment. Les acariens ont prédominé sur les amoncellements de guano en termes de nombre d'espéces et d'abondance relative. Quelques espéces étaient presque toujours dominantes: dans le guano - l'acarien fungivore, Polyaspis sp., et le pseudoscorpion, Hesperochernes occidentalis; dans le guano frais et dans les carcasses fraîches - l'acarien de proie, Ereynetes sp.; et aux endroits éliognés des grandes quantites de guano - la mouche, Bradysia sp., et le groupe de collemboles, Arrhopalites spp. Les mouches et les collemboles parraissent exclues des grandes quantités de guano (i.e. les ammoncellements de guano) par la prédation.

It existe trois différences majeures entre la décomposition de carcasses dans la grotte et la décomposition au dehors: l'importance de la Collembola et l'absence de la Hymenoptera, l'importance des mycétes, et la grande prolongation de la décomposition dans la grotte.

The Control of Karst Development with Reference to the Formation of Caves in Poorly Soluble Rocks in the Eastern Transvaal, South Africa

J. Martini
Geological Survey, Private Bag X112, Pretoria, Republic of South Africa

Abstract

Caves are described in quartzite and barytes. In quartzite weathering progresses along joints and bedding planes, leading to general arenisation without development of karst topography, except in a few places where caves can develop by piping. In barytes, a small but typical solution cave is described from the Barberton Mountain Land. The fact that caves purely due to solution may form in barytes and not in silica rocks, although the former is less soluble that silica, gives some clues about a general rule of the control of karst development. It is suggested that the kinetics of dissolution may be a more important factor that solubility. Because the solution of quartz is extremely sluggish, dissolution in quartziet occurs along crystall boundaries, a process which leads to arensisation. In barytes, a mineral with a fast rate of solution although its solubility as such is very low, in contrast dissolution along crystall boundaries is not possible due to rapid saturation. Dissolution in this case is limited to larger voids like joints and bedding planes which appear to be an essential condition for karst development. It is suggested that if the dissolution rate of silica and silicates were faster, without increase in solubility, karst topography would develop extensively on quartzite, sandstones and possibly also on granite.

Résumé

Des phénomènes karstiques sont décrits dans des quartzites et des barytines de l'Est du Transvaal, Afrique du Sud. Les grottes dans les quartzites se forment par action chimique météorique le long des diaclases, suivi par excavation mécanique. Dans la barytine elle se sont essentiellement formées par dissolution, quoique la solubilité de ce dernier mineral soit inferieure à celle du quartz. On suggère que la vitesse de dissolution explique cette anomalie apparente et représente un facteur important dans le développement des karst en général.

Most of the caves of karst origin occur in rocks considered as "soluble", essentially limestone, dolomite, gypsum and salt. However, they are also found occasionally in "insoluble" rocks like quartzite, sandstone, granite and barytes. The genesis of the latter is of particular interest for the understanding of karst development in general.

In the eastern Transvaal, in high rainfall areas, caves occur sporadically in quartzite of the Black Reef Formation and of the Chuniespoort Group. They are comparable to quartzite caves elsewhere in the world, particularly in Venezuela (Zawidski, et al., 1976). The quartzite karst of the eastern Transvaal has already been published (Martini, 1979, 1981) and therefore it will be only briefly described here. It is best developed 7 km north of Kaapsehoop, where the surface morphology is characterized by large dolines and fields of pinnacles; the cave systems consist of irregular passages and chambers developed immediately adjacent to the contact of an interlayered shaly bed of volcanic ash acting as an impervious horizon very close to the base of the Black Reef. As it has been observed elsewhere in the world, the caves develop close to cliff faces.

A very small solution cave in barytes occurs in an area of high rainfall, on the farm Schoonoord 380 JU, at the point 31°06'42"E/25°52'22"S, in the Barberton Mountains, eastern Transvaal. In the Fig Tree Group (3 400 My) barytes forms two sedimentary layers, slightly overturned and dipping steeply. In these two beds the cave has been intersected by a small mining excavation at a depth of about 10 m. It consists of several narrow anastomoses showing corrosion figures typical of solution caves and with residual material accummulated on the floor (Fig. 1).

The genetic model adopted for the formation of quartzite caves is by initial weathering along joints and bedding planes, transforming quartzite into soft "neosandstone" in which caves develop by piping in a vadose environment (Martini, 1979). A karst topography cannot form on quartzite by dissolution alone as it is the case for carbonate rocks. Mechanical removal of quartz grains (piping) is essential for the appearance of such a morphology. As this process is restricted to specific areas, generally small, the great majority of the landforms on quartzite, on sandstone and on granitic rocks do not exhibit any karst characteristics. Most generally, weathering of quartzite leads to arenisation followed by surface erosion, without development of caves. The fact that arenisation is characteristic of the weathering of quartzite is mostly due to the extremely slow rate of silica dissolution (Siever, 1962), which therefore can act not only along joints, as it is the case for carbonate rocks, but also along crystal boundaries (Fig. 2). The voids along these boundaries are extremely thin and consequently water, due to its vicosity, can circulate only very slowly: saturation is achieved after a short distance unless the kinetics of reaction is very sluggish. It has been suggested that if the rate of silica solution would be faster, without change in solubility, a karst morphology would develop on quartzite and possibly also on granite thus changing considerably the earth sceneries (J. Martini, 1979). Such conditions may have existed during archean time, when the surface temperature was possibly much higher than today (Knaut et al., 1978) or on other hypothetical planets characterized today by dense hot atmospheres, thus increasing both the rate and the solubility of quartz dissolution.

The idea that the kinetics of dissolution is an important factor is confirmed when considering that true solution caves can exist in barytes and not in quartz rocks, although the former is less soluble (0,01 millimole/litre) than the latter 0,1 - 0,2 millimole/litre). The explanation is that the rate of barytes dissolution is several magnitudes higher than for quartz (Blount, 1977) and that therefore in barytes dissolution can occur only along joints, a necessary condition for the development of solution caves. The restricted number of caves in barytes is probably simply due to the scarcity of barytes outcrops, compared to the large surfaces occupied by carbonate and silica rocks. If barytes would be as common as carbonate rocks, caves, dolines and lapiés would certainly occur much more frequently. However, as the solubility of barytes is very low, it would be essential that the rate of surface erosion would be inferior to the rate of karst dissolution, which is realized where the relief is not too accentuated and the vegetation cover well developed.

Speculating further, it is possible to immagine a theoretical case of a mineral with a solution rate so fast that the enlargement of joints and bedding planes would not be possible and that dissolution would occur only at surface, thus preventing karst formation. Therefore it appears that there is a dissolution rate interval which is optimum for karst development: not too fast, not too slow (Fig. 2). The case of carbonate rocks is interesting as it is in fact exceptionally davourable for the formation of cave systems deep below surface, not only because the rate of dissolution is such that enlargement can occur along joints and not along crystal boundaries, but also because of the slow rate of atmospheric carbon dioxide absorption by water. Thanks to this last property, it is possible that the dissolution of carbonate can persist for along time provided that the water remains in contact with air containing carbon dioxide (Jennings, 1971).

In dolomite, dissolution is observed along crystal boundaries (Martini et al., 1976) although the effect is not as marked as in quartzite. This is probably largely due to the slow rate of dolomite dissolution, alower than for calcite (Holland et al., 1964), although the strength of the bond between crystals may also be a factor.

In conclusion it appears that the real control of karst development is not only the solubility, as karst features may occur on rocks which vary from very soluble (salt) to nearly insoluble (barytes), but also the rate of dissolution which seems to be another major factor to consider.

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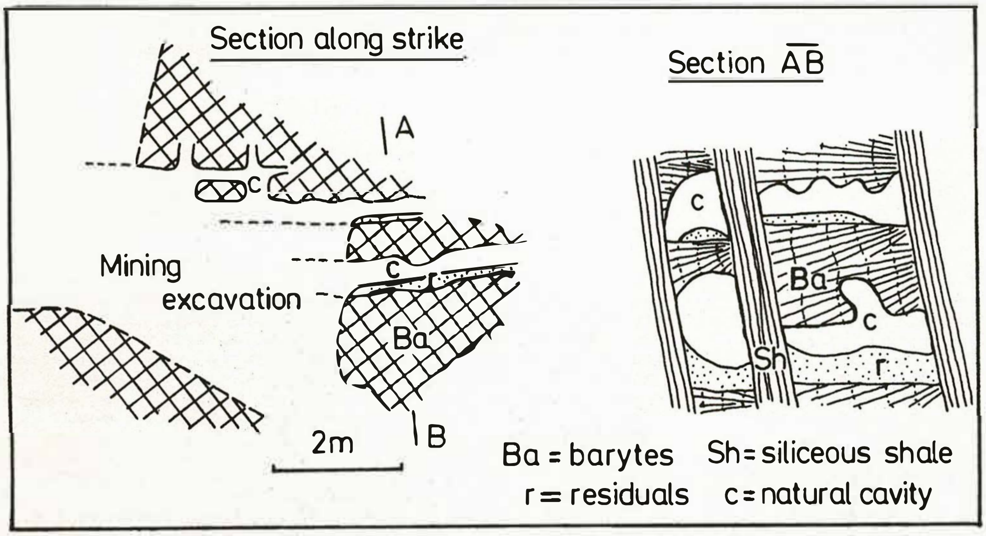

Figure 1. Cave in barytes on Schoonoord, Eastern Transvaal.

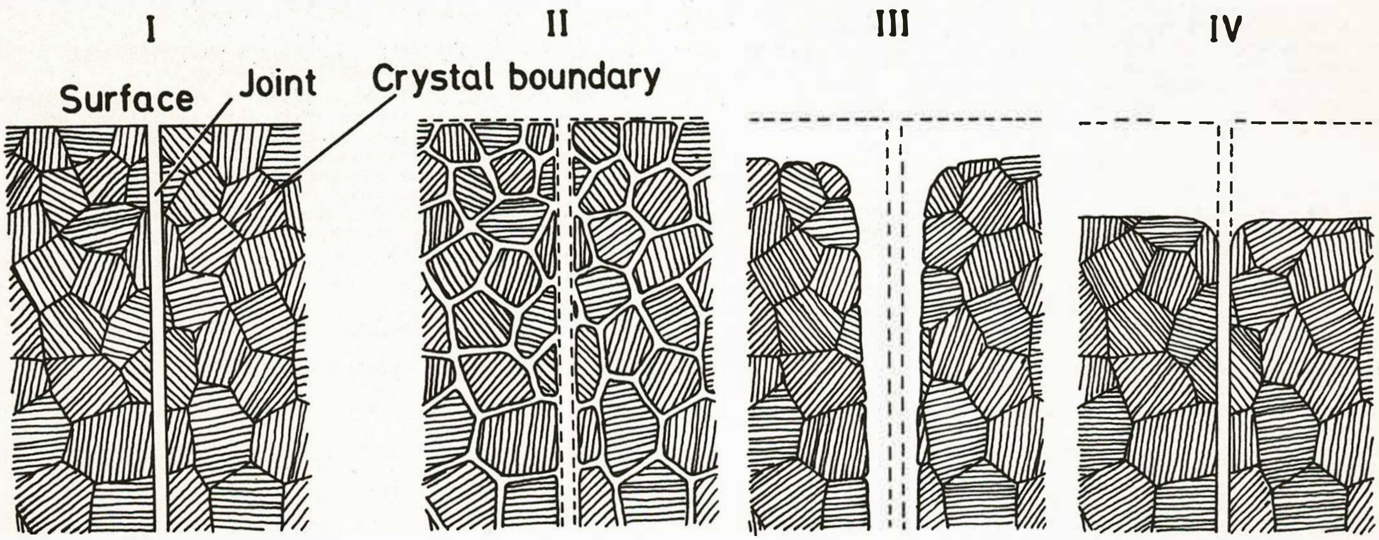

Figure 2. Schematic models of karst evolution according to rate of dissolution. I. Model before dissolution; II. Case of very slow rate of dissolution; note removal of matter evenly distributed from original void (surface, joint and crystal boundaries). III. Case of medium dissolution rate; the dissolution at surface is maximum; it decreases slowly with depth along joint, rapidly along crystal boundaries; only in this case enlargement of the joint is effective enough to form cavities in depth. IV. Case of high rate: dissolution is mostly effective at surface.

Early Proterozoic Paleokarst of the Transvaal, South Africa

J. Martini
Geological Survey, Private bag X112, Pretoria, Republic of South Africa

Abstract

Numerous well preserved paleokarst features occur at the top of the Malmanie Dolomite and appear to have formed before the deposition of the Pretoria Group clastic sediments. They are especially well developed in the Western Transvaal where they have been the host for fluorspar, zinc and lead mineralization and where they have been exposed by mining. These features include paleocaves filled by residual chert and shale, forming extensive networks of phreatic passages, and breakdown chambers with terraced ceilings and scree accumulated on their floor; breccia bodies and "pitch-and-flat" structures represent completely collapsed chambers. Ancient surface features are marked by an irregular layer of chert breccia resting on the top of the dolomite and by paleosinkholes. Intense local deformation and brecciation in the Pretoria strata are linked to late compaction and late collapse of caves.

The shale and chert filling associated with the paleokarts features represents the residuals left after dissolution of the dolomite. Compared with recent karst residuals, it is depleted in iron and manganese, and is enriched in carbon. This indicates a reducing environment during karst development, which is in agreement with the concept of an atmosphere still deficient in oxygen during the early Proterozoic.

Résumé

L'auteur décrit un paleokarst vieux de 2.200 my. Les formes observées consistent en paléodolines, en complexes réseaux de galeries et en salles d'effondrement. Le remplissage résiduel est représenté actuellement par des argilites impures et siliceuses, caractérisées par una teneur elevée en carbone et une déficient en Mn et Fe, ce qui indique que le karst s'est développé dand un environnement pauvre en oxygène.

Geological Setting

The paleokarst features described in this paper are linked to the disconformity separating the Chuniespoort Group form the Pretoria Group, of early Proterozoic age. The Chuniespoort Group includes the thin Black Reef Quartzite at the base, followed by the Malmanie Subgroup, 1500 m of Fe-Mn rich dolomite with bands and nodules of chert, and the Penge Formation at the top, consisting of banded iron formation. The Pretoria Group consists of several thousand metres of shale with intercalations of quartzite and lava. Most of the strata of these two groups are disposed in a 500 km long oval basin located in the south-western Transvaal and show generally shallow dips. These strata are strongly indurated and in places display contact metamorphism. The disconformity mentioned previously never exceeds a few degrees but nevertheless it cuts progressively across the entire succession of the Chuniespoort Group. The age of this disconformity is about 2 200 my (Button, 1973). The paleokarst features are developed in numerous places, but they are particularly spectacular south of Zeerust, western Transvaal, where they are associated with fluorspar, lead and zinc sulphides (Martini, 1976).

Paleokarst Features

Where the Pretoria Group is directly resting on the Malmanie Subgroup, an irregular layer of chert breccia marks the base of the former, representing the paleoresiduals left after the dissolution of the dolomite, also known as the Giant Chert.

Paleosinkholes are most generally represented by abrupt thickening of the Giant Chert developing as pockets protruding deeply down into the dolomite. Where the Penge Formation is still present but reduced to a few metres, it was not thick enough to prevent percolation of rain water from reaching the dolomite and karst dissolution developed below cover, inducing local saging of the banded iron formation. Such palaosinkholes, where remnants of Penge Formation are overlying the paleoresiduals are frequent south of Zeerust (Fig. 1). In many paleosinkholes it is possible to observe that the shale of the Pretoria Group is also involved in the saging process, showing intense small scale chaotic folding, having obviously occurred when the sediment was still soft. This indicates that after the transgression of the sea of the Pretoria Group, differential compaction of karst residuals and collapse of caves took place.

A peculiar paleosinkhole occurs south east of Zeerust, on the farm Rhenosterhoek 343 JP. It consists of a pipe filled with mudstone breccia in a matrix of similar lithologic composition (Fig. 1). This represents a typical paleoresidual and the genesis of this pipe can be attributed to a karst pond into which residuals were washed, accompanied by intermitent periodical subsidence brecciating the deposited sediments.

Paleocaves are generally characterized by their residual filling forming elongated bodies of siliceous mudstone. In some favorable cases, where the topographic surface cuts the paleocave system along its plane, complicated networks of "paleo passages" are exposed (Fig. 2). It seems that the ancient passages were dominantly flat, their shape being essentially controled by bedding planes, which is in sharp contrast with the shape of the passages in modern dolomite caves of the Transvaal, which are nearly exclusively joint controlled. This can be explained by the fact that at the time of the formation of the paleokarst, the dolomite was not indurated but was a soft, poorly jointed rock. At one locality on the farm Strydfontein 326 JP, a paleocave channel filled with quartzite occurs. This is an example of a cave filled by clean marine sand from the base of the Pretoria Group (Pologround Member).

Large chambers developed by ceiling breakdown are also present. The exhibit terraced ceilings and cones of debris accumulated on their floors. They have been subsequently filled by fluorspar which has been mined, thus restauring in their original state these caves which rank among the oldest in the world (Fig. 3).

Nature of the Residual and Interpretation of the Paleokarst Environment

The residual filling consists of shale and massive mudstone, grading to impure chert when the silica content is high. Its colour is often black due to finely disseminated graphite which is inherited from the dolomite. When the carbon content is low, the rock may exhibit a vivid green colour due to a chromiferous phengite. Rutile is a frequent accessory mineral. According to eleven analyses, the chemical composition of this material is as follows:

	Average	Range	
SiO_2	74,92	48,09-	96,52
TiO_2	0,66	0,13-	2,10
Al_2O_3	11,49	2,49-	28,22
Fe_2O_3*	1,29	0,09-	4,12
MnO	0,04	0,01-	4,12
MgO	3,00	0,10	13,67
CaO	0,52	0,07-	1,97
K_2O	3,67	0,09-	9,74
C	0,99	0,14-	4,53

*Probably mostly as FeO

The origin of the high Ti-Cr content is probably linked to detrital minerals like chromite and ilmenite from the Archean greenstone belts. These mineral may have been concentrated in the tidal environment which prevailed during most of the deposition of the dolomite. They have been subsequently transformed into rutile and chromiferous mica by metamorphism. Actual resistate left after dolomite dissolution, consists of wad and red earth; ten samples of such material average 21,26 % Fe_2O_3 and 11,71 % MnO. Compared with the above average analysis it is obvious that iron and especially manganese are strongly repleted in the paleofilling. Another difference is the high carbon content in the paleofilling (Fig. 4), which however, is slightly lower than in the theoretical residual calculated from dolomite analyses, but is higher than in the wad.

The composition of the paleoresiduals seems to indicate a rather reducing environment for the development of the paleokarst, with an Eh below zero and a pH not higher than (-§. Under such conditions the organic matter is not oxidized, Fe and Mn are reduced to valency two and leached away (Garrels et al., 1965). According to what is observed today, there is a drop of Eh from surface to ground water (Garrels et al., 1965). However in an actual karst system, the drop of Eh below the water-table is not sufficient to lead immediately to a strongly reducing environment. Such a reducing level may exist only in the deepest part of a system, where the water circulate slowly enough to be completely depleted in oxygen by reaction with the rock.

If the atmospheric oxygen level decreases, the reducing zone mentioned above will raise from the deepest part of a karst system and will eventually reach the surface. However it is quite likely that it is not necessary that this oxygen level drops to zero to reach such conditions, especially if the carbonate rock is rich in reducing agents. The nature of the paleokarst filling thus confirms the view that the oxygen level 2 200 my ago was zero (Cloud, 1976) or much lower than at present.

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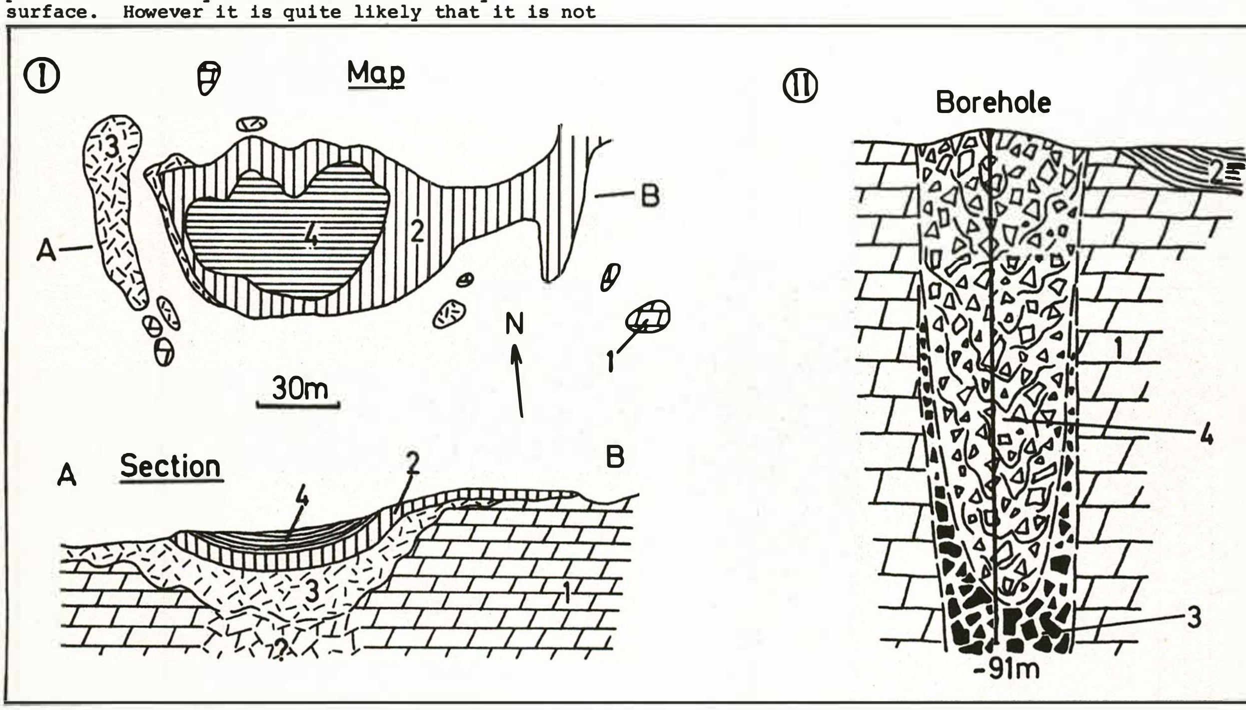

Figure 1. 1. Paleosinkhole on Rhenosterfontein 304 JP;
1) dolomite
2) banded iron formation
3) breccia in black siliceous shale matrix (paleoresidual)
4) shale (Pretoria Group)

2. Paleosinkhole on Rhenosterhoek 313 JP;
1) dolomite
2) Pretoria Group shale
3) dolomite breccia in black shale-mudstone matrix
4) Mudstone breccia in mudstone matrix, black and green.

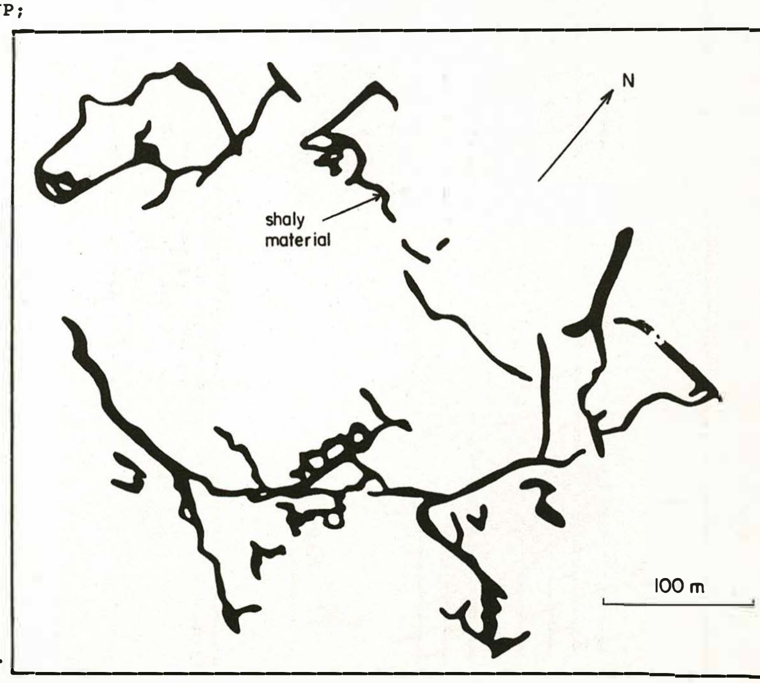

Figure 2. Paleocave passages filled with siliceous shale on southern part of Vaalkopje 111 JO.

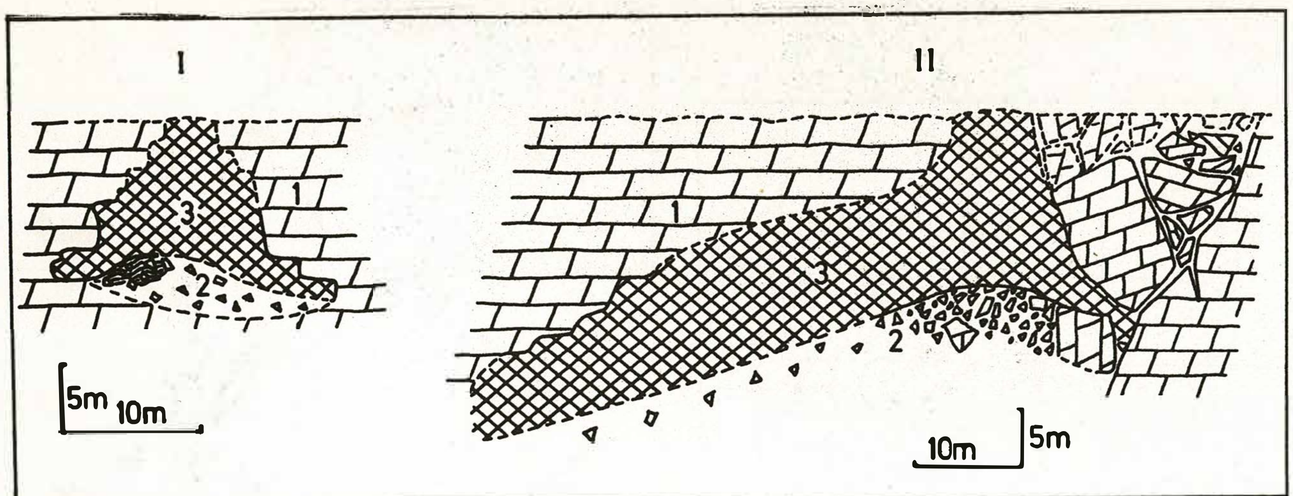

Figure 3. Sections of breakdown chambers filled with fluorspar, mined out. Note terraced ceiling and floor scree. I Blane's Quarry on Buffelshoek 301 JP, II Gubbin's Mine on Dog van Malmanie 333 JP.

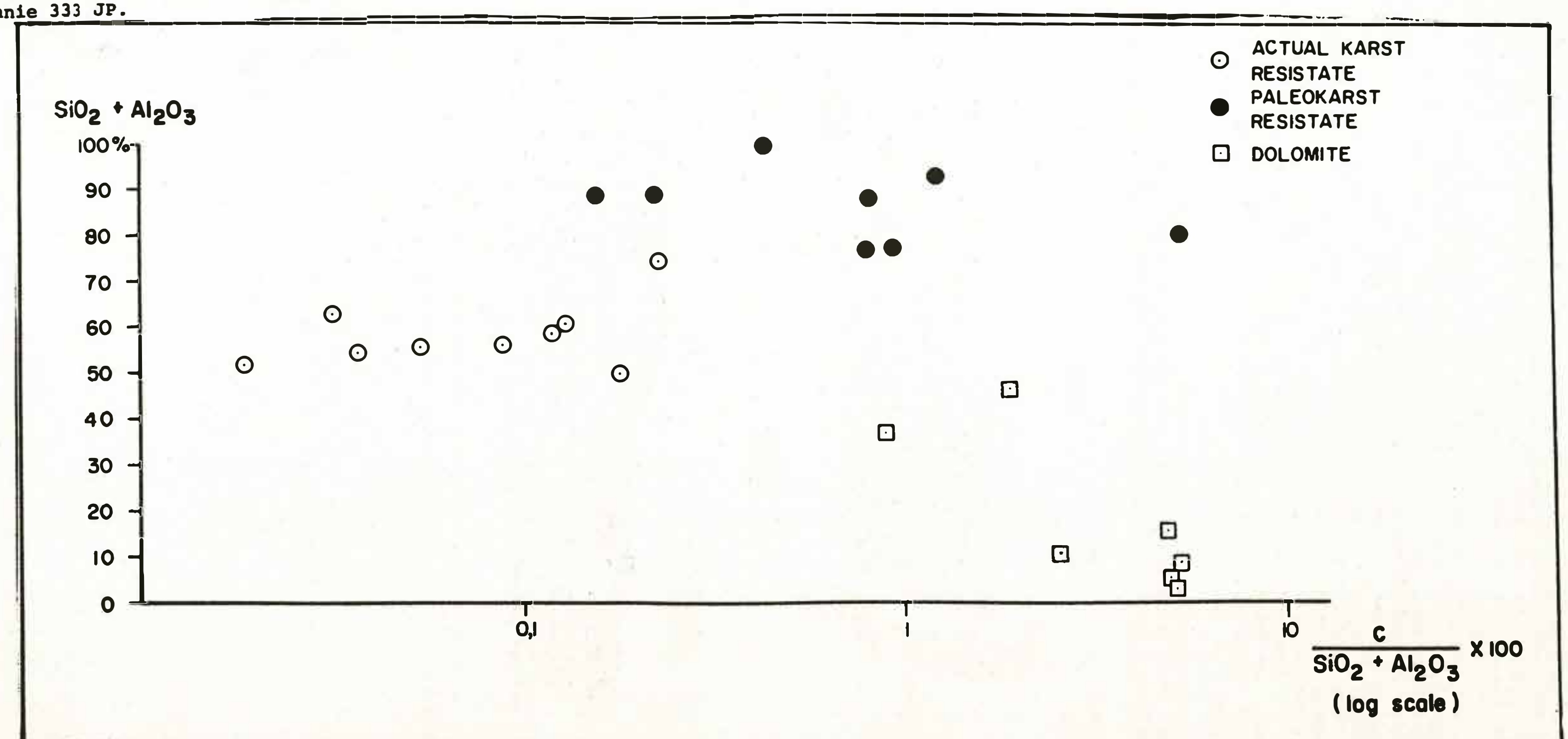

Figure 4. Carbon content in karst residuals.

Evolution of Hypogean Species of Opilionids of North and Middle America

Clarence J. and Marie L. Goodnight
Western Michigan University, Kalamazoo, Michigan 49008

Résumé

La plupart des opilionides qui habitent les cavernes sont membres de la famille Phalangodidae. Les membres de cette famille se trouvent dans les feuilles mortes humides. Ainsi il n'est pas suprenant que beaucoup d'espèces épigées se trouvent a l'entrée des cavernes ou qu'un nombres de ces petites espèces ont évolué dans les habitats de cavernes.

Entre certaines espèces, le rapport entre les espèces epigée et les espèces hypogées se voit aisément. De temps en temps les espèces hypogées son rencontres qui ne semblent pas avoir de rapport avec especes épigée.

Aux Etats-Unis, il y a quelques espèces qui ont leur centre de distribution dans les montagnes Appalaches et sur l'élévation des Ozarks. Au Texas, las cavernes du plateau d'Edward ont des espèces distinctes. Deux de ces espèces sont d'origine du nord et deux de Mexique du Nord.

Un autre complexe d'espèces se trouve dans les cavernes de la Californie. Ces espèces démontrent leur rapport avec l'espèce, main n'ont pas de rapport intime avec les espèces otre de l'Amérique du Nord.

Au Mexique, il y a un assemblage d'espèces au nord et un autre dans la région de Vera Cruz et Oaxaca. Ces espèces ne sont pas bien connues. En Amérique centrale et au Mexique au sud de l'isthme de Tehuantepec, quelques espèces ont été étudiées, mais leurs rapports son difficiles à comprendre.

Otre familles d'opilionides ont les espèce hypogée, mais elles son peu nombreuses et leur distribution es mal connue.

The opilionids or phalangids are abundant invertebrates which are found in a wide variety of habitats and may, at times, become important inhabitants of the cave community.

Popularly, they are known under a variety of names such as daddy-long-legs, harvestmen, Shepherd spiders; scientifically they may be termed either phalangids or opilionids, with the latter name appearing to be somewhat more commonly used.

They are classified as an order, Opiliones, within the larger class Arachnida. They are distinguished from the other members of this large class by the following characteristics:

1. An unsegmented cephalothorax, which is broadly joined to the faintly segmented abdomen.
2. The three segmented chelate chelicerae.
3. The six-segmented palpi.
4. A pair of simple eyes usually located on a tubercle located on the anterior third of the cephalothorax. Eyes may be either partially or totally absent from true troglobitic forms.
5. The genitalia open on the second abdominal segment, usually protected by a genital plate.
6. A pair of scent glands located at the anterior portion of the cephalothorax.
7. Respiration by means of tracheae.

Within the order, two suborders are recognized:

I. The Laniatores: these are tropical and subtropical forms with a few exceptions. This group contains a highly varied assortment of forms in the Western hemisphere which are represented by several families: Cosmetidae, Gonyleptidae, Phalangodidae, Erebomastridae, Triaenonychidae, and Travuniidae. Cave forms have developed within the last four families. So far as is known there are no troglobitic cosmetids or gonyleptids.

II. The Palpatores. This group is represented primarily by long-legged forms which are found in both temperate and tropical regions. Two subgroups are recognized: Dypsnoi and Eupnoi. Among the former group, a few cave adapted forms have evolved.

Relatively speaking, the number of species of truly troglobitic opilionids is small. This is somewhat surprizing inasmuch as the habits of these forms are such that it would seem reasonable that a number could adjust to the cave environment. For example, many may be found within the vicinity of caves, even within the entrances, but still retain their epigeic form. In general, opilionids prefer to dwell in moist, somewhat protected areas--this is particularly true of the smaller forms. The exception to this generalization are some species of long-legged Leiobunums and gagrellinids which are often encountered in relatively drier areas. These, also, under the stress of dry conditions, tend to move inot protected areas to avoid desiccation.

Troglobitic forms developed primarily within those groups whose members are found among the cryptozoic fauna. These small, less conspicuouc forms, are typical members of this highly specialized environment, an environment that tends to be relatively constant in temperature and moisture. In such an optimum habitat, a fauna of possible great antiquity has persisted to the present day. This fact has been born out by our own discovery of members of the genus Caddo in mountainous areas of southern Mexico and the more recent discovery by Briggs of representatives of the family Travuniidae in the Pacific northwest. These latter forms were confined to caves in the moist coastal forest which are characterized by rotting wood or fallen bark within well established stands of spruce and fir.

Though one may encounter members of several different opilionid groups within a given cave, most do not have the typical cave adaptations. It would appear that their presence within the cave is accidental. Those that are true troglobitic forms display certain specific adaptations: elongated appendages, reduced pigmentation, and lack of eyes or reduced eyes. Such adaptations are never found among the long-legged forms, the cosmetids, or the gonyleptids. It appears that the smaller cryptozoic forms are more pliable, possibly adapting to the cave situation more readily than the other larger forms.

With only a few exceptions, caves within the United States are found in areas of limestone, and their estimated age varies. In Tennessee, it appears that most of the caves are probably not much older than the Pliocene and some of them as late as Pleistocene. An exception to the generalization that caves are found in limestone areas are the lava tube caves of our northwest. These, too, appear to be of relatively recent origin, dating from early postglacial periods.

The possibility of relatively recent adaptation to the cave environment may be one explanation of the troglobitic forms, inasmuch as the caves are relatively recent. Thus there are two explanations for the presence of the cave forms: one is that they developed from epigean species and are relatively recent in this adaptation; the other possible explanation is that these species were already basically cave adapted and simply moved into the newly available habitat. This latter possibility is reinforced by the fact that seemingly fully-adapted cave forms have been found in niches considerably removed from caves. To these small forms, there is little or no difference between the environment afforded by the cave and that of the leaf litter. It is not unreasonable to assume that they have been able to move through cracks in the soil or limestone and enter underlying passageways.

Perhaps the explanation for the cave adapted forms is a combination of these two possibilities.

With only a few exceptions, the true troglobitic opilionids of the eastern United States are all members of the families Phalangodidae and Erebomastridae. Among the phalangodids, the most clearly adapted species is Phalangodes armata Tellkampf which occurs in Mammoth Cave, Kentucky as well as in other Kentucky caves. Another population of this very distinctive species was found in the caves of Tennessee. This population, first described as a distinct species, Tolus appalachius, demonstrates the variability that may occur within a species--another characteristic of many troglobitic forms.

The various small species of phalangodids described under the generic names of Crosbyella and Bishopella often are found in caves, and many of the populations show some degree of the development of distinctive cave characteristics. One species, Crosbyella distincta, from Arkansas caves has elongated legs and lacks eyes; thus though showing its relationship to the other members of the genus, it has distinctive troglobitic features.

Erebomaster flavescens (family Erebomastridae) is found in caves in southern Indiana. Though a cave dweller, this species does not show many true troglobitic characteristics. Other members of this family are found in forests along the Oregon coast and in Europe.

Also found in the eastern portion of the United States is the species Nemastoma inops (Palpatores: Nemastomatidae) which was originally reported from caves in Kentucky.

In the western United States, a number of caves may be found, but only a few distinctly cavernicolous forms have been encountered. In the Mother Lode country of the Sierra Nevada of California, several distinctive species have been found in numerous limestone caves. Briggs (1974) has placed these forms in the genus Banksula (Phalangodidae), the type species of which is B. californica (Banks) from Alabaster Cave, El Dorado County, California. In this form, though there is an eye tubercle, the retina is absent and the corneas are very small or absent. Related forms, B. tuolumne Briggs, B. galilei Briggs, B. melones, and B. grahami do have eyes, though B. grahami specimens have small corneas and retinas. All of these above were found in caves, with B. grahami also being found under rocks.

Sitalcina, a phalangodid genus with numerous species, is widely distributed throughout northern California. Briggs has collected these extensively and it appears that the presence or absence of functional eyes is a highly variable character. In some eyes are totally lacking, in others corneal lenses and retinas are lacking. It would certainly appear that these forms could very easily adapt to the cave environment. Only one truly troglobitic form is known from this genus, it is Sitalcina cloughensis Briggs and Hom from Cough Cave, Sequoia National Park.

Briggs (1974) discovered interesting forms inhabiting lava tubes in Idaho and southern Washington. A Travunid discovered in this interesting habitat was Speleonychia sengeri Briggs, a species lacking eyes entirely and with somewhat elongate appendages. Speleomaster levi and S. pecki (Erebomastridae) were described from caves in Idaho. Both are true troglodytes.

Briggs (1974) points out that the animals present serious questions as to how did a taxonomic gap develop between surface and subsurface populations. Specimens collected in lava flows in Washington and Idaho were unrelated to known surface populations. Those collected in the lava fields were of the family Travuniidae, those of the surface were of the family Triaenonychidae. In central Idaho, the surface laniatorids were represented by the triaenonychids, with only erebomastrids in the caves. The possibility does exist, of course, that further collections will disprove this present distribution. Inasmuch as these animals are very small and secretive, such a possibility does exist.

In Utah, a member of the genus Nemastoma, N. packardi (Palpatores: Nemastomatidae) has been reported from a cave in southern Utah.

In the southwestern United States, particularly in Central Texas, there are many caves. One phalangodid genus, Texella has been reported by Goodnight and Goodnight (1976). Two species are known. T. mulaiki and T. reddelli. Related surface forms are unknown at this time. This genus has a wide distribution, throughout the caves of the Edwards Plateau and into New Mexico. This genus does appear related to more northern genera of this family.

The other phalangodid genus found in Texas is Hoplobunus and is related to the fauna of northern Mexico. Two species are known from Texas. These are H. madlae Goodnight and Goodnight and H. russelli. All of these species (including those of Texella) show various degrees of specialization to the cave environment. Eye tubercles are present in all, but the development of the eye itself varies from no eye at all to a very small retina.

In northern Mexico, particularly in the states of San Luis Potosi, Neuva Leon, Queretero, and Tamaulipas, there are numerous cave systems with many cavernicolous forms. The opilionid species, while related to surface forms, often are very large, remarkably interesting forms. This fauna consists of numerous species of the genera Hoplobunus and Karos, both of the family Phalangodidae. Members of the genus Karos, though fairly common in caves, have not become so cave adapted as have the members of the genus Hoplobunus. These latter forms are often very large, with enormously elongated appendages, and with varying degrees of eye development. Some such as H. inops totally lack eyes, while some specimens of H. boneti have varying degrees of development of the eyes. Troglostygnopsis anophthalma (Silhavy) from caves in Chiapas, Mexico also is a true hypogean form. All these forms have the typical light coloration of cave animals. Also, H. boneti was one of the first forms observed in which the unique habit of guarding the eggs was observed. This behavior appears to be common among tropical opilionids and serves to protect the eggs from predation and destruction by molds.

Even less adequately known are the numerous caves to be found in central America. In Belize, two hypogean species were found. Both of these forms, Cynortina mistica and Stygnomma pecki are the first members of their genera to show adaptation to the cave environment. Both were from the Caves Branch area of Belize. This latter species was later found in leaf litter in the area of the caves. It would appear that this species moves freely through the porous limestone of this area of Belize.

Little is known of the cave fauna of South America. Rambla (1978) studied material from caves in Venezuela, but did not encounter any true cave forms, though one species Vima checkeleyi, did show some increase in size as compared to related species.

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Cave Diplura of the United States

Lynn M. Ferguson
Department of Natural Sciences, Longwood College, Farmville, Virginia, U.S.A.

Abstract

The examination of over 380 collections of campodeid diplurans from more than 280 caves in 24 states has revealed at least 10 genera belonging to the subfamily Campodeinae. Species of the following genera are known from both cave (hypogean) and surface (epigean or endogean) habitats: Campodea, Podocampa, Tricampa, Metriocampa (new subgenus), Haplocampa, and Eumesocampa. The cavernicolous species belonging to the first four genera are troglophiles; cavernicolous species of the last two genera are troglobites. The following genera are known only from caves (all are troglobites): Litocampa (formerly Plusiocampa), two new genera from eastern Tennessee and Nevada which are related to Litocampa, and an undescribed genus from southeastern New Mexico and western Texas which is related to Meiocampa. The majority of the 42 known cavernicolous species are in two genera: Litocampa (20 or more species) and Haplocampa (8 or more species).

Résumé

L'éxamination de plus de 380 collêctions des diploures campodéidés de plus de 280 cavernes des 24 états a révélé 10 genres qui appartient à la sous-famille des Campodeinae. L'espèces des genres suivant ont connu de la domaine des cavernes (l'hypogé) et la surface (l'épigé ou l'endogé): Campodea, Podocampa, Tricampa, Metriocampa (une sous-genre nouvelle), Haplocampa et Eumesocampa. L'espèces cavernicoles du prèmier quatre genres son les troglophiles; l'espèces cavernicoles des dernier genres sont les troglobies. ~~Les gen~~res suivant ont connu seul des cavernes (tous sont troglobies): Litocampa (autrefois Plusiocampa), les deux nouvelles genres d'est de Tennessee et de Nevada qui ont raconté à Litocampa, et un genre inédits du sud-est de New Mexico et d'ouest de Texas qui est raconté à Meiocampa. Le Plupart des 42 espèces cavernicoles qui ont connu sont à deux genres: Litocampa (20 ou plus des espèces) et Haplocampa (8 ou plus des espèces).

During his presentation at the First International Congress of Speleology, B. Condé (1953) noted that only five species of cavernicolous campodeid diplurans were known from the United States. These five species were known from seven caves in four states (Condé, 1949). Today over 380 collections of campodeid diplurans from more than 280 caves in 24 states have been examined. At least 10 genera and 42 species belonging to the subfamily Campodeinae are represented.

Species belonging to six of the genera are known from both cave (hypogean) and surface (epigean or endogean) habitats in the United States. The cavernicolous species of the genera Campodea, Podocampa, Tricampa (former subgenus of Metriocampa), and Metriocampa are presumably all troglophiles. Specimens of these genera show little or none of the characteristics associated with cave adaptation in campodeid diplurans. The characteristics common to troglobitic campodeids include an overall increase in body size, a relative increase in the length of appendages (legs, antennae, and cerci), the presence in some genera of well-developed laterotergal crests on the pretarsal claws, and an increase in the number of sensilla in the cupuliform organ of the apical antennal segment (Condé, 1956). The cave inhabiting members of Tricampa have five sensilla in each antennal cupuliform organ instead of four, the number generally found in epigean species.

The following information concerning the distribution of epigean species of campodeid diplurans in the United States is primarily from the published articles of Silvestri (1912, 1933), Gardner (1914), Hilton (1932, 1936), Chandler (1956), Condé and Thomas (1957), Bareth and Condé (1958), Condé and Geeraert (1962), and Ferguson (1978).

A new species (and subgenus) of Metriocampa is known from Wind Cave in South Dakota (Fig. 1). Six epigean species of Metriocampa are known from South Dakota, Wyoming, Montana, Idaho, Washington, Oregon, and California. A species of Campodea is known from two caves in Iowa. Twenty or more epigean species of Campodea are reported from the midwestern and western states as well as from North Carolina and Florida. This genus is essentially cosmopolitan in the warm to temperate regions of the earth (Paclt, 1957). Several species of Podocampa are known from caves in Oklahoma and Texas. Five epigean species are known to occur in Texas and Louisiana. Cavernicolous species of Tricampa are knonw in Illinois, Oklahoma, and New Mexico; four epigean species are known from Montana, Wyoming, ~~Utah~~, Colorado, Iowa, Louisiana, California, Washington, and Alberta, Canada.

Cavernicolous species of the genera Eumesocampa and Haplocampa are probably troglobites. Two epigean species of Eumesocampa have been described from north-central Colorado. A third epigean species which apparently belongs to the genus is E. frigillis (Hilton), which is found in New York, Pennsylvania, Ohio, and Maryland. An undescribed species is known from a cave in West Virginia where it occurs sympatrically with Litocampa fieldingi (Condé). The mid-western cavernicole is morphologically similar to the two Colorado species; the West Virginia Eumesocampa is more like the eastern species.

Eight or more hypogean species of Haplocampa are known from lava tubes in southern Washington, Idaho, and Oregon, from a placer mine overlain by a lava flow in northern California, and from linestone caves in the Grand Canyon, Arizona, and in Utah, Missouri, and Illinois. Six or seven epigean species of Haplocampa are known from northern California, northern Oregon, southern Montana, central and northern Washington (on Mount Rainier at an elevation of 1700 meters and on Mount Baker at an elevation of ca. 1600 meters), and in Alberta, Canada (in Banff National Park). Overall, the distribution of species of Haplocampa appears relictal. The last mentioned occurrence in the Banff region of Alberta, along with the presence of hypogean amphipods and isopods in the same area (Holsinger, 1980), suggests the presence of an ice-free refugium on the eastern side of the Canadian Rockies during the Wisconsin glaciation.

Similar distributional patterns exist for members of the genera Tricampa, Eumesocampa, and Haplocampa. All three have epigean members at high latitudes or at high altitudes in the western mountains, and cavernicolous members at lower latitudes and altitudes. Species identical or very similar to Tricampa rileyi or T. remingtoni are known from three caves in Illinois. Epigean T. remingtoni is known only from Colorado. T. rileyi is known from the mountains of the western states and Alberta, Canada, as well as from the plains of Iowa to Louisiana. In the mountains of Utah and Colorado, it has been found above 3000 meters; specimens were collected at Cottonwood Pass, Colorado, which at 3615 meters is one of the highest locations known for Campodeids. Eumesocampa lutzi Silvestri inhabits the same region, at elevations near 3000 meters (Condé and Geeraert, 1962).

In the United States, species of the following genera are known only from caves; all are troglobites: Litocampa (former subgenus of Plusiocampa) with 20 or more species, two new genera from eastern Tennessee (undescribed genus B of Fig. 1) and Nevada (undescribed genus X) which are related to Litocampa, and an undescribed genus (S) from southeastern New Mexico and western Texas which is related to Meiocampa (former subgenus of Parallocampa). A cavernicolous species from central Texas is tentatively identified as a member of the genus Allocampa, which is currently represented by a single epigean species in Cuba (Silvestri, 1931).

The majority of the known cavernicolous species are in two genera, Litocampa and Haplocampa. The United States species of Litocampa are concentrated in the southern Appalachian region (17 species), with two species in Missouri and Arkansas (the southern Ozarks Plateau), and one species in New Mexico. Species belonging to the group with the most ancestral characters are found in the southern Appalachian Mountains: in the Blue Ridge Province of Tennessee and North Carolina and in the eastern-most part of the Valley and Ridge Province of Virginia. Other United States species of Litocampa could have evolved from the ancestral stock of this species group. Although the single species of Litocampa in New Mexico may be derived from the southern Appalachian stock, future research could show that it is more likely derived from Mexican stock. Mexico may prove to be another point of radiation for species of this genus.

Wygodzinsky (1944) has already indicated the presence of three species of Litocampa there.

The Missouri and Arkansas species of Litocampa are morphologically intermediate between Litocampa and Haplocampa. If cavernicolous Litocampa species were ancestral to the Haplocampa, this would help to explain the presence of well-developed latero-tergal crests on the pretarsal claws of all known Haplocampa--even in the epigean species. The occurrence of a generalized species of Haplocampa in caves of Missouri and Illinois supports this hypothesized affinity of the two genera. However, if Litocampa gave rise to Haplocampa in the Ozarks, it must have occurred long ago (in the Tertiary ?) in order to allow time for the western dispersal of ancestral Haplocampa during favorable climatic periods, followed by speciation during the Pleistocene. The climatic events of the Pleistocene Epoch most certainly accounts for some of the ranges of Haplocampa and Litocampa in the United States today. However, the overall distribution of Litocampa in North America, Europe (France, Spain, and Switzerland), South America (Guyana and northeastern Brazil), and western Africa (Republic of Guinea), along with their generalized (primitive ?) morphology, suggests an ancient group whose range has been fragmented by plate tectonics.

I would like to thank collectively here all those people who have provided specimens for study, or who have aided me in other ways in the collection of material. These individuals will be more properly acknowledged elsewhere.

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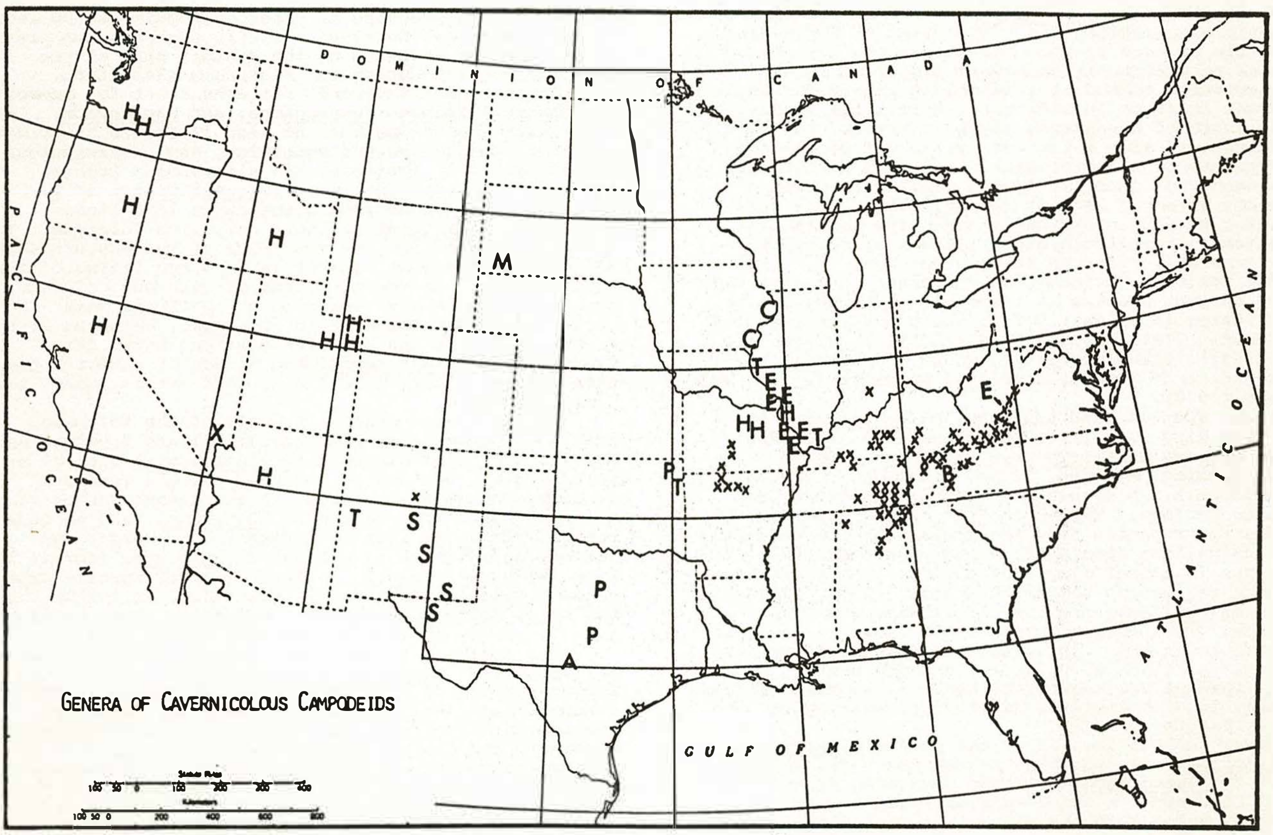

Figure 1. United States, showing distribution of genera of cavernicolous campodeids: Litocampa (small x), Eumesocampa (E), Campodea (C), Metriocampa (M), Tricampa (T), Podocampa (P), Haplocampa (H), Allocampa ? (A), undescribed genus B (B), undescribed genus X (large X), and undescribed genus S (S).

Subartic Karst Geomorphology and the Development of Organo-Karst Landforms in the Hudson Bay Lowland, Ontario

Daryl W. Cowell
Lands Directorate, Environment Canada, Box 5050, Burlington, Ontario, Canada, L7R 4A6

Abstract

The Hudson Bay Lowland is an area of unconfined peatland underlain by Paleozoic strata. Silurian limestone outcrops 90 km west of James Bay along the Attawapiskat River. It is also found on either side of the river in the form of glacially-scoured biohermal reef knobs, within an otherwise continuous organic cover. Circumneutral to acid organic groundwaters are in contact with the limestone reefs and the peatland plain is consequently undergoing active karstification. Prominent sinkholes surround the reefs and are expanding at the expense of the peatland. Three distinct karst morphologies have evolved depending on the height of the reefs relative to the peat surface. The result is an extensive organo-karst complex.

Paralleling each bank of the river is a zone of fluvio-karst characterized by sinkholes and active ponors. Karren forms are poorly represented because of the local lithology but good examples of pit karren and rillen karren have been observed.

Résumé

Les basses-terres de la baie d'Hudson constituent une région de tourbières qui s'étendent à perte de vue et dont le sous-sol se compose de strates paléozoique. La Rivière Attawapiskat s'est creusée un lit de 30 m dans du calcaire biodétritique silurien qui a son centre a environ 90 km à l'ouest de la baie James. On trouve des escarpements de 12 a 15 m le long de la rivière, mais, à l'intérieur des terres, le terrain est plat et recouvert de 1.5 m de tourbe ou davantage. Le terrain organique occupe environ 70% de la superficie et des tourbières émergées et basses, dont l'eau souterraine va d'un pH à peu près neutre - un pH acide, prédominent.

La déglaciation des basses-terres a commence il y a de cela 8000 à 9000 ans et la zone qui fait l'objet de l'étude a émergé de la mer de Tyrrell il y a environ 4000 ans. Depuis lors, il s'est formé deux zones hydrogéologiques et morphologiques de karsts. Ce sont, d'une part, une zone fluvio-karstique longeant la rivière et, d'autre part, une plaine organo-karstique à l'intérieur des terres. Les karsts fluvieux recouvrent 16% de la superficie et se caractérisent par des dolines, des ponors actifs, des lapies-fosses et des lapies-rigoles. Le drainage de cette zone se produit surtout dans les eaux vadoses et alimente les sources de la rivière Attawapiskat.

La zone de karsts organiques représente un exemple unique de plaine de tourbière subissant une karstification active. Elle consiste en affleurements de roches coralliennes dénudées par les glaciers, entourés par des tourbières. La ligne de contact entre le manteau organique et le calcaire est ponctuée de dolines très visibles qui s'agrandissent actuellement aux dépens des tourbières. Trois reliefs karstiques distincts se sont développés en fonction de la hauteur des pinacles corralients par rapport à la surface de la tourbe. Le niveau phréatique demeure élevé dans les tourbières de des cônes de dépression des eaux souterraines entourent les dolines.

Introduction

The conditions which give rise to karst and wetland landscapes are so divergent that the likelihood of their co-existing seems improbable. Karst terrains are best displayed where chemically agressive waters may readily pass into and through a rockmass. Wetland terrains are the product of very poor drainage, usually where impermeable material such as clay or crystalline rock prevents water loss via groundwater seepage. Unconfined peatlands, such as those in the Hudson Bay Lowland, require extremely flat plains where the regional water table lies above the mineral substrate; hence, they are one of the least likely places to find karst processes and landforms. This paper describes an example of subarctic karstification in the Lowland and discusses the development of karst landforms within a peatland plain, herein termed organo-karst (Cowell, in press).

Geology and Morphology

The study area lies 90 km west of James Bay on the Attawapiskat River, at approximately 60 m above sea level (Figure 1). The karst covers at least 200 km^2. It has developed in the Attawapiskat Formation (Middle Silurian). This is a thick-bedded bioclastic limestone with thin-bedded interreefal facies surrounding massive bioherms (Sanford et al., 1968). Strata are flat-lying and jointing is the only structural feature evident. Glacial scour and post-glacial fluvial erosion have exposed many biohermal reef cores which now stand as isolated rock knobs throughout the area. The study area was inundated by a late-glacial marine transgression (the "Tyrrell Sea") 7000-8000 years B.P. (Lee, 1960), and only emerged approximately 4400 years B.P. Since that time the Attawapiskat River has entrenched 30 m into the limestone along a reach of 45 km. The main karst lies at the upstream end of the reach, where abrupt cliffs of 12 to 15 m occur along the river. These grade laterally into expansive peatlands punctuated by numerous bioherman reefs (Figure 2). A veneer of calcareous silty alluvium 40 to 100 cm thick underlies organic deposits between reef knolls.

The area lies within the zone of discontinuous permafrost, having a mean annual temperature of -3.3°C and a coldest month (January) averaging -23°C.

Peatland Morphology

'Peatland' encompasses a suite of wetland types characterized by net accumulation of organic material and formation of organic landforms. Peatlands, averaging 1.5 m of organic deposits, cover 70% of the study area. These occur predominately as typical lowland acid bogs (groundwater pH 3-5) characterized by sphagnum mosses, labradortea (Ledum groenlandicum), leatherleaf (Chamaedaphne calcyculata) and in places, black spruce (Picea mariana). Where lateral movement of water is possible over or through calcareous alluvial substrates, e.g., near to karst dolines or in seepageways draining large bog complexes, less acid fen peatlands occur (pH 5-7). These are characterized by a variety of grasses and sedges, 'rich' mosses (Drepanocladus sp. and Scorpidium scorpioides) and some shrubs.

Karst Geomorphology

There are two distinct karst geomorphological zones in the study area (Figures 2 and 3). These are 1) a fluvio-karst zone on islands in the river and extending up to 1 km inland and 2) the organo-karst zone in the inter-fluvial peatlands.

In the fluvio-karst zone individual dolines have developed on bare limestone or where overburden is shallow (<40 cm). They consist of solutionally enlarged joints which drain small depressions of solution or reefal origin (Figure 3). These features are probably common in this zone, forming wherever water collects on the reef surfaces.

Two intermittent lakes were examined (A6-1 and A7-3, Figure 2). A6-1 is located near the peatland margin and occupies an abandoned channel of the Attawapiskat River. Its surficial overflow drainage flows southwest via a silt-floored channel grown over with trees. Water marks, indicating that the channel is seasonally active, were observed about 60 cm above the base of the trees. Depth of the lake at high stage would be about 1.5 m. Clusters of shallow dolines primarily of collapse origin occur at both ends of the lake. The deepest is 1.5 m below the lake floor. No conduits of explorable dimensions could be penetrated from the dolines.

Karren forms are poorly represented in the area but well developed pit karren and rillen karren were observed in the fluvio-karst zone; Pit karren occur mainly on the dense reef-core rocks. Fine etching occurs on most outcrops of the dense, less-fossiliferous limestone but only 2 examples of true pit karren were found. Pitting was high density and individual pits were sharp-edged. Rillen karren were observed at only one site. Four rills occurred on a near-vertical face of interreefal strata. The largest sloped at 78°, was 90 cm long, crossed 3 bedding planes and narrowed from 5 cm at the top to 1.5 cm at the bottom, bifurcating below the second bedding plane. The entire rock surface at the site, including the rills, was sharply etched.

In general karren and fine-honeycomb etching occurs only on the most dense limestone. Most outcrops in the study area however are composed of porous often very fossiliferous limestone which inhibits the development of recognizable karren forms.

In the organo-karst zone three distinct morphologies have evolved as consequences of differing relationships between the elevations of reef knolls and peat surfaces. The first is found where the top of the knoll is higher than the surrounding bog (Figure 3). Dolines often with intermittent ponds or small lakes, form at the edge of the reef, e.g., sites A6-2 and A8-1, Figure 2. In one case (A6-2) at least six separate dolines almost completely encircle the reef. The largest doline was 70 x 20 m in dimension and 2.5 m deep.

The second morphology occurs where the reef surface is at the same elevation as the surrounding peatland. The bog may encroach onto the reef, particularly if alluvium protects the limestone. In these cases dolines develop wherever water may seep into the rock, e.g., at prominent joints. Site A6-3 is an example of this morphology; there are five sinkholes, the largest being 2 m deep and 16 m in diameter. It has a small circular cave at the base.

The third type of organo-karst morphology develops where the reef surface is lower than the surrounding peatland, e.g., Site A6-4. It has developed on the edge of a bog-pond complex, partly draining it. The surrounding open bog now declines gently into the depression and is broken by annular cracks, evidence that it is slumping into the doline.

Karst Hydrogeology and Development of the Organo-Karst

Rapid peat accumulation has occurred throughout the Hudson Bay Lowland since emergence because of the cool climate and low gradient. In the study area the Attawapiskat River has entrenched significantly into the limestone, creating a fringing zone of higher hydraulic gradients. The fluvio-karst zone, which currently occupies 17% of the area, developed contemporaneously with river entrenchment. Groundwater potential hydraulic gradients in this zone are steeper than 1:100 and there is groundwater circulation into the river channel. Dolines and ponors are hydrologically isolated in small closed basins or drain lakes and small streams perched on alluvium.

Inland, the limestone was protected by alluvium and poor groundwater circulation, enabling organic material to accumulate to 1.5 m. Once a hydraulic gradient steeper than 1:500 was established, karst circulation occurred wherever the aquiclude could be breached (Cowell, in press). This created cones of groundwater depression within the peatland - limestone phreatic aquifer. The organic water could not have been in direct contact with bedrock until after peat had accumulated to nearly its present thickness, because early karst drainage would have prevented the rising water table necessary for organic accumulation. Karst features therefore occur primarily where the peat blanket comes into lateral contact with reef knolls. However the alluvium beneath the peat may have been breached by organic waters in those instances where the reef surface is currently lower than the surrounding peatland. In these cases the increasing hydraulic gradient, concurrent with river dissection, was probably the main control of karstification.

Organo-karst features occupy approximately 13% of the area. To date the effects on the peatland are limited to the immediate vicinity of the sinkholes. The lowest part of the dolines are below the pearched groundwater level in the peat thus limiting its continued accumulation. In places the peat has been visibly disturbed by drying-out and slumping. All the sinkholes and ponors shown flooded in Figure 2 (representing conditions in 1970) were completely drained when studied in 1977. This can be attributed to unusually low precipitation in the previous year because they were again flooded when visited in 1980. This indicates immature karst drainage. It is expected however that drainage will continually improve at the expense of the peatland as karst circulation continues and as potential hydraulic gradients are increased in response to continued isostatic uplift (currently 1.0-1.2 m/100 years) and accompanying river entrenchment.

Conclusion

The organo-karst of the Attawapiskat River is a young, hydrologically immature karst intimately associated with the occurrence and growth of organic deposits. It postdates withdrawal of the Tyrrell Sea and is likely younger than 2500 to 3000 years, allowing for up to 1.5 m of peat accumulation prior to karstification. This is a relatively short time for the formation of well developed surface karst forms. Such rapid development may, perhaps, be attributed to the high acidity of the peatland waters. The juxtaposition of these two landform and hydrologic types, which in the long term are mutually exclusive, provides many insights to the early stages of karstification of a relatively young land mass.

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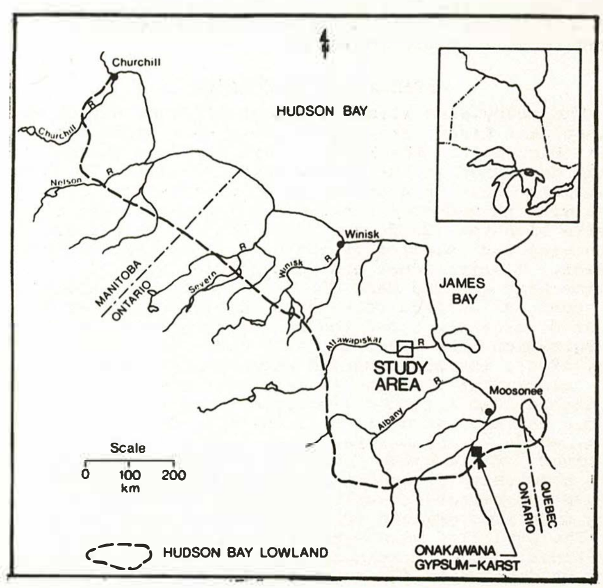

Figure 1. The Hudson Bay Lowland showing the location of the study area.

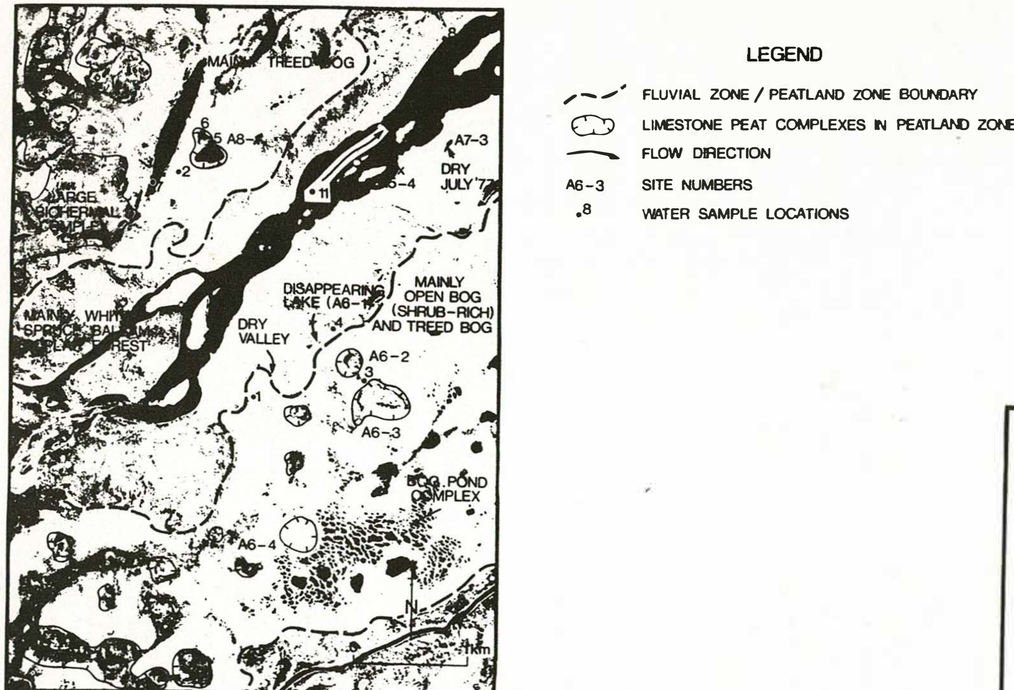

Figure 2. A portion of the Atawapiskat karst showing the area and features investigated during July 1977 (from National Air Photo Library, aerial photo No. A21495-162, taken in August 1970).

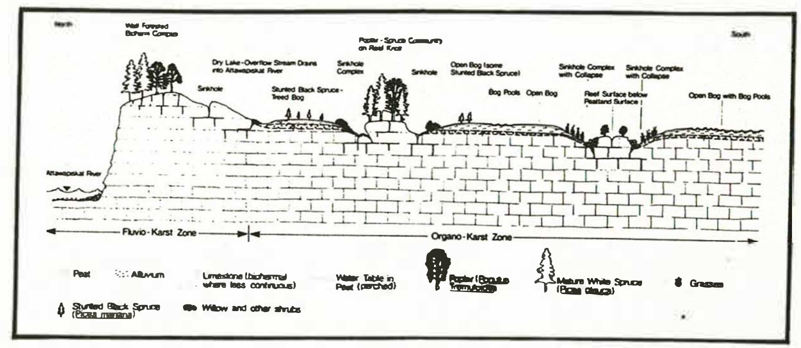

Figure 3. Idealized cross section from south-shore of Attawapiskat River showing karst-peatland relationships (horizontal distance about 3.0 km).

The World's Longest Underwater Cave

Sheck Exley and Ned DeLoach
Florida, U.S.A.

Résumé

Le système "Peacock Springs Cave" dans la Comté de Suwannee en Floride, est un labyrinthe d'embranchement horizontal developé principalement à la base du couche Calcaire Suwannee de l'âge Oligocène. Les vingt-cinq ans d'exploration continuelle de cette grotte sont uniques non pour la longueur d'atteinte (7 Km.) ni pour la profondeur parvenue (67m) mais plutôt pour la manière d'exploration utilisé pour relever la caverne: le plongée de caverne sousmarine. C'est la grotte la plus longue de la Floride, mais plus impressionant c'est le fait que ça continue à être la plus longue caverne sousmarine connue au monde.

"Peacock Springs Cave" a joué un rôle de grande portée dans le dévelopement de l'equipement pour le plongée de caverne dans les Etats Ûnis en étant usé comme "endroit de preuve" pour les equipages et les procés nouveaux. Depuis l'usage d'un seul caisson primitif, avec un regulateur a double tuyau et lampe de poche dans un sac a plasti plastique, utilizé par Vasco Murray en 1956 pour la premiere exploration de l'entrée de la caverne, l'équipement a progressivement evolué jusqu'a permettre les explorateurs NSS à penetrer plus que 700m de l'entrée la plus prôche les voies sousmarines et jusqu'a 67m de profondeur de l'eau. Les doubles caissons de 33m, les tuyauteries a double soupape, les lumieres de quartz halagène, les scaphandres, les scooters sousmarins et des techniques a plongée nouvelles sont en train d'être utilisé par les scaphandriers NSS pour atteindre des temps de submersion saufs pendant plus de 3.5 heures et continuer a maintenir une marge de securité 100%. Pendant l'evolution de cet équipement tout les 7 entrées passables du système Peacock ont été conjugués et de fait tout les passages ont été explorés et relevés, quoique des petits passages de côte continuent a être découvertent.

The exploration and survey of the Peacock Springs Cave System by N.S.S. divers is probably the crowning achievement of American cave diving. While the distance records for individual dives have left the U.S. for England and Australia, the discoveries of extensive air-filled galleries beyond sumps in America have yet to rival the success of the British at Ogof Ffynnon Ddu, Peacock remains the world's longest known underwater cave at over 7.0 km. It has now held that distinction since October of 1975, and appears unlikely to be surpassed for quite some time to come (Exley, 1979).

Located 3 km from the Suwannee River in west-central Suwannee County, Florida, the cave is almost entirely developed in the thinly-bedded, highly fossiliferous Suwannee Limestone of Oligocene age (Fisk and Exley, 1977). Water flow in the cave, which is entirely submerged, is from the north to the south, paralleling the trend of the majority of cave passage. In two areas short sections of the cave descend into the uppermost limestone beds of the thick Eocene Ocala Group. In both areas the general north-south trend of the cave is broken by the development of secondary passages with an east-west orientation. It is estimated that half of the total volume of water moving through the cave moves through these secondary passages to flow downward into the Ocala Group. Of the remaining half that eventually exits at Peacock Springs (measured at 15.0 cfs on 12/6/75), over 90% of the water re-enters the ground at Peacock III Cave. The remaining fraction trickles down a broad, sluggish stream through a picturesque cypress swamp to the Suwannee River.

Contrary to some descriptions (Erving, 1968; O'Keefe, 1975) Peacock is not a maze cave but fits more closely the classic branchwork pattern described by Palmer (1975). The exploration of the cave has been facilitated by the presence of eight passable entrances spaced at regular intervals throughout the system so that no point in the cave exceeds 700 m from the nearest entrance. Further, the water depths generally encountered are relatively shallow (12 to 21 m), with the deeper areas (up to 61 m) being short in nature and close to entrances. These facts have enabled investigation of a substantial portion of the cave at a time when the technology of cave diving was, at least by modern standards, quite primitive.

The exploration of Peacock began with Vasco Murray's tentative dives in the Peacock Springs I and Orange Grove Sink entrances in 1956. However, not until 1965 were any of the entrances connected, when George Krasle, Howard Lilly and Dick Olsen entered the Peacock entrance and exited via Pot Hole 135 m away. Within the next few years Rick Wright and Howard Bradbeer pushed on to the Cisteen Sink and Olsen Sink entrances, then in 1970 Tom Mount and Frank Martz followed a winding tunnel 429 m northward from the upstream Olsen entrance to emerge in Challenge Sink. Later that year John Harper, Randy Hylton and Frank Martz linked Orange Grove Sink Cave to the Challenge entrance via a 538 m-long conduit. The latest and most significant connection came on 7/7/73, when David Fisk, Dana Turner and Sheck Exley connected Waterhole III Cave to Peacock with a world record (for then) cave diving through trip of 704 m. A 5 m breach of the cave at Olsen Sink which effectively divided the cave into two separate systems was bypassed through exploration by Court Smith, Lewis Holtzendorff and Exley on 9/3/73 (Exley and Fisk, 1978).

The survey of the cave, which began in 1975, has been a project of the N.S.S. Cave Diving Section. Using guideline knotted at 3 m intervals, a Suunto diver's compass and depth gauges, more than 7.0 km of passage has been mapped using procedures described in detail by Exley and Maegerlein (1981). A relatively high degree of accuracy has been obtained by correcting to a surface transit survey of the entrances. The fifteen divers who have helped survey the cave have accounted for more than 1000 dives in Peacock since 1965, with absolutely no accidents of any kind.

Perhaps Peacock's greatest contribution has been the role it has played in the development of American cave diving equipment and procedures. From the early days of single tanks with double hose regulators and flashlights in plastic bags, explorers have progressed to twin 100 cu. ft. tanks, dual valve manifolds, octopus regulators and nicad-powered quartz-halogen lights in their quest for the means to explore the more remote areas of the cave. Improved safety procedures such as the "third rule" method of air planning, sharing air in emergencies and silt avoidance practices have also evolved as well as underwater cave surveying techniques. While they have not been necessary for exploration of that particular cave, Peacock has also been used as a proving ground for the most recent innovations in American cave diving technology such as multiple tank staging and the use of motorized Farallon Mark VI scooters. For these reasons alone it is probably that, even should another cave someday eclipse its record length, Peacock will still be revered as the cradle of American cave diving.

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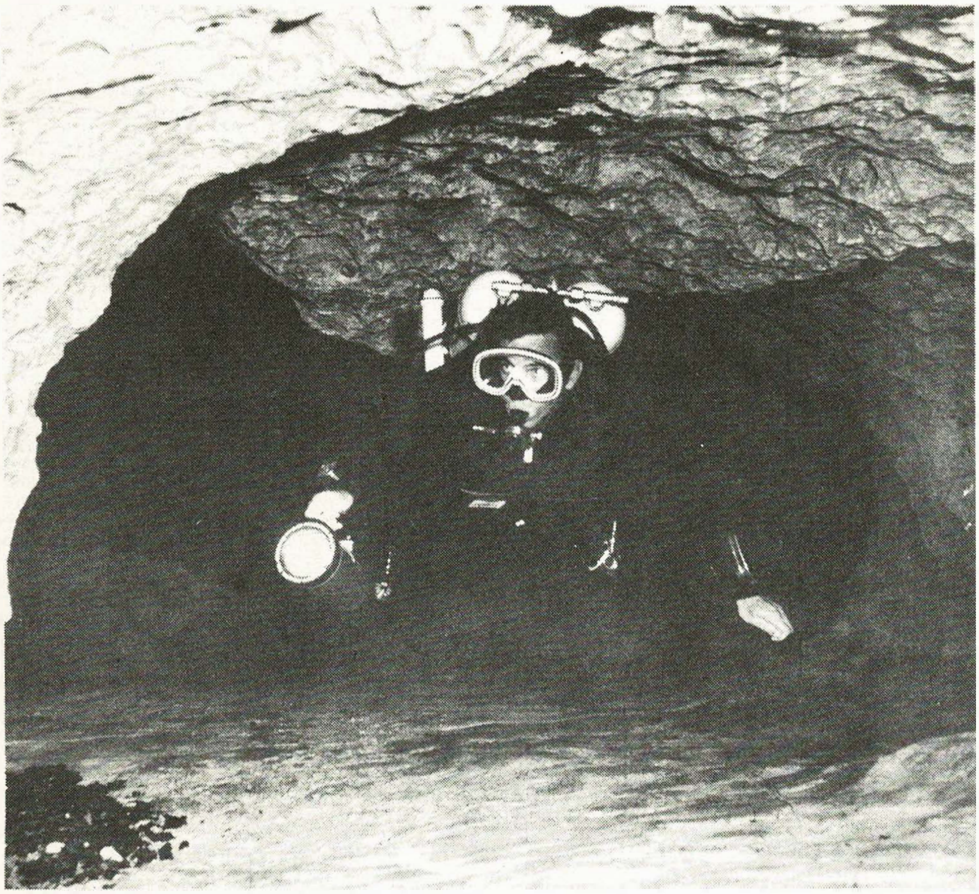
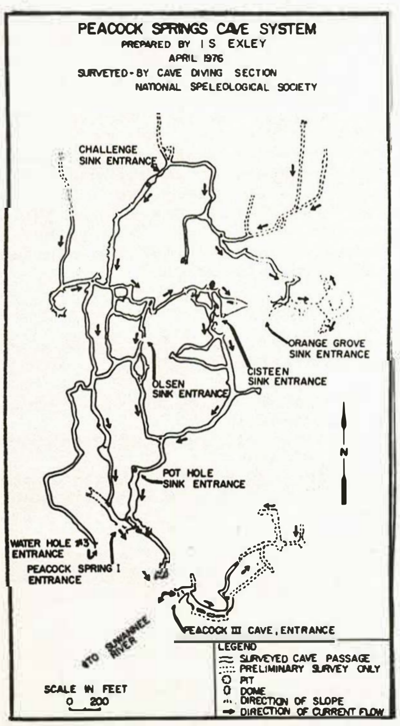
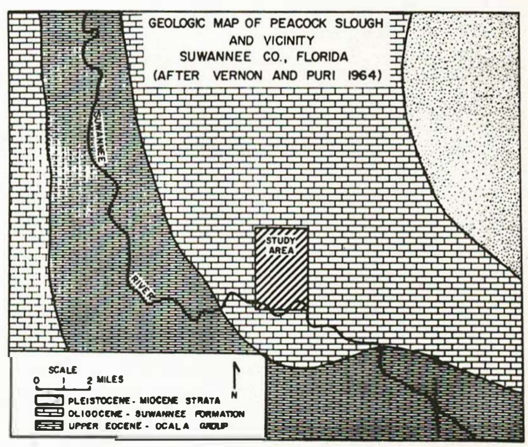


Ned Deloach in the entrance of Orange Grove Sink.
Photo by Pete Velde.





Pebble Investigations in Slovene Caves (Yugoslavia)

Andrej A. Kranjc
Inst. for Karst Research, SAZU, Titov trg 2, 66230 Postojna, Yugoslavia

Abstract

The author has investigated about 30 samples, mostly from active caves. Lithology, size and shape of pebbles were analysed and the following indices were found out: sphericity, flatness and roundness. Indices as well as standard deviation are calculated by computer.

The comparisons between the data from different caves in the same water basin (ponor and spring caves) as well as along the water course in one cave (Skocjanske jame, Jama near Predjama) were made. Some attempts to find out the rate of pebble formation are given too.

Résumé

L'auteur examinait à peu prés 30 échantillons de graviers des grottes actives. Les analyses lithologiques et morphoscopiques ont été fait pour obtenir les indices de sphericité de l'aplatissement et d'émoussé. Les indices ainsi que les courbes de fréquences et les déviations standard ont été fait par l'ordinateur.

On a fait les comparaisons entre les résultats des analyses des grottes différentes situées dans un seul bassin fluvial (grottes-pertes et grottes-sources) et le long d'un cours d'eau dans une seule grotte (Skocjanske jame, Jama prés de Predjama). On a essayer de trouver l'intensivité de l'alt"ration de roche calcaire - c'est le procês qui donne le matériel pour les galets calcaires.

The deficiency of data about cave fluvial sediments is felt at us as well as in the world. Analytical studies of structure, size and shape of pebbles, sand and silt could give us some informations about the material origin. The descriptions and analyses of cave sediments from archaeological finding places predominate, but "archaeological" and "palaeontological" layers are less useful in karstology, because they are not included in local speleomorphological development (Renault 1976, 199). Much more descriptive work is needed before more accurate conclusions can be drawn and diagnostic tables set up. Size ranges of pebbles and sand, roundness tests and variations in stream flow stage need to be related to each other in as many areas as possible, and in turn they must be compared against a background of different source rocks in different climates, past and present (Ford 1976, 59). The first who started the modern studies of cave gravel at us was J. Corbel (1956, 1962) in Škocjanske jame (jama - cave) and in Postojnska jama, but his investigations were limited to some occasional samples. In recent time R. Gospodarič set to this question (1970, 1974, 1974a) but more from chronological than from morphological point of view.

Therefore we decided on our Institute to try to fill the above mentioned deficiently at least for sloverne karst within the several years lasting study aimed to fluvial cave sediments research. The investigations include descriptive, analytical, and synthetical parts. In this paper I report about done gravel investigations and about previous results. In this period about 30 samples from different slovene caves were studied. On principal the sample is composed by 300 pebbles.

According to slovene circumstances we are interested mostly in:

- origin and gravel composition (lithology),
- gravel morphology, carbonate pebble morphology emphasized,
- formation of carbonate gravel.

The samples were treated by uniform methodology. Lithological composition is quite various, depending on rocks in the flow basin, where the sediment was deposited. Usually carbonate pebbles represent an uniform group, while sometimes even the carbonate gravel is distinguished in different groups. Till now the gravel of eight lithological groups was found: limestone, dolomite, quartz, sandstone, shale, marl, magmatic rocks and conglomerate.

Gravel morphology: length, width and thickness of particular pebbles were measured by hand and the data were put on to diskettes (IBM 3741). The computer (IBM S/3 32 K) calculates the parameters for particular pebbles - flatness and roundness (after Cailleux) and sphericity (after Krumbein). The mean values with standard deviations and a part of unexplained variance were calculated too, the extreme values were separated, the pebbles lengths were gathered into groups and the corresponding graphs were drawn.

The formation of carbonate gravel: often in the samples of the cave gravel carbonate pebbles predominate, originating from the cave itself or well from the upstream part of carbonate rocks. To know more about the carbonate pieces formation, from which water is making rubble, we started the investigations in the entrance part of Jama (Predjama). We intend to study the recent superficial and cave rubble to get the properties of that carbonate material of which the gravel originates.

Just for illustration there are some interesting results of previous work.

Gravel lithology: Podpeška jama is the spring cave in the border of about 3 km wide limestone ridge Mala gora. The creek Locica flows on normal relief. Coming to Mala gora it sinks, flows thorugh Finkova jama and reappears in Podpeska jama. The changes in lithological gravel composition among Ločica, through Finkova to Podpeska jama are shown on fig. 1. Between the Locica ponor and Finkova jama there is 0,5 km of distance, between Finkova and Podpeška jama there are 2,5 km. The second case, also shown on fig. 1, belongs to Reka river basin. Reka flows across Eocene flysch, sinks into Škocjanske jame and reappears in Kacna jama. In middle course the river flows only across flysch (mostly sandstone), in Skocjanske jame it sinks after 2,5 km long course through limestone canyon, between the sinking point and Kacna jama there are about 4,5 km of underground flow. In both cases the decrease of the rate of non-carbonate pebbles is characteristic and at the same time the increase of the rate of carbonate pebbles.

Changes of pebbles shape along the flow are illustrated by two examples - gravel from Reka and from ponor creek Lokva near Postojna (fig. 2,3). The mean roundness of carbonate gravel of Reka on sinking point into Škocjanske jame (after 2,5 km long course through limestone canyon) is 163, in Kacna jama (after 4,5 km long underground flow) is 217. Lokva originates in flysch rocks, mostly sandstones, and after about 200 m long flow along limestone slope sinks into Jama (Predjama). The water finally appears in some 12 km distant Vipava springs. On teh ponor the mean roundness of limestone gravel is 117. From the entrance to the first siphon, where the second gravel sample was taken, there are 160 m. On this point the mean roundness of carbonate gravel reaches 155, while in Vipava springs 366.

If we calculate the roundness ratio increase to distance unit the difference is considerable: in Reka course the roundness of limestone gravel increases for index 12/km, in river bed Lokva up to first siphon for 237/km and up to Vipava springs for 18/km.

In short I tried to present the previous work of cave gravel investigations in Slovenia, the previous results and the project of the whole work. I would like to mention that on such limited space it is not possible to give the detailed descriptions and therefore I have chosen only some interesting cases. When we shall know the recent fluvial cave sediments well enough, it will be, after my opinion, much easier to interpret the fluvial sediments in actually dry (fossil) caves.

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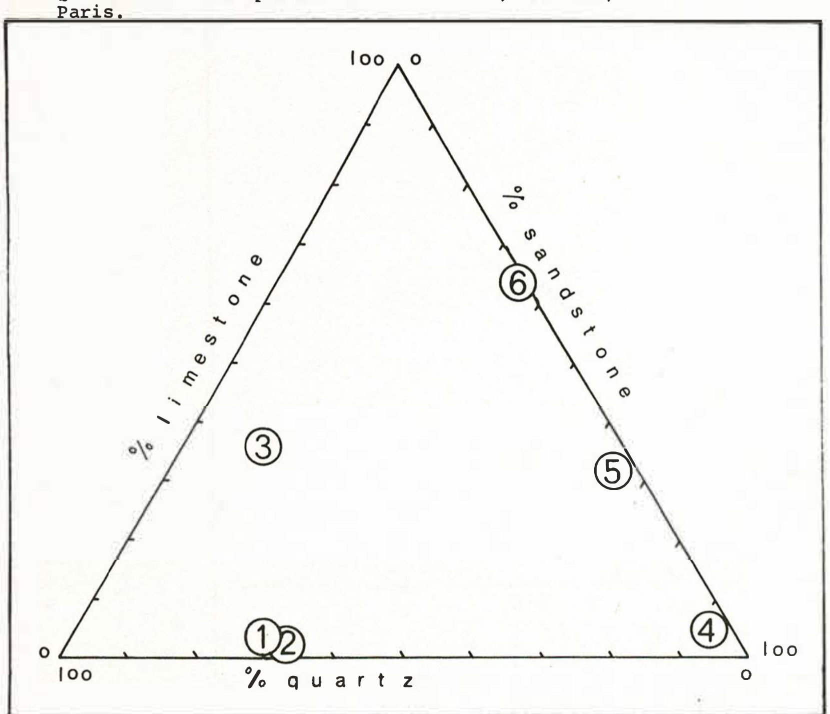

Fig. 1 Changes in gravel lithology between Ločica creek Podpeška jama and downstream Reka river
1 - Ponor of Ločica
2 - Finkova jama
3 - Podpeška jama
4 - middle course of Reka river
5 - Reka river sinking point in Škocjanske jame
6 - Kačna jama

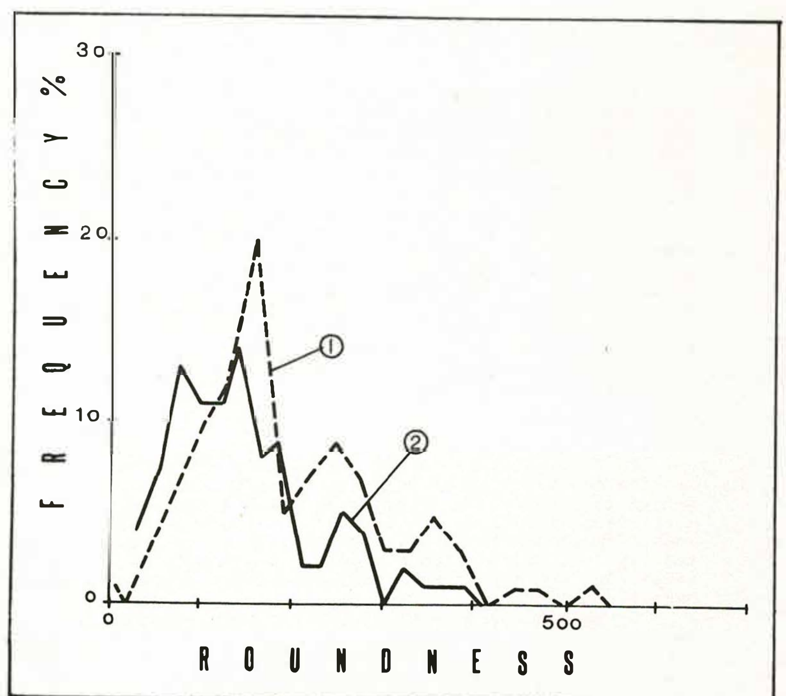

Fig. 2 Roundness of limestone pebbles in the Reka river bed
1 - Kačna jama
2 - Reka river sinking point into Škocjanske jame

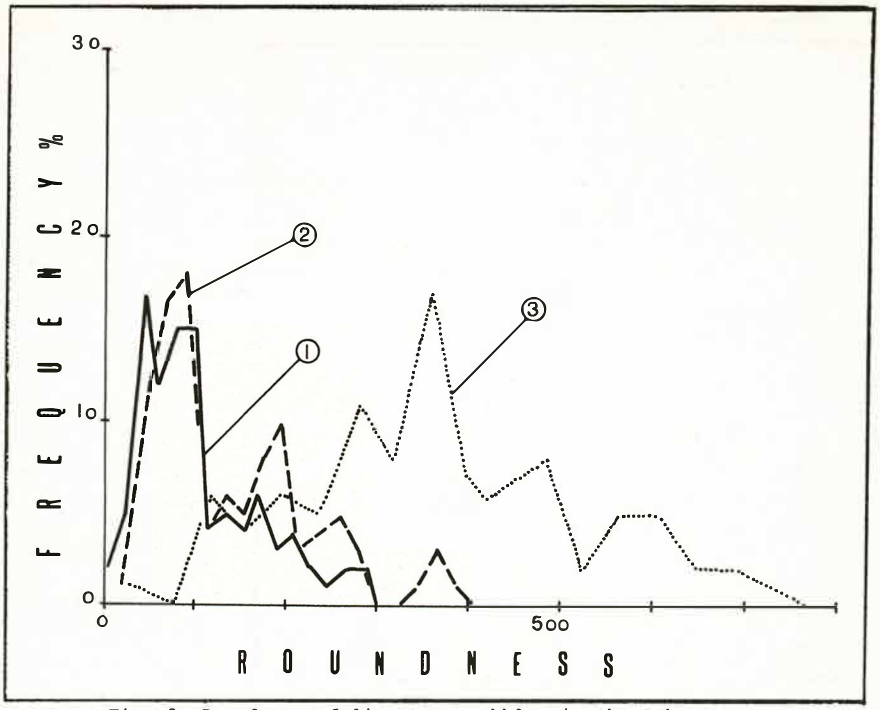

Fig. 3 Roundness of limestone pebbles in the Lokva - Vipava river bed
1 - ponor of Lokva
2 - siphon in the Lokva ponor cave
3 - Vipava springs

Karst, Covered Karst and Interstratal Karst in Glaciated Lowland Terrains of Canada

D. C. Ford
Department of Geography, McMaster University, Hamilton, Ontario, Canada L8S 4K1

Abstract

Palaeozoic reefal, lagoonal and platform limestones and dolomites of great variety, very extensive salt deposits, abundant gypsum and anhydrite, cover the Canadian craton between the Shield and the Western Cordillera. There is little tectonic deformation, 25% of the strata outcrop today, the remainder are covered by varying depths of Mesozoic siliciclastic rocks. Topographic relief is low. The entire area has been repeatedly glaciated by continental ice sheets; the Wisconsin (Wurm) sheet receded 14.5-8.0 Ky B.P. in different localities. The region is south of the modern limit of continuous permafrost.

Inhibiting, obstructing and erasing effects of glacial action upon karst forms and karstification are considered. They most profoundly affect the carbonate rocks, which are least soluble; postglacial karst is limited to 'point-to-point' systems and a few integrated, but small, regional karsts developed because of local preferential factors. An extensive dolomite pavement is preserved intact, hydrologically active but hydrochemically inert, beneath glacial clays at Winnipeg. Karstification of gypsum is scarcely inhibited but the extent to which modern landforms are truly postglacial in origin, rather than rejuvenated, is uncertain. Salt karst shows the greatest variation; some buried palaeokarst forms have been inert since the Palaeozoic, others were rejuvenated as recently as the last deglaciation, some collapses have propagated through 1000 m of cover strata during postglacial times. The role of glacial isostatic flexing as a deep groundwater pumping (rejuvenating) mechanizm is discussed.

Résumé

Entre le Bouclier et la cordillière occidentale, le craton Canadien est recouvert d'une grande varìeté de calcaires et dolomies récifals, laguniers et de plateforme de l'âge paléozoique, de dépôts salins trés vastes et de gypse et d'anhydrite abondants. Il y a plu de déformation tectonique. Seulement 25% de la strate est exposé à ce jour, le reste étant recouvert de roches siliciclastiques Mésozoïques d'épaisseur variable. La topographie est peu accentuée. Toute la région a été recouverte à maintes reprises par de grands glaciers continentaux; le retrait du glacier Wisconsin (Würm) remonte à 14500-8000 ans A.P. dans differéntes laocalitiés. La région se trouve au sud de la limite moderne du pergélisol continu.

L'inhibition, l'obstruction et l'obligation de formes et procédes karstiques par l'action glaciaire sout discutés. Ces facteurs affectent le plus profondément les carbonates, qui le moins solubles; le karst post-glaciaire est limité à des systémes "point-à-point" et a quelques karst régionaux intégrés, mais de petite étendue, développés par l'action de facteurs préférentiels locaux. A Winnipeg, un vaste pavé de dolomie est préservé intact, hydrologiquement actif mais hydrochimiquement inerte, sous les argiles glaciaires. La karstification du gypse est à peire inhibitée, mais à quel point les formes modernes de terrain sout véritablement glaciaires d'origine, plutôt que rajeunies, demeure incertain. Le karst salin exhibe la plus grande variation; quelques paléokarts enterrés sont demeurés inertes depuis le paléozoïque, d'autres furent rajeunis aussi récemment que la dernière glaciation. Quelques effondrements furent propagés à travers 1000 m de strates supérieures pendant l'holocéne. Le rôle due rebondissement isostatique entant que mécanisme de pompage d'eaux souterraines profondes (rajeunissement) est discuté.

The Regularities in the Formation of Gas Composition of the Air in the Large Karst Caves of Podolia and Bukovina

A. B. Klimchuk[1], N. L. Yablokova[1], and S. P. Olshtynsky[2]
[1]Institute of Geological Sciences, Academy of Sciences of the Ukrain, Kiev, USSR and
[2]Institute of Geochemistry and Physics of Minerals, Academy of Sciences of the Ukrain, Kiev, USSR

Knowledge of gas composition of the air of the karst caves is rather poor. In some of the few publications dealing with this problem an increase of the carbon dioxide content in the air of the karst caves is considered to be a general law. Some regularities were revealed by a special investigation of the gas composition of the air in the caves of the Crimea, which was carried out in 1963-1973 by V. Dublyansky and U. Shutov. According to these authors (2,3) CO_2 content of the air in the caves is normally 10-30 times that on the surface. In the cavities laid in the vicinity of fractural dislocations and large faults, carbon dioxide content of the air increases up to 1-7, 5 volume per cents (a 250 times increase compared with the average composition of the atmospheric air). At the same time in fractured zones of the karst caves and shafts the nitrogen content increases (up to 82%), CH_4 appears (from traces to 6,7%) and heavy hydrocarbons (ethene, propene, isobutene, n-butene from traces to 1,08%). V. Dublyansky and U. Shutov consider the anomalies in the content of these components in cave air to be related to the inflow of the dry gas currents of different composition from the abyssal parts of the section along the fractures. V. Dublyansky have noted (2) that carbon dioxide component is of more complex genesis. The quantity of CO_2 in the air of the caves can change influenced by the inflow of the dry gas currents of the CO_2 composition along the fractures, carbon dioxide being taken from the soil together with the air and infiltration waters, in oxidizing processes in zone of aeration, in connection with thermodiffusion processes, owing to CO_2 separation in the formation of carbonate and cave hydrogenous ice (2). The part of each of these processes in the formation of gas composition of the cave air is difficult to determine.

Our knowledge of the dynamics of variation of the gas composition of the cave air is rather poor. A season character of the variations of gas composition may be traced for some caves of the Crimea. In the warm period of the year the abundance of the most variable gases mainly of carbon dioxide, increase, which is connected with decrease of the intensity of the air exchange with the surface as compared to the cool season (2,10).

Recently, a special study of the gas composition of the air of some gypsum labyrinth caves of Podolia and Bukovina (West Ukrain) was fulfiled. Up to present only scanty information about the air composition of some caves of Podolia are available, which could be found in the works on speleotherapy (1).

Method of Investigation

The gas composition of the air of the caves was investigated by means of sampling and their subsequent analysis in the laboratory. The samples were taken into special glass amplules provided with a vacuum rubber tube and a clip at each end. The ampule volume is 50 cm^3. A control measuring has shown stability of the gas composition of such hermetically sealed samples during their transportation and storage. It was established at the same time that if the air samples were sealed in the turned bottles with the salt plug (which is widely used in sampling) their gas composition changes considerably and this mode of sampling does not fit.

Analysis of the ampluled samples had been carried out in the laboratory with the gas chromatograph LHM-7A, on the cores with polysorb-1 of 5m long and molecular sieves 10X of 3m long. Helium was used as a gas bearer with the velocity of 70 ml/min.

In some cases the measurings of CO_2 content were carried out by express-method (8) in the places of sampling with the control purpose (directly in the cave). The agreement with the chromatographic data are within O,I volume %.

The total sampling and measurements were made at 1 m height over the floor. There places of sampling were recorded. At some places the samples were taken successively at 0.1; 0.5; 1.0; 2.5 height to study gas stratification through the cross section of a cave. At the moment of sampling air pressure and temperature were measured.

To solve the problem of carbon dioxide genesis in the air of the caves some samples were taken for analysis of isotopic composition of carbon of their CO_2. The analysis was made by a precision mass-spectrometric method. CO_2 separation for analyzing was carried out by barbotation of the air through sodium hydrate solution. In the laboratory the concentrated product was subjected to the phosphoric acid procession and the escaped CO_2 gas after refining was introduced into mass-spectrometre MI-1201 through the three-channeled injection system SNI-3. The ^{13}C abundance is measured relative PDB standard as the value of $\delta^{13}C$ with ±0,4% deviation.

The Object of Investigation

Large labyrinth caves of the Western Ukraine, the gas composition of which was studied, are located within the South-West edge of the East-European platform, in the interstream surface of the left sub-parallel tributes of the river Dniester. These are well known caves: Optimisticheskaya, Ozhernaya, Cristalnaya, Mlynky, Verteba, Atlantida, formed in the 10-30 metres thickness of upper Neogene and loose Quorternary deposits. In 1975 a new large cave Zolooshka is found in the Dniester-Prut interflave (7). About 60 km of galleries have been mapped in the cave Zolooshka by now. The cave is located in the zone of the Precarpathian depression and the thickness of sedimentary cover increases, as well as of surrounding gypsum. All these caves are horizontal, some of them showing a storied structure.

Noegene deposits of the left bank of the river Dniester are highly dissected by erosion and caves, formed in these deposits are very well aired. In respect of microclymate they all related to the dynamic type. Air exchange factor for various caves ranges from 1 to 2,5 times a day (4). In natural conditions the cave Zolooshka was in the zone of absolute saturation and moved into the zone of aeration as a result of a strong fall of water level, produced during 30 years by a nearby quarry.

In the course of studying of the gas composition of the air of these caves 130 samples are analysed. The most detailed analysis and reanalysis in different seasons was made of the caves Atlantida (70 samples, 15 sampling points, in two of them the samples were taken from different levels) and Zolooshka (30 samples, 4 sampling points, in two of them the gas was sampled from different levels). In the rest of large caves some particular samples or the groups of samples were taken mainly in a summer period (Optimisticheskaya, Ozhernaya, Cristalnaya, Mlynky, Verteba, Bucovinka, Kievlyanka).

Results and Discussion

As a result of present studies considerable variations are established in a gas composition of the air of different caves, in different points of one and the same cave, and in different seasons of the year in the same sampling points. The variations in the CO_2 content range from 0;05 to 4,24 volume %, that of the oxygen from 12,74 to 21,97 vol.%, and of the nitrogen from 77,54 to 84,69 vol. %. No other gas was found in the composition of the air of the caves.

Carbon dioxide is the most changeable component, its content being in all cases considerably greater than the average CO_2 content in the atmospheric air (up to 142 times).

The distribution of CO_2 content perpendicular to the floor of the cave appeared to be very interesting. Layer by layer sampling was carried out in the caves Atlantida and Zolooshka in 4 points; in some of them the sampling was made in different seasons. The CO_2 content in these sets of samples was found to decrease from the level of 0,1 m to 0,5 m and increases at the level of 1,0 m (reaching, as a rule, peak values) and decreases again by the level of 2,5 m. This regularity is illustrated in Figure 1. It is evident from this Figure that the variation of oxygen perpendicular to the floor is in most cases of the opposite character.

The sampling in different seasons was not strictly regular, still allowing to establish some definite peculiarities in season variation of the air in the cave of the air. Thus, the average CO_2 content in 14 points the cave Atlantida at the end of December 1979 - the beginning of January 1980 was 0.61 vol. % varying from 0.17 to 0.95 vol. %. In February 1980 the gas composition of the air was rather variable: CO_2 content of the air in different points of the cave ranged from 0.47 to 3.97 vol. %; the average content was 1.67%. In June the range of CO_2 variation was 0.14 - 0.5 vol.%; the average content being 0.29 vol. %. In November the range of CO_2 variation was 0.19 - 0.55, the average value being 0.36 vol. %.

Considerably higher content of carbon dioxide is characteristic for the gas composition of the cave Zolooshka as a whole: the average content in December - January was 2.74, in May 1.75, in August 0.96, in September 1.40, in October 1.82 vol. %; the minimum CO_2 content being 0.5 vol. %, and the maximum 4.24 vol. %.

A seasonal variation of the gas composition of the air in the cave is illustrated in Figure 2. Oxygen reveals the opposite type of variation, and that of nitrogen is similar to CO_2 variation.

In some samples, taken during a summer - autumn period in Optimisticheskaya, Ozhernaya, Cristalnaya, Mlynky caves CO_2 content ranged from 0.05 to 0.31 vol. %.

Thus, carbon dioxide content in the air of the caves in Podolia and Bukovina clearly shows a seasonal variation. Maximum CO_2 contents correspond to winter period, minimum - to summer - autumn period. It is contrary to the seasonal gas composition variation characteristic of the Crimean caves (2).

Somehwat lowered values of oxygen content in the samples of the cave Zolooshka are worthy of attention. The average oxygen content for all samples from this cave is 17.5 vol. % ranging from 12.74 to 20.58 vol. %; having low values in summer and winter periods. Low O_2 content are established for some points in February for Atlantida cave.

Seasonal variation of gas composition of the cave air of this region is to be related to seasonal character of the processes, forming the peculiarities of gas composition of the cave air on one side, and to seasonal changing of the microclimate regime of the caves on the other hand.

The results of gas analysis being in volume per cents does not permit to evaluate a real degree of changeability of a component from the data on its variations. As the effect of the atmospheric air is the main factor, forming the gas composition of the air of the caves it is necessary to relate the measured gas contents with a certain atmospheric standard. For each sample the following estimations have been made. The relation of any two gas components of the atmospheric air was taken as a standard. On this relation "atmospheric" contents of these two gases for each sample were found by substitution a measured value of the third component. "Atmospheric" contents were compared with measured content of the gas in question in the sample and thus a degree of changing of a given component under the influence of subterranean factors was evaluated.

The analysis performed made it possible to find out that nitrogen content in the cave Atlantida in all seasons of the year appears to be close to a theoretical value, but in February the nitrogen content in several points increases as compared to the theoretical by 3-6%. The ratio of measured oxygen to theoretical O_2 approximates 1 in December - January, July and November. In February the decrease of measured O_2 content as compared to the theoretical value reached 14.5%. A measured carbon dioxide content many times exceeds a theoretical one for all samples (from 6 to 142).

In the air of the cave Zolooshka all components of the air are subjected to changes. Here as in Atlantida carbon dioxide content is subjected to the largest changing as compared to the theoretical value: the ratio of measured to theoretical value of CO_2 content ranges from 10 to 150. In all the seasons the measured value of oxygen is less than a theoretical value by 4 - 20%, reaching sometimes 37%. A measured value of nitrogen content exceeds a theoretical one by 3-10%.

The data presented show that all components of the initial atmospheric air mixture are subjected to some or other degree of changing. In the aerated zone of a sedimentary rock mass subjected to karstification processes occur resulting in carbon dioxide enrichment of the initial atmospheric air, oxygen consumption and producing certain amount of additional nitrogen. At least some of the processes, producing anomalies in subterranian air medium should have distinct seasonal variations. Processes, resulting in oxygen consumption in the air of the caves, its CO_2 and nitrogen enrichment are the most intensive in the cave Zolooshka.

A variety of possible sources of carbon dioxide supply to the cave air makes it difficult to define the processes, causing the increase of its content in the air of the caves in question only on the basis of the data presented. Some additional information may be received from isotopic analysis of CO_2 carbon of the cave air. The analysis was made of eight samples taken in four points of the cave Zolooshka in August and October. $\delta^{13}C$ abundances for analysed samples are given in Table 1.

Table 1. Isotopic carbon composition of carbon dioxide in the air of the cave Zolooshka.

N of sampling points	August		October	
	CO_2 vol. %	$\delta^{13}C$ %	CO_2 vol. %	$\delta^{13}C$%
1	0.5	-38.9	0.8	-42.4
2	1.18	-30.7	1.61	-28.2
3	0.81	-28.3	1.01	-36.4
4	2.57	-31.7	4.24	-38.4

An average $\delta^{13}C$ value for atmospheric air is known to be -7.0% (6). ^{12}C enrichment of carbon dioxide in the air of the cave Zolooshka (average value of $\delta^{13}C$ = 34.4%) excludes the influcnec of the an inflow of endogenous carbon dioxide along the fractures and makes us to look for such sources of CO_2 supply which could provide that considerable light carbon enrichment of CO_2 in the air of the caves.

For conditions characteristic of the cave Zolooshka two most probable processes which could be responsible for the carbon dioxide enrichment of the initial atmospheric air: 1) inflow of soil CO_2 together with infiltration water; 2) oxidation of organic matter present in surrounding deposits and cave clays.

The effect of the former and partly of the latter processes is well correlated with seasonal variations established in CO_2 content. Beside CO_2 generation the latter process would have to result in an oxygen consumption and producing a certain amount of nitrogen which is also established by present study. However, the observed ^{12}C isotope enrichment of carbon dioxide of the air of the cave Zolooshka cannot be explained by these only sources of carbon dioxide. According to E. M. Halimov (5) the average $\delta^{13}C$ value of soil carbon dioxide is -24.7% ranging from -21.1 to -27.5% and isotopic organic carbon composition of lagoon and fluvial deposits has $\delta^{13}C$ = -26.2%, according to W. Sackett and R. Thompson (9).

Carbon dioxide whose carbon is enriched in ^{12}C as compared to organic matter, may be genetically related to nothing else but methane (5).

The conditions in Neogene deposits of the region of the cave Zolooshka are favourable for development of anaerobic microorganisms, methane being one of the products of their metabolism. Methane, produced by anaerobic microorganisms in sedimentary rocks is enriched in light carbon ($\delta^{13}C$ = -63.0%), and with its oxidation to CO_2 this carbon is included to the CO_2 composition. Mixture of carbon dioxide of such genesis with carbon dioxide of the abovementioned sources results in a carbon isotopic composition of carbon dioxide, which is observed in the air of the cave. The fact that we failed to find methane in the samples tested may be due to its complete oxidation into CO_2 on one hand, and on the other hand with high migration ability of the gaseous methane and its transferance into overlying reservoirs or with the outcrop into atmosphere through overlying deposits.

The works carried out are considered to be as a preliminary stage of the more extensive specialized study of gas composition of the air of the caves in order to establish the laws of its formation. To achieve this purpose it is necessary to conduct regime investigations: study of daily and seasonal dynamics of gas composition changing, including isotopic research. The changes in gas composition of the air of the caves are to be closely related to the peculiarities of cave morphology and their current dynamics.

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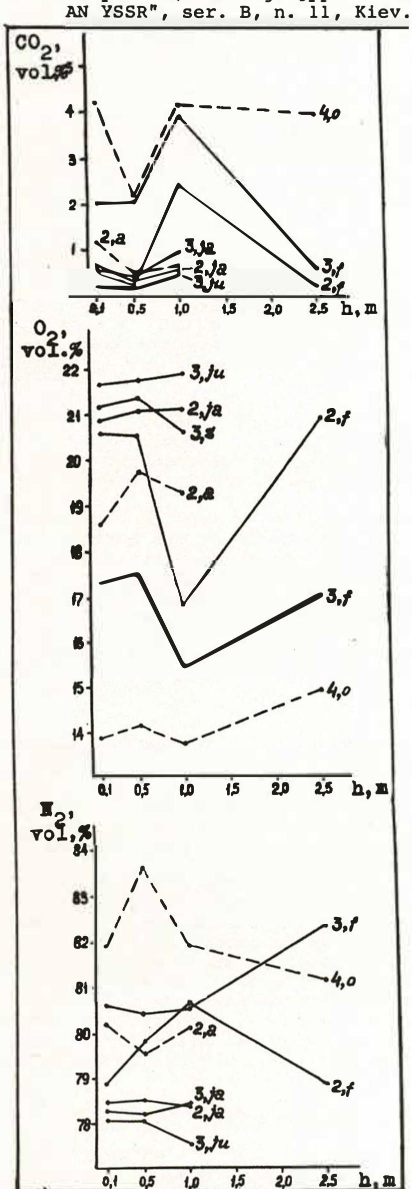

Figure 1. The distribution of separate components of caves air gas composition perpendicular to the floor.

——— the samples from the Atlantida

– – – the samples from the Zolooshka

The points of selection of the samples are given by numbers; the month of selection are given by letter indexes:

ja - January
f - February
ju - June
a - August
s - September
o - October

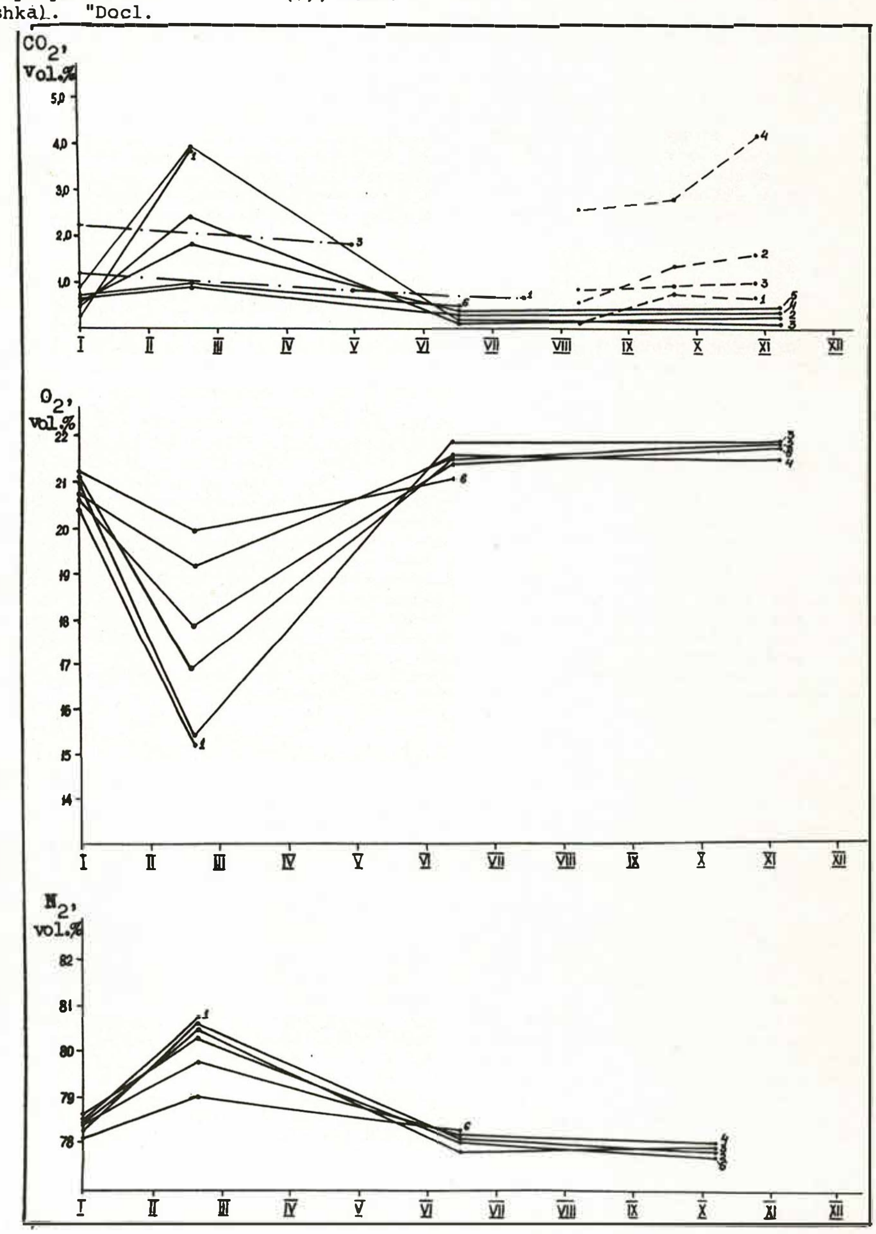

Figure 2. Seasonal variation of gas composition of the air in the caves of Podoliya.

——— the samples from the cave Atlantida (1980)

– – – the samples from the cave Zolooshka (1980)

—·— the samples from the cave Zolooshka (1978)

The points of selection of the samples are given by numbers

Ecology and Taxonomy of Marine Cave Invertebrates in The Bahama Islands

Jerry H. Carpenter
Northern Kentucky University, Highland Heights, KY 41076 U.S.A.

Abstract

The invertebrates of Lighthouse Cave on San Salvador Island, Bahamas, have been studied since 1978 to determine species diversity, food chains, habitat specialization, salinity tolerances, and biological rhythms. Over 25 species have been collected including the following: six isopods, four sponges, three snails, three featherduster worms, one shrimp, two copepods, two ostracods, one tunicate, two pseudoscorpions, one wasp, and one cockroach. At least five of these species are new to science and are in the process of being described by the author and his colleagues. Several other species are suspected to be new.

The entrance to Lighthouse Cave is about 2 km from the ocean, but sixty-cm tidal fluctuations in the cave show that underground connenctions to the ocean exist. The unusual habitat provides a protected area for the volution of endemic marine cavernicoles. Time-lapse movies indicate that some species maintain tidal rhythms after being removed from the cave. At least one endemic appears to have a fairly great tolerance to changes in salinity (from 35% to 12%).

Observations in the cave and laboratory have lead to several tentative conclusions about the food web: (1) bat and cockroach guano seems to provide much of the food for the other terrestrial species; (2) any terrestrial organisms that fall into the water may be eaten by aquatic scavengers, especially crustaceans; (3) aquatic filter-feeders such as sponges, tunicates, and featherdusters grow in fairly large populations due to the tidal mixing of bottom sediments high in organic debris.

The faunas of some other Bahamian caves are compared to that of Lighthouse Cave.

Résumé

Les invertébrés de la Caverne Lighthouse de l' île San Salvador, Bahamas, sont étudiés depuis 1978 pour déterminer la variété des espéces, les chaînes alimentaires, la spécialisation de l'habitat, la tolérance de salinité, et les rythmes biologiques. On a colletioneé é(espéces parmi lesquelles: six isopodes, quatre éponges, trois escargots, trois vers-plumeaux, une crevette deux copépodes, deux ostréidés, un tuniqué, deux pseudoscorpions, une guépe, et une blatte. An moins cing de ces espéces sont nouvelles pour la science, et l'auteur et ses collégues sont en train de les décrire; On suppose que plusieurs autres espéces soient nouvelles.

L'entrée de la Caverne Lighthouse est située à environ 2 km de l'océan, mais les fluctuations de la hauteur de l'eau dans la coverne--fluctuations d'environ 60 cm, dûes à la marée -- indiquent qu'il y a des connexions sous-terraines avec l'océan. L'habitat spécial offre un milieu protéjé pour l'évolution des cavernicoles maritimes endémiques. Les films realisés indiquent que certaines espéces maintiennent leurs rythmes de marée, même aprés avoir été enlevées de la caverne; Au moins une endémie paraît avoir un remarquable degré de tolérance aux variations de salinité (de 35% a 12 %).

Les observations faites dans la caverne et au laboratoire nous ont permis de tirer plusieurs conclusions provisoires en ce qui concerne le reseau alimentaire: (1) le guano des chauves-souris et des blattes parfaît fournir la plupart de la nourriture des autres espéces terrestres; (2) chaque organisme terrestre qui tombe dans l'eau peut être mangé par less éboureurs aquatiques, surtout par les crustacés; (3) les animaux aquatiques qui se nourissent de plancton, tels les éponges, les tuniqués et les vers-plumeaux, se multiplient d'une façon considérable grâce au mélange -- causé par la marée -- des sédiments des profondeurs riches en débris organiques.

Je vais présenter une comparaison entre la faune maritime de la Caverne Lighthouse, et celle des cavernes des autres îles de l'archipel Bahamas.

Introduction

In 1978-81 I examined for invertebrates five caves on San Salvador Island and two on Cat Island, Bahamas. Most of the caves are not presently connected to the ocean, although they were formed thousands of years ago by movements of tidal waters (Mylroie, 1978); these isolated caves contain few organisms and will be mentioned later.

This paper deals mostly with Lighthouse Cave on San Salvador. This small cave differs much from the others in that it connects with the ocean (about 2 km away) so that tidal fluctuations of about 60 cm occur twice daily. Biologically it is the richest, most interesting cave I have seen. This richness comes from a rare combination of factors: (1) large populations of bats and cockroaches provide much food for other organisms, (2) the cave is in a tropical environment, so food supply is fairly constant, (3) the tides bring in food, and (4) ocean water seeps in so slowly that horizontal water movement is nearly undetectable, thus, the aquatic organisms live in a calm, protected, organic soup. The result of these factors is an unusually large assemblage of terrestrial and marine organisms; many of the species grow in rather big populations, some are troglobitic, some are apparently endemic to Lighthouse Cave, and at least five are new species, which are being described by my colleagues and myself. I have observed the species enough to analyze the trophic levels and their interactions and have studied in detail the behavior and ecology of some of the cave's inhabitants.

Materials and Methods:

I found over 25 different species of animals in Lighthouse Cave and a few in other Bahamian caves. These were identified through taxonomic keys, identification guides, original descriptions, taxonomic experts (e.g., from Harvard Museum, Smithsonian Institution, and Scripps Institution), and comparison with museum specimens. In this report I do not identify most species by their species names because in some cases the species descriptions are not yet published and in others the species are not yet conclusively identified; where I do not use species names I use other taxonomic categories.

Food webs were determined by observing the location of organisms in the caves, by baiting the caves, and by studying feeding mechanisms and predatorprey relationships of cultured animals.

I studied activity rhythms of the cirolanid isopods (a new genus and species) by taking time-lapse 8 mm movies of the organisms in plastic cubicles 3 cm square. A Bell and Howell movie camera with close-up lenses was activated by a timer to shoot one frame every 2 minutes. Thus, a 50-foot (=15,3m) film was exposed over about 3 days. After development, the films were analyzed to see how many times/hour each organism moved.

I tested the cirolanid isopods' tolerance to reduced salinity by adding small amounts of freshwater to the culture container over several weeks.

Results and Discussion:

Because Lighthouse Cave contains relatively large amounts of food from several sources and because there are so many species interacting, food webs are complex. To illustrate the interactions simply, I have outlined the food webs by listing the food sources and placing species in trophic levels characterized by type of habitat (terrestrial or marine), type of feeding mechanism, and type of food source.

I. Food Sources at base of detritus food chain:
   A. Affecting terrestrial and aquatic webs;
      1. bat guano containing bacteria, arthropod parts, plant parts from insect gut
      2. bat bodies containing above
      3. roach guano containing bacteria, plant and animal parts from food outside
      4. roach bodies containing above
      5. urine from bats
      6. flying insects: flies, evaniid wasps
   B. Affecting aquatic web only:
      1. saltwater seeping in from ocea -- brings food for suspension feeders
      2. algae growing in cave

II. Aquatic food chain:
  A. Sedentary suspension feeders feeding on bacteria from tide waters, feces, decay: sponges, colonial tunicate, protozoans (e.g., Vorticella), rotifers, featherdusters (Spirorbis, tube worms)
  B. Motile suspension feeders: protozoans (e.g., Paramecium), planktonic cyclopoid copepods
  C. Deposit feeders: benthonic harpacticoid copepods, ostracods, burrowing polychaet worms, and asselote isopods
  D. Scavengers and/or predators: cirolanid isopods, Barbouria cubensis shrimps, and Rivulus marmoratus kilifish

III. Terrestrial food chain:
  A. Scavengers: ~~snails~~ (3 spp.), isopods (4 spp.), roaches (Periplaneta americana)
  B. Predator -- pseudoscorpions

Studies on the rhythmicity of organisms from Lighthouse Cave should be interesting because the habitat is unique. While many terrestrial and freshwater troglobites have apparently lost their diurnal rhythmicity after thousands of generations in a cueless environment, this may not be the case with species from Lighthouse Cave because of the tidal influence. Preliminary experiments were performed on five cirolanid isopods several weeks after removal from the cave and transport to Kentucky. Three specimens seemed to show increased activity roughly every 12.8 hours, indicating some association with tidal activity; I did not detect rhythmicity in the other two. Subsequent tests were also inconclusive. Thus, although I believe tidal rhythmicity exists in this species, more experiments are needed to determine under what conditions the rhythmicity is expressed.

My interest in the cirolanid isopod's tolerances to salinity changes is due to the fact that this is the only troglobitic cirolanid found in a marine environment. This is in contrast to about 180 nontroglotibitic marine species in the family and about 20 troglobitic species in the freshwater caves in Mexico, Cuba, Texas (U.S.A), and Virginia (U.S.A.). It is generally assumed these freshwater species had marine ancestors which were left stranded when high sea waters receded; gradually, with the influx of rain, the marine waters changed to freshwater. For some species this probably occurred in the Cenozoic Era (about 55 million years ago); for others, it probably occurred in the Late Cretaceous Era (about 135 million years ago) (Bowman, 1964). Since the waters of Lighthouse Cave still have a more-or-less direct connection to the ocean the habitat could be described as anchialine. Holthuis (1973) coined the term anchialine (from the Greek anchialos, "near the sea") for the habitat in a "pool with no surface connection to the sea, containing salt or brackish water, which fluctuates with the tides." The cirolanid from this cave may have existed in the subterranean habitat for millions of years. However, since it is the only troglobitic cirolanid known in an anchialine habitat, it is an "ecological missing link" in the evolution of troglobitic cirolanids. It would be interesting to learn how tolerant such a "missing link" is to changes in salinity to determine if it has a pre-adaptation to hyposalinity. Thus, the following experiment was performed.

One specimen was placed in a jar containing 100 ml of saltwater (35%). Small amounts of freshwater were addeded every day for more than 2 weeks, at which time the salinity was calculated to be 12%; the animal acted normal during this period of salinity reduction, but at 12% it became very lethargic, sickly, and lacking in equilibrium. I increased the salinity to 17% by adding water at 35%, and the animal returned to normal within 24 hours. A week later I again started reducing salinity by daily adding small amounts of freshwater; after 10 days and at a salinity of 12% the animal became lethargic and sickly. I again increased the salinity to 13%, let the animal adjust for 3 weeks, then gradually reduced salinity over a period of 6 weeks, at which time the salinity was 10% and the animal suddenly died.

Although I used only one specimen in this experiment, the results are fairly clear. This species apparently can tolerate surprisingly wide ranges in salinity, but it cannot quickly adapt to freshwater conditions. It could probably adapt to freshwater in a few generations, if changing conditions necessitated such adaptation for survival.

In contrast to Lighthouse Cave, other Bahamian caves I have explored contain relatively few organisms even when bats and/or cockroaches are present. However, a few discoveries are worth noting. An unidentified species of symphlan (a uniramian arthropod) was found under a rock in Little Bat Cave on San Salvador. An unidentified amblypygid (a chelicerate arthropod) was found under a rock in Goat Cave on Cat Island. Most caves contained terrestrial isopods, Porcellionides pruinosus and Stenoniscus sp. Blackish Well Cave on Cat Island contains brackish water with numerous unidentified non-troglobitic aquatic snails. Coastguard Cave on San Salvador contains saltwater tidal waters similar to that of Lighthouse Cave; one red shrimp (Barbouria cubensis) was seen, but the physical proportions of the cave make exploration for other marine organisms very difficult.

Conclusion

The marine cave habitat is extremely fruitful for investigation. The food web is surprisingly complex. Few Biologists have explored such caves for several reasons including the fact that this type of cave is relatively rare. I encourage fellow biospeleologists to seek out and study marine caves from around the world.

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Phases of Karstification in the Paleogeographic Development of Poland's Territory

Jerzy Glazek
Institute of Geology, Warsaw University, 02-089 Warszawa, Poland

Abstract

Within the territory of present day Poland the paleokarst of various ages was recorded in many places. This records in the platform territory outside the Carpathians may be grouped in four phases: post-Variscan, Late Carboniferous-Middle Triassic, post-Old Cimerian/Upper Triassic-Middle Jurassic/, post-Young Cimerian/Lower Cretaceous and post-Laramian/Whole Cenozoic. In the northern Carpathians two phases are proved: post-Turonian - pre-Eocene and post-Middle Miocene. In every phase of karstification on the karst development was long and may be divided in some stages.

Spatial Aspects of Histoplasmosis in the United States

George Huppert
Department of Geography, University of Wisconsin, La Crosse, Wisconsin

Abstract

The dimorphic fungus, Histoplasma capsulatum, is the etiologic agent in causing histoplasmosis, a systematic mycosis of animals including humans. The disease manifests itself in a wide variety of symptoms with a great rang of severity.

Histoplasma capsulatum is closely associated with animal droppings, in particular those of birds and bats. In addition, it seems to require moist conditions, low altitudes, a river basin location, and moderate to slight temperature changes. These conditions correlate highly with the environmental conditions which exist in the classic karst areas of much of the United States. Histoplasmosis was discovered to be endemic in the human populations of many of these areas from tests which showed positive results in over eighty per cent of the sampled populations in some locations. Specific regions found to have a high incidence of the disease are the central Mississippi River Valley and its tributaries, sections of the Appalachians, central Texas, and southern New Mexico.

Résumé

Le champignon dimorphique Histoplasma capsulatum est l'agent étiologique responsable de l'histoplasmose, une mycose généralisée dans le système des animaux, humains inclus. La maladie se manifeste par une grande veriété de symptômes dont la gravité est très étendue.

L'Histoplasma capsulatum est en rapport étroit avec la fiente des animaux, surtout celle des oiseaux et des chauvessouris. De plus, ce champignon semble exiger des conditions climatiques humides, de basses altitudes, une localisation dans le bassin d'une rivière, et des changements de températures allant du modéré au faible. Ces conditions correspondent tout à fait avec les conditions du milieu qui existe dans les zones de Karst classiques de beaucoup des Etats-Unis. On a découvert que l'histoplasmose était endémique dans la population de plusieurs de ces zones, d'après des tests qui ont révélé des résultats positifs dans plus de 80% des populations échantillonnées dans certaines locations. Les régions spécifiques, où l'on a trouvé un grand nombre de cas de la maladie, sont localisées dans la vallée centrale du fleuve Mississippi et de ses affluents, dans certaines parties des Appalaches, au centre du Texas, et dans le sud du Nouveau-Mexique.

Speleological literature contains little reference to histoplasmosis with the exception of descriptive writings by W. R. Halliday (1949, 1959, 1966, 1974, and 1976). This is in spite of the fact that it can infrequently be a debilitating, even fatal, disease to which many speleologists are commonly exposed. This author will explain the nature of histoplasmosis and its spatial distribution to a group of individuals intimately exposed to it.

Histoplasmosis is a noncontagious systemic mycosis of animals, including man, caused by the dimorphic fungus Histoplasma capsulatum. The name was erroneously given to the fungus in 1906 by Dr; Samuel Darling, an Army pathologist, in the belief that it was a protozoan (Emmons, 1955, p. 627). Human infection can present itself in a variety of clinical manifestations including an uncommon disseminated type which is often fatal if left untreated. Davies and Jessamine (1975) describe five forms of histoplasmosis, including asymptomatic, acute benign, acute disseminated, chronic disseminated, and chronic pulmonary. The authors (Davies and Jessamine, 1975) describe the types of the disease as follows: The asymptomatic form, as its name implies, shows no overt symptoms of its presence. It is usually only detected by a skin test and/or by X rays of the lungs. Generally no medical action is necessary. The acute benign type is the most commonly occurring variety of histoplasmosis; however, it is often misdaignosed or overlooked as it is frequently quite mild and can mimic other respiratory illnesses. The manifestations of the infection can range from a slight cold to a high fever, cough, and chest pains. Usually recovery is assured without specific treatment. Acute disseminated cases are most often found in infants and young children. Frequently it can resemble tuberculosis. If not properly treated, this form of histoplasmosis is usually fatal. The chronic disseminated type ordinarily occurs only in adult males and exhibits a wide variety of symptoms, depending upon which organs are affected. Fever, anemia, weight loss, endocarditis, and meningitis are typical afflictions. In some victims intestinal lesions suggest that infection was not due to inhalation but rather to ingestion of the spores. The prognosis for disseminated histoplasmosis is poor if left untreated. Various drugs are effective in combatting it as well as chronic and progressive cases. The last form of histoplasmosis is chronic pulmonary which greatly resembles chronic pulmonary tuberculosis on X rays. This variety is again most commonly found in adult males. It generally progresses over a long period of time, though occasionally it goes into remission; sometimes even a spontaneous cure occurs. The chance of cure for primary pulmonary cases is good, with bedrest and decreased activities prescribed.

Darling's later research and that of others shows that histoplasmosis has a spatial pattern of occurrence that is largely restricted to river valleys in warm temperate to tropical climates, but the disease is not unknown in cooler areas. According to Emmons (1955) the determination of the geographic distribution of histoplasmosis has been hindered by the lack of modern laboratory facilities in many of the endemic areas, and because of the ability of the disease to mimic other afflictions, especially in tropical areas. Ajello (1958) states that the disease was considered rather rare until the benign form was detected in 1945. Histoplasmosis soon became recognized as a widely prevalent disease and a serious health problem. Edwards and Billings (1971) shows, through the use of skin test surveys of human populations, that the greatest prevalence of histoplasmin sensitivity is in the United States. Other areas of high occurrence are localized in Central and South America and southeast Asia.

Histoplasma capsulatum has temperature and humidity requirements that limit the infection geographically. Furcolow (1965, p. 5) states:

> These conditions have not been defined, but are associated with rather low altitude, river basins, lack of excessive temperature changes, and rainfall, which in the endemic areas in the United States appears to be between 35 inches and 50 inches per year. Even in the endemic area of H. capsulatum infection, where skin test rates may be as high as 80% among adults, it is clear that the infection is not evenly distributed throughout the area, but is localized to certain areas where the environmental conditions are satisfactory for the growth of the organism.

Another very important factor for the growth of the organism is edaphic enrichment with the manure of birds or bats. With the knowledge that these environmental factors are needed for the growth of the fungus, it can now be seen that the association of histoplasmosis with karst areas is more coincidental than causative, more related to the fact that many karst areas are located in warm, humid regions as are large bat populations. Histoplasmosis is endemic in the human population of much of the Missouri, Mississippi, Illinois, Ohio, and Tennessee River valleys, and much of the southeastern United States, the heart of North American karst country. Incidentally, the south central and southeastern United States are also major regions of poultry production, a source of the necessary manure.

Positive skin test reactions are higher that 80% in adults of some localities (Edwards and Billings, 1971, p. 189). Edwards and Billings (1971, pp. 290-310) also list the results of skin test programs from around the world, which supports their premise of the occurrence of histoplasmosis largely in warm temperate to tropical climates with some exceptions. Interestingly, they record the highest sensitivity (93%) in a group of 14 teenagers who visited a cave near Aguas Buenas, Puerto Rico (p. 305). They also point out an unusual paradox of the disease (p. 310):

> Results of skin-test surveys indicate that

millions of persons have been infected with H. capsulatum, yet only a small proportion of the infected persons develop [sic] clinical disease. Is this a function of the size of the infecting dose or the route of infection? Do most infections involve such small numbers of organisms that development of skin sensitivity is the only sign, whereas clinical disease develops from an unusually large infecting dose?

The available evidence tends to support this latter possibility. Reports of attempts to isolate H. capsulatum from soil illustrate the most invariable association between successful isolations and outbreaks of acute clinical disease in a small group of persons who had a common experience a week or so before the first clinical case appeared. In most instances, a patient's history of possible exposure during some unusual type of activity, such as exploring a cave or cleaning out an old barn, suggested the most likely place to look for the fungus in [sic] the soil or other material.

However, they (Edwards and Billings, 1971) point out that isolating the source of infection is not always that easy, especially in cases where there is no common history of exposure from a point source of contamination.

Several studies (Manos, Ferebee, and Kerschbaum, 1956; Ajello, 1958; Edwards and Palmer, 1963; Edwards, et al., 1969; and Goodwin and Des Prez, 1978) present or reproduce earlier maps of the distribution of positive histoplasmin reaction in the United States. The highest instances of sensitivity in the country are the already mentioned warm temperate to subtropical river valleys. However, some anomalous areas also appear on all of the maps. Some possible explanations for the more notable anomalies are as follows:

1. The high incidence of histoplasmosis in south central Texas, southern Arizona, and southern New Mexico can be related to the occurrence of many caves and large bat populations in all three areas.
2. All of the maps show a high positive reaction level for human populations of the Central Valley of California. Probably this is due to the numerous poultry farms in the area, the warm though dry climate, and moisture provided by the extensive irrigation projects in the area. This is also an area of high occurrence of coccidioidomycosis (valley fever), which is a similar disease that may obscure the mapped intensity of histoplasmosis (Halliday, 1974, pp. 253-254).
3. The Appalachian Mountains show as an area of high positive reaction on all of the maps. Again this is due to the warm, wet climate and the large bat populations, many roosting in caves.
4. The Delmarva Peninsula of the Mid-Atlantic states is another center of poultry farming, which may explain its high positive reaction.

There are several other small and widely scattered areas of high incidence of positive reaction to histoplasmin skin tests which elude immediate explanation without more detailed information on the specific occurrences. They are most likely related to exposure to a point source of infection such as a bat or starling roost or a poultry farm.

Furcolow (1965, p. 4) estimates that in 1965 there were some 30 million Americans infected with the fungus, with an additional 500,000 individuals contacting it each year. Chick (1971, p. 310) estimates that the number of infected individuals had risen to 40 million with the rate of increase still at 500,000 per year. At the present time, ten years later, that growth rate would give an amazing number of 45 million. This means that about 20% of all United States citizens have been infected with histoplasmosis, and this is most likely a conservative estimate.

It can readily be seen that histoplasmosis is not an uncommon disease and that quite high rates of infection exist in the classic karst areas of the United States, though for reasons generally unrelated to the karst. Speleologists should be aware of the possibility of contacting the disease; that some of its forms, while quite rare, can be very severe or even fatal; and that it can frequently go unrecognized by the medical profession.

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Palaeokarst as a Key to Paleogeography, Poland's Territory as an Example

Jerzy Glazek
Institute of Geology, Warsaw University, 02-089 Warszawa, Poland

Abstract

Current paleogeographic synthesis are constructed on the interpretations of marine or huge continental formations. But these formations cover less than 50% of geological time in platform areas. Within the time of stratigraphic gaps here and there were preserved deposits filling the karst forms. These deposits had recorded very important data for palaeogeographic speculations, but they need special care during investigation. Some examples are discussed.

Complex Groundwater Basin Migrations in Roppel Cave, Kentucky

Miles E. Drake and James D. Borden
Box 357, Franconia, New Hampshire 03580 and 9315 Friars Road, Bethesda, Maryland 20034

Abstract

The Central Kentucky Karst, the area surrounding the Flint-Mammoth Cave System, is certainly one of the most famous karst regions of the entire world. This area has been extensively dye-traced to delineate the basic, modern groundwater basins. As present cave streams may somewhat reflect past groundwater basins, general flow-trends can be inferred from dye-tracing. Several major cave systems have been found in this region; and one, in particular, seems to lie in an area that straddles several groundwater basins, past and present.

Roppel Cave, one kilometer east of Mammoth Cave National Park, consists of a series of large tubes and canyons that interconnect in a complex way that can be shown to be indicative of multiple groundwater basin migration. Past basins were clearly undercut by encroaching, more efficient basins. Series of individual intra-basinal cutoffs were found in the vicinity of a beheaded basin's previous boundary. Each successive cutoff represents headward propagation in an attempt for the basin to achieve its own equilibrium. These cutoffs may be separated from the true interbasinal stream piracies.

Two modern groundwater drainage basins; one draining to Pike Spring, to the northwest, and the other to Turnhole Spring, to the west; have been dye-traced from active streams in Roppel Cave. Some of the low-gradient passages of the Turnhole Basin were pirated into the lower-level, higher gradient Black River component of the Pike Basin. There is some evidence indicating that other passages, perhaps in other paleohydrologic groundwater basins, may have had streams that migrated to both the Turnhole and Pike Basins.

As groundwater studies and surveys of caves continue in the Central Kentucky Karst, it is likely to be found that groundwater basin migration in the vicinity of Roppel Cave is more complex than presently known; and may include other major groundwater drainage basins, such as Lawler Blue Hole, Echo, and others. Work on this very complex problem will continue with earnest into the future.

Résumé

Le Karst du Kentucky Central, la région qui entoure le système des grottes Flint-Mammoth, est certainement une des règions les plus connues du monde entier. Cette règion a été colorée assez souvent pour suivre la piste des bassins souterrains de base modernes. Comme les ruisseaux actuels peuvent avoir un certain rapport à des bassins souterrains anciens, on peut inférer la direction générale d'écoulement. Plusieurs systèmes majeurs de grottes ont été découverts dans cette région; un d'entre eux, en particulier, semble se trouver dans une région contenant plusieurs bassins souterrains anciens et actuels.

La Grotte Roppel, d'un kilomètre à l'est du Parc National de la Grotte Mammoth, comprend une serie de grands conduits et de canyons qui se relient d'une manière complexe qui indique la migration multiple des bassins souterrains. Des bassins anciens étaient évidemment interceptés de dessous par d'autres bassins plus efficaces qui s'avançaient. Une série de détachements intra-bassinals isolés était trouvée dans les environs des bornes antérieures d'un bassin tronqué. Chaque détachement successif représente la propagation vers le cours supérieur tandis que le bassin essaye de parvenir à un équilibre. On peut séparer ces détachements des interceptions regulières des ruisseaux interbassinals.

Deux bassins de drainage souterrains modernes, l'un qui draine dans l'eau de source Pike au nord-ouest, et l'autre qui draine dans l'eau de source Turnhole à l'ouest, étaient tracés par coloration des ruisseaux actifs dans la Grotte Roppel. Quelques passages de gradation bas du Bassin Turnhole étaient enlevées au niveau plus bas et à la gradation supérieure de la Rivière Black, une partie composante du Bassin Pike. Il y a des indications que d'autres passages existent, peut-être dans d'autres bassins souterrains paléohydrologiques, et qui ont pu avoir des ruisseaux émigrant au bassin de Turnhole, ainsi qu'au bassin de Pike.

Pendant que les études des eaux souterraines et des grottes continuent dans le Karst du Kentucky Central, il est probable qu'on découvrira que la migration du bassin souterrain aux environs de la Grotte Roppel est plus complexe que ce qu'on connâit actuellement. It pourrait exister d'autres bassins de drainage majeurs, comme le Lawler Blue Hole et l'Echo. Le travail sur ce sujet trés complexe continuera avec beaucoup d'effort dans l'avenir.

Roppel Cave is located under the Mammoth Cave Plateau within the Central Kentucky Karst, two km east of Mammoth Cave National Park. Although the entrance is in a small valley that drains part of the western flank of Eudora Ridge, most of the surveyed passages lie under the northern lobe of Toohey Ridge.

Roppel Cave has more than 40 km of surveyed passages. Passage configurations vary from low, wide elliptical tubes to high, narrow canyons. At least 12 km of Roppel Cave are passages suggestive of regional origin, having carried water from the sinkhole plain three km to the south and east, to springs along the Green River.

Complex interrelationships between at least two groundwater basins has led to the development of a zone of interbasinal piracies. In this zone, a long history of groundwater basin migration can be observed.

Two modern groundwater basins have been delineated by dye-tracing from active streams in Roppel Cave with the cooperation and support of Dr. James F. Quinlan, National Park Service, Mammoth Cave National Park. Black River has been traced to Pike Spring, 6.3 km to the northwest. Upper Logdon's (Hawkins) River has been traced to Cedar Sink of the Turnhole Spring basin, 13.3 km to the west. As will be shown, many of the major known passages in Roppel Cave at one time drained to the vicinity of one or the other above mentioned streams.

For the purposes of this paper, some of the past basins shall be defined as Turnhole or Pike Basin when suggested paleoflow seems to have drained to the vicinity of the present groundwater basin. The distinction between "piracy" and "cutoff" shall be defined in terms of their basinal relationships. Piracies occur between two groundwater basins. Cutoffs occur within the same groundwater basin.

Migration of the groundwater basins through piracy is suggested by radical changes of flow direction, which can be found within Roppel Cave. The oldest known evidence of a master river within Roppel Cave is the Currens Corridor/Yahoo Avenue drainage (Map I), whose flow direction was north and west. This is supported clearly by scallop configuration. Several associated levels suggest that this was a primary corridor for an extended period of time.

At "B" (Map I) Yahoo Avenue trends more westerly, first as a breakdown filled stoopway, then for over a kilometer as a 3-4 meter high, 5-7 meter wide tube with excellent solution pockets in the ceiling. Yahoo Avenue is lost at a deep canyon known as the Rift. It is expected that paleoflow continued at the same elevation prior to the formation of the Rift, but further exploration of this area is needed to confirm this.

Water was "pirated" away from Yahoo Avenue at "B" down a slightly lower-level passage, Downy Avenue. Well-defined scallops on the walls confirm paleoflow from "B" to "E". The passage at "E" has been more recently interrupted by a series of domepits. Although plugged with breakdown at this point, the continuation may be reached by way of another passage. Down Avenue continues beyond this breakdown to the north at the same elevation with similar size and paleoflow to "F", where it becomes almost filled with sediment and is lost. This abrupt change of flow direction is believed to be an indication of an early basin migration. Water flowing down Yahoo Avenue to a spring to the west is pirated to a groundwater basin draining to a spring to the northeast.

A later piracy, this one from Downy Avenue, occurred at "D". A three meter high and five meter wide passage, Arlie Way, formed to the east, turned south at "G" to "I" and beyond. This latter point has been hydrogically connected to the stream dye-traced to Turnhole Spring. Paleoflow from "D" to "G" was confirmed by scallop analysis but paleoflow from "G" to "I" was difficult to determine. Two intersections give evidence suggestive of southward flow. The floor of Hobbit Trail grades into Arlie Way and the passages join at a graded angle to the south. The direction of paleoflow in Hobbit Trail has been established by scallops and associated canyons as being towards Arlie Way. It does not seem likely that water flowing down Hobbit Trail would make such an abrupt turn back to the north. At "H", where Arlie Way splits into Walter's Way and South Arlie Way, the former is incised below the latter. If flow was to the south, water must have abandoned South Arlie Way for Walter's Way. Floors slope southward along both passages, and because the incision would most likely have been made under more vadose conditions, flow would have had to be to the south.

The Arlie Way piracy may be the most extreme example of groundwater basin migration yet to have been discovered in Roppel Cave. Water flowing north out of Downy Avenue was captured by another basin which attracted the flow to the south underneath its headwaters. The outlet to the west for this piracy may have been in the vicinity of Turnhole Spring.

A series of lower levels intersect Arlie Way south of the junction of Hobbit Trail. These levels are sub-parallel to Arlie Way and are for the most part vadose canyons with scallops and ceiling gradient clearly showing paleoflow to the south. This evidence strongly indicates a southward paleoflow in Arlie Way.

The North Crouchway is a phreatic tube eight to 12 meters wide and less than two meters high that meanders between "G" and "K". Paleoflow evidence is lacking, thus no strong conclusions can be made. No scallops have been found and the various passage intersections provide conflicting evidence. Local drainage trends, however, do suggest flow was possibly to the north as a later, parallel component to Downy Avenue. Several cross passages connecting Downey Avenue and North Crouchway suggest such a relationship.

The Black River Complex (Map II) contains many examples of intrabasinal cutoffs. At its earliest, the flow trended westward in Kangaroo Trail as a tributary to the North Crouchway. The flow was later beheaded in the vicinity of Pirates Pot, and flowed as a tributary to Lower Level Arlie Way, part of the Turnhole drainage. Later, water was again pirated--this time northward towards Pike Spring. This northward flow, Black River, pirated water from Kangaroo Trail in increasingly more efficient routes ("X_n"s on Map II). At present, water flows down a vertical shaft, Pirates Pot, to flow directly into Black River, en route to Pike Spring.

As Roppel Cave is viewed from an overall perspective, it is apparent that a complex hydrologic history was involved in the formation of its passages. Roppel Cave is one of the few caves known in the Mammoth Cave Region that straddles such a large number of major groundwater basins. Roppel Cave is a large and crucial piece in the overall hydrologic puzzle of the famous cave region.

As groundwater studies and surveys of caves continue in the Central Kentucky Karst, it is likely to be found that groundwater basin migration in the vicinity of Roppel Cave is actually more complex than presently known. As the cave is explored further, other groundwater basins may be encountered such as Lawler Blue Hole, which receives drainage from Crumps Cave to the north and Echo Spring, which receives some drainage from Mammoth Cave. Work in this very complex system will continue through the very determined efforts of its project members.

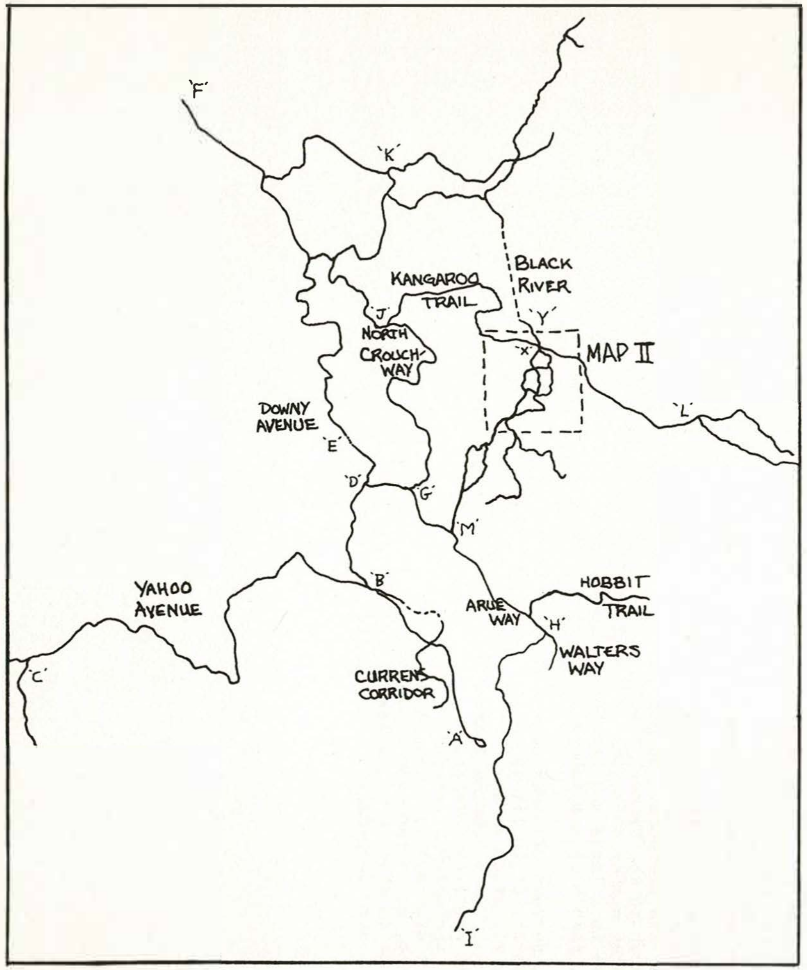
Table 1. Dye Tracing Data

Trace	Distance	Transit Time
Logsdon's River to Turnhole Spring (Cedar Sink)	13.3km	40d
Black River to Pike Spring	6.3km	8d
Entrance to Pike Spring	7.6km	14d
South Arlie Way to Pike Spring	7.5km	10d
The Rift to Pike Spring	5.5km	32d

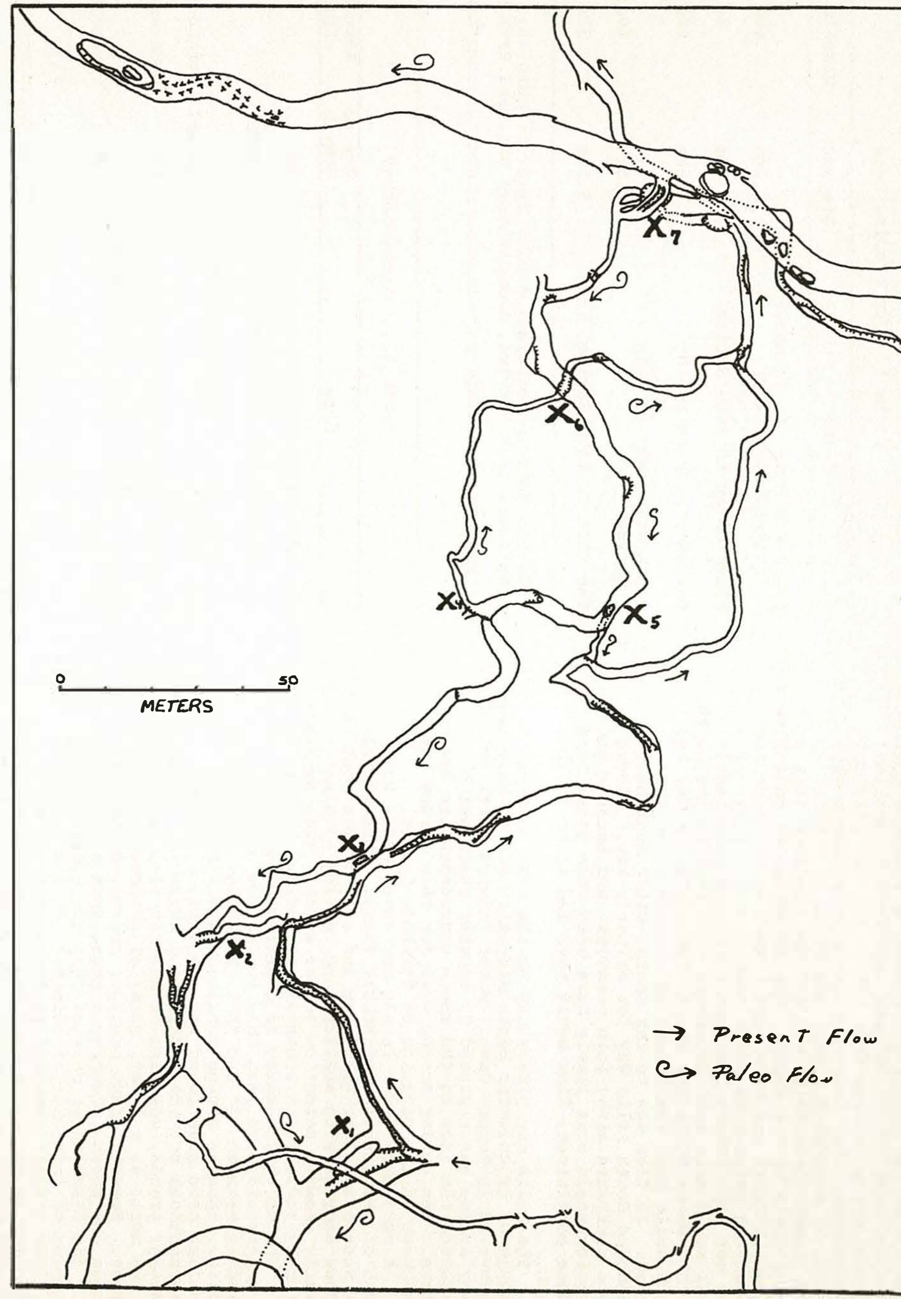
- Traces done in cooperation with James F. Quinlan, National Park Service, Mammoth Cave National Park

Table 2. Paleohydrology

Flow	Key to Map I	Associated Spring
Currens Corridor/Yahoo Avenue	ABC	?
Currens Corridor/Downy Avenue	ABDEF	?
Currens Corridor/Downy Avenue/ Arlie Way	ABDGHI	Turnhole
Kangaroo Trail/North Crouchway	LJ	Undetermined
Kangaroo Trail/Lower Level Arlie Way	LM	Turnhole
Kangaroo Trail/Black River	LXY	Pike



Map 1. Roppel Cave—Barren and Hart Counties, Kentucky.



Map 2. Roppel Cave-Black River—Hart and Barren Counties, Kentucky.

Proteidae Prey Detection and the Sensory Compensation Problem

J. P. Durand[1], J. Parzefall[2], and B. Richard[1]
[1]CNRS, MOUSIL 09200, France and [2]Zoologische Institut, D 2000 Hamburg

Abstract

This series of experiments is intended to show the possibility of blind cave living animals perceiving their preys at a distince by chemoreception. The experiment was conducted in choice chambers which received two kinds of water: tap water and water which passed over the Gammarus or the Chironomid larvae. The Proteus much better than the epigean Proteidae, Necturus, show a definite preference for the water which had passed over living preys. An experiment was done with preys, immobilised by freezing, to eliminate detection by vibrations. The reaction of the animals is the same as in the previous experiments but only the delay of reaction is lengthened. In all these experiments Proteus react slowly but more regularly and resolutely than Necturus.

Résumé

Dans cette série d'expériences on montre la possibilité pour les animaux cavernicoles aveugles de percevoir leurs proies à distance par la chémoréception. Les expériences sont faites dans des "chambres à choix" qui reçoivent deux sortes d'eau: de l'eau sans rien et de l'eau qui a traversé une chambre contenant des Gammarus ou bien des larves de Chironomidae. Le Protée bien mieux que le Proteidae épigé Necturus montre une nette préférence pour l'eau ayant passé sur des proies vivantes. Une expérience est faite avec des proies immobilisées par congélation pour éliminer la détection par les vibrations. La réaction des animaux est la même que précédemment, mais les délais de réaction, quand il y en a, sont allongés. Dans toutes ces expériences, Proteus réagit lentement mais plus franchement et avec plus de régularité que Necturus.

Preface

In memory of Albert Vandel, Member of the Institute, founder of the subterranean Laboratory of Moulis, deceased in 1980. His scientific work in Evolutive Zoology and in Biospeleology will always have a place in our work.

Introduction

From Murray (1857) to Matic (1958), naturalists think that the loss of vision, confirmed in real cave animals, is necessarily accompanied by a "conpensatory hypertrophy" of other sensory organs. The history of research on cave living animals is based mainly on the idea of "regressive evolution". In 1909, Eigenmann called his work on the cave Vertebrates of America "A study in degenerative evolution", and after works of other authors, Thines in 1969, published "Regressive evolution of cave and abyssal living fishes". However, Jeannel (1926-1930) points out errors in the theory of sensory compensation. Vandel (1964-1965) states that the negative cases are as frequent as the positive if one compares the cave living animals to their counterparts on the surface. This phenomenon appears not only with the cave animals, see Vandel, 1965, but also in the same manner with the abyssal fishes, see Thines, 1969; Menzies et al., 1973.

We compared the chemoreceptors performances of Proteus anguinus with those of another Proteidae, Necturus maculosus, of the lakes and streams of North America. First it was necessary to prove the existence of the chemoreception of the two species, this faculty not yet having been proved with many Caudata living on the surface, as Madison (1977) and Joly (1979) state. For this purpose we used the vital necessity for a blind animal living exclusively in a cave biotop to localise its prey and to identify its sexual partners.

Material and Methods

The tests were conducted with 10 Proteus of 150 to 250 mm in length and 28 Necturus of 250 to 350 mm in length, maintained in brightness of 2 to 4 lux. The animals were placed in methacrylate choice chambers. The preys were placed in a receptacle which communicated with the chambers by a filter and a tube of 2 meters long. In another identical tube tap control water flowed. Wilcoxon matched-pairs-signed ranks test was used in the calculation.

Results

A. Detection of Living Prey at a Distance

Test 1 - Detection of Chironomidae Larvae by Proteus. After trial test the flow of water is fixed at 120 cm^3/mn and the number of larvae at 30. The Proteus significantly chose the tube receiving water from the Chironomidae receptacle.

Test 2 - Detection of Chironomidae Larvae by Necturus. After trial test the number of Chironomidae larvae was 40. After 5 minutes there was no significative response; but after 3 h and 8 h, the response was significative. The movements of Necturus are more rapid but the choice is established after a longer period of time, while the number of larvae is 25% greater.

Test 3 - Detection of Gammaridae by Proteus. The water flow is 250 cm^3/mn. The number of Gammarus is 60. Proteus clearly prefer water coming from the Gammarus receptacle.

Test 4 - Detection of Gammaridae by Necturus. The number of Gammarus is doubled (120). No significative response, but a slight preference is shown for water coming from Gammaridae.

Test 5 - Detection of Lumbricidae by Necturus. The poor performance of Necturus with Gammarus and Chironomus led us to test its favourite food in rearing, the Lumbricidae (12 gr) but without success: 5 mn (n = 12, ns), 3 h (n = 12, ns) and 8 h (n = 12, ns).

B. Detection of Dead Prey at a Distance

The preys are frozen to isolate the chemical information transported by the particle or dissolved in water;

Test 6 - Detection of Dead Chironomidae Larvae by Proteus. Proteus significatively prefer water flowing from 8 g Chironomidae.

Tests 7 and 8 - Detection of Dead Chironomidae Larvae by Necturus. The test is insignificative with 8 g and 24 g of Chironomidae: 5 mn (n = 14, ns), 3 h (n = 14, ns) and 8 h (n = 14, ns).

Test 9 - Detection of Dead Gammaridae by Proteus. The choice of Proteus is insignificative with 6 g of dead Gammaridae after 5 minutes but is however significative after 3 hours.

Test 10 - Detection of Dead Gammaridae by Necturus. Results insignificative with 6 and 8 g of dead Gammaridae; a slight preference evident with 12 g.

The 10 tests lead us to believe that Proteus recognize water having passed over prey but the Necturus performance is lower.

C. Control Experiments

Test 11 - Control with Proteus. The animals can choose between 2 tubes receiving the same water. The test indicates that null hypothesis can be accepted: 5 mn (n = 10, ns), 3 h (n = 10, ns) and 8 h (n = 10, ns).

Test 12 - Control with Necturus. No difference for Necturus. 5 mn (n = 15, ns), 3 h (n = 13, ns) and 8 h (n = 12, ns).

Test 13 - Reinforcement of the Choice of Proteus by its Markings. After a short delay (5 to 10 mn) the animal doesn't recognise the tube visited, but after a longer delay (3 to 8 hrs) a reinforcement is possible.

Test 14 - Reinforcement of the Choice of Necturus by its Markings. Necturus perhaps recognises its tube after a short delay (5 to 20 mn) but not after.

Test 15 - Influence of Rheotropism on Proteus. The rheotropism test is very positive.

Test 16 - Influence of Rheotropism on Necturus. Necturus shows only a slight preference for running water.

In conclusion, thigmotactism and rheotropism can incite animals to enter the tubes but cannot influence them on their choice. This choice is perhaps fixed after many hours by the marking of the animal. Proteus can mark their substrat by a substance it secretes which remains stable for 3 or 5 days (Parzefall, 1976). Chemical information plays a social role by marking of territory by the male and the recognition of sexes. This substance has been found with the Necturus. Intra and inter-specific recognition can also be made by substance transported by water (Parzefall, et al., 1980).

Discussion

Proteus, and in a less degree Necturus, can recognise territory, hiding place, sexual partners and related species by chemoreception. Proteus performances are superior to that of Necturus in detection of prey by substance transported by water. The good performance is a sign of adaptation to aquatic life. Proteus only take live and mobile prey and its mecanoreceptors have a place in predation. The difference between the chemoreceptors performances of Proteus and Necturus is probably not only sensory. On the other hand, Poulson (1963) in connection with the cave fishes, underlines that "capacity to integrate sensory information as reflected by ability to detect prey and avoid obstacles or remember their position also increases". Proteus is probably better adapted to find prey more rare in its biotope than that of Necturus.

The problem of compensation that we have raised would be badly posed if it were posed in anthropomorphical terms of intentional compensation to the loss of vision. If it evokes the possibility of life in a particular environment as the hypogean one despite the loss of vision and owing to the development of other senses such as the olfactive sense, it enters into the general case of adaptation to its biotope. Our results therefore show that with cave living animals there is no compensation but supplying and improving of senses.

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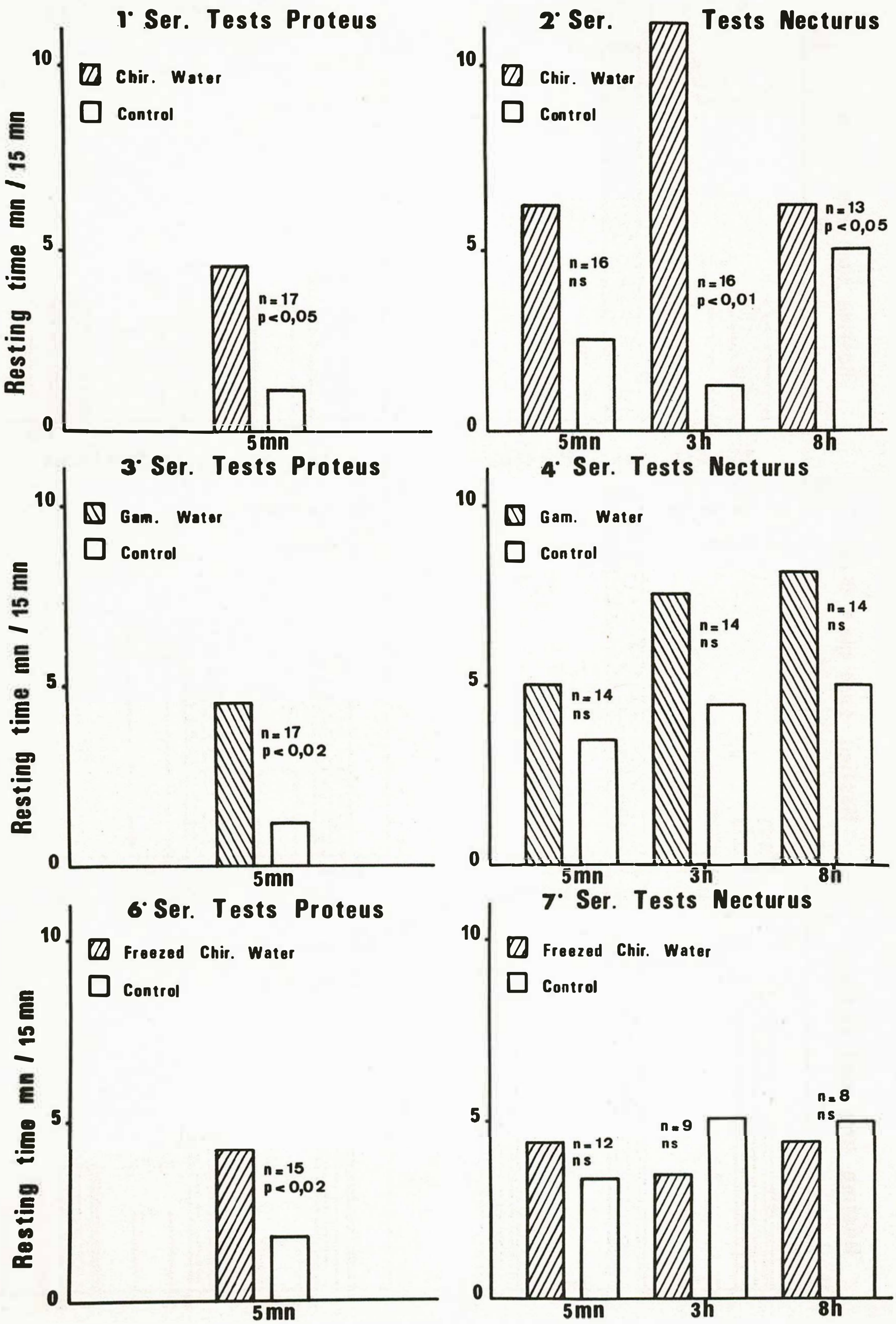


Figure 1. Summary of test results (1, 2, 3, 4, 6, 7).

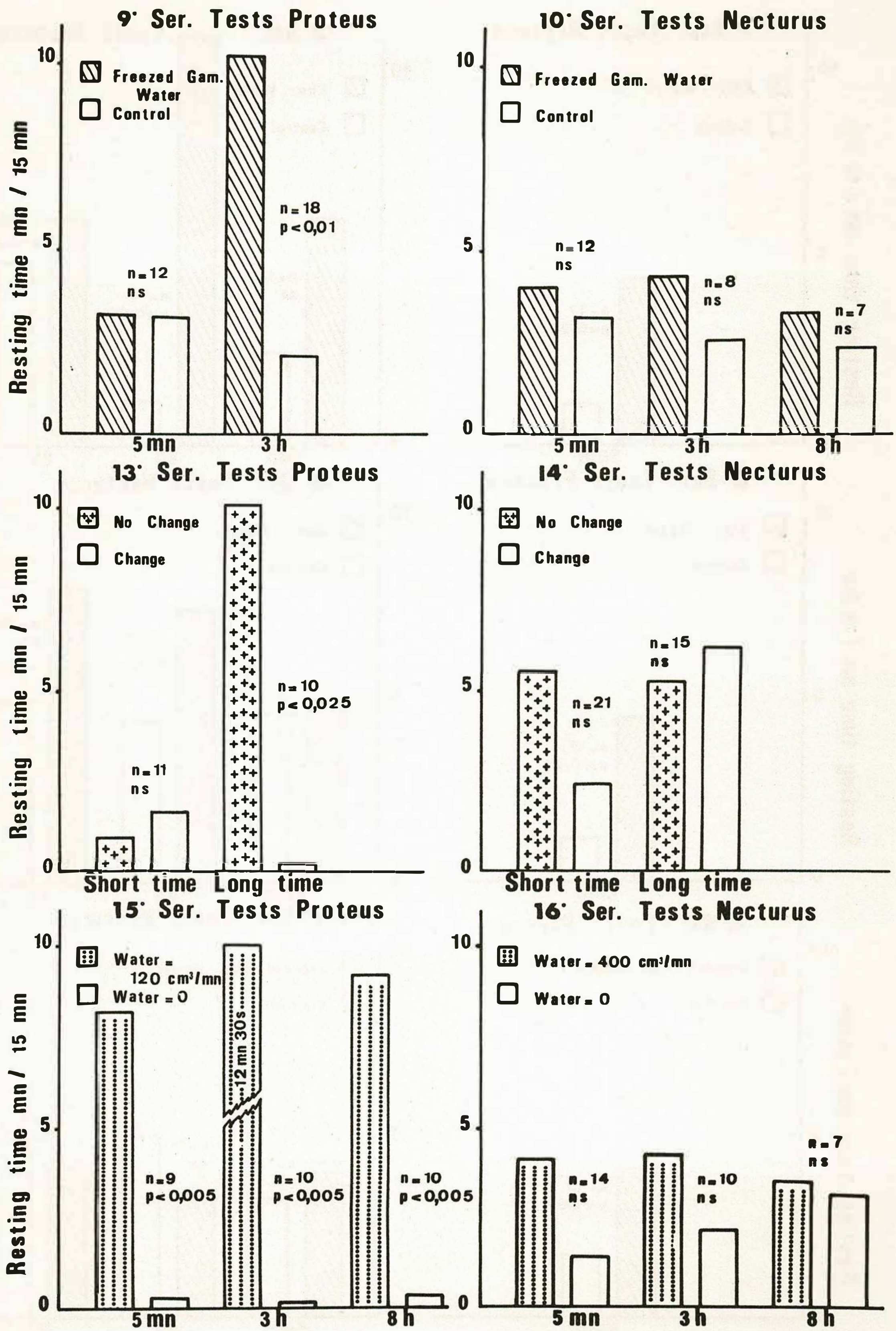


Figure 2. Summary of test results (9, 10, 13, 14, 15, 16).

Organizational Principles of Complex Stationary Researches of Karst

A. B. Klimchuk, V. M. Shestopalov, and G. V. Lisichenko
Institute of Geological Sciences, Academy of Sciences of the Ukrain, Kiev, USSR

1. Karst-speleological researches, active conducted last decades, give us a possibility to reveal many important general and regional regularities in karstification. In spite of wide scope, detailization and duration of these works, even for well-studied regions of the USSR in kars-speleologic respect mainly is typical "ronte" degree of research. For all that, many important problems of karstology and hydrogeology of karst area can not be decided (especially in quantitative respect) on the stage of "ronte" researches. Statement of regime stationary investigations of karstification in typical natural situations is up to date. In connection with preparation of such works in some karst regions of the Ukrainian SSR there were defined principles of organization of complex stationary investigations of karst, problem and direction of created stationary, mastered of optimal composite of methods and ways for the complex investigation of karst in different conditions.

2. Karstologic stationar is natural object which offers active karst system of that or another level (order) or functionally significant element of such system, which for long time was investigated on quantitative parameters of karst process.

Stationary investigations in karstology can have narrow direction in the decision of any private problems. But most important in science and practical relation is stationary directed to reveal regularity of the dynamic process in whole.

Surface water and underground water are the main active agent in karst, which different interaction with rock are the essence and specific character of karst process; the peculiarities and display of these interactions, mainly define hydrodynamic and chemical characteristics of kars water. It is clear that in karstological stationary of general type the principal attention must be spared to investigation of formation and regime of karst water in hydrodynamic and hydrochemical aspects. All-round research is a detail calculation and investigation of different factors (climatic, landscape, geostructural, lithological) which define main character of the dynamic of karst process, character interaction of underground with rock, and phenomenons which formed under these conditions.

3. The problem of definition of the level (order) of the object for karstological stationary of general type is principal too (drainage basin - cave - spring system; block with some elements of water-bearing system or karst system of more high level). Orientation of this stationary on elemental karst water-bearing system (drainage basin - cave - spring) is ineligible in connection with difficulties of the distinguish of this system which has a distinct and constant hydrogeological individuality. An individual element of this system, which has only private functional role (drainage basin - recharge; cave - transit; spring - discharge) is so much the more useless from this point of view. Statement of the regime stationary karstological investigation on the karstifiable block is methodically correct at that such block must has evidential hydrogeological independence and it is possible to make quantitative estimation of the recharge and discharge, to investigate peculiarities of the formation of different components of underground runoff under different conditions, and regime of underground runoff to investigate cooperations of elemental water-bearing systems within limits of block in different regimes.

The choice of the concrete object for the organization of the regime karstological stationar is very important (according to principales formulated above - of karstifiable block). The main demands for this block are:

- sufficient level of primary geological and karst-speleological research;
- typical geological, geomorphological, hydrogeological and climatic conditions for a great part of territory;
- presence in this territory complex of surface and underground karst forms, which represented of this region in whole;
- independence of hydrogeological regime of block (recharge, transit, discharge in the limits of block).

It is necessary to note, that in some cases is expedient organization of regime stationary researches in the objects which don't present the great part of territory and are unique, but permit to research some regularity of the process in a "pure" condition and the second and third points of demands formulated above are not absolute.

4. As an example we shall give characteristic of karstifiable block, choiced for the organization of regime karstilogical stationar in Podolsko-Bykovinsky karst region. Block is situated within the limits of monoclinal slope of southwestern outskirst of East-European platform. Sedimentary cover of old folded foundation of this territory is presented in the region of investigation by Paleozoic, Mesozoic and Cenozoic deposits. Among them subjected to karstification carbonate rocks Silurian and Cretaceous period, greatly, Neogene gypsum and anhydrite deposits. Left subparallel tributaries of river Dnister out into sedimentary cover at the depth of 100-150 m and divide this territory on separate platean-shaped massif. One of this massif - interstream of r.r. Seret-Nichlava - was chosen for the organization of the regime karstological stationar. From the south this block is limited by r. Dnister, from the west and east by r.r. Seret and Nichlava, and from the north by large tectonic dislocation, which has regional character. Surface of the block are characterized by the presence of typical closed karst basins with swallow holes and karst ponors. Groundwater recharge of the block is provided by influent and infiltration way. Discharge of different water-bearing horizons take place in slopes of erosional pattern and valleys of rivers both by means of descending springs from the upper water-bearing horizons and by means of discharge hearths of pressure waters from fissure-karstic zones in Silurian deposits. This hearths of discharge is covered by alluvium of r.r. Seret, Nichlava and Dnister and seldom visual observed.

The choice of this block for regim stationary investigations was conditioned also by so an important fact as presence of the great flooding karst caves such as Ozhernaya (109 km), Optimisticheskaya (140 km), Verteba (8 km) founded in gypsum stratum inside of the block. Presence of large cave systems in the region of block allow:

- detail investigate lithology-textural peculiarities of enclose rocks; detail investigate of jointing with distinguishing of hydrogeologically active systems; give objective quantitative estimation of inside karstification of gypsum series;
- to establish conditions and quantitative characteristics of recharge of underground water of water-bearing horizon of typsum stratum and lower situated water-bearing horizons by infiltrational, influational and condensational components; directly to researche the character of movement of underground waters in different parts of karst water-bearing systems; to receive calculate characteristics of underground flows; to estimate of underground water value storaged inside of karst caves; to study the character of co-operation of water-bearing horizon of Neogene gypsum with upper and lower situated water-bearing horizons;
- to obtain materials for differential estimation of intencity of sulphate karst at components of underground runoff and for different parts of karst water-bearing system;
- to obtain paleohydrogeological and paleogeographical information to the history of karst territory development and speleogenesis by means of morphologo-sedimentational analysis of caves and their deposits.

Therefore, the presence of large cave systems inside of the block choosed for the organization of regime karstological stationar is one of main demand to them.

5. Even under good initial geology-hydrogeological and karst-speleological study of block, choosed for stationary, detail complex "ronte" and half-stationar researche of territory must be first. Having purpose a quality estimation and something like quantitative study of conditions and factors of karstification in this block, these works must give a detail and concrete information for a very important stage in the preparation of stationar - programme-methodical stage. In the result of preceding stationar detail karst-speological researches must be secured opportunity:

- to elaborate common programm and method of regime stationar investigation, including common calculation schemes corresponding to studed natural conditions of this block;
- to elaborate concrete methods for each type of regime observations on stationar, include concrete calculation schemes, corresponding to the object of

application and its place of block;

- composition of surveyor network plan securing methodically well-grounded quantitative characteristic of the regime of process in whole and distinguish the most essential of it components.

The stage of detail complex "ronte" and half-stationar researches of block and programme-methodical stage are the most important moments in the organization of stationar, securing of it representative character, science and practical effectiveness, revealing the most essential regularities and correct quantitative characteristic of karst process.

6. On the Figure 1 is given a scheme of consecution and co-ordination of main stages of organization of regime stationary researche of karst.

7. As an example of optimal and necessary complex of research at the stage of detail investigation we show the programme for karstifiable block in West Podolye, characterized above. This programme being executed at a present time; separate types of these works and methods, which contain this programme, were mastered during hydrogeological and karst-speleological researches in different regions of Podolye conducted by the authors last years. The contents of this programme is given below.

a) The research of tectonic, neotectonic, lithological and geomorphological conditions of karst block development.

Types of researches:

- aerial photograph interpretation; morphometric analysis of topograptic maps by Filisofov method with distinguishing of main tectonic dislocations, corresponding them zone of jointing and local morphostructures;

- geological survey of the block (1:10000) with complex investigations of different lithological series of the block section and jointing in outcrops;

- research conditions of disclosure of different lithological-stratigraphic series of geological section by erosional-karst pattern;

- researche of geology of containing rocks under speleological observesion: researche of lithology-structural changes of gypsum stratum along the area (within the bounds of cave fields) and in section, researche of jointing typsum stratum with distinguishing of speleoinitiating, pre-speleogenetic passive and post-speleogenetic jointing systems. Revealing of geology-structural conditionality of different morphological elements of caves.

b) Research conditions of recharde of underground water of the block.

Types of researches:

- complex survey drinage basin of block with cartographical characteristic of landscape, topographic and geomorphological, conditions, defining redistribution of surface runoff (soil cover, vegatation, talwegs and lines of runoff, nidus of inflow); dismemberment of block alimentation region on elemental drainage basins and its classification according to the character of transferense surface runoff into underground runoff;

- analysis of meteorology data; definition maximum, minimum and average of several years seasonly and yearly characteristics of meteoelements;

- half-stationar and experimental researches for the definition of the landscape conditions of drainage basins (gradients, explosure of slopes, soil, vegatation, etc.) at a correlation of infiltration with surface runoff (or inflow).

c) Research of underground water discharge of the block.

Types of researches:

- mapping of all watercourses and springs in the area of the block, ascertainion belonging of springs to different water-bearing horizon, half-regime research of discharge and chemical composition of springs;

- by means of hydrometrical and radonometrical investigations - revealing of nidus of intake runoff in watercourse of r.r.Seret, Nichlava and Dnister; by means of electrical profiling - revealing and tracing of watery fissure-karstic zones, connected with these nidus, in Silurian carbonaceous deposits.

d) Research of underground water transit and interconnections of different water-bearing horisons of the block.

Types of researches:

- drilling works on divides and in the river valleys and conducting of water performance tests;

- mapping and studying of all types of waters in the caves of the block (dropwater, watercourse, laces, etc.); half-stationar observation for a level regime of underground water in caves; revealing of conditions, character and quantity inflowing water from surface and infiltration from situated above water-bearing horizons on the level of gypsum stratum; research of conditions and character of trasferense of underground water of the gypsum stratum into the situated below water-bearing horizons; estimation of cave of underground water quantity, storaded in caves;

- research of chemical composition of different components of underground runoff in several part of water-bearing complex (water sample taking on the point of intake in boreholes from different water-bearing horizons in different parts of caves of flowing, lake and condensational waters);

- by means of water trasing experiments - revealing of interconnections between separate water-bearing horizons, between elemental drainage basins on one side and concrete points of discharde on the other hand; revealing of transit directions and velocities of underground streams in different parts of the block.

i) Research of genesis and the history of development karst and caves of the block. Paleohydrogeological and paleogeographical reconstruction.

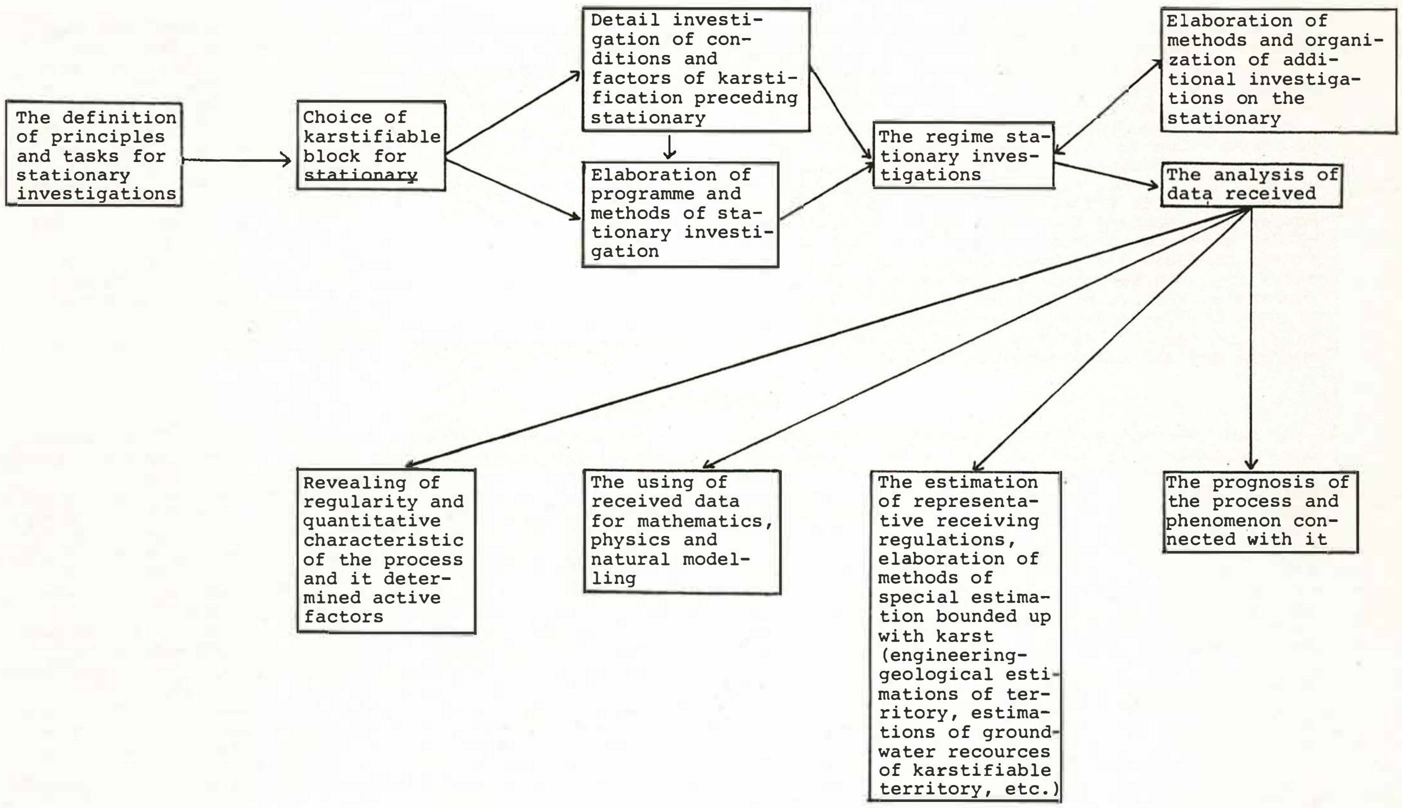
Types of researches:

- special morphological survey in Optimisticheskaya, Ozhernaya and Verteba caves with mapping of hydrogeologically significant meso- and microforms; definition and research of geologo-structural, lithologo-textural, hydrogeological factors of speleomorphogenesis. Morphological analysis with attraction of data from sedimentational and geochronological research of cave deposits - revealing of relative and absolute age of different morphological elements of cave systems and historical stages of cave systems formation;

- research of secondary deposits of caves, especially fluvial deposits; lithologic and stratigraphic parting of fluvial cave deposits sections; research of granylometric, mineralogical and chemical compositions of deposits along of sections and in different parts of cave systems, dating of cave deposits by paleomagnetical, palynological and other methods, that can be applied; paleohydrogeological analysis of the received data with definition of paleodischarges and paleorates of underground water on different stages of karst water-bearing systems development.

Fulfilment of this programme at the stage of detail complex research of karstifiable block, have been chosen for the organization of stationar, give a possibility to work out method and programme of redime stationar research in supplement of this block and at that properly take into consideration the concrete conditions of karst development. Only in this case one may to hope that organized a many years stationar research will be scientifical and practical effective and will be reveal of actually general and essential regularities of karst process.

Figure 1. Scheme of consecution and co-ordination of general stages of organization of regime stationary researche of karst.



Geology, Claciology and Geomorphology of the Castleguard-Columbia Icefield Area

D. C. Ford
Department of Geography, McMaster University, Hamilton, Ontario, Canada. L8S 4K1

Abstract

The karst and caves are developed in a plinth of resistant middle Cambrian limestones and dolomites 800+ m in thickness. At the base, the Cathedral Formation (300+ m, base unseen) is of very massively bedded, crystalline limestones: it hosts the principal caves. Succeeding it is the Stephen Formation, 60 m of argillaceous limestone, calcareious shale, minor gypsum and a prominent dolomite; it functions as an aquitard. The Eldon and Pika Formations total 400 m of limestone and dolomite laminates. Strata dip SE at 5-6°. Joints are few but of great lateral and vertical extent, as are a remarkable series of sedimentary dykes. The karst strata form a benchland intersected by a broad strath, the Meadows, and bounded by deep glacial valleys. Upper Cambrian clastic rocks are weaker and survive as horn-arête summit masses on the benches; they supply copious glacial debris.

The Columbia Icefield is a temperate icecap 10+ km in diameter and 300+ m thick resting on the highest benches. Saskatchewan and South glaciers drain it via the deep valleys. There are lesser, cirque glaciers draining to the Meadows or underground. Modern glaciers have receded 500-1000 m from prominent Neoglacial Terminal moraines. Outside of these, the benches are felsenmeere surfaces above 2300 m asl. At lower altitude are patches of till and moraine ridges of Wisconsin (Wurm III) age. In Holocene times and alluvial fan has built on the Meadows and local river gorges have been incised. Elsewhere, the carbonate terrain is a karren and doline alpine karst.

Résumé

Le karst et les cavernes sont développées dans un socle de calcaires et dolomies résistants datant du milieu du Cambrien et 800+ m d'épaisseur. A la base, la formation Cathedral (300+ m, base invisible) est composée de calcaires cristallins massivement stratifiés: on y retrouve les cavernes principales. Suit la formation Stephen d'une épaisseur de 60m, composée de calcaire argilleux, d'argile schilsteuse calcaire, de gypse mineur, et de dolomie proéminente; la formation agit en tout qu'aquitard. Les formations Eldon et Pika, d'une épaisseur totale de 400 m, sont formées de calcaire et de dolomies laminées. Le pendage des strates est de 5-6°. On compte peu de joints mais ils sont d'une étendue latérale et verticale considérable, tout comme une série remarquable de dykes sédimentaires. Les strates karstiques forment traversé par une large vallée, les meadows, et délimité par de profondes vallées glaciaires. Les roches clastiques du Cambrien supérieur sont plus faibles et subsistent sous la forme de sommets pic-arête sur les planches: ils provient beaucoups des depots morainiques.

Le champ de glace Columbia est une calotte glaciaire tempérée, 10+ m de diamétre et 300+ m d'épaisseur, reposant sur les planches plus élevés. Les glaciers Saskatchewan et South le drainent via les vallées profondes. Il existe de plus petits glaciers de cirque, drainant vers les Meadows ou sous la surface. Les glaciers modernes se sont retirés à une distance de 500-1000 m de moraines terminales néoglaciaires proéminentes. a part celles-ci, les planches sont les surfaces de felsenmeere au dessus de 2300m anm. A basse altitude, on retrouve des morceaux de till et des crêtes de moraine datant du Wisconsin (Wurm III). Au cours de l'Holocéne, une delta fluviale ont. développé sur les Meadows et des gorges de riviére ont ete incisees. Ailleurs, le terrain carbonate est un karst alpin de lapiés et de dolines.

Hydrology and Water Chemistry of Upper Sinking Cove, Franklin County, Tennessee

Jerry D. Davis and George A Brook
Department of Geography, University of Georgia, Athens, Georgia 30602

Abstract

Upper Sinking Cove, consisting of three closed depressions: Cave, Farmer, and Wolf Coves, developed when part of a former stream system that originated on the Pennsylvanian-age sandstone caprock of the Cumberland Plateau, was pirated underground as it encountered the underlying Mississippian-age carbonates. All three depressions collect acid surface runoff from the surrounding sandstones. In Cave Cove, the most headward depression, Cave Cove Creek has a total hardness of 5 p.p.m. $CaCO_3$ on the sandstones but acquires an additional 71 p.p.m. from the Mississippian carbonates before sinking in the depression floor. pH increases from 5.4 to 7.9, SI_c from -7.90 to -0.64, and $logPCO_2$ from -3.62 to -3.30. At times of low and moderate discharge, water sinking in Cave Cove passes beneath Farmer Cove where it is joined by flow from Farmer Cove Creek (total hardness 94 p.p.m., pH 7.3, SI_c -1.21, $logPCO_2$ -2.65). After heavy rains, however, some water may enter Farmer Cove via an estavelle in its floor, and together with surface inputs inundate the floor of the depression. In March 1980 Farmer Cove flooded to a depth of 12 m. Diffuse recharge (total hardness 167 p.p.m., pH 7.6, SI_c -0.47, $logPCO_2$ -2.76) added to conduit recharge from Cave and Farmer Coves eventually resurges at the western end of Wolf Cove (total hardness 134 p.p.m., pH 7.7, SI_c -0.58, $logPCO_2$ -2.94) and after a short distance as a surface stream sinks in a blocked ponor at the eastern end of the depression. The stream reappears in Sinking Cove Cave 400 m downvalley and can be followed a further 1.5 km downvalley to Sinking Cove Cave Spring. Fourteen measurements of soil $logPCO_2$ made at a variety of locations in upper Sinking Cove during summer 1980 ranged from -2.77 to -1.77 and help explain the pattern of solution in the area and the higher than atmospheric levels of CO_2 in both conduit and diffuse groundwater recharge.

Zusammenfassung

Das Upper Sinking Cove, bestehend aus den drei in sich geschlossenen Poljen Cave Cove, Farmer Cove und Wolf Cove, bildete sich, als ein Teil eines ehemaligen Flussystems, das seinen Ursprung auf den Sandsteindeckschichten pennsylvanischen Alters des Cumberland-Plateaus hatte, bei Erreichen der darunter gelagerten Karbonate von Mississippi-Alter angezapft wurde. Alle drei Depressionen sammeln sauren Oberflächenablfluss von den umliegenden Sandsteinen. Im Cave Cove, der am weitesten stromaufwärts gelegenen Eintiefung, hat der Cave Cove Creek (=Bach) eine Gesamthärte von 5 p.p.m. $CaCO_3$ auf Sandstein, erhält aber zusätzliche 71 p.p.m. von den Mississippikarbonaten, bevor er im Boden der Depression versickert. Der pH-Wert nimmt von 5.4 auf 7.9 zu, SI_c von -7.60 auf -0.64 und $logPCO_2$ von -3.62 auf -3.30. Zu Zeiten niedriger und gemässigter Schüttung strömt das im Cave Cove versickernde Wasser unter dem Farmer Cove durch, wo sich ihm Wasser aus dem Farmer Cove Creek (Gesamthärte 94 p.p.m., pH 7.3, SI_c -1.21, $logPCO_2$ -2.65/ anschliesst. Nach schweren Regenfällen jedoch kann eine gewisse Wassermenge durch eine Estavelle (reversibles Schluckloch/ in das Farmer Cove eindringen und zusammen mit Oberflächenzufluss den Poljenboden überfluten. Im März 198+ war das Farmer Cove 12 m überflutet. Sickerwasser (Gesamthärte 167 p.p.m., pH 7.6, SI_c -0.47, $logPCO_2$ -2.76), das sich zum Strömungwasser von Cave Cove and Farmer Cove hinzuaddiert, taucht schliesslich am Westende des Wolf Cove wieder auf (Gesamthärte 134 p.p.m., pH 7.7, SI_c -0.58, $logPCO_2$ -2.94), ausserdem nach einer kurzen Strecke, wo ein Oberflächengewässer sich in ein blockiertes Ponor am Ostende des Polje ergiesst. Das Gewässer erscheint von neuem in Sinking Cove Cave 400 m talabwärts und kann weitere 1.5 km talawärts bis zur Sinking Cove Cave - Quelle verfolgt werden. 14 Messungen der $logPCO_2$-Werte des Bodens, im Sommer 198+ an einer Reihe von Messorten im Upper Sinking Cove durchgefürt, reichen von -2.77 bis -1.77 und helfen die Lösungsmechanismen in dieser Region sowie die - höher als in der Atmosphäre anzutreffenden - CO_2-Werte in Grundwasserzufluss aus Sickerund Strömungswasser erklären.

Introduction

Upper Sinking Cove in Franklin County, Tennessee consists of three closed depressions: Cave, Farmer, and Wolf Coves. These are aligned along the head of Sinking Cove, a blind valley 6.5 km long, which dissects the eastern flank of the Cumberland Plateau (Fig. 1). This system of closed depressions developed when a former stream system flowing on the Pennsylvanian sandstone caprock of the Cumberland Plateau encountered the underlying Mississippian carbonates and was pirated underground. Cave and Farmer Coves are shallow depressions approximately 20 m deep developed in the Bangor Limestone. Wolf Cove, down valley from Farmer Cove, is a 70 m deep uvala that has breached the resistant shale and sandstone beds of the Hartselle Formation and has penetrated the less resistant underlying Monteagle Limestone (Fig. 1). This paper examines the hydrology of upper Sinking Cove and looks at spatial and seasonal variations in water chemistry.

Hydrology

Cave, Farmer, and Wolf Coves collect surface runoff from the surrounding sandstones. The main flow into the most headward depression, Cave Cove, is Cave Cove Creek, which has its headwaters on Warren Point Sandstone at 540 m a.s.l. When this stream reaches the upper Pennington Formation limestones at the base of a sandstone bluff it sinks in Still Cave at 520 m elevation. The stream resurges several times at major shale beds before returning to the surface when it encounters the dolomites and shales of hte lower Pennington Formation. It finally sinks in massive Bangor limestones at the head of Cave Cove at an elevation of 410 m. Underground flow from Cave Cove has been traced using Rhodamine W.T. dye and activated charcoal inserted at several springs in the area. The water was found to pass beneath Farmer Cove and to resurge 2 kn down valley in Wolf Cove, drop 10 m over a series of waterfalls and then sink again at 310 m elevation in a ponor in Monteagle limestones. This water then flows into Sinking Cove Cave, which is accessible from an entrance at the eastern end of Wolf Cove. The stream flows through the lower-level passages of the cave for 2 km before resurging at Sinking Cove Cave Spring at the head of Sinking Cove 260 m a.s.l. (Fig. 2).

Even under low and medium flow conditions perched water is common in the trunk vadoes cave system that drains upper Sinking Cove. Perching usually occurs above the Hartselle Formation; for example several water bodies perched above this formation have been discovered in the lower passages of Cave Cove Cave. Because there are restrictions to flow, heavy rainfall may overload the conduit drainage system causing water to back up at various locations along it. After a heavy storm in March 1980, the floor of Farmer Cove, which is underlain by the Hartselle Formation, was flooded to a depth of 10 m. Flooding resulted partly because of increased surface and spring flow into the heavily alluviated cove, and partly because of increased surface and spring flow into the heavirly alluviated cove, and partly because water sinking in Cave Cove filled the lower passages of Cave Cove Cave causing water to flow from an estavelle in the floor of Farmer Cove. These combined inputs to the cove exceeded the drainage capacity of the alluviated ponor system causing flooding.

Surface and Ground Water Chemistry

Spatial Variations in Summer 1980

Between August 14 and 21, 1980, water samples were collected to examine spatial variations in surface and ground water chemistry in upper Sinking Cove (Table 1, Fig. 2). The headwaters of Cave Cove Creek on Pennsylvanian sandstone were found to be acid (ph = 5.4), highly undersaturated with respect to both calcite and dolomite (total hardness = 4 p.p.m. $CaCO_3$), and in equilibrium with atmospheric carbon dioxide levels (T1). Hardness increased rapidly once Cave Cove Creek encountered the Pennington Formation limestones. At an elevation 20 m below the sandston-limestone contact hardness had increased to 31 p.p.m. and pH to 7.3 (T2). Water had picked up carbon dioxide from soils on the limestone increasing $logPCO_2$ to -3.20. At the sink point in Cave Cove the stream was still undersaturated (SI_c = -0.64) but had acquired an additional 44 p.p.m. $CaCO_3$ and pH had increased to 7.9 (T6).

When water flowing in the trunk vadose cave system surfaced again in Wolf Cove its hardness had increased to 131 p.p.m. and $logPCO_2$ to -2.96. These changes in chemistry resulted from continued solution in the cave system between Cave and Wolf Coves, and from mixing with waters sinking in Farmer Cove. The main recharge at Farmer Cove is from a spring in the western wall which sinks after flowing a short distance across the alluviated floor of the depression (f). The spring water had a higher hardness (94 p.p.m.) and a higher carbon dioxide content (log PCO_2 = -2.65) than waters sinking in CaveCove.

At Wolf Cove there is additional mixing of conduit flow waters. Dye tracing has revealed that flow through Wolf and Waterfall Caves in the northern wall of Wolf Cove joins the trunk vadose drainage in Sinking Cove Cave (W). This tributary vadose flow has a hardness of 86 p.p.m., it is rich in carbon dioxide ($logPCO_2$ = -2.38) and is highly undersaturated (SI_c = -0.91). After mixing occurs water in Sinking Cove Cave has a hardness of 140 p.p.m., a $logPCO_2$ of -2.96, and is still undersaturated (SI_c = -0.57).

Between Wolf Cove and Sinking Cove Cave Spring the main ground water flow is through Sinking Cove Cave. There is conduit recharge at the Boulder Entrance (B) and also diffuse recharge in the form of cave drip waters. In summer 1980, 8 cave drip waters were samples. They had a mean total hardness of 167 p.p.m. and a mean $logPCO_2$ of -2.76 (D 1-8). There was little change in water chemistry as water flowed through Sinking Cove Cave to the spring indicating that diffuse recharge was not significant enough to affect water chemistry (T9).

Seasonal Variations

It is apparent that water chemistry in upper Sinking Cove varies considerably with season. Samples collected in December 1980 were of lower hardness and lower $logPCO_2$ than those collected in August 1980, flow conditions were similar (Table 1). In both summer and winter all water samples were undersaturated with respect to both calcite and dolomite. At Sinking Cove Cave Spring, for example, summer and winter values for hardness, $logPCO_2$ and SI_c were 133 and 55 p.p.m., -2.94 and -3.25, and -0.58 and -0.52 respectively. These differences reflect reduced soil carbon dioxide levels rather than differences in discharge. The mean soil carbon dioxide at two sites with both summer and winter measurements was -2.07 in August and -2.38 in December.

Discussion

Upper Sinking Cove has an underground vadose drainage system. This system is dominated by a trunk conduit, two parts of which Cave Cove Cave and Sinking Cove Cave have been thoroughly explored. This trunk conduit parallels the floor of the Sinking Cove blind valley. Several caves in the walls of Cave, Farmer, and Wolf Coves feed water into the trunk conduit either directly or first via springs onto the floors of the three closed depressions. The largest of these tributary flow systems that has been discovered to date is the Wolf-Waterfall Cave system in the norther wall of Wolf Cove. It is clear, however, that the drainage network is not a simple underground dendritic system. Water sinking in Farmer Cove has been dye traced to a spring at the western end of Wolf Cove and also to the trunk passage of Sinking Cove Cave. Water flowing in Wolf Cove Cave has been dye traced to Sinking Cove Cave and also to the spring at the western end of Wolf Cove. The caves of upper Sinking Cove therefore form a braided or anastomosing system in three dimensions explaining why ground water may take alternate routes to reach the same destination.

High-level cave passages have been discovered in the walls of the three coves. They contain stream cobble deposits and appear to be relics of a former vadose conduit drainage system in the limestones. Flow directions indicated by imbricated stream deposits and scallops on the floors and walls of these caves indicate that paleoflow directions broadly paralleled those of today.

Chemical analysis has revealed that ground waters in upper Sinking Cove are undersaturated with respect to both calcite and dolomite. Low saturation levels probably reflect the predominance of conduit ground water recharge and low aquifer residence times. Substantial conduit recharge is also indicated by the range of $logPCO_2$ in summer ground water (-3.62 to -2.94). These waters were not in equilibrium with summer soil carbon dioxide (range of 8 measurements was -2.70 to -1.77) as would be expected if diffuse recharge were significant. Seasonally variable soil carbon dioxide levels lead to lower water hardness in the winter compared to the summer months.

Table 1
Chemical Characteristics of Surface and Ground Waters in Upper Sinking Cove, Tennessee

Season	Chemical Variable	Samples[a] T1	T2	T3	T4	T5	T6	T7	T8	T9	F	W	B
Summer[b]	pH	5.4	7.2	7.7	7.8	8.0	7.9	7.7	7.7	7.7	7.3	7.7	7.8
	Total Hardness (p.p.m. $CaCO_3$)	4	31	53	53	68	75	131	140	133	94	86	121
	log PCO_2	-3.62	-3.20	-3.33	-3.34	-3.35	-3.30	-2.96	-2.96	-2.94	-2.65	-3.17	-3.06
	SI_c	-7.66	-2.17	-1.25	-1.01	-0.59	-0.64	-0.61	-0.57	-0.58	-1.21	-0.91	-0.56
Winter[c]	pH	5.7	7.2	7.6	7.8	7.9	7.7	8.1	8.1	8.2	7.8	8.1	7.5
	Total Hardness (p.p.m. $CaCO_3$)	5	10	20	23	30	29	54	66	68	55	43	59
	log PCO_2	-2.07	-3.30	-3.45	-3.59	-3.49	-3.45	-3.50	-3.45	-3.55	-3.17	-3.60	-1.65
	SI_c	-5.38	-3.15	-2.17	-1.83	-1.45	-1.81	-0.76	-0.63	-0.52	-1.02	-0.96	-1.29

a Sample locations are shown in Fig. 2

b August 14-21, 1980

c December 23-31, 1980

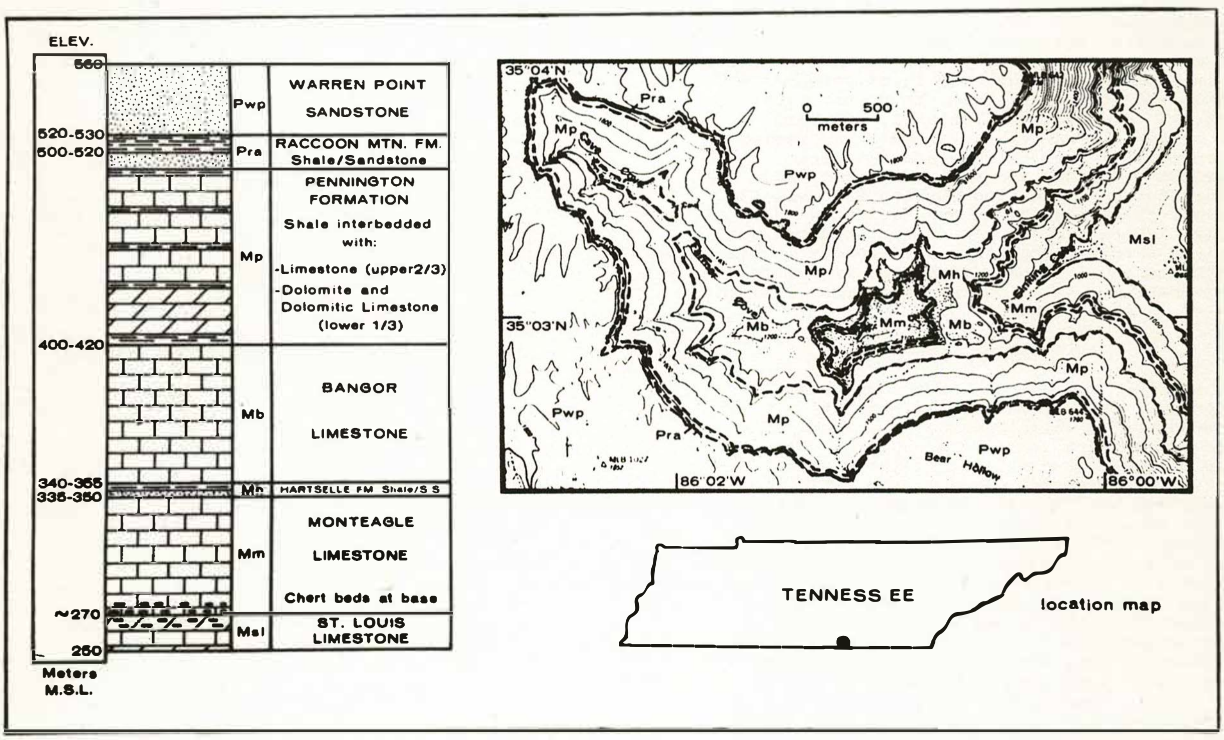


Figure 1. Topography and Geology of Upper Sinking Cave, Tennessee.

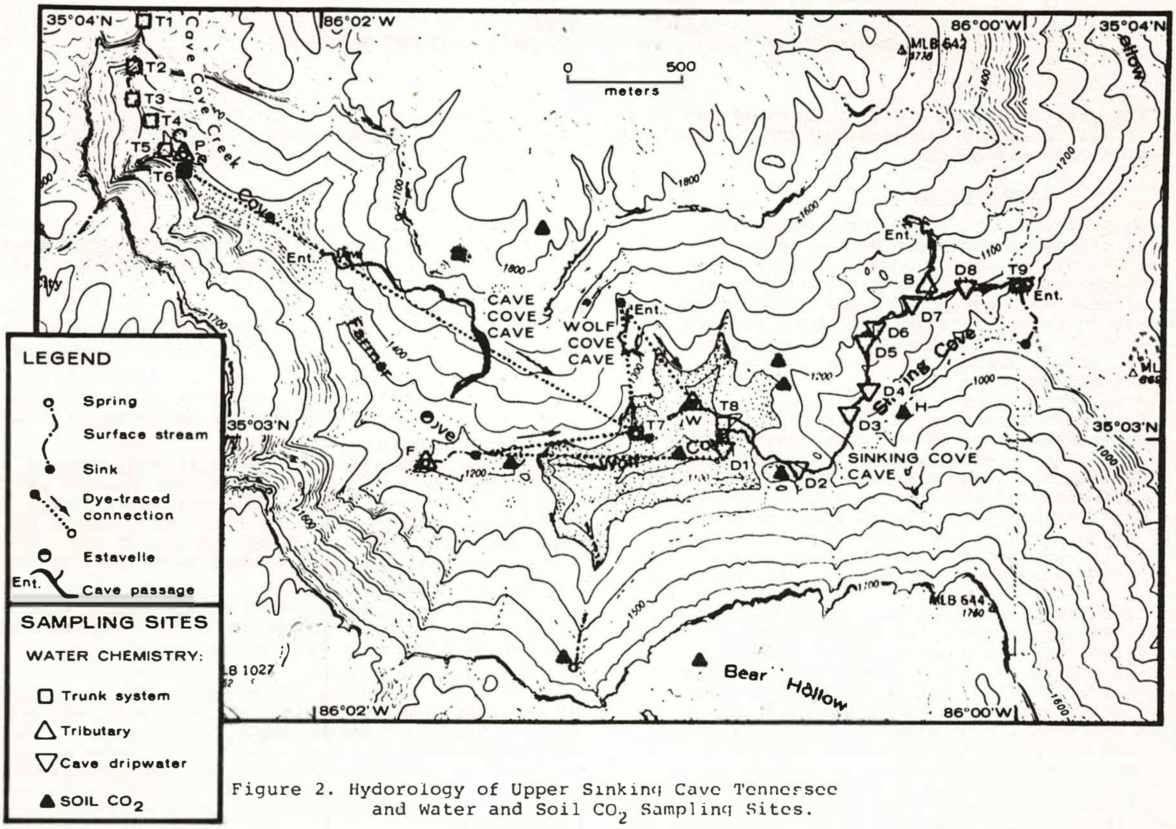


Figure 2. Hydrology of Upper Sinking Cave Tennessee and Water and Soil CO_2 Sampling Sites.

Provisional Specification for Caving (S.R.T.) Ropes

Andrew J. Eavis
5 Sycamore Close, Selby, North Yorkshire, YO8 0HZ England

Abstract

In the next **few years a** U.I.S. standard for caving ropes will be produced in the same sort of form **as** the U.I.A.A. standard for climbing ropes. This paper puts forward a basic format and hopefully will be a **step** in this direction.

Introduction

Ropes have been used in caving for a great many years, but only comparatively recently has their importance been magnified by the advent of Single Rope Techniques. These methods of ascending and descending vertical subteranean passageways have been used in the USA for the last 20 years or more. Gradually the rest of the speleological world has transferred to single role techniques, Britain being one of the last to fall in line in the last six years or so.

Obviously in SRT work one is totally dependant on the rope and failure will result in serious injury or worse. As soon as these rope methods were used people became more interested in the quality of the ropes they were using. In the USA "Nylon Highway" has contained much useful information on SRT equipment for many years. In Britain a certain amount of investigation into the properties of certain ropes with regard to SRT started in about 1974. It soon became apparent that people were using unsuitable ropes and fatal rope accidents resulted.

In 1976 after the setting up of the National Caving Association Equipment Committee the British Standards Institute invited members of the above to attend their meetings on climbing ropes with the idea of eventually producing a BSI specification for caving ropes. During the 1977 International Congress many ideas and work by Michael Kipp extended work in Britain by Andy Eavis and others were discussed. In 1979 a working group to produce the caving rope specification was set up, the convenor being Andy Eavis the chairman of the UIS Equipment Commission. The object now is to produce a British Standards Institute specification for caving ropes and use this as a basis to set up a UIS specification similar to the UIAA specification for climbing ropes.

At this point in time there are a lot of things still to be decided and one reason for publishing it here is to stimulate feedback from the caving world to help fill in some of the blanks.

The full specification for SRT caving ropes will follow the following format.

1. Material
   The rope shall be composed of man-made fibres.

2. Size
   The rope shall have a maximum diameter of 12mm measured in accordance with the UIAA procedure.

3. Construction
   The tope shall be of a balanced combination showing no tendency to rotate when a mass is freely suspended from the end.

4. Mass
   The rope shall not weigh more than 11.0kg per 100m after it has been wetted in the manner that will be prescribed later.

5. Pretreatment
   All ropes tested shall be pretreated by several cycles of immersion in water and air drying at room temperature. Only new ropes that have been pretreated will be subjected to the tests and during pretreatment a measure of the shrinkage of the rope will be noted. The rope should not become shorter than the manufacturers specified length.

   Where requirements are specified herein for "dry" ropes this should refer to the dry pretreated state. In cases of dispute the pretreated ropes shall be conditioned in accordance with UIAA requirements. Where requirements are specific for "wet" ropes this should refer to ropes which have been soaked for 24 hours in water at room temperature and drip dried for a prescribed length of time.

6. Ultimate Tensile Strength
   The minimum breaking strength of a rope tested in accordance with procedures to be laid down later shall be 20 kN and shall be at least twice the peak force measured in the dynamic test (9). (There may be some provision here for also testing the ropes at elevated temperatures.)

7. Elasticity
   The elongation under the force exerted by a mass of 80kg shall not exceed 2%. This shall be measured in accordance with UIAA procedure.

8. Flexibility in Knotting
   The mean performance shall be greater than 50% and less than 130% when measured according to UIAA procedure.

9. Maximum Dynamic Force
   The maximum force developed at a fall factor of 0.75 with a weight of 80kg shall not exceed 12kN.

10. Energy Absorption
    It is preferable that there is some sort of specification for energy absorption but this has not yet been decided. It could consist of a destruction test where the dynamic energy needed to break the rope is measured or a durability test where the number of drops with fall factor 0.75 and 80kg are counted until the rope fails.

11. Sheath Slippage
    The maximum displacement of the sheath when tested in accordance with UIAA procedures shall be measured and not exceed a value to be decided later.

12. Abrasion Resistance
    The minimum number of cycles to give total failure of the rope when it is reciprocated over a stone edge with a prescribed weight shall be specified. The edge radius and material, the weight on the rope and the distance of reciprocation have not yet been decided. It may be that both horizontal and vertical reciprocation at the edge is necessary to give a true measure of abrasion resistance.

13. Marking
    Caving ropes complying with the above specifications shall be predominately light in colour and have one or more coloured yarns.

    New ropes shall have a label attached giving:
    1 - The manufacturers name and address and the product name;
    2 - The type of material the rope is made from;
    3 - An indication that the tope complies with the above specification;
    4 - The length of the rope which should not be less than that measured after preconditioning;
    5 - The diameter of the rope;
    6 - Any particular warnings. For example, susceptability to acids or alkalis, ultra violet light, high or low temperature, etc.;
    7 - Date of manufacture.

Conclusions

It can be seen that a lot more work is needed to complete the UIS specification for caving ropes but the above forms a basis. Hopefully before the next equipment review in 1981 many of the gaps will have been filled in. Once the above specification for SRT ropes has been completed it is hoped to amend certain sections to include life lining ropes. Subteranean climbing conditions are covered by existing UIAA specifications.

The Weak Link

Andrew J. Eavis
5 Sycamore Close, Selby, North Yorkshire, YO8 OHZ England

Abstract

This article examines the various pieces of an S.R.T. system from belay to caver. It includes figures derived from practical tests and ideas gained from caving experience. Arguments for and sometimes against increasing the strength of component parts are put forward and some recommendation on a device utilization made.

When considering the strength of an S.R.T. system you have to look at the strength of each individual component. There is little point in insisting on using karabiners with an operating strength of 3,500 kgf. if the actual usable strength of the reop is only 1,000 kgf. To start with it is worth going through the system starting with the body and finishing with the belay.

The Body

There have been many discussions over what force a human body can withstand in an S.R.T. situation without permanent damage. A figure for a person taking a dynamic load onto a good seat or body harness of 1,200 kgf is often used as the point up to which only bruising occurs. This has been arrived at by looking at a lot of test data produced by the U.S.A. National Aeronautics and Space Administration and also actual drop tests performed by climbers. From personal experience 600 kgf in a good sit harness is painful and I would think that bones could start breaking at nearer 1,000 kgf than 1,200 kgf.

The Harness

Most modern harnesses when new are adequately strong, but after hard use they can soon suffer damage sufficient to reduce their strength very considerably. Caving must be the most punishing use harnesses are put to and most climbing harnesses are not designed for continuous rubbing as in a tight cave situation. Most harnesses fail in a progressive manner and are fairly so they have reasonable energy dissipating characteristics. In a dynamic load situation on an S.R.T. system one would not expect the harness to fail unless it had been damaged by abrasion, etc.

The Karabiner

There are a lot of popular falacies connected with karabiners. People have tended to think of them as being so super strong there is no chance of them ever failing; this has now been shown to be totally untrue. Karabiners are normally very strong when the gate is closed and they are loaded along their long axis (typically 2,000 kgf), if the gate is not closed this drops dramatically to say 1,000 kgf or less, and if loaded across the long axis this strength is typically below 500 kgf. This means that in practice that if a caver takes a fall, if in the moment before the rope goes tight the karabiner twists or the gate opens, it could easily fail. The most common reason for this happening are the use of badly designed karabiners, not screwing up screw-gates and carrying gear on load bearing karabiners.

The Descenders

It is possible that a dynamic load could be applied to an S.R.T. system while the participant is descending, so it is worth considering the strength of descenders.

The weakest common descender will be the rapel rack, destruction tests have unrolled a simple pig-tail at less than 500 kgf and snapped rack bars at forces only slightly higher. It must be remembered however that unless the falling caver has his rope locked off to his rack, slip must occur to dissipate energy. The rack itself fails progressively again dissipating energy so it is fairly unlikely to totally fail. The same is not true of self-looking descenders where rope slippage is unlikely as a falling caver would probably release the operating handle thus locking-off the device.

The Ascenders

The philosophy of the strength of a prussiker/rope system is an interesting one. It is no real advantage if the device is very strong but cuts through the rope at a low force. In many situations it is going to be much more serious if the rope is cut through than if the device fails. If the top device fails in a fall situation, the second or third prussiker will almost certainly hold, but if the top device cuts through the rope it is obviously a disasterous situation.

Appendix 1 gives some idea of the strength of some devices. It is interesting to notice that the strongest sprung cam device has an ultimate tensile strength of 550 kgf, whereas the strongest rope walker is about 1000 kgf. If we consider a human body capable of taking 1,000 kgf there is obviously a good arguement for the other components in the system taking the same force or dissipating energy in a way that prevents this force being produced. Since with a fall onto an ascender there will be little or no slip it would be ideal if they would fail at a force between 1,000 and 1,200 kgf without curring through the rope.

The Rope

Modern S.R.T. ropes should be carefully designed pieces of engineering. If the human body is fatally damaged by a certain force there is no real point in making the actual useable strength of the rope higher than this. Ideally an S.R.T. rope is not to be elastic when being used normally, and very elastic when having to arrest a falling body. This is difficult to achieve in practice. Some ropes have a very stiff core which actually fails at a load greater than that normally applied, the elastic sheath then holds the fall giving forces never greater than 1,000 kgf. If an absolute figure has to be given for the recommended strength you could say that a body would be very badly damaged at 1,500 kgf so to take into account the knots in the system, wear, degredation etc this should be doubled to give say 3,000 kgf. There seems little point in an S.R.T. rope being very much stronger than this.

The Belay

This is the first link in the chain where the rope is attached to the rock. If the rope is tied to a natural belay the attachment is as strong as the knot or the cutting action of any sharp rock etc. This is largely taken into account if a 3,000 kgf rope is used. If a second belay material is used (tape or wire rope for example) they must also be at least 3,000 kgf as must the karabiner. Many wire belays are not as strong as this and often badly placed tape slings would fail considerably below this force. If a bolt is used as a belay each component of this system must be examined. The shear strength of a 7mm bolt may not be as high as 3,000 kgf and if it has been overtightened the actual tensile strength available could and often is very much lower than this figure. The bolt hanger is also a potential weak link with a strength often as low as 500 kgf. If the main bolt fails any back-up bolt will almost certainly then fail from the shock load.

Conclusion

A human body is able to withstand a force of about 1,000 kgf in a good harness and dynamic fall situation. This means that the other components of the system should be at least as strong as this. At present many components are not this strong. Many descenders fail below this force as do all sprung-loaded ascenders. Ropewalker type devices often cut through the rope below this force and many types of artificial belays are not strong enough.

Manufacturers should be striving to increase the strength of the component parts of the S.R.T. system. Rope manufacturers should be trying to reduce the peak force produced in a fall but not at the expense of losing inelasticity at low loads.

Appendix 1

ASCENDERS

	Ultimate Tensile Strength	Notes
Rope Walkers		
Gibbs	1,000 kgf	Elongation of holes in sheath allowed cam to turn inside out. Rope damaged and probably close to breaking.
Lewis	775 kgf	Distortion of sheath holes and deformation of rope contact area on sheath allowed cam to turn inside out. Slight increase in sheath thickness would give much stronger device.
Sprung Devices		
Jumar	550 kgf	Distortion of cam which allowed device to turn inside out. New Jumar has stronger cam.
CMI 5000	530 kgf	The wrap around opened out allowing the cam to pull through. New device is stronger in this respect.
Petzl Jammer (Early)	500 kgf	The cam distorted and pulled through. Later devices have stronger cams.

N.B. The spring clamps are very much stronger if the cams are prevented from turning inside out. A karabiner in the top hole of most of them stops this and greatly increases the strength of the rope/device system. Typically the rope would fail by severe cutting by the cam at about 1,000 kgf.

Geomorphology and Hydrology of the Carlsbad Gypsum Plain, Eddy County, New Mexico

Alberto A. Gutierrez
7927 Jones Branch Drive, McLean, Virginia 22102

Abstract

The geomorphic evolution of fluvial systems developed on gypsum karst is complicated by the dependence of both fluvial and solutional landforms on the hydrologic of karst ground water. Rapid recharge from floodwaters results in temporary storage in the zone of ground-water fluctuation and local increases in the groundwater table. A corresponding increase in hydraulic head produces flow felocities exceeding 1 m/sec, calculated according to the method described by Curl, 1974. Recovery times for sinking streams in the study area are very rapid (10-24 hrs.). Surface drainages are largely inactive and alluviated except downstream from resurgences. Arroyo incision and terrace development result from base-level lowering and subterranean capture. Sinking streams above blind valleys' termini are characterized by single, paired terraces, but below resurgences several unpaired terraces result. Late Quaternary geomorphic history involves a successive lowering of base-level and formation of fluvial terraces and associated cave levels; however, correlation of terraces in semiarid karst is complicated by the interdependence of surface and subsurface drainage. Joint and fracture trends in the Castile Formation control cave-passage orientation, morphology, and sinkhole development.

Zusammenfassung

Die geomorphische Entwicklung von fluvialen Systemen, welche sich im Gips des Karsts gebildet haben, wird durch die Abhangigkeit der fluvialen wie auch der solutionalen Landformen von der Hydrologie des Karstgrundwassers. Schnelle Auffullung durch Oberflachenwasser bewirkt eine temporare Wasseransmmlung und damit eine lokal begrenzte Erhohung des Grundwasserstandes. Die damit verbundene Erhohung des hydraulischen Druckes erzeugt Stromungsgeschwindigkeiten von mehr als 1 mßsek wie aus der Curl'schenBerechnungsmethode (1974) hervorgeht. Die Normalisierungsperiode fur diese Strome in der untersuchten Gegend zu durchschnittlichen Geschwindigkeiten ist sehr kurz (10 bis 24 Studen). Die Oberflachenwasserkanale uber den unterirdischen Wasserkanalen sind relativ inaktiv und mit Sedimenten aufgefullt. Arroyo Erosion and Terrassen sind abhangig von dem Hohenunterschied der Wasseroberflachen. Die gemorphische Entwicklung im spaten Quartar weist ein aufeinanderfolgendes Einsinken der unter-und Oberirdischen Wasserlaufe auf. Die Identifizierung verschiedener Terrassen im halbwustenartigen Karst wird jedoch erschwert durch die Abhangigkeit unter-und oberirdischer Wasserlaufe von einander. Die Richtung der Joint und Fracture in der Castile Fromation bestimmt die Orientierung der Wasserlaufe, die Morphologie und die Sinkhole-Entwicklung.

Bedrock Geology

The Carlsbad Gypsum Plain is underlain by the Permain Castile Fm. (Hayes, 1957). It is a thich (1,800 ft.) sequence of nearly horizontal anhydrite, gypsum and limestone beds. These beds have a slight 1°dip to the N.E., although dips may vary locally due to flowage of gypsum. Very little work has been done on the structural geology of the Castile, although a series of small N.E. trending faults have been identified in the S.W. portion of the study area (Yeso Hills) (Hayes, 1957). A prominent series of joints are possibly associated with the same tectonic activity that created the small displacements in the Yeso Hills. Northeast and northwest trending joints measured on the surface and in caves in the study area coincide with the general trends of surface drainages and clearly exert a s strong control over cave-passage orientation and initial sink development.

Surficial Geology

Several episodes of erosion and deposition are visible in the surficial deposits of the study area. Filled paleochannels incised into an uneven erosion surface on the Castile are exposed in arroyos and caves and are visible on the surface, in addition to bedrock and gypsiferous residual material. Hunt (1977) has mapped the surficial deposits of the area as residual gypsiferous deposits. Most of the paleochannel fills in the Gypsum Plain are characterized by poorly sorted deposits ranging from clay and silt particles to angular gypsum gravels and cobbles. The geometry of these paleochannels appears similar to that of existing low W/D ratio channels incised into the Castile Formation.

Surface Drainage and Karst Development

The most distinctive features of the Gypsum Plain result from dissolution and the creation of extensive Karst topography.

Two main types of sinks have been identified on the Gypsum Plain. The classic solution sink filled with unconsolidated material weathered in place has been observed in the south-central portion of the study area, near Ben Slaughter Draw (Fig. 1). These sinks are closed, approximately circular depressions usually less than 1.5 m deep, ranging from 10 to 80 m in diameter. These sinks comprise approximately 3-5% of the recharge points to the subsurface drainage of the study area. The majority of the sinks on the Gypsum Plain are better described as sinking stream sinks. These are elongate depressions containing a defined channel which nearly always sinks rapidly and directly into a solutionally widened fracture or joint. These sinks drain areas ranging from .1 to .5km^2. Small sinking streams with well defined drainage areas are especially common in the Yeso Hills and in the interfluves between Ben Slaughter Draw and the north fork of Hay Hollow (Fig. 1). These features are easily recognized in the field and from the air as they characteristically have large bushes or trees growing on top of or near the swallow hole due to the increased avialable moisture. In areas where unconsolidated material overlies the bedrock the streams are developed on the fill and sink into fractures in the bedrock at the contact between the fill and the bedrock surface. The channels contained in the small sinks of the Ben Slaughter Draw and the Yeso Hills area develop as a result of successive flows sinking into fractures within enclosed depressions. Some sinking streams contain more than one swallow hole at different levels, possibly representing either a change in base level or a flood flow route. In areas where the alluvial cover is thin to non-existant, similar features are developed entirely in bedrock.

In contrast with the sinking-stream sinks described above, sinking streams with larger drainage areas, characteristic of the Chosa Draw region, are dinstinctly related to the surface drainage development of a basin. These sinking streams appear to be developed along preexisting surface-flow paths and do not sink into obvious fractures in the bedrock. The discharge in these sytems are usually much greater due to the increased drainage area. It is not uncommon to find several of these sinking streams aligned along areas of past concentrated surface flow grading to the local base level of Chosa Draw (Fig. 1).

Another type of recharge to the subsurface drainage system is characterized by Chosa Draw sink located in Sec. 28, T.25S., R.25E. Upstream of this sink Chosa Draw is a deep incised channel with a low W/D ratio flowing on bedrock or shallow alluvial fill. At this point all the flow that is produced by the 2.8 km^2 drainage area of upper Chosa Draw sinks into a cave system. This has caused the abandonment of an old, alluviated, wide, channel-surface downstream of the sink. Approximately 1,500 m downstream the channel-surface downstream of the sink. Approximately 1,500 m downstream the channel again becomes incised below a resurgence (Blowhole exit of Chosa Draw Cave) characterized by a steep deposit of large rounded gypsum cobbles. Flood flows in Chosa Draw Cave appear to exit via the Blowhole when normal subsurface flow routes are backed up. This resurgence releases approximately 1/3 of the flood flow that enters at Chosa Draw sink back into the channel of Chosa Draw.

Cave development is most extensive in the Chosa Draw area between the Yeso Hills and the Black River. Passage orinetations are strongly controlled by joint patterns, except in the lower portion of caves near the ground-water table where passages widen along bedding planes. Base flow through the caves is supplied by springs and is usually very low. In the lower levels of the caves of the Chosa Draw area, wide passages are developed along bedding planes and end in pools which fill the passages to the ceiling, apparently intersecting the local ground-water level. Flood flows fill these caves to the ceiling, flushing out sediments accumulated during small flow events and modifying the entire height of the main passages. Flow velocities and discharges calculated from measurements made in caves on the Gypsum Plain are given in Table 1.

Table 1

Flow Velocities and Discharges of Selected Caves

Location of Scallop Measurements	Velocity (m/sec)*	Discharge (m^3/sec)**
Plunging Stream Cave	1.21	.971
Chosa Draw Sink	14.55	15.87
Bowhole Resurgence	9.39	5.64

*Velocity calculated from scallop measurements on walls of caves according to the method presented by Curl, 1974.
**Discharge of peak flow calculated full passage using:
$Q = \overline{u}\, A_x sec$ where $\overline{u}$ = calcuated average velocity and $A_x sec$ = passage cross-sectional area.

There are four perennial resurgences in the study area: Jumping, Ben Slaughter, Terrace and Cottonwood Springs. These springs characteristically occur in the bottom of washes with well developed incised chanels below the spring and wide flat alluviated reaches above the springs. The springs have small discharges (usually less than 1 cfs) except during floods when flows increase significantly. After flooding, there is no evidence of flow in the channels above the springs; but below the spring, flood stages occur 1-2 m above channel bottom.

Hydrology, Channel Morphology and Geomorphic History

The hydrologic system of the Carlsbad Gypsum Plain is a complex intersection of both surface and subsurface processes that produce characteristic solutional features and channel morphology. The ratio of surface to subsurface drainage increases toward the Black River (closer to base level) reflected in the more active incised channels of Chosa Draw, as compared to the Ben Slaughter Draw area. Large trunk-passages in the Chosa Draw area (Chosa Draw Sink) enable flood discharges to be carried rapidly in the subsurface recharging groundwater levels and discharging to the surface at Terrace Spring and Blowhole resurgences. It is evident from scallop data and field observation that the movement of the flood pulse is extremely rapid in both the Ben Slaughter and Chosa Draw areas (Fig. 2). The recovery time to normal base flow ranges from several hours to one day, depending on the magnitude of the event. Specific conductance and salinity were measured in all the resurgences in the area and no appreciable seasonal variations were noted. During flood events specific conductance and aslinity decreased, but 10 hours after a major flood event, springs showed no significant variations from mean levels. This phenomena is due to the rapid movement of the flood pulse and the rapid return to base flow conditions.

It is evident from the channel morphology and soil development in alluviated channels that they presently they carry little or no runoff. The sandy residum provides rapid infiltration and most runoff produced on bedrock surfaces sinks directly into the subsurface. Most of the flow carried on the surface occurs immediately below resurgences that discharge flood flows. Channel cross-sections above and below resurgences show appreciable differences in morphology. Width to depth ratios are significantly higher in the "abandoned" alluviated channesl above resurgences. Below resurgences channels, incised in bedrock, have characteristically low width to depth ratios. Broad alluviated washes in the Ben Slaughter Draw and Yeso Hills areas are parts of a largely abandoned drainage network which neither controls nor resembles the present fluvial system. In areas downstream of resurgences, however, incised channels usually follow pre-existing drainage trends. Chose Draw represents an abandoned drainage network which has been incised by the combined effect of karst processes (incision below insurgences) and adjustment to the local Black River base level.

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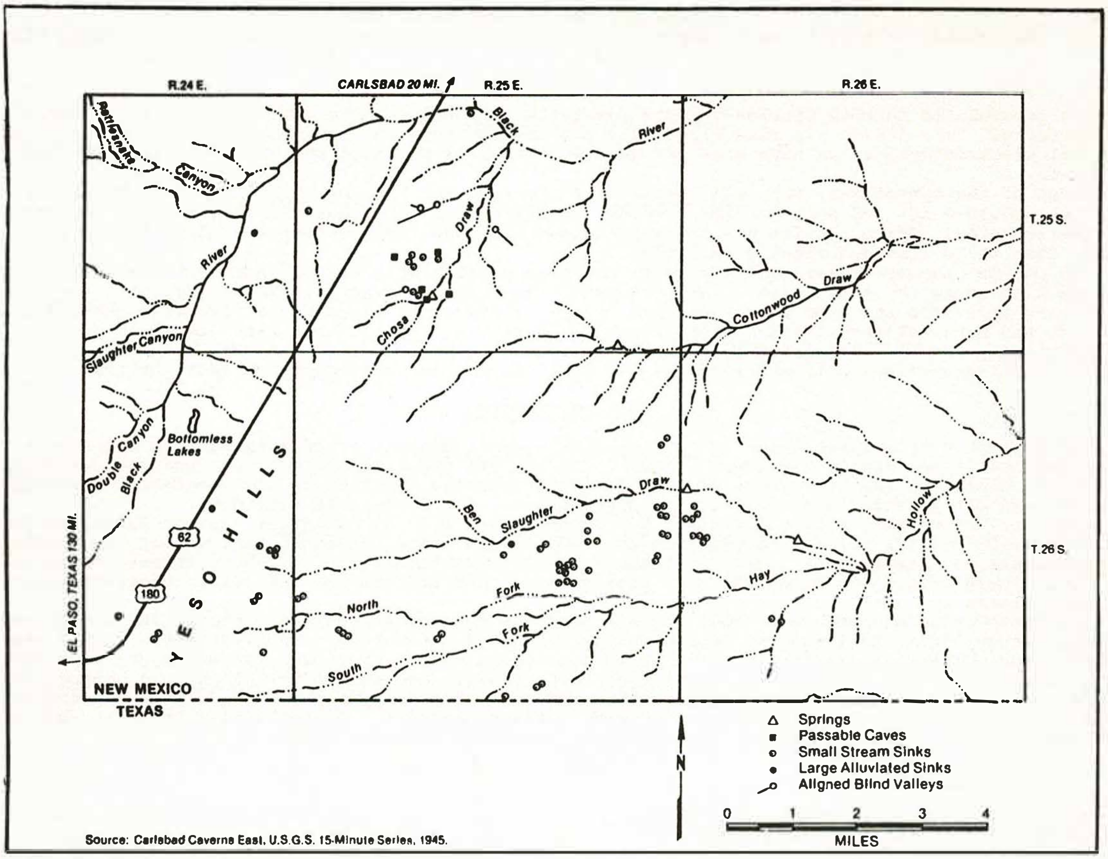

Figure 1. Distribution of Karst Features

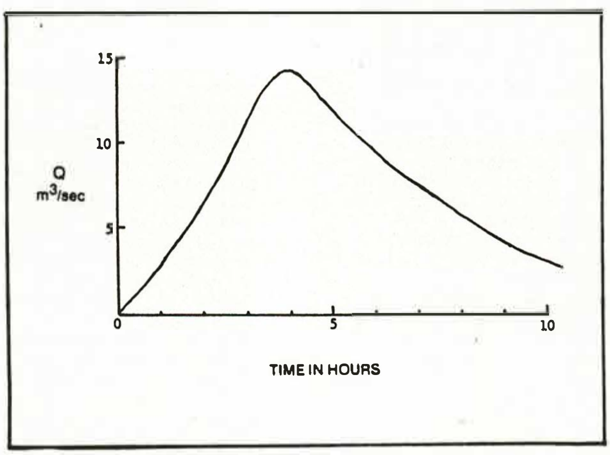

Figure 2. Hydrograph for Chosa Draw Silk Cave System

The Ecological Genetics for Four Subspecies of Neaphaenops tellkampfi (Coleoptera: Carabidae)

George Brunner and Thomas G. Kane
Department of Biological Sciences, University of Cincinnati, Cincinnati, Ohio 45221, USA

Abstract

The troglobitic carabid species Neaphaenops tellkampfi has an extensive range in the caves of west central Kentucky. Barr (1979) has recognized four subspecies based on morphological and geological criteria. Using gel electrophoresis, we have measured genetic variability within and genetic similarity among these subspecies.

Three of the subspecies, N.t. tellkampfi, N.t. henroti and N.t. meridionalis, show levels of heterozygosity (H=0.10-0.17) and polymorphism (P=0.50) equivalent to those occurring in simliar surface inhabiting invertebrates. These results are somewhat unique for cave limited species. Data for N.t. viator suggest that it is less genetically variable.

The phosphoglucose isomerase locus (PGI) has been particularly useful in examining genetic similarity and gene flow among the subspecies. Three variants have been uncovered at this locus with meridionalis populations fixed for the slow migrating form, viator populations fixed for a form with intermediate mobility, and both tellkampfi and henroti fixed for a variant coding for a fast migrating protein. One polymorphic population, containing both the fast and slow migrating variants, has been found. This population is also morphologically intermediate for meridionalis and tellkampfi characteristics.

Zussammenfassung

Die troglobitische Carabidenart Neaphaenops tellkampfi besitzt einen ausgedehnten Lebensraum in den Höhlen des westlichen Zentral-Kentucky. Barr (179) hat auf Grund morphologischer und geologischer Kriterien vier Unterarten identifiziert. Durch Gel-Elektrophorese konnten wir die genetische Variabilität innerhalb und die genetische Ähnlichkeit zwischen diesen vier Unterarten bestimmen.

Drei der Unterarten, N.t. tellkampfi, N.t. henroti und N.t. meridionalis, zeigen Werte der Heterozygosität (H=0.10-0.17) und des Polymorphismus (P=0.50) die denen von ähnlichen, an der Oberfläche lebenden Invertegraten entsprechen. Diese Resultate sind für ausschliesslich in Höhlen lebende Arten in gewissen Sinne einzigartig. Die Daten für N.t. viator lassen den Schluss zu, dass diese Unterart genetisch weniger variabel ist.

Das Phosphoglucose-Isomerase (PGI) Gen hat sich als besonders nützlich erwiesen für die Untersuchung der genetischen Ähnlichkeit und des Genflusses zwischen den Unterarten. Drei Varianten dieses Gens wurden entdeckt, wobei meridionalis Populationen auf die in der Elektrophorese langsam wandernde Form fixiert sind, viator Populationen auf eine Form mit mittlerer Beweglichkeit und sowohl tellkampfi wie henroti auf eine Variante, die für ein schnell wanderndes Protein codiert. Eine polymorphe Population wurde gefunden, die sowohl die langsam wie auch die schnell wandernde Variante enthält. Diese Population steht auch morphologisch zwischen den für meridionalis und tellkampfi charakteristischen Merkmalen.

Introduction

Neaphaenops tellkampfi (Coleoptera: Carabidae) is one of several troglobitic trechines which inhabit the caves of west central Kentucky. Barr (1979), using morphological and geological criteria, has divided the species into four subspecies. The degree of cave adaptation in N. tellkampfi suggests that it has a farily long history of cave isolation (Barr, 1979; Peck, 1975). Local populations of N. tellkampfi are often quite large and N. tellkampfi is generally more abundant than the species of the closely related genus Pseudanophthalmus with which it co-occurs.

Two studies (Giuseffi et al., 1978; Turanchik and Kane, 1979) have examined genetic variability within and genetic relationship among eight populations of the nominate subspecies N.t. tellkampfi using gel electrophoresis. The levels of genetic variability in N.t. tellkampfi populations (average heterozygosity (H) = 0.154; average oplymorphism (P) = 0.47) approach those reported for surface dwelling invertebrates (Selander, 1976). The genetic similarity values (Nei, 1972) among the eight populations (I-0.94-0.99) fall within the range reported by Selander and Johnson (1973) to be common for continuously distributed conspecific populatins in continental regions. Further, these data suggest that surface rivers, such as the Green and Barren Rivers which lie between some of these populations, are not dispersal barriers for this species.

It is of interest now to examine the genetic relationships among all four subspecies of N. tellkampfi. The nominate subspecies N.t. tellkampfi occurs in the west central portion of the range including the caves of Mammoth Cave National Park. This subspecies also tends to be locally most abundant of the four. Barr (1979) notes that morphologically N.t. meridionalis, the southern subspecies, is the most distinct of the four. This subspecies overlaps narrowly with tellkampfi fomring apparently hybrid populations in two known caves. Neaphaenops tellkampfi viator, the eastern subspecies, is morphologically more similar to nominate tellkampfi than is meridionalis. Barr suggests a rather broad zone of hybridization between viator and nominate tellkampfi with several caves harboring hybrid populations. Neaphaenops tellkampfi henroti, the northern subspecies, is the most puzzling of the four subspecies. It possesses a high degree of morphological similarity with nominate tellkampfi and viator, yet there are no known cases of hybridization between henroti and either viator or nominate tellkampfi (Barr, 1979). The lack of hybridization is the apparent result of the presence of a sandstone ridge and an extensive fault zone at the southern edge of the henroti range (Barr, 1979).

Methods

Three populations of N.t. viator, two populations of N.T. henroti and two populatins of N.T. meridionalis were sampled in 1979 and 1980. In addition a single population reported by Barr (1979) be morphologically intermediate between tellkampfi and meridionalis was also sampled during this period. Individuals were returned to the laboratory live where they were prepared for vertical slab gel (polyacrylamide) electrophoresis using an Ortec apparatus. Data have been obtained on all populations for five enzyme systems encoding for a total of seven loci. These systems include xanthine dehydrogenase (XDH) (1 locus), malate dehydrogenase (MDH) (2), alkaline phosphatase (ALP) (2), posphoglucose isomerase (PGI) (1), and phosphoglucomutase (PGM) (1). The average proportion of heterozygous loci per individual (H) and the proportion of polymorphic loci per population (P) were calculated for each population of each subspecies sampled. Also, comparisions of genetic similarity and genetic distance (Nei, 1972) were made for populations within and between subspecies. Similarity comparisions were also made between the three subspecies examined in this study and N.t. tellkampfi using the data of Turanchik and Kane (1979).

Results and Discussions

Genetic variability estimates (Table 1) suggest that meridionalis, viator and henroti populations have levels of heterozygosity and polymorphism which are relatively high for cave invertebrates and approach the levels reported for nominate tellkampfi (Turanchik and Kane, 1979). Although variability seems to be lower in the hypothesized meridionalis x tellkampfi hybrid population (Table 1), it is difficult to attribute much significance to this given the small sample sizes we were able to obtain.

The phosphoglucose isomeras (PGI) locus has proven to be particularly interesting in assessing genetic relationships among the four subspecies. Three alleles have been uncovered at this locus for N. tellkampfi. Turanchik and Kane (1979) showed that all eight populations of N.t. tellkampfi they examined were fixed for an allele coding for a fast migrating protein. The present work shows that the viator populations examined are all fixed for an allele coding for a protein with intermediate mobility and that the two meridionalis populations are fixed for yet a third allele coding for a slow migrating protein. The henroti populations are fixed for the fast allele and are identified to nominate tellkampfi in this regard. The only population thus far that has been shown to be polymorphic at the PGI locus is one which Barr (1979) has reported to be morphologically intermediate between nominate tellkampfi and meridionalis and therefore an apparent hybrid of the two subspecies. The fact that this population is uniquely polymorphic and contains what can be considered to be the nominate tellkampfi (fast) and meridionalis (slow) alleles would seem to be conclusive evidence of this hybridization.

The overall similarity data for the seven loci examined (Table 2) are for the most part consistent with Barr's (1979) morphological data and his taxonomic designations. All comparisins of populations within subspecies yield similarity values in the range of 0.70-0.80. These are remarkably close to those reported by Ayala et al. (1974) for subspecies of Drosophila. The meridionalis x tellkampfi hybrid population has a much higher affinity with tellkampfi than with meridionalis. This is consistent with the fact that, although this population was polymorphic at the PGI locus, the tellkampfi allele has the highest frequency (0.97). Therefore, this population appears to receive a much greater amount of gene flow from nominate tellkampfi than it does from meridionalis.

The large degree of similarity between henroti and nominate tellkampfi (Table 2) is contrary to Barr's (1979) taxonomic designation. Geological evidence suggests that henroti should be the most isolated of the four subspecies with no gene flow between it and subspecies to the south or east. It is interesting to note that the genetic similarity data are consistent with the fact that henroti and nominate tellkampfi are the most similar morphologically of the four subspecies. It should be noted that the two henroti populations examined in this in this study occur in caves located near the southern margin of the henroti range. It will be important to examine some northern henroti populations in order to more accurately assess its genetic relationship to the other subspecies.

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Table 1
Genetic Variability in Four Subspecies of Neaphaenops tellkampfi

SUBSPECIES	P	H
henroti	0.571	0.091
viator	0.428	0.082
meridionalis	0.500	0.137
tellkampfi	0.470	0.154
tell. x merid. (hybrid)	0.429	0.050

A locus was considered polymorphic if the commonest variant had a frequency less than 0.95. P = proportion of loci polymorphic. H= average heterozygosity. Data for N.t. tellkampfi taken from Turanchik and Kane (1979).

Table 2
Genetic Similarity Values (I) Above the Diagonal and Genetic Distance Values (D) Below the Diagonal For Four Subspecies of Naephaenops tellkampfi

	henroti	viator	merid.	tell.	tell.x merid.
henroti	0.982	0.733	0.777	0.966	0.970
viator	0.311	0.940	0.758	0.767	0.674
meridionalis	0.252	0.277	0.958	0.785	0.758
tellkampfi	0.035	0.265	0.242	0.973	0.923
tell.x merid.	0.030	0.394	0.277	0.080	NA

Values of the principal diagonal represent within subspecies similarities. Data for N.t. tellkampfi were calculated from Turanchik and Kane (1979).

Subsidence Susceptibility Models for Dougherty County, Georgia From Sinkhole and Fracture Distribution Data

George A. Brook and Terry L. Allison
Department of Geography, University of Georgia, Athens, Georgia 30602
Phillips Petroleum Company, 266-H Frank Phillips Building, Bartlesville, Oklahoma 74004

Abstract

Dougherty County is a covered karst with 1,011 subsidence sinkholes that are developed in surface residuum over fracture-located cavities in the Eocene Ocala limestone. In the last five years thousands of wells have been drilled into the Ocala aquifer to provide water for pivot irrigation systems. Continued extraction could lower the piezometric surface and increase the likelihood of ground subsidences. Subsidence susceptibility maps have therefore been developed using a geographic information system DBMANG/CONGRID. DBMANG is used to build a grid-format data base, CONGRID to manipulate the data base and procuce maps. Dougherty County was partitioned into 855 cells each 1.18 km^2 in area. Five cell variables were used in the modeling: sinkhole density, sinkhole area, fracture density, fracture length, and fracture intersection density. Cells most susceptible to subsidence were assumed to be those with moderate values for sinkhole area and high values for the other four variables. Sinkholes were mapped from 1:24,000 scale color infrared images. Bedrock fractures, obscured by up to 52 m of residuum, were mapped by a new method involving detailed analysis of sinkhole distributions and shapes. Broadly similar subsidence susceptibility models were developed from cell data by intersection, and separately by linear combination. In the intersection technique cells having specified values for all variables were located and mapped. In the linear combination technique a map value $MV = W_1 r_1 + \ldots W_n r_n$, where W is an assigned variable weight, and r an assigned value weight, was calculated for each cell. The subsidence susceptibility and fracture maps generated should prove useful in water resource and land use planning.

Zussammenfassung

Das Dougherty-County ist ein bedecktes Karstgebiet mit 1011 Dolinen, die in der Oberflächen-Deckschict über in Bruchzonen angelegten Höhlungen in Eozänen Okala-Kalkstein ausgeprägt sind. In den letzten fünf Jahren wurden zur Gewinnung von Wasser für Sprinkler-Bewässerungsanlagen Tausende von Brunnen in die wasserspeichernde Okalaschicht gebohrt. Fortgesetzte Pumptätigkeit könnte den hydrostatischen Spiegel sinken lassen und die Wahrscheinlichkeit von Bodensenkungen erhöhen. Daher wurden Kartzen zur Darstellung der Sekingsanfälligkeit angefertigt, die sich auf das geographische Informationssytem DBMANG/CONGRID stüten. DBMANG dient zur Erstellung eines Datenkorpus im Flächenraster, CONGRID zur Verwertung der Datengrundlage und zur Anfertigung von Karten. Das Dougherty-County wurde in 855 Flächeneinheiten von je 1.18 km^2 Fläche aufgeteilt. Zur Erstellung des Modells wurden fünf Parameter benutzt` Dolinendichte, Dolinenefläche, Verwerfungsdichte, Verwerfungslänge and Dichte von Werwerfungsschnittpunkten. Als Rastereinheiten mit der grössten Senkungsanfälligkeit wurden diejenigen Planquadrate angenommen, die mässige Werte für die Dolinenfläche und hohe Werte für die anderen vier Variablen aufweisen. Zur Kartierung der Dolinen dienten Infrarot-Farbaufnahmen im Masstab 1`24,000. Verwerfungen im Grundgebirge, durch die bis zu 52 m mächtige Deckschicht verwischt, wurden nach einer neuen Methode kartiert, die eine eingehende Analyse der Dolinenverteilung und -form beinhaltet. Weitgehend ähnliche Modelle für die Senkungsanfälligkeit wurden aus den Rasterdaten per Kreuzungspunkt und, getrennt davon, in linearer Anordnung entwickelt. Im Kreuzungsverhafren wurden Rastereinheiten lokalisiert und kartiert, die spezifizierte Werte für alle Variablen aufweisen. Im linearen Kombinationsverfahren wurde ein Kartenwert $MV = W_1 r_1 + \ldots W_n r_n$ für jede Flacheneinheit ermittelt, wobei W eine Festgelegte Variablengewichtung und r eine festgelegte Wertgewichtung haben. Die erstellten Karten zu Senkungsanfälligkeit und Bruchzonen dürften sich als nützlich in der Wasservorrats- und Landnutzungslanung erweisen.

Introduction

The Dougherty Plain of southwest Georgia is underlain by upper Eocene Ocala limestone, which is covered almost everywhere by Oligocene to Recent Surface residuum up to 5+ mm thickness. The area is a highly developed covered karst region with numerous dolines, uvalas, semi-blind and blind valleys, sinking streams, and springs. Closed depressions have developed by subsidence and/or suffosion of residuum into cavities in the underlying Ocala limestone.

As a re-ult of severe droughts during the 1954 and 1977 growing seasons agriculture in the Dougherty Plain has become increasingly dependent upon ground water from the Ocala aquifer for irrigation. In 1970 less than 8 million m^3 of water were withdrawn from irrigaion, in 1977 more than 150 million m^3 were withdrawn. In Alabama an estimated 4,000 man-induced sinkholes or related features have formed since 1900, most of them due to a decline in the water table (Newton, 1977). Increased use of the Ocala aquifer, therefore, even if it does not ultimately lower the regional piezometric surface, could accelerate sinkhole development across the Dougherty Plain near cones of depression produced when irrigation wells are in use.

An attempt has been made to develop maps of ground subsidence susceptibility, which could be of use to land use and water resource planners, by using easily available sinkhole and bedrock fracture data. A sample area - Dougherty County - was selected for study. The county covers an area of 845 km^2 and only the extreme southeast corner lies outside of the Dougherty Plain topographic province.

Modelling Procedure

A geographic information system DBMANG/CONGRID was used in data analysis (Hokans, 1977). The program DBMANG builds and maintains grid-format data bases. CONGRID is used to display data in choropleth form via a line pointer. CONGRID has four maps output options: (1) simple variable display, (2) intersections of variables, (3) unions of variables, and (4) linear combinations of variables. Options 2 and 4 were used in this study.

The relative susceptibility of an area in Dougherty County to ground subsidence was considered to depend on the number of subsurface cavities in the Ocala limestone, and on the likelihood of subsidence or suffosion of residuum into them. Ogden and Reger (1977) concluded from studies in Monroe County, West Virginia, that areas underlain by the most cavernous rock display the most dolines. Ford (1964) has demonstrated that in the central Mendip Hills of England the formation of one doline (the "mother") tends to promote subsurface conditions that are conducive to the formation of additional dolines (the "daughters") in the same area. Data on sinkhole density and on the percent area in sinkholes were used as being indicative of both the number of cavities in the limestone and of the likelihood of further subsidence or suffosion of residuum occurring. In addition, as there is preferential development of solution voids in zones of high secondary premeability because these concentrate ground water flow, data on fracture density, fracture intersection density and total length of fractures in an area were also used in modelling the presence of solution cavities in the limestone.

In order to develop sinkhole and bedrock fracture date files in DBMANG, Dougherty County was partioned into 855 cells in 19 rows and 45 columns. Cell size was 1.0 x 1.1 km.

Sinkhole and Fracture Data Collection

Sinkholes were mapped from 1973, 1:24,000 scale, color infrared images. Planimetric control was established by also mapping roads. Photographic distortion was removed and sinkhold boundaries transferred to 1:24,000 topographic maps using a Bausch and Lomb Zoom Transfer Scope. In total 1,011 sinkholes were mapped giving a density of 1.1 sinkholes/km^2. The number of sinkholes in each cell and the percent area of each cell covered by sinkholes were measured, encoded, and entered into DBMANG. The maximum number of sinkholes in any cell was 15, 32 cells contained more than 10 sinkholes. Five cells had more than 30% of their area covered by sinkholes, 26 cells had more than 20% covered.

The distribution and shapes of sinkholes were used to map possible fractures in the underlying Ocala limestone. Mapping was completed in three stages. In the first stage all prounounced sinkhole long axes and other linear shape elements were identified and marked. In the second stage linear shape elements were connected where these appeared to lie along a single fracture. In addition, fractures were drawn where several sink fell along a straight line. In the final stage of mapping the color infrared images were examined for evidence of additional fractures. In total 1,298 possible fractures were mapped the mean length being 1.9 km/km^2. DBMANG data files were developed for the number of fractures, the number of fracture intersections, and the total length of fractures in each cell. Thirty cells had more than 9 fractures and 276 cells more than 5 fractures; 155 of the 855 cells had no fractures. Three cells had more than 15 fracture intersectins and 20 cells had more than 45 km of fractures.

Subsidence Susceptibility Models

The sinkhole and fracture data files in DBMANG were used to model via CONGRID the relative susceptibility of cells in Dougherty County to ground subsidence. Separate models were produced by intersections and by linear combination of the five variables. The susceptibility of a cell was assumed to increase with an increase in all variables except sinkhole area. For this variable susceptibility was assumed to reach a maximum when 15-24% of the cell was occupied. This assumption was based on the observation that when 20% of the cell area is covered by sinkholes further development is dominated by lateral growth and coalescence of sinkholes rather than by the development of new sinkholes.

Intersection

Intersection modelling of susceptibility involved the use of CONGRID to identify and map cells with specified value of the five variables. Four intersections were mapped (Table 1). Intersection 1 identified only one cell, which is considered to be the most susceptible to ground subsidence (Fig. 1).

Linear Combination

In linear combination modelling the variables and the values for each variable were weighted according to their judged influence on the susceptibility of an area to ground subsidence (Table 2). Each cell was assigned a map value based on the equation:

$$\text{map value} = W_{k_1} r_{k_1} + W_{k_2} r_{k_2} + \dots W_{k_n} r_{k_n}$$

where W = variable weight, r = value weight, and k_{1-n} = index of the variable. Map values for each cell were calculated by CONGRID and then were classified into five groups, each group covering an equal portion of the total range of map values assigned for mapping (Fig. 2).

Discussion

The interception and linear combination models of relatively susceptibility to ground subsidence shown in Figs. 1 and 2 are broad agreement. Furthermore, their accuracy is supported by other data. The most susceptible areas correlate with: (1) areas of shallow residuum (particularly less than 10m) where subsidences may be more rapid, (2) troughs in the potentiometric surface of the Ocala aquifer, which probably indicates areas in which the limestone is cavernous, and (3) regions where the difference between the lowest potentiometric surface on record (December 1977) and the highest potentiometric surface on record (March 1978) exceeds 3 m; in these areas there is a maximum loss of hydrostatic support for the residuum during drought periods.

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Table 1
Values of Variables Specified for Intersection 1-4

VARIABLE	SPECIFIED VALUES OF VARIABLES			
	INTER-SECTION 1	INTER-SECTION 2	INTER-SECTION 3	INTER-SECTION 4
Number of Sinkholes	12-15	10-15	4-15	2-15
Percent Area of Cell Covered by Sinkholes	15-24	10-29	5-35	5-35
Number of Fractures	7-9	5-9	3-9	1-9
Number of Fracture Intersections	12-19	8-19	4-19	2-19
Length of Fractures (km)	3.7-7.2	2.8-7.2	1.9-7.2	1.0-7.2

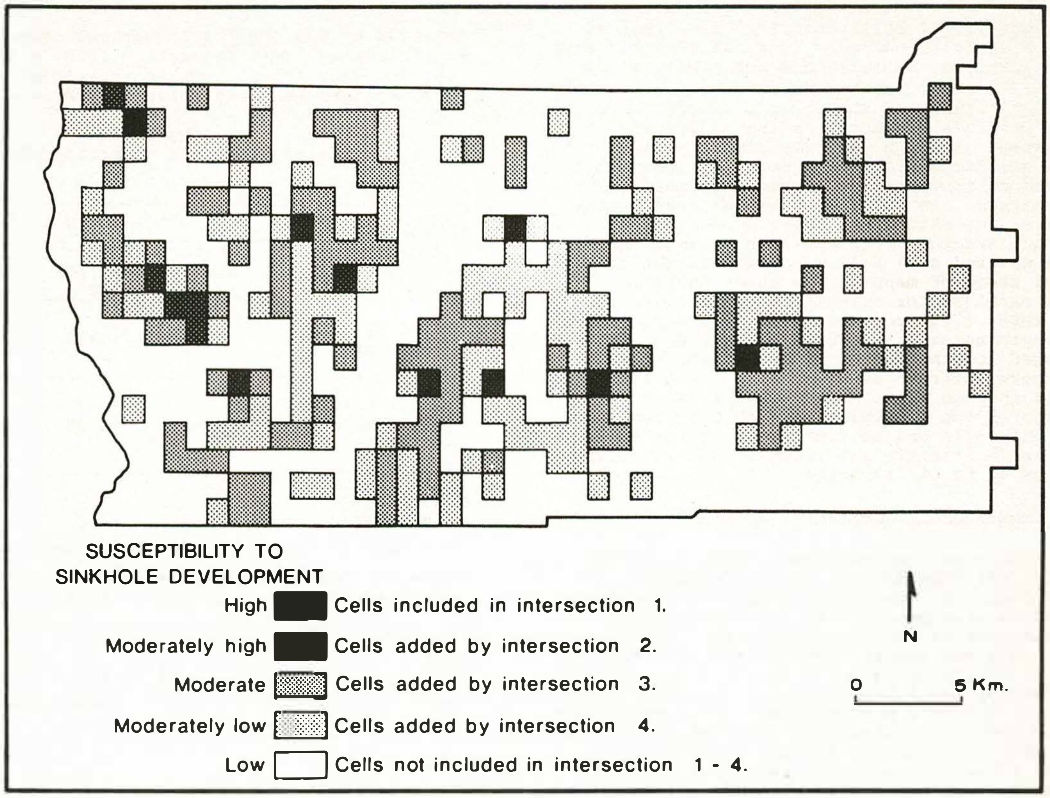

Figure 1. Intersection Model of Relative Susceptibility to Ground Subsidence, Dougherty County.

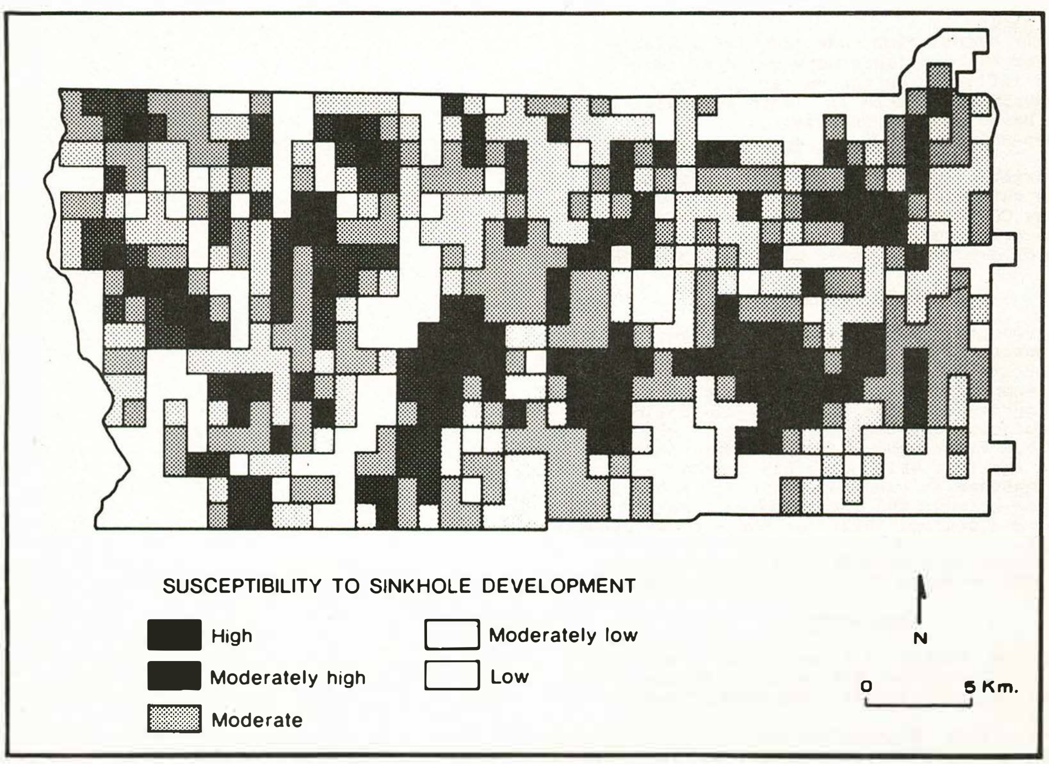

Figure 2. Linear Combination Model of Relative Suspectibility to Ground Subsidence, Dougherty County

Single and Double Fourier Series Analysis of Cockpit Karst in Puerto Rico

George A. Brook and Ronald L. Mitchelson
Department of Georgraphy, University of Georgia, Athens, Georgia 30602

Abstract

Fourier transforms have been used to quantitatively analyse the topography of a 2x2 km area of cockpit karst in the Utuado region of Puerto Rico. The karst is predominantly developed in Oligocene and Miocene Montebello limestone but a few depressions penetrate to the underlying Oligocene Lares limestone beds. Single Fourier series analysis of E-W and N-S linear transects with 26 data points used to determine a suitable fundamental wavelength for double Fourier series analysis. Results showed the cockpit karst to be a relatively simple landscape with a few frequencies adequately describing transect topographies. It also indicated that the fundamental wavelength of topographic variation lay between 2,100 m and 2,900 m and suggested discrete values within this range which might be appropriate for further analysis. Double Fourier series analysis of 996 irregularly spaced values, including all depression floor and hill summit elevations and 656 elevations collected at the intersections of a 26x26 grid superimposed on a map of the study area, indicated that the best representation of the karst landscape could be obtained using a fundamental wavelength of 2,200 m. Sequential filtering of high, medium, and low frequency spectral bands within this wavelength revealed that the greatest relative contribution to this representation came from medium sized wavelengths in the range of 265 m to 700 m. Fourier series analysis may provide a new means of characterizing karst styles such as doline, cockpit, and labyrinth karst. It may also be useful in isolating the various topographic elements that make up a karst landscape and in determining the degree and character of structural control.

Zussammenfassung

Unter Vermendung von Fourier-Transformationen wurde eine quantitative Analyse der Topographie eines Kegelkarstgebietes von 2x2 km Fläche in der Utuadoregion von Puerto Rico durchgeführt. Der Karst ist vorwiegend in oligozänen und miozänen Montebello-Kalken ausgerprägt, aber einige Depressionen dringen in die darunter lagernden oligozägt, Lares-Kalkschichten vor. Einen einfache Fourier-Analyse wurde auf West-Ost und Nord-Süd verlaufende linienhafte Abschnitte mit 26 Datenpunkten angewandt, um eine geeignete Baiswellenlänge für eine doppelte Fourier-Serienanslyse zu ermitteln. Die Ergebnisse zeigten, dass der Kegelkarst eine relativ einfache Landschaft darstellt, wobei ein paar Frequenzen die Streifentopographie ausreichend widerspiegeln. Ebenso wurde deutlich, dass die Basiswellenlänge der Topovarianz Werte liefert, die für weitere Untersuchungen geeigent sein könnten. Von 996 räumlich unregelmässig verteilten Messwerten, einschliesslich aller Depressionsgrundflächen udn Hügelkuppen sowie 656 Erhebungen an den Schnittpunkten eines auf eine Karte des Untersuchungsgebietes übertragenen 26x26 Rasters, wurden Fourier-Dopple-Serieanalysis durchgeführt. Dabei stellte sich heraus, dass die beste Darstellung der Karstlandschaft unter Verwendung einer Basiswellenlänge von 2200 mm zu erzielen war. Schrittweises Herausfiltern von hohen, mittleren und niedrigen Frequenzbändern innerhalb dieser Wellenlänge ergab, dass der grösste relative Beitrag zu dieser Darstellung von den Wellenlängen mittlerer Grössenordnung im Bereich 265 m bis 700 m geleistet wurde. Die Fourier-Serienanlyse dürfte einen neuen Weg zur Charakterisierung von Karstformen wie Dolinen-, Kegelund Labyrinthkarst weisen. Ebenso kann sie zur Isolierung der verschiedenen topographischen Elemente dienlich sein, die eine Karstlandschaft ausmachen, sowie zur Bestimmung des Ausmasses und der Beschaffenheit struktureller Beeinflussung.

Introduction

Morphometric techniques have been applied to the study of karst to develop unambiguous methods of karst landform description, to search for any fundamental organization or interrelationships, and to provide new data useful in the formulation of hypotheses of karst landscape evolution. To date, there has been only limited application of Fourier analysis in karst landform studies and yet it is one of the most powerful and efficient methods for describing topographic variation. In addition, the technique may be particularly appropriate for karst analysis where the topographic data may be contain spatially repetitive elements. Davis (1973, p. 364) has noted that the mechanical response of crustal rocks may be such that perodicities, or a form of regularity, are inherent in the location of the major fracture systems. As karst depressions develop preferentially along fractures, which are lines of increased secondary premeability, this implies that there may be spatial regularity in karst topography.

In double Fourier series analysis map data are fitted by an approximating function based on the geographic coordinates of the data points. This approximating function is used to separate the variability of the data into two components: a regional trend represented by the function, and local residuals represented by deviations. In addition, the approximating function can be filtered in the frequency domain and then inverse transforms used to reconstruct filtered versions of the original topography in the spatial domain. A complex karst topography can therefore be broken down into a series of simpler component models which together make up the terrain. These models could provide an important insight into the spatial organization of karst topography, and could provide information pertinent to the development of hypotheses of karst landscape evolution.

This paper is essentially a report of work in progress on several different karst terrains, and is limited to illustrate the methods being employed and some early results.

Study Area

The 2x2 km study area is included on the Utuado topographic quadrangle of Puerto Rico. It is located east of the Rio Grande de Arecibo 1-2 km northeast of Lago dos Bocas, and has been described as a mogote region with karst valleys and some dolines (Monroe, 1966). Elevations range from 180 m to 365 m a.s.l. The area is located on the norther flank of the principal fold of the Puerto Rican anticlinorium. Sediments in the study area are uniformly titled at 4-5°N and locally they have been gently warped. A majority of the closed depressions are developed in the Oligocene and Miocene Montebello limestone, a member of the Cibao Formation. This limestone reaches a maximum thickness of 275 m. In the southeast of the area a few depressions penetrate into the underlying Oligocene Lares Limestone, which ranges up to 180 m thick.

Data Collection

Topographic data used in Fourier analysis were obtained by digitizing two samples of elevations from the 1:24,000 scale Utuado topographic map, which has a 10 m contour interval. The first sample consisted of 340 irregularly spaced observations of all depression floor and hill summit elevations. The second sample consisted of 656 regularly spaced observations collected at the intersection of 26x26 grid superimposed on the study area. In total 996 topographic elevations were recorded.

Single Fourier Series Analysis

Single Fourier Series analysis of the 26 east-west and 26 north-south linear transects of the study area prov,ded by the 656 regularly spaced observations was undertaken to provide a initial assessment of the relatively complexity of the cockpit terrain and to aid in the selection of a fundamental wavelength of topographic variation that could be used in double Fourier series analysis. A generalized subroutine "Spectra," which assumed a fundamental wavelength equal to the dimensions of the study area, (2,000 m) was used in the analysis (Sall, 1979).

One-dimensional Fourier transformation of the 26 east-west transects and examination of their periodograms showed that wavelengths ranging from 2,100 m also appeared significant. The results of single Fourier series analysis therefore suggested that the fundamental wavelength for the two-dimensional data array was either 2,100, 2,200, 2,300, 2,700 or 2,900 m.

Examination of the entire set of 52 periodograms also revealed that the topography of the cockpit karst is relatively simple. Transcets could be represented adequately with an uncomplicated Fourier transformation composed of a few wavelengths.

Double Fourier Series Analysis

Two-dimensional Fourier coefficients are easily obtained from gridded data where the fundamental wavelenths are chosen as the grid lengths plus one. Coefficients are more difficult to estimate for irregularly spaced data but a major advantage of this approach is that there is no restriction on choice of fundamental wavelengths, this can lead to more meaningful trend maps. Also fundamental wavelengths may be chosen so that extrapolation beyond the control area is possible, in the case of algorithms designed for gridded data the surfaces merely repeat themselves upon extrapolation beyond the control grid. For these reasons double Fourier series analysis was conducted using an algorithm designed for surface fitting of irregularly spaced data (James, 1966).

All five candidate fundamental wavelenths were used in double Fourier series analysis of the cockpit terrain. The 2,200 m wavelength was found to give the best statistical fit, explaining approximately 75% of the variation in the topographic data. The Fourier transform for this fundamental wavelength was then filtered inthe frequency domain to ascertain the relative importance of low, medium, and high frequency spectral bands. Bands 1 and 2, the long and medium wavelength bands, were found to contribute the greatest proportion of the explained variation. The high frequency, short wavelength band 3 appeared to be relatively unimportant (Table 1). This indicates a predominance of topographic elements spaced at intervals of > 275m and the relative unimportance of relief elements spaced at 183-275 m.

Table 1
Relative Contributions of Low, Medium, and High Frequencies to the Two-dimensional Fourier Transform of Cockpit Karst Topographic Data

Fundamental	Filtered Frequency Band	Wave-lengths (m)	Reduction in SS	F-Ratio
	1 (low)	733	5721	35.8
2,200	2 (medium)		7891	48.9
	3 (high)	183-275	1739	10.5

Attention was therefore focused on bands 1 and 2. Inverse transforms were used to reconstruct each band separately in the spatial domain to allow the spatial domain to allow the spatial characteristics of their contributions to the cockpit karst topography to be assessed. The reconstruction of band 1 depicts the most general trends in the karst topography to be assessed. The reconstruction of band 1 depicts the most general trends in the karst and provides an insight into the broad pattern of solutional denudation that produced it. In the spatial domain band 1 is a subdued surface dominated by elongated relief elements that parallel mapped fracture directions in a limestone area 20 km to the northwest (Rinker, 1974). The most prominent of these elements are oriented east to west or parallel with the regional strike of host limestones (Fig. 1C). Broad scale variations in the topography of the cockpit karst are therefore controlled by the distribution and orientation of the major fracture zones. Probable tension fractures, parallel with the bedrock strike, appear to have had the greatest influence on topographic development. The reconstruction of band 2 closely resembles that of band 1 depicting the same elongated relief elements. Band 2, however, identifies a number of additional hills and depressions and therefore better represents the cockpit karst topography (Fig. 1D).

When the two bands were combined in the spatial domian using a low pass filter, which excluded all wavelengths of less than 260 m, the resulting trend surface was a relatively close approximation of the landscape of the study area (Fig. 1A and B).

Conclusions

Single and double Fourier series analyses of topographic data have shown that what appeared to be a relatively complex and chaotic cockpit karst terrain in Puerto Rico is in fact a simple landscape with a farily high degree of spatial regularity. The terrain can be represented adequately by an uncomplicated two-dimensional Fourier transform composed of a relatively small number of wavelengths. The low and medium frequency components of this transform, when reconstructed in the spatial domain, have revealed a highly oriented karst topography with regularly spaced cones and cockpits. The locations of these hills and depressions appear to be controlled by four major fracture systems.

These results illustrate the benefits of an analytical procedure that can filter karst topographic variation into several frequency components and thereby emphasize broad relief trends and spatial regularity. It is possible that filtered versions of different karst styles may help reveal basic similarities and/or differences between them. Low frequency spectral bands may contribute significantly to topographic variation in some styles, they may be unimportant in others. Fourier series analysis could be useful in the quantitative description of karst landforms and could provide a means of differentiating between landform styles on a substantive basis.

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Table 2
Variable and Value Weights Used in Linear Combination Modelling

Variable	Variable Weight		Values (V) and Value Weights (VW)									
Number of Sinkholes	20	VW	0-1 1	2-3 4	4-5 4	6-7 6	8-9 6	10-11 9	12-13 9	14-15 9		
Percent Area Covered by Sinkholes	6	V VW	0-4 1	5-9 4	10-15 6	15-19 9	20-24 9	25-29 4	30-30 4	35 1		
Number of Fractures	20	V VW	0 1	1 4	2 4	3 6	4 6	5 6	6 9	7 9	8 9	9 9
Number of Fracture Intersections	15	V VW	0-1 1	2-3 4	4-5 4	6-7 6	8-9 6	10-11 6	12-13 9	14-15 9	16-17 6	18-19 9
Length of Fractures (km)	12	V VW	0-0.9 1	1.0-1.8 4	1.9-2.7 4	2.8-3.6 6	3.7-4.5 6	4.6-5.4 9	5.5-6.3 9	6.4-7.2 9		

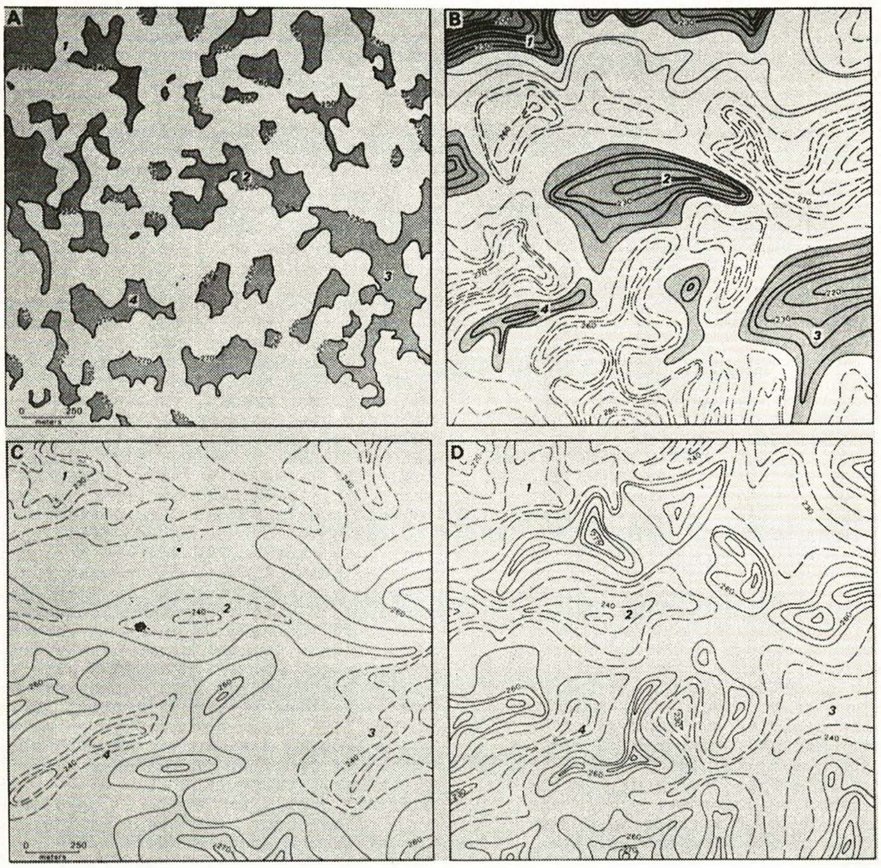

Figure 1. Depression Morphology and Double Fourier Series Trend Surfaces of a Cockpit Karst in Puerto Rico. Closed depressions in the karst are shown in A, B shows a reconstruction in the spatial domain of bands 1 and 2 combined, C shows band 1 and D band 2 reconstructed separately in the spatial domain. Numbers 1-4 identify similar depression features on all four maps.

How Food Type Determines Community Organization in Caves

Dr. Thomas L. Poulson and Dr. Thomas C. Kane

Department of Biological Sciences, University of Illinois at Chicago Circle, P.O. Box 4348, Chicago, Illinois 60680, U.S.A. and Department of Biological Sciences, University of Cincinatti, Cincinatti, Ohio 45221, U.S.A.

Abstract

The terrestrial fauna in the Mammoth Cave System involves six component communities. Each community is characterized by the rank ordered importance values of the species found in that community. Each species has a total importance value obtained by summing its frequency + density + biomass across all seven food-community types for 18 consecutive months of census. Of the 44 regular species, 30 have 95%+ of their total importance values on one food, 7 on two, 6 on three, and 2 on four of the six foods. Seasonal stress of excess water or deficient moisture reduces densities of some species. Deep within the cave, addition of a food found at entrances, such as fresh leaf litter, attracts only expected specialists but an unnatural food, such as horse manure, repels local specialists, attracts new species, and allows rare species to become highly dominant. More species occur and specialist importance values decrease when component food types are mixed in a compound community setting.

Energy availability is the main basis for species specialization to food type. The averaga and variance of energy available / area / time is highest for raccoon feces and lowest for water-leached litter. Cave rat feces, fresh leaf litter, cricket guano, and highly scattered cricket and beetle feces are between the extremes. Species occurring on mutliple foods face similar energy availability by picking different times in successional decomposition or different places along a gradient of food concentration.

Résumé

La fauna terrestre dans le système des grottes Mammoth enveloppe six communautés composantes. Chaque communauté est caractérisée par les valeurs en ordre d'importance des espèces trouvées dans cette communauté. Chaque espèce a une valeur totale d'importance obtenue par l'addition de sa fréquence, sa denisté, et sa biomasse pour toutes les six communautés de type d'aliments pendant 18 mois consécutifs d'étude. Parmi les 44 especes habituelles, 30 ont 95%+ de leur valeur totale d'importance pour un seul aliment, 7 pour deux, 5 pour trois, et 2 pour quatre des six aliments. Un excès d'eau ou une humidité insuffisante dûs aux changements de saisons réduit les densités de quelques espèces. Dans la profondeur de la grotte, l'addition d'un aliment trouvé aux entrées, tel que la litière fraîche des feuilles, attire seulement les spécialistes attendus, mais un aliment non naturel, tel que le fumier de cheval, répugne les spécialistes locaux, attire les nouvelles espèces, et permet aux espèces rares de devenir très dominantes. Quand il y a un mélange des types d'aliments dans une communauté composée, plus d'espèces arrivent et les valeurs d'importance des spécialistes diminuent.

La disponibilité d'énergie est la raison principale pour le spécialisation d'espèces au type d'aliment. La moyenne et la variance de l'énergie disponible / la region / le temps sont les plus hautes pour les fèces de raton laveur et les plus basses pour la litère filtrée par l'eau. Les fèces de rat cavernicole, le litère fraîche des feuilles, le guano des grillons, les fèces de grillon et de coléoptère très dispersées sont entre les deux extrêmes. Les espèces se nourissant de divers aliments font face à une disponibilité semblable d'énergie en choisissant des temps différents de décomposition successive our des places différentes le long d'un gradient de concentration de nourriture.

It is not clear whether communities are real entities. If real then they might be expected to show emergent properties which cannot be deduced from the collective properties of their species as studied alone. Most evolutionary ecologists agree that species interactions that result from coevolution are emergent and that the chance of coevolution is greater with stronger selection of species on one another. Thus +/- interactors such as parasite/host are more likely to coevolve than a general predator with a variety of prey. Also, -/- competitors that harm or interfere with each other are more likely to coevolve than if they just exploit the same food resource. It is not clear or agreed that all species in a community interact enough to coevolve nor is it clear whether boundaries are distinct enough to have real communities. Many forest community ecologists believe that tree species react individually to abiotic factors and that is why species composition changes gradually along environmental gradients of soil, nutrients, moisture, and temperature. From a zoological perspective the difficulty of delimiting boundaries of a community of mobile organisms are even greater but this has been somewhat alleviated by the concept of component and compound communities. A component community includes all the organisms associated with a common resource whether it is a food source or a well-defined microhabitat. A compound community occurs when resources are interspersed and so it is made up of many component communities. This is the approach we take for food resources in caves.

The forest floor and caves are both decomposer systems but the cave has the advantage of being simpler and more amenable to study. The forest floor is different only in having more food types, more interspersion of food types, and more topographic, microclimatic, soil, and seasonal differences which affect the availability of each food type and complicate the analysis. The forest litter is also hard to study becuase it grades vertically into the soil so that indirect methods of sampling, such as Berlese, must be used to extract the animals. In caves leaf litter and other food types rest on firm substrates so the only gradation possible is horizontal and complete censuses can be made visually and combined with unbaited pitfall trapping for rare species and tiny immatures of the smallest mites and collembola. Finally, the patches of food are often discrete. This has allowed us to compare isolated component communities to the same communities in a compound setting with several food types interspersed.

The first step in our analysis of the Mammoth Cave System terrestrial fauna was to determine whether there is sufficient species specialization to be the basis for distinct component communities. We censused all individuals of all species for 18 consecutive months in patches either where the food types occurred alone naturally -- raccoon feces, cave rat feces, cricket guano, beetle feces, and flood-leached fine and dissolved organic matter with clay-mud -- or had to be created by us on mud in non-flood zones -- for fresh leaf-twig litter. We did not do a detailed assessment of some other food types because they are either rare, as with wood and carrion, or their study would disrupt the animals that contribute to the foods that we did study, in the case of nests of cave rats. The minimum size of food patches censused was determined by the area where no new species are added with increased census area. Such species-area curves are obviously steeper, and so require less census area, for an energy-rich resource like feces compared to an an energy-poor one like flood-leached organic matter with clay-mud. Finally either of flooding or cold-dry-windy conditions near entrances. There is little or no winter effect at the near entrance sites where we have censused.

We have used the plant ecologists' Importance Value to assess the species specialization to food types. It is a composite measure based on Distribution + Abundance + Biomass. It is used because no one measure of occurrence adequately reflects a species impact on the food or other species. Distribution is measured on a frequency basis by month for at least two pure patches of each food type. Abundance is measured as numbers / m^2. Biomass is based on live weight. We have made two changes from the way plant ecologists use Importance Value. We have used the absolute value because scaling each species to 100% gives equal weight to common and rare species and so does not fairly reflect their impacts on food or in interactions like competition and predation. We have two reasons for not using frequency by quadrat. First, meaningful quadrats would be much larger for mobile, large species like carabid beetles than for sedentary, small species like snails. Second, areas needed to adequately sample food types are different for highly concentrated vs highly dispersed types (see above and Figure 2).

Figure 1 summarizes the evidence for food specialization and suggests that it is based on energy availability of different food types. Refer to Figure 1 where all graphs are on a common horizontal scale from 10^{-3} to 10^{+6} calories / m^2 / month. The vertical lines, from top to bottom of the figure, represent the average energy availability for each food type specified at the top of the figure. The top graph gives semiquantitative values for the actual availability, as area under each food type curve. It is the area available of each type in the cave as a whole reduced by the time that some of the areas are not available for use because of seasonal flood or winter effects. The second graph shows that potential energy availabilities for some food types overlap with energy availabilities of adjacent food types. This overlap is either in successional = decompositional time, mainly for the energy-rich concentrated foods to the right, and/or in seasonal time and in space = dispersion, mainly the energy-poor dispersed foods to the left. However, the overlap of actual availabilities (top graph) is less since the energy-poor and rich ends of each food type distribution are less common than the mid ranges and since patches of some types are relatively rare, small, and not usable because of high abiotic risk of flooding or desiccation. Using data only for pur patches of each food type, we see that the total species importance values, summed across all the food types on which each occurs, tend to be separated enough to suggest that there is specialization to food type as well as to energy availability per se. The area under each species curve (bottom half of Figure 1) represents its total importance value. In fact, of the 44 species, 30 have 95%+ of their total importance value on one, 7 on two, 5 on three, and 2 on four of the six food types.

We believe that the basis for food specialization is primarily energy availability. This availability is modeulated by abiotic risk, resource predictability in time and space, area of a patch, vertical structure, and horizontal dispersion of the food resource. This is illustrated by four fecal food types in Figure 2. Fecal resources in the cave have clear specialists because the patches are discrete and they are neither leached by rain nor removed quickly by the dung-rolling and burying scarab beetles present outside of caves where the dung is rare and highly dispersed. In contrast there is little or no clear specialization on litter in the cave even though it is the most available resource outside on the forest floor. There are two kinds of experimental evidence which reinforce our view that energy availability is paramount. First, Lavoie (these Proceedings) has taken one facal type, rat, and formed it into the shapes and structures of natural raccoon and cricket feces (Figure 2). She finds that invertebrates and fungi treat it all like rat feces as long as the amount mimics that available fresh in a new and natural rat latrine. The abundances of the species are affected, however, because of great differences in surface area/volume for the different shapes. Second, we find that an unnatural fecal type, horse manure, attracts the species expected for natural raccoon dung if the horse manure pieces are the same size as raccoon scats. In greater amounts the energy availability is more than for any natural cave food and this energy-rich manure attracts some new species, repels some of the raccoon dung specialists, and allows otherwise rare generalists to become highly dominant.

Our indirect evidence for the influence of energy availability is shown by the results on Figure 1. That is, species that occur across more than one food type face similar calories / m^2 / month by picking different times in successional decomposition or different places along a gradient of food concentration. Two millipede species illustrate this point. For Scoterpes, most of the total importance value is centered on the dispersed cricket guano. It has a much lower importance value on very dispersed leaf litter that has completed any successional decomposition, and on leached bits of organic matter washed in through vertical shafts and then deposited by gentle backflooding as thin veneers on passage walls and ceilings. Beetle feces are in the range of energy availabilities used by Scoterpes but the sand where most beetles forage for cricket eggs (Kane and Poulson, 1976) seems to be problematic for millipede locomotion. Like Scoterpes, Antriadesmus specializes on cricket guano but occurs over a narrower and more energy-rich zone and has a higher proportion of its total importance value there.

The basis for millipede specialization to different energy availabilities, as with other pairs of species such as spiders (Poulson, these Proceedings), is difference in foraging, energetics, and life history. Scoterpes is a mobile searcher and reproduces on an irregular basis when adults find a patch of food slightly richer in energy concentration than that needed by adults. Adults may live 3-5 years and reproduce several times after the 3-4 year immaturity period. In contrast, Antriadesmus is nearly sedentary and the entire population of adults mate in near synchrony in spring. Then the adults die and the young grow quickly, mature, and mate the next spring in the same place. Interestingly the snail Carychium and pselaphid beetle Batrisodes are, like Antriadesmus, nearly sedentary, specialized on cricket guano, and have relatives in deep litter outside of caves.

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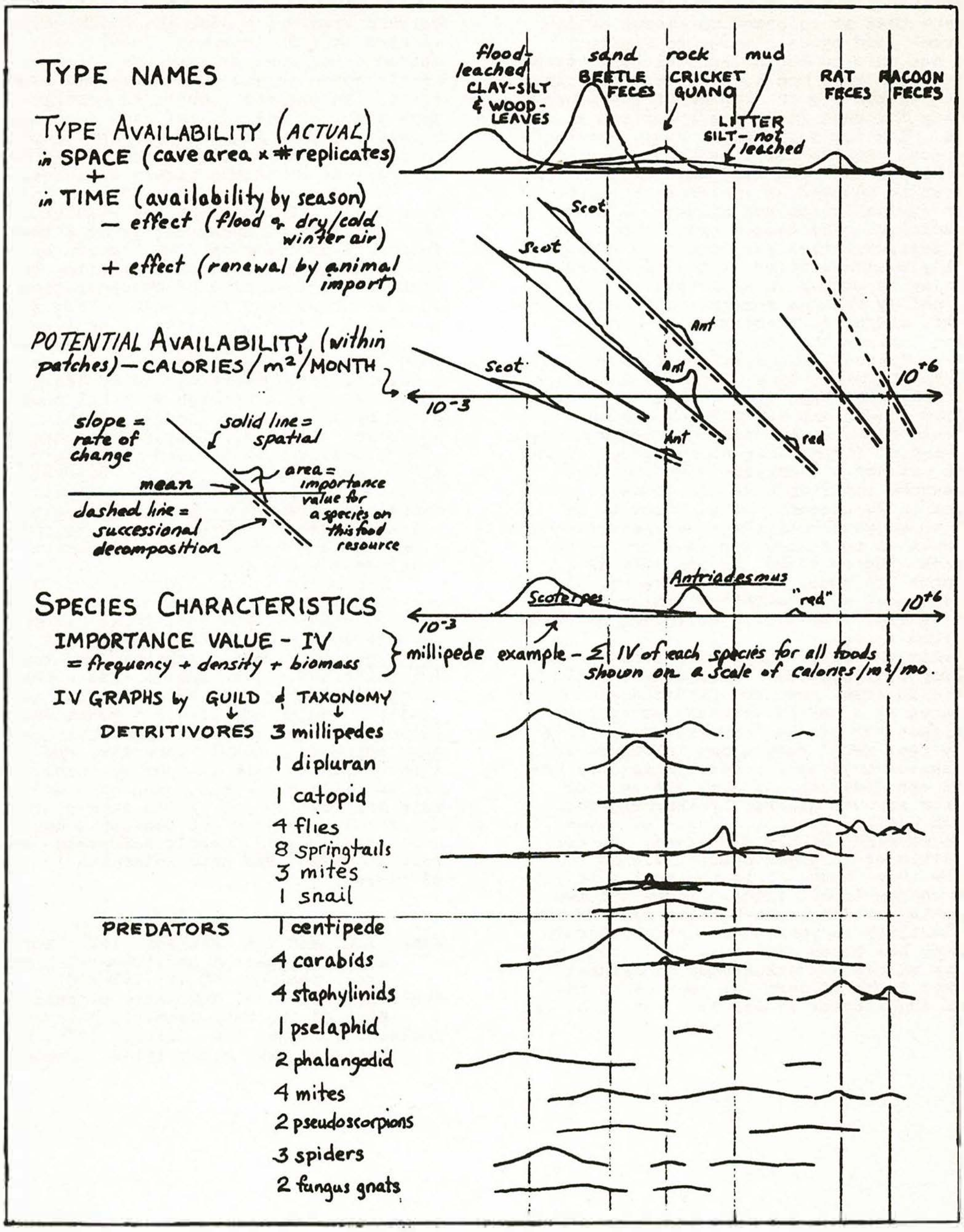

Figure 1. Summary of evidence for food specialization.

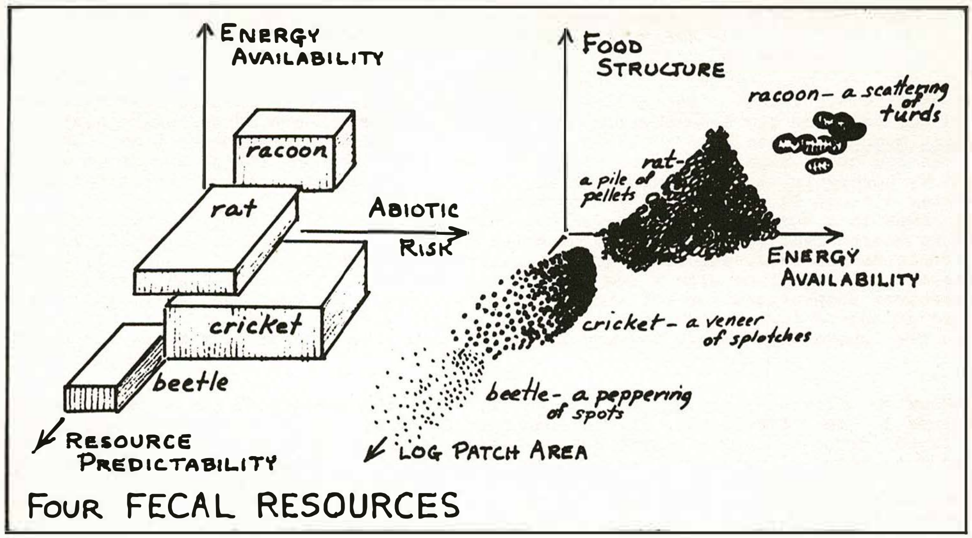

Figure 2. Characteristics of four fecal food types in the Mammoth Cave System.

Variations in Life History of Linyphiid Cave Spiders

Dr. Thomas L. Poulson
Department of Biological Sciences, University of Illinois at Chicago Circle
P.O. Box 4348, Chicago, Illinois, 60680, U.S.A.

Abstract

Two species of small (about 1 mg) and closely related obligate cave spiders have different life histories. On the basis of eye degeneration, which results from absence of selection against loss mutations, Anthrobia monmouthia has been isolated in caves for a longer evolutionary time than Phanetta subterranea. On the other hand, reduction of exoskeleton thickness and in the amount of silk used in egg cases and webs by Anthrobia can be regarded as due to both accumulation of loss mutations and mutations favored by energy economy in a food-poor environment.

Phanetta lives in a somewhat variable and unpredictable abiotic and biotic environment near cave entrances and is short-lived with a high reproductive effort. It is extremely flexible in its energy efficiency, developmental rate, and final size at maturity. Anthrobia lives in a stable environment far from entrances and is long-lived with a low reproductive effort. It is essentially inflexible: All of its biology involves adaptations for extreme energy efficiency. Between cave, site, and year differences in Phanetta are accounted for by its range of physiological, developmental, and life history flexibility as observed in the laboratory. There is very little between site or year difference for Anthrobia.

Résumé

Deux espèces de petites (environ 1 mg) araignées, de proche parenté et obligatoirement cavernicoles, ont des histoires de vie différentes. Sur le fondement de la dégénération des yeux, qui provient de l'absence de la sélection naturelle contre les mutations de perte, Anthrobia monmouthia a été isolé dans les grottes pour un temps d'évolution plus long que Phanetta subterranea. De l'autre côté, la réduction de l'épaisseur de l'exosquelette et le réduction de la quantité de soie employée pour l'enveloppe des oeufs et les toiles par Anthrobia peut être regardées à cause de l'accumulation de mutations de perte et aussi de mutations favorisées par l'économie d'énergie dans un environnement pauvre en nourriture.

Phanetta habite dans un environnement près des entrées des grottes quelque peu variable et non prédicable en abiotique et biotique. Il a une vie courte avec un grand effort reproductiv. Il est extrêmement flexible pour son éfficacité de l'usage d'énergie, son taux de développement, et sa grosseur à maturité. Anthrobia habite dans un environnement constant, loin des entrées et a une vie longue avec un petit effort reproductif. Il est essentiellement inflexible: toute sa biologie engage les adaptations pour l'éfficacité extrême de l'usage d'énergie. Les differences en Phanetta entre les grottes, entre les endroits, et entre les années sont expliqées par son étendue de flexibilité en la physiologie, le développement et l'histoire de vie remarquée dans le laboratoire. Il y a peu de différence entre les endroits ou les années pour Anthrobia.

This is another of my studies that show how variability, predictability, and rigor (extremes) of abiotic and biotic factors have constrained life history, foraging behavior, and energetics during evolutionary adaptation to different environments. Both within and between sites Phanetta faces more kinds of and more variation in prey, predators, competitors, microhabitats, and microclimates than for Anthrobia (Poulson, 1977 figures 11 and 14). Phanetta avoids twilight areas but occurs close enough to entrances to experience seasonal fluctuations in microclimate which are associated with cycles of high to moderate food availability which have somewhat unpredictable durations between sites and years. Anthrobia is restricted to areas of stable and non-rigorous microclimate with very low food availability and only slight differences between sites and years. The separation of the two species is not the result of ongoing competition because the pattern holds whether the species are along or together along a transect from entrance to deep cave. I have both direct and indirect evidence which shows that Anthrobia cannot tolerate either seasonal desiccation or high risk of predation near entrances and that Phanetta cannot tolerate the low food availability away from entrances; if the food supply is artificially increased then Phanetta can survive in deep cave areas.

The spiders are superficially similar but close examination shows differences in body shape and build (Figure 1). When compared to Phanetta at the same cephalothorax length of 0.6 mm, Anthrobia is less robust, has more attenuated legs, shows no external eye remnants, and has a thinner exokeleton (seen in the translucent legs with transmitted light). Anthrobia has a lower ratio of weight to length but has relatively longer legs. This results in lower food needs but with no sacrifice in mobility.

Spider density and web spacing in the field are similar and density dependent web patterns and spacing in the laboratory do not reveal the differences in competitive intensity predicted by the theory of r- vs K-selected species (Pianka, 1970). However the life history of Phanetta is toward the high r end and that of Anthrobia toward the low r end of a continuum between r-selected and K-selected species. Figure 2 is a reconstruction of these life history patterns. It is based on field data on densities of egg cases, immatures, and adults coupled with lab data on time to hatch, grow, mature, and lay eggs. For Phanetta there is an even risk of mortality throughout life. It is based on predation by staphylinid and carabid beetles on immatures and adults. This mortality is balanced by a high output of eggs, most of them early in adult life when a female's reproductive value is highest. This also allows Phanetta to capitalize on the high densities of prey that are available in summer and fall before bad times return again with cold-dry air in winter. Anthrobia has most of its mortality at the hatchling-immature stages and it is due to starvation; adequate densities of small Collembola are rarely present so Anthrobia spreads this risk of early mortality by continued output of single egg clutches.

Figure 3 shows how the energy bottleneck for young Anthrobia is partially reduced by large egg size. The result is that hatchlings are large and so can eat slightly larger prey and can go longer without food. As an adult laying single egg clutches Anthrobia need not be large and the small size is an advantage with reduced food needs. For Phanetta there is little food restriction and the large adult size allows the female to lay large clutches of eggs when food is plentiful.

Long life with repeated reproduction is critical for Anthrobia given the rarity with which it survives the energetic bottleneck between hatching and maturity. This explains why behavioral specializations which reduce the risk of predation have been so favored by selection (Table 1, column 3 bottom). The selection of clay-mud over silt or sand substrates is seen over distances less than a meter along which spider density decreases from 3.5 to 0.1 and the predator Neaphaenops increases from 0.2 to 3.3 per square meter (see Kane and Poulson, 1976). Anthrobia is rarely seen out of a web in the field and lab observations show that it often jumps when touched; this would interrupt chemical tracking by a predator. We also have shown that Anthrobia does not move to areas of high prey concentraion as close as 1-2 meters away when food is artificially increased (Poulson, 1977 Fig. 16). Such food enrichment attracts a variety of general predators which are not normally present. In contrast Phanetta is not only attracted by local food enrichment but also increases its reproductive rate after arrival. The wandering behavior of Phanetta results in finding and capitalizing on local concentrations of prey and the increase in reproduction more than offsets the increased risk of predation. This behavioral flexibility is a reflection of an overall plasticity in Phanetta and is characteristic of many short-lived troglobites that face different conditions from site to site and from year to year.

Figure 4 summarizes the kinds of data I have for flexibility in Phanetta when it is given the maximum food it can eat vs 1/4 of the maximum ration. Note that Anthrobia food rations are about 5-fold lower due both to a lower body weight (4 E) and lower matabolic rate (4 D). Flexibility, coupled with a short life, allows

Phanetta to maximize reproduction in the best times and still adjust to poor times of low food and/or short growing season; The departure from maximum food conditions in the lab of eggs per egg case (4 B), wandering (4 C), body weight (4 D), and mature size (4 E) tells how close a field population approaches optimum conditions. Thus the life history data of Figure 2 are for a population with egg output and adult body size about 60% of the maximum measured for the same population in the laboratory. The web is the only trait in which Anthrobia is as flexible as Phanetta but even here the flexibility is in spacing and not in amount, density, or rate of spinning with different food rations (4 A). The web spacing by Anthrobia is, as with most of its traits, an adaptation for energy economy. With low prey densities of a sedentary prey, such as Folsomia, Anthrobia builds small webs interconnected by trip lines and alternates its time among the webs. This "traplining" is not obvious in Phanetta even though it could conceivably spread the time it waits evenly among all parts of its large and continuous web. Having dealt with most of the progressive traits of Anthrobia it si appropriate to now consider regressive traits and those that may be a mix of regressive and progressive in their origin (Table 1).

Whether or not Anthrobia had the same common ancestor as Phanetta or passed through a Phanetta-like stage in its evolution, the two species are similar enough to meet the criteria needed for valid comparisons of evolutionary adaptation to different cave environments (Culver and Poulson, 1971). Referring to column 1 of Table 1, I agree with Wilkens (these Proceedings) that structures that are not maintained by selection will regress as loss mutations accumulate and I extend this argument to losses in metabolic, developmental, and reproductive flexibility. Unlike eyes, pigment, or epicuticular wax which require little energy for development or maintenance, the regression of exoskeleton, egg case, and web may be reinforced by selection for energy economy (column 2, Table 1). The exoskeleton is metabolically active, is a high proportion of a small arthropod's weight, and is renewed at each molt. The reduction in egg case complexity is also an energetic economy. Phanetta has a 3-layered egg case with a weight of .30 mg, about 10 times that of a single egg. The outer layer is shiny and S.E.M. shows only small spaces between the dense strands. Then there is a dense middle layer and a looser but sticky inner layer. This layering has the dual function of reducing predation by mites and desiccation. Neither of these selection pressures is a problem for Anthrobia which maintains only the inner sticky layer. The case weight is only.015 mg, about a quarter that of its single egg. The reduced prey-catching web is less of an energy saving since it is a one time investment and can be eaten and recycled if damaged. Anthrobia food needs are reduced and the only common prey, Arrhopalites, is small compared to the Sinella and Tomocerus Collembola that are potential prey for Phanetta.

In conclusion I suggest implications of past cave adaptation for future evolutionary change. The extreme phenotypic flexibility of Phanetta allows adjustment to a wide range of conditions without genetic differentiation. Such flexibility will allow adaptation to major quantitative change in the future and perhaps even evolution of 'innovations' in the face of qualitative change. Deme sizes of 50-200, high migration rates, and phenotypic flexibility reduce the chance of local genetic differentiation for Phanetta. In contrast for Anthrobia deme sizes of 15-40, little or no movement, with little phenotypic flexibility increase the chance of local differentiation. This may preclude adaptation to rapidly changing environments but such small populations do not necessarily result in genetic drift or lack of genetic variability (Lande, 1980).

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Table 1. Evolutionary Trends in Anthrobia (as compared to Phanetta).

REGRESSIVE TRAITS not maintained by selection	MIXED TRAITS Regressive and/or Progressive	PROGRESSIVE TRAITS favored by selection
REDUCTION/LOSS DUE TO ACCUMULATION OF MUTATIONS OF POLYGENES (each with a small effect)	REGRESSIVE (no desiccation) PROGRESSIVE (no energy economy)	ENERGY ECONOMY (low food) body size and weight per length reduced--1
Eyes	Exoskeleton thinner	Web placement efficiency. Trapline.
Pigment Melanin Ommochromes?	Egg case reduced from 3 to 1 layer	1 egg clutch STARVATION FOR YOUNG
Epicuticular wax?	REGRESSIVE (large prey rare) PROGRESSIVE (energy economy)	Egg size increased: bigger hatchling--3
Flexibility Metabolic: 4D Weight loss	Web reduced--4A	Long life with repeated reproduction --2
Developmental: time to and size at maturity--4E	Area Strand density	PREDATION RISK FOR ADULTS
Reproductive: timing and number of eggs per egg case --4B		Avoid sand-sild carabid habitat
		No wandering--4C
		No emigration to areas of high food density
		Jump if touched

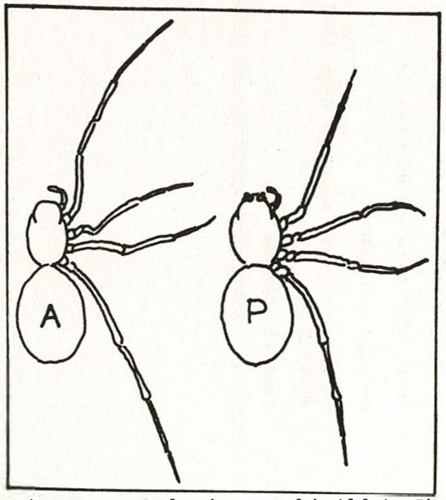

Figure 1. Body shape and build in Phanetta (P) and Anthrobia (A) of the same cephalothorax length (0.6 mm).

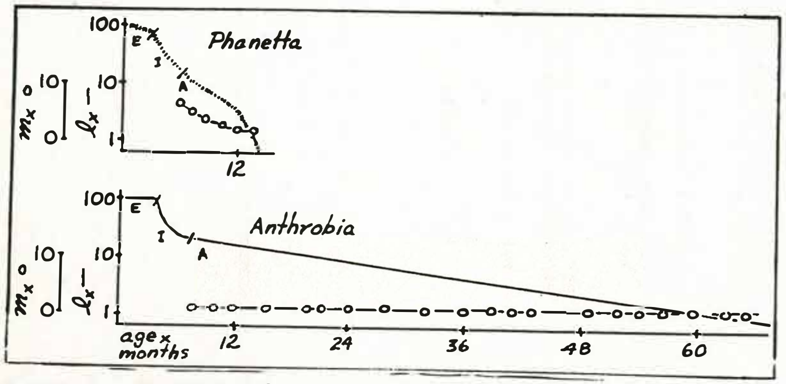

Figure 2. Estimates of age-specific survivorship (l_x) and reproduction (m_x). Egg (E), immature (I), and adult (A) stages are shown.

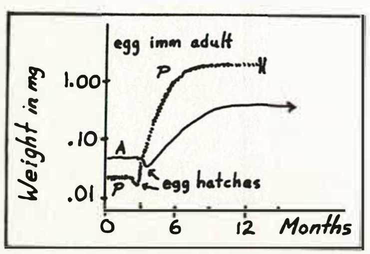

Figure 3. Phanetta (P) has small eggs and hatchlings but large adults whereas Anthrobia (A) has large eggs and hatchlings but small adults. Lab data with no food limitation.

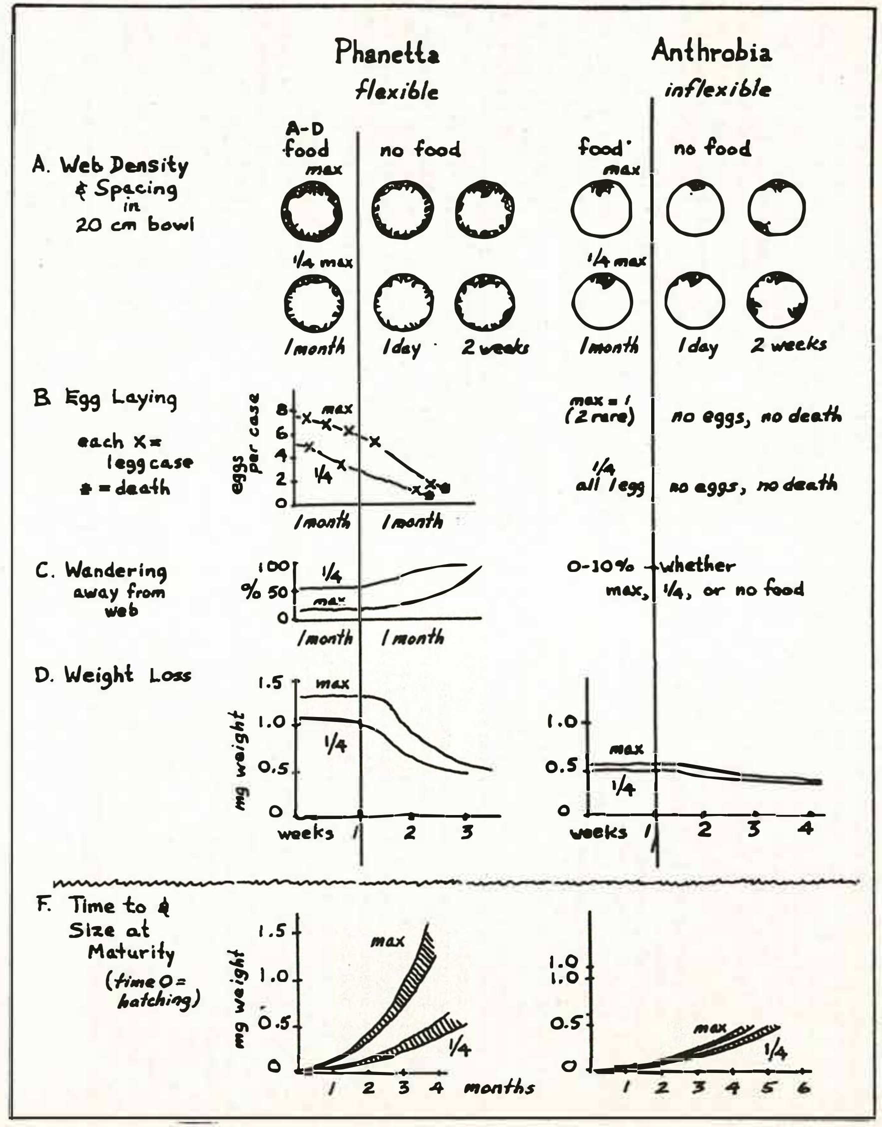

Figure 4. Lab Comparisons.

Pseudokarst on Mars

Victor R. Baker
Department of Geological Sciences, The University of Texas at Austin, Austin, Texas 78712

Abstract

Features resulting from piping, suffosion, thermokarst, and related phenomena appear to be widespread on Mars. Piping is probably a significant process in the development of valley networks that extensively dissect the ancient heavily cratered terrain of Mars. The Martian valleys locally terminate at depressions and reappear as surficial features at points further fown the topographic gradient. Piping on Mars may have been facilitated during an ancient epoch of warmer climate and denser atmosphere on Mars. A thick megaregolith of impact breccia and hydrothermally altered volcanic rock probably formed a relatively weak medium for subsurface fluid movement that undermined more resistant caprocks of pristine lava flows. Probable thermokarst forms on Mars include immense collapse features and prominent examples of backwasting. Scalloped cliff lines and broad, flat floored depressions are common and may form by analogous processes to thermocirques and alas valleys, respectively. Thermokarstic development on Mars was probably facilitated by extensive ice-rich permafrost, perhaps 1 to 3 kilometers thick.

Résumé

Topographies resultantes de la formation de retassures, suffosion, thermokarst, et de tels phénoménes sont apparement universels sur la planéte. La formation de retassures est apparement un procédé important dans le dévelopment des réseaux de vallées qui traversent partout l'ancien terrain pleins de cratéres de Mars. Les vallées de Mars se terminent localement aux depressions et reparaissent comme traits superficiels â certaines localités plus bas sur la rampe topographique. Surs Mars la formation de retassures était peut-être facilitée pendant une époque ancienne du climat plus chaud et d'atmosphére plus dense. Un megaregolith épais de bréche d'impact et du rocher volcanique altéré hydrothermiquement a probablement façonné un moyen assez maigre pour le mouvement sousterrain de fluide lequel a érodé le terrain de recouvrement plus résistant de la lave premiére. Formations probable due recourvrement plus résistant de la lave premiére. Formations probable du thermokarst sur Mars y comprennent topographie d'affaissement immense, et exemples prononcés d'érosion. Communs sont bords de falaises en feston et vastes depressions â plat, lesquels était peut-être formés par un procédé analogue aux thermocirques et vallées alas, respectivement. Le développement thermokarstique sur Mars était probablement facilité par un permafrost trés répandu et plein de glace, qui était peut-être d'un â trois kilometres d'épaisseur.

Introduction

The N.A.S.A. Viking Space Mission generated nearly 60,000 orbital images of the planet Mars. The highest quality images can resolve surface features as small as 10 meters. The landscape revealed by these images is fascinating for the indicated abundance and variety of geomorphic processes that have probably operated on the Martian surface. Reviews of the research results are only now appearing in the literature (Arvidson and others, 1980); Carr, 1980a; Sharp, 1980). This paper will treat one element of Martian geomorphology; space limitations preclude the necessary development of background information on Martian geography (Batson and others, 1979), geology (Mutch and others, 1976; Carr, 1980b), and climatology (Pollack, 1979).

Pseudokarst landforms are those similar in morphology to karst but formed by processes other than solution. Otvos (1976) would restrict the definition to processes and forms involving predominantly piping (suffosion) and thermokarst. These features appear to be abundant on Mars and will be emphasized here. However, the problems of remote viewing of a planetary surface (Mutch, 1979), preclude such a rigorous restriction. The paper will therefore also consider karst-like forms that develop in Martian volcanic terrains and labyrinthine tophographies.

True karst has not yet been identified on Mars. However, the CO_2 atmosphere, evidence of past surface water (Baker, 1978, 1979), and conditions favorable to carbonate accumulation (Booth and Kieffer, 1978) allow for its local occurrence and possible future discovery.

Thermokarst

Thermokarst is the process of melting ground ice to produce local collapse of the ground surface (French, 1976; Washburn, 1980). The extent of thermokarst development depends on the ice content of the ground material and on the degree and rate of disruption of the thermal equilibrium in the permafrost. The process is most effective in materials with high ice contents, such as the eolian silt deposits of Siberia which contain up to 90% ice by volume (Czudek and Demek, 1970).

In addition to vertical collapse, thermokarstic development also proceeds by a backwasting process, leading to extensive cliff retreat by the headward recession of scarps exposing the ground ice. Often the scarp retreat is localized, perhaps by higher water contents, to produce a scalloped cliff line known as "thermocirque" topography (Czudek and Demek, 1970).

The backwasting process may produce broad depressions with steep slopes and flat floors. Extensive alas development occurs in Siberia where the features range up to 15 km in diameter (Washburn, 1980).

Carr and Schaber (1977) described probable thermokarstic features on Mars, interpreting irregular depressions and scalloped scarps of a table land as alases and thermocirques respectively. However, the Maritan examples result in extensive planation surfaces, whereas terrestrial alas development does not usually produce such large lowland surfaces.

Theilig and Greeley (1979) described a high albedo mantling unit overlying the heavily cratered terrain of the Lunae Planum region. This mantling unit, which is interpreted as eolian sediment, has locally been eroded to form steep sided, flat-floored depressions averaging 8 km in diameter. Knobs of material along the inner depression walls appear to be slump blocks from a backwasting process. The correspondence to terrestrial alas valleys appears correct even to the scale.

The heavily cratered terrain provinces of Mars also have features that appear to be of thermokarstic origin. Unfortunately, orbital images alone do not suffice to establish an unequivocal origin for various flat-floored depressions that are remarkably common erosional features on Mars.

Chaotic Terrain

The Martian chaotic terrain was defined by Sharp (1973), as follows: "a jumbled chaos of slump and collapse blocks in lowland depressions bounded by steep walls with arcuate fractures." The individual blocks may be up to 10 km long, and the chaos zones may be several hundred kilometers wide. The bounding arcuate fractures appear to form as arc-shaped slump blocks moved from adjacent escarpments. Arc-shaped fractures may extend into adjoining upland terrains, perhaps indicating incipient stages of chaos development.

Many chaos zones display a progressive change in block shape with distance from the bounding scarps or fractures. Large equant blocks occur near the scarp, but smaller blocks of pyramidal shape occur further away, and finally isolated blocks may occur on a floor that is otherwise relatively smooth. The transition implies an erosional process and removal of the eroded debris.

Chaotic terrain is a likely result of large-scale collapse. The great channels that emanate from many chaotic terrains indicate a fluid release associated with this collapse (Baker, 1978), although fluids other than water have been proposed. Chaotic terrain is probably a very spectacular form of thermokarst, but it has no satisfactory terrestrial analog.

Fretted Terrain

Sharp (1973) defined Martian fretted terrain as a complex of smooth, flat, lowland areas separated by abrupt escarpments from relatively heavily cratered uplands. The planimetric pattern is strikingly irregular. Outliers of the heavily cratered uplands are often separated from the main escarpments, and sinuous flat-floored chasms often are developed for hundreds of kilometers back into the main zones of cratered uplands. These chasms were named "fretted channels" by Sharp and Malin (1975).

The Martian fretted terrain is best developed in a 500-km wide band along the cratered upland/northern plains boundary from about 220°W longitude to 30°W longitude (Mutch and others, 1976). Along this band, which extends half way around the planet, the fretted terrain has clearly developed at the expense of the old cratered uplands (Sharp, 1973).

The escarpments along the fretted terrain margins seem to have a remarkably uniform height of about 1 to 2 km. Sharp (1973) suggested that this may result because the otherwise relatively homogeneous nearsurface Martian material has a sharp, planar, physical discontinuity at a depth of 1 to 2 km. This discontinuity may have formed because of the development of ice-rich permafrost to that depth. The planet-wide evidence for such a layer has been summarized by Soderblom and Wenner (1978). Thermokarst on Mars derives from various disruptions of this permafrost zone.

Brook (1980a) noted that the various landforms of labyrinth karst (Brook and Ford, 1978) are very similar to the Martian fretted terrain. However, the process of fretted terrain development is probably not solutional, but rather thermokarstic (Brook, 1980b). Some fretted terrain has a similar appearance to the ice-wedge thermokarst actively occurring today on Banks Island, Canada (French, 1974).

Volcanic Features

Volcanic features abound on Mars (Carr, 1975). Viking pictures of Alba Patera, one of the largest volcanic structures on the planet, reveal well-preserved lava flow features extending from the central caldera complex (Carr and others, 1977). By analogy to Hawaiian lavas (Carr and Greeley, 1980), the lavas comprise anastomosing complexes of channelfed and tube-fed flows. These data plus other considerations all converge on a probable iron-rich basaltic composition for Martian lavas (Arvidson and others, 1980).

The low viscosity basaltic lavas of Mars probably produced numerous examples of tubes and collapse, as in Hawaiian pahoehoe flows (Greeley, 1971; Swanson, 1973). Chain craters occur along the flows of the Martian volcano Olympus Mons, perhaps indicating over lava tubes.

Some Martian volcanism appears to have been of the explosive variety (Malin, 1977), perhaps because of phreatic eruptions generated by the interaction of magma with an ice-rich permafrost (Riemers and Komar, 1979). In the Elysium volcanic field, where such activity appears highly probable, large collapse troughs abound on the volcano flanks. Large channels, sculpted by fluid flows, emanate from some of these troughs (Mouginis-Mark and Brown, 1980), perhaps indicating karst-like relationships.

Piping and Suffosion

The theater-headed valleys that dissect some Martian volcanoes appear similar to terrestrial valleys formed by piping and spring sapping (Baker, 1980a). Networks of theater-headed valleys are abundant in the heavily cratered terrain of Mars (Figure 1) and also appear to form by the erosion of subsurface fluids (Baker, 1980b; Pieri, 1980). Small filamentous channels appear to drain crater rims and ejecta blankets, while larger valleys drain the intercrater plains. Many channels or valleys begin and/or terminate in depressions.

Piping is the intraformational erosion of rock or soil by the mechanical action of groundwater flow (Parker, 1963; Kälin, 1977). "Suffosion" is a related term that includes chemical attack on certain grains or cements in otherwise insoluble rocks and sediments (Otvos, 1976). These processes can produce networks of valleys by the headward growth of springs (Dunne, 1980). The only requirements appear to be a suitable medium and the requisite ground-water flow system.

Parker and Jenne (1967) found that materials rich in smectite clays were highly susceptible to piping. Mars appears to have abundant smectite clays. Many of the Martian lavas were probably erupted into subsurface ice, forming palagonite, which is highly susceptible to decomposition (Soderblom and Wenner, 1978). The Viking lander experiment results suggest that the lava alteration products are predominantly iron-rich smectite clays, plus some sulfates, carbonates, and iron oxides (Toulmin and others, 1977).

The Martian ground-water system is more speculative. Mars probably has an immense regolith of impact debris or eolian sediment. Under present conditions, permanent ice can exist to within a few centimeters of the Martian surface for latitudes poleward of ±40°(Farmer and Doms, 1979) Equatorward the ice could exist at greater depth, especially if blanketing deposits of fine-grained soil inhibit diffusion and equilibrium with the atmosphere (Smoluchowski, 1968). The permafrost zone, limited by internal heat flow from the planet, might extend to depths of 1 km at the equator and 3 km or more at the poles (Fanale, 1976). Beneath this ground ice zone would be liquid water, perhaps in confined aquifers (Carr, 1979).

Outbursts of water confined by ice, climatic warming, local volcanism, impact events, and scarp retreat may have all led to disruptions of the ice-water subsurface system on Mars. Extensive valley networks formed by sapping where slow seepage undermined resistant caprocks. These networks are extremely ancient (Pieri, 1980) and may have formed during an epoch of warmer climate and denser atmosphere (Pollack, 1979). Thermokarstic collapse occurred where melting was localized. Differences in scale and morphology of Martian features, in comparison to terrestrial ones, may derive from (1) the immense spans of time available for pseudokarstic development on Mars, and (2) the apparent absence of rainfall and related overland flow processes on Mars.

Acknowledgments

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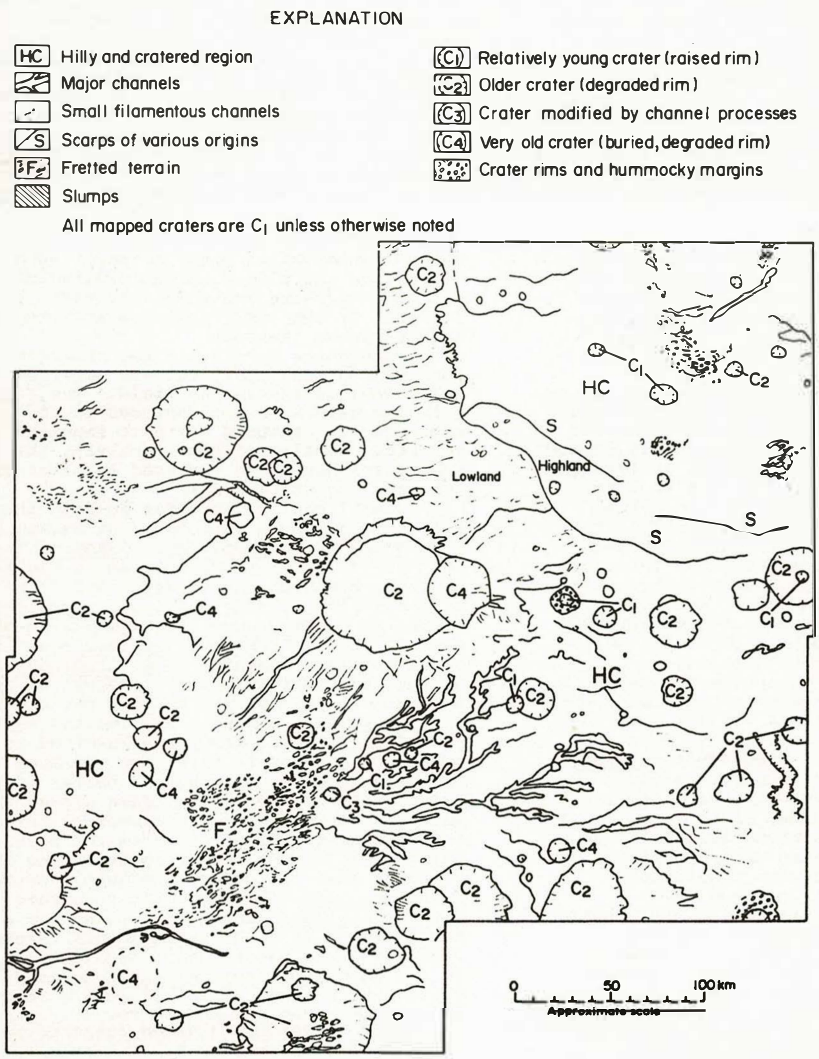

Figure 1. Geomorphic map of valley (channel) networks near Lat. 21°S, Long. 9°S. on Mars.

Preliminary Observations on Foraging Behavior in a Hypogean Crustacean Community

David L. Bechler
Mundelein College, 6363 Sheridan Dr., Chicago, IL 60660 USA
Anna G. Fernandez
Northeast Louisiana University, Monroe, LA 71201 USA

Abstract

Foraging behaviors in three syntopic, hypogean crustaceans were examined in the laboratory and in the field. The troglobitic isopod, Caecidtoea stygia, was not observed to eat in the laboratory. While foraging, the troglophilic amphipod, Gammarus troglophilus, moved twice as fast as the troglobitic amphipod, Bactrurus brachycadus, covered two-thirds as much distance and located food three times faster. Bactrurus brachycaudus was more efficient at locating a food source once it was within 20 cm of the food source than was G. troglophilus. In the field, the two amphipods engaged in a scramble type of competition at the food source. The largest individuals of each species appear to have an advantage over their competitors. Caecidotea stygia does not compete directly for the food source, but forms a loose column downstream from the food source. Smaller individuals are forced to the rear and periphery of the column by the action of the larger isopods. Once the amphipods have reduced their feeding frenzy, the larger isopods will move in and eat. From these findings it is predicted that B. brachycaudus and C. stygia, which appear less proficient at locating and securing food, will have significantly lower active metabolic rates, thus compensating for the behavior differences between them and G. troglophilus.

Résumé

On a observé au laboratoire et aux champs le comportement fourrageur chez les trois crustacées syntopique; On n'a jamais pu observer l'isopod Caecidotea stygia en train de manger au laboratoire; L'amphipod troglophilique, Gammarus troglophilus, s'est déplacé deux fois plus vite que l'amphipod troglophilique, Bactrurus brachycaudus en cherchant de quoi manger. Ils ont couvert deux tiers plus de distance et ont trouvé leur proie trois fois plus vite; Une fois à 20 cm de la source de leur nourriture le Bactrurus brachycaudus était plus habile à la degager que ne l'était le G. troglophilus. Hors du laboratoire les deux amphipods ont fait concurrence devant leur proie; Les plus grands de chaque éspeces semblent avoir l' ascendance sur leur concurrents; Caecidotea stygia ne s'engagent pas directement dans la lutte, mais ils se groupent en colonne en aval de la source de nourriture. Les plus petits se sont déplacés en arriére et de côté de la colonne par l'action des plus grands des isopods; Lorsque la faim frénétique des amphipods s'est calmée, les plus grands des isopods s'approchent pour manger; De là on prévoit que B. brachycaudus et C. stygia qui paraiisent moins efficaces à procurer leur nourriture auront une allure métabolique nettement moins active, compensant ainsi les différences dans le comportement entre eux et le G. troglophilus.

Introduction

A comparative study of the foraging behaviors of three syntopic, hypogean crustaceans was begun in order to determine the relative foraging efficiency of each species and competitive interactions involved in the acquisition of a localized food source. This paper presents the preliminary findings of this study, and draws some tentative conclusions.

Rice cave is located in the northern edge of Jefferson County, Missouri. Running the length of the cave is a small stream ranging between 0.5 to 1 m wide and 3 to 30 cm deep in the pools. Riffles rarely exceed 3 cm in depth. One small tributary is known to feed the main stream. Heavy rains result in only a 4 to 8 cm increase in the depth of the main stream with almost no change in the tributary. Increased flow resulting from heavy rains tends to lag 24 to 48 hours behind the rains. This, combined with the fact that the only two accessible entrances are at the mouth of the spring, has resulted in an extremely low input of organic matter. The result is a stable aquatic system markedly depauperate in visible, organic debris which can serve as a food source for the crustacean community.

Food found in the aquatic cave system can be classified as either a point source or a nonpoint source. Point sources or localized food items in Rice Cave include guano from a species of solitary bat, larva from Eurycea salamanders, an occasional dead adult Eurycea, and crustaceans from within the community. A fifth point source may be leaf particles which work their way through the ceilings of two domes at the end of the cave. Heterotrophic microorganisms living in the mud substrate of the pools may serve as a nonpoint source of food for some members of the crustacean community (Poulson and White 1969, Dickson 1975).

The crustacean community consists of a troglobitic isopod, Caecidotea stygia, a troglobitic amphipod, Bactrurus brachycaudus, and a troglophilic amphipod, Gammarus troglophilus. No other troglophilic invertegrates have been observed in the cave stream. On occasion, a very small apparently troglobitic planarian has been seen. Approximately 67% of the individuals observed in the cave were G. troglophilus, 28% C. stygia and 5% B. brachycaudus. Immature C. stygia and B. brachycaudus approximately 5mm long h[illegible] been observed in the cave but no small G. troglophilus. This suggests that the G. troglophilus population may not always reproduce, but consists of individuals emigrating from the spring and creek outside the cave.

Field observations were made by placing a piece of smelt or salamander muscle in the upper portion of a pool. The time, species, number and actions of individuals approaching the baits was recorded for periods of 1.5 to 3.0 hours. Laboratory observations were made using glass trays 30 by 45 cm with a glass top placed over them. The bottom of the trays were covered with 1 cm of sand and deionized water 7 cm deep. A piece of smelt muscle stuffed in a glass tube was placed in the midline of the tank 10 cm from the opposite end where the test specimen was located. The path of the individual was then traced on the lid as it approached the bait.

Caecidotea stygia was not observed to eat during the foraging pattern test, but was observed eating smelt and salamander muscle in the field. The fact that native clays from the cave were not included in the substrate of the experimental chambers may have impaired C. stygia's ability to feed. Similar effects involving the absences of native substrates have been observed in other subterranean fauna (Poulson and White 1969).

Significant differences in both the elapsed times and distances traveled were found to exist between G. troglophilus and B. brachycaudus. Gammarus troglophilus located bait 222 s. after it was placed in the test chamber, while B. brachycaudus traveled 312 cm before locating the bait ($P<0.01$). Additionally, G. troglophilus traveled 203 cm and B. brachycaudus traveled 312 cm before locating the bait ($P<0.05$). Bactrurus brachycaudus had an average speed of 34 cm/min as opposed to G. troglophilus which had an average speed of 69 cm/min ($P<0.005$). Gammarus troglophilus was more likely to swim through the water column while B. brachycaudus almost always walked on the substrate.

Foraging efficiency was examined as a function of the number of changes in direction required to locate the bait. This was done by counting the number of turns made in consecutive 10 cm wide rings drawn around the bait. Turning rate was expressed as the number of turns/10 cm^2/individual for each ring. Figure 1 shows the results of this analysis. Outside of 30 cm both amphipods turned at about equal rates as they approached the bait. Between 20 to 30 cm B. brachycaudus increased its turn rate to 0.13 turns, while G. troglophilus maintained a turn rate of 0.06 turns. Between 10 and 20 cm B. brachycaudus reached a maximum of 0.37 turns and maintained a similar turn rate between 0 and 10 cm. Gammarus troglophilus increased its turn rate to 0.27 turns between 10 and 30 cm and reached a maximum of 0.45 turns between 0 and 10 cm.

Bond (1980) has divided foraging patterns into extensive and intensive phases. The extensive phase represents a region of superficial sampling while the intensive phase represents a localized region of more thorough sampling. Both amphipods appear to have intensive phases extending up to 20 cm from the bait (Fig. 1). Bactrurus brachycaudus which makes fewer turns appears to be more efficient during its intensive phase. Cody has predicted that an efficient forager will not cross its own path (Morse 1980). Within the intensive phase, 45% of the B. brachycaudus crossed their own path. Gammarus troglophilus was significantly less efficient with 80% crossing their own paths ($P<0.001$). Within the intensive phase B. brachycaudus moved in a relatively direct path without circling around the bait 27.3% of the time. Gammarus troglophilus used a similar path only 6.7% of the time ($P<0.10$).

The key physical difference between the test chambers and the pools in the field was the presence of a current. Species composition and frequence also varied between pools. Brod (1971) divided the first 930 meters of the cave into three segments. The last of these segments and the areas beyond are the only regions of the stream where pools contained all three species. The first two sections of the cave contained all three species. The first two sections of the cave contained only C. stygia and G. troglophilus. Gammarus troglophilus appeared to be much denser in the first segment than in the rest of the cave, and the density of C. stygia appeared to be lower.

The presence of a current strongly influenced the foraging patterns of all three species. As expected, all individuals approached from downstream. Both C. stygia and B. brachycaudus crawled across the substrate. Gammarus troglophilus frequently swam up into the water column as it moved towards the bait. This behavior was observed as far as 3 meters downstream, but was not observed prior to placing the bait in the pool. Generally, G. troglophilus moved steadily up against the current. If it passed the bait it would swim back and forth at right angles to the current. Eventually it would move back downstream and reapproach the bait. Bacturus brachycaudus and C. stygia were never observed to overshoot the bait.

Once at the bait, both ~~amphipods would~~ move onto it and engage in scramble competition (Smith 1980) in order to gain access to the bait. This resulted in considerable pushing and shoving with larger individuals possessing an advantage over smaller ones. Occasionally an amphipod strongly flicked its uronites to repel another individual. The B. brachycaudus that engaged in this scramble competition were equal in size or larger than the G. troglophilius. Small B. brachycaudus were only observed to approach bait occupied by small C. stygia.

Caecidotea stygia moved onto the bait if it was not occupied by amphipods or if the number of amphipods was low, leaving much of the bait exposed. Generally, though, the bait would be covered with amphipods. In this case C. stygia formed a loose column up to 16 cm long by 3 or 4 cm wide. As more individuals joined the column a distinct, size related pattern would develop. Small C. stygia were forced to the rear and sides, leaving the larger ones at the anterior and center of the column. Mere contact was often enough to force the small individuals to the edge of the column. Occasionally a large individual would simultaneously swing its anterior and posterior ends toward a conspecific, forming a U-shaped pattern. The result would be the rapid movement of the smaller individual away from the interior of the column.

The isopods maintained the column until disturbed by an amphipod or until an opening developed on the bait. Once enough room existed on the bait to accomodate the isopods, the largest individuals advanced forward and moved onto the bait. Smaller C. stygia did not advance forward, but simply maintained their positions in the column.

Gammarus troglophilus under controlled conditions in the laboratory and the field, was able to find a localized food source more rapidly than either of the troglobites, but other evidence suggests that its behavior may not be as economically efficient. The rapid movement during foraging and propensity for swimming rather than crawling probably requires a greater percentage of G. troglophilus' energy budget than the slower crawling of the two troglobites. The greatest densities of G. troglophilus are towards the front of the cave so that the majority of the population engages in intraspecific competition with large numbers of individuals of roughly equal ability and behavior. Non-foraging G. troglophilus moved rapidly with an average speed of 36.6 cm/min. Bactrurus brachycaudus was much more conservative and moved at an average speed of 4.1 cm/min. The fact that G. troglophilus may not be reproducing in the cave suggests that the high activity rate do not permit this species to budget adequate energy for reproductive success in this food scarce cave.

The troglobites possess other advantages over G. troglophilus. During the intensive phase, B. brachycaudus made fewer turns and followed a more direct path as it approached the food. Similar results were obtained by Cooper (1969) working with hypogean and epigean Orconectes. This suggests that the increased efficiency observed may be a relatively universal trait that hypogean crustaceans possess over epigean species. The larger size of the B. brachycaudus allowed it to displace the smaller G. troglophilus and gain access to the bait even though it arrived later. Intraspecific competition was controlled by body size in C.stygia, but this species is even more conservative than the amphipods with the smaller individuals readily acquiescing to the touch of the larger ones.

The troglobites may exploit a nonpoint food source in the form of heterotrophic microorganisms (Poulson and White 1969, Dickson 1975) not available to G. troglophilus. This combined with lowered activity rates and suspected lowered metabolic rates associated with cave adaptation (Poulson 1963) may provide the troglobites with sufficient caloric intake to successfully reproduce and thus outcompete G. Troglophilus in this stable, but resource-depauperate aquatic cave system.

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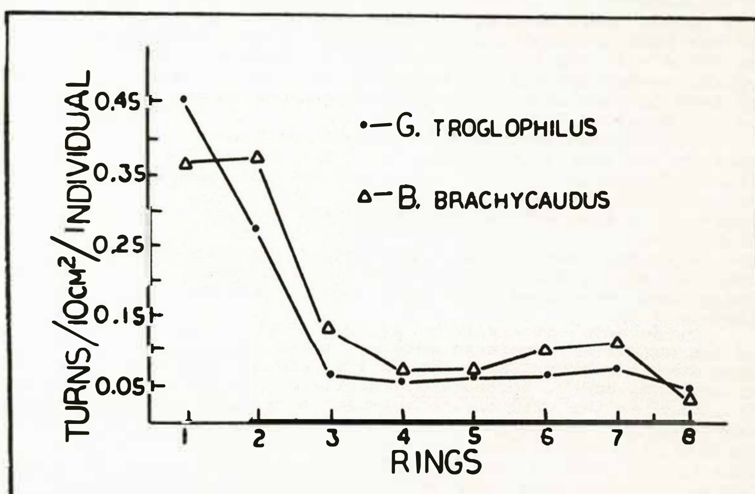

Figure 1. Foraging pattern turning rates. The number of turns/10 cm^2/individual is given for each ring and each amphipod species. Rings 1 and 2 correspond to the intensive phase of the foraging patterns. All other rings represent the extensive phase of the foraging patterns. Food was located at the center of ring 1.

Agonistic Behavior in the Amblyopsidae, the Spring, Cave and Swamp Fishes

David L. Bechler
Mundelein College, 6363 Sheridan Rd., Chicago, IL 60660 USA

Abstract

The diversity of behavior found in the Amblyopsidae was analyzed using "Shannon's H". No agonistic behavior was observed in the epigean species, Chologaster cornuta. It was found that diversity decreased with increasing cave adaptation, and occurred in the order Chologaster agassizi, Amblyopsis spelaea, Typhlichthys subterraneus and Amblyopsis rosae. This decrease in diversity was typified by reduced repertoire, a decrease in the frequency of all aggressive acts except tail-beating which increased, and an increase in the interrelatedness of acts. The frequency and length of bouts also decreased in the more highly adapted cave species. Bouts involving C. agassizi and A. spelaea were determined by body size. Amblyopsis rosae bouts were dependent on prior residency and T. subterraneus employed a combination of prior residency and body size as the primary determinant of the outcome of a bout. The overall picture is one of decreasing overt aggressive behavior paralleled by a concomitant improvement in the efficiency of energy utilization. The changes observed represent a shift from overt agonistic behavior to some other life history trait such as longevity, parental care, etc. as the primary competitive trait determining the fitness of an individual.

Résumé

En se servant du "H" de "Shannon", on a analysé la diversité de comportement chez l'Amblyopsidae. On n'a observé aucune manifestation de comportement antagonique dans les espéces épigiennes Cnologaster cornuta. On a trouvé que plus l'espéce s'adaptait à la cave, plus la diversité se diminuait. Ce phénomene avait lieu dans l'orde des Chologaster agassizi, Amblyopsis spelaea, Typhlichthys subterraneus et Amblyopsis rosae. Cette diminution de diversité ce manifestait par un réspertoire reduit: tous les actes agressifs éstaient moins fréquent sauf les battements de queue qui augmentaient par contre elle se manifestait aussi par plus de relations mutuelles en corrélation; La fréquence et la durée des luttes se sont diminuées aussi chez les espéces mieux adaptées à la cave; Des buttes entre le C. agassizi et A. spelaea se determinaient par la taille des corps; Les luttes entre Amblyopsis rosae dépendaient des droits de territoire tandis que T. subterraneus gagnaient par raison droits de territoire et selon la taille des corps. Dans l'ensemble on voit que le comprotement aggressif se diminue au fur et à mesure que les combattants se servent de leur energie de façon plus efficace. Les changements observés répresentent une evolution depuis la periode d' autres caractéristiques tells que la longevité, les soins maternels etc. C'est cette évolution qui semble être le trait principal de concurrence qui détermine le bien-être et le survivance des mieux adaptés.

Biospeleogical research has made considerable progress during the last 25 years, but detailed studies of complex behavior involving mating, territorial defense and aggression are lacking in the literature. This paper describes agonistic behavior in five of the six known amblyopsid species and discusses the relative importance of the observed behaviors as they relate to other life history traits.

Five to seven individuals of each species were paired conspecifically in all possible pairwise comparisons and all agonistic acts recorded on video tape. The standard length of the intruder or second fish placed in the tank was divided by the standard length of the resident or first fish placed in the tank 24 hours earlier. This produced an I/R ratio such that the lowest values represented the small intruder and the largest resident, and vice versa for the other end of the scale. A value of 1 would then represent an intruder and resident of equal size. These I/R ratios were then grouped by quintiles producing five classes of pairings such that 20% of the smallest intruders matched against 20% of the largest residents made up class 1. Class 3 then represented 20% of the pairs which centered around the central I/R ratio of 1, and class 5 represented 20% of the smallest residents. First and second order diversity as computed from "Shannon's H" was then examined against each size class. It should be noted that the size classes are not strictly comparable since differences exist in the relative sizes of each species, therefore only comparisons in the trends observed can be made.

Six aggressive acts and two submissive acts made up the agonistic repertoire of the family (Table I). Chologaster cornuta, an epigean species, engaged in no observable agonistic behavior. Chologaster agassizi, a troglophile, and Amblyopsis spelaea, a troglobite, employed all eight agonistic acts. Of the two remaining troglobites, Typhlichthys subterraneus employed all acts but jaw-locking, and Amblyopsis rosae used both submissive acts, tail-beating and head-butting.

First order diversity or H_1, provided a measure of the number of agonistic acts and their frequency used during a bout. From Figure 1 it can be seen that C. agassizi and T. subterraneus displayed increasing diversity as the size of the intruder approached and exceeded that of the resident. Once the intruder was sufficiently large, the diversity then decreased markedly as seen in size class 5. The observed increases in diversity resulted from an increase in both the number of acts employed by a pair of combatants and a more uniform distribution of the frequencies of the acts performed.

Amplyopsis rosae follows a similar trend, but in actuality probably possesses a pattern similar to that of A. spelaea. Amblyopsis rosae engaged in very few bouts per observation period. Amblyopsis rosae residents almost always won a bout regardless of the size of the intruder. Tail-beating was employed almost to the exclusion of other aggressive acts. It was also unusual for the intruder to display any aggressive behavior. Because of this uniformity in bouts involving A. rosae, two unusual events served to elevate the diversity of size classes 3 and 4. A single act of head-butting occurred in size class 3 and the only time an intruder behaved aggressively and the resident submissively, occurred in size class 4. Had these two unusual events not occurred, the diversity of size classes 3 and 4 would have more nearly equaled the others.

Relatively little change occurred in diversity from one class size to another in A. spelaea. This resulted from the fact that pairs of A. spelaea employed about the same number of agonistic acts with roughly equal frequencies regardless of the size differences between combatants.

Second order diversity or H_2 provided a measure of the interrelatedness or probability that one act would follow another. The trends observed for H_2 were similar to those observed for H_1. Greater randomness developed as the size of the intruder approached and exceeded that of the resident for both C. agassizi and T. subterraneus. The occurrence of head-butting in class 3 and aggression by the intruder and submission by the resident in class 4 increased the diversity in these 2 classes for A. rosae.

The primary difference is seen in A. spelaea. The diversity of H_2 across the 5 size classes more nearly resembles that of T. subterraneus. The increase in diversity seen in T. subterraneus resulted mainly from the addition of new acts to its repertoire. These new acts changed the interrelationship of acts, but the frequency with which one act followed another did not change appreciably. Amblyopsis spelaea is different. It did not vary its repertoire size markedly from one size class to another. But, as the size of the intruder became larger, the randomness with which one act followed another increased. This resulted in more similar patterns for the 2 species as they pertain to H_2.

Size differences between two opponent strongly influenced the length of C. agassizi and A. spelaea bouts. Bouts involving individuals of nearly equal size lasted as long as 500s for C. agassizi and 450s for A. spelaea. Bouts involving individuals of considerable size difference were relatively brief with C. agassizi bouts less than 50s and A. spelaea less than 25s.

Regardless of size differences, T. subterraneus bouts and A. rosae bouts were relatively uniform in length. Typhlichthys rarely exceeded 50s and A. rosae rarely exceeded 20s with no observable increase in bouts involving opponents of equal size.

Dominance and the eventual outcome of a series of bouts was strongly dependent on the size of C. agassizi and A. spelaea opponents. In most instances the larger fish displayed more aggression towards an opponent and controlled or won the last bouts engaged in. Amblyopsis rosae bouts were dependent on prior residency. Regardless of size, the resident was the aggressor and winner of a series of bouts in all but 1 of 20 pairings.

Body size was important in the determination of T. subterraneus bouts, but prior residency also played a strong part in the outcome of some bouts. An intruder had to be approximately 30% larger than its opponent before it consistently gained dominance and won a series of bouts. Bouts involving intruders less than 30% larger than the resident were controlled by the resident, suggesting that prior residency conferred an advantage on these residents.

Taking into account the basic trends observed in the analysis of first and second order diversity and the importance of body size and/or prior residency upon the length, dominance relationships and eventual outcome of a series of bouts, I have ranked the hypogean amblyopsids according to decreasing overall diversity as follows: C. agassizi, A. spelaea, T. subterraneus and A. rosae. This ranking represents what I believe to be the evolutionary steps involved in the development of agonism in the family. Using as a base past works on the amblyopsids, it is possible to intepret these findings with respect to possible selection pressures and the role of agonistic behavior in the overall life history strategies of the various species.

Chologaster agassizi, which is believed to currently be colonizing a subterranenan environment (Poulson 1961) unlike its epigean relative C. cornuta, has encountered a food-depauperate environment (Poulson 1961, Poulson and White 1969). Additionally, C. agassizi and the other hypogean amblyopsids have assumed the top trophic position in the subterranean community, a position where energy transfer between trophic levels may be considerably poorer (Pianka 1974). These facts combined with relatively energy costly life history traits such as higher fecundity and metabolic rates, and less efficient swimming, have caused C. agassizi to perceive its energy supply as scarce. In order to defend this food supply, C. agassizi has developed long bouts involving relatively strong, diverse agonistic behavior.

As cave adaption increased, fecundity and metabolic rates were reduced, swimming efficiency improved (Poulson 1961), and the caloric demand per individual on the aquatic environment was decreased (Poulson 1969). These adaptations allowed the more highly evolved amblyopsids to consume energy and redirect it into reproductively profitable traits such as larger ova, greater longevity, and increased foraging time. These adaptations also allowed the more cave adapted species such as A. rosae to perceive the food supply as more abundant. The end result was a decrease in selection for agonistic behavior, with bouts becoming shorter and less diverse. Concomitantly, the more advertisement of an individual's presence via tail-beating became sufficient to cause an opponent to move to other feeding areas. This resulted from the fact that an opponent not only perceived food as being more abundant, but possessed the physiological capacity to abstain from eating while it searched for an unoccupied feeding area.

Parzefall (1974) concluded that Peocilia sphenops reduced its agonistic behavior to tail-beating as a means of insuring successful mating in an aphotic enviroment. It appears that the amblyopsids have evolved a similar reduction in agonistic behavior, but this reduction is due to a difference in their perception of the food supply. As energy was conserved the competitive emphasis shifted from locating food to the production of more mature offspring better able to survive the rigor of the cave environment.

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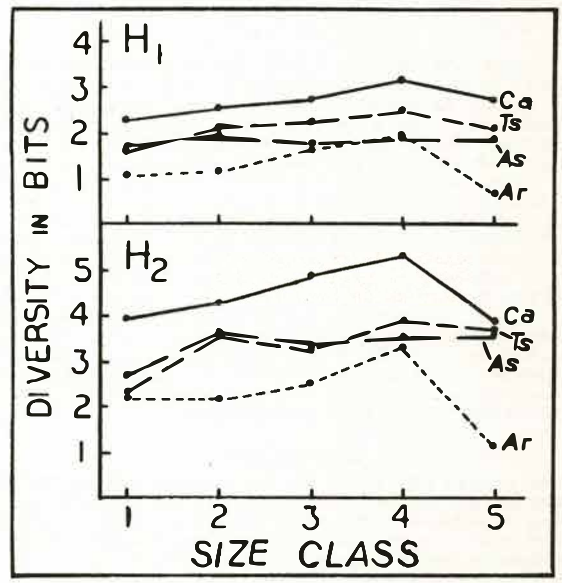

Figure 1. First order and second order diversity for each amblyopsid species. Size classes represent intruders' standard length/residents' standard length. The resulting ratios were then grouped by quintiles to produce 5 size classes. A single bit equals $\log_2 2$. (Ca=C. agassizi; Ts=T. subterraneus; As=A. spelaea; Ar=A. rosae).

Table I. Repertoire of agonistic acts. A plus (+) indicates the agonistic act was performed by the species, and a minus (-) indicates agonistic acts not performed.

	C. cornuta	C. agassizi	A. spelaea	T. subterraneus	A. rosae
Submissive Acts					
Freeze	-	+	+	+	+
Escape	-	+	+	+	+
Aggressive Acts					
Tail-beat	-	+	+	+	+
Head-butt	-	+	+	+	+
Attack	-	+	+	+	-
Bite	-	+	+	+	-
Chase	-	+	+	+	-
Jaw-lock	-	+	+	-	-

Accuracy Evaluation of Electromagnetic Locating

Charles S. Bishop and Frank S. Reid
Frankfort, Kentucky, U.S.A. 40601

Abstract

Horizontal positions on the surface and depths to underground points are being obtained using electromagnetic locating equipment. Accuracy of the results obtained has been mostly speculative. Work has been conducted to obtain quantitative values for the errors associated with positions and depths obtained using this equipment. Sixty determinations were made at Blue Springs Cave, Indiana, and Mammoth Cave, Kentucky, determining both horizontal position and depth. These results were then compared with similar results obtained from precise surveys. Surveys were to a precision exceeding 1:5000 but less than 1:10,000 for horizontal position. Elevation differences were based on leveling that exceeded third order accuracy requirements.

The accuracy of horizontal positions obtained is directly related to depth. At depths of less than 30 meters, errors in horizontal position of less than 15 cm resulted. At depths of 60 meters, the error in horizontal position averaged 2.1 meters. Depth determinations were consistently less than the actual value. At a depth of 22.5 meters, the determined depth was 97.6% of the actual value, and at 60 meters, 95% of the actual value was obtained.

Results of this project indicate that there are limitations to the capabilities of this type of equipment. The values for the errors are directly related to depth and the associated factors of signal strength, null width, and atmospheric noise. With the limiting factors known, it will be possible to better plan the use of electromagnetic locating equipment to obtain the most accurate results for controlling and checking cave surveys.

Résumé

On obtient des points horizontaux à la surface, et la profondeur des points souterrains, par un équipment de repérage électromagnétique. L'exactitude des mesures obtenues avait surtout été conjecturale. On a essayé de trouver des valeurs quantitatives pour les erreurs de position et de profondeur dues à cet équipment. On a fait soixante déterminations avec un point horizontal et un point en profondeur à Blue Springs Cave, Indiana et à Mammoth Cave, Kentucky. Ensuite on a comparé les mesures obtenues avec d'autres mesures obtenues par des relevés précis. Ceux-ci étaient d'une précision dépassant 1:5000 mais inférieure à 1:10,000 pour les points horizontaux. Les différences de niveau se basaient sur une dénivellation qui dépassait les exigences requires pour une exactitude de troisiéme ordre.

L'exactitude des points horizontaux obtenus est en fonction directe avec la profondeur. A des profondeurs de moins de 30 métres, la moyenne d'erreur pour le point horizontal était de 2,1 métres. Les déterminations de profondeur étaient réguliérement inférieures à la valeur réelle. A une profondeur de 22,5 métres, la profondeur déterminée était 97,6 pour cent de la valeur réelle, et à 60 métres, on a obtenu une a valeur de 95 pour cent de la valeur réelee.

Les conclusions de ce travail indiquent qu'il y a des limites aux possibilités de ce genre d'équipement. Les valeurs pour les erreurs sont liées directement à profondeur et aux facteurs associées à celle-ci, c'est-à-dire, la puissance du signal, la largeur nulle, et les bruits atmosphériques. Une fois connues les facteurs limites, il sera possible de mieux éstablir des plans pour l'emploi de l'équipment électromagnétique de repérage afin d'obtenir les mesures les plus exactes en vue de contrôler et de vérifier les relevés des cavernes.

Introduction

Horizontal positions on the surface and depths to underground points can be obtained using electromagnetic locating equipment. The accuracy of the results obtained has been mostly speculative in the past, being based on personal experiences and intuitive reasoning. In only a few instances has the accuracy been checked in any manner. A need has existed to determine quantitatively the accuracy of the results obtained using this equipment.

To make an evaluation of the results obtained with electromagnetic locating equipment, the exact location, horizontal position and elevation, of the underground point has to be compared to the location of the point determined on the surface. Having bench marks and control surveys of known accuracy, both underground and on the surface, is essential. Without appropriate levels of accuracy, the data obtained would be meaningless.

During the fall of 1974, planning and field work were begun to obtain the required data. The site chosen for performing the field work was Mammoth Cave in Mammoth Cave National Park, Kentucky. This site provided the unique situation of having numerous surface and underground bench marks which are well monumented. Thirty-four bench marks were placed in the cave during the 1935-36 survey by H. D. Walker (1). All marks in the Park are of third order traverse and leveling accuracy. Blue Springs Cave in Indiana was also chosen for making determinations. It provided an ideal situation for depths of less than 30 meters, with a minimum of control surveying required.

The electromagnetic locating equipment used on this project was constructed by F. S. Reid. It operated at a crystal controlled frequency of 3500 Hz. Both transmitting and receiving coils were 48.3 cm in diameter. Power was supplied to the transmitter by a 12 volt battery. Power output from the transmitter was 10 watts. The receiving unit operated at ± 9 volts and had an operating band width of 3 Hz. Range of the equipment was 400 to 500 meters from the ground zero point.

Accuracy of Control Surveys

In Mammoth Cave, the Walker surveys provided the control. They were run using third order transit and tape techniques. Six angles were turned at each station both above and below ground using a 30-second transit. Distances were double-taped and further checked with stadia rod readings. Observations on Polaris were made at surface stations which tied to underground lines. Third order traverse accuracy calls for a closure precision of not less than 1:5000 for the unadjusted traverse data. As a check on survey accuracy, the latitudes and departures were summed for one loop through the cave and over the surface using data from the Walker field books, which are stored in the archives at Mammoth Cave National Park. The resulting value for closure precision was 1:14, 524.

Level lines were also run by Walker through the cave to determine elevations for the bench marks. The level lines were run using a Dumpy level and Philadelphia rods or sawed-off New York rods where low ceilings required. These were also run to third-order accuracy. Review of the field books shows no error of elevation closure greater than 3.1 cm.

At Blue Springs Cave, an open traverse was required to provide control both in the cave and on the surface. These traverses were run using a Wild T-2, 1-second instrument set up. Distances were measured twice using either a 30-meter steel tape under 9 kg pull with slope and temperature corrections being applied, or with a Wild DI-10 electronic distance meter.

To provide elevation control, temporary bench marks (TBM's) were set in close proximity to the surface and underground points. Three-wire leveling procedures were used to include the TBM's in closed loops. In all cases elevation closures of 1.5 cm or less resulted.

In order to determine the relative accuracy of horizontal positions obtained, plane coordinates need to be used. At Mammoth Cave the obvious choice was the Kentucky State Plane Coordinate System which is based on the Lambert Conformal Conic Projection. During the 1935-36 survey, Walker calculated values for geodetic position to 0.001 second. These values appear in his field books and were used for this project because it was felt that they would more truly represent the relationships between bench marks. Plane coordinates were calculated based on procedures given in the

U.S. Cost and Geodetic Survey publication G-115, Plane Coordinate Projection Tables in Kentucky. At Blue Springs Cave in Indiana an arbitrary coordinate system was used.

Field Procedures and Data Reduction

The field procedures and measurements to make location and depth determinations using the electromagnetic equipment followed very closely those described by Mixon and Blenz (1964) (2). Horizontal position (ground zero point) was found using a systematic search routine and depth was determined by multiple measurements of magnetic field inclination at various distances from ground zero.

On completion of the needed measurements with the electromagnetic equipment, the actual position and elevation of ground zero was obtained. The position of ground zero was determined by one of two methods: turn angle and distance, or trilateration, which involved measuring the distance from two TMB's. All distances were obtained using horizontal taping procedures. To establish the elevation of the ground zero point, differential leveling procedures were used to tie to a TBM or bench mark. Similar procedures were used underground to determine the horizontal position and elevation of the transmitter.

Calculations for depth determination were made based on the equations from Mixon and Blenx (1964) (2) given below. The inclination of the magnetic field is described by Equation #1 below, where d = depth, ℓ = distance from ground zero, and θ = angle of magnetic lines of force from vertical. Solving this equation for depth using the quadratic formula yields Equation #2 below.

(1) $\theta = \mathrm{Tan}^{-1} \dfrac{3\ell d}{2d^2-\ell^2}$ (2) $d = \dfrac{(3+9+8\mathrm{Tan}^2\theta)}{4\mathrm{Tan}\theta}$

Equation #2 was used to determine the depth of the transmitter. Readings of θ were taken at several ℓ distances and the equation solved for all values, after which an average was taken.

Horizontal position and depth determinations were made at four depths, those being: 23, 61, 65 and 91 meters. Twenty determinations were made for each of the three depth ranges. This allowed statistical evaluations to be made.

Results for Horizontal Position

The results for horizontal position determinations are summarized in Table 1. Errors in position were calculated from the differences in plane coordinates for the transmitter and the determined ground zero point. All values given in Table 1 are average values for all determinations at that depth. The direction is the bearing of the error taken from the underground transmitter point to the surface point. Distance difference is the difference between the distances between transmitter points and the distances between ground zero points. Distance differences can be considered to be a measure of how well the pattern of points in the cave reproduced on the surface.

TABLE 1. HORIZONTAL POSITION DETERMINATIONS

Number of Determinations	Depth (Meters)	Average Error (Meters)	Direction	Distance Difference (CM)
19	22.5	0.09	RANDOM	-1.5
7	60.4	2.68	N 80° E	17.4
10	64.6	2.08	N 45° W	17.5
20	90.8	9.92	N 15° E	42.2

At the 22.5 meters depth, the average error in horizontal position was 8.8 cm, the direction of the errors was random, and the relative positions of the points in the cave reproduced almost exactly on the surface as indicated by the distance difference. At a depth of 60.4 meters the average error in position was 2.68 meters and at a depth of 64.6 meters the average error was 2.08 meters. The errors which resulted were in a consistent direction and had distance differences of 17.5 cm. For the 90.8 meters depth, the average error in horizontal position was 9.92 meters, the direction of the error was consistently in one direction, and the distance difference was 42.4 cm. Of the 60 position determinations, 4 had such large errors in position that they were excluded from the averages.

Results for Depth Determination

The results for depth determinations are summarized in Table 2. Each determination consisted of 10 or more field inclination measurements taken at various distances from ground zero. For all the determinations made the determined depth was consistently less than actual.

Reviewing the data of Table 2, it can be seen that a nearly linear relationship exists between the percentage of actual depth determined and actual depth. With increasing depth, the error in determined depth increases approximately linearly. Applying theories of error propagation to the formula for depth determination, we found that the error in the determined depth was directly related to the error in the ground zero position.

TABLE 2. DEPTH DETERMINATIONS

Number of Determinations	Actual Depth (Meters)	Determined/Actual (%) Depth
19	22.5	97.6
7	60.4	95.1
10	64.6	94.8
17	90.8	92.1

Depth determinations at an actual depth of 22.5 meters yielded a value which was 97.6% of the actual. At 60.4 meters 95.1% resulted and a correspondingly close value of 94.8% resulted at 64.6 meters. A value for depth of 92.1% of the actual value resulted at the depth of 90.8 meters.

Conclusions and Recommendations

The capabilities and limitations of electromagnetic equipment and procedures were evaluated to some extent by this project. Accuracy appears to be directly related to depth. Reasons for this relation can be directly tied to the decrease in signal strength and increasing diameter of the null with increasing distance from the transmitter. These factors limit the capabilities of the equipment.

The following general statements with regard to the accuracy of the results can be made:

1. At depth of 30 meters or less, the error in the determined surface position (ground zero) will be less than 15 cm. Depth determinations will be approximately 97% of the actual depth.
2. At depths of 60 meters, the error in the determined surface position will be approximately 2.1 meters. Depth determinations will be approximately 95% of the actual depth value.

For the position determinations made at 91 meters the average error of 9.92 meters appears to be too large considering the average distance difference of 42.4 cm. An error in horizontal position of 4 to 5 meters would be more reasonable. The accuracy of depth determination would be greater than the 92% obtained.

From the experience obtained on this project the following recommendations regarding electromagnetic locating can be made:

1. When determing the position and depth of underground points, multiple determinations should be made.
2. For the multiple determinations a pattern of points should be used. One determination should be directly on the desired point and one or more additional points at known distances and directions from the desired point would constitute a known pattern.
3. How well the pattern of points reproduce on the surface will give an indication of the relative accuracy of the determinations made.

These results and recommendations should make it possible to better plan the use of electromagnetic locating equipment for obtaining most accurate results to control and check cave surveys.

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Comparisons of Acute Toxicity for Cd, Cr, and Cu Between Two Distinct Populations of Aquatic Hypogean Isopods (Caecidatea sp.)

Arthur D. Bosnak and Eric L. Morgan
Department of Biology, Tennessee Technological University
Cookeville, TN 38501 U.S.A.

Abstract

It has been documented that heavy metal pollution is occurring throughout the subterranean karst drainages of the United States. Little attention has been given to the toxicological evaluation of wastes entering the aquatic hypogean ecological system. To provide insight into these concerns, studies were designed to evaluation the lethality of selected heavy metals imposed on two distinct populations of aquatic hypogean isopods.

In the late summer and fall of 1980, isopods of the genus Caecidatea were collected and tested under laboratory conditions to establish acute LC_{50} values for cadmium, chromium, and copper in flow-through aquatic toxicological assays. Caecidatea spp. employed in these studies were taken from two distinct stream habitats: Merrybranch Cave, White County, Tennessee, and Caney Branch Cave, Clinton County, Kentucky, U.S.A.

Resulting acute LC_{50} values and their 95% confidence intervals for each toxicant were derived by log-probit analyses and are discussed in light of species specific responses.

Résumé

La pollution par métaux lourds des bassins karstiques souterrains de drainage à travers les Etats-Unis a été documentée. Jusqu'ici peu d'attention a été consacrée à l'évaluation de l'effet de ces éléments toxiques sur les organismes hypogés. Dans le but d'éclaircir cette question, nous avons conçu des études qui essaient la sensibilité des organismes hypogés à certaines substances toxiques;

Pendant la fin d'été et l'automne de 1980, nous avons réunis et soumis à des essais de laboratoire des isopodes du genre Caecidatea afin d'éstablir les valeurs LC_{50} (concentration mortelle pour 50% des individua) à court terme pour le Cd, le Cr et le Cu dans des essais toxicologiques en courrant d'eau. Les Caecidatea sp. utilisés dans ces études ont été pris dans la grotte Merry Branch Cave, White County, Tennessee, et dans la grotte Carney Branch Cave, Clinton County, Kentucky, U.S.A.

Les valeurs de la LC_{50} qui en résultent et leurs intervalles de fiabilité à 95% pour chaque élemént toxique ont été déterminées par des analyses logarithmiques-probabilistes. Ces valeurs sont discutées à la lumiére des résponses spécifiques à l'espéce.

Introduction

Although not as dramatic and apparent as surface water pollution, degradation of the quality of subsurface waters in karst aquifers has become widespread (Branstetter 1974; Smithson 1975; Barr 1976; Quinlan and Rowe 1977). Studies show that man-induced stresses introduced as toxic heavy metals and organic substances may bring about impositions which alter the community of aquatic organisms (Cairns 1977).

A paucity of literature exist on the fate of heavy metal pollutants in waters which flow through subterranean karst drainages and the subsequent impositions on hypogean benthic macroinvertebrates communities. In meeting the objective of this investigation, studies were designed using aquatic toxicological assay methods to establish acute LC_{50} values (a toxicant concentration estimated to result in 50% mortality of members of a population within a specified period of time) for Cd, Cr, and Cu subjected to two distinct populations of troglobitic isopods (Caecidotea bicrenata and Caecidotea stygia).

Materials and Methods

Troglobitic isopods (C. bicrenata) were collected from Merrybranch Cave, White County, Tennessee, and (C. stygia) were taken from Caney Branch Cave, Clinton County, Kentucky, U.S.A., by removing rocks from the water, washing the isopods and small amounts of food material into a 5-L plastic containers, and covering containers with black plastic for transport to the laboratory. Isopods were acclimated in the laboratory to 13±1°C and to small additions of dilution water (dechlorinated city tap water) for at least 4 days before exposure to experimental treatments. Routine physical/chemical water quality characteristics for the dilution water are reflected in analyses done on control treatments (Table 1). Procedures for acute toxicological testing were taken from U.S. EPA (1975) and Sprague (1973). All tests were carried out in the fall and winter of 1980. A vacuum siphon proportional diluter was used to administer toxic treatments and was based upon modified design and construction materials suggested by Mount and Brungs (1967). The diluter was designed to generate a range of treatment solutions over which the mortality response of the isopods was evaluated, i.e., by delivering in replicates five different toxicant concentrations plus a control to 20-L glass aquaria with slate bottoms at 10 min. intervals. Ten isopods were positioned at random in each aquarium giving a total of 20 organisms per treatment. Photoperiod was total darkness except for direct fluorescent lighting during placement, mortality checks, and collecting of water samples. Once tests were initiated, observed mortality for each organism was determined by probing the organisms with a small paint brush to note lack of movement.

The following parameters were measured at the start and termination of each test: temperature (°C) and dissolved oxygen (mg/L) values, YSI Oxygen Meter (model 51A); pH, Orion Specific Ion Meter (model 407A); conductivity (μMHOS/cm), YSI S-C-T Meter (model 33); and total alkalinity and hardness (as $CaCO_3$) measured by titrametric analysis (American Public Health Association 14th ed. 1975). Water samples for heavy metal detection were taken at the beginning and every 24-hr. interval thereafter for each test. Heavy metal water samples were acidified with concentrated HNO_3 and analyses were performed by atomic absorption spectrophotometry (Perkin-Elmer 372).

Regent-grade chemicals were used for all toxicity tests. They were: cadmium chloride ($CdCl_2 \cdot 2\frac{1}{2}H_2O$), potassium dichromate ($K_2Cr_2O_7$), and cupric chloride ($CuCl_2$). Concentrated toxicant solutions of each chemical compound were premixed in 50-ml of concentrated nitric acid and brought to volume in an 18-L Mariotte bottle with dilution water. The Mariotte bottle containing the concentrated toxicant solution was then connected to the toxicant metering system of the dilutor.

Results were statistically evaluated by the method provided by Litchfield and Wilcoxon (1949) using log-probit transformation for dose-effect mortrality curves.

Results and Discussion

An aquatic toxicity study typically identifies the lethal effect of a chemical or toxicant on selected species in a specified time period. In the laboratory this will provide a LC_{50} value for that toxicant under known water quality conditions. Changes in a single water quality parameter (i.e. temperature, pH) may alter the toxic effect. Resulting LC_{50} values thus found are then multiplied by an "application factor" (A.F.) for that waste to estimate a "safe" concentration believed to have no biological consequence for the species (maximum acceptable toxicant concentration). Application factors for a particular toxicant may be derived by long term life history studies or selected on the bases of best scientific judgement, i.e. 0.01 (Table 2).

Wastewaters flowing into subterranean drainages may exhibit multivariate impositions to stream communities. The toxic potential of substances entering these drainages may not only be regulated by existing water quality characteristics but influenced by associated wastes relationships. Additionally, interplay between numerous biological functions are key factors in regulating the intoxication-detoxication mechanisms important to the success of the aquatic organism, i.e. behavioral, morphological, physiologial.

Water quality criteria established for known toxicants are based upon the studies of epigean aquatic organisms and do not take into account the unique environment of hypogean ecological systems. Since surface water drainages contribute in large part to the subsurface contamination, comparative aquatic toxicological efforts are crucially needed to assure that the permisable levels of toxicants allowed will be sufficiently low to maintain the biological integrity of simplified hypogean communities.

Cadmium Toxicity Tests

Lethal cadmium values have been reported for 10 freshwater invertebrate species from 8 families. Acute lethal sensitivities range from 0.0035 mg Cd/l for the

Cladoceran, Simocephalus serrulatus to 28.0 for the May-fly, Ephemerella grandis grandis. However, insects and other invertebrates are more sensitive during molding, which usually does not occur among most individuals during tests lasting 96 hr. or less (U.S. EPA 1980a).

Criteria established by U.S. EPA (1980a) provide concentration limits of total recoverable cadmium that should not exceed 0.0015, 0.0030, and 0.0063 mg Cd/l at the corresponding hardnesses 50, 100, 200 at any time or 0.000025 for a 24-h average. After 96-h exposure, C. stygia were found to be more sensitive to cadmium treatments than C. bicrenata, revealing LC_{50}'s of 0.29 (0.20 to 0.41) and 1.20 (0.57 to 2.50) mg Cd/l, respectively. By taking the recommended 24-h average value of 0.000025, we may derive an A.F. of 0.0001, which is considerably lower than the typical value used several years ago and may imply increased tolerance of these organisms over the estimated mean epigean community tolerance. Therefore, should a potential waste discharger wish to acquire a variance to release greater amounts of Cd into the aquatic ecosystem, he must first prove that higher levels have no biological consequence via accepted long-term studies before permitted consideration for a larger A.F. Possible causes of the fourfold increase in Cd tolerance of C. bicrenata over C. stygia have been discussed elsewhere by Bosnak and Morgan (1981, in press) and appears to be related to high ambient levels of Cd in the stream water of Merrybranch Cave.

Hexavalent Chromium Toxicity Test

Acute values for lethal concentrations have been reported for six freshwater invertebrate species from five families. Toxic levels range from 0.067 mg Cr/l for the scud, Gammarus pseudolimnaeus to a high concentration of approximately 60 for a midge larvae. Invertebrate species are generally more sensitive to hexavalent chromium than fish species (U.S. EPA 1980b).

Recommended criterion set by U.S. EPA (1980b) establish a concentration of total recoverable hexavalent chromium that should not exceed a maximum at any time of 0.021 mg Cr/l or a 24-h average of 0.00029. C. stygia had 50% mortality at 2.4 (1.7 to 3.8) mg Cr/l in the 96-h toxicity test. Based on our 96-h LC_{50}, a calculated A.F. of 0.0001 would be necessary to yield the 24-h average concentration of 0.00029 mg Cr/l. Thus, a reduction of two orders of magnitude in the generally employed A.F. of 0.01 could be projected in meeting the new criterion recommended by Y.S. EPA (1980b).

Copper Toxicity Tests

Acutely lethal concentrations of copper have been reported for 10 freshwater invertebrate species from 7 families. These acute values range from 0.007 mg Cu/l for the water flea, Daphnis pulicaria to 8.3 for the Stonefly, Acroneuria lycorlas (U.S. EPA 1980c).

Criteria recommended by U.S. EPA (1980c) establish concentrations of total recoverab copper that should not exceed 0.012, 0.022, and 0.043 mg Cu/l at the corresponding hardnesses (mg/l as Ca CO_3) 50, 100, and 200 at any time or not to exceed an average 24-h level of 0.0056. In our 96-h tests, 50% mortality was observed in C. bicrenata at 2.2 (1.5 to 3.5) mg Cu/l and C. stygia similarly responded to 2.3 (1.4 to 3.4). The slightly lower value obtained for C. bicrenata may have been influenced by a shift in the pH from 7.6 in the control to 5.8 in the maximum copper treatment. When considering the theoretically safe short-term concentration of 0.022 mg Cu/l at hardness of 100 mg/l as Ca CO_3, and then multiplying our LC_{50}'s by the 0.01 A.F., we calculate concentrations that meet the EPA recommended maximum instantaneous levels. A factor of approximately 1/400 (0.0026) would be needed to achieve the EPA 24-h average value of 0.0056 (Tables 1 and 2).

Conclusion

Theoretically safe toxic concentrations believed to have no biological consequence to epigean aquatic ecosystems under representative water quality conditions are being recommended by U.S. EPA. Considering these guidelines in light of heavy metal LC_{50} values obtained for two species of hypogean isopods, we find that application factors ranging from approximately 0.01 to 0.0001 would be derived in meeting recommended epigean criteria. Transformations of this magnitude may or may not prove adequate in establishing acceptable concentrations of heavy metals subjected to aquatic hypogean communities. We must emphasize that these results should be viewed with considerable caution since assumed rather than actual A.F.'s were used in calculating "safe" levels. Before making sound judgements in this regard, long-term reproduction and growth studies need to be performed over several generations in order to establish observed "safe" concentrations from which actual A.F. values may be derived.

Acknowledgment

Appreciation is extended to Dr. Jerry Lewis of University of Louisville for the identifications of the two troglobitic isopods species and for additional help and advice in sexing isopods.

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Table 1. Mean physical/chemical water quality values for the control and the various toxic treatments in 96-hr. toxicological tests with Caecidotea bicrenata and Caecidotea stygia, 1980

		Caecidotea stygia						Caecidotea bicrenata					
	Parameters	C	1	2	3	4	5	C	1	2	3	4	5
CADMIUM	Alkalinity (mg/l as $CaCO_3$)	58	57	54	53	55	55	66	66	65	66	66	66
	Conductivity (μMHOS/Cm)	130	131	131	131	131	132	130	139	139	139	140	141
	Dissolved Oxygen (mg/l)	8.0	7.9	8.0	7.9	7.9	7.9	8.3	8.2	8.2	8.2	8.2	8.1
	Hardness (mg/l as $CaCO_3$)	68	68	70	70	72	73	78	78	82	84	86	88
	pH	7.6	7.5	7.5	7.5	7.4	7.5	7.3	7.3	7.2	7.2	7.2	7.2
	Toxicant (mg Cd/l)	N.D.	0.2	0.4	0.7	0.9	1.3	N.D.	0.3	1.0	1.6	2.2	3.5
CHROMIUM	Alkalinity (mg/l as $CaCO_3$)	81	81	81	81	81	81						
	Conductivity (μMHOS/Cm)	140	145	147	150	151	154						
	Dissolved Oxygen (mg/l)	7.8	7.7	7.7	7.8	7.7	7.6						
	Hardness (mg/l as $CaCO_3$)	92	86	86	86	85	86						
	pH	7.3	7.2	7.2	7.1	7.1	7.1						
	Toxicant (mg Cr/l)	N.D.	1.0	1.8	2.9	3.9	6.9						
COPPER	Alkalinity (mg/l as $CaCO_3$)	63	63	62	50	48	42	72	56	54	48	40	22
	Conductivity (μMHOS/Cm)	130	132	138	140	148	158	130	136	140	145	155	180
	Dissolved Oxygen (mg/l)	8.1	8.1	8.1	8.0	8.1	8.0	8.2	8.1	8.1	8.1	8.0	8.0
	Hardness (mg/l as $CaCO_3$)	72	72	70	70	68	68	84	84	82	82	82	80
	pH	7.3	7.2	7.0	6.9	6.7	6.6	7.6	7.0	6.7	6.4	6.3	5.8
	Toxicant (mg Cu/l)	N.D.	0.85	1.40	2.20	3.20	5.00	0.03	0.85	2.50	3.10	4.40	6.30

N.D. = No detection C = Control.

Table 2 Estimated 96-h LC 50 and "safe" concentration values with 95% C.I. and EPA criteria (mg/l) for Cd, Cr, and Cu for Caecidotia bicrenata and Caecidotea stygia, 1980

Treatments	96-h LC 50 values (mg/l)	Typical Application factors (0.01 x LC 50)	EPA Criterion (mg/l)
Cadmium			
C. bicrenata	1.20(0.57 to 2.50)	0.0120(0.0057 to 0.0250)	0.0030*
C. stygia	0.29(0.20 to 0.41)	0.0029(0.0020 to 0.0041)	0.000025**
Chromium			
C. stygia	2.4(1.7 to 3.8)	0.024(0.017 to 0.038)	0.021 0.00029
Copper			
C. bicrenata	2.2(1.4 to 3.5)	0.022(0.014 to 0.035)	0.022
C. stygia	2.3(1.5 to 3.4)	0.023(0.015 to 0.034)	0.0056

*Maximum instantaneous concentration at hardness of 100 mg/l as $CaCo_3$
**24-h average concentration

Speleogensis Models for the Mammoth Cave Region, and Their Use As Predictive Tools for Southern Toohey River, Hart and Barren Counties, Kentucky

James C. Currens
Kentucky Geological Survey, University of Kentucky, 311 Breckinridge Hall, Lexington, Kentucky 40506

Abstract

Several speleogenesis models for the Mammoth Cave region, or which are applicable to the region, have been proposed in the English literature. These models were reviewed and compared for compatibility with recen cave discoveries in the norther half of Toohey Ridge, a significant geographic feature in the region. The models which seemed to best explain the trend and location of major passages in northern Toohey Ridge are used to snythesize predictions of major passsage locations and trends in southern Toohey Ridge.

It is hypothesized that a series of vertically separated tubular passages, developed at base level, cross southern Toohey Ridge from east to west. The trends of these passages would be controlled by a local structural high and the regional hydologic gradient. Their location would be controlled by the presence of a topographic low crossing the ridge. Ground water from part of the west flank of Toohey Ridge and parts of Roppel Cave drained south to this base level passage in a series of tubular passages. Water from the eastern flank of the ridge and Monroe Sink drained north to the base level passage in a complex series of canyons.

Zusammenfassung

In der englischen Literatur sind mehrere Modelle für die Bildung der Höhlen in der Gegend von Mammoth Cave, wie auch andere Modelle die fär dieses Gebiet angewendet werden können, hervorgesetzt worden. Diese Modelle wurden überschaut and mit neugefundenen H-hlen in der nördlichen Hälfte von Toohey Ridge verglichen. Toohey Ridge ist ein geographich bedeutender Grundzug in selben Gebiet wie Mammoth Cave. Die besten Modelle für die Vorhersagung der Lage und Richtung der grossen Durchflüssen im nordlichem Toohey Ridge wurden dann gebraucht um die Lage und Richtung von grossen Durchflüssen in südlichem Toohey Ridge vorherzusagen.

Es wird vorausgesetzt dass das südliche Toohey Ridge von östlich auf westlich von einer Serie von senkrecht getrennten röhrenatigen Durchflüssen von verschiedenen Denudationsniveaus geschnitten worden ist. Die Richtungen der Durchflüssen wurden von einem örtlichem Höhepunkt der Struktur, und von der hydologischem Neigung des Gebietes kontrolliert. Die Lage wurde von einem topographischem Tietfgebiet dass den Höhenzug scheidet kontrolliert. Grundwasser von Teils der westlichen Seite von Toohey Ridge und von Teilen von Roppel Cave. floss südlich in diesen Durchfluss des Denudationsniveau, in einer Serie von röhrenartigen Durchflüssen hinein. Wasser von der östlichen Seite von Monroe Sink, floss nördlich in den Durchfluss des Denudationsniveau in einer komplizierten Serie von Canonen hinein.

Geologic Setting

Toohey Ridge is one of several flat-crested ridges in the Mammoth Cave Plateau. The Plateau is bounded on the east by the Chester Cuesta and to the west by Green River. A thick (100-140m) sequence of relatively pure carbonates dips gently to the northwest and is roughly concordant with local hydrologic gradient (Figure 2). The ridge is capped by up to 40 meters of Mississippian Upper Chester clastics and carbonates. Toohey River lies on the eastern edge of the Plateau and forms about 2 miles of the Chester Cuesta. The ridge is approximatley equal in area to Mammoth Cave Ridge.

Knowledge of past and present sursurface drainage basins is a significant factor in applying the speleogenesis modesl for the Mammoth Cave region. Dye tracing indicates that the present drainage divide between Pike Spring drainage and Echo-Turnhold Springs drainage crosses Toohey Ridge about 200 meters north of the Barren-Hart County boundary, and rougly parralels it (Quinlan, personal communication, 1980; Quinlan and Rowe, 1977). White and Deike (1964) confirmed that "drainage in Mammoth Cave has been consistently to to west and that of Flint Ridge System has been to the north" (p. 86). Preliminary paleohydrology in Roppel Cave indicates southern migration of the divide in passages at 600 feet elevation (185 meters). Dieke (1967) theorized resurgence sites developed progressively along the Green River in a downstream direction as entrenchment increased. The shift in the sites available for the development of springs, and their increased number, had a profound effect on the size and sequence of development of the underground drainage routes.

Speleogenesis Models

Davies (1960) noted a strong relationship between passage location and the flanks of ridges and plateaus. The formation of passages parallel to surface valleys was ascribed to the inclination of the piezometric surface towards major surface valleys (i.e., regional base level). Hence, the greatest concentration of subsurface flow tended to parallel the smaller valleys.

Deike studied the relationship between joining and passage trends in the Mammoth Cave Region (Deike, 1967). Most passage orientations were apparently controlled by "vagaries of the bedding" and not jointing. On the other hand, Cushman (1968) held that jointing had a profound effect on the control of passage trends. "The orientation of the caverns, such as a Mammoth Cave and the estimated paths of subsurface drainage coincides roughly with the joint pattern in the rocks in the area, trending northwest and northeast" (p. 246). Deike also noted these joint trends, but demonstrated that jointing was not a regional factor in controlling passage trends.

John Thrailkill (1968) published a model which held that in areas where impermeable rocks capped ridges of karstic rocks, depressions occurred in the piezometric surface beneath the capped ridge. Ground water would tend to move toward these depressions, resulting in a concentration of flow and passage development under the ridge crest.

In a summary of their investigation of the relaionship between the passages of the Flint-Mammoth Cave System and surrounding topography, Miotke and Palmer (1972) discuss several factors governing the location and trend of major passages. They restate Davies' observation that "the large upper-level passages such as Salts Cave and similar trunk passages in Mammoth Cave are apparently related to preglacial valleys." They also observed that "the few passages that do cross under the undissected parts of the ridge are generally isolated trunk passages with angular trends that alternate between strike and dip orientation" (p. 10).

Palmer (1977) states that "canyons were found almost invariably to extend directly down the local dip," while tubular passages were "most commonly oriented along the local strike" (p. 409). Both canyons and tubes initiate development on top of less soluable units at the bedding plane parting. Flow routes, active at any given time, are roughly dendritic. The complexity of the cave systems derives from the superposition of the dedritic systems with time and the development from the interconnecting complex of piracy routes.

In his dissertation on the hydrology of the "coves" of eastern Tennessee Crawford (1978) noted that during the retreat of an escarpment, similar to that of the Mammoth Cave region, breaching of the caprock overlying the karstic rocks may occur back of the retreating escarpment front. This may happen "where there is a structured high (such as a slight anticline), in back of the retreating escarpment." Then the caprock will be eroded away and the underlying limestone invaded by the stream. This author believes similar processes occur in the Mammoth Cave region. This author believes similar processes occur in the Mammoth Cave region. Monroe Sink, near the southern end of Toohey Ridge, is one possible example. The breaching of the caprock at Monroe Sink may have played an important role in the development of passages in southern Toohey Ridge and must be taken into account in any predictive scheme. The genesis of Monroe Sink is beyond the scope of this paper but three observations may be made from geologic and topographic maps: (1) it is centered on the axis of a locally significant anticline, (2) its size indicates it probably began developing early in the erosive history of the surface valleys in its vicinity, and (3) it probably resulted from the headward migration of a surface stream flowing to the south.

Models Relevant to Northern Toohey Ridge

Passages in norther Toohey Ridge are located along ridge flanks. The norther end of the ridge is dissected into four prominent spurs, and much of the cave can be found under the flanks of these spurs. The models of Davies (1960) and Miotke and Palmer (1972) both note the tendency of passages to locate along ridge flanks. Besides following the ridge flanks, several major passages in Roppel Cave underlie a shallow linear depression crossing northern Toohey Ridge from the southeast to the northwest. This depression may be a "preglacial valley" (terminology of Miotke and Plamer, 1972). Miotke and Palmer note that major passages crossing ridges are frequently beneath preglacial valleys. In northern Toohey Ridge exceptions seem to be limited to passages crossing surface divides between closely approaching valleys.

Comparison of the map of the Toohey Ridge Cave system and a structure map for the area on the base of the Big Clifty Sandstone (Haynes, 1964) suggests that local passage orientation is generally controlled by structure. However, detailed structure maps of Toohey Ridge have not been prepared for any horizon below the Big Clifty, and only rudimentary relationships can be recognized. Portions of two phreatic, tubular trunks in Roppel Cave are strike are strike oriented and a third tubular crawlway is also strike oriented. Reaches of these passages aligned with the dip grade into more canyon-like cross sections. Canyon passages in Roppel Cave tend to be normal to the strike, and paleoflow is down dip. The relationships conform to those observed by Miotke and Palmer (1972) and Palmer (1977) in the Flint-Mammoth system.

Unfortunately, subsurface explorations in Toohey Ridge have not yet revealed a situation comparable to Crawford's area of study in Tennessee. There is no basis, then, for accepting or rejecting the suitability of his model for Toohey Ridge. However, the probability that water has been draining to the subsurface in Monroe Sink for a long time, and its situation on a structural high, lend credence to applying the model.

In summary, passages in Toohey Ridge tend to be located along ridge flanks or other areas where cover is relatively less than surrounding areas such as preglacial valleys and valley head conjunctions. Their trend tends to be controlled by the local hydraulic gradient, the trends of the valleys, and local sturcture. Areas where the caprock was breached early provided points of infiltration where speleogenesis may be relatively more concentrated.

Hypothesized Speleogenesis in Southern Toohey Ridge

A glance at a topographic map of Toohey Ridge quickly reveals that, in comparison to the norther half, the southern part is relatively compact and undissected by karst valleys. Also, there are few obvious linear topographic lows suggestive of shallow preglacial valleys crossing this part of the ridge. However, there is one impressive topographic feature at the south end of the ridge, Monroe Sink.

Early speleogenesis in Toohey Ridge was primarily influenced by the youthful karst topography and the local structure of the region (Figure 3a). Although they are obscure, one or possibly two preglacial valleys do cross the southern part of the ridge (Figure 2). The most distinctive valley, and the one most likely to have influenced early cavern development extends from the vicinity of Renick Cove, westward to the cemetery (Figure 1). Also, high-level caverns are likely to have developed south of Monroe Sink, in alignment with the valley to the south. Due to the overriding effects of topography and hydrology, structure had relatively less control of the passags trends but did determine the cross section (i.e, canyon vs. tube). The development of Indian Cave was also early in the karst development of Toohey Ridge. Its alignment with the strike, hydraulic gradient, and a series of sinks, possibly derived from a preglacial valley, portend major segments in its vicinity.

During the middle stages of karst development, the developing karst valleys surrounding Toohey Ridge began to have a profound influence on its caverns. The retreating Chester Cuesta to the east provided a high volume of ground water flow to the west. The developing Hamilton Valley to the west created ridge flanks for cavern development and additional recharge area. Although regional hydrologic gradient was more to the north, a developing master conduit from the east created a local base level attracting the flow to the south. The base level, tubular conduit from the east took advantage of the shallow preglacial depression mentioned earlier and followed closely the contours of the structural high repsonbile for Monroe Sink (Figure 3b). The originally southernly flow from Monroe Sink was increasingly pirated to the master conduit flowing just north of it. The downdip orientation of this flow probably produced canyon passages. Speleogenesis in the vicinity of Indian Cave may also have continued during this period. Trend and location of the conduit would be similar to the known cave, but at a lower level than the earlier conduit.

The late stage of development is a continuation of the middle phase (Figure 3c). Most of the flow in the northern half of Toohey Ridge has been diverted to the north, primarily to Pike Spring (Quinlan, personal communication, 1980). The base level tubular conduit coming in from the east shifted downdip, to the north, following lowering of base level. Most drainage from the eastern flank of Toohey ridge and Monroe Sink flows downdip to this passage. The steep dip off the flanks of the structural high at Monroe Sink overcomes the thick cover. Some flow from Monroe Sink may flow downdip to the southwest.

While this paper was in preparation, a major base level trunk (Logsdon River) was discovered by Don Coons and the Cave Research Foundation in Morrisons and Proctor Caves. Although as of this writing no information has been released on its exact location, reliable hearsay indicates it to be very close to the predicted location. Recent explorations in Toohey Ridge have also revealed a major base level trunk, again aligned with the postulated location and trending towards Logsdon River. The passage is blocked by permanent siphons. Dye tracings work supported by Quinlan indicates Turnhold Spring is the outlet of this water. The prediction of the location of this base level trunk was fixed prior to both of these discoveries.

In summary, it is postulated that southern Toohey Ridge has been crossed from east to west by a series of base level tubular passages. The location of these passages ha been locally controlled by topography and structure. The base level trunks provided outlets for drainage from Monroe Sink and the western and eastern flanks of the ridge, and parts of Roppel Cave.

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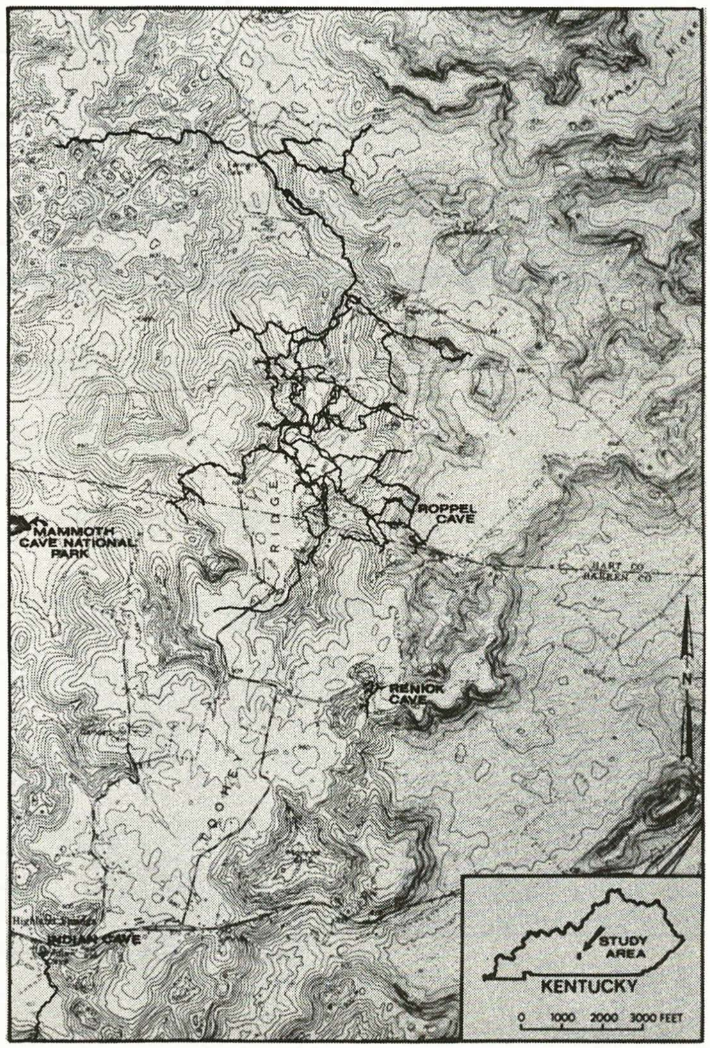

Figure 1. Topographic map of Toohey Ridge and parts of Eudora and Gisher Ridges showing passages in Indiana, Renick, and Roppel Caves.

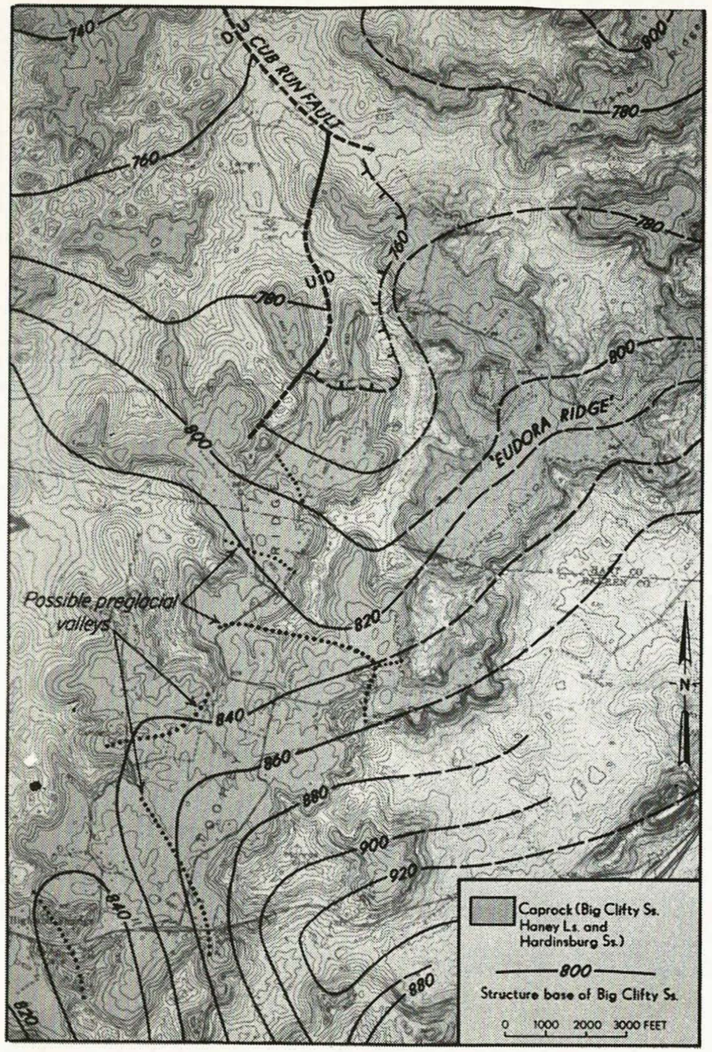

Figure 2. Simplified geologic map of Toohey Ridge and vicinity. Structure contours are solid where transcribed from the Mammoth Cave geologic quadrangle map and dashed where constructed from published geologic maps. The dotted lines delineate topographic lows which may be vestiges of preglacial valleys.

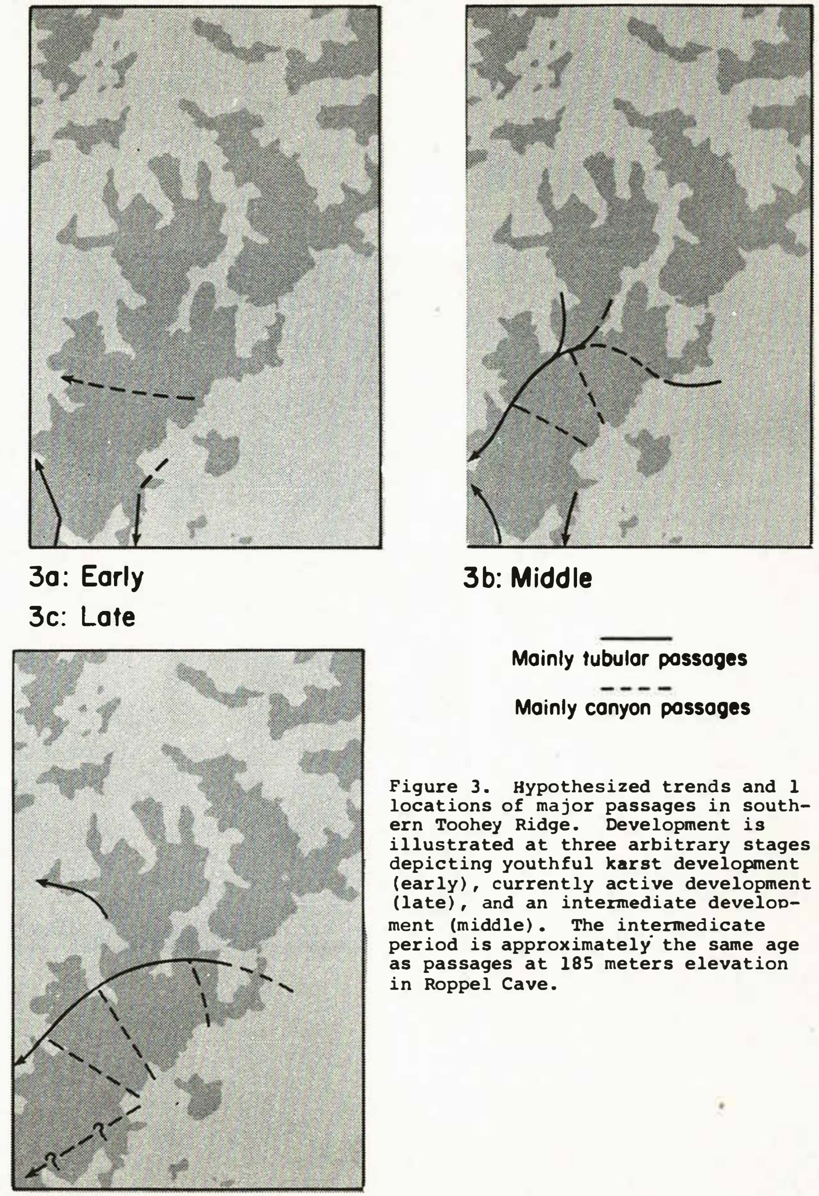

Figure 3. Hypothesized trends and l locations of major passages in southern Toohey Ridge. Development is illustrated at three arbitrary stages depicting youthful karst development (early), currently active development (late), and an intermediate development (middle). The intermedicate period is approximately the same age as passages at 185 meters elevation in Roppel Cave.

The Incidence of Iron Bacteria in an Australian Cave

H. Jane Dyson and Julia M. James
School of Chemistry, University of N.S.W., Kensington, N.S.W. 2033, Australia and
Inorganic Chemistry, University of Sydney, N.S.W. 2006, Australia

Abstract

Colonies of iron bacteria can be observed in many surface streams in Australia, preferring shallow semi-stagnant conditions. Such a colony can be observed intermittently in the pool at the bottom of Odyssey Cave, Bungonia, N.S.W. These bacteria appear to thrive under conditions different from those generally accepted for similar iron bacteria which live in surface waters. The colony in the cave is particularly convenient for study, as this cave is the subject of an extended research project on the composition of its atmosphere and waters. Studies to determine the conditions under which the colony flourishes, and what physical and chemical components are necessary in the cave to allow the growth of the colony will be discussed.

Résumé

Des colonies de bactéries de fer peuvent être observées dans un grand nombre de ruisseaux de surface en Australie, les conditions semi-stagnantes et peu profondes de ces ruisseaux étant celles préferées par ces bactéries. Une telle colonie peut être observée par intermittence dans une mare située au fond d'Odyssey Cave, Bungonia, N.S.W. Ces bactéries semblent se développer vigoureusement dans des conditions différentes de celles généralement acceptées pour de semblables bactéries de fer qui vivent dans les eaux en plein air. Il est particulièrement convénient d'étudier la colonie de cette caverne parce que la composition de son atmosphère et de ses eaux a été le sujet d'un projet de recherche pendant plusieurs années. Nous allons décrire ici des études dont le but est de déterminer les conditions sous lesquelles la colonie fleurit et quelles sont les facteurs chimiques et physiques nécessaire à sa croissance dans la dite caverne.

Introduction

Iron bacteria are members of a loosely associated group of microorganisms which appear to metabolise iron. Many of them require large amounts of soluble iron, in the form of aquated or complexed Fe^{2+}, and a characteristic heavy and extensive precipitate of hydrated ferric oxide is associated with the bacterial colony. These organisms inhabit the soil or surface streams normally. Different members of the group exist in widely different habitats, for example, *Thiobacillus ferrooxidans* grows at very low pH in acid mine waters, while other organisms live at intermediate-acid and neutral pH's. When the pH is close to 7, as is usually found in natural systems, the organisms are of the type *Leptothrix* or *Gallionella* (Figure 1).

A colony of iron bacteria periodically exists in a pool in Knockers Cavern, at the bottom of Odyssey Cave, Bungonia Caves, N.S.W., Australia (Ellis *et al*., 1972). The colony has been identified (Trudinger pers. comm.) as probably *Leptothrix* sp., containing some *Gallionella* sp. Colonies of similar microorganisms are found in typical conditions on the surface: semi-stagnant water, fairly shallow and with a sufficient through flow of water that a constant supply of the iron nutrients required by the colony is maintained.

Within the cave, conditions are somewhat different to those on the surface. The constancy in some factors (temperature, humidity, light level) allows the effects of other factors (atmospheric CO_2 and O_2, dissolved CO_2 and O_2, pH) to be estimated, since these vary considerably in Knockers Cavern, which is unusual in that high levels of CO_2 (in the order of 4%) persist over long periods. Conditions in this cave are at present being monitored (James, 1975). Results presented in this paper correlate the appearance of the colony with conditions in the cave.

Iron bacteria have been studied as a group extensively and for a long time. They are implicated in the formation of iron ore bodies, especially Precambrian banded iron formations (James, 1966), which contain some of the earliest known bacterial fossils. There is only scant data on their metabolism and the conditions under which they thrive. Some evidence is presented in this paper for an absolute requirement for iron, implying a definite dietary role for Fe^{2+} in the colony.

Methods

Bungonia Caves are located about 200 km from Sydney. A programme of sediment, air and water sampling in several caves and springs (Figure 2) has continued over a period of seven years. Water samples are collected and air temperature, atmospheric CO_2, water temperature, pH and dissolved oxygen measured. A less extensive series of similar measurements has been made in other caves in the area.

Analysis for atmospheric CO_2 was by Drager apparatus, and for dissolved O_2 was by an International Biochemical dissolved oxygen meter 300. The iron content of the water samples was analysed by atomic absorption spectrophotometry (AAS) on a Varian Techtron AA6. The figures quoted are for total iron, which includes aquated Fe^{2+}, complexed Fe^{2+} in solution, colloidal ferric oxides and Fe^{3+} complexes present. Some of the iron analyses may be abnormally high, due to the presence of solid matter, especially sediment material, which may contain a high proportion of ferric oxides (James, 1975). Part of the method of preparation of samples for AAS involves acidification to a pH at which these compounds would dissolve.

Results and Discussion

Measurements of total dissolved iron for three caves and the spring associated with them are shown in Table 1. Locations of these sites are shown in Figure 2.

Table 1

Cave	Mean Total Fe (ppb)	n^1	s^2	Presence of colony	Remarks
The Efflux	10	37	10	no	
Argyle Cave	120	10	30	no	Low CO_2 level, drainage from limestone and argillite.
Grill Cave	200	25	50	no	Foul air cave, drainage from laterites, limestone and argillite.
Odyssey Cave	1000	37	500	yes	Foul air cave, large amounts of banded sediments. Stream collects from other foul air caves.

^{1}n = number of estimations
^{2}s = standard deviation

It is noticeable that the cave in which the colony of iron bacteria is observed is also the one which has the highest total dissolved iron in the water. There is very little iron emerging from the spring only a few hundred meters from the pool containing the iron bacteria in Odyssey Cave. This indicates that there must be a mechanism for the removal of iron from the water in the unexplored passages between the two sites, possibly an extensive series of iron bacteria colonies.

The colony of iron bacteria is variable, and sometimes disappears entirely over periods of months at a time. These disappearances are correlated with the amount of total dissolved iron (Figure 3). At values of less than 600 ppb Fe the colony is not visible, while above this figure it is apparently viable. Three data points are present on the left of the line representing 600 ppb, and would appear to indicate that the colony was present even in conditions of low dissolved iron. These may signify times when the colony was in fact non-viable, although the ferric oxide debris from the colony was still visible.

The data points from 1978, most of which appear on the left of the line at 600 ppb, show the effects not only of the iron concentration, but also the mechanical effects of flooding in the cave. 1978 in particular was a very wet year, and several floods occurred in the cave. Flooding has several effects on the colony - increased water flow disturbs the colony, and it may be washed away or covered with a layer of silt. In addition, dissolved O_2 in the water increases. Dissolved iron decreases, due both to the elevated O_2 level and to dilution. After a flood the colony may take a while to re-establish itself. Therefore we believe that the figure of 600 ppb may be a high lower limit for the iron concentration above which the bacteria will live. A lower figure would be consistent with the observation of small colonies in other caves (Drum Cave and Hogans-Fossil Extension) under conditions of low O_2 and high CO_2. The data have been plotted as a function of the percentage of atmospheric CO_2. Data plotted in Figure 4 show the definite inverse correlation of the dissolved O_2 with total iron in the water.

The existence of the colony of iron bacteria in Odyssey Cave is probably a function of the very high concentration of dissolved iron in the waters of the stream in Knockers Cavern. The behaviour of this quantity as a function of dissolved O_2 in the water indicates that a significant proportion of the iron is present as Fe^{2+}, since colloidal $Fe_2O_3.xH_2O$ and any Fe^{3+} species present would be unaffected by changes in oxygen tension. At the pH and Eh of the system (6.9 ± 0.2, 0.25 v) the Fe^{2+} would not be stable as the equated species, but would be rapidly oxidised to Fe^{3+} and thence precipitated as the hydrated ferric oxide, even in the absence of bacteria or similar agents. The Fe^{2+} must therefore be present as complexes. Possible ligands include organic material, common in the system, and carbonate or bicarbonate, which would be present in abundance in the water, due both to the solution of limestone and the high atmospheric CO_2 levels.

The source of the iron in Argyle and Grill Caves is probably the limestone itself, which contains a minimum of 0.1% Fe_2O_3 (Carne and Jones, 1919). The Grill Cave figure is supplemented from the laterites which overlie the cave. Dye-tracing has established that the stream in Odyssey Cave has its source in the other deep caves of the Bungonia Plateau (Figure 2), with only a small contribution from the Odyssey Cave stream itself. The water would therefore be expected to have a similar composition to that of the other caves. It has, however, a much higher concentration of iron. Calculations using flow data and the concentration of Ca^{2+} in the Odyssey Cave water indicate that the contribution of solution of the limestone to the total figure is approximately 180 ppb. We believe that the source of the considerable additional iron is a series of banded sediments present in the cavern which are at present being eroded and which are known to contain bands of hydrated ferric oxide and other bands rich in decayed organic matter with some sulphides. The initial establishment of these iron-rich banded sediments indicates a local source of iron. A likely source is the bands of iron oxide reactate along stylo-bedding planes (terminology of Logan and Semeniuk, 1976), which are present in Knockers Cavern (Francis pers. comm.).

The increase in dissolved iron with increase in atmospheric CO_2 may be symptomatic of several conditions which occur under circumstances when CO_2 is elevated (James, 1977). The pH of the water falls (due to solution of CO_2), atmospheric O_2 falls (due to its use by the aerobic microorganisms which produce the CO_2), dissolved Ca^{2+} and CO_3^{2-} increase (due to solution of limestone caused by increased acidity of the waters). All of these conditions would be conducive to mobilisation of iron: more limestone is being dissolved by the acid waters, whose acidity would also increase the stability of the Fe^{2+} in solution. Lowered O_2 would contribute to this stability, and increased microbial activity in the water would increase the availability of organic material for complexing of the iron. In addition, a major effect may occur due to the CO_2 itself, which undoubtedly forms carbonate complexes with ions in solution, and may also affect the growth of the iron bacteria directly.

The iron bacteria present in Odyssey Cave are known to be of the type whose sources of food (reducing power and carbon) are in doubt. The bacteria produce large quantities of hydrated ferric oxide as a by-product of their growth. For these genera it is not known whether this accumulation reflects an actual metabolic waste product (of the process $Fe^{2+} \rightarrow Fe^{3+}$) or simply a product of the utilisation of the organic matter attached to the Fe^{2+}, which, stripped of its ligands, is rapidly oxidised by O_2 and precipitates as the ferric oxide. The data presented in this study indicate that, under the fairly static conditions of the cave, the bacteria only thrive when sufficient iron is present in the water. No colonies of iron bacteria are observed in Grill Cave (200 ppb Fe). Small colonies are occasionally present in Drum Cave and the Hogans-Fossil Extension under conditions of high CO_2. A large and thriving colony exists for long periods in Odyssey Cave and has been observed to be present as long as the dissolved iron exceeds 600 ppb. If the effects of flooding are taken into account, this figure may be considered high for a lower limit. Accordingly we give as the estimated lower limit of viability of the iron bacteria a figure of 400 ppb total iron in the water, under the conditions described.

The dependence of the total dissolved iron on the absence of dissolved O_2 indicates that the iron figures represent a substantial proportion of Fe^{2+}. Iron in this form is utilised by organisms known to be true "iron bacteria" as an electron source, and would thus be available for use by the bacteria in Odyssey Cave. The theory that it is the complexed material around the Fe^{2+} which is being used by the bacteria seems less likely in this case, in view of their apparent absolute requirement for iron in a medium rich in organic matter and complexes of other metals.

Acknowledgements

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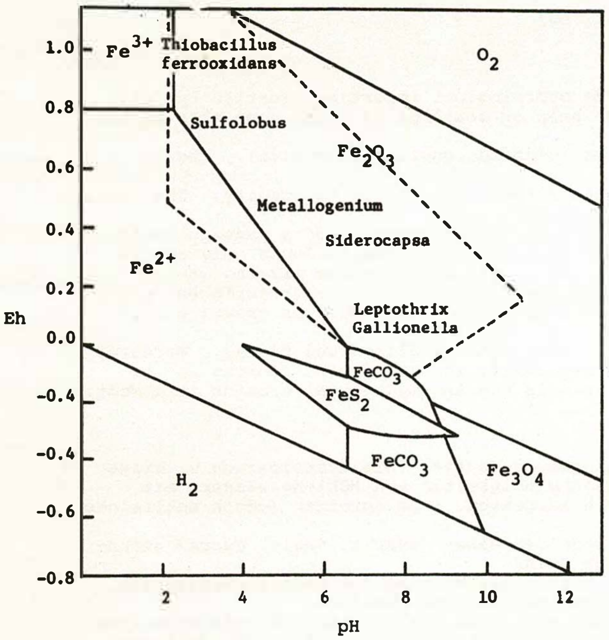

Figure 1. Eh-pH Diagram for Iron, showing areas where various iron bacteria are viable (after Lundgren and Dean, 1979).

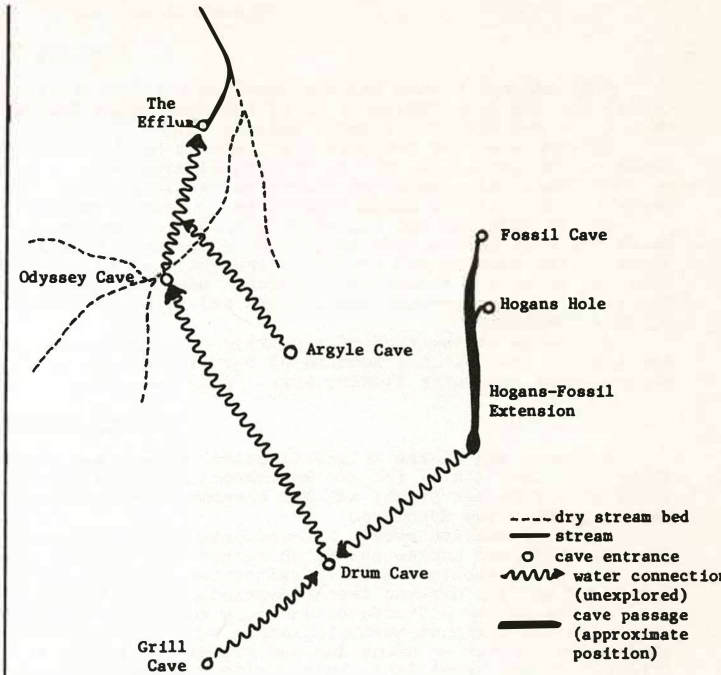

Figure 2. Water Connections Between the Deep Caves at Bungonia

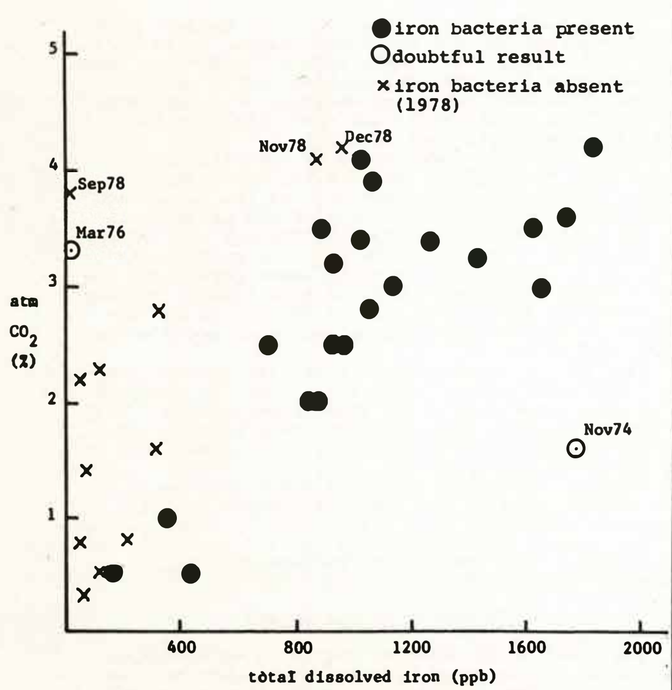

Figure 3. Total dissolved iron, plotted as a function of % atmospheric CO_2, monthly measurements in Odyssey Cave, 1974, 1976, 1978.

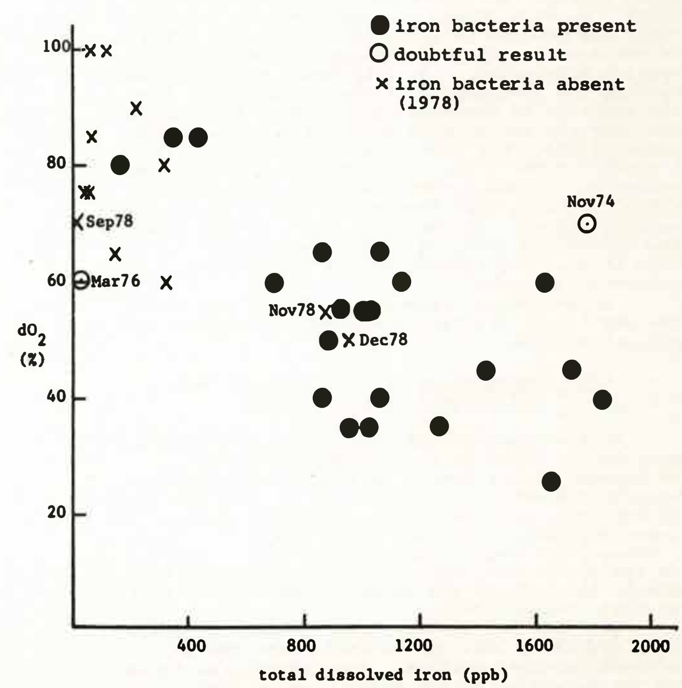

Figure 4. Total dissolved iron, plotted as a function of % dissolved O_2 (dO_2), monthly measurements in Odyssey Cave, 1974, 1976, 1978.

Scallops

Alfred Bögli
Hitzkirch and Zürich (Switzerland)

Abstract

Scallops and flutes are explained as corrosional forms. The hydrological important equation by Curl (1974) for the computation of v_m of the cave water flow with the help of scallops is based upon this hypothesis. - But many facts speak against it:

a) Occasionally scallops are found on hard insoluable rocks (granite, gneiss, quartzite). These forms may be explained only by mechanical erosion.

b) The distribution of flutes and scallops in a cave passage reveals the effect of gravity. That manifests the activity of solid components in water: mechanical erosion too.

c) If scallops and flutes were formed by corrosion each place in a cross-section of a passage would be of the same morphologic value and independent of gravity. But scallops are normally found only on the floor of the passage and flutes at the inclined adjacent flancs. As a rule scallops are missing at the roof and never are flutes found there. However, where water flows towards overhanging rock-surfaces, e.g. the roof, a pressure-component occurs and by a sufficiently great water speed silt, sand or gravel hurled up form scallops.

d) Dents at the roof of a passage are always flat and much larger than scallops and flutes. Moreover the typical longitudinal section of normal scallops is missing, especially the steep part looking in the direction of the water flowing away. Only corrosion is active in this cae and mechanical erosion is absent.

Zusammenfassung

Scallops und Flutes (Fliessfazetten) werden als Korrosionsformen gedeutet. Die dydrologisch wichtige Formel von Curl (1974) für die Berechnung der mittleren Fliessgeschwindigkeiten von Höhlengewässern mit Hilfe dieser Formen beruht auf der Annahme einer Entstehung durch Korrosion. - Es sprechen jedoch zahlreiche Fakten gegen diese Hypothese.

a) Gelegentlich werden Fliessfazetten auf harten, unlöslichen Gesteinen (Granit, Gneis, Quarz/ gefunden. Diese Formen können nur durch mechanische Erosion entstanden sein.

b) Die Verteilung der Fliessfazetten in Höhlenquerschnitt verrät die Wirkung der Erdanziehungskraft. Das lässt auf die Wirkung fester Bestandteile in Wasser schliessen` mechansiche Erosion.

c) Wären die Fliessfazetten durch Korrosion entstanden, dann wäre jede Stelle eines Gangquerschnittes annähernd von gleichem morphologischem Wert und unabhängig von der Erdanziehungskraft. Aber die Scallops sind meist nur nur am Gangboden und Flutes nur an den seitlich anschliessenden stärker geneigten Flaken zu finden. In der Regel fehlen die Scallops an der Decke und Flutes wurden dort noch nie gefunden. Wo jedoch Wasser gegen überhängende Felspartien oder die Decke strömt, da entsteht eine Druckkomponente und bei genügend hoher Fliessgeschwindigkeit werden dort Schluff, Sand und Kies mitgerissen und formen die Scallops - jedoch nie Flutes.

d) Dellen in der Gangdecke sind dagegen immer flach und viel grösser als Fliessfazetten, und es fehlt der typische assymmetrische Längschnitt. In diesem Falle ist nur Korrosion wirksam, während mechanische Erosion völlig fehlt.

1. Introduction

Scallops and related forms originate from the degradation of rocks by flowing water. This effect is mainly found in caves. Their morphology was studied by a great number of authors, partly by field surveys, partly by experimental investigations. H. Bock (Graz, Austria) was the first to study the problem of scallops intensively (1913).. He assumed that they are caused by mechanical erosion §corrasion/. He propounded a formula concerning the depdendence of the scallop size from the velocity of the water flow. With new methods Curl has set the formula which is since accepted (1966, 1974). For that purpose he used the flutes, a special type of scallops. As cause he assumed corrosion. Allen investigated all types of erosional marks by experiments and published a comprehensive report. He wrote (p. 177): "These marks, now recognized to be of solutional origin, ..." From this we may suppose that he previously assumed corrasion as right.

The following statements are based on field studies and on literature but not on experimental investigations.

2. Morphography of the Erosional and Corrosional Marks in Caves

My principal places for investigations are alpine caves, first of all Hölloch (Hell-Hole, Switzland) with a length of 141 km and a vertical interval of 856 m (2-1-1981). This cave lies within very pure Urgonian limestone (upper part of the lower cretaceous) called "Schrattenkalk". That is a dense homogeneous, thick bedded rock. And I kept an eye on the scallops in Flint Ridge Cave (KY, MCNP), too. There are three different main types of shell-shaped marks.

Type A: The scallops are the most frequent. They are shell-like with a small side and an adjacent concave surface. The steep parts shows in the direction of the water flowing away. For details see Benalt (1967, 1967a), Curl (1966, 1974), Allen (1971, 1972), Blumberg (1970) and Bögli (1978, 1980). They form homogeneous, conjugate assemblages of marks. In Hölloch they occur on many thousands of m^2 and on many km of passages. Obviously they originate mostly under phreatic conditions but under vadose ones, too. In the "Solitude"(Hölloch) a passage floor with an inclination of more or less 10% has been overflown for a long time and shows very typical, relatively small scallops. In the last more than 100,000 years this area of the cave was never fallen under phreatic conditions.

Type A predominantly happens on the passage floor; it is irrelevant for the occurence whether it is horizontal or inclined. But under special conditions there are exceptions, e.g. in narrownesses and in narrow passages, whereever the water velocity is great, scallops are found on the walls and more rarely on the roofs, eto. (see 3.2, last section).

Type B: On the lower parts of the walls which are inclined to the floor we find the wave-shaped flutes. The angle between the axes of the flutes and the direction of flo respectively of the passages is not only a function of the surface dip but also of the water velocity. It should therefore be possible to calculate the velocity of flow by these parameters and a coefficient which must be found especially. Because well developed flutes are rare in Hölloch it was impossible to specify critical values or ti state mathematical relations.

Type C: On the passage celing flat concave cavities often occur, being much larger than the scallops on the floor (Type A) in the same cross-section. They are more uniform in size, and the steep size of the scallops is absolutely missing. It is evident that they are of phreatic origin.

Type D: Exceptionally there occur very small flute-shaped forms on the roof. According to their appearance they could have been formed by flowing water - but the cause of their origin is not yet cleared. This Type is not a main-one, not to mention that it is frequently overlooked.

3. Corrasion or Corrosion?

The question is, whether corrasion or corrosion are forming scallops and flutes. The answer to this is important, then Curl's formula for the calculation of the water velocity in a cave passage with the help of the size of flutes is based on corrosion. But there are some arguments for corrasion!

3.1. Scallops and flutes are found on insoluble and very hard rocks (Maxson, 1940). Allen (1971, p. 182) writes: "Flutes are widely known from rock surfaces affected by powerful currents of sand-laden water. . . ." I took pictures of assemblages of scallops on gneiss at different places in the river-bed of the Maggia near Ponte Brolla (Switzerland, Ct. Ticino), each a few m^2. On the granite at Handegg (Grimselpass, Switzerland) I found others. They were formed by mechanical erosion (corrasion). I do not see why scallops in limestone, which is much less hard than granite, would not have been formed by corrasion. Feldspar and quartz the main minerals in granite and gneiss are 8 respectively 16 times harder than calcite, the main mineral of limestone (Klockmann, 1978).

3.2. Scallops and flutes are predominantly located on the floor and on the adjacent rising rock surfaces. This localization is easily explained by gravity. Therefore, the presence of solid particles e.g. of sand and gravel, must be assumed. By their weight they put pressure on the surface of the rock. If the particles move the surface becomes affected and dragged away. It forms erosional marks, scallops and flutes.

In narrownesses and narrow passages high velocities happen and sand and gravel are hurled up to the walls and even to the roof. In contact with the rock a pressure-component originates and consequently the particles can erode and form scallops.

According to Hjulstroem (1935, cit. in Bögli, 1980) fine sand with a granulometrical diameter of 0.1 mm needs a minimal velocity of flow v_m of 0.9 cm s^{-1} to be transported. Coarse sand with a diameter of 2 mm needs a v_m of 15 cm s^{-1} (540 m h^{-1}); this is equal to a discharge of Q of 0.4 m^3 s^{-1} on each m^2 of the cross-section. That is a high value but real for phreatic conditions. The granulometry of fine deposits in Hölloch shows normally about 90% of silt and sand. This almost correspond to the values of the diameters and v_m mentioned before.

In short: The localization of scallops and flutes in the lower part of the passages in Hölloch and in many other caves shows the dominant influence of gravity and with that the presence of solid particles driven by the flow which cause corrasion. Sometimes scallops are missing on the passage floor but occur on the walls. May be that they are destroyed on the floor by gravel or covered up with debris. Remaineders of former deposits often prove that thick layers of loose sediments protected the floor. The surface of these sediments was the old river bed in the cave conduit; in the formerly narrow passage the ---- flew faster and with the sand dragged along the wall scallops formed on the rock.

3.3. Corrosive water dissolves limestone and consequently shows a gently higher density at the contact area with the rock. That induces a convection flow which is so small that it is normally irrelevant in comparision to moving cave-water. For that reason each place in a water-filled cross-section of a passage has the same morphological value in regard to gravity. If scallops and flutes were formed by corrosion they ought to occur everywhere without preference, in consequence on walls and roofs as well as on the floor - but normally they do not! Moreover I have never seen flutes on overhanging rocks!

3,4, Corrosion by flowing water has a molding effect and creates marks of the Type C. They are formed by slowly moving water, too - perhaps exclusively by slowly moving water. They are mostly found on the roof of larger passages with lenticular cross-sections. At inclined axes of the lens the hollows of the Type C occur not only on the roof, but as well on the upper part of the rising slope where moving sand does not get, or on the inner side of a bend.

The Type C shows some differences to the scallops in the same cross-section. The most striking differences are the rounded borders of the marks which do not show sharp rims, the lack of the steep side, the larger size which at least is two times longer. The directions of the flow cannot be deduced from this form.

Why do the marks of the Type c not appear in the whole cross-section? Theoretically they ought to do so! But in the slowly moving water at the bottom and on the upper sides of rocks it forms thin coatings of clay which hinder the corrosion of limestone. The removal of this clayey cover demands a velocity of 100 cm s^{-1} by pure water but only 5 to 10 cm s^{-1} in case of corrasion by sand-laden one. And with such velocities it is possible that scallops are formed which destroy all former marks of the Type C.

4. Some Unsolved Problems

4.1. Does corrosion have an influence on the forming of scallops which originates by corrasion? At the actual state of the investigations it is not possible to give a clear answer, but I think that it is probable. In this case corrosion would work more or less in the same direction like corrasion. That leads to the next question.

4.2. Is Curl's formula (1966, 1974) for the dependence of the size of flutes on v_m valid if the forming is not due to corrosion but to corrasion? The density, the vicosity coefficient and Reynolds number of sand-laden water are different from those of pure water. That is the field of the physicists and the answer must be given by them.

4.3. It is possible to determine v_m by the size of scallops which are much less regular than the flutes? This problem is under treatment by statistical methods. But the investigations are not advanced enough to give a negative or positive answer.

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Geomorphologic Evolution of a Karst Area Subject to Neotectonic Movements in the Umbria Marche Apennines (Central Italy)

Mauro Coltorti
Scienze Geologiche, Via Lauro de Bosis 17, 60035 Jesi (AN) ITALY

Abstract

The Frasassi gorge, covered by the Sentino stream from West to East, dissects with the same direction the northern portion of an Adriatic vergency anticline of the Umbria-Marche Apennine (NNW-SSE). Inside the gorge and on the eastern side of the structure there are more than 100 hollows, situated on at least 8 subhorizontal and superimposed levels, sometimes connected by wells and chutes, from the talweg (m 200 a.s.l.) to over m 600 a.s.l.. The four most important levels (I, III, V, VII from the bottom) drained to the same height of alluvial terraced deposits attributed to Olocene, Würm, Riss and Mindel respectively and correlated with these periods while the interposed floors involve minor events. The higher galleries and the Gorge are mainly developed on jurassic fractures trending EW testifying primitive drainages formed by parallel and independent pipes. Afterwards, during a sudden sinking of the water table, the activity of close fractures and side-slip faults trending NE catched the older drainages orienting the karstification of the new galleries that widened alos owing to the reaction of mixed water-table with sulphureous waters arising along neoformation fractures. The older galleries were dislocated with dip-slip higher than 100 m and new levels set up during this strong tectonic Mindel/Mindel-Riss phase increasing the structural asimmetry. The new leftside karstic network flowing with acute angles into the Sentino enlarged more than those on the opposite side that, joining upstream became few and small galleries. Inside the hypogeal system are recorded the macroscopic swinging of the water-table, connected with climatic or tectonic events occurred after the Villafranchian smoothing and during the pleistocene differentiated uplifting.

Résumé

La Gorge de Frasassi, traversée par le torrent Sentino de W vers E coupe dans la même direction la partie septentrional d'un anticlinal, se tournant vers l'Adriatique, de l'Apenin Umbro-March giano (NNW-SSE). A l'interieur de la gorge et dans la côté oriental de la structure s'ouvrent plus de 100 cavités, placées au moin sur 8 niveaux subhorizontaux superposés et parfois communicants par des puits et des glissières de la nappe phréatique (m 200 s.n.m.) jusqu'à plus de 600 m s.n.m.. Les quatre niveaux principaux (I, III, V, VII de bas en haut) drainaient à la même hauteur de dépôts alluviaux terrassés attribués respectivement au Olocène, au Würm, au Riss et au Mindel et ils sont contemporains tandis que les niveaux interposés montrent des événements moin importants. Les galleries les plus élevées ainsi que la gorge se développent sur des fractures EW d'epoque giurassique, témoignant ainsi que le primitif drainage etait constitué par des conduits parallèles et entre eux indeépendants. Par la suite et lors d'un brusque approfondissement de la nappe phréatique, l'activation d'une nombreuse série de fractures et failles à direction NE, captura les drainages primitifs en orientant la karstification des nouveaux conduits, qui grâce aux reaction de mélange entre les eaux de nappe et celles sulfureuses montantes le long des fractures néo-formées, prirent des dimentions considérables. Le conduits précédents furent deplacés par des rejects qui complessivements sont supérieurs aux 100 m et des nouveaux niveaux furent instaurés pendant cette intense phase tectonique Mindelién et Mindel-Rissien qui augmenta l'asymmétrie de la structure. A partir de ce moment, le réseau karstique dans sa droite hydrographique en confluant par de angles aigus dans le torrent Sentino, fut énormement étendu, tandis que celui du versant opposé, en confluant à contre-courant, s'est réduit e peu de galierie minuscules. A l'intérieur du complexe hypogée, on peut donc enregistrés les oscillations de la nappe phréatique, dûes soit à des raisons climatiques ou neotectoniques, avenues aprés l'aplanissement villafranchien et pendant l'"uplifting" differentié pleistocénique.

The Umbria-Marche Apennines, that lie on the northern side of the Central Apennine chain, are formed by a series of NW-SE anticlinoria and sinclinoria. The higher zones of this structure correspond to the top of the anticline composed of jurassic-eocenic rocks; the lower ones to the sincline where miocenic formations are known. The mountain chain has a series of farily homogeneous reliefs whose altitude are seldom higher than 2000 metres and normally constitute the watershed of the streams flowing to the Adriatic and Tyrrhenian Seas.

The most karst-bearing formation is the "Calcare Massiccio (Hettangiano-Sinemuriano P.P.) composed exclusively of limestone thicker than 600 metres. This formation is normally placed in the anticline nucleous surrounded by less karst-bearing and/or water-tight rocks. Some of the largest italian karst complexes like the one we are going to describe open inside it.

The Frasassi karst area is located in the Valmontagnana anticline, on the eastern side of the "Dorsale Marchigiana", an anticlinoria oriented in apenninic direction with adriatic vergency. The northern side of this structure is more than 500 metres cut down into the "Calcare Massiccio" by the Sentino stream, a tributary of the Esino river. The "Bugarone" (Early Lias-Early Titonico), the "Maiolica" çLate Titonico-Aptiano), the "Marne a Fucoidi" (Aptiano-Cenomaniano) and the "Scaglia Bianca" and "Rosata" (Cenomaniano-Middle Eocene) formations outcrop on the top and on the northern side of the anticline. The first two of these are partly karst-bearing because of their secondary porosity (fractures and faults) (Passeri, 1976), while the "Fucoidi" represent the typical impermeable horizon that prevents the seepage into the lowlying rocks. The jurassic heteropic rocks of the "structural high" Bugarone formation, outcrop on the heteropic rocks of the "structural high" Bugarone formation, outcrop on the eastern side of the structure, beneath the "Maiolica", with a much thicker deposits. This sedimentary differentiation lies along a NS fault scarp which borders the eastern side of the anticline. Similar differentiations, in this area, sometimes follow the EW direction, whilst the "Basso strutturale" formations are buried. In fact it is the "Fucoidi" one to delimit the karst basin on this side. This formation, which is placed like a barrier against the karst rocks, orientates the hypogeal sought toward the Frasassi Gorge entry (Bocchini-Varani, 1971; Bocchini & Coltorti, 1978), where some uncovered risings of conspicous mineralized water (solphoureous) are known. The first dry and concretioned subhorizontal galleries lie few metres above, testifying a drainage no more in equilibrium with the actual one. Seven subhorizontal main sistem, located at progressive elevation on the water-table, have been recognized at the Grotta Sulfurea, on the right side of the Sentino stream. These karst floors are represented by subparallel galleries forming a very thick network. Room more than two dozen metres large and hundred metres long, often very straight because of their fault-line origin, lie where the primitive pheatic tubes anastomozed or where the water level had a free air flow. Also the collapses have contributed to the widening of the primitive tunnels. Sometimes two or more superimposed ones joined to form rooms higher than 100 metres. The communication between two or more superimposed floors are often due to the erosion connect eighter with vadose water or with a sudden sinking of the water-table. Thus many chutes and waterfall wells are present. Many deep lakes, located at about the same altitude, are known in the lowermost parts of this caves. Their waters flow slowly towards the above mentioned emergences where the flow-speed increases and some subterraneous stream with good competency and energy appear. The speleogenetic motions are still acting and furnish the key to the comprehension of the growth of the older galleries. Apart from the areas of intense drip, only a few thin water veins percolating toward the water level are present in the upper galleries. Anyway the karst network is well developed, given that the greatest capacity periods of the hypogeal streams, almost immediately follow the rainy seasons.

The main water laid deposits, apart from the concretionary ones, are represented by thin layers of marl and clay sometimes interposed by microcrystalline gypsum levels and, more rarely, by alloctonous gravel deposits normally located in the rooms close to the entrance. On the same side of the gorge, at higher elevation, there are some other caves like the Paradiso, Faticchiana and Orso Bruno, while the Diavolo, Buco Cattivo, Infinito, Grottone and Inferno-Valle Stretta caves open on the south eastern side. The collapses and the concretions obliterate the primitive morphology of these caves. In fact, deposits similar to the above mentioned ones have been observed only at the Buco Cattivo, a cave more than 3 km long. One floor lying above the seven ones of the Grotta Fiume-Vento is known in this cave. It corresponds to the galleries of the Grotta Paradiso. All the caves opening at high altitude in and outside the gorge, are connected with the older karst phases (7th and 8th floors). Furthermore, the Grotta Inferno-Valle Stretta, which developes along the jurassic fault scarp is now dissected from the stream erosion. It is hanging 50m above the stream bed. This cave, which is the closest to the terminal areas of the karst system, like an open air stream near the water-shed, is represented by fairly gradient galleries. Besides these there are about 100 caves which can be entered only a few dozens of metres.

In the previous chapter we have been discussing the right side of the gorge. It is here, in fact, that the larger parts of the "Calcare Massiccio" outcrop, and that, subsequently most of the caves open. Only a few small caves are present on the right side, near the talweg, whilst the Mezzogiorno-Frasassi (more than 2 km), the Occhialoni, the Grotta Verde, of appreciable length, lie at higher altitude. None of these ever reaches the dimention of the ones known on the other side. Also these last caves develop on subhorizontal floors coinciding with the 7th and the 8th ones. The whole area should be envisaged as a wide unic karst complex although the connection between the caves were obliterated by breakdown, concretions and neotectonic movements we will talk about later.

For a chronological frame of the karst phenomena I have been looking for their links with the alluvial terraces of the Esino valley and the Frasassi gorge. All along the Esino valley side, there are three alluvial terraced units situated at progressive altitude on the talweg. After a morphological, pedological and palaeoetnological study, they have been ascribed to the Würm, Riss and Mindel glaciation (Coltorti, et al., 1980). In the Marche, the periglacial climate favoured the deposition and the superelevation of the gravel deposits, while at the advent of the biostasia conditions the deepening processes of the talweg prevailed. At the entrance of the gorge, the top of the würmian terrace is about 12 m above the talweg, whilst the rissian one lies about 22 metres. The mindelian one is located some 100 m higher, even it is deeply embanched inside the canõn. On the tope of the gorge the landscape becomes suddenly gentle, without steep slopes, and one can reach the top of the mountain easily (930 m). This summital morphology correspond to the "Surface Villafranchien" also known in the nearby Abruzzo region (Demangeot, 1965). It is modelled inside an older smoothing surface that the above mentioned Author refers to Pliocene morphology (Surface de sommets). These data allow us to say that the karst phenomenon of the Frasassi gorge is later than the villafranchian modelling actions. It is w'.h this moulding that the reliefs began to have mo. energy than before. This suggest that the upli..ing movements, active so far, started in that pe..od. To these uplifting conditions followed another .ut-tendecy that formed the deepening of .ne Sentino and consequently the opening of the gorge. At the same time, on the eastern side of the structure, the Esino river was deepening its talweg and the calcareous rocks were brought to light progressively. This allowed a major water flow inside the karst complex.

The uppermost caves of the anticline open on EW, NNW-SSE and NS fractures and faults of jurassic age (8th floor). They constitute a series of drainages oriented both towards the Frasassi gorge and the Esino river (Figure 2). Therefore it seems to me that besides the high primarily porosity of the rock, it was the tectonic dislocation to direct the hypogeal flow. The 8th floor of the Frasassi gorge is represented by a phreatic tube, probably formed by leaks of the Sentino towards the Esino across the Anticline. The existence of this phreatic tube shows that the tectonic movements where not very intense. In fact they showed generalized uplifings that favoured the reactivation of the jurassic faults. These pipes were later dislocated by side NE faults. It is only thanks to their vertical and/or horizontal karstification that today one can enter most of these old galleries. A new water table equilibrium allowed the development of a new subhorizontal level. The difference in height with the upper floor varies from place to place depending on the intensity of the tectonic movements meanwhile occurred. Inside the Grotta Mezzogiorno-Frasassi there are 25-40 m between the two levels while, on the opposite slope of the gorge, more than 50 m separate the Paradiso from the Orso Bruno cave. About the same situation is known inside the Buco Cattivo.

During this new equilibrium the karstification mainly interested the neoformation fractures, so that the new karst floors developed mostly along the NE trending that will carry on to direct the karstification until the most recent floors. One of these faults lies at the entrance of the Frasassi gorge dislocating the water-tight covering of the "Fucoidi", bringing into contact the karstified rocks. The progressive deepening of the talweg was favoured in this was as well as the progressive piracy of the whole hypogeal system towards this area. It is along this fault that the Fiume-Vento system opens.

The first gypsum deposits have been observed in the NE galleries of the 7th floor. They show that these fractures reached the lowlying "Anidriti di Burano" formation (Upper Trias). Between watertable and solphoureous water rising along the new fractures start miscelation corrosion reactions that contributed to the enlargement of the karstic network. The rising of solphoureous water is testified by the mineralize of halloisite and barite (Bertolani, et al., 1977) along the trending NE fault planes and by the high percentage of Cl an SO_4 inside the waters (Centamore, et al., 1976). This new dislocations delimits some short galleries raising at their approach with the anticline axis, so that the NE faults, trasverse to the structure, are closely connected with the differentiated uplifting movements increasing the anticline structural asimmetry. The climatic condition that made the equilibrium profile of the stream stationary, favoured the horizontal karstification that, interacting with the uplifting of the anticline, allowed the formation of the hanging galleries along the dislocation lines. The 7th floor, which is correlated with them, drained at the same altitude of the mindelian alluvial deposits. At a later stage, also the pipes of this floor were dislocated along more than 60 m during a period of morphological crisis (Final Mindel-Early Mindel-Riss (?)) that caused a new change in the profile of the fluvial equilibrium. In this period the hanging galleries stopped forming and chutes and waterfall wells began to open. On the left side of the valley, the conditions favourable to a horizontal karstification seem to stop at the 7th floor, given that when the wide karst floors of the Grotta Fiume-Vento formed on the opposite side, only small caves opened on this one. This phenomenon is due to the changed relationship between the hypogeal pipes and the Sentino stream, because only neotectonic events occurred during the deepening of the hypogeal network. Before this period, the drainage took place with normal angles to the stream, but now, after the activation of the NE fractures, the confluence has low angles on the right side, while on the opposite side it is against the stream way. Furthermore, the NE faults displace the NNW-SSE jurassic fractures which should be normal to the isopheatic lines, so that the water has to follow a tortous way between the neoformation and the more or less removed jurassic faults in search of the shortest way of confluence, dispersed in thousand small veins which can karstify only short galleries (Gr. Bagno, Baffoni, Buco del Falco, Leonardo). Other hanging galleries can be seen in the karst floors developed on the right side in a later period showing even though with less throw.

The lowermost of the other six floors stratified below the mindelian one, opens above the actual talweg. It is separated by active zone by a small cutting. That is why it can be referred to the Olocene. The second floor opens at the same altitude of the terraced würmian alluvium. The third floor at the top of the rissian one. Faunal remains attributed to the Würm have been found in the hypogeal rooms of the third floor (Coltorti & Sala, 1978). This might confirm our chronological "ante quem" attribution. The 4th, 5th and 6th floors did not yield any find so that no proof of their chronological attribution can be confirmed so far. In fact it is not a sequence of older and older galleries from the bottom to the top, but a sequence where the tunnels originated during the periglacial climate lie above those of the preceding and of the following interglacial.

Conclusions

At the light of the data available is widely accepted that, in this area, the floors formed both during the periglacial and the interglacial periods, when the deepening of the alluvial deposit stopped. Less important floors, often hanging, indicate the persistence of differentiated upliftings also when the equilibrium profile remained the same. On the contrary, wells and chutes suggest the existence of hard variation of the neutral point along the stream, usually connected with the passage from periglacial to mediterranean climatic conditions. If, during these periods of talweg deepening, the tectonic differentiated upliftings were in action, the differences in height between the horizontal level and still forming one were increasing.

The karst has different aspects according to the climatic conditions. The tectonic regime of the Umbria-Marche area has been essential for his origin. In fact the karst did not develop since the pleistocene uplifting did not permit the erosion of the impermeable covering and the jurassic fractures did not reestablish. Furthermore one can observe that the increasing of galleries happened after the area was interested by a new system of faults. The dislocation line did form immediately an ideal subterraneous passage between the rainfall on the top of the relief and the watertable. However the orientation of the new fractures is extremely important as regards the Sentino. If they are oriented with the flow isophreatic lines, they are strongly karstified, while if they oblige the water to have a long and tortuous way, they are karstified only a little.

The macroscopic swingings of the watertable are recorded inside the hipogeal system. They are connected with climatic and/or tectonic events occurred after the villafranchian smoothing and during the pleistocene differentiated uplifting. Estimating the slip of the horizontal floors and the difference in height between one floor and the subsequent one, it's possible to locate the tectonic succession and to attribute to the Mindel/Mindel-Riss a strong phase of differentiated upliftings in connection with the faults trasverse to the anticline. These movements, still active, affected the following growth of the karst network but also conditioned the present landscape of the Umbria-March region.

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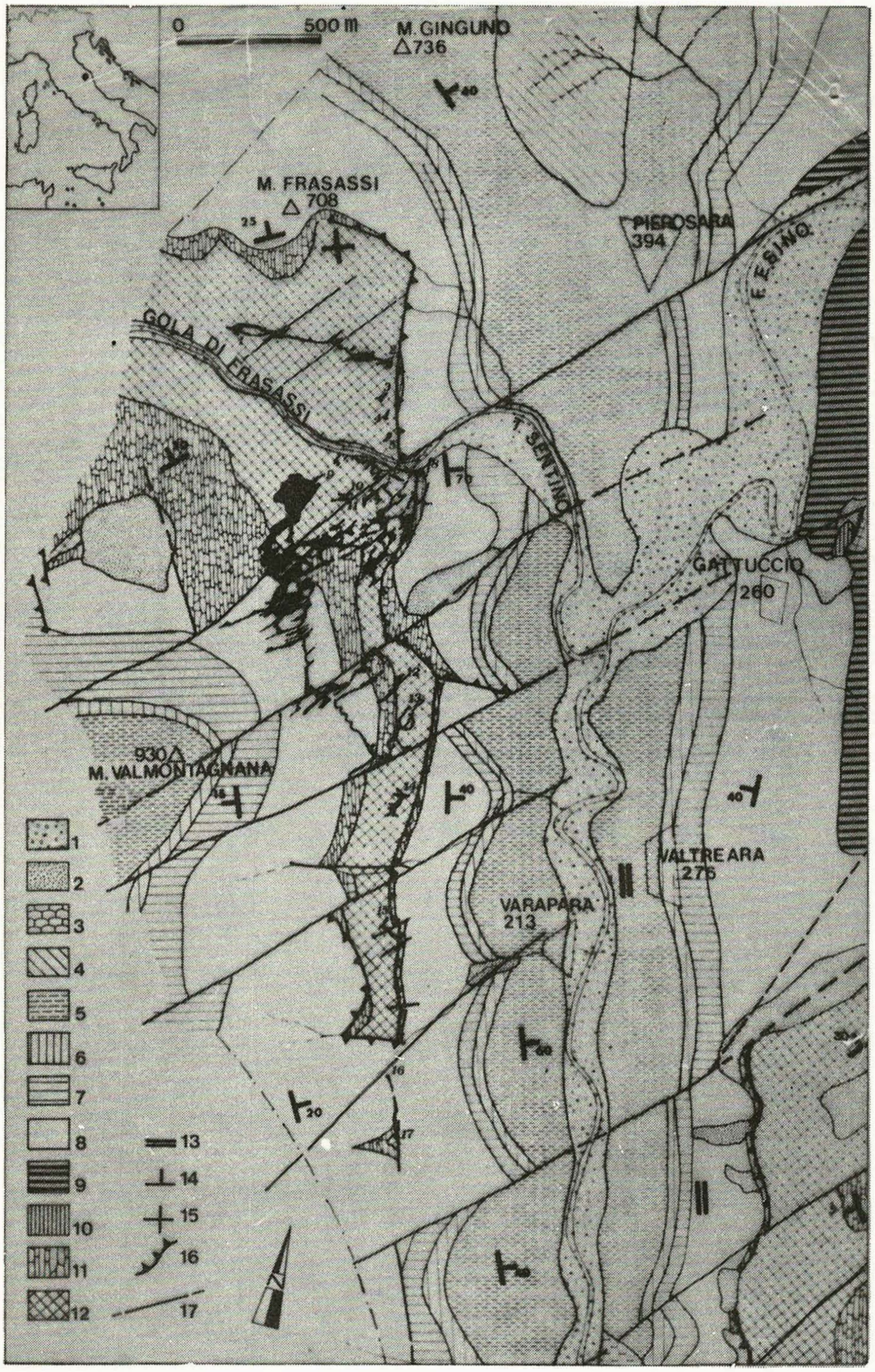

Figure 1. Geologic map of the karst-area of Frasassi with the entry and planimetry of the main caves. Geology: 1, Alluvium; 2, slope waste deposits; 3, landslide; 4, Scaglia Variegata e Cinerea; 5, Scaglia Rosata; 6, Scaglia Bianca; 7, Marne a Fucoidi; 8, Maiolica; 9, Calcari Granulari con Selce; 10, Formazione del Bosso; II, Formazione del Bugarone; 12, Calcare Massiccio; Strata: 13, vertical; 14, inclined; 15, horizontal; 16, jurassic fault scarp; 17, fault. Caves: 1, Frasassi; 2, Mezzogiorno; 3, Occhialoni; 4, Verde; 5, Baffoni; 6, Fiume; 7, Bella; 8, Solfurea; 9, Vento; 10, Orso Bruno; 11, Paradiso; 12, Diavolo; 13, Buco Cattivo; 14, Infinito; 15, Grottone; 16, Valle Stretta; 17, Inferno.

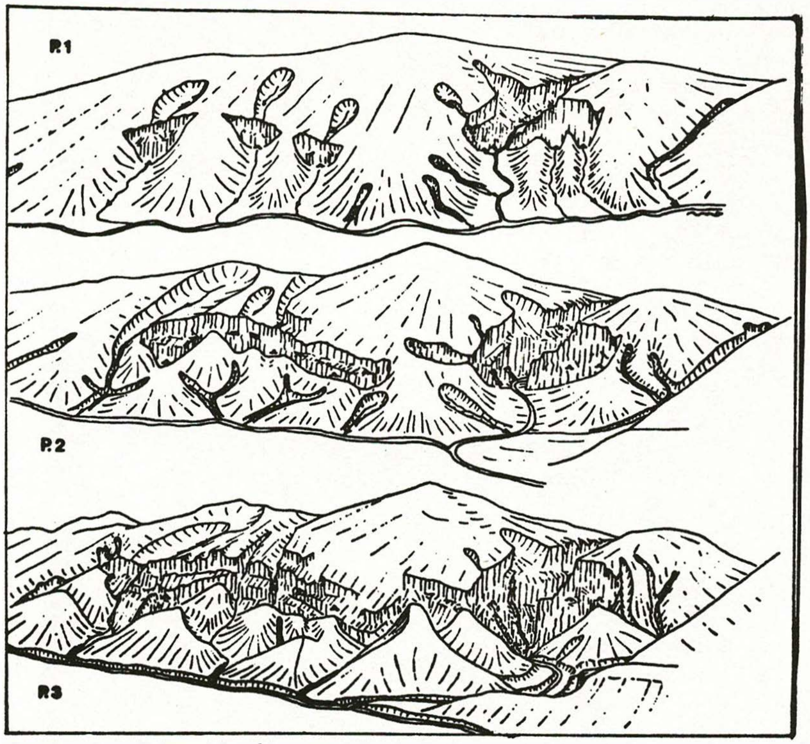

Figure 2. Schematic diagram showing the evolutional phases of the Frasassi-Karst. P.I, before Mindel and after the Villafranchian smoothing; P.2, Mindel/Mindel-Riss; P.3, Today.

The "Breathing" of Coldwater Cave

Warren C. Lewis, M.D.
119 N. Church Street, Rockford, Illinois, 61101, U.S.A.

Abstract

Coldwater Cave acts as a microbarometer. Studies were made of the movement of air in and out of the cave. The apparatus was sensitive to periods from 10 seconds to 12 hours. One series of irregular oscillations were recorded in the 55 to 70 second band. These were found to correspond to gravity acoustic waves that are primarily of auroral type originating in the ionosphere or below it in the stratosphere. The second type with periods from 6 to 30 minutes corresponds to gravity acoustic waves generated primarily by the jet stream at about 10 km. in height. These observations may throw light on some of the problems of "cave breathing".

Résumé

"Coldwater Cave" est identique à un microbaromètre. La circulation de l'air à l'intérieur et à l'extérieur de la chambre a été étudiée. La sensitivité de l'instrument allant de 10 secondes a 12 heures. Une série d'oscillations irrégulieres ont été enregistrées entre 55 et 70 secondes; elles correspondent à des ondes de gravité accoustique de type auroral prenant naissance dans l'ionoshpère ou en dessous, dans la stratosphère. Une deuxieme série enregistrée entre 6 et 30 minutes correspond à des ondes accoustiques produites principalement par le jet de courant à 10 kilomètres (kms.) d'altitude. Ces observations pourraient apporter certaines clarifications à quelque problèmes concernant le "cave breathing".

In 1977 we discovered quite by accident that the flow of air was periodically reversing at an artificial opening of Coldwater Cave. The cave was "breathing". On subsequent trips we continued to monitor this phenomenon each time that it was present. We gradually refined equipment to record the alteration of air flow into and out of the cave.

In 1947 a party composed of Petrie, Mitchell, Carter, Stephenson, and Faust were exploring "Salt Petre Cave" near Burnsville, Virginia, U.S.A. While waiting in a narrow spot in the righthand crawlway, Burton Faust observed a periodic reversal of air movement. The air would start moving slowly, increase rapidly to a maximum, slow down to an apparent standstill and remain stationary for a period of time. It would then start moving in the opposite direction, passing through a maximum velocity to rest. After remaining so for a period of time, the cycle would start over again. The entire cycle occupied about four minutes. They renamed it Breathing Cave.

While Dan Nigh was observing Cassell Windy Cave, Pocohantas County, West Virginia, U.S.A., he beheld to his great consternation a tongue-shaped cloud of fog emerge from the entrance. It floated across the ground in front of the cave for about 1 3/4 minutes. Suddenly further progress stopped. The air currents changed for no apparent reason causing the fog to retrace its path back into the opening. The time of inhalation was similar in duration to the time of exhalation.

Clyde M. Senger was investigating a talus cave in Skagit County, Washington. He was hiking over very rough terrain in the rain. He reported a distinct layer of cold air in the low places. Several times he saw a distinct layer of fog form and then dissipate in one of the depressions.

I. O. Chapman found that Cave No. 2 at Crooked Swamp was inhaling for 38 seconds and exhaling for 40 seconds. Cass Cave was reported to have a period of about 2 minutes. Air reversal was observed in the upstream portion of Mystic Cave above the Big Room. It was also noted at the Jumping Off Place in Schoolhouse Cave. Casparis Cave was also observed to reverse its flow. A blow hole on McKittrick Hill in New Mexico was noted to reverse in 90 minutes. Further observations at Breathing Cave on one occasion showed a period of approximately one minute. On other occasions, the reversal varied from two minutes to over twenty minutes. Air reversal has been reported in the passage leading to an ice chamber in Dobšimá Cave in Slovakia. In August the period was 1 minute, 30 seconds and winter 1 minute, 40 seconds. Some longer periods were observed.

July 17, 1977 air was noted to be moving in and out of a drill shaft connected to Coldwater Cave. Nine complete cycles were noted ranging in duration from 50-96 seconds. Then after two long cycles, the cave blew continuously outward. We chose to monitor the air movement by a temperature-sensing device. We utilized the difference in temperature between the temperature on the surface and the temperature of the cave air. A sensing element of fine copper wire wound on a micarda frame was used. It was chosen because of its fast response to temperature change.

The associated circuitry consisted of a 12 volt battery, a voltage regulator and the bridge. The voltage regulator was to compensate for changes in the battery voltage. The copper sensing element was connected to the bridge. The voltage output from the bridge varied with the resistance of the sensor. This, in turn, would change as the air temperature changed. Initially we used a 50 microamp. ammeter to monitor these changes. Manual recording of the readings was necessary. When an 120 volt gasoline-powered generator became available, we added a strip chart recorder. The chart speed showed some variation due to variations in the output of the generator. Because of this the time was marked periodically on the chart.

Our drill pipe extends 25 metres to the Mainstream Passage or Master Trunk of the system. This is 3 to 10 metres wide and 2 to 10 metres high. It is about 5 km. long with 8 km. of mapped side passages. The main passage is sealed to air flow at each end by sumps or siphons. The side passages have openings to the surface. This is shown by the rapid influx of water into the cave with each heavy rain. Such openings to the surface have not been traced.

On October 20, 1977 we placed the temperature-recording device in the shaft. We recorded ten hours of air movement. At the start the cave blew air constantly so that we recorded a straight line on the graph. By evening the cave air was moving in and out strongly four or five times an hour. Toward the end of the recording period, small oscillations appeared on the inward blowing segments of the tracing. Twenty-nine cycles were recorded in 27 minutes. On December 17 and 18 we recorded the temperature for 32 1/2 hours. Short cycles were recorded. In 8 segments of the tape, 196 cycles were recorded. On January 21 and 22, 1978, we recorded for 29 hours and 50 minutes. On February 18, 1978, 19 hours were recorded.

From the start we recorded two types of waves. One had a period of about 1 minute. The other varied from 10 to 15 minutes or more. We had hoped that the waves would tell us something about the size and perhaps the shape of the cave. Each set of waves showed variations in the period. They were quasi-sinusoidal in form or pseudo-sinusoidal. We attempted to apply resonance theory to our findings. Helmholtz resonator and organ pipe formulas were applied to the average period of the cycles. The results did not seem to fit the size of our cave. We attempted to apply the theories of air or water trapping. We failed to find a place in the cave that would act as a trap for water or moving air. We were unable to find an opening across which the wind might blow with force. The drill shaft itself was located within a metal farm building and was not subjected to the direct force of the wind. The cave waterfalls seemed to be inadequate sources of resonant energy for the air in such a large system.

We finally turned out attention to sources of variable pressure lying outside the cave. We found a body of meteorological studies that matched quite well the waves we were recording at Coldwater. Our periods corresponded with those generated by long acoustic waves in the atmosphere.

There are two distinct regimes of internal waves on the dispersion diagrams. (I follow the nomenclature of Beers.) One regime exists with a period less than the acoustic cut-off frequency of Vaisala-Brunt. This is a frequency at which air will not support a traveling wave with a vertical component. These are identified as acoustic waves. The second regime consists of long period waves lying above the isothermal Vaisala-Brunt frequency. These low-frequency, long-period waves are the internal atmospheric gravity waves.

First Regime - Acoustic Waves (Subsonic or Infrasonic Atmospheric Waves)

Period below 306 seconds. Velocity over 333 m/sec. They may reach 500 to 740 m/sec.

Waves of this type are constantly found on microbarographs tuned to this frequency. They are increased in amplitude during periods of high geomagnetic activity. They are the background "noise" of the meteorologist and originate primarily in the outer layers from turbulence induced by solar ratiation.

This regime also registers waves of great interest to the meteorologist. These include atmospheric waves caused by earthquakes, volcanic explosions, auroral discharges, tornados and meteorites. It includes such man-made noises as large explosions, rocket and satellite firing and reentry. It even records the firing of large guns, traffic noises and surface winds. Waves may travel long distances at high speeds. They may be channeled between atmospheric layers.

It would appear that most "breathing" caves with a period of less than five minutes were responding to atmospheric waves of this type. A good example was recorded by a team led by Don Cournoyer to Breathing Cave. This was published by Morre and Sullivan in Speleology The Science of Caves.

These waves originate in auroral or lower atmospheric waves or objects traveling at suprasonic speeds. They may appear in groups. Continuous sinusoidal wave forms from a harmonic source sar rarely if ever seen. Waves from secondary sources are best seen on superimposed records from an array of microbarographs. These give much information on the wave itself and eliminate artifacts due to local conditions.

Second Regime - Internal Atmospheric Gravity Waves

Period over 306 seconds. Velocity below 333 m/sec.

These waves are seen almost continually but at irregular intervals when the cave is "breathing". They are generated by the jet stream. This band of rapidly moving air flows across mid-American much of the year. It may be 200 km. wide, 5 km. thick and a thousand km. long. It is approximately 10 km. high. It swings its position, divides, converges and dips in unpredictable ways. It is tipped or tilted from South to North. It is often associated with storm fronts, tornados and clear air turbulence.

A series of waves are generated at right angles to the direction of the jet stream. They advance along the ground as a plane wave with the jet stream flow. These slower moving waves are weakened by wind and temperature changes. They rarely carry over 200 km. They may be recorded for weeks or months from a suitably located station. Similar waves of somewhat longer period may be generated by local storm fronts. This regime blends imperceptibly with variations cause by convection movements from heating and cooling of the atmosphere. It shows the semi-diurnal and diurnal tides.

This type of wave was also recorded by Don Cournoyer at Breathing Cave as seen in his article on The Speleo-Barometer in the NSS Bulletin. It would appear that most "breathing" caves with a period over 306 seconds are of this type.

Coldwater Cave acts like a microbarometer. It has a large well-insulated air chamber. It has slow leaks to the outside air. These maintain the internal pressure in near equilibrium with outside pressures when barometric changes are slight. It has a tube in which air motion can be measured.

The Conns demonstrated that much major air movement in and out of caves was of barometric origin. We show that minor air movement is also possibly associated with slight changes in the pressure of the outside air.

Acknowledgments

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Subsonic Atmospheric Waves

Type	Period	Origin
Microbaroms	4-7 sec.	from ocean waves during storms at sea
I - First Regime nonperiodic waves due to turbulence	40-80 sec. or more	Fast waves from geomagnetic polar storms in the ionosphere and below. Earthquakes. Volcanic eruptions. Many other sources.
Vaisala-Brunt discontinuity	306 sec.	No waves
II - Second Regime Trophospheric gravity waves. More uniform sinuoidal waves generated in areas of turbulence.	900 sec.	Slow waves originating in the jet stream 10 to 20 km. high.
More irregular waves	3600 sec.	Convection waves from heating and cooling of the atmosphere. Nearby weather systems.
Daily variations	24 hours	Semi-diurnal and diurnal tides.

Carbon Dioxide in Coldwater Cave

Warren C. Lweis, M.D.
119 N. Church Street, Rockford, Illinois, 61101, U.S.A.

Abstract

Levels of carbon dioxide gas are higher than normal in the atmosphere of Coldwater Cave. Readings from 0.5% to 2.5% are not uncommon in the mainstream passage. Elevated readings are associated with a lowering of the oxygen content. From our experience on many trips into the cave, we have learned to recognize the signs and symptoms of CO_2 toxicity. This has allowed us to accomplish much work in the cave even at times when the air was of poor quality and to do this with an adequate margin of safety.

Résumé

Le pourcentage de gaz carbonique dans une atmosphère de "Coldwater Cave" est définitivement au dessus de la normale. Des valeurs allant de 0.5% a 2.5% ont été obtenues dans le conduit principal, et ces élévations sont associées à une baisse de contenu en oxygène. Après avoir été dans la cave en plusieurs occasions, nous avons finalement appris à bien reconnaitre les signes et symptomes associés à la toxicité du gaz carbonique. Ceci nous a permis de travailler plus longuement et avec une suffisant marge de sécurité même pendant des périodes où l'air environnant a été impur.

Carbon dioxide is one of the most common pollutants of air of caves. It is heavy and inert. It will neither burn nor support combustion. Being 1.53 times as heavy as air it tends to collect in low areas in caves. In such locations the oxygen content of the air may be greatly reduced. Carbon dioxide has a direct effect on the respiratory center of the brain. At modest elevations there is stimulation of the respiratory center causing rapid, deep breathing. At higher levels the respiratory center is inhibited and breathing is slowed. The burning of matches, candles and the acetylene of carbide lamps may be affected at higher levels.

The carbon dioxide most commonly encountered in caves is a product of the decomposition of organic material. It is commonly found in soil where it is produced by organic processes. It is produced in many chemical and physical reactions of limestone. It is released from seepage water in the deposition of calcium to make cave formations. It is given off by soda springs and from other geothermal waters. It may be a product of volcanic activity. The respiration of animals, especially bat colonies, produce significant amounts of carbon dioxide.

Almost any organic substance especially when it is decomposed in the presence of oxygen can be a source of this gas. Of the breakdown processes perhaps that of fermentation is one of the oldest known. The Roman writer Pliny, the Elder, knew of the toxic gas from fermentation of grapes. He warned that before a person be allowed to enter a wine vat, a lighted candle should be lowered into it to see whether or not the air was fit to breathe. He died in the "bad air" of Vesuvius in 79 A.D.

Tamozzini in 1713 warned that grain stored in underground places in Tuscany gave off a gas the might cause death to a person entering there. McNally in 1937 noted that CO_2 was often the cause of death of persons entering wells, caves or other low-lying or confined spaces.

Coldwater Cave lies under a broad expanse of rich Iowa farmland. Every rain brings fresh mud and fine organic debris into the cave from the fields and temporary waterways. It is deposited as mud banks along the stream and its tributaries as the high water recedes. It settles out in the stream bed wherever there is slow flow or standing water. The degradation of the organic debris in the soil by bacteria, molds and fungi is apparently the chief source of carbon dioxide in Coldwater Cave.

The levels of carbon dioxide are highest in the warm months of the year. The reason for this is unclear. The temperature of the air 48°F and water 47°F in the cave remain almost constant throughout the summer and winter. One exception is a rapid drop in water temperature due to rapid influx of rain water or snow melt. We believe the carbon dioxide rise has to do with the greater availability of the organic substrate with the spring and summer rains.

Concentrations of the gas vary from one part of the cave to another but no definite pattern has been found. In general the highest concentrations are found in crawlways in which no air movement can be detected. Some caving teams have reported high levels in the far downstream portion of the cave because it lies at a slightly lower altitude than the rest of the cave.

Coldwater is basically a horizontal dendritic stream cave so few low areas exist. The mainstream drops about 3 meters per kilometer. All side passages rise from this level. Fifty domes or dome pits are present but all extend upward from base level. If carbon dioxide moves down the mainstream passage, the movement must be slow because of the low gradient. The role of the stream in solution and transportation of carbon dioxide is unknown.

The formation of carbon dioxide from vegetation uses oxygen in most of the biologic processes. When this occurs in a closed space, there is a reduction in the level of oxygen. In Coldwater, a rise of 1% in the level of carbon dioxide is associated with a drop of almost 1% in the oxygen level. Almost all the signs and symptoms are a combination of the effects of changes in the levels of these two gasses.

The air in Coldwater Cave is undergoing constant change with outside air. When the shaft is opened, there is almost always an immediate movement of air in or out of the cave. When National Weather Service maps show a high pressure weather system lying over the cave, the air will be entering the cave sometimes at a rapid rate. The cave is said to be sucking air. When a low pressure system is passing, the cave will be blowing air. If such a system is stable, then over a period of several days a large volume of air will enter or leave the cave. The entrance of outside air lowers the level of carbon dioxide in the cave especially near the shaft opening.

The major barometric changes act as a pump to remove carbon dioxide from the cave. The per cent of air exchanged at any one time is small though the volume of air exchanged may be large. Under extreme shifts of barometric pressure, for example from 29.5 to 30.5 mm. of mercury, one thirtieth of the cave air might be exchanged. This will depend on the size of the cave openings and the duration of the pressure system. Coldwater Cave is lacking in large openings to the surface. Air exchange in the main passage is retarded when the shaft is closed.

On two occasions a heavy rain has caused a rapid change of cave air. The reason for this is not clear.

Few horizontal stream caves present problems with bad air. The lower portion of Mystery Cave, Perry County, Missouri above the downstream sump is one that accumulates high levels of the gas. Many pit-type caves are known to have high CO_2. These include Cave Canem and Anderson Pit in Clayton County, Iowa and Level Crevice, Dubuque, Iowa. Culvert Cave, Perry County, Missouri, Bad-Air Cave in Arkansas, Vanishing River Cave, Colorado and Gorman Falls Cave, Texas have air that restricted exploration. Many of the large Texas bat caves have high CO_2 levels when the bats are present. The air in the nursery chamber of Frio Cave will not support the flame of a carbide lamp. Avoid Webb Cave, Margarite Cave, 10 Mile Cave, Kyser Cave, Longhorn Bad Air Cave and Snelling Cave. In Twiggs Cave, West Virginia, a rescue was effected under extremely difficult conditions because of the presence of high levels of carbon dioxide.

Bugnonia Caves in Australia have extremely high levels. Special technique and apparatus have been devised by local caving groups to allow exploration and study of these caves. The cave literature reports a number of harrowing experiences from CO_2. One rescue was necessary in an atmosphere of only 0.5%. Another rescue was mentioned that might have had very serious consequences. See reports by Julia M. James and others.

In some pits the drainage area and organic debris carried into the cave seem inadequate to account for the high levels of carbon dioxide. One might suspect that such pits were part of a deeper and more extensive cave system. Atmospheric pressure changes may bring the carbon dioxide into the upper level pits from deeper levels depending on the geometric configuration of the cave. High CO_2 levels may be a helpful clue to persons who are searching for an unknown cave.

We enter Coldwater Cave through a 94 foot shaft with a fixed ladder installed. A corrugated metal farm building has been constructed over the shaft. This building has been fitted with bunks and furniture for use of the cavers. We used to leave the shaft open when caving teams were in the cave. We woke up some mornings with a headache. Our oil stove would not work properly, perhaps for a number of reasons. One evening our trip coordinator could not light his cigarette. He used up a whole pack of matches unsuccessfully. He finally stepped outside and lighted it with the first match. The cave was blowing air. After that we kept a plexi-glass cover on the shaft. We had unwittingly been exposing ourselves to the toxic atmosphere when the cave was blowing.

On only one or two occasions carbide lamps gave trouble due to bad air in the cave. One member reported that his burned with a long smoky yellow flame. His lamp went out in about twenty minutes. This is a warning sign. The water had been used up. Usually there is no lamp trouble even on long trips in bad air.

One early symptom of CO_2 intolerance is nausea. The most common is shortness of breath. One will find that he is panting from only mild exertion. Experienced cavers can estimate the degree of "bad air" by the effort it takes to travel at a normal pace. Some get headaches. It is not uncommon to get a headache after coming out of the cave. These are due to vasoconstriction and dilitation of cerebral blood vessels. These are usually relieved by aspirin or its compounds.

We have not seen symptoms of severe toxicity. Some Twiggs Cave rescue team members vomited repeatedly while working in the crawlway. Another became confused. He stared at his Gibbs ascender for twenty minutes before he could turn it over to put it on the rope. Disorders of thinking may assume any form. Twitching and shaking have been described. Others get dimness of peripheral vission. Air hunger is almost universal. Fatigue sets in rapidly. Discoordination is common.

The primary treatment is to remove the victim to the outside air. If this is impossible, he may be given oxygen or air to breathe. Oxygen should not be continued any longer than necessary. Gas masks filled with fresh soda lime will remove CO_2. Air hunger will remain. This can be temporarily relieved by a few whiffs of oxygen. Only experienced rescue personnel should operate such equipment except in extreme emergency.

If a visitor of novice caver feels sick, he is escorted out of the cave. Experienced cavers try to estimate the degree of bad air and plan the trip accordingly. In spite of elevated CO_2, the goals of the work have usually been accomplished, even in 12 or 15 hour trips. On only a few occasions trips have been cut short.

Low CO_2 is felt more keenly by some persons than others. It seems to be more toxic to those in poor physical condition. Each person entering the cave must be aware of the possible effects of high CO_2 and low O_2 levels.

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Table of Estimated Values of Combined High CO_2 and Low O_2 Levels.

CO_2	O_2		
0.03	20.9		Outside air.
0.5	20.5	Mildly toxic.	Some persons get nauseated and weak. This is the level set by the U.S. Bureau of Mines on the upper limit allowable for an 8 hour day.
1.0	20.0		Most cavers tolerate this well. No equipment problems.
2.0	19.0	Moderately toxic.	Weakness common with exertion. Crews are able to work. Candle burns poorly.
3.0	18.0		Shortness of breath at rest or with minimal exertion. Other symptoms. Candle, matches, propane lighter will not stay lit.
5.0	16.0	Highly toxic.	Severe symptoms. Carbide lamp, poor.
10.0	11.0	Rapidly lethal.	Carbide lamp, out.

Stygobromus Canadensis, A Troglobitic Amphipod Crustacean from Castelguard Cave, with Remarks on the Concept of Cave Glacial Refugia

John R. Holsinger
Dept. of Biological Sciences, Old Dominion University, Norfolk, Virginia 23508, U.S.A.

Abstract

Stygobromus canadensis, the first troglobitic amphipod recorded from Canada, was discovered in Castleguard Cave in 1977 and described in 1980. The species is not closely related taxonomically to any other member of the genus. In addition to S. canadensis, 11 other subterranean amphipods (9 in Stygobromus; 2 in Bactrurus) occur in glaciated areas of North America and 6 are local endemics. Several species of subterranean isopod crustaceans (Asellidae) occur in glaciated parts of North America as well, including Salmasellus steganothrix, which is also found in Castelguard Cave.

The occurrence of small, subterranean crustaceans with limited powers of dispersal in isolated ground water biotopes in areas formerly covered by Pleistocene glaciers poses some interesting biogeographic questions. Did these species migrate northward following retreat of Pleistocene ice sheets as some workers have suggested, or were they established there prior to glaciation and thus able to survive a part of the Ice Age in subglacial refugia? There is now good evidence in support of a hypothesis suggesting that some species, such as S. canadensis, which lacks close affinity with species living farther south in unglaciated areas, survived glacial periods in unfrozen groundwater habitats beneath the ice and have remained in the same general locality for long periods of time. The availibility of Castelguard Cave, which was previously covered by glaciers and even today remains partly covered, as a potential habitat for both amphipods and isopods for at least 155,000 years and possibly for 700,000 years is strong evidence for the theory of subglacial refugia.

Zusammenfassung

Stygobromus canadensis, der 1977 in der Castleguard Höhle entdeckt und 1980 beschreiben wurde, ist der erate Amphipod der in Kanada gefunden wurde. Diese Art ist taxonomisch nicht nahe mit anderen Arten dieser Gattung verwandt. Ausser S. canadensis kommen noch 11 andere unterirdische Amphipoden (9 in Stygobromus: 2 in Bactrurus), von denen 6 in dieser Gegend endemisch sind, in vereisten Bereichen Nordamerikas vor. Mehrere Arten unterirdischer isopoden Crustaceen (Asellidae), einschliesslich Salmasellus steganothrix der auch in der Castelguard Höhle gefunden wurde, kommen ausserdem in vereisten Teilen Nordamerikas vor.

Das Vorkommen kleiner, unterirdischer Crustaceen mit begrenzten Verteilungsmächten in isolierten Grundwasserbiotopen in Gegenden, die ehemals von Pleistozän Gletschern bedeckt waren, werfen einige interssante biogeographische Fragen auf. Sind diese Arten nordwärts gewandert, nachdem die pleistozänen Eisschichten zurück gewichen sind, wie einige Wissenschaftler andeuten, oder waren sie schon vor der Ausbildung der Geltscher dort und überlebten einen Teil der Eiszeit im subglazialem Refugium? Gegenwärtig gibt es gutes Beweismaterial das die Hypothese unterstützt, welche nahelegt, dass einige Arten, wie S. canadensis der nahe Verwandschaft mit anderen, weiter südlich in unvereisten Gegenden lebenden Arten fehlt, glaziale Zeiten in ungefrorenen Grundwasserhabitaten unter dem Eis überlebt haben und in diesem Standort für lange Zeitperioden geblieben sind. Starkes Beweismaterial dieser subglazialen Refugium Hypothese kommt von dem Vorhandensein der Castleguard Höhle, die vorhergehend mit Gletschern bedeckt war und sogar heute noch teilweise vereist ist den Amphipoden und Isopoden die dort ein potentielles Habitat seit weningsten 155 000 Jahren und wahrscheinlich sogar seit 700 000 Jahren haben.

Introduction

Troglobitic and/or phreatobitic organisms (i.e., obligatory cave and/or groundwater species) are rarely found in glaciated areas of the northern hemisphere, and it is generally assumed that subterranean faunas which might have existed there prior to the Pleistocene were subsequently extirpated by the effects of glacial or periglacial conditions (Vandel, 1965). In North America only a small number of subterranean amphipod and isopod crustaceans are recorded from glaciated regions, and most workers have attributed their presence there to postglacial dispersal from the south (See Holsinger, 1980).

In Canada, which was extensively glaciated in the Pleistocene, troglobites or phreatobites were unknown (see Fenton et al., 1973) until the recent discovery of a subterranean isopod, Salmasellus steganothrix, in Alberta (Bowman, 1975; Clifford and Berstrom, 1976). Shortly thereafter, a subterranean amphipod, Stygobromus canadensis, was collected from Castleguard Cave in Alberta (Holsinger, 1980). More recently, a second subterranean amphipod was found in a spring near Rocky Mountain House in Alberta (Bousfield and Holsinger, in ms.). The discovery of these subterranean crustaceans is of great interest zoogeographically, not only because they are the first phreatobites reported from Canada, but because they occur in glaciated areas farther north than any other subterranean species in North America.

At present a total of 12 subterranean amphipod species (2 in Bactrurus, 10 in Stygobromus) are recorded from the region north of the southern limit of glaciation in North America, and 7 of them do not occur outside of glaciated areas (Fig. 1). In addition to S. steganothrix, several species of subterranean isopods also occur in the glaciated region (see for example, Peck and Lewis, 1977).

Observations

In two recent papers (Holsinger, 1978, 1980) I suggested that under certain conditions some subterranean species might have survived extended periods of glaciation in deep groundwater refuge beneath the ice, and that their present ranges have not resulted from northward migration since Wisconsin time but instead probably reflect very old, preglacial distribution.

This theory was discussed in greater depth in my 1980 paper and the arguments in favor of the hypothesis are summarized as follows: (1) a significant number of amphipod species living at present in glaciated areas are local endemics and some are only distantly related taxonomically to species living in unglaciated areas, (2) it is improbable that tiny, hypogean crustaceans would have migrated great distances northward in the relatively short period of time since the Wisconsin glacial age, (3) the fact that groundwater remains unfrozen beneath glaciers depending on depth and is thus potentially available for colonization by subterranean crustaceans, (4) the occurrence of certain species of crustacenas beneath the Ross Ice Shelf, 475 km from the open Ross Sea in Antarctica, (5) the low metabolic rate, slow growth rates, reduced energy budgets and tolerance for lowered water temperature of hypogean crustaceans which might allow for their extended existence in an austere, subglacial environment, and (6) Castleguard Dave, itslef, which is located in a glaciated area, is presently inhabited by both troglobitic amphipods and isopods, extends in part beneath an alpine glacier, and has apparently remained internally ice-free and available as a potential habitat for aquatic organisms for at least 155,000 years.

What does a careful examination of the ranges of the 12 subterranean amphipods from glaciated North America tell us about the historical biogeography of these species? Do all of the ranges reflect old distributional patterns from preglacial times or can some be attributed to postglacial dispersal? How substantial is the evidence for subglacial refugia? A brief biogeographical analysis follows.

Exclucing the range of S. lucifugus, a probable synonym of S. subtilis (Holsinger, 1969), three different types of ranges are indicated by the distributions plotted in Fig. 1: (1) contiguous distributions extending north and south of the Pleistocene glacial limit (B. brachycaudus and S. subtilis); (2) disjunct distributions not contiguous from glaciated to unglaciated areas (B. mucronatus, S. allegheniensis and S. tenuis); and (3) distribtuions restricted to the glaciated region (S. borealis, S. canadensis, S. iowae, S. putealis, and undescribed species from Alberta and

Montana).

Type 1 ranges. - The ranges of these two species do not extend for more than 150 km into the glaciated region; both species are more common and widespread in unglaciated areas. Moreover, the northern extent of their ranges are in areas not covered by ice since Illinoian glaciation, 180,000 to 130,000 BP (see also Peck and Lewis, 1977). Based on these facts, I interpret the northern part of these ranges as having resulted from postglacial dispersal.

Type 2 ranges. - Depending on the species, several interpretations are possible for ranges of this type. First, the range of B. mucronatus is disjunct and all records but that of a single, isolated cave population in southern Illinois are from glaciated areas. The ecology of this species is rather unique, inasmuch as most populations have been sampled from the outlets of shallow drains on the edge of cultivated fields in glacial drift plaints. The principal habitat of this species is apparently interstitial in loosely consolidated drift near major stream valleys, and since this biotope has resulted directly from glacial deposits, it obviously could not have been colonized until post-Pleistocene time. This fact, combined with the occurrence of an apparent relict population south of the glacial limit, strongly suggests a northward migration following glaciation.

Only three disjunct populations of S. tenuis are recorded north of the glacial limit, and none is more than 150 km north. Whether these populations are isolated relicts of a formerly continuous distribution subsequently fragmented by glaciation or have resulted from postglacial dispersal is open to further interpretations.

As shown in Fig. 1, parts of the range of S. allegheniensis lie within the glaciated region, and the central New York populations are disjunct from those farther south. Based on its geographical and ecological vagility (see Holsinger, 1978), the dispersal potential of S. allegheniensis is apparently rather great, leading one to speculate that its distribtuion far north of the southern glacial limit might be attributed to postglacial dispersal. However, mushc of its range in glaciated areas is not contiguous with that in unglaciated areas, and many of the caves it inhabits in east-central New York are apparently of preglacial origin (Cullen et al., 1979). Therefore, it can be argued just as easily that this species survived glaciation in grounwater refugia and that its range has remained little changed since the Pleistocene.

Type 3 ranges. - With two exceptions, distributions of this type offer the most convinving evidence for subglacial refugia. The excpetions are S. iowae and S. putealis, whose ranges are close to or associated with the unglaciated Driftless Area of southwestern Wisconsin and northeastern Iowa. Both species, but especially S. putealis (see Holsinger, 1974), have strong taxonomic affinities with species in unglaciated parts of North America. Their present ranges are probably relicts of distributions which were broader in the past but which contracted to refugia in and around the Driftless Area during glaciation.

The remaining species with ranges restricted to the glaciated region include: S. borealis from Morris Cave, Rutland Co., Vermont and a spring in Rensselaer Co., New York; S. canadensis from Castleguard Cave in Alberta, an undescribed species from a spring 32 km south of Rocky Mountain House in Alberta, and an undescribed species from two caves in Glacier Co., Montana. None of these species appears to be closely allied taxonomically with species from unglaciated areas farther south and all are apparently locally endemic.

The species from the spring in Alberta occurs in an area just east of the Canadian Rockies which might have remained ice-free during much of Wisconsin time. There is some evidence for an extensive ice-free corridor between the Laurentide and Cordilleran ice sheets in this part of Canada (Clifford and Bergstrom, 1976; N.W. Rutter, in ms.), but the details have not been worked out (Holsinger, 1980). What effect such a corridor might have had on the present distribution of subterranean amphipods, such as the species in question, is open to speculation, but the possibility of a low-elevation, ice-free refugium, as suggested by Clifford and Bergstrom (1976), warrants further consideration.

The range of the undescribed species from Montana lies only about 100 km north of the southern limit of continental glaciation, but alpine glaciation during the Pleistocene was extensive in this part of the Rockies for hundreds of kilometers beyond the limit of the continuous ice sheet, thus this species occurs much deeper in glaciated territory than is implied in Fig. 1. Pending further study of this species and the caves it inhabits, I tentatively conclude that a subglacial regugium is the best explanation for its present distribution.

The range of S. borealis is situated at least 200 km north of the southern limit of glaciation. The type-locality, Morris Cave, is developed in marble of Ordovician age and contains a lake of phreatic water on the lower level. It is evident from glacial deposits that this cave was covered by ice in the past, and its origin was almost certainly preglacial. If the phreatic water in Morris Cave remained unfrozen during glaciation, it might have served as a subglacial refugium for subterranean amphipods like S. borealis.

The occurrence of S. canadensis in Castleguard Cave offers the most compeling evidence gathered to date in support of a theroy of subglacial refugia. This species ranges approximately 500 km north of the southern limit of glaciation and is only distantly related taxonomically to other amphipods in the Cordilleran region of North America (Holsinger, 1980). Castleguard Cave has been intensively investigated by Prof. D.C. Ford and his coworkers (see other papers in this Proceedings). The cave was covered by glaciers in the past and even today extends in part beneath the Mount Castelguard glaciers and Columbian Icefield. Chronological study of speleothems indicates that it has remained intact and internally ice-free for as long as 700,000 years (Ford et al., 1976; Ford, pers. comm.). The age of this cave and evidence that it has remained wet but unfrozen suggest that it could have been a potential habitat for subterranean crustaceans since the Yarmouth interglacial stage, and that it could have provided a subglacial regufium for these organisms during glacial maxima in both Illinoian and Wisconsin times.

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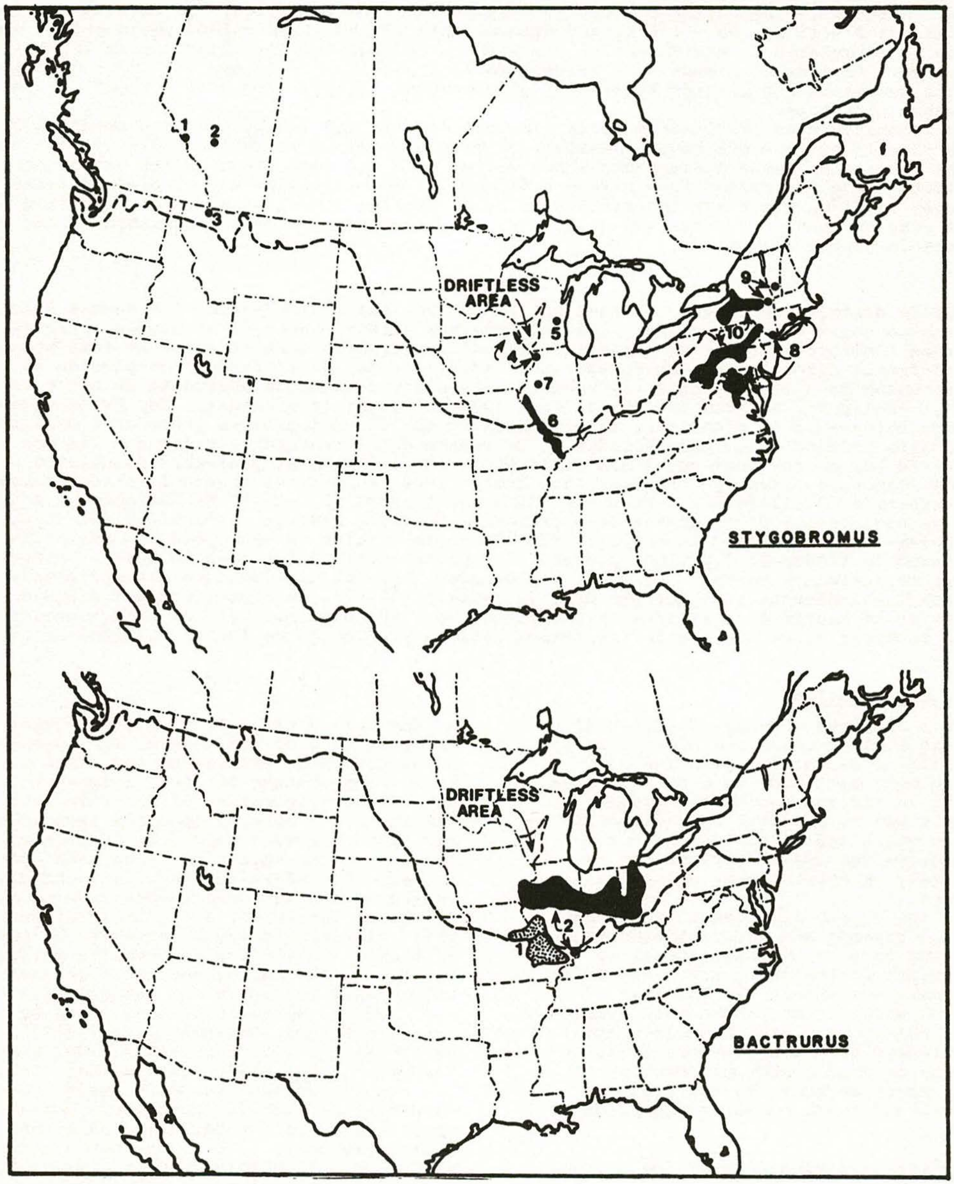

Figure 1. - Geographic distribution of subterranean amphipods in North America with ranges completely or partly north of the southern limit of Pleistocene glaciation. Disjunct or single localities for species indicated by closed circles; contiguous distributions shown as solid ranges. Heavy dashed line indicates approximate maximum extent of continental glaciation. Discontinuous alpine glaciation in western mountains not shown. Stygobromus (upper map): (1) S. canadensis, (2) new sp. from Alberta, (3) new sp. from Montana, (4) S. iowae, (5) S. putealis, (6) subtilis, (7) S. lucifugus, (8) S. tenuis, (9) S. borealis, (10) S. allegheniensis. Bactrurus (lower map): (1) B. brachycaudus, (2) B. mucronatus. Map based on Seyfert and Sirkin (1973).

A Climate Record of the Yorkshire Dales for the Last 300,000 Years

M. Gascoyne
Department of Geology, McMaster University, Hamilton, Ontario, Canada

Abstract

The Craven District of the Yorkshire Dales is thought to have been glaciated at least three times during the Quaternary period. Broken, buried and eroded speleothems in many of the caves in this area are mute testimony to major depositional/erosional cycles in the past, and are possibly related to these climatic events. Uranium-series dating of over 80 speleothems from this area, has clearly shown abundant growth in the periods 0 - 15 ky, 90 - 130 ky and greater than 180 ky (1 ky = 1000 years before present). These events can be correlated to the Flandrian, Ipswichian and earlier interglacials in the British Quaternary sequence. Periods of almost zero growth are 15 - 35 ky, 70 - 90 ky, and 140 - 170 ky which correspond to the Devensian and perhaps Wolstonian glaciations. Intervening cool periods are recognised by lower speleothem abundance.

A detailed reconstruction of climatic variations between 170 and 300 ky has been obtained from stalagmites and flowstones from one cave. Analysis of stable isotopic variations (mainly ^{18}O, expressed as $\delta^{18}O_c$) in the calcite of these speleothems shows marked warm and cool events which can be correlated to the paleoclimate curve determined from marine sediments. The speleothem record also contains several very steep changes in $\delta^{18}O_c$ which are interpreted as rapid cooling and warming trends, occuring perhaps over periods of 2 ky or less. If these are real, then they are of the utmost importance in the prediction of future changes in global climate.

Résumé

On croitque le district de Craven, faisant partie des vallons du Yorkshire, fut soumis à au moins trois glaciations au cours du quaternaire. Des spéléothèmes brisés, enterrés et érodés retrouvés dans plusierus cavernes témoignent de cycles majeurs de déposition/érosion dans le passé et sont possiblement reliés à ces irénéments climatiques. Le datage (par radio-isotopes de l'uranium) de plus de 80 spéléothèmes provenant de cette région a clairement indiqué une croissance abondante au cours des périodes 0-15 Ky, 90-130 Ky, et plus de 180 Ky (Ky = 1000 ans avant le présent). Ces événements peuvent être mis en corrélation avec le Flandrien, l'Ipswichien et des interglaciaires précédents dans la séquence quaternaire britannique. Les périodes ou on remarque une croissance presque nulle sont 15-35 Ky, 70-90 Ky et 140-170 Ky, ce qui correspond aux glaciations du Devensien et peur-être du Wolstonien. Des dîminutiens dans l'abondance des spéléothèmes sont indicatives de périodes fraîches intermédiaires.

Une reconstruction détaillée des variations climatiques entre 150 et 300 Ky fut obtenue à partir de stalagmites et de concrétions d'écoulement échantillonnés dans une caverne. L'analyse des variations isotopiques stables (principalement le rapport $^{18}O/^{16}O$) de la calcite de ces spéléothèmes révèle l' existence d'événements tièdes et frais qui peuvent être mis en corrélation avec la courbe paléoclimatique établie à partir de sédiments marins. De plus, les données obtenues de l'analyse des spéléothèmes indiquent plusieurs changements très abrupts dans le rapport $^{18}O/^{16}O$, interprétés comme étand des refroidissements et réchauffements rapides se produisant en 2 Ky ou moins. Si ces changements sont véritables, ils revêtent alors une grande importance dans la prédiction de futurs changements du climat terrestre.

Introduction

There is almost a complete absence of surficial deposits in north-west England which are older than the last glaciation. Evidence of earlier warm and cold events in Britain can only be found south of this area, in the Midlands, East Anglia and southern England. Most of these deposits cannot be dated by radiometric methods and so only complex and often tenuous inter-correlations and relative age determinations can be assembled, based largely on stratigraphy and floral and faunal assemblage data.

In the caves of the Yorkshire Dales in north-west England, however, many ancient and modern speleothems may be found, attesting to past climatic events by their presence or absence in the cave, and their relation to clastic sediment sequences. In the last fifteen years, several workers have shown that speleothems can be used to obtain both the chronology and intensity of past climates from uranium-series dating methods and variations in stable isotopic content of speleothem calcite. These methods are reviewed by Gascoyne et al. (1978) and their climatic significance is summarized below.

Climate and Age Distribution Frequency of Speleothems

Because speleothems require flowing water and excess bicarbonate ion in solution to grow, their very presence in a cave suggests that the climate at the time of deposition was non-glacial (so that water was not frozen as ice) and, more probably, it was mild to warm (so that the excess bicarbonate may be acquired by solution of CO_2 produced by vegetation overlying the cave). Periods of abundant speleothem growth may therefore be characteristic of a warm, interglacial-type climate, whilst periods of low or zero growth may indicate a periglacial or full-glacial climate. This type of approach has been used by Harmon et al. (1977) in the Canadian Rocky Mountains and North West Territories, and by Atkinson et al. (1978) in the Mendips, England, to determine ages of interglacial and glacial events in the Middle and Late Pleistocene.

Climate and ^{18}O Content of Speleothems

Variation in ^{18}O content of speleothem calcite (expressed in the notation $\delta^{18}O_c$) is a function of climate change for deposits formed in isotopic equilibrium with their drip waters. Such variations are caused by change in temperature of deposition and change in $\delta^{18}O$ of the drip water, which in turn varies in response to a shift in $\delta^{18}O$ of the source, i.e. seawater, (due to ice accumulation or wasting on the continents) and to changes in the temperature gradient between the sites of evaporation and precipitation of the rainwater. The latter factor is not only of opposite sign to the other two, but its value may vary depending on proximity of the cave to the ocean, and vapour exchange with other air and water masses. Therefore the resulting effect of temperature change on the isotopic composition of speleothem calcite may be an inverse or a direct relationship. The sign of this relationship may be obtained by comparison of $\delta^{18}O_c$ of fossil speleothems from cooler periods than the present, with that of modern speleothems (present-day values will be typical of interglacial conditions).

Such an approach has been used by Emiliani (1971) in southern France, Thompson et al. (1976) in West Virginia, Harmon et al. (1978) in several North American sites, and Gascoyne et al. (1980) in Vancouver Island.

In the present study, U-series methods have been used to date over 80 speleothems collected from major cave systems in the Yorkshire Dales and their age distribution frequency is interpreted in terms of paleoclimatic variation and correlated to the British Quaternary sequence. Variations in $\delta^{18}O_c$ for one dated flowstone deposit are correlated to the global climatic record as determined from deep sea sediment cores.

Results

A. Age Frequency Distribution

Figure 1 shows the age frequency distribution for speleothems from caves in the Yorkshire Dales. Ages were determined by the $^{230}Th/^{234}U$ dating method. Speleothem growth frequency in the Holocene is artificially suppressed in Figure 1 because although many obviously-young speleothems were initially collected, few were dated because interest lay mainly in older deposits. The periods 90 - 130 ky (1 ky = 1000 years before present) and greater than 180 ky are periods of abundant growth which may be correlated with the last interglacial (Ipswichian + ?) and penultimate interglacial stages (Hoxnian ?, Cromerian ?) of the British Quaternary sequence. Lower abundance is seen between 35 - 70 ky, corresponding to the Upton Warren interstadial complex (35 - 45 ky) and earlier interstadials. Periods of zero growth are 15 - 35 ky and 140 - 170 ky. The former is well-recognised as defining the Late Devensian glaciation, and the latter may be correlated with the penultimate glaciation which is regarded as the Wolstonian stage by most British workers. The low, but finite, abundance in the interval 70 - 90 ky indicates that full glacial conditions were not attained for most of the Early Devensian stage, in good agreement with other Quaternary evidence.

B. Variations in $\delta^{18}O_c$

Seven out of eight $^{230}Th/^{234}U$ age determinations show good agreement with stratigraphy for a complex flowstone sequence about 30 cm deep from Victoria Cave, near Settle. Continuous growth is found between 300 and 250 ky and from about 220 ky to 190 ky (the tope of the deposit). The break in growth shows clear erosional and clastic sediment inclusions. Most of the deposit was formed in isotopic equilibrium with its seepage water (determined by stable isotopic analysis of five growth layers) although one section dated at about 260 - 270 ky shows some kinetic isotope fractionation, probably due to evaporation of water. The variation in $\delta^{18}O_c$ along the growth axis is shown in the lower part of Figure 2. Two periods of comparable warmth to the present (determined by comparison to modern cave calcite $\delta^{18}O_c$) are seen at about 220 and 280 ky, and cooler periods occur at about 200 ky and 270 ky (although the latter is probably exaggerated by kinetic isotope effects). Excellent agreement can be seen between the speleothem record and the marine record, represented here by variations in $\delta^{18}O_c$ of benthonic foraminfer in cores V19-29 and V19-30 from the eastern Pacific Ocean (data from Ninkovitch and Shackleton 1975, Shackleton pers. comm.). The warm periods at 220 and 280 ky are tentatively correlated to isotope stages 7c and 9e respectively and the prominent break in growth correlates to glacial stage 8. The speleothem results are realistic because there are few 'one-point' spikes in the record and good continuity of data is found for most peaks and troughs.

Of special interest are the steep changes in $\delta^{18}O_c$ seen at several sites in the speleothem, suggesting rapid changes in climate, possibly occuring over 2 ky or less (determined from the observed growth rate).

Conclusions

These results clearly demonstrate the possibility of obtaining paleoclimate records for the Pleistocene period using U-series dating methods and stable isotopic analysis of speleothem. The results presented here, and other isotopic records will be published in greater detail elsewhere.

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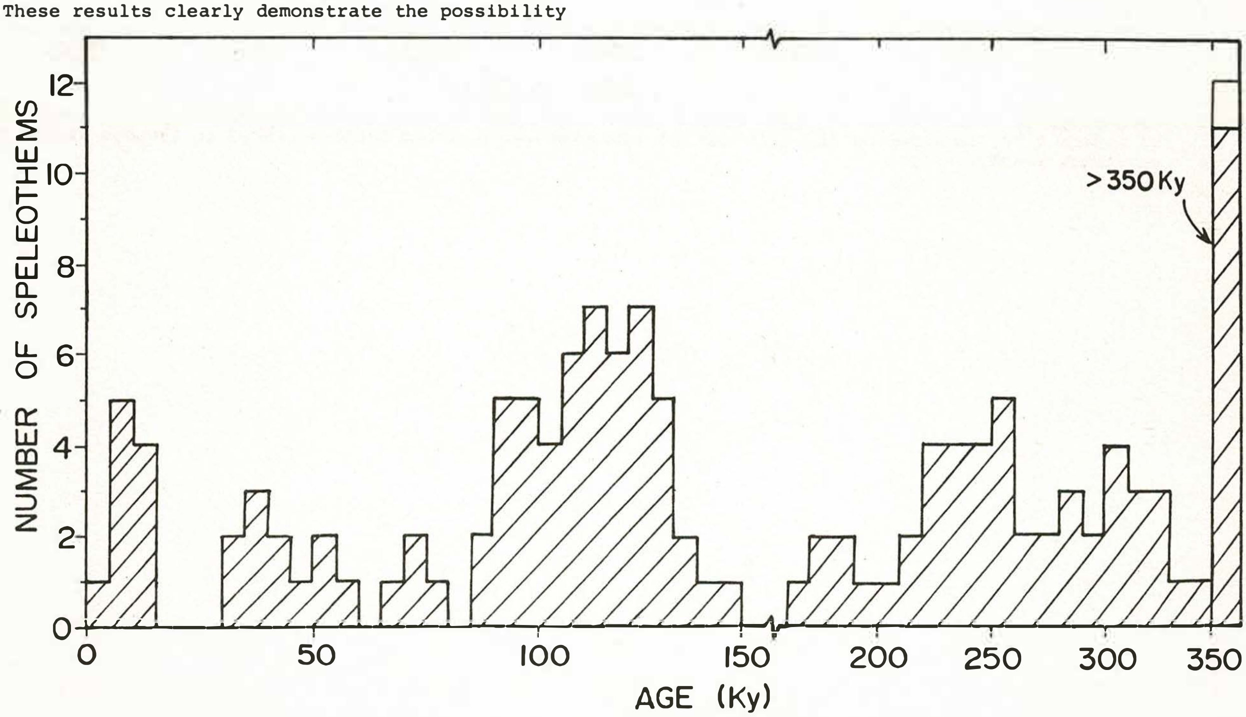

Figure 1. Age frequency distribution for speleothems dated by the $^{230}Th/^{234}U$ method, from caves in the Yorkshire Dales, north-west England.

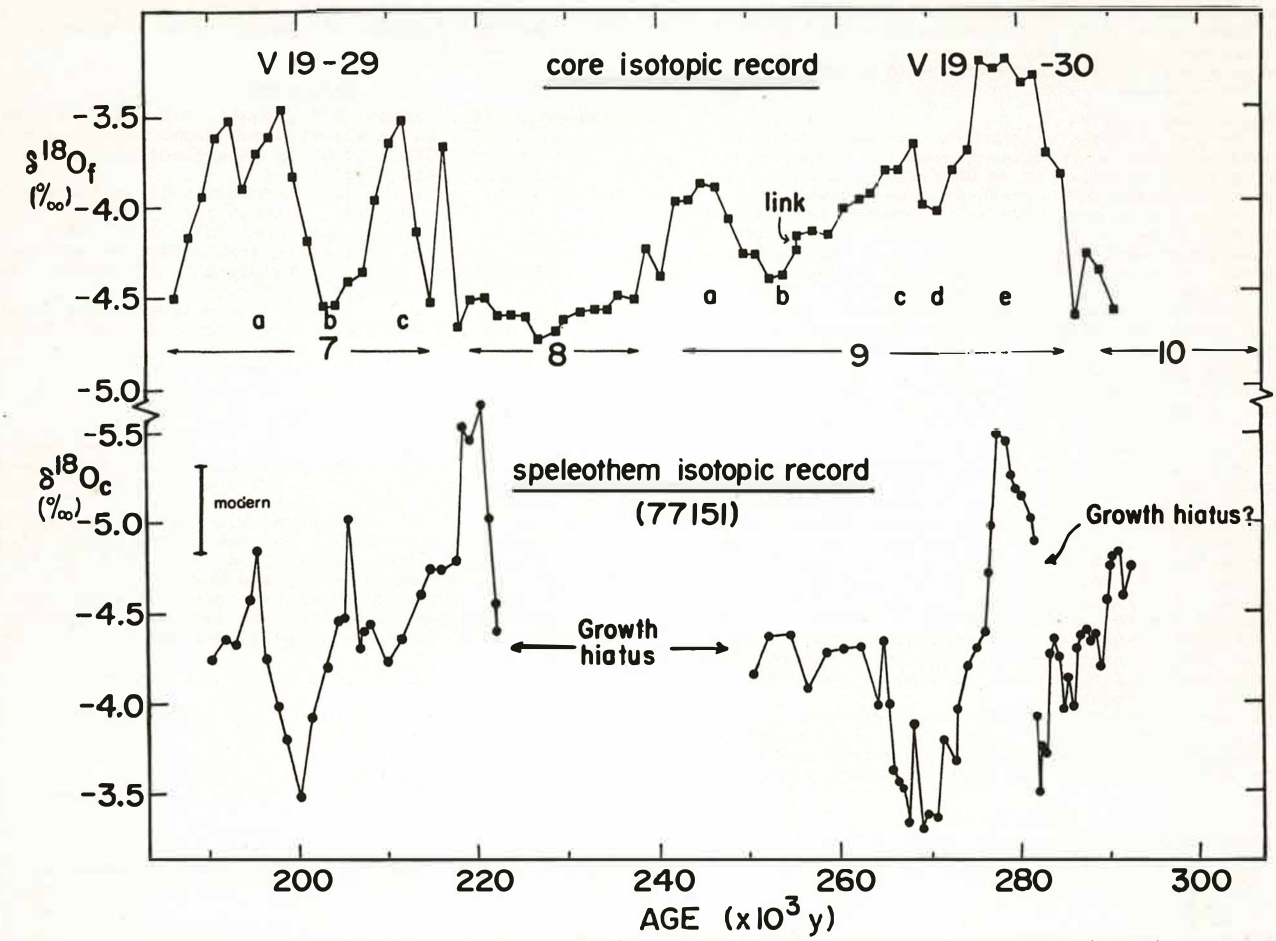

Figure 2. Comparison of a speleothem isotopic record (lower) with marine core isotopic record (upper). The position of modern $\delta^{18}O_c$ is shown on the left and the numbered and lettered sections refer to isotope stages and substages respectively.

Rates of Cave Passage Entrenchment and Valley Lowering Determined from Speleothem Age Measurements

M. Gascoyne
Department of Geology, McMaster University, Hamilton, Ontario, Canada

Abstract

Conventional techniques for determining rates of cave development and karst denudation include bedrock erosion monitors and water chemistry budgets. Because these methods are all based on measurements that describe intervals which are short relative to the age of the cave or karst surface, their applicability to different climatic regimes in the region is therefore questionable.

A more realistic assessment of average local and regional erosion rates may be obtained from the ages of in situ speleothems and their relation to the cave passage and modern stream level. Uranium-series ages of flowstones from four caves in the Craven District, northern England, give maximum rates of passage entrenchment of 2.2 to 8 cm/1000 y over the last 300,000 y. Comparison of these ages with the present difference in levels between the speleothem and the valley floor into which the caves debouch, indicates an extreme maximum rate of valley lowering of 20cm/1000 y.

A similar study of age-elevation relationships for speleothems from caves in Jamaica suggests a maximum passage entrenchment rate of 15 cm/1000 y and a valley lowering rate of 20 cm/1000 y. Although tentative, these results do suggest that limestone erosion occurs more rapidly in the tropics than in temperate climates.

Résumé

L'usage de moniteurs d'érosion de la roche-mère et le budgetage de la chimie des eaux sont par mis les techniques conventionnelles employées dans la détermination des taux de développement de cavernes et de dénudation du karst. Parce que toutes ces méthodes sont basées sur des mesures décrivant des intervalles de temps courts par rapport à l'âge de la caverne ou de la surface karstique, leur applicabilité à différents régimes climatiques est par conséquent douteuse.

On peut obtenir une évaluation plus réaliste des taux d'érosion moyens à l'échelle locale et régionale en se basant sur l'âge de spéléothèmes in situ et de leur relation avec la galerie de caverns et le niveau moderne des sources. La détermination par radio-isotopes de l'uranium de l'âge de roches d'écoulement en provenance de quatre cavernes du district de Craven, dans le nord de l'Angleterre, donne des taux maximums de retranchement de galerie de 2.2 à 8 cm/1000 ans au cours des dernières 300,000 années. La comparaison de ces âges avec la différence présente de niveau entre le spéléothème et le fond de la vallée dans laquelle les cavernes débouchent indique un taux maximum extrême d'abaissement de vallée de 20 cm/1000 ans.

Une étude semblable de la relation âge-élévation dans le case de spéléothèmes provenant de cavernes en Jamaïque suggère un taux maximum de retranchement de galerie de 15 cm/1000 ans et un taux d'abaissement de vallée de 20 cm/1000 ans. Bien que préliminaires, ces résultats suggèrent bien que l'érosion du calcaire s'effectue plus rapidement sous un climat tropical que sous un climat tempéré.

Introduction

Conventional methods available to the geomorphologist for measuring the rate of limestone erosion include solute budgets for runoff from limestone areas, solution of limestone tablets held in suspension in aggressive streams, and erosion meters clamped directly onto an eroding limestone surface. Sweeting (1972) describes results of the solutional methods and Coward (1975) has used the erosion monitoring technique in caves in West Virginia. Unfortunately, the results of all these methods are based only on periods of measurement that are short relative to the age of exposure of the limestone. Furthermore, they apply only to modern climate regimes. The effects of climate change at the site may accelerate or retard solution rates and only analyses made over periods of several thousands of years will adequately describe these effects.

A method of determining more realistic rates of erosion and downcutting in karst terrains involves the measurement of ages of speleothems which are in a fixed position relative to local base levels. This is best described by an example: consider a speleothem with a basal age of 100 ky (1 ky = 1000 years before present) still in its growth position, at an elevation of 2m above a stream in a cave passageway. Providing that the stream has always taken the same route, a mean maximum passage entrenchment rate of 2 cm/ky may be calculated for the 100 ky period since deposition.

This method may also be used to determine rates of valley deepening, based on ages and elevations of in situ speleothems in caves located in valley walls. Atkinson et al. (1978) used this technique to interpret ages of two ancient speleothems from the Yorkshire Dales, north-west England, as evidence that most of the valley deepening occurred prior to 400 ky, and was probably caused by an early glaciation. Ford et al. (1981) have recently determined entrenchment rates for two areas in the Canadian Rocky Mountains, using the greatest ages obtained for speleothems in these areas.

This paper presents relevant results obtained in the course of dating over 100 speleothems from caves in Jamaica and north-west England and then discusses their significance in terms of valley-deepening rates and the age of prominent landforms.

Method

Basal ages of several in situ speleothems were determined by $^{230}Th/^{234}U$ dating methods, summarized by Gascoyne et al. (1978). Estimations of the present elevation of the speleothem with respect to the floor of the cave passage, and with respect to valley floor level adjacent to the cave, were made using published cave surveys.

Results

Relatively few ancient speleothems were found still in the growth position and near to active stream passageways. Most of the older deposits were no longer in situ and it was not immediately clear where they had originally grown. The results for three fossil, in situ speleothems from the Yorkshire Dales and two deposits from Jamaica are given in Talbe 1. Results are also included for two other ancient deposits which were not in the growth position when collected, but whose location suggested that little vertical displacement had occurred since deposition.

Discussion

For the temperate caves, mean maximum passage entrenchment rates range between 2 and 8 cm/ky, whereas for the tropical caves, the rates appear to be substantially larger, from 13 to 20 cm/ky. Although insufficient data are available for tropical sites, these findings are in general agreement with values of karst denudation rates for temperate (2 - 10 cm/ky) and tropical (7 cm/ky) regions (from Sweeting, 1972, p 42).

The main shortcoming in this method of determining down-cutting rates is that the erosive agent may have bypassed this section of the cave for part of the time following deposition of the speleothem, and so the calculated entrenchment rate is no longer a maximum value. It is therefore necessary to choose speleothems in cave passageways which do not contain alternative drainage routes. For most of the sites described in Table 1, no alternative route for the stream is known. Kingsdale Master Cave and Ingleborough Cave are possible exceptions. The Lost John's site best demonstrates this requirement because the deposit lies directly above the stream in the 'Main Drain', a passage which acts as a master cave for several systems in that area and for which no alternative routes are known or even suspected. The remarkably low rate of entrenchment given here (< 2.2 cm/ky) therefore appears to be a definitive result.

Rates of valley down-cutting for the Yorkshire Dales may also be determined from these data. Using the present elevations of valley floors and cave passages containing the dated speleothems, mean maximum rates of about 10 to 20 cm/ky may be determined for the valleys of Kingsdale and Chapel-le-Dale, for the last 350 ky. Because this period contains probably three glacial/interglacial cycles (Shackleton and Opdyke, 1973;

Gascoyne et al., 1980), the amount of valley deepening, therefore, ranges from about 12m to 25m per cycle. If this rate can be extrapolated into Early Pleistocene times, then the minimum period required to deepen the Yorkshire Dales from the upper limestone benches to their present form, ranges from about 0.8 to 2 million years.

Conclusions

The use of uranium-series age measurements of ancient, in situ speleothems enables the determination of more realistic down-cutting rates than conventional methods, for the following reasons: (1) time periods approaching the age of the landform (several hundred ky) are used in the calculation rather than short intervals (< 0.1 ky), (2) the effect of changing climate regimes at the site are incorporated into the age-elevation method; in conventional methods only estimates can be made of the effect of climate on solution rate.

Providing that optimum deposits are available, at clearly definable locations, the age-elevation method may be used either to closely determine the rate of cave passage entrenchment by a perennial stream, or to determine the relative importance of glacial and interglacial erosive power in developing a karst landscape.

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Table 1. Age and elevation data with calculated down-cutting rates for caves in north-west England and Jamaica.

Location	Cave	Type of deposit	Height above Stream (m)	Basal age (ky)	Mean maximum downcutting rate (cm/ky)
North-west England	Lost John's Cave	wall flowstone	~2.5	115	2.2
	Kingsdale Master Cave	re-solutioned roof flowstone	~11	300	3.7
	Ingleborough Cave	flowstone	~4	> 120	~3.2
	Easegill Caverns	loose flowstone*	~20	240	8.3
	White Scar Cave	loose flowstones*	~20	> 350	~5.7
Jamaica	Coffee River Cave	stalagmite originally in roof of cave	~10	~80	~13
	Oxford Cave	wall flowstone	~40**	190	~20

* N.B. samples were not in growth position
**estimate of height above valley floor outside cave

The Antiquity of Castleguard Cave as Established by Uranium-Series Dating of Speleothems

M. Gascoyne , A. G. Latham
Department of Geology, McMaster University, Hamilton, Ontario, Canada and

Abstract

Several sections of Castleguard Cave contain abundant, massive fossil speleothem deposits. Many have been dated by the 230-Th/234-U method and, in most cases, were found to be older than 350 ky (1 ky = 1000 y before present). Included in this group are 1) a massive in situ flowstone in the Waterfall Chamber along First Fissure, 2) a prominent indurated stalagmite projecting through the false floor in the Grottos, and 3) the base of a large flowstone boss near the start of Second Fissure. More recent deposits include a false floor overlying laminated mud in the Grottos (144 ky) and a similar veneer between Holes-in-the-Floor and Second Fissure (38 ky).

It is possible to correlate these few finite ages with known warm events in the past, but the size and relative abundance of the deposits older than 350 ky suggests that they grew during a period much warmer than present, when a more extensive, temperate vegetation must have been established above the cave.

Speleothems (1) and (2) above, have been found to be magnetically reversed, indicating an age of greater than 700 ky, but probably less than 1 My from examination of their 234-U/238-U ratios.

These ages clearly demonstrate the antiquity of the cave and show that 1) First Fissure, the Grottos and at least the lower part of Second Fissure were vadose by 700 ky, 2) the mud deposits along First Fissure and in the Grottos are older than 100 ky, and if of glacial origin, must therefore be from the penultimate glaciation, or earlier, and 3) the presently active (but unexplored) drainage system of the cave is likely to be very old and, therefore, well developed.

Résumé

Plusieurs sections de la caverne de Castleguard contiennent des dépôts fossiles, abondants et massifs de spéléothèmes. Plusieurs ont été datés par la méthode 230-Th/234-U et, dans la plupart des cas, leur âge fut estimé à plus de 350 Ky (1 Ky = 1000 ans avant le présent). Inclus dans ce groupe sont 1) une roche d'écoulement massive, in situ, dans la chambre Waterfall le long de la Première Fissure, 2) un stalagmite endurci prominant, projetant à travers le faux-plancher dans les Grottes, et 3) la base d'une grosse bosse de ~~concrétion d'écoulement~~ près de l'origine de la Deuxième fissure. Des dépôts plus récents incluent un faux-plancher recouvrant de la boue lamellée dans les Grottes (144 Ky), une couche de concrétion d'écoulement recouvrant apparamment de la boue lamellée dans la Première Fissure (110 Ky) et un couvert semblable entre Holes-in-the-Floor et la Deuxième Fissure (38 Ky).

C'est possible d'établir une corrélation entre as quelques âges définis et des périodes tempérées connues dans le passé. Apendant, les dimensions et l'abondance relative des dépôts excédant 350 Ky en âge suggère que leur croissance prit place au cours d'une période beaucoup plus chaude que le présent, lorsqu'un couvert végétal luxuriant était peutêtre établi au-dessus de la caverne.

On a trouvé que les spéléothèmes 1) et 2) décrits ci-haut étaient d'un magnétisme inversé, indiquant un âge excédant 700 Ky, mais probablement inférieur à 1 My d'après leur rapport 234-U/238-U.

Ces âges démontrent clairement l'autiquité de la caverne et montrent que 1) la Première Fissure, les Grottes et au moins la partie inférieure de la Deuxième Fissure étaient vadoses dès 700 Ky, 2) l'âge des dépôts de boue le long de la Première Fissure et dans les Grottes dépasse 100 Ky, et s'ils sont d'origiue glaciaire, doivent donc dater de l'Illinoien ou d'avant, et 3) le présent système de drainage de la caverne (encore inexploré) est vraisemblablement très ancien et, par conséquent, bien développé.

Introduction

One of the most striking aspects of Gastleguard Cave is the presence of massive fossil flowstone deposits in many sections of the cave, which are in marked contrast to the limited growths currently forming. This would suggest that at some time(s) in the past, the climate in this area had been comparatively warmer than at present, with a greater vegetal activity at the surface.

Over the last ten years of exploration in the cave, a comprehensive suite of samples of these speleothem deposits has been assembled for uranium series dating by several workers. Initially, little evidence of the cave's great antiquity was found, because the oldest speleothem ages obtained only extended to 150 ky (Harmon et al., 1977, Table 1). This paper reports data which clearly demonstrate the antiquity of the cave and allow better estimations of the age of the clastic sediment accumulations, and of the vadose entrenchment of the phreatic sections.

Analytical Techniques

Small samples (10 - 30 g) of calcite from the speleothems were dated by the $^{230}Th/^{234}U$ method, developed for speleothems by Thompson (1973) and modified and fully described by Gascoyne (1977). One sample was analysed in duplicate, using the alternative dating technique $^{231}Pa/^{230}Th$. Two in situ speleothem samples were also analysed to determine paleomagnetic polarity by the method described by Latham (1981).

Results

Radiometric ages and sample descriptions are summarized in Table 2. Over half of the ages determined were found to be > 350 ky, the useful limit of the $^{230}Th/^{234}U$ dating method. Of the remaining ages, most correlate approximately to recognised warm periods in the Late Pleistocene (100 - 140 ky: the last interglacial (Sangamon); 38 ky: the mid-Wisconsin interstadial). Two flowstone veneers apparently overlying laminated mud deposits in First Fissure and the Grottos, were dated as about 110 ky and 140 ky respectively (Table 2), suggesting that the mud is of pre-Sangamon age, possibly resulting from the penultimate glaciation.

Most of the older speleothems analysed came from massive flowstone deposits showing re-solution features, and in many cases, these deposits have been dissected by vadose streams. Paleomagnetic analysis of oriented samples from the speleothems represented by samples 77033/79014 and 77034 has shown that certainly the former, and probably the latter, are of reversed polarity, indicating a minimum age of 700 ky (the end of the Matuyama chron). The relatively low $^{234}U/^{238}U$ ratios for these deposits (see Table 2) concur with this age estimation and, when compared to modern $^{234}U/^{238}U$ values, suggest that the deposits are < 1 My old.

These results indicate that:

1) First Fissure and the Grottos were de-watered and partially entrenched by over 700 ky ago, but from the eroded nature of speleothem 77033/79014, it is clear that the Grottos has returned to a phreatic state at least once since this time. The adjacent flowstone (79016), overlying the mud deposits which surround this ancient speleothem, is dated at about 140 ky, therefore indicating that this phreatic condition occurred prior to 140 ky. It is not clear whether the massive flowstone in the Waterfall Chamber of First Fissure (77034) was similarly innundated because the deposit may simply have been eroded and dissected by the stream inlet at this point.

2) Second Fissure was de-watered and probably entrenched by at least 350 ky. No paleomagnetic data is currently available for the deposits in this section of the cave although it is likely that at least the lower part of Second Fissure was de-watered by 700 ky because of the proximity of the deposit of this age in the Grottos. Some clastic sedimentation prior to 38 ky is indicated near the Holes-in-the-Floor, by the flowstone currently forming a false floor (77036) in this area.

3) Significant vadose development by 350 ky is also indicated in the farther reaches of the cave, from the flowstone (77031) collected from the aven just upstream of the Big Room and the eroded flowstone (80025) in situ in the passage below the Crutch.

Summary and Conclusions

The results summarized in Table 2 and the paleomagnetic data, clearly demonstrate the antiquity of

Castleguard Cave, indicating that most of the cave was de-watered, entrenched by vadose streams, and had become a site of active speleothem deposition, over 350 ky, and in places over 700 ky ago. It is therefore likely that the main drainage of the area, which has abandoned the known cave for up to 700 ky or more, will be found in well-developed passages, at a lower level.

Acknowledgements

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Table 1. Sample descriptions, analytical data and $^{230}Th/^{234}U$ ages of speleothems from Castleguard Cave (from Harmon et al., 1977).

Speleothem number	Location and description	Analysis number	U con. (ppm)	$^{234}U/^{238}U$	$^{230}Th/^{232}Th$	$^{230}Th/^{234}U$	Age ± 1σ (ky)
73008	bulk sample of fs from deposit in First Fissure	-3	2.6	1.08	42	0.405	57 ± 2
73009	top layer of short sg from Camp I	-3	5.0	1.33	>1000	0.012	1 ± 0.5
	basal layer of same	-4	19.1	1.34	35	0.024	3 ± 0.2
73010	top layer of sg growing on eroded boss in Grottos	-7	2.5	1.09	26	0.58	92 ± 3
	basal layer of same	-6	2.5	0.08	159	0.75	147 ± 12
73011	bulk sample of edge of sg found loose at base of 80 feet pitch	-2	8.7	1.34	68	0.69	120 ± 6
80501	bulk straw sc from end of Holes-in-the-Floor	-1	3.3	1.54	17	0.05	6 ± 0.7
80502	bulk sc from Ice Passages	-1	15.4	0.82	>200	0.11	13 ± 1
80503	bulk sc from Pools	-1	2.4	1.65	>200	0.06	7 ± 0.6

fs = flowstone sg = stalagmite sc = stalactite

Table 2. Sample descriptions, analytical data and $^{230}Th/^{234}U$ ages of recent collections of speleothems from Castleguard Cave.

Speleothem number	Location and description	Analysis number	U conc. (ppm)	$^{234}U/^{238}U$	$^{230}Th/^{232}Th$	$^{230}Th/^{234}U$	Age ± 1σ (ky)
77031	base (?) of loose fs from bottom of aven upstream of Big Room	-1	4.16	1.036	330	0.964	332.0 +> 34.7 - 44.4
77032	base of loose 15cm long sg from bottom of 80 foot pitch	-1	2.62	1.401	202	1.080	>350
	top of same	-2	2.51	1.362	274	0.995	277.8 + 26.1 - 21.6
	duplicate of -2	-3	-	1.334	430	-	>350*
77033	top layer of youngest section of massive eroded sg in Grottos	B-1	1.96	1.065	105	0.982	>350
79014	approximately equivalent sample to 77033 B-1	B-1	2.34	1.067	61	1.019	>350
77034	top layer of huge eroded fs boss at Waterfall Chamber, First Fissure	A-1	1.07	1.117	33	1.007	>350
	base of same	F-1	1.66	1.057	35	1.066	>350
77035	base of large eroded sg boss in Second Fissure	-1	2.16	1.087	58	1.053	>350

Table 2 continued

Speleothem number	Location and description	Analysis number	U conc. (ppm)	$\frac{^{234}U}{^{238}U}$	$\frac{^{230}Th}{^{232}Th}$	$\frac{^{230}Th}{^{234}U}$	Age ± 1σ (ky)
77036	piece of 1.5cm thick fs forming false floor between Holes-in-Floor and Second Fissure (appears to overlie mud deposits)	-1	4.13	0.368	61	0.300	38.0 ± 1.5
77037	top layer of loose fs block in Helictite Passage, near 80'pitch	-1	1.90	1.172	>1000	0.107	>350
79011	base of 3cm thick veneer of fs apparently overlying mud deposits in First Fissure	-1	0.99	1.270	11	0.654	$109.3 \begin{smallmatrix} +3.6 \\ -3.5 \end{smallmatrix}$**
79012	top (?) layer of loose fs in floor of inlet into Helictite Passage	-1	1.34	1.102	635	0.916	$242.8 \begin{smallmatrix} +22.0 \\ -18.4 \end{smallmatrix}$
	basal layer of same	-2	1.52	1.075	116	1.027	>350
79016	top layer of 5cm thick false floor in Grottos, upstream of cave pearls pool (overlies most of mud deposits)	-1	1.03	1.221	19.1	0.759	$144.0 \begin{smallmatrix} +6.6 \\ -6.3 \end{smallmatrix}$
80024	piece of fs forming false floor in narrow passage below Big Room	-1	3.11	1.113	134	0.683	$121.1 \begin{smallmatrix} +6.2 \\ -5.8 \end{smallmatrix}$
80025	top layer of eroded fs boss in passage below Crutch	A-1	2.00	0.090	161	0.987	>350

* $^{231}Pa/^{230}Th$ date

** decreases to $99.5 \begin{smallmatrix} +4.0 \\ -3.9 \end{smallmatrix}$ if corrected for detrital thorium contamination using $(^{230}Th/^{232}Th)_o = 1.5$

fs = flowstone sg = stalagmite

Mathematic Simulation of "Thermic" Airflow in Complicated Dynamic Caves

Antonin Jancarik
Institute of Geology and Geotechnis, Prague

Abstract

There are three basic causes of airflow in dynamic caves: - different weight of air columns at different temperature (thermic airflow) - changes of air pressure in free atmosphere (baric airflow); - airflow in free atmosphere (dynamic airflow).

In this contribution a mathematic simulation of airflow generated by different weight of air columns at different temperatures (thermic airflow) is described. Air temperature in cave from heat balance of system "air-wall" is computed. The surface temperature of wall using this balance, changes of temperature in free atmosphere and geothermic gradient is computed. Friction forces are expressed by the aerodynamic resistance. For airflow nets aerodynamic modification of Kirchhofs laws are used. System of equations by a numerical integration is computed.

This model on caves of Koneprusy (Bohemian karst, Czechoslovakia) on a simulation of microclima before opening for public partly, for a simuation of microclima changes after opening a new entrance partly was aplicated.

Résumé

L'écoulement de l'air dans les cavernes dynamiques et causé par trois raisons fondamentales: - poids différent des colonnes de l'air à température différente (écoulement thermique); - changements de la pression de l'air dans l'atmosphère libre (écoulement barique); - l'écoulement de l'air dans l'atmosphère libre (écoulement dynamique).

On décrit le modelage mathématique des courants de l'air, provoques par le poids différent des colonnes d'air à températures différentes (écoulement thermique). La température dans la caverne (grotte) est calculée à partir du bilan thermique du système "air - taille". Pour les calculations de la température superficielle des tailles, on utilise le bilan mentionné, les changements de la température de surface et le gradient géothermique. Les forces de friction sont exprimées à l'aidede la résistance aérodynamique. Pour les points nodaux des courant de l'air, on utilise les modifications aérodynamiques des lois Kirchhoff. La solution du système de ces équations est réalisée par intégration numérique.

Le modèle décrit a été appliqué à la situation concrète des grottes de Koněprusy (Le karst bohémien, Tchécoslovaquie) pour le modelage des conditions climatiques avant l'ouverture des grottes pour le public et pour la calculation des changements du climat aprés l'ouverture envisagée d'un nouvel accès public.

Morphogenesis and Sedimentology in a Quebec Cave: The "Spéos de la Fée" (Matapedia)

Camille M. Ek
Université de Liège, Belgium

Abstract

The "Spéos de la Fée" has a total known length of 1000 ft. The main passage-way is a long "tube" dipping at 20°. The upper end of the tube is connected to open air by a 15 ft pit.

The cave study gives rise to two major problems. At first, the entrance pit now opens on to the open air, at its upper end, on a small hill: there is thus to-day no drainage area at all, and one can wonder how water and sediments could reach the entrance pit. Secondly, the sediments in the "tube" indicate a downward stream, but scallops on the wall show an upward current.

The sedimentological study gives the main outlines of a solution to these problems. The sediments are partly derived from a till and the cave was for the main part hollowed out before the end of the last glaciation.

Résumé

Le Spéos de la Fée a un développement total de 300 m. La galerie principale de la grotte est une longue conduite forcée cylindrique en forte pente qui s'ouvre à l'extérieur par un puits aboutissant à l'extrémité la plus élevée du "tube". Deux problèmes majeurs se posent lorsqu'on étudie la grotte: le puits s'ouvre à l'extérieur, à son extrémité supérieure, sur une petite éminence: son bassin d'alimentation potentiel est donc actuellement nul et on peut se demander comment l'eau et les sédiments l'ont envahi. D'autre part, si la conduite forcée est partiellement comblée de sédiments venus de la surface (et qui ont donc descendu la pente de la conduite), elle présente cependant des traces de longs coups de gouge indiquant que l'eau a jadis parcouru la galerie en remontant.

L'étude sédimentologique apporte une intéressante contribution à la solution de ces deux problémes. Les sédiments sont en partie dérivés de dépôts glaciaires et la grotte a donc été essentiellement creusée avant la fin de la dernière glaciation.

Introduction

The Appalachians form the southeastern part of Québec, and particularly the whole of Gaspe Peninsula. The "Spéos de la Fée" is located in this region, at La Rédemption, Co. Matapedia. This cave is the first one in Gaspe Peninsula to provide reworked glacial sediments (Ek, 1980).

The field study was supported by a generous grant from the Natural Sciences and Engineering Research Council Canada.

Geological Structure and Morphology of the Cave

The Lake Matapedia Syncline displays the Silurian Sayabec Formation, which is part of the Gaspe - Connecticut Valley Synclinorium (Heroux, 1975; Heroux, et al., 1977; Beaupre, 1980). The lower part of the formation includes mainly massive and stratified limestones and dolomites, and the upper part, mainly limestone nodules in a mudstone matrix.

The "Spéos de la Fée" is developed in this formation. It is a 1000 ft long, two-entrance cave. The geological structure is clearly expressed by the morphology of the cave: the main and most graded passage-way (the so called "galerie Ti-Panthé-Plante") is a tube dipping north at 20°, exactly as the bedding planes (see the map, fig. 1). The part of the cave which lies in the massive and stratified limestones is much better developed than the part lying in the nodular limestone; the latter part display cave breakdowns, gelifraction talus and a very irregular morphology.

Sedimentology

Various minor solution forms occur at the roof of the cave (roof pendants, etc.), indicating that almost the whole of it was at one time filled with sediments. In the "galerie Ti-Panthé-Plante", running water brought silt, sand and pebbles. In the northern part ("la Grande Allée"), deposits are predominantly clayey, and related to shallow-phreatic conditions. In the western part ("le Petit Spéos") frost shattered talus occur. Speleothems are generally small: they consist mainly of stalagmites, stalactites and curtains; but moonmilk is abundant. A stalactite was dated 7355 ± 190 by Cl. Hillaire-Marcel (UQ - 101).

Three sections were studied in greater detail in the "galerie Ti-Panthé-Plante", respectively at 110, 150 and 230 ft from the entrance shaft. At the three places, the material is mainly silt and sand, but includes pebbles at the top. These pebbles are bigger in the first section than in the second one, and in the second one than in the third one: the filling was thus coming from the entrance shaft; this is confirmed by the dip of internal bedding.

The lower layers, and particularly the layers n°2 and n°3 in each section, consist of well-sorted stratified silt and sand; 20 to 33% of the sand grains are angular polycrystalline (composite) grains, indicating the regional origin of an important part of the material; 30 to 50% of the sand grains are calcareous. Fine sediments consist thus of a partly regional material, settled in running water, in conditions where limestone solution was slow. Sedimentological analyses have shown that the same material is abundant in proglacial deposits outside the cave.

The upper layers are different; bed n°4, particularly, is a diamicton, including rolled pebbles in a poorly sorted matrix. Pebbles display a roundness index (following Cailleux) around 120; some of them are facetted and some display striae; more than one half of them consist of limestone or dolomite. All these features indicate a not much reworked till material.

Morphogenesis

The main passage of the cave (the "galerie Ti-Panthé-Plante") is a pressure flow tube whose dip is controlled by structure. Older stages of the history of the cave are not obvious.

The entrance shaft is younger: it cross-cuts the tube. The shaft now opens at the top of a 20 ft hillock; however at the time when sediments filled the tube, the shaft must have been in a depressed area. This can be explained in three ways:

1°) the shaft may have absorbed sediments before the last erosional phase, i.e. before the hill was etched into relief; this is not very likely, since some of the sediments of the cave were deposited at the end of the last glaciation;

2°) the filling may have occurred when the bedrock topography was as to-day, but covered by a thin glacier, split by the hillock and featuring there a "moulin" (glacier mill);

3°) the end of the last glaciation gave rise to thick proglacial deposits whose remnants are widespread in the basin of the Lake Matapedia Syncline: the filling can have occurred when the hillock was enveloped by these fluvio-glacial and lacustrine sediments, some of which are very similar to those observed in the cave.

Flutes on the walls of the tube are older than the filling, since some of them are still buried under the cave fill. These flutes clearly indicate an upward flow (Roberge, 1980); water was then rising from the cave.

After the filling of the tube, small-scale solution sculpture occurred on the roofs: meandering roof channels and rock pendants (see the map, fig. 1).

The northern and western parts of the cave display typical features of a very slowly moving groundwater: a succession of broad and narrow passages, sculptured in spongework and displaying clay as only detrital material. Thaw floods are still active to 30 ft above the bottom of the cave.

In the upper part of the cave, frost shattering is the present-day main process; it is very active near the western entrance, where limestone is nodular, and where frost action extends up to 100 ft from the entrance. Also still active to-day are the processes of water condensation on the walls and moonmilk formation.

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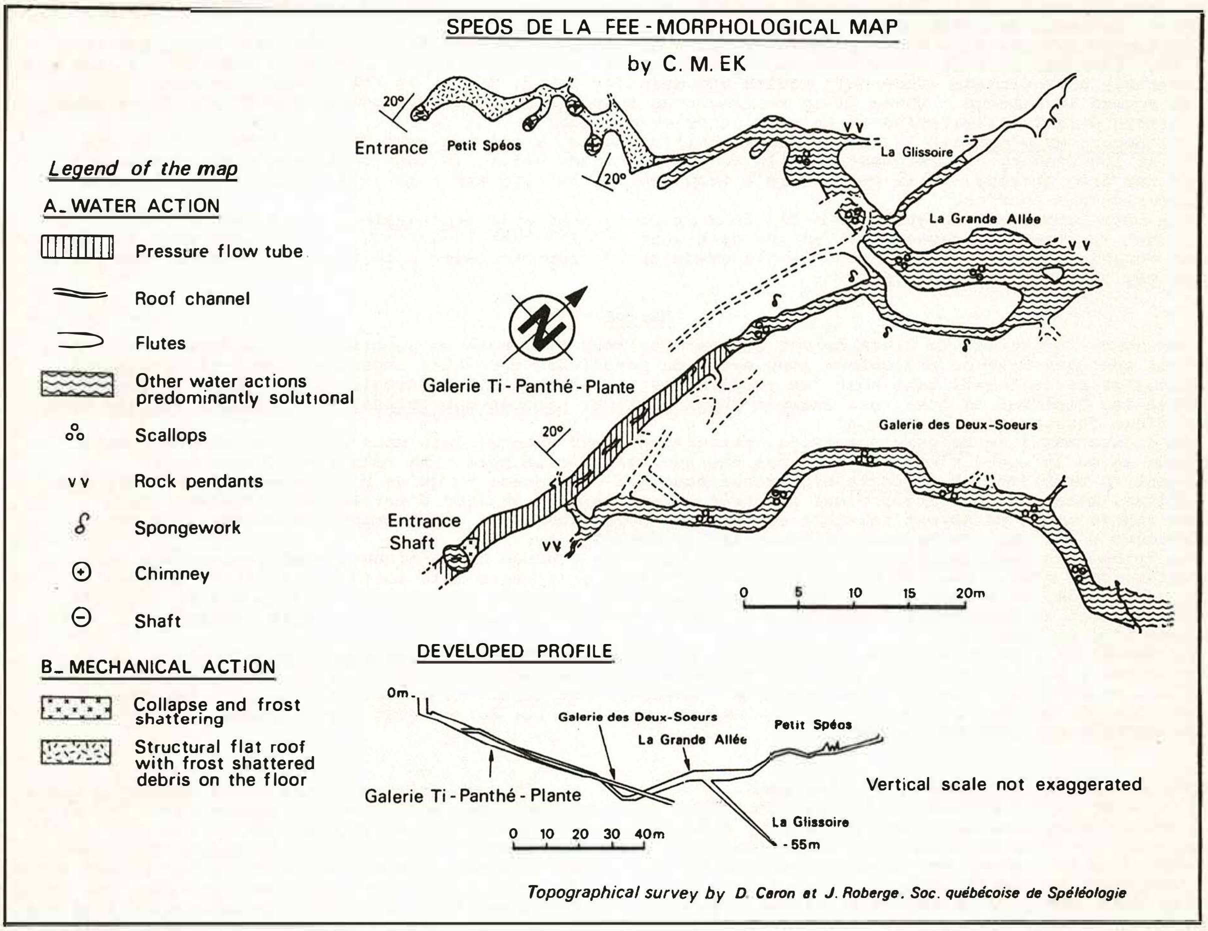

Figure 1. Morphological map of Speos de la Fee.

Diptera in British Caves

G. T. Jefferson
Department of Zoology, University College, P.O. Box 78, Cardiff, CF1 1XL, Great Britain

Abstract

Many species of Diptera have been recorded from British caves but only a few occur with sufficient regularity to be considered truly cavernicolous and these are either regular trogloxenes or troglophiles. In the cave threshold adult Diptera such as Culex pipiens, Limonia nubeculosa, and Heleomyze serrata form part of a 'parietal association'.

Heleomyza serrata also occurs, sometimes in considerable numbers, far into the dark zone, but only where the thickness of rock overburden is not very great. Such occurrences present a problem: H. serrata is presumably a trogloxene since only adults are normally found, but it is not markedly seasonal and its mode of access is unknown. These flies represent an appreciable input of organic matter but there seems to be little direct exploitation of this by other cave animals.

Trichocera maculipennis is widespread in British caves, sometimes even deep in them. Adults are usually at low density but oviposit readily on proteinaceous baits; in some caves the natural source of food is far from obvious. This species is a troglophile, as also are some sciarids and possibly some sphaerocerids and phorids.

The most completely cavernicolous fly in Britain is Speolepta leptogaster; it is rarely seen on the surface but is common in caves, both in the dark zone and the deep threshold. Adults show some variation in wing venation, but there is, here, little evidence to support claims either that the larvae are predatory or may have depigmented eyes.

Résumé

Bon nombre d'espèces de Diptères ont été enregistrées provenant de grottes britanniques mais seulement quelques-unes se présentent avec assez de régularité pour être regardées comme véritablement cavernicoloes et celles-ci sont soit des trogloxènes réguliers soit des troglophiles. Dans l'entrée de la grotte les Diptères adultes, par example Culex pipiens, Limonia nubeculosa, et Heleomyza serrata font partie d'une 'association pariétale'.

On trouve aussi le Heleomyza serrata, parfois en grand nombre, loin dans la région obscure, mais seulement là ou la roche n'est pas très épaisse au-dessus de la tête. De telles manifestations présentent un problème: H. serrata est probablement un trogloxène vu qu'on n'en trouve normalement que des adultes, mais son apparition n'est pas très saisonnière et sa mode d'entrée est inconnue. Ces mouches représentent un ~~apport sensible~~ de matières organiques muis apparemment les autres animaux cavernicoles n'en font pas beaucoup d'exploitation directe.

Le Trichocera maculipennis est fort répandu dans les grottes britanniques, même quelquefois dans les regions profondes. Les Adultes sont d'habitude à densité basse mais pondent volontiers sur les appâts protéiques; dans certaines grottes leur source naturelle de nourriture est loin d'être évidente. Cette espèce est un troglophile comme le sont aussi certaines Sciaridae et, peut-être, certaines Sphaeroceridae et Phoridae.

La mouche le plus complètement cavernicole en Grande-Bretagne est Speolepta leptogaster; on la voit très rarement à l'exterieur, mais elle est fréquente dans les grottes, tant dans la région obscure que dans l'entrée profonde. Les adultes présentent quelques variations de la nervation de l'aile, mais il y a, ici, peu de preuves a l'appui de l'affirmation soit que les larves sont carnassières soit qu'elles ont quelquefois les yeux dépigmentés.

Over 120 species of dipteran flies have been recorded from caves in the British Isles, but few of these occur underground with any great regularity and the vast majority can only be considered as accidentals. There are some, however, which are found in caves with sufficient frequency to appear truly cavernicolous although even these can only be ranked as either regular trogloxenes or as troglophiles; it is very doubtful whether any dipteran occurring in Britain can be considered to be troglobitic although at least one species comes close to it. Matile (1970) has published a comprehensive treatment of cave diptera with an extensive bibliography, and my intention in this paper is merely to review some of the British cavernicolous species and to discuss their status.

A 'parietal association' in the original sense in which Jeannel (1926) used the term can be recognized in British caves. This is an association of species, all either insects or arachnids, occurring on the walls of cave thresholds. The composition of the association changes with the seasons but several characteristic species can be recognized. Those occurring most regularly in Britain are two spiders, Meta menardi (Latreille) and Meta merianae (Scopoli), two moths, Triphosa dubitata (L.) and Scoliopteryx libatrix (L.), a trichopteran, Stenophylax permistus McLachlan, and three dipterans: the tipulid Limonia nubeculosa Meigen, the mosquito Culex pipiens L., and the heleomyzid Heleomyza serrata (L.).

The two spiders are present throughout the year, being threshold troglophiles, but the moths and the trichopteran are regular trogloxenes, the former overwintering underground and the latter apparently aestivating. The dipterans also differ in their seasonality: Culex pipiens is usually seen in caves in winter and Limonia nubeculosa in summer; both are regular trogloxenes, but the status of Heleomyza serrata which occurs underground throughout the year is doubtful and will be discussed shortly. Other dipterans which, although less common in British caves, also form part of the parietal association include the mycetophilid Rymosia fasciata (Meigen) and the sphaerocerids Copromyza nigra (Meigen) and Leptocera silvatica (Meigen).

In most British caving areas Heleomyza serrata is probably the most numerous component of the parietal association but is also occurs in the dark zone. It is not unusual to find adults in appreciable numbers - I have counted as many as twelve to the square metre of cave wall - far from any known entrance, but in my experience this is a reliable indication that the cave is running close to the surface at that point. They are never present in such numbers in those parts of the dark zone where the depth of rock overburden is at all great.

Since only adults are found, Heleomyza serrata would appear to be a trogloxene and those occurring far into the dark zone are presumably accidentals, although how they come to be there is far from clear. It may be that the larvae are coprophagous on the surface and burrow into the soil to pupate. Perhaps some drop into fissures with the possibility that the adults eventually emerging might find their way into any underlying cave. Unlike observers in some countries I have not found Heleomyza serrata in Bratain to be markedly seasonal in its appearance underground. Such a lack of seasonality might be taken to indicate that this species is troglophilic were it not for the fact that neither larvar nor puparia seem to be found in caves. A noticeable feature, also commented upon by Leruth (1939), is the considerable variation in size of the adults.

Whatever the means by which Heleomyza serrata may gain access to parts of the dark zone, many certainly die there and represent an appreciable input of organic matter into such parts of the cave. Their dead bodies, in various stages of fungal decomposition, are often numerous on the cave walls but, curiously, one sees very little evidence of this material being utilized directly as food by the cave fauna. Nevertheless the spores eventually produced and dispersed by the fungi must make some contribution to the organic detritus which is a major source of food for cave invertebrates.

Trichocera maculipennis (Meigen), one of the Trichoceridae or 'winter gnats' is widely distributed in British caves. It ~~occurs~~ in the dark zone and although generally more numerous in the shallower parts of cave systems, it can also be found at considerable depth. The adults are not usually very numerous, but if baits of animal protein, particularly rotting liver, are put down, these are often oviposited upon and yield large numbers of larvae which can be reared without difficulty. This is true of parts of caves which are otherwise devoid of abvious sources of suitable organic matter and it is not at all clear how, in the absence of artificially introduced food material, the populations manage to maintain themselves. Incidentally this is the species which Cabidoche (1968) found to have oviposited regularly on baits consisting of crusts of ewes'-milk cheese put down in the course of work on Aphaenops in La Verna, deep in the Pierre-Saint-Martin system.

Trichocera maculipennis is distinctly uncommon in surface habitats and there is little doubt that it is a troglophile. Some sciarids also maintain themselves underground and are troglophilic, but the specific identity of these is uncertain and further work on them is needed. The sphaerocerid Leptocera racovitzai (Bezzi) v. microps (Duda) has been recorded from a few caves in the more southerly parts of Britain where it may be a troglophile as it is in continnental Europe. Several phorids have been found in British caves and of these one, Triphleba antricola (Schmitz), is a common and widely distributed troglophile in Europe. It is, however, quite rare in Britain and there is little evidence that it is troglophilic here. Dr. R. H. L. Disney (personal communication) considers that Triphleba antricola is part of a complex group of forms and I understand that there is considerable doubt about the precise identity of the British records.

The mycetophilid Speolepta leptogaster (Winnertz) is both common and widely distributed in British caves and similar underground habitats; it occurs in both the dark zone and the deep threshold. The adults are rather short-lived and are seen less frequently than the larvae or even the pupae. Matile (1962), in a detailed account of the adult, has drawn attention to the curious variations which occur in the wing venation, particularly differences in the shape of the radial cell resulting from the variable position and length of the transverse vein which he labels R2+5. British specimens vary in much the same way, supporting Matile's view that this is not a case of geographical variation, and, as he also found, in an appreciable number of individuals the wing on one side differs from that on the other.

The glistening, transparent larvae of Speolepta leptogaster must be familiar to many cavers as the species seems to be distributed throughout much of the Holarctic region. In Britain they are most often seen on bare rock walls surrounded by a few filaments of webbing attached to irregularities of the rock, apparently in a more or less random fashion. The food of Speolepta leptogaster larvae has been the subject of much discussion; they have been said to feed on guano and there have been claims, among the more recent being one by Thinès and Tercafs (1972), that they are predatory. Most authors, however, have suggested that they feed on micro-organisms or general organic detritus and this accords with my observations. I have never seen any evidence to indicate that they are predatory and they certainly occur commonly in situations devoid of guano. Examination of gut contents is not very helpful although fungal spores can often be recognized. The larvae characteristically sweep the head from side to side over the rock surface in what appears to be a browsing action, and it seems likely that they feed on particles of organic detritus including the micro-organisms it contains.

It has sometimes been stated that the larvae of Speolepta leptogaster have depigmented ocelli (e.g. Leruth, 1030). This seems to have arisen from a misreading of Schmitz (1913) who, as far as I am aware, is the only person actually to have observed this. Of the many larvae examined he found just five devoid of eye pigment and a sixth with partial depigmentation; these were all collected on one day in 1909 near Maastricht. The only loss of pigment I have observed has been an artefact caused by certain procedures used in mounting the larvae, something specifically excluded by Schmitz. Presumable larvae with unpigmented eyes are mutant forms occurring very infrequently.

Speolepta leptogaster is usually considered to be a troglophile; adults have been found above ground but only rarely, and in the more northern parts of its range. This does not preclude the possibility of troglobitic status; it would have to be shown to breed in surface habitats for that. It is true that the usual troglobite modifications are absent, at least in the adult which is heavily pigmented and has well developed eyes, but whether an animal is troglobitic or not is strictly a matter of ecology, depending on where it occurs and not on morphology. Perhaps Speolepta leptogaster is a regional troglobite, being merely troglophilic in the more northerly parts of its range. Certainly in Britain it comes nearer to being a troglobite than any other of our limited number of cavernicolous dipterans.

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Choosing a Rope for SRT (Single Rope Techniques)

Mike Cowlishaw
Hilston, 29 Cleveland Walk, Bath, BA2 6JW England

Abstract

It is no longer intuitively obvious which ropes are safe for vertical caving; and with the introduction of ropes of composite construction, traditional measures of strength have become misleading.

The author has used practical testing, computer modeling, and other techniques to investigate the low-stretch performance, strength, and energy absorption of most of the ropes used for vertical caving around the world. Figures on nearly twenty different "speleo" ropes are presented, and the trade-offs between the safety and other desirable characteristics of caving ropes are discussed.

Also included are some practical suggestions on how the intelligent caver should choose his or her ropes, depending on the conditions under which they are to be used.

Résumé

Il n'est plus évident de déterminer quelles cordes sont sûre pour effectuer les descentes en spéléologie; d'autre part avec l'introduction de cordes composées de plusieurs matériaux, les mesures traditionelles de résistance deviennent trompeuses.

L'auteur à l'aide de testes practiques, de modèle sur ordinateur, et d'autre techniques a analyser l'élasticité, la résistance, et la résistance au choc de la plupart des cordes utilisées dans la monde pour les descentes en spéléologie. Les résultats d'environ 20 cordes différentes sont présentés, ainsi que les compromis entre sécurité et autres charactéristiques des cordes sont discustés.

Enfin l'auteur donne quelques suggestions practiques sur la façon dont le spéléologue intelligent doit choisir ses cordes, suivant les conditions dans lesquelles elles sont utilisées.

Introduction

Cavers have always taken the breaking force of a rope to be a guide to its strength and hence its suitability for use in caving. Over the last few years however, the introduction of very low stretch ropes and ropes composed of more than one type of fibre means that the breaking force is no longer a good measure, and indeed can be very misleading.

The highest stress in a rope will occur when the caver accidentally puts a shock load on a rope, for example by falling a short distance while attempting to leave the rope at the top of a prusik climb (Cowlishaw, 1977). In this event we must consider two aspects of rope safety: first, in the (small) falls possible in caving, the rope must not break; and second, in arresting such a fall the forces involved must not be so high that the caver attached to the rope is badly injured (or that his attachments to the rope fail).

These qualities are called the energy absorption which is a measure of the ropes ability to absorb the energy of a fall, and the peak force which is the highest force in the rope while the fall is being arrested.

My work over the last few years has shown that with the aid of a computer these figures may be estimated to an adequate accuracy from static tests of the ropes, and the results and conclusions are presented in the following sections.

I would like to take this opportunity to thank Arova (Switzerland), Bridon Fibres, and Marlow Ropes for carrying out many of the tests on which these results are based; and also my employers, IBM UK Laboratories, for the computer time for analyses.

The Energy Absorption of Speleo Ropes

The simplest useful measure which I have been able to devise to indicate the ability of a rope to absorb energy is the "shock strength". This is the amount of energy which can be absorbed by the rope before the force in it reaches one half of the breaking force. This allows some margin for reduction in the breaking force of the rope due to knots, water, mud, abrasion, or the cutting effect of a rope passing over rock. I have chosen the 50% point as a realistic figure, although there is some evidence (Kipp, 1977) to suggest that 30% might be a safer criteria.

The shock strength is a handy figure, since it may be divided by the weight of the caver (in Newtons; approximately kilogrammes multiplied by 10) to give the fall factor (severity of the fall) that will in the worst case produce the 50% breaking force. For example, if we have a rope with shock strength of 600 J/m, and a caver of mass 80kg, then dividing 600 by 800 gives a fall factor of 0.75. Thus a fall of 3 metres on to 4 metres of rope could produce a force which reaches half the breaking force.

I have also been able to calculate the worst case peak force for a number of ropes. This figure is quoted for a small fall which might be expected in caving, i.e. a fall factor of 0.75. Even with this mild fall it is surprisingly easy to achieve a very high force with many of the ropes listed in the table below. A suggested maximum figure for this is 12kN.

Fortunately, the figures obtained in practice will be rather lower than that shown in the table, as in small falls a significant amount of energy (30% ?) is absorbed by one's body and harness. Even so, the forces which can be realised with modern low stretch ropes can be very high, and could easily exceed 8kN (1760 lbf - over 3/4 of a ton). Therefore ascending/descending devices - and the way you are attached to the devices - should be at least this strong. Also of course the rope attachment point must be adequately strong: in most cases the only sensible way to try and ensure this is to backup every attachment. For increased safety, the slack should be kept to a minimum in the rope between the attachment points.

Since true climbing in caves could result in fall factors of 1.5 or higher, low stretch caving ropes must never be used for this purpose. The high forces resulting from a severe fall would surely break the rope or the caver.

Table 1

All tests refer to dry new ropes, and the columns have the following meanings:

- A - The breaking force in thousands of Newtons. Divide by 10 to get kg force, or by 4.55 to get pounds force. Note that there is little correlation between this figure and the others.
- B - The extension (stretch) under a force (load) of 80kg (160lb), measured according to the ISO draft specification (ISO, 1979).
- C - The shock strength in kiloJoules per metre. This is derived from the results of a static test by setting up a computer model for each rope. Anything over 400 J/m is adequate.
- D - The peak force expected for a small fall of F.F. 0.75. This figure includes an allowance for dynamic effects, but does not allow for energy absorption by body, harness, etc.

Rope type (Nylon unless stated)	A Break Force kN	B Extn. @80kg %	C Shock Strg. J/m	D Peak Force kN
11mm Typical climbing rope	25.00	5.0	1500	5.6
11mm Bluewater II	28.94	1.1	655	12.3
10mm Bridon staple polypropylene	14.71	3.1	517	7.3
10mm Bridon Super-Braidline	27.47	3.7	783	9.6
10mm Bridon Super-Braid polyster	18.15	2.7	282	12.4
11mm Bridon Viking nylon/kevlar	16.19	1.9	175	11.1
11mm Columbian R.C. Goldline	25.86	8.8	1386	5.3
10mm Downs polyster spin. sheet	27.27	1.5	607	12.1
10mm Edelrid Riverdry	25.51	4.8	910	7.4
11mm Edelrid Speleo Superstatic	30.90	3.1	917	9.6
10mm Edelweiss (Yellow)	23.05	2.6	904	7.3
10mm Edelrid Speleo Superstatic	25.19	2.8	706	9.9
11mm Interalp (1979 version)	26.70	1.2	698	10.1
10.5 Mammut Speleo	22.96	1.5	621	10.1
11mm Marlow SRT	28.25	0.9	434	14.6
10mm Marlow 16-plait matt	16.97	2.1	339	10.4
11mm Pigeon Mountain Industries	28.92	0.9	693	11.1

The Trade-Offs Between Safety and Other Characteristics

Clearly, shock strength and peak force are not the only characteristics to be considered when choosing a rope, although they are probably the most important. This section discusses most of the other characteristics, and their relationship to those described above.

Abrasion resistance: This is a very important characteristic, even though most cavers take care to minimise rope abrasion. A rope with a high resistance to abrasion should be chosen if possible, and Brian Smith's results (Smith, 1980) may be used for this comparison. In general, most of the ropes listed have an adequate resistance to abrasion, though 10mm ropes, and those ropes not designed specifically for caving, should be rigged with extra care.

Melting point: Nylon and polyester ropes have a melting point which is high enough for this not to be a big concern. However, a polypropylene ropes have a low melting point which means that they have a poor abrasion resistance (in dry conditions at least), and are more likely to fail when cut by an edge. It is possible, too, for a descender to reach a temperature which exceeds the meling point of polypropylene (Eavis, 1974). For these reasons, polypropylene ropes should only be used on short wet drops, and are perhaps best avoided altogether.

Resistance to chemicals: Nylon is affected by many chemicals, but especially acids. Polyester can be affected by strong alkalis. Polypropylene and Kevlar fibres are hardly affected at all by either acids or alkalis. A polyester or Nylon/Kevlar rope is probably preferable to a pure Nylon rope from this point of view.

Loss of strength with use: This is a largely unexplored subject, but there is some evidence to suggest that waterproofing treatment reduces the loss of strength with use (Smith, 1980). The only ropes listed above that are treated in this way are the Edelweiss and the Edelrid Riverdry. Intuitively, a tightly braided rope should help prevent deterioration, but there is as yet no conclusive evidence of this.

Sheath Slippage: This is not a significant problem once a rope has been washed or shrunk (Ramsden, 1977).

Stiffness: Very stiff ropes have grown to be fashionable recently, however a stiff rope only helps for the first few metres of climbing near the ground. It is always awkward to handle, and may lead to unsafe knots. All Nylon ropes get stiff with use, and PMI and the Bridon Viking ropes are especially unpleasant to handle. Polyester ropes do not appreciably stiffen up with use, and are to be preferred in this respect.

Stretch at low loads: A low stretch under body weight is highly desirable for prusiking up big pitches, and it is mainly this characteristic that identifies true epeleo ropes. However a low stretch tends to imply a low shock strength (see table), and this should be remembered. In many situations the need for increased safety must override the need for comfort and ease of prusiking. The figures shown in the table are from my tests on the ropes listed, all performed to the draft ISO standard for climbing ropes; It should be noted that the figures are for a dry rope: untreated Nylon ropes get much more stretchy when wet - as a rule of thumb, double the figure shown for these ropes. Polyester ropes are hardly affected by water: add about a third to the figures in the table to allow for wet conditions.

Spin: The three strand ropes (Goldline, polyproplene) spin unpleasantly if used on a free drop. None of the other ropes cause significant spin.

Weight: The lighest ropes are polypropylene, followed by Nylon and then polyester. In general, good polyester ropes are about 20-25% heavier than the equivalent Nylon ropes (Eavis, 1978). There are currently no waterproofed polyester ropes, though this would help in wet conditions.

Diameter: All of the ropes listed have a suitable diameter (i.e., less than 12mm). The thinnest ropes are more susceptible to damage, and are psychologically less reassuring. Thicker ropes tend to be heavy.

Cost: The ropes designed for cavers tend to be more expensive than more general purpose ropes, and imported ropes are more expensive anywhere. This will be relevant for many cavers - especially younger ones - but probably for most the cost of ropes is small compared to costs of transport and entertainment, and should not therefore be a major criteria.

How to Choose a Rope

No rope is perfect for all conditions, and in certain caves it may be necessary to take along several types. The choice of a rope will be governed by any or all of the factors mentioned in the last section, and by personal preference.

The following guidelines are presented as an opinion only, and are based on my experiences underground with most of the ropes discussed. Some cavers will (rightly) disagree with parts of this section.

For "wild" caving, big river caves, etc.: Choose a rope mainly for safety. Unless big or free drops are expected (see below) it takes a lot to beat a 3-strand climbing rope (e.g. Goldline); especially if there is likely to be any technical climbing involved. In general avoid Kernmantle climbing ropes, most are not designed to cope with the conditions experienced underground.

For big (deep) drops: Use a low stretch rope (e.g. Bluewater II, Marlow SRT, PMI, Interalp) for big drops: on damp or wet drops PMI or Marlow perform best. People naturally tend to be extra careful over big drops, so the safety of a rope is less important.

For drops of up to 30 metres in known caves (i.e. general vertical caving): Use any of the ropes with a shock strength greater than 400 J/m, according to personal preferences. In general avoid 3-strand, very stiff, or very thin ropes. Reliable ropes include Bluewater, Edelrid Superstatic, Marlow SRT, Mammut, and Edelweiss. Use a polyester rope if you want the best handling characteristics and/or you do many wet trips; but expect to have to carry extra weight and take care to minimise slack between attachment points.

For handlines, short traverse lines, etc.: Use a stretchy rope which is easy to handle: e.g. a 3-strand Nylon. Polypropylene is worth considering, being cheap and light, but be careful of abrasion and don't be tempted to use it for "real" pitches.

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On Some Cave Spiders From Papua-New Guines

Paolo Marcello Brignoli
Istituto di Zoologia dell'Universita, L'Aquila (Italy)

Abstract

Some general biogeographical considerations are made on the cave spiders of Papua-New Guinea and some neighbouring countries, based primarily on the material collected by Dr. P. Beron (Sofia, Bulgaria) during the British Speleological Expedition.

Introduction

In recent years our knowledge on the spiders living in tropical caves has greatly advanced, but still much has to be done in this field. The importance of this kind of research is considerable, not so much because of the large number of taxonomic and faunistic novelties that easily derive from it, but because of the problem of the existence, also in a tropical environment, or species adapted to a subterranean way of life.

For along time it was believed that the troglobites (blind or with reduced eyes, depigmented etc.) were limited to the termperate caves in which the conditions of life are, as a whole, harsh (principally through scarceness of trophic resources) and were derived from ancestors "pushed" in the caves by climatic changes influenced by the Pleistocene glaciations.

In a recent paper (Brignoli, 1980) I have exposed my own conclusions on this problem, but through lack of space, considered only the Paleartic species.

What we know on the spiders living in tropical caves (or, more exactly, in caves with a tropical climate) is still not enough for coming to any definitive conclusion; a considerable number of apparently adapted speices is already know (see my review of 1973, which is not more completely up-to-date) but most of these seem more soil-dwellers than true troglobites.

Still, a certain number of my conclusions in 1973 are supported by the examination of these New Guinean spiders: tropical caves have a characteristic spider fauna which is more or less the same (at family or even genus level) all over the world.

Review of the Examined Material

As my definitive taxonomic paper shall appear much later than the present article and as some minor problems must still be cleared (through examination of tyeps, etc.) I shall abstain from using specific names (which, as most of the material is formed by species new to science, would be nomina nuda).

The Beron-Chapman collection includes 43 species belongin to 15 families; for appreciating these numbers it may be noted that from the caves of Southern Mexico (Veracruz, Oaxaca, Chiapas, Tabasco, Campeche, Yucatan), which is probably the best explored tropical region, about 76 species of 19 families are known (Gertsch, 1971, 1973a, 1977; Brignoli, 1972a, 1974), but no less than 33 of these 76 species belong to the single family Pholcidae. Of a well explored not tropical country, as Italy, no less than 200 species of 30 families are known (Brignoli, 1972b, 1981b). From this it may be concluded that no tropical country is biospeleologically sufficiently explored.

A considerable number of arachnological papers of the period 1880-1910 has deal with New Guinea and the Bismarck Archipelago, but nothing at all was known of the cave spiders of this region; it is highly unfortunate that very little is known of the smaller spiders living on the ground, in the forest-litter and undergrowth. It is therefore exteremly difficult, if not impossible, to understand how many species of this collection are truly cavernicolous. Even five blind or microphthalmic species may be litter-dwellers.

For the reasons already exposed, I shall limit myself to list the collected families and to make a few general notes.

Fam. Dipluridae: two not adapted species, one from New Britian and another from New Guinea (a juvenile Masteria). This last genus (see Raven, 1979) includes few species living in litter and caves. Diplurids are not rare in tropical caves; some species are blind and may be troglobites.

Fam. Oonopidae: three blind or microphthalmic species, all from New Guinea; they belong to the probable cosmotropical genera Ischnothyreus and Opopaea. Many blind or microphthalmic Oonopids are known (Brignoli, 1973), but all are probably litter-dwellers or termitophiles.

Fam. Pholcidae: eight species of four genera were collected; in the caves of the Bismarck Archipelago were found only the common not cavernicolous Pholcus ancoralis (L. Koch, 1865) and a species apparently belonging to the poorly known genus Uthina (of which only three Oriental species were known. In New Guinea were found three species each of the genera Spermophora and Trichocyclus (?). Spermophora is a rather Ethiopian Oriental element, many African species are known from caves and, according to Gray (1973) also two Australian species are cavernicolous. Of the three collected species one (represented unfortunately only by a juvenile) is blind. From my experience the Spermophora are quite common in the tropics on the undergrowth of well preserved forests. What I call Trichocyclus (a poorly known genus, of which only one Australian species was known) is probably identical with the Psilochorus or Physocyclus of the other authors; many individuals of each of the three species were collected in different caves, it can be therefore concluded that members of this genus are normal components of the cavernicolous communities of New Guinea.

Fam. Araneidae: two closely related species of a genus still not identified were found in some caves of New Guinea and New Britian; until now no species of this family (from which I separate the Metidae) may be considered troglophilous.

Fam. Metidae: two closely related species of a genus provisionally identified with the exclusively Oriental Neoprolochus were found in many caves of the Bismarck Archipelago and a few of New Guinea; to this family belong Meta and Metellina which are quite common in the European caves, Gray (1973) noted the presence of some unmodified Orsinome in Australian caves. The finding of comparatively large orb-web builders in this region is quite interesting as until now no species of this group had been recorded from tropical caves.

Fam. Linyphiidae: in tropical caves species of this family (very common in the Holartic caves) are quite rare; of the two individuals collected in New Guinea one is somewhat similar to an Erigone described from a cave in Hawaii (Gertsch, 1973b) and the other belongs to the Nynogleninae which, until now, were known for sure only from Africa and New Zealand (Blest, 1979). The family was practically unknown from New Guinea, but I am fairly sure that this is only due to insufficient field-work.

Fam. Theridiosomatidae: in some New Guinean caves a species related to the Australian Theridiosoma brauni(Wunderlich, 1976)was found; many not adapted species of this group have been found in recent years in tropical caves probably by chance as, from my own experience, members of this family (including small and not brightly coloured species) are very common on forest undergrowth.

Fam. Mimetidae: two closely related species from New Guinea, of a possibly undescribed genus. Juding from recent findings in caves of Ceylong and Indonesia (Brignoli, 1972c, 1981d) species of this curious group, including spider-eating spiders, are relatively easy to find in tropical caves (see also Gray, 1973, about their presence in Australia). As the Spermophora and Theridiosomatidae, also the Mimetidae may be captured by beating the forest undergrowth.

Fam. Nesticidae: no less than six closely related species were found (three each of the Bismarch Archipelago and New Guinea); all belong to the Oriental-Austral genus Nesticella (Lehtinen & Saaristo, 1980) of which, very recently, some species have been described from Papua-New Guinea. Until a few years ago this group was considered typical of caves (and especially of those of the Holartic region); in recent times it has been discovered that it is quite common in the forest-litter of many tropical countries.

Fam. Theridiidae: four species of the genera Argyrodes, Achaearanea and Theridion were collected (some also in more than one cave). Our knowledge on the Oriental and Austral species of these large genera is too poor to come to any conclusions. As a whole, very few Theridiids are in some way linked with caves; some Steatoda, Robertus and Achaearanea are troglophies and probably more species of these (and other) genera shall have to be included in this category.

Fam. Gnaphosidae: two species from New Guinea, one of a genus unknown to me (apparently only by chance captured in a cave) and another, blind, of a possibly undescribed genus of the "Prodidominae" (represented unfortunately only by a juvenile). To this last group belong mostely deserticolous (?) species but a few (even blind or microphthalmic) have been found in forest litter, termites' nests or even caves (Platnick & Shadab, 1976). As in the case of the Oonopids, also these species are probably no true troglobites.

Fam. Eusparassidae: many juveniles and a single adult (of a genus unknown to me) of this group including large, wandering species living on trees and vegetation were found in New Guinean caves. No troglobites of this family are known until now; their frequent presence in tropical caves (see also Gray, 1973) may bring to consider some species as troglophiles.

Fam. Agelenidae: a single specimen from a New Guinea, belonging apparently to Orepukia, until now believed endemic of New Zealand (Forester & Wilton, 1973). Species of this family (sometimes even adapted) are common in Holartic caves, but are quite rare in tropical caves.

Fam. Stiphidiidae: some specimen of a large Cambridgea from New Ireland (a genus known until now only from New Zealand and New Caledonia); of this small, exclusively Austral group, a few cavernicolous (also adapted) species are known, from Australia and New Zealand.

Fam. Desidae: three species, probably of Badumna (a poorly known Oriental and Austral genus) from New Guinea and New Ireland; some species of this group, morphologically somewhat recalling the Amaurobiidae common in the Holartic caves, are known from Australian caves (Gray, 1973).

Fam. Uloboridae: three species of three (?) genera from New Guinea and New Ireland; one belongs certainly to a typically Austral genus (Daramulunia). Not adapted species of this widespread family are rather common in tropical caves.

Biogeographical Conclusions

As could be expected, the cave spiders of New Guinea and of the Bismarck Archipelago are a mixture of Oriental and Austral elements (with perhaps a certain predominance of the second group).

Most of the species seem both to fit in already described genera (not endemic) and to be new to science (probably endemic). This points to an ancient territorial connection with the Oriental region and with Australia and to a successive, comparatively recent separation.

The three investigated areas in New Guinea (in the Western, West Sepik and Chimbu provinces) are faunistically rather similar at generical but not at specifical level. Only one species seems to be present in two of these areas, but most of the genera including the commonest cave spiders are known from all three areas.

New Britain and New Ireland have a cave spider fauna; this would not be surprizing in the case of the presence of a large number of troglobites, but most of the examined species are simple troglobites or have been captured in caves purely by chance. This diversity could be attributed to insufficient collections, but it must be noted that in the cases of no less than five genera common to two or more areas, all congeneric species were apparently allopatric.

Until now, judging by what is known on few well-studied families of tropical spiders (as the Theridiidae and some Araneidae), it seemed that most tropical species were quite widely distributed; the apparently limited range of these New Guinean spiders and of many (not adapted) Southern Mexican cave spiders justifies the supposition that what is true for the larger forms living on vegetation is not true for all spiders.

Very remarkable is the finding in Papua-New Guinea of some species related to groups believed "typical" of New Zealand; still, we know too little on the spiders of Australia, where the "missing links" may well exist.

It is still too early to appreciate the value of the proposal of Lehtinen (1980), of abandoning the traditional Oriental and Austral regions in vafour of an Indo-Pacific and a South Gonduanian region, but I would like to observe that, if it is probably possible to accept the limited value of Wallace's and Weber's lines for spiders, I do not see avery definite border between the two new regions proposed by Lehtinen.

Biospeleological Conclusions

No cave spider of New Guinea, with the possible exception of the blind Spermophora, is similar to the classical Holartic troglobites. The species with reduced eyes are on the other hand similar to many litter-dwelling species of other tropical countries.

This evidently does not mean at all that there are no "true cave-spiders" in New Guinea; it means simply that there are none adapted in the way we consider typical of a troglobite. The equation "blind = troglobite" has a limited value in my opinion. Metabolic changes (on which we know still very little) may be more important than blindness.

New Guinea has a richer cave spider fauna than the Bismarck Archipelago, which is demonstrated by the presence of only 9 (against 15) families found in these last islands. This fact may be interpretated in many different ways, but the most obvious explanation is the different age and size of these islands.

If we compare the Beron-Chapman collection with the Australian cave-fauna, we can observe that, according to Gray (1973), Australia has a rather similar fauna, but richer (90 species of 23 families) and that some groups, present in Australia, are lacking in New Guinean caves (as the Gradungulidae, Hickmaniidae, Miturgidae, Textricellidae, etc.).

The Hawaiian cave spider fauna (Gertsch, 1973b) on the other hand, is much poorer in species (20 of 14 families) hand has apparently very little in common with that of New Guinea.

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Deep Ice in the Cave of Scarasson, Marguareis Massif, Haritimes, Italia

Michel Siffre
34 Rue Trachel, Nice 06000, FRANCE

Abstract

Thirty meters deep stratified ice has been found between 100 and 130 meters of depth in an alpine cave, the "gouffre du Scarasson".

Ice taken from a bore-hole has been analyzed cristallographically and electrically, by means of pollens and deuterium analysis, in order to discover its age and origin. Analysis of radioactivity and C14 analysis has failed.

A list of pollens is given. 018/016 shows values almost identical to those found in bore-holes made by U.S. and French scientists in Antartica, indication that this glacier is possibly a relic.

Observations made in 1962, 1963, and cave discoveries made in 1976 and 1979 has shown definitely how fresh snow can accumulate to this depth and can be kept under 0°C.

Résumé

Le gouffre du Scarasson, à 2,050 métres d'altitude, posséde, entre 100 et 130 métres de profondeur, une masse importante de glace stratifée une carotte de glace et divers prélévements ont été exécutés sur les deux fronts principaux de fusion. La glace a été analysée par deux glaciologues réputés aux points de vue cristallographique, électrique, palynologique dans l'espoir de découvrir son âge et son origine. Les analyses du Deuterium montrent des valeurs trés proches de celles observées par les glaciologues dans les forages récents de l'Antartique indiquant par là que le glacier souterrain est peut-être une relique fossile. Des observations faites depuis 1962 et de nouvelles découvertes spéléologiques réalisées en 1976 et 1979 ont permis de comprendre comment la neige pouvait s'accumuler à si grande profondeur et se maintenir en dessous de zéro.

Long-Term Single Free-Run Experiments and Their Results as a Performance Predictability Index in Astronauts

Michel Siffre
34 Rue Trachel, Nice 06000, FRANCE

Abstract

During one decade the Institut Francais de Speleologie has conducted some of the longest and most sophisticated human biological studies made in a constant environment known as "free-run" or beyond time experiments. Caves have been chosen, for their constant climatic environment, in France and The U.S.A. (Texas). These experiments have been conducted under the supervision of top U.S. and French scientists belonging to universities, or military, space, or atomic agencies and working in the field of sleep, biological rhythms, performance, vision and time. Some of the results are the following:

1. Living beyond time in caves induces in man a 48 hour sleep-wakefulness rhythm with the following distribution: 34-36 hours of continuous activity without undue fatigue for only 12-14hours of natural sleep.
2. The quality of the sleep has been studied by 3,000 hours of electroencephalography recording allowing us to study the restoring value of the various sleep stages (REMS,S_4, S_{1-2-3}).
3. Quantitative evaluation of phsyco-motor performance has been made during circadian ($T \simeq 24$ hours) and bi-circadian ($T \simeq 48$ hours) rhythms.
4. Intensive computer analyses in the biological and psychological functions have been made authorizing us to predict in any human, following his or her duration of sleep and his or her amount of the rapid eye movement stage (REMs), the quality of performance (reaction time) the following day.

Résumé

Pendant dix ans, l'Institut Francais de Spéléologie a réalisé sur l'homme quelques unes des plus longues et plus sophistiquées expériences en librecours en milieu constant. Les expériences ont été supervisées par des scientifiques de haut niveau, francais et américains, appartenant à l'Université et aux organismes de recherche militaire, spatiable et atomique. Les cavernes ont été choisies pour leurs conditions climatologiques constantes. Parmi les résultats et études exécutées, on peut citer:

1. La vie en libre-cours induit chex l'homme un rythme veille-sommeil de 48 heures faisant alterner 34-35 heures d'activité continue à 12-14 heures de sommeil.
2. La qualité du sommeil a été étudiée grâce à l'enregistrement de 3.000 heures d'enregistrements électroencéphalographiques. Nous avons pu ainsi contrôler la valeur restoratrico des différents stades de sommeil (Réve, Sommeil 4, Sommeil 1-2-3).
3. L'écaluation quantitative des performances psychosensorielles et psycho-motrices a été etudiée lors des rhythmes circadiens ($T \simeq 24$ hrs) et bi-circadiens ($T \simeq 48$ hrs) de l'organisme.
4. Des analyses intensives sur ordinateur ont été exécutées sur les fonctions biologiques et psychophysiologiques. Nous pensons être capables de prédire la qualité des performances psychomotrices d'un individu en fonction de ses différents stades de sommeil, en particulier en fonction de la durée et du rythme du sommeil paradoxal (REMs).

Mondmilch (Moonmilk): Two Questions of Terminology

R. Bernasconi
CH-3053 Münchenbuchsee, Switzerland

Abstract

For all subterranean two-phases-systems, of which the solid phase is either a chemical deposit or a detrital deposit of white colour and of which the liquid phase is water, a new general term "plastic white mass" is suggested.

It is proposed that the historical term "Mondmilch" (moonmilk) be no longer used to indicate a facies and that it be reserved to plastic white masses of which the solid phase is composed of a minimum of 90% mineralogically verified calcite.

The second question regards the term lublinite used to describe the solid phase of calcitic moonmilk. This term should be either abandoned or newly defined.

Résumé

Pout tout système à deux phases souterrain, dont la phase solide est soit un dépôt chimique, soit un dépôt détritique de couleur blanche et dont la phase liquide est de l'eau, on propose un nouveau terme général, soit "masse blanche plastique". On propose que le terme historique "Mondmilch" (lait de lune) ne soit plus employé pour désigner un faciès et qu'il soit réservé aux masses blanches plastiques dont la phase solide est formée d'au moins 90% de calcite identifiée minéralogiquement.

Le deuxième question concerne le terme de lublinite utilisé pour désigner la phase solide du mondmilch calcitique. Ce terme devrait soit être abandonné soit être redéfini de manière précise.

The first question to be treated here is the term of mondmilch itself. The term "lac lunae = mondmilch" (Gessner, 1555) (moonmilk) relates etymologically and historically (Bernasconi, 1959; Heller, 1966) to two-phase systems consisting of water and calcite in subterranean cavities. This was verified and documented by numerous authors (Geze et al., 1956; Gradzinski, and Radomski, 1957; Baron et al., 1959; Melon and Bourguignon, 1962; Geze and Pobeguin, 1962; Thrailkill, 1963; Lis and Stepniewski, 1967; Habe, 1970; Mattioli, 1970; Tintilozov et al., 1974; Rajman and Roda, 1974; Bernasconi, 1975; Maalev and Philipov, 1975; Keupper and Niggli, 1976; Harman and Derco, 1976; Coase, 1977).

After Geze (Geze, 1961; Geze and Pobeguin, 1962) had interpreted the term "mondmilch" as a facies, numerous subterranean two-phase systems have been described, their solid phase being of chemical or detrital origin and composed of different minerals belonging to carbonates, sulphates, phosphates, silicates (see Appendix 1). This is confusing.

It is recommendable to use from now on the new term "white plastic masses" for all moonmilklike subterranean deposits. This term includes all two-phase systems where the solid phase is ~~either~~ a chemical or a detrital deposit - colored clay deposits being excluded - and the liquid phase is water. Roda and Rajman (1976) proposed the term "soft sinter" for calcitic moonmilk; however the sense of this term is too restricted and is only suitable for chemical deposits. The historical term of "mondmilch" (moonmilk) should no longer be used as facies, but should be reserved for white plastic masses the solid phase of which is composed of at least 90% mineralogically identified calcite.

The second question concerns the term "lublinite". Iwanoff discovered in 1905 a new type of calcium carbonate, in the shape of mould or cottonwool between joints and fissures of little cavities in Paleocene marly rocks near Nowo-Alexandria (=Pulawy). This mineral was examined and described by Iwanoff (1906) and Tschirwinsky (1906), then by Opolski (1921). Iwanoff interpreted it as a hydrocarbonate, Lang (1914, 1915) as a new monocline modification of calcium carbonate.

Morozewicz (1907, 1911) named this mineral "lublinite" with regard to its origin (government of Lublin) and interpreted it as a calcite of which the rhomboedron was elongated in the direction of the pole edge, forming a felt of thin needles and fibres able to imbibe water. This interpretation was confirmed by crystallization experiments by Thugutt (1929) and by X-ray diffractometry by Mizgier (1929).

Other authors (Quercigh, 1921; Pelisek, 1944) characterized lublinite found particularly in cretaceous rocks as a fibrous variety of calcite. Table 1 recapitulates the characteristics of original lublinite.

First Kristafowitsch (1906), then Morozewicz (1907) thought that mondmilch (moonmilk) or Bergmilch (mleko gornego) was identical with lublinite and Muegge (1914) described as lublinite a moonmilk-deposit found in a cave near Brno. Table 2 recapitulates the characteristics of lublinite in the shape of moonmilk according to various authors.

Table 1. Original lublinite from government of Lublin

Author	Morphology Type (See Appendix 2)	Genesis Type (See Appendix 3)
Iwanoff, 1906 (*)	b + c	1
Tschirwinsky, 1906 (*)	b + c + h	1
Morozewicz, 1907 (**)	b + c	1
Opolski, 1921	b + c	1

(*) samples from Gora Pulawski
(**) samples from Wyskoie

Table 2. Presence of lublinite in calcitic moonmilk

Author	Morphology Type (See Appendix 2)	Genesis Type (See Appendix 3)
Muegge, 1914	b + c + g	5
Balogh, 1956	(b + c ?)	?
Gradzinski and Radomski, 1957	a + b	2.1.
Melon and Bourguignon, 1962	a	2.1.
Broughton, 1972a	f	3.2.
Stoops, 1976 (*)	i	?
Coase, 1977	d (or f)	2.2.
Urbani, 1977a (*)	i	2.1.

(*) cauliflower samples

In consideration of
- the great variety of calcite crystal forms - especially of the fibrous ones - which constitute the solid phase of calcitic moonmilk and can coexist in the same sample (see Appendix 2),
- the great variety of possible genesis and juxtaposition of genesis in the same sample (see Appendix 3),
- the actual uncertainty about correlation between genesis type and crystal type (e.g. type b/1; g/5),
- the incomplete knowledge on the crystal growth of calcite (Cser and Fejerdy, 1965; Reddy and Nancollas, 1971),
- the fact that only crystal types b + c associated with the genesis type 1 can be identified with reliable certainty with the original lublinite,
- the fact that interpretations of lublinite made later than Morozewicz differ more and more from the original description (see Tables 1 and 2),

- the fact that formerly Geze (1961) thought that it is of no interest to maintain and utilize the term lublinite,

we propose that the term lublinite will not be used any longer in relation with calcitic moonmilk and that it will be definitively abolished.

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<u>Appendix 1: Minerals which form the solid phase of white plastic (moonmilk-like) masses other than calcitic moonmilk</u>

1. <u>Carbonates</u> (often associated with calcite)

Aragonite	:Geze, 1961; Geze and Pobeguin, 1962; Fischbeck and Mueller, 1971; Thrailkill, 1971; Novak, 1974; Diaconu *et al.*, 1977
Hydromagnesite	:Geze, 1955; Geze *et al.*, 1956; Davies and Moore, 1957; Baron *et al.*, 1959; Balconi and Giuseppetti, 1959; Halliday, 1961; Geze and Pobeguin, 1962; Fischbeck and Mueller, 1971; Thrailkill, 1971; Broughton, 1972a, 1974; Rogers and Moore, 1976; Diaconu *et al.*, 1977
Magnesite (Giobertite)	:Pobeguin, 1960; Broughton, 1972a
Nesquehonite	:Geze, 1955; Fischbeck and Mueller, 1971; Broughton, 1972a
Huntite	:Baron *et al.*, 1957, 1959; Geze, 1961; Geze and Pobeguin, 1962; Thrailkill, 1971; Broughton, 1972a; Rogers and Moore, 1976; Diaconu *et al.*, 1977
Dolomite, Protodolomite	:Pobeguin, 1960; Geze, 1961; Moore, 1961; Fischbeck and Mueller, 1971; Broughton, 1972a, 1974; Rogers and Moore, 1976; Urbani, 1977b

2. <u>Sulphates</u>

Gypsum	:Diaconu, 1974; Rogers and Moore, 1976; Urbani, 1977b, associated with dolomite; Calandri, 1979

3. Phosphates

Brushite, Monetite	:Sztrokay, 1959
tri-Calcium phosphate	:Baron et al., 1959, associated with calcium carbonate
Calcium phosphocarbonate	:Geze and Pobeguin, 1962
Aluminium and Calcium phosphate	:Minieri, 1957; Geze, 1961: minervite

4. Silicates

Palygorskite	:Schneider, 1975/Empa, 1973, associated with calcite
Quartz	:Rogers and Moore, 1976, doubtful
Kaolinite	:Urbani, 1977b, associated with calcite and quartz
Muscovite	:Bernasconi, 1980

Appendix 2: Types of crystals which form the solid phase of calcitic moonmilk
Author = with figures

(a) macro-lamellae and lamellar rods 20 to 300 x 4 to 30 x 0,5 to 4/um	:Rose, 1856; Gradzinski and Radomski, 1957; Baron et al., 1959; Melon and Bourguignon, 1962; Bernasconi, 1975; Kuepfer and Niggli, 1976; Coase, 1977
(b) macro-needles and prismatic rods 20 to 300 x 1 to 3/um	:Rose, 1956; Muegge, 1914; Gradzinski and Radomski, 1957; Melon and Bourguignon, 1962; Hock, 1962; Bernasconi, 1975; Bonzano et al., 1980
(c) macro-fibres (filamentary rods) ≤ 1000 x 1 to 3/um	:Rose, 1856; Meugge, 1914; Gradzinski and Radomski, 1957; Baron et al., 1959; Melon and Bourguignon, 1962; Maalev and Philipov, 1975; Bernasconi, 1975
(d) micro-lamellae and lamellar rods 2 to 30 x 0,5 to 6 x ≤ 1/um	:Gradzinski and Radomski, 1957; Rajman and Roda, 1974; Coase, 1977
(e) isodiametrical microcrystals 1 to 10 x 1 to 10/um	:Rose, 1856; Gradzinski and Radomski, 1957; Geze, 1961; Ohde and Takii, 1978
(f) micro-needles and prismatic rods 2 to 30 x 0,2 to 2/um	:Rose, 1856; Baron et al., 1959; Broughton, 1972a; Rajman and Roda, 1974; Harman and Derco, 1976; Kuepfer and Niggli, 1976; Urbani, 1977a; (Coase, 1977 ?)
(g) micro-fibres ≤ 30 x 0,03 to 0,3/um	:Muegge, 1914; Habe, 1970; Rogers and Moore, 1976; Moore and Sullivan, 1977; Coase, 1977; Billy and Blanc, 1979
(h) rods sensu latu with serrated edges or surfaces with ± diagonal structure (owing to secondary crystallization, recrystallization or deposit of colloidal clay)	:Rose, 1856; Rajman and Roda, 1974; Maalev and Philipov, 1975; Harman and Derco, 1976; Moore and Sullivan, 1977; Coase, 1977; Urbani, 1977a; Billy and Blanc, 1979
(i) rods sensu latu stepped (en échelons) (owing to juxtaposition ~~of microcrystals~~ or to corrosion)	:Stoops, 1976; Rogers and Moore, 1976; Moore and Sullivan, 1977; (Coase, 1977 ?); Urbani, 1977a; Billy and Blanc, 1979
(k) particular forms (triangles, lamellae terminating in a needle; dendrites)	:Broughton, 1972a; Harman and Derco, 1976; Billy and Blanc, 1979

Appendix 3: Types of possible genesis of the solid phase of calcitic moonmilk

1. Slow crystallization of evaporation or cooling of a calcium bicarbonate solution, frequent in caverneous masses (geodes) (Geze, 1961; Geze and Pobeguin, 1962; Melon and Bourguignon, 1962; Bernasconi, 1975; Bonzano et al., 1980). A low temperature may bring about the elongation of the principal axis of calcite crystals (Koenigsberger, 1926) and the degree of saturation of the solution may determine the crystal variety (Pobeguin, 1955).
2. Precipitation in a calcium bicarbonate solution, either by exceeding the solubility product or by fall of CO_2 partial pressure;
2.1. the ions are the result of classical karst corrosion (limestone + water + CO_2) (Gradzinski and Radomski, 1957; Bernasconi, 1961; Melon and Bourguignon, 1962; Mattioli, 1970; Rajman and Roda, 1974; Diaconu, 1976; Urbani, 1977a);
2.2. the ions are the result of metabolism of microorganisms, e.g. reaction of ammoniac and CO_2 on calcium (Pochon et al., 1964; Billy et al., 1979); particularly of Macromonas bipunctata (Mason-Williams, 1959, 1961); of ammonifying microorganisms (Pochon et al., 1964; Jaton et al., 1966); of heterotrophic nitrifying microorganisms (Ohde and Takii, 1978); of Bacillus brevis (Billy et al., 1979).
2.3. the ions are the result of biochemical corrosion of sinter and rock by organic acids produced by microorganisms such as Cyanophyceae (Hoeg, 1946), Perabacterium spelei (Caumartin, 1957; Caumartin and Renault, 1958) Actinomycetes and Algae (Broughton, 1972a, 1974).
3. Corrosion of sinter and rock
3.1. Inorganic process by aggressive water and by classical reaction of karstic corrosion (Trimmel, 1962; Diaconu, 1976)
3.2. Organic (biochemical) process by organic acids produced by microorganisms such as Perabacterium spelei (Caumartin and Renault, 1958).
4. Paramorphoses on aragonite (Rose, 1856; Harmon and Derco, 1976; Urbani, 1977a).
5. Pseudomorphoses on mycelia of Fungi, on filaments of Algae or Bacteria, on chains of Bacteria (Muegge, 1914; Ulrich, 1938; Rogers and Moore, 1976; Moore and Sullivan, 1977; Billy and Blanc, 1979).
6. Particular mechanisms:
6.1. Crystallizations, such as secondary crystallizations on monocrystalline needles (Harmon and Derco, 1976; Billy and Blanc, 1979); screw dislocation growth (Maalev and Philipov, 1975); whisker crystals growth (Kuepfer and Niggli, 1976); juxtaposition of microcrystals giving stepped polycrystals (Stoops, 1976; Urbani, 1977a); twin-growth of needles (Gradzinski and Radomski, 1957; Bonzano et al., 1980); formation of dendrites (Melon and Bourguignon, 1962; Broughton, 1972a; Harman and Derco, 1976);
6.2. Partial isomorphoses, such as partial substitution of calcium by magnesium (Geze et al., 1956; Broughton, 1974; Novak, 1964); partial substitution of carbonate by hydrocarbonate $(OH)_2CO_3$ (Lis and Stepniewski, 1967); partial substitution of carbonate by phosphate (Billy and Blanc, 1979);
6.3. Formation or transformation of hydrated calcite, such as hydrocalcite and ice (Trombe, 1952), monohydrocalcite (Fischbeck and Mueller, 1971; Broughton, 1972b); tri- and pentahydrocalcites (= lublinite ?) (Novak, 1974).

Karst Drainage Patterns in the Quatsino Limestone, Northern Vancouver Island, Canada

Paul Mills
Department of Geography, McMaster University, Hamilton, Ontario, Canada

Abstract

Karst drainage patterns in the steeply dipping and massively bedded Quatsino Limestone are controlled by the framework of structural pathways available to route groundwater. Allongenic stream sinks are concentrated only along one side of the valley, where the hydraulic gradient is roughly concordant with the stratal dip. The dip exceeds the topographic gradient in most situations and sinking waters utilize joints to move upwards stratigraphically or along the strike to their outlets. Separation between springs discharging allogenic waters and springs discharging autochthonous infiltration is made by consideration of their topographic position. The ability of this classification to separate different waters was affirmed by statistical analysis of spring chemical data.

Résumé

Dans le calcaire Quatsino fortement incliné et massivement stratifié, les réseaux de drainage karstiques sont controllés par l'ensemble de voies structurales disponibles au cheminement des eaux souterraines. Les trous d'infiltrations de ruisseaux allogènes sont concentrés seulement le long d'un des côtés de la vallée, là où la pente hydraulique concorde à peu près avec le pendage stratal. Le pendage excède la pente topographique dans la plupart des cas et les eaux qui s'infiltrent utilisent des fissures pour remonter stratigraphiquement ou le long de diaclases longitudinales vers leur sortie. On a séparé les sources déversant des eaux allogènes et les sources déversant des infiltrations autochtones en considérant leur position topographique. La capacité de cette classification de séparer différentes eaux a été confirmée par une analyse statistique de données chimiques provenant des sources.

Introduction

This paper outlines the influence of geologic structure on groundwater drainage patterns in a steeply dipping carbonate terrain. Research was carried out in the Benson River Valley on northern Vancouver Island. Investigative techniques included dye tracing, water chemistry, mapping of geological structure, and interpretation of surficial and subsurface geomorphology.

Karst development in northern Vancouver Island occurs primarily in the Upper Triassic Quatsino Limestone. The limestone is a massively bedded deep water carbonate, which was subjected to uplift, faulting and dyke intrusion during late Mesozoic and early Tertiary tectonism, (Muller, Northcote and Carlisle, 1974). Extensive karst occurs in a 30 km long section of the strike-oriented Benson Valley. Relative relief in the valley exceeds 1,000 m but the Quatsino Limestone is restricted to the basal 600 m, outcropping along the valley floor. The stratal dip is to the West at 30°, across the valley. The valley floor is uplifted into cuesta blocks which reach 1 km in length and 400 m in height. The Benson River and its principal tributary, the Raging River, dissect the inclined karst surface and function at the base level for surficial and subsurface drainage.

Structural Controls on Cave Development

The influence of geologic structure on drainage patterns in the Quatsino Limestone is of fundamental importance. Pathways for subsurface routing occur along bedding planes, joints orientated along the strike and joints parallel to the dip. Locally, infrequent high angle faults of variable orientation control groundwater movement. The various structural pathways are not of equal importance. Allogenic streams reach the limestone along the east and west flanks of the valley, but the pattern of subsurface recharge is distinctly asymmetric (see Table 1). Streams invading the limestone from the east, where the hydraulic gradient and stratal dip are roughly concordant, sink close to the geologic contact and resurge at base level springs. However, streams invading the limestone from the west, where the dip is into the mountainside and direct bedding plane routes to the base level do not exist, remain at the surface and incise gorges up to 20 m in depth.

TABLE 1

	SINK	REMAIN ON SURFACE
Allogenic streams from West	2 (i)	4
Allogenic streams from East	7	1 (ii)

(i) both streams sink on faults
(ii) stream perched on deltaic deposits

The structural dip of the limestone is greater than the topographic gradient in most situations. Few sinking waters reach their outlets along pathways composed of single structural elements except where waters are routed along faults. A notable example of the latter is the Vanishing River-Reappearing River cave system where waters move some 2 km within a fault zone, from the watershed of the Benson River into the Raging River valley.

The more common situation, however, is where karst conduits are driven below local base level subsequently to rise upwards in the stratigraphic sequence and/or to drain along the strike to an outlet. The greatest change in stratigraphic position between sink and spring points is found in the Malook Creek cave system where sinking waters were traced over a straight line distance of 1.1 km, in limestone dipping at 28°-33°. This implies a stratigraphic rise in excess of 500 m. Four karst windows provide the only observation points along the drainage route. Short sections of passage up and downstream of the windows terminate in sumps and exhibit vertical joint or bedding plane structural control. The karst windows are apparently drained apices of a cave system composed of phreatic loops descending to an unknown depth (see Figure 1).

The height to which water will rise in an individual joint or "joint chimney" (Ford, 1968) is dependent on the stratigraphic distance between penetrable bedding planes, the planimetric spacing of vertical joints and the externally defined hydraulic head above the base of the joint chimney. Two cave systems in the Benson Valley exhibit situations where water is inferred to have risen over 30 m and 60 m respectively in single shafts. The larger lift occurred in the Devil's Bath system (see Figure 2) where piracy of the Benson River occurs over a distance of 600 m. During summer base flow periods all discharge in the Benson River is routed downdip to the Devil's Bath, a large cenote-like depression. Drainage from here is along the strike to the Devil's Springs, 400 m away, where waters debouch along a major vertical joint. The Devil's Bath measures 80 m x 60 m in plan with the elongation along the strike orientation. The water level is approximately 20 m below the rim of the near-vertically walled depression. Scuba divers report reaching the base of the depression 25 m below the water surface where a discrete input shaft, rising from an unknown depth, was encountered. Drainage from the river sinks 150 m away rises stratigraphically through 80 m of limestone to reach the present water surface in the Bath, although the extent of any individual lift is unknown.

The Devil's Bath is a large collapse feature not readily explained by development under the present hydraulic conditions. It appears that prior to collapse, waters were sinking at a higher level into a cave system developing under greater hydraulic head. A bedding plane, solutionally modified by large scale phreatic scalloping, is located at the downdip margin of the Bath, perched 12.5 m above the present water level. Extrapolation of this bedding plane to a position above the input shaft in the Bath demonstrates that water may have ascended 40 m above the present water level, i.e. 20 m above the depression rim, in the joint chimney before the shaft was destroyed (see Figure 2). The maximum elevation of observed paleosinks above the present Bath water surface is 30 m, but many meters of bedrock were probably removed from this valley bottom position during the Pleistocene glaciations. Consequently a high level sink may have been erased. The drainage competency of the cave system is apparently reduced from an earlier maximum, most probably in association the collapse and head loss resulting from lower input sites. The present discharge of the system does not exceed 1 $m^3 s^{-1}$. The narrow incised gorge channelling the Benson River, comprising several 1 m and 2 m waterfalls, is probably of more recent origin and has developed by routing drainage more efficiently along a shorter route at the expense of the cave system. Thus in the present situation there is river piracy of a cave system.

The ground plan of most known cave systems in the Benson Valley is an asymmetric pattern consisting of a relatively large, strike oriented, "subsequent passage" (Ford, 1968) developed by the integration of drainage from smaller dip tubes aligned in a sub-parallel array along the up-dip side. Drainage along the strike in this manner occurs in steeply dipping strata where available discharge sites are along the strike at the flank of the outcrop or in joint chimneys developed above certain dip tubes. Similar cave systems are described in other steeply dipping karst terrains e.g. the Mendip Hills of England (Ford, 1968) and the Long Mountains of the Eastern United States (Saunders, Medville and Koerschner, 1977). Ewers (1977, and in preparation) has demonstrated from physical analogues of such situations that subsequent drainage routes develop from the stepwise integration of individual strike segments between the dip tubes in sequence from the outlet.

In the Benson Valley one major dip tube/subsequent passage cave system, Minigill Cave, occurs in limestone compartmentalised by vertical dykes oriented parallel or sub-parallel to the dip. Nine dykes, raning from 40 cms to 1 m in width, traverse the subsequent passage along its 700 m length. All are breached by the active vadose stream routed through the system, but two remain as sumps even in lowest water conditions. Two shafts ascend 32 m and 24 m from the river passage to the surface in particular compartments between dykes. The hydraulic head required to raise waters through these shafts would have been available from sink points located on the adjacent mountainside. Prior to complete breaching of the dykes and the lowering of the water table of its present position, waters flowing down the dip were apparently drained by short subsequent passages connected to the shafts.

Springs

Eleven of the fourteen springs known in the Benson Valley occur along the flanks or down dip margins of the limestone outcrops. No active or fossil exsurgences were discovered along the scarps at the up-dip margins of the cuesta blocks. The springs were divided into two groups, based on their topographic/stratigraphic position. Group A springs occur down-dip of allogenic stream sinks and are assumed to discharge allogenic waters routed in large conduit passages. Group B springs occur at the margins of the cuesta blocks. These sites are assumed to discharge only autochthonous infiltration routed in networks of small passages; their waters consequently have longer residence times in the aquifer.

The saturation status (SI_C) of the waters was employed to test the validity of the classification. Table II demonstrates that the chemistry at springs debouching allogenic waters is distinctly undersaturated with respect to $CaCO_3$, while the percolation waters discharged by the cuesta block springs are saturated or slightly supersaturated. Group C comprises allogenic streams at the limestone contact and is presented for comparative purposes.

TABLE II

		SI_C	
	No. of samples	mean	s.d.
Group A	6	-1.02	0.34
Group B	5	+0.31	0.19
Group C	6	-1.66	1.07

The Student's t-test affirmed the validity of the spring separation into the two groups at the 99% significance level. It is pertinent to note that 5 of the 6 springs in Group A were connected to stream sinks by dye traces. A second Student's t-test was employed to test the contention that the allogenic waters routed in large conduits would exhibit little evolution towards saturation between sink (Group C) and spring points (Group A) along the average conduit flow path length of approximately 950 m. No significant difference in the means of Groups A and C was apparent at the 95% significance level, which demonstrates that extensive solution or addition of different waters does not occur in the underground flow paths.

Summary

Karst drainage patterns in the Benson Valley are controlled by the distribution and orientation of structural pathways in the limestone. The nature of this structural control is exhibited clearly in many cave systems. The asymmetric pattern of sinking allogenic streams and the concentration of springs along the flanks and down-dip margins of the limestone outcrops demonstrate that the various structural pathways are not of equal importance.

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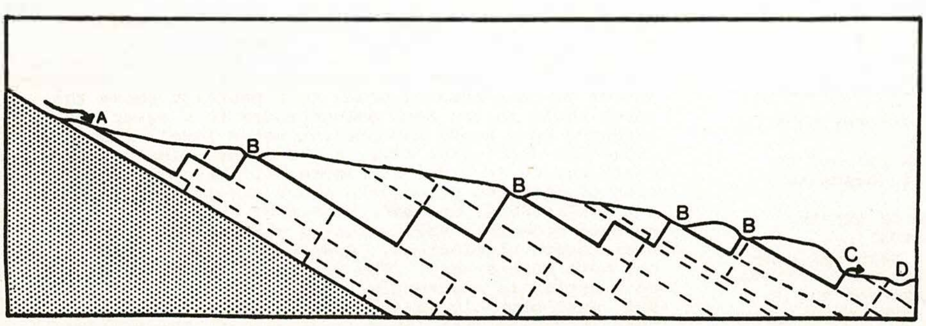

Figure 1. Idealized Drainage Pattern in the Malook Creek Cave System. A. Stream Sink, B. Karst Windows, D. Spring, D. Benson River.

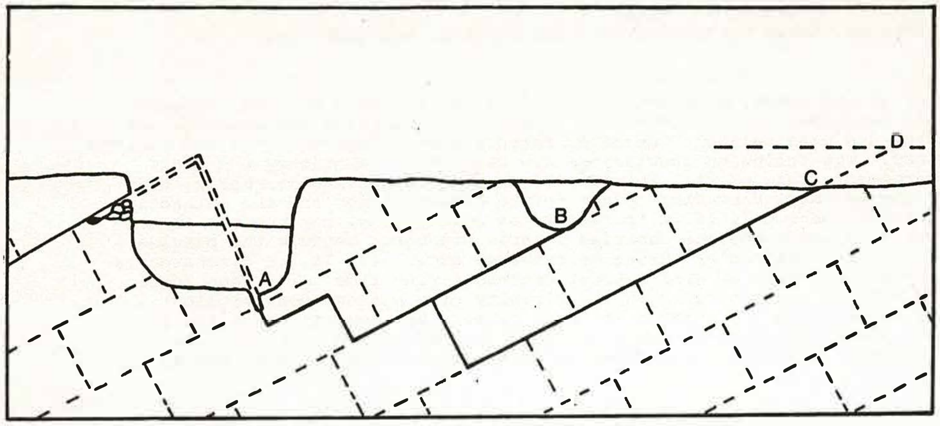

Figure 2. Idealised Drainage Pattern in the Devil's Bath Cave System. A. Input Shaft, B. River Sink in Gorge, C. Intermediate Level Sink, D. Paleo River Level.

Hydrochemical Factors in the Origin of Limestone Caves

Arthur N. Palmer
Department of Earth Science, State University College, Oneonta, New York 13820

Abstract

Within the normal pH limits for ground water, experiments show that the solution rate of limestone is controlled mainly by the chemical reactions at the rock-water interface. Combining the equation for solution rate with those for velocity and mass balance, the major factors controlling the rate and pattern of cave development can be determined. The following conclusions are support by laboratory and field data: (1) the rate of passage enlargement (rate of wall retreat) rises with increasing discharge, but levels off at a maximum of roughly one mm/year, depending on the solute concentration and the saturation concentration. (2) A cave passage grows large only if it is active for a long time, not because it contains a large discharge. When forming, a large passage contains a large discharge because the passage has been active long enough for it to have captured an extensive recharge area. (3) If the discharge remains constant while a passage enlarges, the rate of wall retreat decreases with time. (4) When local hydraulic gradients increase during a flood (particularly in the vicinity of a passage constriction), many alternate paths of flow become competitive and enlarge at rapid rates. Anastomotic mazes and some network mazes form in this way. (5) Where ground water has a low gradient, alternate paths of flow generally enlarge at far different rates. Downstream branching to form closed loops is rare, and a dendrític pattern develops.

Résumé

Dedans les limites de l'acidité dans l'eau karstique, les expériences hydrochemiques indiquent que la vitesse dissolutionale du calcaire est régler surtout par les réactions chemiques à la surface des roches. En combiner des équations dynamiques pour la réaction et pour l'écoulement d'eau avec cela de la continuité, peut on démontrer le rapport entre ces variables et la vitesse d'agrandissement des cavernes: (1) la retraite dissolutionale d'une surface calcaire s'accroît avec le débit, mais avec une vitesse maximale d'approximativement un mm de l'an, dépendent de la concentration ionique et la concentration saturée. (2) Un passage parvient grand surtout à cause de la durée prolongée, au lieu des débits forts. Les passages les plus grands avent les debits aussi grands, parce qu'ils ont le temps suffisant pour la capture d'un écoulement etendu. (3) Si le débit reste constant en même temps qu'un passage s'aggrandit, la vitesse d'agrandissement diminué. (4) Quand l'inclinaison hydraulique s'accroîte pendent un déluge (surtout dans les environs d'un resserrement), peuvent beaucoups des routes d'écoulement alternatives se présenter en concours, une situation qui produit les labyrinthes anastomotiques ou fissurés. (5) Les routes alternatives avec les inclinaisons hydrauliques faibles s'agrandent à les vitesses très diverses, et rien qu'un petit nombre des passages se forment, dans un configuration dendritique.

Rates of Solutional Cave Development

One of the major constraints in the solutional enlargement of a cave is that the increase in cave volume must be equal to the volume of dissolved rock carried away by flowing water. This mass balance can be expressed as

$$\frac{dV}{dt} = \frac{Qdc}{\rho} \times 10^{-6} \text{ cm}^3/\text{sec} \qquad (1)$$

where dV/dt = rate of increase in cave volume, Q) discharge of water through the cave (cm^3/sec), dC = increase in concentration of dissolved rock within the water, (mg/liter), and ρ = density of wall rock (g/cm^3).

Within an increment of passage length (dL) in a conduit of circular cross section,

$$dV = 2\pi r dr dL \qquad (2)$$

where r = passage radius. (A circular cross section is chosen only for convenience. The dynamics within other passage shapes are similar, and although numerical values vary from those of a circular cross section by as much as 50%, the geomorphic principles outlined here are no different.) The growth rate of such as passage increment is therefore

$$\left.\frac{dr}{dt}\right|_{dL} = \frac{Q}{2\pi r\rho}\left(\frac{dc}{dL}\right) \times 10^{-6} \text{ cm/sec} \qquad (3)$$

Plummer and Wigley (1976), building on work by Berner and Morse (1974), have shown that within the pH range 4-6, typical of most solutionally aggressive ground water, the solution rate of calcite is controlled mainly by the chemical reactions at the bedrock/water contact, rather than by the diffusion rate of ions through the water. Hydraulic factors such as turbulence are therefore less significant than in a system where the solution rate is controlled by mass transfer in the water. Curl (1968) and Picknet (1976) give additional insight into reaction rates. The following semi-empirical equation for the solution rate of calcite at pH 4-6 is modified from Plummer and Wigley:

$$dc = k\frac{A}{V_w}(C_s - C)^2 \, dt \times 10^{-3} \text{ mg/liter} \qquad (4)$$

where k = reaction constant (cm-liter/g-sec), A = surface area of calcite in contact with water, V_w = volume of water, and C_s = saturation concentration of dissolved calcite (mg/liter). Experiments by Plummer and Wigley show that k is approximately 0.0003 cm-liter/g-sec for pure, finely crystalline calcite at 25°C and slightly less for impure or coarsely crystalline calcite. However, this figure is valid only at solute concentrations less than about 90%. Beyond 90% saturation, the value of k drops sharply one to two orders of magnitude (Berner and Morse, 1974; see also discussion by White, 1977). Equation (4) is strictly valid only where C is measured at the rock surface, but because the ions disperse so rapidly through the water, C can represent approximately the average concentration of solute throughout the entire volume of water that exits from a given length of passage.

Combining equations (1) and (4), the solutional history of almost any cave passage can be determined with numerical analysis, solving for r in increments of L, C, and t, provided the solution takes place by the CO_2-$CaCO_3$ reactions. However, for geomorphic interpretations a more generalized approach is useful.

If r is constant over a given length of passage (L), equation (3) becomes

$$\frac{dr}{dt} = \frac{Q(C-C_o)}{2\pi r\rho L} \times 10^{-6} \text{ cm/sec} \qquad (5)$$

where C_o = concentration of dissolved rock in the water at the upstream end of the passage segment. Integrating equation (4), solving for C, and recognizing that $A/V_w = \frac{2}{r}$ in a conduit of circular cross section,

$$C = C_s\left[1 - \left(\frac{.002rLkC_s}{Q} + \frac{C_s}{C_s - C_o}\right)^{-1}\right] \text{ mg/liter} \qquad (6)$$

Equations (5) and (6) are plotted on the accompanying graph for dr/dt in cm/yr; $(C_s - C_o)$ = 200 mg/liter $CaCO_3$ equivalent, a typical value for cave water; and ρ = 2.7 gm/cm^3, the maximum density of calcitic limestone or marble. In passages where Q and r are small or L is large, water exits from the passage almost totally saturated with dissolved calcite, so k values are used that vary from one to two orders of magnitude lower than the 0.0003 cm-liter/g-sec used at the top of the graph. Closed-conduit flow is assumed, and the relationship shown between hydraulic gradient (i) and discharge (Q) is valid only for laminar flow. The solution rates shown on the graph agree well with experimental values obtained by Howard and Howard (1967) and Rauch (1972), with field measurements by Coward (1971), and with the rates required for the evolution of postglacial caves (e.g., Palmer, 1972).

In narrow openings the solvent water approaches saturation in a very short distance. If it were not for the great decrease in k beyond about 90% saturation, almost all of the solution would occur near the entrance of such a passage, restricting the solutional growth of the downstream sections almost to zero. The reduction of solution rate caused by the decrease in k allows the remaining 10% or so of the solution to be spread out over a long distance. Otherwise cave passages more than a few meters long would be very rare, except where different chemical reactions are involved.

Relationship Between Discharge and Rate of Passage Growth

In any given passage, the graph shows that as Q increases, the solution rate (dr/dt) also increases but begins to level off as the solute concentration at the downstream end falls below 90%, approaching the following maximum solution rate:

$$\left(\frac{dr}{dt}\right)_{max} = \frac{0.0316k(C_s-C_o)^2}{\rho} \text{ cm/yr} \qquad (7)$$

This equation also applies to the rate of wall or floor retreat in stream passages only partly filled with water, provided the discharge is comparable to that shown for closed-conduit flow at the top of the graph. For (C_s-C_o) = 200 mg/liter, $(dr/dt)_{max}$ is approximately 0.14 cm/yr, equivalent to an increase in diameter of one meter in only 357 years. This surprisingly high solution rate agrees well with measurements by Coward (1971), which show an average rate of floor retreat of 0.12 cm/yr during periods of high flow in stream passages in a West Virginia cave. Mechanical abrasion by stream-borne sediment may cause even higher enlargement rates (Palmer, 1972).

If the hydraulic gradient (i) is held constant while the passages grow, as in the case of underground conduits fed by a body of surface water, the maximum solution rate can be reached rapidly, especially in short conduits. Where the gradient is particularly steep, for instance in the vicinity of artificial dams, the maximum solution rate may be achieved in cracks in limestone almost immediately, causing rapid growth of numerous solution conduits and significant leakage through the bedrock, even where there are no preexisting solutional openings.

As shown on the graph, if a cave passage does not increase in groundwater discharge as it enlarges, the rate of enlargement decreases. Only those openings that can acquire an increasing discharge, at least during the initial stages of solution, are able to develop into traversable cave passages. For this reason, only a few of the numerous fractures and partings in a limestone formation become caves.

Because large cave passages generally have (or once had) a correspondingly large discharge, it is often assumed that the size of a passage depends mainly on the amount of flow through it. This idea is not necessarily valid, as nearly all turbulent flow having the same values of (C_s-C_o) will dissolve limestone at the same rate, regardless of discharge. Although underground flow having a large discharge commonly has a lower value of C_o, as well as a relatively large area of contact with the cave walls in vadose passages, the existence of an upper limit for solution rate at given (C_s-C_o) suggests that the length of time a passage carries water is more important than discharge in forming a large cave. As it grows, a passage that is active for a long time acquires a greater drainage area, mainly by piracy (Palmer, 1975; Ewers, 1978). Large passages therefore develop under the combined influence of increasing discharge and duration of active flow paths.

Dendritic Caves

Most caves fed by drainage from an overlying karst surface have a predominately dendritic pattern, although the branching pattern of many dendritic caves is obscured where there are few enterable tributaries or several superimposed stages of passage development. Because the initial openings in limestone have a broad variety of widths and flow rates, there are great differences in their rate of early solutional growth. In a closed loop, where the flow of water divides into two branches that combine again further downstream, one of the branches almost always has a significantly greater rate of growth. Therefore, closed loops in caves of this type are rare, except where they form as the result of diversion of water from one flow path to a different (usually lower) path.

Maze Caves

Maze caves can form in two different ways (Palmer, 1975): (1) Where water enters the limestone initially through an overlying permeable but insoluble rock such as sandstone, each fracture in the limestone receives nearly identical amounts of water of similar chemical character, regardless of the relative sizes of the fractures, creating network caves. (2) Where limestone is subjected to steep hydraulic gradients, particularly during floods, many alternate flow paths are enlarged by solution to form an anastomotic maze or crude network maze, depending on the relative prominence of bedding-plane partings versus fractures.

In case (1), the discharge per unit fracture length at the sandstone/limestone contact increases only logarithmically with crack width (Palmer, 1975). This small increase in discharge is not enough to allow wide cracks to enlarge any faster than narrow cracks, so a network of rather uniform fissures is formed.

In case (2), a local obstruction such as breakdown can act as a barrier to groundwater during high flow. Turbulent floodwater becomes ponded upstream from the passage constriction. Steep hydraulic gradients develop around the constriction that increase with the square of the discharge. The rate of laminar flow through the fractures and partings in the limestone increases proportionally to the hydraulic gradient. Solutional enlargement reaches its maximum rate in many alternate flow paths, regardless of carck width, creating a local maze pattern in which every crack enlarges at roughly the same rate.

In such a situation, local values of i/L may reach values as high as 10^{-3}. Under these temporary flood conditions, all openings with an effective radius (or crack width) greater than 0.1 cm enlarge at virtually the same rate, and openings as small as 0.01 cm require only a few years of this type of flow before they reach the same solution rate. Openings much narrower than this grow so slowly that they probably never become competitive in size.

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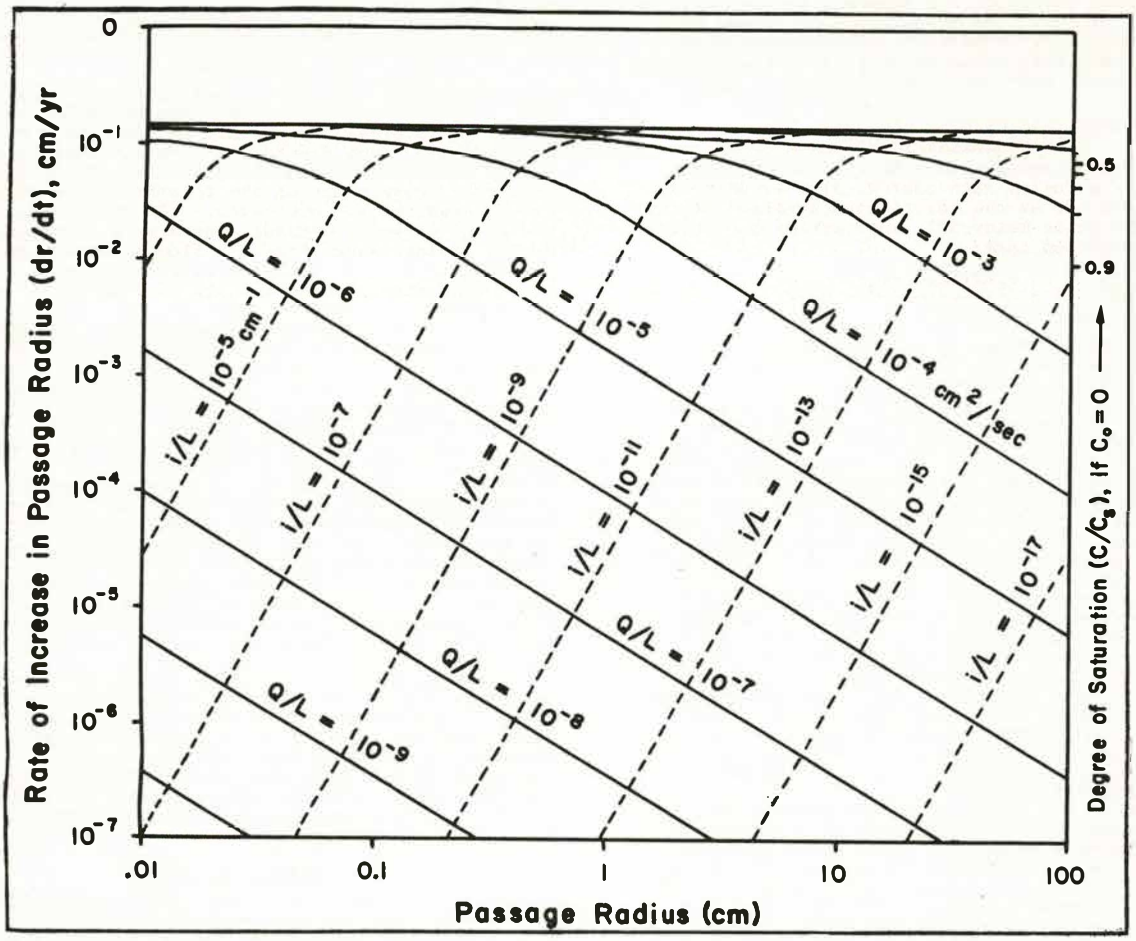


Rate of increase in passage radius (dr/dt) in cm/yr, for (C_S - C_O) = 200 mg/liter, at different values of discharge (Q), passage length (L), and radius (r). Hydraulic gradients (i) are for laminar flow only. High-calcite limestone or marble is assumed. Rates of solution are valid only for closed-conduit flow, although the maximum solution rate also approximates the rate of wall or floor retreat in open-channel flow.

Communication on a Preliminary Survey of the Fauna of Caves in some Regions of Brazil

Eliana M. B. Dessen, Verena R. Eston, Marietta S. Silva, M. Thereza Temperini-Beck, and Eleonora Trajano
Consolacao 2570, op. 42, 01416 Sao Paulo, Brazil

Abstract

This article presents a preliminary survey of the faune of 28 caves in 5 regions of Brazil. The identification of many of the animals is restricted to the higher taxonomic levels, because of the lack of knowledge, in Brazilian scientific circles, of the systematics of cave-dwell fauna. It was found that the populations of the caves studied were smaller and less diversified than the cave-dwellers of the northern hemisphere. In relation to the distribution of the fauna and their relative abundance, five different situations were found: groups which were frequent in all the caves; groups frequent in some caves and rarely found in others; groups frequently found in some caves and not found in others; groups not very frequent but widely distributed, and groups rarely observed.

Amongst the invertebrates the most frequent groups are: Araneae, Opiliones, Amblypygi, Diplopoda, Orthoptera and Diptera and amongst the vertebrates the Siluriformes.

The existence of morphological adaptations characteristic of cave-dwellers was observed in many groups: lack of pigmentation and eyes with a high degree of reduction (Aegla, Trichomycterus, Tiphlobagrus some Diplopoda and few Opiliones); reduction of wings in different stages (Grylloidea and Blattariae); greatly elongated antennae (Grylloidea and Aegla) and highly developed feelers (Siluriformes). Evidence of reproduction in the cave environment, such as females with eggs in ootheca, cocoons, larvae and pupae were found for many groups (Araneae, Diptera, Opiliones, Amblypygi, Oligochaeta, Crustacea and Siluriformes).

Résumé

Ce travail presente une estimation preliminaire de la faune de 28 gouffres de 5 regions du Bresil. L'identification de plusieurs animaux s'est limité aux niveaux taxonomiques les plus elevés, à cause de la petite connaissance, au milieu scientifique bresilien, de la sistematique de la faune cavernicole. On à constaté que les populations des gouffres etudiés sont plus petites et moins diversifiées que celles-la des cavernicoles du himisphère nord. En ce qui concerne la distribuition de la faune et à sa abondance relative cinq situations distintes ont été observés: groupes frèquents dans tous les gouffres; groupes frèquents dans quelques gouffres, et peu souvent reucontrés dans les autres; groupes frèquents dans quelques gouffres, mais non reucontrés dans les autres; groupes peu frèquents mais amplement distribués; et groupes rarement rencontrés.

Parmi les invertebrés, les groupes les plus frèquents sont: Araneae, Opiliones, Amblypygi, Diplopoda, Orthoptera et Diptera et parmi les vertebrés, les Siluriformes.

On a constaté l'existence d'adaptations morfologiques caracteristiques des cavernicoles obligatoires dans plusieurs groupes: depigmentation et yeux avec gros reduction (Aegla, Trichomycterus, Tiphlobagrus, quelques Diplopoda et rares Opiliones); reduction des ailes en étages distintes (Grylloidea et Aegla) et barbillons developpés (Siluriformes). Evidences de reproduction dans le milieu cavernicole, tets que femmelles en portant des oeufs, des oothèques, cocons, larves et pupes de plusieurs groupes ont été reucontrés (Araneae, Diptera, Opiliones, Amplypigi, Oligochaeta, Crustacea et Siluriformes).

This communication pretends to bring some light, incomplete as it may be, on the fauna observed in some caves of different areas of our country. There is no biological survey of brazilian caves, which may lead to a better understanding of the relations between cave organisms, their specialization, and their evolutive origin. Few are the papers on biospeleology and those existent are usually restricted to registration and description of some species (Costa-Lima, 1940; Pavan, 1945; Schubart, 1946; Lebret, 1966; Vedovini, 1968; Strinati, 1968; Strinati, 1971; Brignoli, 1972; Turkay, 1972; Mauriès, 1974, Silhavy, 1974; Eickstedt, 1975; Strinati, 1975). Cave-dwell animals are also mentioned at some papers not especifical of cave fauna (Mello-Leitão, 1937; Schubart, 1956; Nogueira, 1959; Jakobi, 1969; Christoffersen, 1976). This absence is explained by scarce divulgation of speleology in Brazil.

Methodology

Samples have been made sporadicly and irregularly since 1971, by biologists as well as people with different professional backgrounds. This survey is therefore not complete, both from qualitative and quantitative points of view. Survey may be considered complete however at caves as Santana, Alambari de Cima, Paivo (São Paulo) and the São Matheus-Imbira system (Goiás) since they have been subjected to a systematic sample.

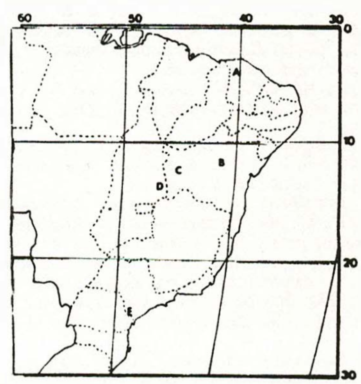
Most of the specimens were collected by hand, using glasses and plastic bags. In some instances however formaline traps for Arthropoda, sucking pumps, hand-held nets for fishes and zooplancton nets were used. During our activities no special light was used, only carbide lamps as is usual at our cave visits, and which give a rather limited field of vision.

In the cases when capture of a specimen has not been possible, its occurrence was registered on notebooks. The specimens obtained however were labelled, prepared, and preserved, and afterwards directed to institutions as Butantan Institute, the Museum of Zoology, and the Oceanographic Institute of the University of São Paulo for identification.

Areas Studied

28 caves of 5 different limestone areas of Brazil were included at this survey and their geographical situation is shown below at a map of Brazil:

A - Ubajara (Ceará)
B - Irecê-Morro do Chapéu (Bahia)
C - São Desidério (Bahia)
D - São Domingos (Goiás)
E - Ribeira Valley (São Paulo)



Caves of the Irecê-Morro do Chapéu area (Bahia), São Desidério (Bahia) and São Bomingos (Goiás) are situated on limestone plateaus of the Bambuí group, to which is also stratigraphically related the limstone at Ubajara (Ceará). Limestone of the Ribeira Valley (São Paulo) belongs instead to the Açunguí group: it is limestone of syncline origin favoring development of caves with great level differences, in opposition to the former areas which feature caves with a preferable levelled development.

The Ubajara area (with a single cave included) is situated on the morphoclimatic domain of the "caatingas", with a local moist climate however, which favours an exuberant vegetation there enclaved. São Domingos (which also includes only one cave, the São Matheus-Imbira system, with about 22 km the longest one in Brazil) and São Desidério areas belong instead to the "cerrado" morphoblimatic domain, while Irecê-Morro do Chapéu (with two of its caves here included) is situated on the transition belt between both "caatinga" and "cerrado" domains. On the other hand the Ribeira Valley area (to which most of the caves studied belong, a total of 18 included at this survey) is situated on the transition between the araucaria woods domain and the tropical atlantic domain. (Ab'Saber, 1977).

Discussion

As can be seen in the results (which are much too lengthy for presentation here, but are available to whoever really gest interested in them), the identification of most of the animals has been restricted to higher toxonomic levels, in some cases not surpassing their Classes. That was due both to lack of specialists in certain groups, as well as to little knowledge in our scientific circles, of the systemcatic of tropical cave fauna.

We have used surveys of northern hemisphere caves (Vandel, 1964; Reddell, 1969; Mitchell, 1971; Reddell, 1971; Juberthie, 1975), as a means of comparison with the fauna of the caves studied. It was found that there is not a significative difference on the representation of the higher taxa, although on those of northern hemisphere diversity in all toxonomic levels is greater. That can be seen to be the case of spiders, whose survey at our caves is considered to be complete. While at Texas caves 100 species of spiders were registered (from which 30 were troglobia), here only a few dozens occur, all troglophyla or trogloxena.

The Arthropoda are the prevailing animals at our caves (as well as on caves all around the world), especially Araneae, Opiliones, Amblypygi, Diplopoda, Orthoptera, Diptera and Hemiptera, common to all caves. Yet there is a great difference with regard to Coleoptera and Crustacea, prevailing at northern hemisphere but poorly represented at our caves.

Among non-Arthropoda one must emphasize the existence of Nemathelminthes and Platyhelminthes at northern hemisphere caves, but not observed here. About vertebrates, bats and fishes characterize the cave-dwell fauna, as all around the world. Amphibia are also largely distributed on caves: cave Urodela, typical of temperate regions however do not occur here, because the distribution of this Order does not include Brazil.

Outstanding differences were found on the size of populations: although precise quantitative figures are not available, we can affirm that populations on the caves studied were smaller than those of related species on temperate regions. As this survey has a rather qualitative character, more than a quantitative one, we have not used absolute figures of individuals; a relative density was looked for instead. When we say therefore that a certain species is frequent at a cave, we mean its population slthough small, is greater than that of other species around.

The following situations were found at present survey, regarding the distribution of the fauna and its relative abundance:

(a) Groups frequent at all caves: Chiroptera, Grylloidea, Diplopoda, Opiliones, and Araneae (specially Ctenidae and Scytodidae families);

(b) Groups frequent at some caves but seldom observed at others: Siluriformes and Blatariae, frequent at the São Domingos area but rare at the other regions studied; Keroplatidae at São Paulo caves, especially those crossed by a river; Theridiosomatidae, especially in some caves at São Paulo; Chironomidae and Oligochaeta, more frequent at the São Domingos area and at some caves of São Paulo.

(c) Groups frequent at some caves but not observed at others: Gymnotoidei were found only at the São Domingos area; Amblypygi and Araneae-Orthognata only at Goiás and Bahia; Aeglidae at São Paulo caves; _Tiphlobagrus_ at the Areias system (São Paulo).

(d) Groups not very frequent, but widely distributed at the caves studied: Anura, Hemiptera and Lepidoptera, near entrances.

(e) Groups rarely observed: Lycosidae, Pholcidae, Drassidae, Theraphosidae, Coleoptera, Chilopoda, Symphyla and Characidae are really rare, although the method detected their presence quite well. Mustelidae and Didelphidae are hardly seen, probably because they feel the human presence and hide quickly. _Hyallela_, Isopoda and Pseudoescorpiones were hardly seen due to the difficulty of their observation, although specific methods for their capture would certainly enlarge their occurrence. (As a matter of curiosity one of the Pseudoescorpiones was really only discovered back at home, while examining a close-up picture of a mould at the floor of the cave.)

The presence of a given group in a cave is subjected at least to two conditions: a) its geographic distribution comprehending at least in some geologic period, the area around the cave and b) pre-adaptation of the group to cave environment.

Available data allow only a few considerations about present geographic distribution. Therefore _Aegla_ is found only at southern Brazil caves, since the northern border of the distribution area for the genus is placed at the north of São Paulo (Schmitt, 1942). Also related to geographic distribution is the occurrence of _Peripatus_ at the São Domingos area, where it is fairly common, although it has not been registered at areas of south of Minas Gerais (Peak, 1975).

The fact that the São Matheus river belongs to the Amazonic basin explains the greater amount of fish species found, as the Amazonic basin represents a source of new taxa of South American fishes (Menezes, 1976). Therefore, genus _Sternachorhyncus_ found at the São Matheus-Imbira system could not possibly have been registered at any other studied cave, as it does occur only at the Amazon basin. Siluriformes and Gymnotoidei are among fishes, the best represented groups in caves, something related to their nocturnal habits, a pre-adaptation cave live. On the other hand Characidae, diurnal animals, are rarely found at caves.

The occurrence of certain groups at some caves but not at others can not always be explained only by its geographical distribution, as is the case of Theraphosidae (Araneae) which, while occurring all around Brazil, do only enter caves at Goiás and Bahia.

Some animals are restricted to the entrance of caves, not surpassing their twilight areas as is the case with Gastropoda. These animals look for such areas due to their microclimate's favorable conditions. Other groups as Hemiptera, Lepidoptera, Heterocera, Armadillidae and _Peripatus_ although found at the dark zone, are restricted to the entrance's vicinity.

Animals as Mustelidae, Didelphidae and Rodentia do visit caves in search of food or to build nests. Although not typically cave-dwellers, they play an important role in cave communities, contributing to its food chain, likewise as other animals which have entered by accident and not returned (represented by bones and dying individuals). In many cases it is difficult to tell apart visitors from those astray, as is the case with Anura.

Adaptations to the cave environment were observed in some groups: in cases as of _Aegla, Trichomycterus_ and _Tiphlobagrus,_ some Diplopoda and a few Opiliones, depigmentation was absolute and eyes presented considerable atrophy. Wing's reduction at distinct stages was observed in Grylloidea and Blattariae. Quite elongated antennae occur in Grylloidea and _Aegla,_ and developed feelers in Siluriformes.

Evidence of reproduction within caves exists for several groups. Females with eggs, eggs in oötheca or cocoons were found for: _Aegla,_ Theridiosomatidae, _Loxoscelles adelaida,_ some Opiliones, Amblypygi and Oligochaeta. Individuals at different sizes were observed in these groups, an indication that development occurs within the cave. Survival of populations of _Hyallela curvispina_ and _Trichomycterus_ in entirely isolated water pools, also suggests a life cycle within the cave although no clearer evidence of reproduction was observed. Hatching adults, larvae and pupae of Keroplatidae observed within the caves prove their reproduction in the environment. Once hatched, the adults probably leave the cave, as they were only found outside.

Evidence of predatory attitude within the cave was observed in:

a) Theridiosomatidae feeding on Diptera captured on its net.

b) _Ctenus_ and _Loxoscelles adelaida_ seen hunting. This is an unusual behaviour for _L. adelaida,_ as outside it uses a net to capture its prey.

c) Hemiptera sucking Opiliones.

d) Otters having preyed _Aegla,_ as is clear by the presence of depigmented shelles of this crustacean on their feces within the cave.

Our cave-dwelling fauna although less diversified than that of northern hemisphere (especially regarding troglobia), presents a similar pattern of adaptation to the life within the cave. Cave animals use such environment in a similar way, both as shelter and as a source of food, and present the same kinds of morphologic adaptations, a similarity certainly due to the same physical characteristics common to all cave environments.

Differences regarding diversity of fauna are then probably due to historic factors. Caves are doubtless a shelter for animals which are unable to survive changes of climate, be it progressive cooling or desiccation of the area. We have observed within the caves studied, a lesser diversity leading to the formation of troglobia fauna, when comparing our cave-dwelling animals to those of northern hemisphere. Such phenomenon may be explained by the lesser intensity of climate changes which happened at the southern hemisphere during quaternary glacial cycles. That does not explain however the great diversity of cave fauna on some tropical areas as Venezuela (Pietri, 1956) and southern Mexico (Reddell, 1971), something that warns that the problem of diversity of cave-dwell fauna represents a field still open to newer contributions.

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Visitors and Climatic Regime of Caves

Irene Halbichová & Antonin Jančařík

CSS ZO 1-02 "tetin", Beroun, Institute of Geology and Geotechnics, Prague, Czechoslovakia

Abstract

In this contribution the computation of influence of visitors on climatic regime of caves is described. Influence of heat "pollution" on changes of airflow regime (using the mathematic simulation of thermic airflow) partly, on heat strain of surface layer of wall partly is computed. The used method is applied to a concrete situation in caves of Koněprusy (Bohemian karst, Czechoslovakia).

Résumé

On décrit, dans cette contribution, l'influence d'un nombre reletivement élevé des visiteurs sur le régime climatique d'une caverne (grotte). On calcule l'influence de la "pollution" thermique sur les altérations du régime des courants d'air (en utilisant le modèle mathématique des écoulements thermiques), ainsi que l'effort thermique qui se manifeste sur les couches superficielles des tailles de roches. Les métodes discutées sont appliquées sur la situation réelle des grottes de Koněprusy (Le karst bohémien, Tchécoslovaquie).

The Geohydrology of the Ingelborough Area, England

Dr. R. A. Halliwell
Academic Office, The University, HULL, HU6 7RX, England

Abstract

This paper reviews the geological and meteorological factors influencing the karst geohydrology of the Ingelborough area of west North Yorkshire, England. The effects of overlying and underlying non-limestone rocks on water input, resurgence location and cave passage direction are discussed. Surface water sampling results are used to classify the risings in the area into five groups based on $CaCO_3$ mean content and variability. Water sampling within the caves revealed that although mean $CaCO_3$ hardness varied little with depth, variability of $CaCO_3$ hardness did decrease with depth. Statistical analysis and water tracing results suggest flowthrough times of 30 to 40 days for most diffuse-flow waters and around 1 day for most conduit-flow waters. A model of the hydrology of a typical cave system in the area is outlined.

Zusammenfassung

Die geologischen und meteorologischen Faktoren, welche die Karsthdrogeologie im Ingleborough Gebiet im westlichen Teil von North Yorkshire, England, beinflussen, werden hier untersucht. Die Wirkungen von darüber- und darunterliegenden nicht kalkaltigen Gesteinen auf den Wasserzufluß und -austritt und auch auf die Höhlengangrichtung werden besprochen. Die Ergebnisse der Oberflächenwasserproben werden zur Klassifizierung der sich in diesem Gebiet befindenden Quellen in fünf auf Durchschnittsinhalt und Variabilität von $CaCO_3$ gegründeten Klassen verwendet. Wasserproben innerhalb der Höhlen zeigten, daß, obgleich die Durchschnittshärte von $CaCO_3$ nur in geringem Maße von der Tiefe bestimmt wurde, die Verringerung der Härte mit der Tiefe verbunden war. Statistische Analysen und die Ergebnisse von Markierungsversuchen deuten darauf hin, daß der unterirdische Abfluß für die meisten "Diffuse-flow waters" von 30 bis 40 Tagen, für die meisten "Conduit-flow waters" aber ungefähr 24 Stunden dauert. In großen Zügen wird ein Modell der Hydrogeologie von einem typischen Höhlensystem in Ingleborough Gebiet dargestellt.

Introduction

The Ingleborough area has always been regarded as one of the best developed karst areas in Britian. The Geological Survey in their report (Tiddeman, 1890) stated ". . . the neighbourhood of Ingleborough presents examples of this kind of underground erosion which are second to none in the Kingdom for numbers, extent and interest. . . ."

The geological structure of the area is the key to much of its unique character. In a much simplified approach the geology can be considered to consist of three elements; the older basement beds, the Carboniferous (Great Scar) limestone, and the younger overlying beds. At the base of the limestoen is a major unconformity with a marked fossil topography. As a consequence of this the near-horizontal limestone varies widely (100-205m) in thickness around Ingleborough. Lithologically the rock is mainly a fine grained bioclastic limestone of a pale gray to cream colour with around 50% micrite and sparite matrix and only 2% insoluable residue. Joint directions, integral shale beds and lithological variations within the limestone have all been shown to influence thepresent day hydrology (Halliwell, 1979). The area has been heavily glaciated with the valleys cutting deeply into or through the limestone allowing vadose erosions at great depth. The area is bounded to the south by a major fault zone, the Craven Fault.

Annual precipitation averages 2000mm/year with a fairly even distribution throughout the year. Heavy rainfalls are common with 31% of the rain falling on days when the daily total was in excess of 20mm. The average annual temperature is just below 8°C giving estimated annual evapotranspiration losses of around 600mm. The rainfall contains 4 to 7ppm $CaCO_3$.

Effects of Rocks Overlying the Limestone

Around Malham there are no large areas of rock overlying the limestone and the result of glaciation has been the production of large areas of limestone pavement with no major sinkholes. In contrast Ingleborough has a large area of overlying rocks on which rainfall can gather and form streams before flowing onto the limestone and sinking in the extensive cave systems. Intermediate between these two extremes is the Scales Moor area. Here there was once a caprock cover which has since been removed. Cave systems can be found around the presumed edges of the now removed cover but these caves are tight and immature reflecting the short period of time when streams were available to develop them. Precipitation falling on the area now is not longer concentrated into these cave systems but sinks equally across the whole area.

Differences within the overlying rocks are reflected in the water chemistry of the water flowing off them. Water flowing off the grit and peat areas tends to have a $CaCO_3$ content of 5 to 7ppm whilst the water which has drained through the Yoredale Series, which includes thin limestone beds, has a $CaCO_3$ content of 35 to 50ppm.

Influences of Rocks Underlying the Limestone

The impermeable basement beds which act as a base-limit on the erosion of the limestone are exposed in parts of the deeply cut valleys around Ingleborough. The unconformity at the base of the limestone has a high amplitude fossil topography and this influences the present day hydrology.

This influence may be most easily seen in the location of risings at the base of the limestone. All the major risings in the area are located in troughs in the impermeable basement with only minor risings being situated at high points on the basement fossil topography. This locational influence can be extended to include the caves themselves which provide some evidence for influence of their lower regions by the basement topography. This influence is not often total with the bed of the cave stream being developed on the impermeable basement although this does occur. It may be seen near the downstream end of Skirwith Cave; and near the rising and at Grit Falls in White Scar Cave. Indirect evidence of flow very close to the basement is provided by the basement pebbles in the streambed of Dry Gill Cave. Even more indirect evidence is provided by the flooded passages of Meregil Skit developed behind the basement ridge of God's Bridge. It may also be argued that the northward underground flow of the streams sinking on Fountains Fell is evidence of their diversion by the fossil hill to the west of them, isolating them from the normal southward surface drainage.

Classification of Rising Into Types

Using solute variability, water temperatures and rising location, it is possible to identify five groups of sites (Halliwell, 1977).

The first group of those sites where streams flow off the overlying rock onto the limestone mass. These sites have low mean $CaCO_3$ contents (56ppm) and great variability of $CaCO_3$ concentration. The annual range of values at individual sites varies from 20 to 68ppm with an overall group mean coefficient of variation of 40.2%. This reflects high maximum values under low flow conditions resulting from water flow through the thin Yoredale limestone beds and very low minimum hardnesses (down to 8 ppm) under high lfow dilution conditions. Being surface sites these sites also experience wide ranges of water temperature (range at individual sites 0 to 22.5°C, group mean coefficient of variation 50.8%).

The second group are the major risings situated in troughs in the basement rocks at the base of the limestone. This group has mean $CaCO_3$ hardnesses (89ppm) slightly above that of the surface samples in group 1 but the variations in hardness are less extreme (mean coefficient of variation 25%). The variations in hardness which do occur result from the flowthrough of flood pulses which rapidly lower the solute concentration from their seasonal norms. As with solutes so water temperatures at these sites are only slightly less variable than at surface sites. Individual temperatures recorded at sites vary from 3.3°C to 12.6°C with the mean temperature at each site being in the range 7.1 to 8.3°C. Distinct flood related events have been recorded with 4°C snow-melt pulses passing through White Scar Cave, the speed of their passage having restricted normal heat exchange processes.

The third group are the permanent flow smaller risings which comprise the majority of the risings in the area. Like themajor risings these are usually sited at the base of the limestone but at relatively high spots on the fossil landscape. These sites all have farily consistent discharges, solute concentrations and water temperatures. All the sites have mean $CaCO_3$ contents within the range 100 to 200ppm with an overall group mean of 143ppm. The coefficients of variation of $CaCO_3$ content range from 7% to 32% with a mean of 18.7%. Only a few of the sites have coefficients in excess of 20% and these are thought to be in use as flood overflows by major resurgence systems. Many of the sites, especially those at the foot of Scales Moor, have coefficients of less than 10%.

The fourth group of sites consists of many of the small risings within the Craven Fault zone. These sites all have mean $CaCO_3$ concentrations in excess of 200ppm with coefficients of variation in excess of 10%. It is believed that these sites are fed at least partially by local soil drainage with the high $CaCO_3$ content reflecting erosion at the soil-bedrock interface. These sites mainly drain better quality agricultural land than the groups mentioned above. Hence it appears likely that within their catchments soil biological activity and therefore soil carbon dioxide contents will be higher thus accounting for the high solute values whilst still allowing the variability.

The final group of sites are similar to the previous group with agricultural catchments and mean $CaCO_3$ contents in excess of 200ppm. However the coefficients of variation of the sites within this group are all below 10% and in one case the coefficient is only 1.8%. This is taken to imply that the sites are entirely diffuse-flow fed with little or no conduit-flow water reaching them.

Both the group 4 and group 5 sites have above average magnesium contents for the Ingleborough area and it is believed that this reflects dolomitization of this area of the Craven Fault zone. Such dolomitization has been recognized in other areas of the zone where the faults are more clearly exposed.

Subsurface Sampling

Samples were collected over a 12 month period from a 300m near horizontal section of Swinsto Hole approximately 13m below the surface, and from over 2km of the White Scar streamway at an average depth of 150m. The initial, and not unexpected, result to emerge from the sampling was that the diffuse-flow inlets joining the main conduit-flow streamway had higher mean $CaCO_3$ content than the streams. The shallow depth Swinsto inlets were considerably more variable in solute content than the deeper Wite Scar inlets whilst the streamway content was only slightly more variable. This was found to be true regardless of season with the solute concentrations in both caves rising in the summer. On the diagram (Fig. 2) the degree of discharge control of solute concentration is indicated by the line length. Thus, for Swinsto discharge related variations in solute concentration are greater than seasonal related variations. In the case of the inlets the effects of catchment size must also be taken into consideration, in dry weather some of the Swinsto inlets ceased to flow whilst the White Scar inlets although reduced in flow under drought conditions never ceased to flow. Streamway sampling, expecially under high flow conditions, supported the conclusions of Stenner (1970) that increases in solute concentration were stepwise reflecting inlets joining the cave streams rather than resulting from streambed erosion.

Water temperatures were measured in both caves and the streamways were found to have very similar mean water temperatures, 7.5°C for Swinsto and 7.6°C for White Scar. These are both close to the average air temperature for the area of just below 8°C. However, the two streamways did diffuse in their temperature variability reflecting the fact that Swinsto is a sink/input whilst White Scar is a resurgence/output. The mean annual range of streamway temperatures recorded in White Scar was 1.3°C whilst in Swinsto the mean was 9.6°C; but this itself covered a spread from an annual range of 14.4°C near the entrance to 7.3°C 250m into the cave. As with solute variations the two caves were found to differ significantly in their inlet water temperatures, again reflecting the more direct precipitation response of the Swinsto inlets. In Swinsto the inlets were found to have a mean temperature of 7.36°C, a mean coefficient of variation of water temperature of 20.5% and a mean range of 5.2°C; similar figures for White Scar are 8.1°C, 3.3% and 1.1°C.

Flowthrough Times

The fluctuations in solute concentrations at the sampling sites were linked in partial and multiple linear correlation and regression analysis with variations in antecedent meteorological conditions for differing delay periods. The theoretical background to this methodology has been detailed by Pitty (1966, 1968) and the practical problems outlined by Halliwell (1977).

The analysis produced farily consistent results across the area as a whole with all the sites which showed evidence of experiencing dilution pulses having strong negative correlations with rainfall one day prior to sampling. The majority of sites also revealed a fairly strong positive relationship with air temperatures together with a negative response to precipitation, 30 to 40 days prior to sampling. This was interpreted as the average flowthrough time for the diffuse flow water onto which is superimposed the effects of the 1 day dilution effect conduit-flow water.

Hydrological Summary

Figure 3 attempts to outline water flow under average conditions. Measurements of sink-resurgence systems around Ingleborough suggest that under average conditions the sinks input about 20% of the outflow water. Study of catchment characteristics, especially the area of limestone pavement, suggests that 20% of input is from bare rock. Surface sampling above Swinsto suggested that much of the clay rich soil drains almost horizontally to closed depressions rather than vertically. However, once the water enters the limestone it tends to travel along fast response routeways.

Under high flow conditions the percentage input from stream sinks may rise as high as 45% of output flow. The percentage of water entering via the bare rock routeways will also rise because of this pathway's speedier response to increased precipitation. Sampling under flood conditions in both Swinsto and White Scar has shown that the streamway and fast flow vadose trickles respond very rapidly to precipitation although there may be a delay between the peak discharge and minimum solute concentration reflecting push through effects.

Under low flow conditions the percentage input via swallets decreases to around 10% whilst the bare rock input will drop to around zero. The cave streamway and to a lesser degree the fast flow vadose trickles decrease in flow but the flow seepages remain fairly constant in real terms and thus become more important in percentage terms.

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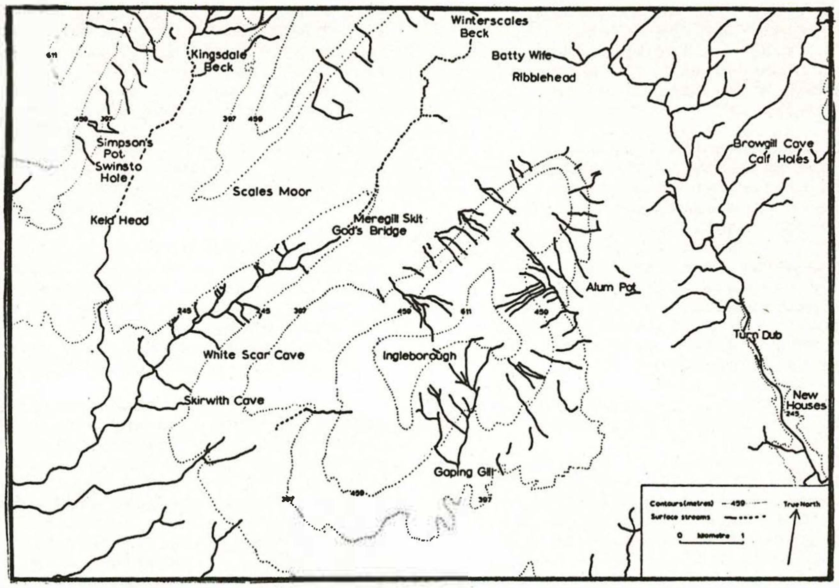

Figure 1: Map of Study Area

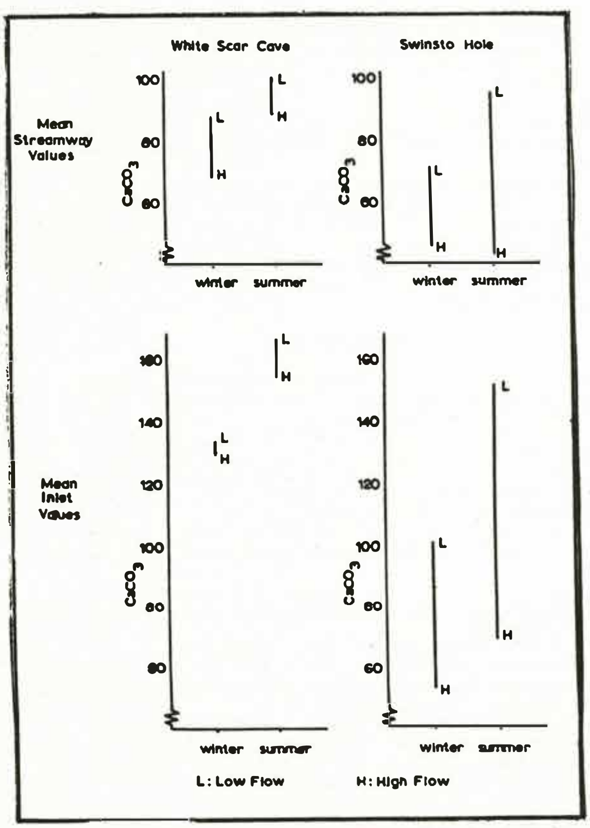

Figure 2: $CaCO_3$ (ppm) ranges recorded in Swinsto Hole and White Scar Cave.

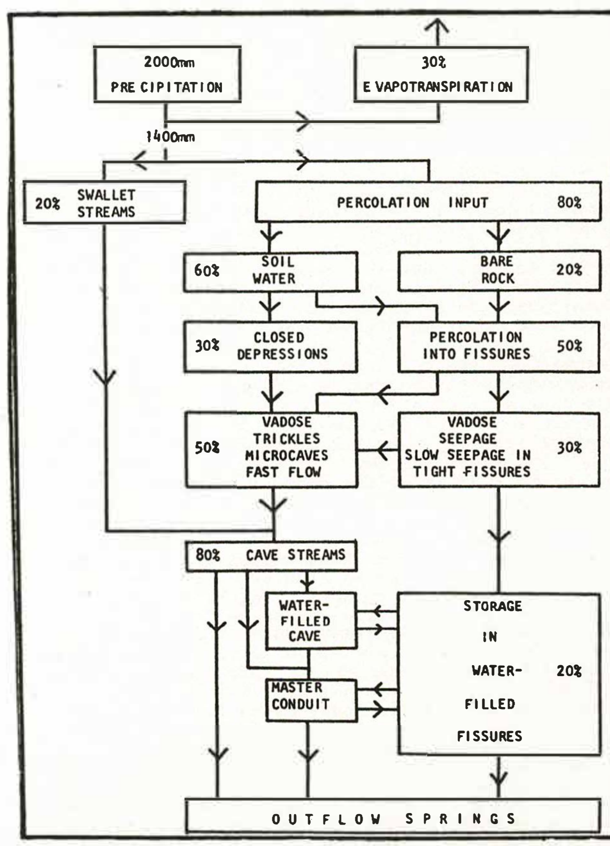

Figure 3: Theoretical hydrological pathways in the limestones of the Ingelborough area (average conditions).

Population of the Troglobitic Isopod Crustacean Antrolana Lira Bowman (Cirolanidae)

T. Lynn Collins and John R. Holsinger
Department of Biological Sciences, Old Dominion Unversity, Norfolk, Virginia, USA

Abstract

The cirolanid isopod Antrolana lira is known only from population in deep lakes in Madison Saltpetre Cave, Augusta Co., Virginia, and a nearby limestone fissure. The family Cirolanidae is predominantly marine. Most of the species living in freshwater are subterranean and occur near coastal marine areas or in parts of the world exposed to marine transgressions in the Cretaceous or Tertiary. A. lira is the only cirolanid found in an island area unexposed to marine waters since the Paleozoic.

Populations from one of the cave lakes and the fissure were sampled monthly for one year, using frozen shrimp as bait. All specimens obtained were measured alive and returned to their habitat. In addition, preserved samples were taken seasonally and examined closely in the laboratory for size, sex and state of reproduction. Data from the samples provided approximate monthly size frequency distributions, seasonal size frequency distributions and sex ratios. Both the lake and fissure populations fluctuated monthly in numbers of isopods accessible to baited areas. The size range for animals in both populations was 3.5-21.0 mm, but there was a domination by animals in the size range of 9-16 mm. Although large females were common, all lacked brood plates. However, dissection revealed that some females contain what are apparently oocytes.

The overall population structure is both the cave lake and fissure was skewed toward larger animals dominated by females, with some seasonal change in size frequency distribution. It is tentatively concluded that ovigerous females are rare and secretive, and do not forage in areas accessible to sampling.

Zusammenfassung

Der cirolanidische Isopod Antrolana lira ist nur von Populationen in tiefen Seen der Madison Saltpetre Höhle im Augusta Co., Virginia and den benachbarten Kalkstein Spalten bekannt. Die Familie Cirolanidae kommt hauptsächlich im Meer vor. Die meisten Arten, die im Süsswasser leben sind unterirdisch und sind in Küstengegenden in der Nähe des Meers oder in Teilen der Welt zu finden die Meerstransgressionen in der Kreide oder in Tertiär ausgesetzt waren. A. lira ist die einzige cirolanid Art die in einem Inselgebiet vorkmmt, das seit dem Paäozoikum nicht mehr von Meerswasser beeinflusst wurde.

Populationen einer dieser Höhlenseen und Spalten wurden monatlich für ein Jahr lang gessammelt. Garnelen dienten hier bei als Köder. Alle gesammelten Exemplare wurden ausserdem saisonmässig gesammlt, preserviert, und im Labor entsprechend genau nach Grösse, Geschlecht, und Fortpflanzungsstadium untersucht. Die Ergebnisse dieser Proben geben ungefähre Häufigkeiten der Verteilung, saisonbedingten Grösse und Geschlechtsquotienten wieder. Die Seen- und Spaltenpopulationen schwankten monatlich in der Anzal der Isopoden die Zugang zu den Ködern halten. Die Körpergrösse der Tiere in beiden Population varierte von 3,5-21, 0 mm, wobei die dominierende Körpergrösse im Bereich von 9-16 mm lag. Obwohl grosse Weibchen häufig aufraten, fehlten ihnen die Brutlamellen. Oöcyten ähnliche Strukturen konnten jedoch in einigen Weichen gefunden werden, wenn diese seziert wurden.

Die allgemeine Populationsstruktur der Höhlenseen und Spalten war jedoch zu den dominierenden grossen Weibchen hin verschoben, wobei einige Saisonänderungen in der Grössenverteilung auf traten. Es wird somit vorläufig angenommen das die eiertragenden Weibchen selten sind und abgescholossen leben und nicht in Bereichen Futter suchen die für die Sapmlung zugagnlich waren.

Introduction

The subterranean isopod Antrolana lira is known only from lakes of phreatic water in Madisons Saltpetre Cave and Stegers Fissure on the east side of Cave Hill just west of South River in Augusta Co., Virginia (Figs. 1, 2). This rare species was first described by Bowman (1964) and further details on its biology were given by Holsinger (1979). A brief description of Madisons Cave and its geology are found in Holsinger (1975).

Antrolana lira is the only subterranean, freshwater cirolanid isopod found in North America north of Texas, Mexico and the West Indies and is therefore of great interest biogeographically and ecologically. Because only a small number of cirolanids inhabit freshwater and the majority of them are troglobitic/phreatobitic species which live either in close proximity to the sear or in old marine embayment areas, it has been hypothesized that the subterranean, freshwater forms were derived directly from marine ancestors (Bowman, 1964; Vendel, 1965; Cole and Minckley, 1966; Holsinger, 1979; J. H. Carpenter, in ms.). If this theory is applied to the evolution of A. lira, then it can be speculated that this species is a relicit of an ancient lineage dating back to the Paleozoic when the Appalachians were last subjected to marine transgressions.

In order to learn more about the ecology of this unusual species and to augment our meager knowledge of the biology of subterranean cirolanid isopods in general, we began a 1-year ecological study of A. lira in the late summer of 1979. Some preliminary results of this investigation are given in this paper. A more detailed treatment will follow at a later time (TCL, in thesis).

Methods

Isopods were sampled monthly from the east lake in Madisons Cave and from Stegers Fissure (Sept. 1979-Sept. 1980). A fruit jar baited with frozen shrips was submerged for 30 minutes at each site. Isopods attracted to the jars were removed, counted and measured alive to the nearest 1 mm; then returned to their habitat. Seasonal samples were made in Nov. 1979, and Feb., May and Sept. 1980 by the same method, except that they were restricted to the nearest 0.1 mm. Isopods less than 9 mm in length could not be sexed and were designated juveniles. Females were also examined for state of reproduction.

Observations and Results

The physical habitat of A. lira consists of 3 lakes of deep phreatic water which occupy passages developed along bedding planes in strata dipping ca. 67° NW (Fig. 2). The fissure lake is 165 m NNE of the cave lakes, and, although the lakes were not physically connected by scuba divers, all presumably share the same boyd of phreatic water. The water temperature varied only slightly during the year; the range in the east lake was 11-12.5°C and in the fissure, 12-14°C. Temperature differences did not appear to correspond closely with change of seasons. Organic material (usually wood) was present in all 3 lakes but was more abundant in the fissure. The isopods were usually relatively common in the east lake and the fissure but very rare in the west lake. Troglobitic amphipod crustaceans, Stygobromus stegerorum Holsinger, also inhabit the lakes but were much less common than the isopods.

There was a wide variation monthly in numbers of isopods attracted to the bait in both the cave lake and fissure (Fig. 3). The mean size (length) varied also, but greater fluctation was recorded in the fissure population (Fig. 3). Seasonal variation in size was less than that recorded from month to month in both populations, although a rather sharp decrease was noted in the fissure samples from late summer (Sept. 1980). The mean length of the animals from the fissure tended to be slightly greater throughout the year.

The size frequency histograms (Figs. 4, 5) probably give the best estimate of the population structures. The size range of the 2 populations combined was 3.5-21 mm, but the majority of animals fell within the range of 9-16 mm. Females greatly outnumbered males throughout the year. Juveniles were absent from both populations in the fall sample, but were present in the cave lake samples during the following 3 seasons. Juveniles did not appear in the fissure sample until spring but were present again in summer. With the exception of the appearance of juveniles, the structure of the cave lake population remained relatively stable. The structure of the fissure population, however, although relatively stable during fall, winter and spring, shifted to smaller individuals in late summer (Figs. 3, 5). The appearance of juveniles approximately mid-way through the year and the shift to a smaller size structure in one of the populations probably signaled the recruitment of young isopods into the population and may also, with more careful analysis, indicate something about reproductive timing in this species. However, as pointed out below, the lack of ovigerous females makes it difficult to reach any conclusions about reproductive cycles.

Females with brood plates or pouches were not found in the seasonal samples and because of this, larger females were dissected to determine whether they were brooding eggs internally as has been occasionally reported for other cirolanid isopods (see Bowman, 1971). The results were negative except that a few females from the fissure contained tiny, spherical structures (ca. 0.1-0.3 mm diameter) believed to be oocytes. Because most isopods brood their eggs externally, the absence of females with brood plates is surprising. Ruling out ovoviviparity for the time being because fertalized eggs or embryos were absent internally, we have tentatively concluded that reproducing females are probably rare and either do not forage in areas accessible to sampling or for some reason are not attracted to bait.

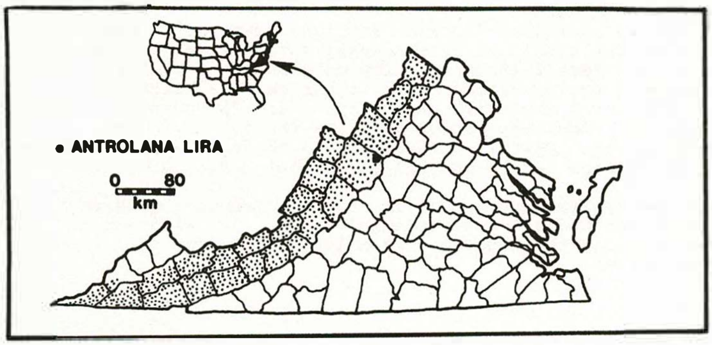

Figure 1. Range of Antrolana lira in Virginia, U.S.A. Shaded area indicates Appalachian Vally and Ridge province.

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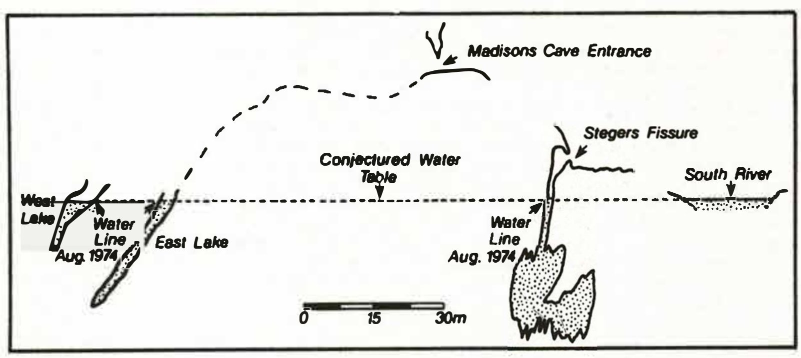

Figure 2. East-West profile section showing relationship of lakes and entrance of Madisons Saltpetre Cave, Stegers Fissure, South River and conjectured water table. From overland survey by J.A. Estes and G.D. Corbett, 24 Aug. 1974, and underwater survey by D.G. Whall and K.E. Wark, Dec. 1980.

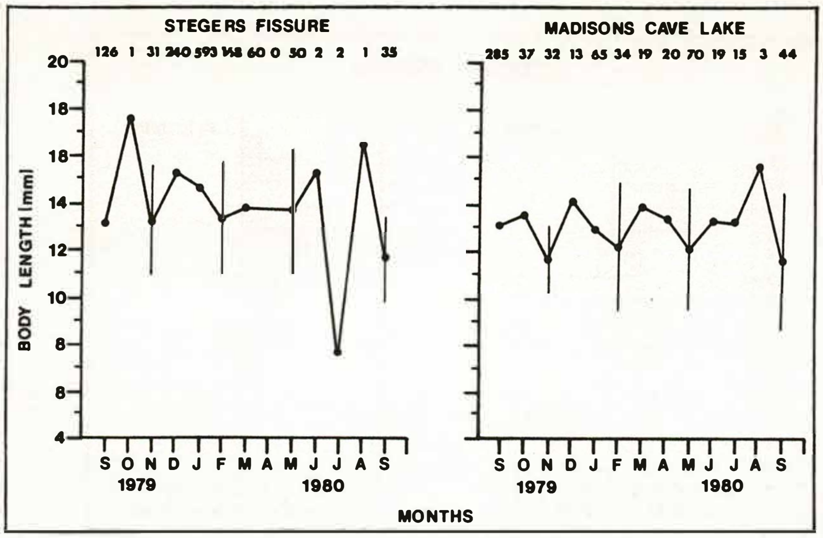

Figure 3. Monthly variation in length of Antrolana at 2 stations as indicated. Dots represent means; bar lines represent 1 standard deviation above and below the mean for seasonal samples taken in Nov. 1979, and Feb., May and Sept. 1980. The numbers of specimens sampled each month are indicated at the top of the figure.

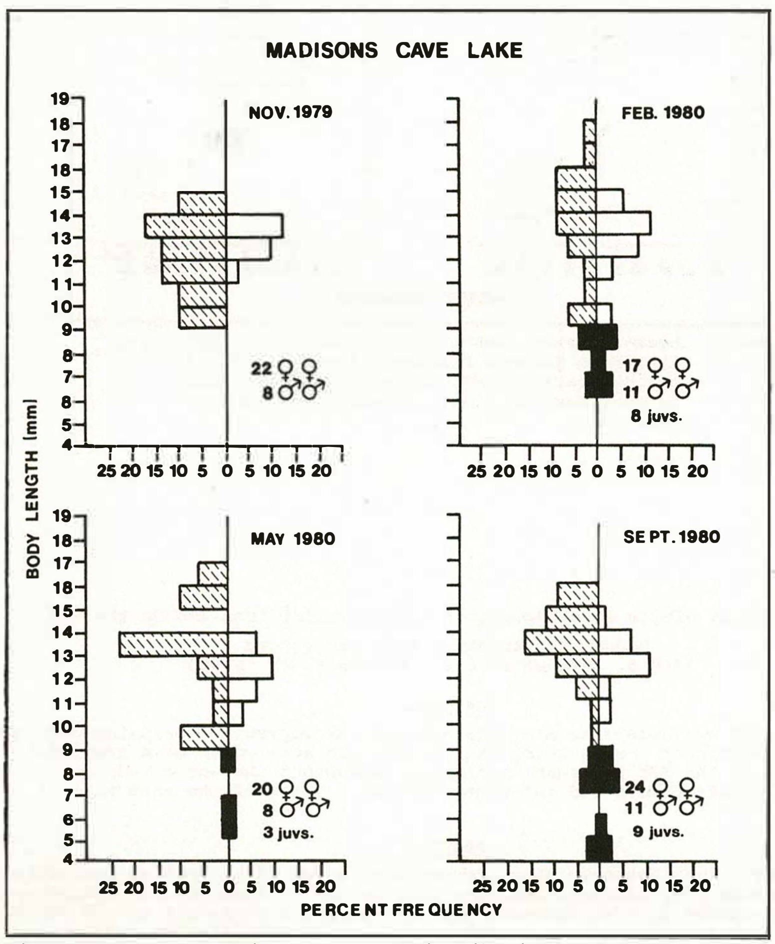

Figure 4. Seasonal size frequency distribution of Antrolana lira from lake Madisons Saltpetre Cave. Females shown by hatched bars to left of vertical line, males by open bars to right, juveniles (<9.0 mm) blackened.

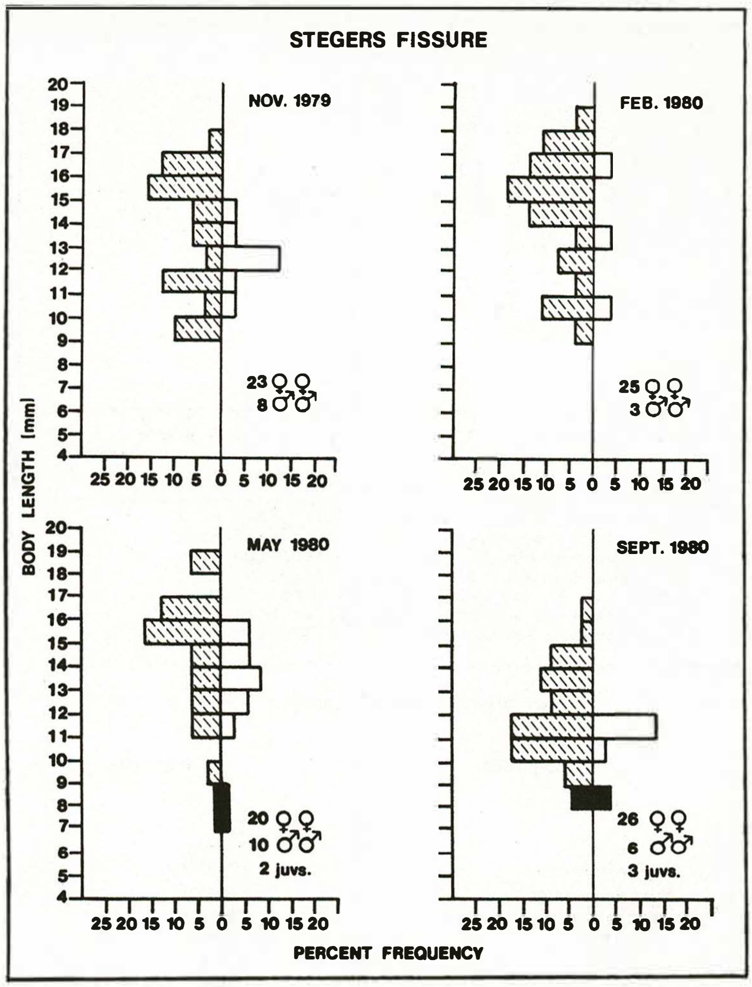

Figure 5. Seasonal size frequency distribution of Antrolana lira from Stegers Fissure. Females shown by hatched bars to left of vertical line, males by open bars to right, juveniles (< 9.0 mm) blackened.

A Brief Look at Single Rope Techniques and Equipment from Around the World

Donna Mroczkowski & Niel Montgomery
1218 S. Marguerita Ave., Alhambra, CA 91803

Abstract

Since its beginning, SRT has undergone many changes and developments - bringing onto the scene a variety of techniques and equipment - some which have lasted and some which have completely disappeared. This paper deals with much of the SRT equipment available throughout the world today, including how it is being tested, both by the manufacturers and interested cavers. A few of the more popular climbing systems will also be mentioned.

Résumé

Depuis son début la SRT a subi beaucoup de changements et s'est développeé en introduisant une variété de techniques et d'equipements-pour lesquels certains sont restés et d'autres ont complétement disparu. Cet article donne une description de l'equipmement SRT se trouvant aujourd'hui sur le marche dans le monde; avec les différents tests faits à la fois par le fabriquant et les spéléologues intéressés. Quelques unes des techniques d'escalade les plus populaires sont également mentionnées.

Fold Development in the Anticlinorio Huizachal-Peregrina and Its Influence on the Sistema Purificacion, Mexico

Louise D. Hose
Geology Department, California State University, Lose Angeles, 5151 State University Drive, Los Angeles California 90032, U. S. A.

Abstract

Sistema Purificacion in northeastern Mexico is developed in a thick sequence (more than 400 meters) of middle Cretaceous carbonates, the Tamaulipas and Tamabra Formations. The units were formed in a basinal to peri-platform environment near the Plataforma Valles - San Luis Potosi, allarge carbonate platform that was simultaneously developing to the south and southwest. Much of the material in the Tamabra Formation was derived from turbidite and debris flows off of the the platform.

The cave system is situated on the west flank of the Anticlinorio Huizachal-Peregrina in the northern portion of the Sierra Madre Oriental. Formed between the Late Cretaceous and the Eocnen Epoch, during the Laramide Orogeny, the anticlinorium is one of the many folds that make up the Sierra Madre Oriental. Associated with the regional structure are large concentric folds complemented by smaller kink and chevron folds on the flanks. Few faults resulted from this deformation.

Strong joint sets, trending N5W and N85E, parallel and perpendicular to the regional fold trend, have provided zones of higher permeability and enhanced karst conduit development. Passages in Sistema Purificacion are developed predominantly along these joint sets. Much of the development of the cave system has been controlled by a large syncline and anticline, numerous smaller kink folds, with axes parallel to the regional trends and accompnaying axial fractures. The sumps in the lowest parts of the cave represent a perched water table, the result of underlying impermeable shale beds and the synclinal trough in which it is developed.

Zusammenfassung

Sistema Purificacioń in nord-ost Mexico ist in dicken (mehr als 400 Meter) Schichten entwickelt, die aus Kreide-Karbonaten, den Tamaulipas und der Tamabra Formation bestehen. Dies Einheiten wurden in Beckengegenden geformt nahe der Platforma Valles-San Luis Potosí, einem grossen Karbonat Plateau, das sich zur gleichen Zeit im Süden und Südwesten entwickelte. Viel von dem Material in der Tamabra Formation stammt vom truben Fluss und Einsturzen aus dem Plateau.

Das Höhlensystem liegt an der Westflanke der Anticlinorio Huizachal-Peregrina im nordlichen Teil der Sierra Madre Oreintal. Das Antiklinorium ist eine von vielen der grossen Falten, aus denen die Sierra Madre Oriental besteht und wurde zwischen der Späten Kreide und der Eozänischen Epoche qährend der Laramide Orogeny geformt. Verbunden mit dieser regionalen Struktur gibt es grosse konzentrische Falten zusammem mit kleineren Knicken und Chevron Falten an den Flanken. Wenige Verwerfungen resultierten aus dieser Deformation.

Starke conjugale Verbindungen, die sich N&W und N85E parallel und recht-winklig zur Faltenrichtung halten, liessen Zonen mit hoher Durchlässigkeit und angehobener Karst Enwicklung entstehen. Durchgänge im Sistema Purificacíon wurden vorzüglich entlang dieser Verbindungen entwickelt. Die Entstehung des Höhlensystems wurde hauptsächlich von zwei grossen, knozentrischen synkline-antikline Falten, zahlreichen kleineren Knickfalten mit Achsen parallel zur geionalen Richtung und damit verbundenen axialen Frakturen kontrolliert. Lange lineare Durchgänge entwickelten sich entlang oder nahe synklinalen und antiklinalen Achsen. Die Schlammgrube im untersten Teil der Höhlen representiert einen gehobenen Wasserspiegel, der das Result der unterliegenden Tonschieferschichten und der synklinalen Rinnen, worin sie gebildet sind, ist.

* * *

Sistema Purificacion, the longest known cave in Mexico and the 18th longest in the world, is located in the northern protion of the Sierra Madre Oriental in northeastern Mixico (Figure 1). In addition to its world-class surveyed length of 38 kilometers, the system's total depth of 895 meters is the second deepest known in the Western Hemisphere. The potential for extending both the known length and depth of the system by further exploration and survey is excellent.

The cave is developed in a thick section of carbonates within a mountain range that extends two kilometers above the Gulf of Mexico coastal plain. The carbonates were deposited in a basinal to peri-platform environment during the middle Cretaceous while contemporaneous development of the Plataforma Valles-San Luis Potosi, a large carbonate platform, occurred to the south and southwest. The upper levels of Sistema Purificacion are formed in the Tamabra Formation, a thick sequence of autochonous mudstone, massive allochthonous channelized debris flows, bedded allochthonous debris flows, and turbidity currents deposits of dolomite and limestone primarily derived from the platform (Hose, in prep.).

The middle and lower levels of the system are in the Tamaulipas Formation, a unit of limestone and minor quantities of interbedded shale representing a long, uninterrupted period of quiet, basinal deposition. The limestone is a fine calcarenite to calcilutite. It is a nearly pure carbonate with a low initial permeability. The Taraises and La Caja Formations are sequences of interbedded limestone and shale below the Tamaulipas Formation. While no cave has been found in these units, the water from Sistema Purificacion apparently passes through them and emerges at the La Caja-La Joya contact (Hose, in prep.). The La Joya is a Jurassic flysch deposit.

The cave-forming tendencies of the limestone unit varies. Some parts of the heterogeneous Tamabra Formation are more susceptible to conduit-development than others. The nearly homogeneous, thick-bedded Tamaulipas Formation restricts passage development except along fractures. The inhibited conduit development characteristics of the underlying Taraises and La Caja Formations and the impermeable shale beds in the La Joya Formation change the manner of groundwater flow. Conduits in the lower parts of the system are filled by water as flow is slowed, following smaller, more diffuse paths through the Taraises and La Caja Formations.

The cave system is situated on the west flank of the Anticlinorio Hizachla-Peregrina, one of many large folds that make up the Sierra Madre Oriental. The area was raised and folded between Late Cretaceous and the Eocene Epoch, during the Laramide Orogeny. The area has been tectonically stable since the Eocene.

Large thrust faults formed during the Laramide Orogeny throughout western North America and the eastern edge of the Laramide Thrust Belt is approximately 20 kilometers west of the study area (Tardy et al., undated). Apparently, the stress that caused the large thrust faults to the west was accomodated by folding and bedding plane slippage in the Cretaneous beds in the Sistema Purificacion area. Many of the folds in the area die at depth along decollement surfaces. Except for slippages along bedding planes, faults are rare and have offsets of less than three meters. The few faults exposed in the cave have had only minor effects on passage development. In three places, passages have formed along the trends of a fault. All other observed faults cross passages causing only a slight enlargement of the diameter of the passage or no effects at all.

The area is on the western flank of an anticlinorium and the overall dip of the beds is to the west. A large, second-order fold, the Sinclinal de Infiernillo is about 150 to 400 meters west of the western known edge of the system and is parallel to the dominant passage trend (Fibure 2). This fold has significant influence on the cave's development. As a direct effect, the trough formed by the fold combined with the underlying, less soluable formations and the impermeable La Joya Formation, has caused a perched water table represented by a series of sumps in the lowest known passages of the system.

Increased compressional stress with increased elevation along the limbs of the syncline has formed third- and fourth-order folds. The folding on the west limb is intense and seems to have inhibited significant cave development probably because the frequency of the folds prevents accumulation of water along specific paths. The folds on the east limb are less frequent and, generally, concentric with limbs of relatively low-angle dips. Because of the variability of the conduit-forming tendencies of the various rocks in the area, these folds have had a significant influence on the development of Sistema Purificacion.

In the middle and upper beds of the Tamabra Formation, chert beds up to 12 centimeters thick act as hydologic barriers, often forcing groundwater to the surface. However, fourth-order chevron folds in Sotano de la Cuchilla, a physically unconnected but probably hydrological part of the systems, have fractured the chert and allow infiltration of water and cave development.

The upper part of the system is formed in the Tamabra Formation. Passage development was influenced by both the lateral and stratigraphic changes in the unit but tends to follow the intersection of bedding planes and prominent joints or, in one case, a small fault, that trend approximately N85E. This trend is parallel to the regional dip and the upper cave becomes depper to the west.

A syncline and anticline in the middle part of the cave are parallel to the predominant N5W trend of the system. They are third-order folds that disappear along a decollement surface within the lower cave. On the surface, they are exposed in the village of Conrado Castillo. In two places, a near sump is caused by the trough formed by this third-order syncline and the nearly impermeable underlying Tamaulipas Formation. Just west of this trough, in the World Beyond, the water flow south along strike. This passage is nearly on the syncline's west-dipping axial hinge line and formed along parallel fractures in the top of the Tamaulipas limestone. Usable to pass through this unit, the passage continue along a low-gradient path to Lisa's Lampfall, where the passage changes dramatically. The main passage trends to the west and northwest, rapidly dropping in elevation and stratigraphic levels. Remaining in the east-dipping limb of the folds, the water follows a path through the thick-bedded, nearly homogeneous Tamaulipas Formation along fractures that are parallel and perpendicular to the regional fold trend. Presently, the water follows a younger, similar path along fractures a few hundred meters to the north.

The water and most of the cave follow fractures in the limestone until reaching the decollement surface below the third-order folds. The slippage has fractured the rock, also parallel to the regional trend, and much of the lower-half of the middle cave is formed along the intersections of joints and the decollement surface. The cave passes under the anticline's axial hinge which is exposed only in passages and rooms where ceiling collapse has resulted in exposing beds above the level of solutional enlargement.

The lower part of the system, Cueva de Infiernillo, is in the lowest section of the Tamaulipas Formation in uniformly west-dipping beds. Most of the known passages are part of an irregular network-type maze cave, probably formed by floodwater recharge as described by Palmer (1975). This area is appropriately named the Confusion Tubes. Most of this part of the cave is formed along hte intersections of joints, or in two places small faults, and bedding planes.

The lowest known points in the cave are four sumps where water levels have been observed to fluctuate more than 64 meters in elevation but remain approximately level with respect to each other. They apparently are the result of perchment caused by the poor conduit-forming character of the underlying Taraises and La Caja Formations, the impermeable La Joya Formation, and the trough created by the Sinclinal de Infiernillo.

The variability in the stratigraphy, the folds, and the joints resulting from the folding have been primary factors influencing the development of Sistema Purificacion. The joint sets trend N5W and N85E, parallel and perpendicular to the regional fold trend and were probably produced during the Laramide Orogeny. Since the Late Cretaceous, 1200 to 1500 meters of overburden have been removed from above the cave (Carrillo B., 1961). The release of the lithostatis stress has probably had a significant effect on enlarging joints during isostatic rebound. Throughout the cave, the intersections of joints and bedding planes control the path of development.

Acknowledgements

My thanks to Peter Sprouse, Terri Tracey, David MacKenzie, and others in the Proyecto Espeleologico Purificacion and the Association for Mexican Cave Studies for assistance in the field and providing survey data on the system; to Gerald L. Atkinson, Thomas R. Strong, and Dr. Perry L. Ehlig for assistance in the field and many helpful suggestions and discussions; to Dr. Diego A. Cordoba and Dr. Zoltan de Cserna of the Instituto de Geologia for providing aerial photographs, geologic maps, and official approval of my work; and to the National Speleological Society Research Advisory Committee and the Graduate Research Grants Committee of the Associated Students of California State University, Los Angeles for grants supporting my field work.

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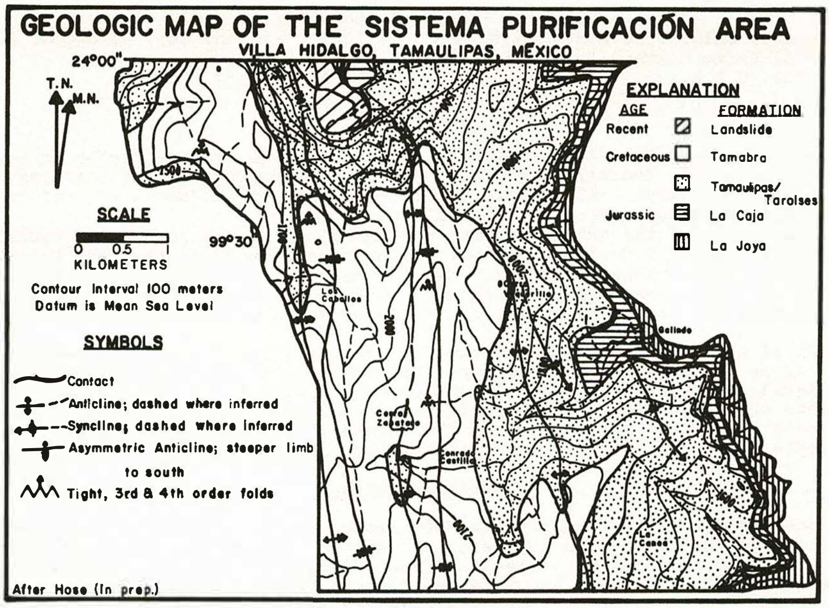

Figure 1 - Geologic Map of the Area

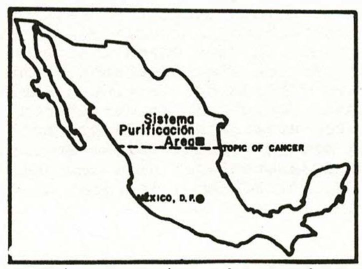

Figure 2 - Location of Map of Mexico

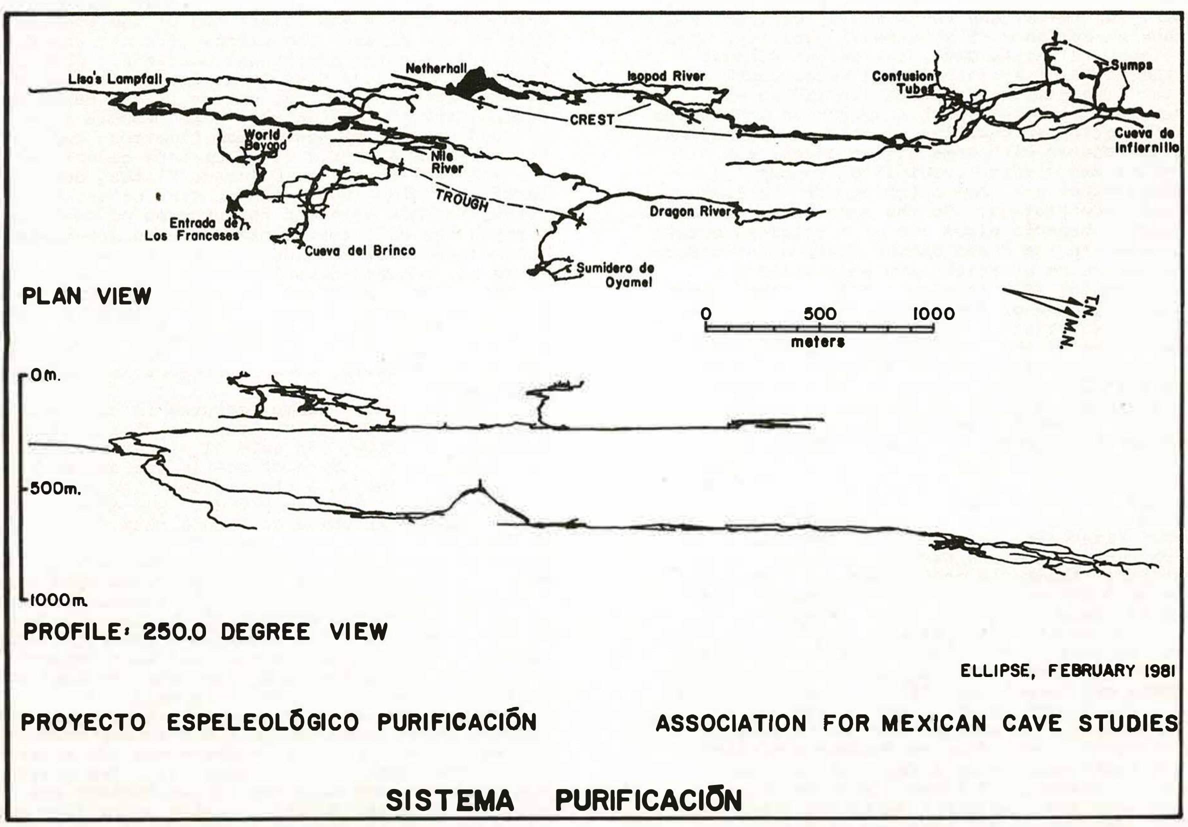

Figure 3 - Maps of the Sistema Purificacion

The Genetic Relationship Between Breccia Pipes and Caves in Non-Karstic Terranes in Northern Arizona

Louise D. Hose and Thomas R. Strong
Geology Department, California State University Los Angeles, 5151 State University Drive, Los Angeles, CA 90032, U.S.A.
1134 S. Holland St., Lakewood, CO 80226, U.S.A.

Abstract

Caves and pits in the Late Paleozoic formation of the Colorado Plateau region in northern Arizona are the result of collapse into underlying voids. One of the largest of these features is Paiute Cave, the second-deepest cave in Arizona (-151 meters). At least some of the caves are second-stage collapse features associated with previously developed breccia pipes.

Prior to the deposition of the Pennsylvanaian Watahomigi Formation, extensive cavers development took place in the Mississippian Redwall Limestone. Deposition throughout the Late Paleozoic and Mesozoic left 1800 to 2600 meters of sediments over the Redwall. Blocks from the overlying beds collapsed into the voids, sometimes creating breccia pipes extending hundreds of meters above original caverns. Water flowing through the pipes and in the Redwall conduits removed the soluble material within the collapsed debris.

With the uplift of the Colorado Plateau during the Tertiary Period, the groundwater base level became progressively lower in the Paleozoic section. Dissolution of calcareous material in the pipe occurred. As the base level approached the Redwall Limestone, dissolution of that unit was revitalized. Further collapse into the enlarged voids was initiated. These processes probably continue in areas where the present groundwater level is near the top of the Redwall, such as the Paiute Cave area. Caves now exist about 600 meters above the original voids in the Redwall Limestone.

Zusammenfassung

Höhlen und Gruben in den spät-päleozoischen Formationen in der Colorado Plateau Gengend von Nord Arizona sind das Resultat von Einbruchen in die unterliegenden Höhlungen. Eines der grössten dieser Vorkommen ist die Paiute Höhle, die zweit-tiefste Höhle in Arizona (-151 m). Manche dieser Höhlen sind zweit-stufige Einbrüche, die mit früher entwickeltem Breccia Röhren in Zusammenhang stehen.

Vor der Deponierung der Pennsylvanischen Watahomigi Formation entwickelte sich ein ausgedehntes Höhlensystem im Mississippianischen Redwall Kalkstein. Während der späten päleozoischen und der mesozoischen Periode wurden 1800 bis 2000 Meter Sedimentschichten deponiert. Blöchke aus den oberen Schichten brachen in die Höhlungen und so entstanden manchmal Breccia Rohren die mehrere hundert Meter tiefer als die originalen Höhlungen waren. Das wasser, welches durch die Röhren und die Redwall Schichten floss, entfernte alles wasserlösliche Material von dem eingebrochenen Trümmer.

Mit der Hebung des Colorado Plateaus während der Tertiären Periode sank der Grundwasserspiegel fortschreitund tiefer in die päleozoischen Schichten. In der Röhren wurde kalkiges Material aufgelöst. Als der Wasserspiegel die Redwall Schicten erreichte, wurde die Auflösung dieses Gesteins new belebt. Einbruch in die vergrösserten Höhlungen begann erneut. Diese Prozesse gehen wahrscheinlich noch heute in Gegenden weiter, wo der jetztige Grundwasserspiegel nahe dem oberen Ende der Redwall Schichten liegte wie zum Beispiel in der Paiute Höhlen Gegend. Höhlen existieren heute ungefär 600 Meter über den originalen Höhlungen in dem Redwall Kalkstein.

* * *

Several caves and pits in the Colorado Plateau region of northeastern Arizona are in non-karstic, Late Paleozoic formations. They result from collapse into underlying voids, and their walls, ceiling, and floors show no evidence of solutional activity. One of the largest in Paiute Cave, the second-deepest cave in the state of Arizona with a total depth of 151 meters. Two similar features are Indian Pit and Ah Hol Sah, also near Marble Canyon on the Navajo Indian Reservation (Figure 1). In the same area, and directly associated with some of the caves, are breccia pipes and surface subsidence troughs.

Breccia pipes are common throughout the southwestern Colorado Plateau. To the east and north of Marble Canyon, breccia pipes are of a volcanic origin (Hack, 1942). In the Grand Canyon there are numerous breccia pipes, some of which have been mined for copper and uranium (Billingsley, 1974). These pipes result from collapse of everylying rocks into voids created by dissolution of the Mississippian Redwall Limestone. None of the breccia pipes in the Grand Canyon is known to extend below the base of this unit, and therefore, they cannot be of a volcanic origin. The breccia pipes in the Marble Canyon vicinity lack volcanic material, their clasts are derived from the adjacent or stratigraphically higher beds, and the clasts are angular even near the pipe boundaries. For these reasons, the pipes are believed to be the result of collapse.

The lowest cavernous unit below the caves is the Redwall Limestone, approximately 600 meters below the entrance of Paiute Cave (Figure 2). It is a fine-grained, thick- to massive-bedded limestone with some dolomitebeds. The Redwall contains many caves and is about 175 meters thick in Marble Canyon. Prior to the deposition of the Pennyslvanian Watahomigi Formation, the oldest unit of the Supai Group, extensive karst developed in the Redwall Limestoen (McKee and Gutschick, 1969). In many areas a sinkhole plain formed on the surface, and large caverns developed. Throughout the Late Paleozoic and the Mesozoic, deposition of various sediments buried the karst surface to a depth of 1800 to 2600 meters. Stopping of blocks from the overlying beds into the previously developed voids was initiated. Because of the enhanced premeability in the brecciated zones, plumbing systems developed that allowed groundwater to flow through the pipes at greater rates than through the surrounding country rock. The pipes were enlarged by continuing dissolution of carbonate clasts and cement and of the Redwall at the base of the pipes. The process further undermined the area and promoted additional collapse. Changing water chemistry may have dissolved and redeposited the pipe matrix materials and the cement in the sandstone clasts several times. Ultimately, some breccia pipes nearly reached the top of the Kaibab Limestone and were consolidated by a matrix of calcareous cement and sand.

The uplift of the Colorado Plateau during the Tertiary Period led to the removal of the Mesozoic strata in this area and the erosion of deep canyons through the Paleozoic rocks. As the groundwater level became progressively lower in the Paleozoic section, there was renewed dissolution of calcareous material in the pipes, including the cement bonding the clasts. As the base level approached the Redwall limestone, dissolution in this unit was revitalized. Since the Colorado River in Marble Canyon is presently near the top of the Redwall, these processes are probably still continuing.

Large, linear slump features in the surface exposures of the Kaibab Limestone indicate underlying collapse activity. In several places near Paiute Cave and Indian Pit, strata of nearly horizontally-bedded Kaibab Limestone have slumped into troughts up to 10 meters deep and 50 meters wide. One of the most prominent slumps in the area trends N68E in two segments separated by flat-lying beds. The segments are terminated at the eastnortheast by Paiute Cave and Indian Pit. At Paiute Cave a previously-developed breccia pipe was less competent than the surrounding wallrock, possibly due to the removal of the calcareous cement in the matrix, and the brecciated rocks collapsed more readily. Paiute Cave is the void left between the predominantly brecciated breakdown and the more competent wallrock (Hose and Strong, in press).

Throughout much of the cave there is no original bedding left in the Kaibab and Toroweap formations. The walls and ceiling in those areas are a breccia that has obliterated bedding (Figure 3). The clasts in the breccia above the Kaibab-Toroweap contact are derived entirely from the Kaibab. Clasts below that contact are a mixture of rocks derived from the Kaibab and Toroweap formations. The clasts are predominantly subangular. The breccia has a clast-supported framework with a calcareous, sandy matrix. Although not indicated in Figure 3, this breccia pipe is exposed across the ceiling of the passage from northeast to southwest, and collapsed breccia blocks are on the floor immediately below the entrance.

The only distinctive structural feature within the cave, otherthan the pipe, is a fault wall approximately 115 meters east of the entrance. Slickensides indicate vertical movement, but there is no displacement of the wall relative to surrounding beds. The slickensides were caused by local stoping along a joint and not by tectonic movement.

Paiute Cave is one large room. The floor is entirely breakdown and slopes down from the entrance area at about 45° angle. In plan view, the room has a traversable length of 165 meters. The edge of the room throughout the cave is defined by the convergence of the ceiling with the breakdown floor. The cave extends through the lowest 66 meters of the Kaibab Limestone, the entire Toroweap Formation, a sandstone and argillaceous limestone with some thin, discontinuous gypsum lenses, and most of the Coconino Sandstone, a siliceous, well-sorted, cross-bedded, eolian deposit. The Hermit Shale and the Supai Group are not exposed in the cave as the breakdown has apparently filled the voids within them. The top of the Redwall Limestone is approximately 450 meters below the lowest explored part of Paiute Cave.

Indian Pit has a vertical entrance drop of 30 meters and reaches a total depth of 69 meters. It is also one large room, but unlike Paiute Cave, the Toroweap Formation is not exposed, nor has breccia been found within the cave. However, aerial photographs reveal a nearby breccia pipe. Although the evidence is less conclusive than at Paiute Cave, we believe Indian Pit is presently forming by the mechanism previously described and is probably the site of an older karst breccia pipe that has collapsed and the remnants are now covered by breakdown.

Ah Hol Sah is another pit in the Marble Canyon area. It is approximately 150 meters in diameter and 50 meters deep with no traversable cave passage. It has also formed by collapse of the Kaibab Limestone, exposed on the surface, into an underlying void. Unlike the two nearby caves, neither slumping nor breccia has been noted in association with this feature.

Conclusions

Caves and pits on the Navajo Indian Reservation in northeastern Arizona are developed in non-karstic terranes and result from toping of overlying rocks into older caverns developed in the Redwall Limestone. At least one, Paiute Cave, is a second-generation stoping feature resulting from the renewed collapse of a karst breccia pipe. Part of the collapse was concurrent with further dissolution of the Redwall and carbonate clasts and matrix material in the breccia. It is likely that this process is still active at the present time.

Acknowledgments

The authors wish to express their appreciation to the members of the National Speleological Society who helped survey Paiute Cave and to Dr. Peter W. Huntoon and R. Mark Maslyn for helpful discussions and suggestions.

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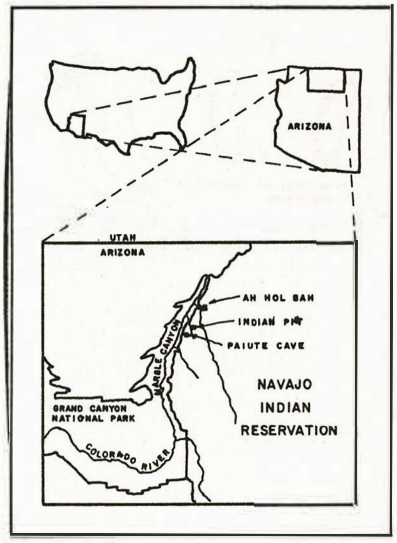

Figure 1. Location map.

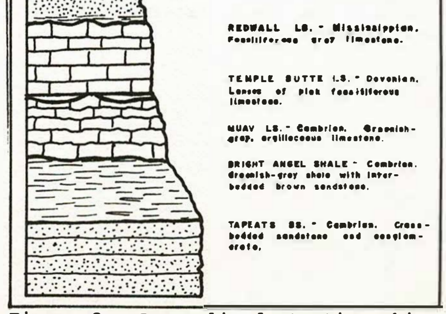

Figure 2. Generalized stratigraphic column (after Hamblin, 1968).

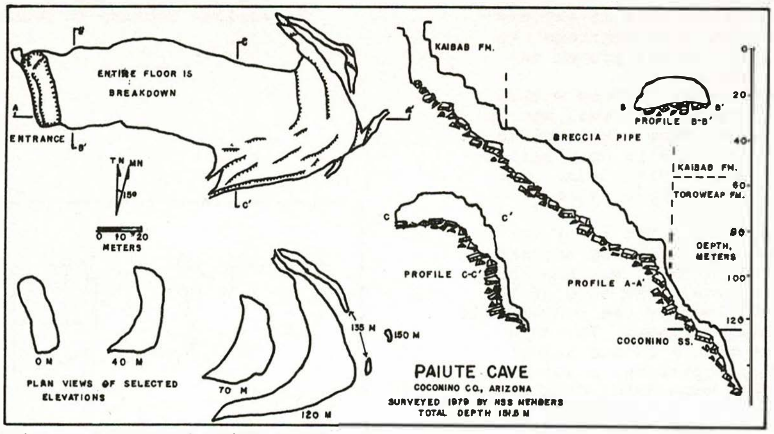

Figure 3. Map of Paiute Cave.

Facial Reconstruction of an Easter Island Skull

G. L. Nogrady, K. Szekeley and K. Arpas
Univeristy of Montreal, Canada, Hungarian Cave Protection Agency,
Budapest and National Museums of Hungary

Abstract

The Medical Expedition to Easter Island in 1964-65 included beyond medical studies also a soil microbiology project. At the occasion of one soil sampling operation, an apparently man-made mound was spotted. Hoping that the interior chamber - if any existing - will yield a quite undisturbed sample, it was decided to enter. One of the boulders gave way, leaving a passage, which lead to a cavity, open on the top. In the centre there was a skull, but no other skeletal remains. Later, in Canada, it was identified as that of a male Polynesian. Age determination was not attempted, because it would have led to the entire destruction of the sample. Instead, a silicone rubber mould and an epoxy cast were prepared and a facial reconstruction was performed. When completed, it depicted a man in his thirties. The same estimate was made independently based on the bone structure. Thus, this sculpture represents a unique reconstruction of Polynesian physiognomy of a man who lived once on Easter Island. Caves provide many skeletal findings related to man and this method would permit to reconstruct the physiognomy of long extict races, which is missing from illustrations in prehistoric cave art.

Résumé

En plus des études médicales, l'Expedition médicale à l'île de Pâques comprenait un projet sur la microbiologie du sol. A l'occasion d'un échantillonnage du sol on a observé une butte faite apparemment par l'homme. Espérant trouver une chambre intérieure (s'il y en a) où nous pourrions trouver un échantillon de sol vierge, nous avons décidé d'y entrer. Un bloc a laissé un passage menant à une cavité avec une ouverture au plafond. Au centre il y avait un crâne, sans aucun autre ossement. Plus tard, au Canada, il a été identifié comme originaire d'un mâle polynesien. La détermination de l'âge n'a pas été tentée car elle aurait demandé la destruction totale de l'échantillon. Au lieu, un moulage de caoutchouc silicone et une réplique de résine époxy a été préparée et la reconstruction faciale exécutée. Quand elle fut achevée, elle montrait un homme dans la trentaine. La même estimation a été conclue indépendamment basée sur la structure osseuse. Ainsi, cette sculpture représente une reconstruction unique de la physionomie polynésienne d'un homme qui a véçu jadis à l'île de Pâques. Les cavernes permettent à l'homme d'effectuer de nombreuses fouilles squelettiques d'homme et cette méthode pourrait permettre la reconstruction de la physionomie des races disparues depuis longtemps et qui manquent dans l'illustraction de l'art préhistorique des cavernes.

Some Characteristics of Karst Hydrology in Guizhou Plateau, China

Song Lin Hua
Institute of Geography, Academia Sinica, Beijing, China.

Abstract

Guizhou plateau is about 1000-1500 m above sea level. It has a subtropical climate, warm and humid. Carbonate rocks cover c. 110,000 km^2, 64% of the total area of Guizhou province. Regional geological structure is very complicated. Since Yenshan Movement (Triassic) and especially in the Quarternary, Guizhou plateau has been continuously exposed to erosion by intermittent uplift. All these conditions are very favourable to the development of karst geomorphology hydrology.

Some main features of karst hydrology are as follows: (1) karst ground water is directly fed by meteoric water, it fluctuates with the meteorologic factors. (2) Surface and subsurface drainage systems have a convex profile. In the upper reaches, the gradient is gentle and valleys have a wide "U" shaped cross section, a narrow "U" shape in the middle reaches, and narrow and deep "V" shape with high gradient in the lower part. At the knock points, waterfalls and rapids are usually formed. (3) The development of karst drainage systems shows a series of superimposed levels, each deeper than the last. (4) Vertically, the circulation of karst groundwater may be divided into three zones, vertical, horizontal and deep circulations. Some big caves extending deep beneath the drainage base resulted from deep circulation. (5) Capture is common between the surface and subsurface drainage systems. (6) The main hydrochemistry patterns are HCO_3-Ca, Mg or HCO_3, SO_{4-}, Ca, Mg. Water qualities in different carbonate rocks are very different, hardness of dolomite water is higher than of limestone water.

Introduction

Guizhou plateau, with a mean altitude of 1000-1500 m above sea level, forms the eastern part of Yunnan-Guizhou plateau (Fig. 1). It is the one of the best karst development provinces in China.

Carbonate rocks cover about 110,000 Km^2, 64% of total area of Guizhou province. The total thickness of carbonate rocks which were deposited from Sinian Period to the Tertiary is several thousand metres. Guizhou plateau has undergone several serious tectonic movements, and folds and faults are well developed.

Since Yenshan Movement (Triassic) created the basic geomophological framework of Guizhou plateau, it has been intermittently uplifted and continuously exposed to erosion. Since the Wuarternary, uplift has totalled at least 500-1000 m. Intermittent strong uplift of Guizhou plateau has caused the development of multiple levels or erosion surfaces and made the deep valleys of the Wujiang, Yuanjiang, Nanpanjiang and Beipanjing rivers as the regional drainage bases strongly cut down (Fig. 1).

Since the Quaternary, the climate has been warm and humid which greatly strengthens karst development. Today the climate is subtropical, with annual mean temperature 12-16°C, precipitation 1000-13000 mm.

The peculiar and marvellous karst landforms and hydrology have attracted geologists, geographers, tourists and others. The great geographers Xu Xia Ke (1586-1641), Wang Shi Xing, Te Wuang, Chen Ting and others investigated karst geomorphology and hydrology (Ju Ji We and Pan Fong Ying, 1979). More recently, Chen Su Pan (1954), Zeng Zhao Xuan (1964), Zhou Hui Xiang (1965) and others have done a lot of research work on karst geomorphology and hydrology. Recently Geographic Institute of Academia Sinica, Nanjing University, Guizhou Technical College, Guizhou Hydrogeological Team and other units have studied karst hydrology in detail and have got very good results.

Factors Affecting karst hydrology

The basic types of karst ground water in Guizhou plateau are voidfissure water and conduit or cavern water. Karst ground water within a certain catchment area collects and flows in a fixed course and drains at one or several points as springs. This kind of karst flow may be defined as a karst drainage system which may have both underground and surface sections or may be totally subsurface. In the process of development, the subsurface conduit is continuously enlarged and the conduit ceiling may consequently collapse and expose the conduit to form a surface flow. The unexposed part, or the underground section, caused by the surface stream sinking down into carbonate rock through a sinkhole is termed subsurface flow. The bigger subsurface flow may be called underground rivers with some properties of surface streams.

The development of karst hydrology in Guizhou is controlled by the following factors:

a. Lithology

The amount of calcite and dolomite in carbonate rocks caries with the evolution of geological history and depositional environment (Fig. 2). The degree of karstification of carbonate rocks is essentially determined by the amount of dolomite and insoluble materials; the weaker the karstification, the higher the content of dolomite (Jing Yu Zhang, 1962; Li Cui Zhong and Zhang Shou Yue et al, 1962; Rauch and White, 1977; Sweeting, 1979). Karst underground drainage systems are chiefly developed in the pure and thick limestones such as the Ordovician Honghuayuan Limestone, CArboniferious Huanglong-Maping Limestone, Permian Qixia, Maokou and Zhangxing Limestones and Triassic Yulongshan Limestone. There generally is void-fissure water in dolomite.

b. Geological structure

Geological structure is the dominant influence on the development of karst hydrology, by providing the best structural conditions for water circulation. In an anticline, the disperse flow is commonly formed, although sometimes conduit flow also occurs along faults. A Syncline is a good structure for collecting and storing water. There, karstification is very strong and large underground channels such as the Shilinguang cave could be developed (Song Lin hua and Zhang Yao Guang et al, 1978). In the nose pitching anticlines and axial closures of synclines or mid-limb sections of various folds, the fault structures and underground drainage systems are well developed. Sometimes subsurface drainages such as the Chaoshuihe system are formed in these structural settings even in dolomite in which karstification is usually very weak.

c. Drainage base

The changes of the drainage base greatly control the development and distribution patterns of water systems. In areas where the drainage base is relatively stable, the distribution pattern is dendriform or netted form such as the upper reaches of Huanghe underground drainage system. Large downward shifts of the drainage base caused by uplift and major valley downcutting will raise the underground water gradient and promote the water circulating, corrosion and erosion. In this case, the movement and distribution of ground water become extremely nonhomogeneous, the water flow mainly concentrates in the conduits. The intermittent downward movement of the base level results in the development and distribution of karst water systems with multi-levels and terraces. In the transitional zone between two terraces, the hydraulic gradient is steeper.

Some Features of Karst Hydrology in Guizhou Plateau

a. Water Table and Discharge Fluctuations

Because karst ground water is directly fed by meteoric water, i~~ts regime dep~~ends on the climatic factors. Though there is a Chinese word to describe Guizhou climate, "No three days without rain", it may be divided into rainy season and dry season according to distribution of rainfall in a year. The precipitation in rainy season is more than 80% of annual rainfall. The high level and discharge of karst ground water are also in the rainy season, the lowest in dry season. The ratio of highest to lowest discharge may reach over 100 for subsurface drainage, the ratio is big surface rivers such as Wujiang may be up to 50 (at Sinan Gauging Station in 1967). The fluctuation of the water table differs from place to place. For instance, in the upper reaches of Huanghe drainage system, it is several metres, but 54-90 m in the middle reaches. The regime of karst void-fissure water is very sensitive in response to rainfall, for example, the peak values of ground water table in some boreholes in Guiyang appear only 4 days after rain. The curves of both water table fluctuation and discharge have an irregular dogtooth shape.

b. Erosion Surfaces and Effects on Karst Hydrology

Guizhou plateau was tectonically stable for a long time ~~after t~~he basic geomorphological ~~framew~~ork formed during Yenshan Movement, and as a result the Daloushan erosive surface was formed (Fig. 3). Later the region underwent several elevations and stopages and new erosive surfaces were formed i.e. two Shanpen Stage surfaces. During the Quaternary, the strong uplift of the plateau caused Wujiang, Yuanjiang Nanpanjiang and Beipanjiang drastically to cut down and form the Xiagou (narrow valley) Stage surface (Fig. 3). The multiple levels of surfaces can give rise to several levels of local drainage bases. A good example is in Dejiang, the ground water systems in both Longtang valley and Jingtouba valley (both with altitude 700 m) drain into Dejiang basin with 500-600 m altitude, but the springs are about 5-15 m higher than the bottom of the basin. In the Quaternary, the strong uplift of the earth crust lead to the sapping and headward erosion of the drainage systems but the capacity and speed of the sapping and erosion of the branches were smaller than the main course. Therefore, the branch valleys hang above the main valley (Fig. 4), and sometime waterfalls of several dozen metres may be formed (Zhou Cheng Jie and Dai Chun Jing, 1962). Upstream of the knickest points of highest headward erosion the karst water system will keep their original features, for example, the Xiasi-Mawei part of the Huanghe underground drainage system in Dushan County is characterized by small hydraulic gradient, shallow water table, frequent alternation between surface flow and subsurface flow with a large channel, many deep karst lakes, some of them over 50 m deep, and a Fenglin-basin* landscape (Institute of Geography, Academic Sinica, 1977). The longitudinal profiles of karst drainage systems are convex in shape (antiequilibrium profile). The turning point of gradient is named as knick point. There are six knick points in Huanghe system (Song Lin Hua, 1979). The famous Huanggoushu waterfall is a knick point of Dabanhe River which is a tributary of Beipangjiang. The subsurface flow of the underground drainage system generally occurs where the hydraulic gradient is steepest (Group of Karst, Institute of Geology, 1979). One of the principle features of underground drainages on Guizhou Plateau is alternation of surface streams and subsurface streams, for example, Liuchonghe River sinks into underground about six times.

c. Deepening and Succession of Karst drainage systems

The uplift of the earth's crust causes karstification downwards as its main direction; and when it is stable, the main function of karstification is to widen its course. The alternation of uplift and periods of stability in the earth's crust result in interchange of vertical and lateral karstification, and lateral karstification widening and ramifying the lower parts of the channels formed by vertical development. The strongest karstification always takes place in the most favourable location in lithology and structure. Therefore, karst develops in time and space by deepening and a succession of levels. Take for example, Shantang underground river, Zhijin County, which has developed four levels of channels. The first and second levels are now dry, the third is a flood course, and the fourth, lowest channel, is a small modern river still developing downwards. The different levels of channels are connected with shafts (Ghizhou 114 Geological Team, 1978).

d. Zones of groundwater circulation

The movement of karst groundwater may be vertically divided into vertical, horizontal and deep conduit circulation zones (Zhou Shi Jie, Dai Chun Jiang, 1962; Yang Ming De, He Cai Hua, 1976). The thickness of the vertical circulation zone varies greatly from place to place. In the upper reaches of Huanghe underground drainage system it is only several metres, in the middle reaches about 54-90 m, in the lower reaches up to several hundreds of metres. The thickness of horizontal circulation is controlled by fluctuation of the ground water table. The deep circulation can reach down to several hundred metres below beds of major rivers, for instance, the 9.4 m high cave found by drilling about 220 m below Wujiang bed is the result of karst water circulation along faults.

e. Drainage capture

Capture is common between surface and subsurface karst drainage systems. For example, in Tianshengqiao (natural bridge) area (Fig. 5) at the first stage, Shuiliandong-Tianshenqiao underground river captured the Shanchahe surface river and made a meander of the river dry. Later, Gengjaba-Zianrendong subsurface river developed very quickly and seized the water from the upper part of Shanchahe. It is believed that the latter capture will eventually make the valley from Gengjaba to Zianrendong completely dry (Fig. 5). (Duan Zhi Chang, Chen Zhen, 1978). In Dejiang County, Naoshuiyan Subterranean drainage system pirates the water from Lengshuiyan system, and the underground watershed has been forced to move toward Lengshuiyan system (Song Lin Hua, Zhang Yao Guang et al., 1978).

f. Chemistry of karst water

The surface water strongly alternating with groundwater ~~causes hyd~~rochemistry differences to be small in vertical direction (Yang Ming De, He Chai Hua, 1976, Jan De Pu, Mo Zhong Da, 1978). Generally, the total dissolved solids content of karst water is less than 0.5 g/l (Group of Karst, Chengdu Geology College, 1962). The chemical patterns belong to HCO_3-Ca, Mg or HCO_3-Ca, Mg groups, the latter just occuring in gypsum limestone or in belts near sulphide minerals. According to regional hydrochemistry study, it has been found out that the karst water hardness in dolomite, 10-24 German degrees, is higher than that in limestone, generally less than 15. G.D, while the water hardness in deep buried dolomite may reach up to 66 G.D.

*Fenglin - a landform name given to tower karst in which the bases of the towers are contiguous or separate.

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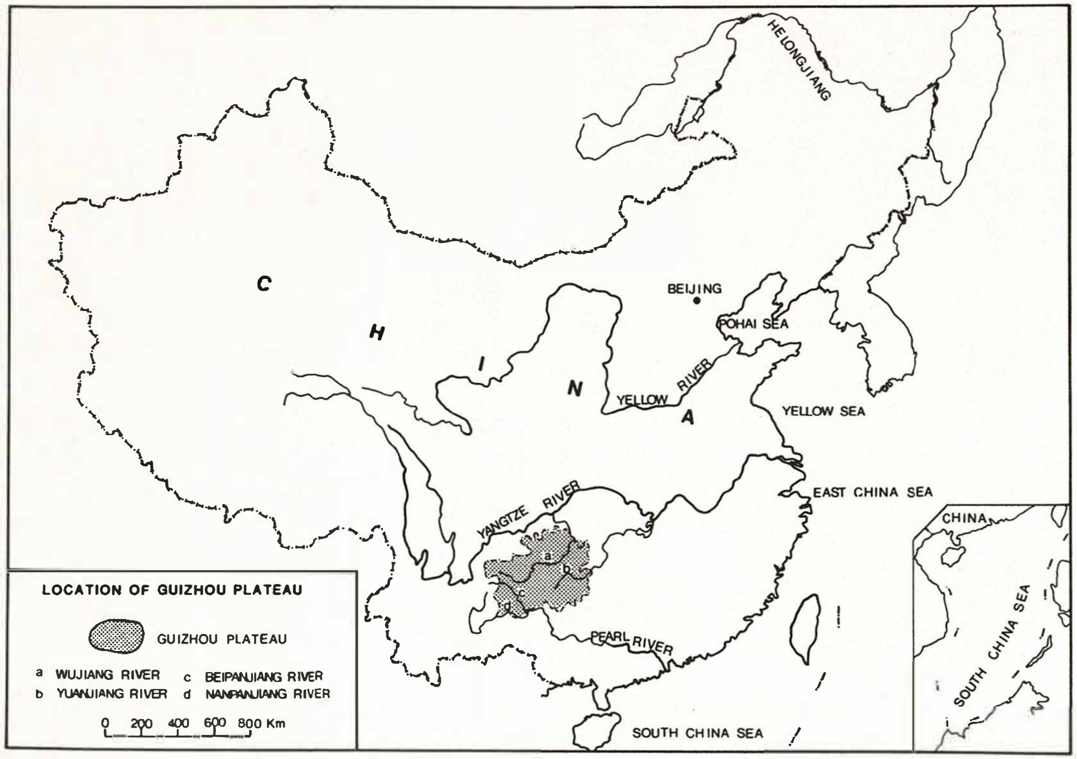

Figure-1

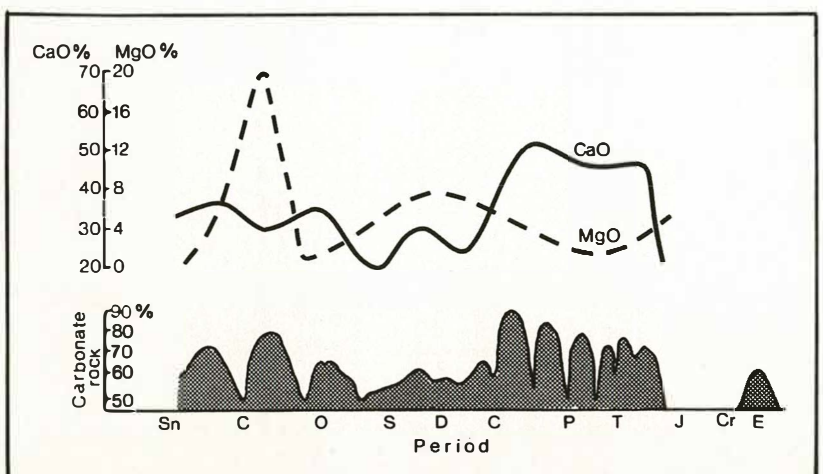

Figure-2 The contents of CaO MgO in carbonate rocks, Guizhou

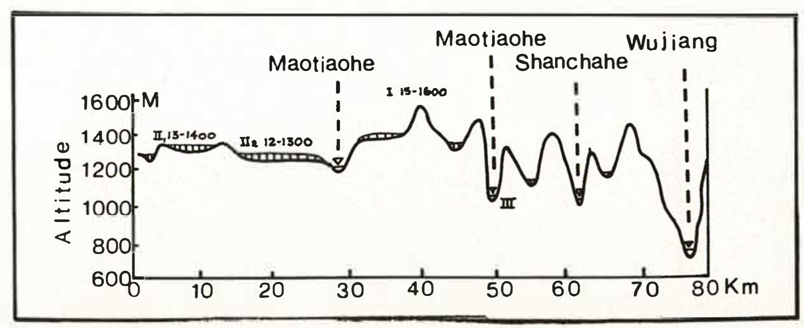

Figure-3 Geomorphological profile of Maotiaohe drainage basin. (From Zhou Cheng Jie et.al, 1962)

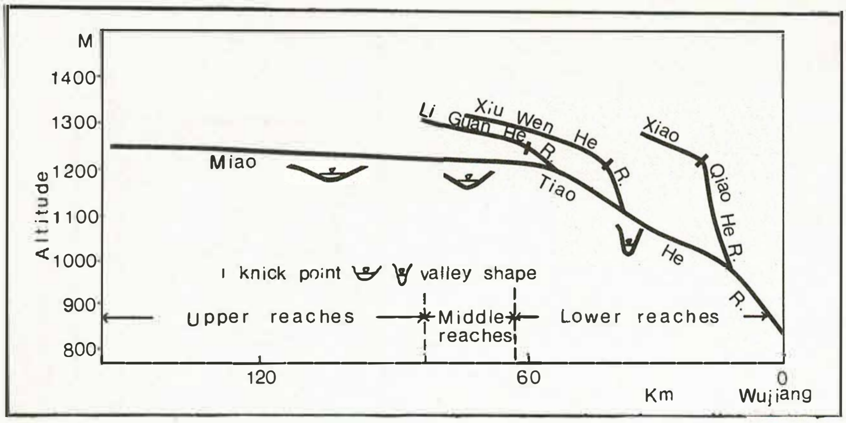

Figure-4 Longitudinal profile branch and major valleys, Maotiaohe River.

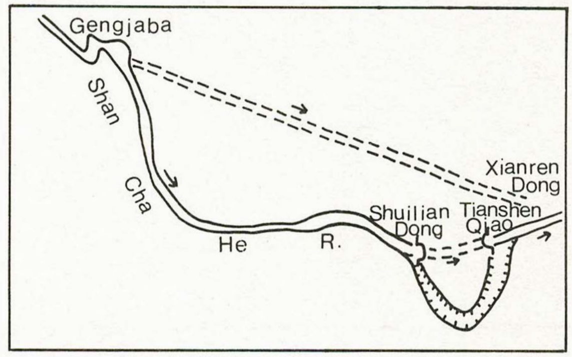

Figure-5 The capture between the rivers, Tianshenqiao area. ---- Underground river Dry valley (Based on Duan Zhi Chang et.al, 1978)

Mathematic Simulation of "Baric Airflow"

Jirí Botur & Antonin Jancarík
Institute of Geology and Geotechnics, Prague, Czechoslovakia

Abstract

Changes of air pressure in free atmosphere are one of basic causes for airflow in caves. In contribution a mathematic method of simulation of airflow generated in this way is described. Model is based on a premise of air compressibility and on definition of aerodynamic resistance. There are two methods of measurement of air pressure differences described and their accuracy is estimated. Results of computation are compared with those of measurements.

Résumé

Les changements de la pression de l'air dans l'atmosphére libre représentent une des causes fondamentales de l'ecoulement de l'air dans les cavernes. Das cette contribution, on décrit la méthode du modelage mathématique de l'ecoulement ainsi provoqué. Le modéle s'appuit sur la prémisse de la compressibilité de l'air et sur la définition de la résistance aérodynamique. On décrit aussi deux méthodes fondamentales de la mesure des différences de pression et on compare leur précision. Les résultats du calcul sont comparés avec les résultats réels, obtenus par mésurage.

Speleogenesis of Carlsbad Caverns and Other Caves of the Guadalupe Mountains

Carol A. Hill
Cave Research Foundation, Box 5444A, Route 5, Albuquerque, Nex Mexico 87123, USA

Abstract

Sulfur isotope data, whole rock analyses, and pH-dependence of the clay mineral endellite, $Al_2Si_2O_5(OH)_4 \cdot 2H_2O$, support the hypothesis that the caves of the Guadalupe Mountains, southeastern New Mexico, were dissolved primarily by sulfuric acid solutions. The gypsum blocks and native sulfur in the caves are significantly enriched in S^{32}: δS^{34} values as low as -21.1 indicate that the sulfur and gypsum are the end products of biological (Thiobacillus and Desulfovibro) oxidation and reduction reactions.

The general stratigraphic sequence of cave deposits is (oldest to youngest): limestone bedrock, endellitized clay, ~~spar, rounded~~ cobbles, orangish silts, primary gypsum blocks, breakdown, and speleothems. Clay and spar fillings have been truncated by large cave passages and date from an earlier solution episode. The spar record a slow-flow regime of supersaturated water in the aquifer, possibly contemporaneous with Pliocone Ogallala gravels and peneplain conditions.

As the Guadalupe Mountains were uplifted and tilted to the northeast in late Pliocene-early Pleistocene, hydrogen sulfide migrated updip into the Capitan reef from the gas and oil fields of the Permian Basin. It mixed with downward-moving oxygenated groundwater at the water table, thereby forming sulfuric acid. The acid dissolved the limestone, but insoluble, residual clay filtered out of suspension to the cave floor as finely laminated orange silts. Gypsum chemically precipitated on tope of the silts: $H_2SO_4 + CaCO_3 + 2H_2O \rightarrow HCO_3^- + H^+ + CaSO_4 \cdot 2H_2O\downarrow$. Laminations, microfolding, angular unconformities, breccia texture, and limestone inclusions within the gypsum blocks attest to precipitation and solidification mechanisms. Possible reflooding interrupted the final subaerial, speleothem-forming episode.

Résumé

Les points de repére des isotopes du soufre, les analyses de la roche totale, et la dépendance-Ph du minéral d'argile endellite, $Al_2Si_2O_5(OH)_4 \cdot 2H_2O$, corroborent l'hypothése que les grottes des Montagnes Guadalupe au sud-est du Nouveau-Méxique ont été dissoutes principalement par des solutions d'acide sulfurique. Les quartiers de gypse et le soufre natif des grottes sont enrichis de maniére significative en S^{32}: des valeurs δS^{34} aussi basses que -2L, 1 indiquent que le soufre et le gypse sont les produits finis de l'oxydation biologique (Thiobacillus et Desulfovibro) et des réactions de réduction.

La succession stratigraphique générale des gisements de grotte (du plus vieux au plus récent): roche de fond calcaire, argile endellitisée, spath, gaillettes, lais orangés, quartiers de gypse primaire, débris, et spéléothémes. Les comblements d'argile et de spath ont été tronqués par de larges couloirs de grottes et remontent à un épisode de dissolution plus ancien. Le spath enreigstre un débit au ralenti d'eau sursaturéé dans la roche aquifére, peut-être contemporain des cailloux de l'Ogallala datant du Pliocéne et des conditions de la pénéplaine.

Alors que les Montagnes Guadalupe étaient soulevées et penchées vers le nord-est vers la fin du Pliocéne-debut du Pleistocéne, de l'hydrogéne sulfuré s'acheminait par le pendage vers le haut jusqu'au recif calcaire du Capitan en partant du gaz et des champs de pétrole du Bassin Permien. Il se mêlait au niveau de la nappe aquifére avec l'eau souterraine oxygénée qui se dirigeait vers le bas, formant ainsi de l'acide sulfurique. L'argile dissolvait le calcaire, mais de l'argile résiduel et insoluble s'échappait de la suspension et venait se déposer sur le sol de la grotte en lais orange finement laminéa. Du gypse se précipitait alors chimiquement sur les lais: $H_2SO_4 + CaCO_3 + 2H_2O \rightarrow HCO_3^- + H^+ + CaSO_4 \cdot 2H_2O\downarrow$. Des laminages, des micro-plissements, des angles inattendus, une contexture de bréche, et des inclusions de calcaire dans les quartiers de gypse rendent témoignage de mécanismes de précipitation et de solidification. Une autre inondation a peutêtre interrompu l'épisode final subaérien où se forment les spéléothèmes.

Introduction

The origin of Carlsbad Caverns and other caves of the Guadalupe Mountains remains one of the great unsolved mysteries of speleogenesis. Geomorphically these caves bear little similarity to other cave systems of the world. Rooms are huge--yet, passages are not long and they terminate abruptly. The caves seem unrelated to surface topography or to recharge and resurgence points. Especially enigmatic are the large blocks of primary gypsum and the colorful waxy endellitized clays in the caves.

For over thirty years the prevailing theory of speleogenesis has been that Guadalupe caves formed similar to other caves--that is, by carbonic acid dissolution (Bretz, 1949). In the last seven years three new hypotheses have been proposed, all of which differ significantly from one another and from Bretz's theory. Jagnow (1979) speculated that sulfuric acid derived from overlying pyritic limestones helped dissolve the caves. Egemeier (1973) and Davis (1979) also invoked sulfuric acid as the dissolving agent but with hydrogen sulfide as the source of the acid. Queen, Palmer, and Palmer (1977) proposed a completely different origin for the caves: limestone replacement by gypsum at the mixing zone between fresh meteoritic water and saturated brine.

Speleogenesis

Based on the stratigraphic sequence of cave deposits, a number of sequential cave episodes can be identified.

a. Solution I Caves

Large cave passages cut across smaller, spongework passages of an earlier (Cretaceous?) "Solution I" episode. These maze caves were dissolved along primary pores, joints, and bedding planes to produce a honeycombed network of passages. The insoluble residue released from the dissolvement of Solution I caves filtered down into maze pockets. This same clay residue was changed to the mineral endellite in a later geologic episode.

b. Spar Episode

~~Stagnant~~ aquifer conditions prevailed in the Pliocene when Ogal lala gravels were being deposited on the above, low-lying peneplain. Calcite spar crystallized in Solution I cavities from the static, highly mineralized water. Ogallala sands and gravels washed into Solution I caves to become sandstone dikes and possibly the cobble gravels found in Carlsbad Caverns. These cobble gravels unconformably underlie cave silts and recently rounded black chert pebbles (Ogallala?) have been found in the cobble gravels.

Sulfuric Acid Dissolution of Solution II Caves

Three different lines of evidence support a sulfuric acid hypothesis:

1. Endellitized clay. Endellite is a kaolin mineral which forms under low pH, sulfuric acid solutions (Keller et al, 1966). Sulfuric acid dissolved the large "Solution II" cave passages and changed the insoluble residues already present in Solution I cavities into endellite.

2. Primary Gypsum Deposits. Caves with thick (up to 7.5 m) gypsum blocks occur over a regional area of 650 sq km and an elevation range of 840 m. Chemistry experiments indicate that when cave limestone reacts with sulfuric acid, gypsum forms as a precipitate. The silt-gypsum stratigraphic sequence as seen in the caves has been duplicated by the chemsitry experiments.

3. Sulfur Isotope Ratios. Cave gypsum and native sulfur are significantly enriched in the light isotope of sulfur (S^{32}) (i.e. they have large negative δS^{34} values; see Table 1). These results are extremely important because they imply that:

(a) The gypsum could not have been deposited according to the Bretz, Queen-Palmer-Palmer, or Jagnow models of speleogenesis. The gypsum of the Castile Formation has an average value of δS^{34} =+10 and redeposition of cave gypsum from a Castile-derived brine (such as has been proposed by Bretz and Queen-

Palmer-Palmer) should have δS^{34} values of +10 to +13. The heterogeneity of isotopic values (+5 to -21) discredits a pyritic source for the gypsum blocks as proposed by Jagnow. Pyrite-derived sulfates which are oxidized at their source should be relatively homogeneous in δS^{34} by the time they reach the caves.

(b) The extreme enrichment of S^{32} is the result of biological oxidation and reduction reactions. According to Ivanov (1962), compound of sulfur with a δS^{34} value more negative than -4.4 is usually of biogenetic origin. Heterogeneity of δS^{34} values is another diagnostic indication of biologically-derived systems (Goodwin et al, 1976).

Based on the isotopic data, I propose that the sulfuric acid ultimately derived from the oil and gas fields of the Permian Basin; first from reducing conditions in the basin and later from oxidizing conditions in the Capitan reef aquifer.

Cave Silts

The orangish-tan silts present in Guadalupe caves are authigenetic residuum liberated from the limestone when it dissolved under low velocity flow in the aquifer. Support for this claim is:

1. The silts are always located near argillaceous or arenaceous limestone facies.
2. The floor silts correspond in abundance, color, grain size, and composition to clastic residues within nearby limestones (as determined by insoluble residue experiments).
3. Thin laminations and fine cross-bed sets in the silts indicate that they settled out of suspension in quiet water.
4. No evidence of active streams (scallops, incised meanders, or graded bedding) exists in the caves.

The authigenetic cave silts do not support Bretz's claim of a vadose stream episode in Carlsbad Caverns, or his corollary hypothesis that an "ancestral" Pecos Valley must have existed at the time of speleogenesis in the Guadalupe Mountains. Based on this interpretation, large cave passages date from the Pleistocene, not the Pliocene.

Gypsum Precipitation and Solidification

The primary gypsum precipitated from solution and is not a replacement of limestone as suggested by Queen, Palmer and Palmer (1977). Evidence for this interpretation is:

1. Laminations and other textures in the gypsum blocks.
2. Very low sulfate (abg. value: 0.008%) up to 20 cm into the wallrock as determined by drilling experiements.
3. Presence of orange silt beds between limestone bedrock and gypsum blocks: the gypsum and limestone should be in direct contact if one was replaced by the other.
4. A low percent (<1%) of insoluble residue (chert and rounded quartz) and lack of orange clay and silt in the gypsum: if the gypsum replaced the limestone it could have the same amount and type of insoluble residue as the limestone.

Laminations (transparent selenite alternating with the opaque gypsum) formed at the time of precipitation. Slickensides, slumping, angular unconformities, and flow features occurred while the gypsum was still in a plastic state. Microfolding probably resulted from shrinking of the blocks. Pieces of hardened crust sunk down at various angles into the plastic ooze to create the breccia texture and pieces of limestone (sometimes fossiliferous) fell into the coalescing gypsum.

Origin of Sulfur

Native sulfur (S) occurs in Cottonwood Cave (Davis, 1973) and has recently been discovered in Carlsbad Caverns. In both caves the native sulfur is intermixed with gypsum and has been exposed by erosion of a gypsum block. In Carlsbad Cavern, the sulfur occurs in a secondary, probably subaerially-formed, coarsely crystalline crust. This occurrence suggests that the sulfur derived from the gypsum, possibly by outgassing of H_2S in the caves after the water table had dropped. The proposed reaction for the origin of the native sulfur in the caves is:

$$SO_4{=} + H_2S \rightarrow 4S + 2H_2O + 2\ OH^-$$

Resolution of Gypsum

The primary gypsum is highly eroded in many cave passages and is completely absent in others. While vadose drippage is the most obvious method of gypsum reduction, aquifer resolution contemporaneous with gypsum deposition was probably far more extensive. Normal fluctuations of the water table before the final drainage of the caves carved out such resolution features as "commodes", rounding on the undersides of gypsum blocks, and streamlined shapes of gypsum blocks next to pits and fissures.

Subaerial Episode

Most of the breakdown fell after a short subaerial episode subsequent to gypsum precipitation and water subsidence from the caves. Subaerial deposition of speleothems has occurred for at least 200,000 years.

Acknowledgements

I wish to thank the National Park Service, Forest Service, Bureau of Land Management, and the joint venturers of the Cave Research Foundation for their research support.

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Table 1. Stable Isotope Ratio Analyses, Gypsum and Sulfur, Guadalupe Caves.

Sample Description	δS^{34}
Gypsum Block, Balcony Room, Dry Cave	-12.4
Gypsum Block, Lower Maze, Endless Cave	- 8.6
Gypsum Block, Upper Gypsum Passage, Cottonwood Cave	+ 5.0
Gypsum Crust (secondary speleothem), Lower Gypsum Passage, Cottonwood Cave	+ 0.8
Sulfur, Lower Gypsum Passage, Cottonwood Cave	-14.6
Gypsum Block, Salt Flats, Big Room, Carlsbad Caverns	-13.9
Sulfur mixed with gypsum, Jumping Off Place, Carlsbad Caverns	-20.0 (sulfur) -19.0 (gypsum)
Gypsum Block, Polar Regions, Carlsbad Caverns:	
Level #1	-17.6
Level #2 (0.3 m below Level #1)	-19.9
Level #3 (0.3 m below Level #2)	-21.1

Analyses done by Krueger Enterprises, Geochron Laboratories.

The Geomorphological Features of the Karst in Guilin District

Zhu Dehau and Tan Pengjia
Institute of Karst Research, Ministry of Geology, China

Abstract

Guilin is situated at latitude 25°15'N with an altitude 155m above sea-level. It has a humid subtropical climate with mean annual temperature 19°c and average annual precipitation of 1900 mm. The total thickness of carbonate rocks in this district reaches 3000m mostly belonging to the upper Palaeozoic age. In this district karst landforms may be classified into two major types, namely: peak-cluster-depression type and peak-forest-plain type.

In the vicinity of Guilin city limestone towers arise from peak-forest plain, and the mean height of tower is 74m (n=221). Their diameters range from 59 to 700m and have an average value of 208m. Tower width/length ratios show a range from 0.197 to 1.00, with a mean of 0.66 (n=221). A proper correlation exists between tower height and diameter in this area (r-0.77). Balazs' morpho-genetic index range from 1.013 to 8.25, and an average value is 3.0. Of those towers, 55.7% have diameter/height ratios between 1.5 and 3.0. This figure characterizes the tower of Guilin between the Organos type and Sewu type. Directional orientation of the long-axis of towers are evidently. The occurrence of cliffs may be correlated into three main levels namely: 160 m, 190m and 250m above sea-level. Their dominant strikes are between 80° to 90°, and 290° to 300° (n=378).

The elevations of more than 600 summits are analysed statistically, and correlation betweeen tower height and it's distance from main limestone mass is calculated. Both of them show that there are not obvious multi-leveled summit planes in the area and that peak-forest plane type and peak-cluster-depression type have their particular different evolutionary processes.

Résumé

Guilin est situé à latitude 25° 15' N. et d'un altitude de 155 m. Le climat y est humide et subropical avec la température annuelle moyenne de 19° c et une précipitation annuelle de 1900 mm. L'épaisseur totale des roches carbonat es dans cette région atteint presque 3000 m. dont la plupart appartient au Paleozoique suppérieur. Les reliefs karstiques de cette région peuvent être classifiés en deux types majeurs soit: 1) le type de pitons en groupe enfermant des dépressions et 2) le type de plaine parsemée de pitons isolés.

Au voisinage de la ville de Guilin, des monts calcaires en forme de tourelle se dressent sur la plaine karstique d'une dénivélation moyenne de 74 m (n=221). Les diamétres deleur bases varient de 59 a 700 m. avec un moyen de 208 m. Le rapport largeur longueur des tourelles varie entre 0.197 et 1.00 avec un moyen de 0.66 (n=221). La répartition des hauteurs des pitons isolés a une obliquité positive. Il semble qu'une corrélation assez bonne existe entre la hauteur et le diamétre d'un piton de cette région (r=0.77). L'indice morpho-génétique de Balazz est de 1.0L3 a 8.25 avec le moyen de 3.0. De ces tourelles calcaires 55.7% ont le rapport diamétre/hauteur tombant entre 1.5 et 3.0. Ce chiffre place les tourelles calciares de Guilin a une position intermédiaire entre le type Organos et le type Sewu. L'orientation préférentilles des axes longitudinales est évidente. Les escarpements se rencontrent souvent autour des cotes de 160 m., 190., et 250 m. Les directions dominantes de ces escarpements sont 80-90, 290 et 300 (n=378).

Nous avons mesuré les distances entre 600 sommets isolés et le massif calcaire et les fait confronter avec les cotes des sommets. Nous n'en ont pas trouvé des étages multiples évidents des sommets. Il est proabable que les deux types de relief karstique mentionés ci-dessus se sont évolues dans des processus particuliers et différents.

桂林地区岩溶地貌的形态特征

朱德浩　谭鹏家

地质部岩溶地质研究所

（摘要）

桂林位于北纬25°15'，海拔高度为155米，具湿润的亚热带气候，年平均温度19℃，年平均降水为1900mm。本区碳酸岩总厚度达3000米，时代主要是古生代晚期。本区岩溶地貌可被分为二个主要类型：峰林平原和峰丛洼地。

桂林市区附近峰林平原中石峰（塔）的平均高度为74米(n—221)，石峰直径变化于59—700米之间，平均为208米。孤立石峰高程的分布是正偏态。石峰宽度和长度的比值从0.197到1.00，平均数为0.657(n—221)。石峰高度和石峰直径相关关系显著(r—0.77)。Balazs的形态成因指数变化于1.013—8.25之间，平均为3.0。其中，1.5—3.0的石峰占55.7%。这一数字表明石峰介于Organos和Sewu类型之间。峰长轴走向的方向性明显，陡崖出现的高程有三个峰值，分别为海拔160米、190米和250米。主要走向为80°—90°，290°—300°(n—378)。

对六百多个峰顶高程进行了统计分析，计算了石峰高度和离主要灰岩块体的距离之间的相关关系，说明本区不存在明显的多级峰顶面，峰林平原和峰丛洼地各有其特殊的不同的演化过程。

Some New Methods in Exploring Technique of the Water and Vertical Caves

Mladen Garasic
President of Caving Techniques and Equipment, Comm. Speleological Association of Yugoslavia, 4100 Zagreb, Nova Ves 73 a Yugoslavia

In the latter years the great surge in the development of the speleological equipment is noted. Most of it is completely new and replaces the earlier improvisations. The bigger part of this new equipment is made to be used with speleological ropes (ascenders, descenders, spits, etc.) and a much smaller part of the equipment is made for the exploration of water caves.

It is well known today what kind of the equipment is necessary and evaiable to speleologists - divers and what is the cost of it. The water caves for whose examination the scuba diving is not necessary, but which are full of water all around the year, are being explored by using only the diving suits, without the breathing aparathus. In some of the countries, like Great Britain, due to the morphology, size and temperature of caves, this kind of exploring is almost always used (with the diving suits).

The Yugoslav speleologists (cavers) are not generally in favour of the usage of this suite, because they are useful only in explortion of the water flows and barriers. Moving in this kind of suits in the dry parts of the caves is very difficult, mostly because of the increase of the temperature. They consider that the waterproof overalls, which are put over the usual ones, are much more useful. Mainly they are put on just before the need arises. Because they are very light and of small volume, they are easier to transport in deeper parts of the caves (types: "Speleoglys", "Frankstein", etc.). The Yogoslav cavers also constructed and assembled some of the aparathus which greatly help in examination of the water caves. The constructions are mostly very simple and cheap.

(a) Being in the narrow and low cave channel with 15 cm of water covering the floor, results for cavers, with the intense coldness and quick tiredness- the possible movements are greatly restricted. To evade this the idea of "bench - klupica" was realized. The caver lies on such a bench while the water is going under it. They are very light, easy to dismantle, very cheap and simple in the construction. It was shown that the use of such a bench is much better than to thread through the water even in the waterproof diving suits. Two benches are always used in pairs, forward motion is made by their conveyance. It might look that this kind of going on is very slow, but, it is often of much more importance that the cavers are not cold. For the deeper waterflows and for short "crawling", the diving suit are indispensable.

(b) While going through the small and short periodical siphons - that is the places in which the channel is completely submerged in the water, only a few cm of air is left under the ceiling, the cavers tend to use the diving suits. But, if it is necessary that some part of the equipment of some members of the team stay dry, the following could be done: One member of the team crosses to the next side of the siphon, tugging along the plastic PVC tube o.5 m in diameter. The rest of the group can go through the tube without any disturbance, taking care that the tube is not damaged anywhere. This way had shown it usefulness for the short crossing of 5 m (in 1977, the siphon of 3 m was covered in that way, as well as some of 900 m of channels in Veternica Cave).

In vertical caves, which are very often in Yugoslavia - about ten thousands in number (80%), not a rare occurrences are shafts, more than a hundred meters, and that is why in this kind of caves the combination of two ropes are used for the several reasons.

(a) Safety,
(b) easier and quicker climbing (ascending) in pairs,
(c) While teaching and training the young and less experienced members of the team, the instructor is always beside the caver,
(d) in the case of eventual rescuing, the less work is to be done in securing the second rope,
(e) it is easier to transport the equipment if somebody is climbing (ascending) along it.

This method is used only in the very deep pits, more than 200 m deep, and it has confirmed value in the matters of safety and usefulness.

In the deep caves (vertical pits) with waterflows making waterfalls through which is the only possible way down, the walkie-talkie is used, but constructed to be operated without using of hands. The sets are on, while the aparthus itself can be transported in the plastic wrapping, the receiver and microphone are in the helmet. This kind of constant radio connection is very useful in exploring and rescue work, but in the most countries, from unknown reasons, the radio is not used in speleology at all, only the wire telephone which is the source of the constant problem.

I believe that I have pointed but some ideas about the direction which should be followed in the development of the speleological equipment in the following period, likewise its practical usage, based on the experience of Yugoslav cavers which can be used in the conditions similar to that in Yugoslavia (the classical Dinaric karst area).

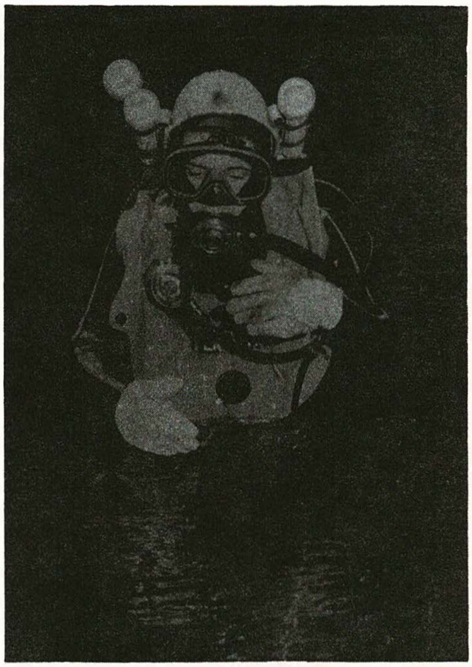

Fig. 1. Before Cave Diving

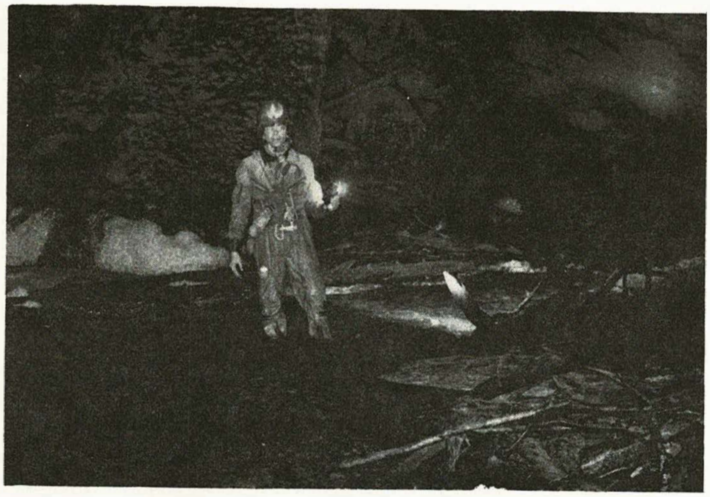

Fig. 2. Inside Great Vertical Water Cave Rokina bezdana in Yugoslavia

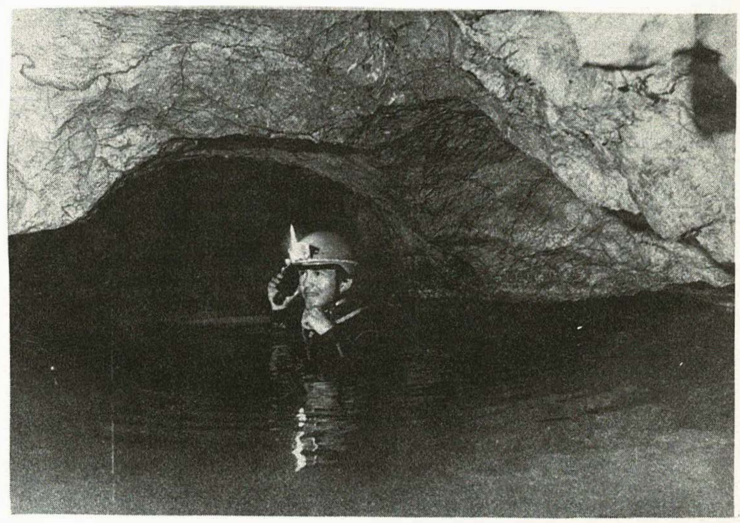

Fig. 3. Diving Suites in Use in Yugoslav Caves

Neotectonics in Some of the Speleological Objects in Yugoslavia

Mladen Garasic
41000 Zagreb, Nova Ves 73 a, Yugoslavia

Introduction

The neotectonic shifting or moving is the tectonics movement, generated from the middle of Miocene (Tertiary) through the Quarternary till today. Generally, almost all the movements in the speleological objects (caves) in Yugoslavia, although genetically they belong to the relatively younger period, are considered as the neotectonic movements (Nikolaev, N., 1962). By this work we would like to point out some of the regularities of this movements and fundamental methods for their researches.

The Survey of the Up Today Researches

Neotectonics, as the specific science in the field of the science of geology, appeared rather lately - so it is understandable that the number of the work in this field is not great. The first good neotectonic map of Yugoslavia was made by Arsovski, M. & sur. (1974), a little bit later the neotectonic map of Croatia was made by Prelogovic, E., (1975).

The neotectonic movements in the speleological objects (caves) in Yugoslavia were also written upon by Garasic, M. (1976) in the work describing the detailed working out and use of morphometric maps in the exploration of the longerst cave in Croatia - Jopiceva spilja (Jopic's cave). The neotectonic map of the surrounding of the cave was also made, by which the great similarities of the cave channels found inside and the supposed neotectonic fault or fissures are noted. Garasic, M. (1980) and his coworkers, speleologists from Zagreb, placed the measuring (scale) instruments in some of the caves in the Western part of Yugoslavia, following the movements of marked rock blacks. The rates of absolute movements are collected, but measuring is still going on.

Elements for the Researches into the Neotectonic Activity in Caves

The data from up today neotectonic maps and detailed geological mapping, which were made in the surroundings of the chosen object, were used for the analysis of the neotectonic activity. In the first place, the use were made of the areas of diffusion of the Neogene-Quarternary strata with its anomalies (deformations), erosive denudation and accumulative areas, morphostructural elements and all other elements obtained by working out the morphostructural (geomorphologic) maps.

In the caves which were chosen between cca 12000 explored objects in Yugoslavia, the new surveying, with the special addition of the tectonic elements and structural geology, were made. Noted and marked were all the separated block, all faults and fissures. Accounts were taken of the sediments, especially in places were the measurements of the movements were taken. Instruments self constructued (inductive microprocessors) were put exclusively on the primary blocks of stones (fundamental, basic) and not on the stalactite or stalgmite (speleothems) so that the records of the movements of the stalactite overaly should be avoided (the sliding of the speleothems overaly over the rock is an often occurence). The several block diagrams were made by which was easier to calculate the intergrity of the rock mass inside the observing interval in the cave. The special attention was payed to the measurings of the vertical parts (shafts) of the caves.

The Survey of the Composition of the Prognostication Maps of the Tectonic in Caves, Based on the Morphometric Methods

Garasic, M. (1976) tried in 1977, to assert using the outside and during the 1977 using inside geomorphological methods, the (neo) tectonic connection and diffusion of the cave channels. The following elements were used:

- observation of the various midsts of sediments, facies layers and lithological relations,
- assertation of the geomorphological maps (morphometric and morphostructural),
- composition of the prognostication tectonic maps with the presupposed measures of the vertical movements,
- geomorphological analysis of the air photos.

After complex work, following the above mentioned, some of the basic elements for any of the speleological object neotectonic map can be deducted:

(a) Fault indications:
- the sharp contures of the cave channels and river beds,
- anomalies in cave channels and river beds,
- elevation above the erosion surfaces,
- the sharp changes in the heights of the channels, levels or terraces, their reduction or sudden discontinuence,
- appearance of the cascades, waterfalls, shafts, and sharp anomalies of the longitudinal profile,
- uniting of the tributaries along one direction,
- the series of the dolines, ponors, pits, springs, the new land slides,
- geologically abnormal contact between the layers (beds) in the caves.

(b) The elevation indications:
- the sudden narrowing of the cave channels, valleys, terraces,
- thining of the alluvium thickness along with the increase of the heavy grim material and heavy materials,
- increasement in the number of the levels and longitudinal profiles (inclination),
- meandar incisements of the cave river beds (erosion),
- the lowering of the underground water level,
- increase of the erosive denudation and accumulative areas in caves, etc.

(c) Depression indicates:
- enlargements of the cave channels,
- increase of the alluvium thickness,
- increase of the light grain material,
- decrease in number of the terraces and levels, the lower decline of the longitudinal profile,
- increase of the underground water level,
- decrease of the horizontal disjointment of the relief and decrease of the bed erosion.

The Direct Method of the Measuring and Following the Movements in Caves

To know better the neotectonic movements, it is necessary to measure their intensity (dimensions). Up to now, the dimensions of the movements were measured only in the shape of relative relations - absolute values were not known.

After the consultation and with help of the professional team of the "Gradjevinski Institut" in Zagreb, the inductive microprocessor was constructed - able to note the slightest movements. The accuracy of the instrument is high, the price rather low and it was shown by the tests that it can answer all the conditions prevailing in Yugoslav caves. The main working principal of the instrument is following: the mechanical movements (neotectonic movements) are transmitted by the electronic concatenation into the electric impulses, whose voltage is measured by the precise digital microvoltmetre. The voltage change of 1 microvolt is corresponding to move of 1 micron (micrometre). This construction allows measuirng to be taken on the distance of $\pm$ 1 0mm (2 cm), which is enough for present movement discernible by naked eye. The microprossesscr is tested and prepared for the temperature between the -20° C till 40° C, it can also work without any difficulties under the water because the complete electronic part of the instrument is enveloped in the plastic.

Types and Manifestations of the Neotectonic Movements In Some Caves in Yugoslavia

The author of this article, after chosing of the objects (caves) in the tectonic active parts in western Yugoslavia, had put the instruments down in the underground. The measuring is going on uninterrupted from December of 1979. - the new data are added all the time.

After the first reading of the recorded movements, the diagrams of them were made. The results are following: the horizontal movements are of the Dinaric direction with the average intensity of 15 till 20 microns by month, vertical movements are of the greater intensity 32 till 59 microns by month. From the majority of measurements already made and area diagrams it could be concluded that the horizontal movements are mostly of the primary origin, while the vertical movements are of secondary origin. That is why the vertical movements is one of the greater intensity. (for example - the vertical movement on the northern Velebit mountain is + 0.624 mm/ by year, while on the northwest part of the southern Velebit is even + 2.147 mm/ by year. One of the reasons of the appearance of the great number of the caves in this area of Yugoslavia is constant presence of the vertical movements. The best example of this is the pit Ponor na Bunovcu (Ponor on Bunovac), with depth of 534 m (Fig. 1).

Summary

Here by the relation between the neotectonic and appearances of caves, methods of the following and the direct noting of the present movements in caves is shown. The author describes the inductive microprosessor which notes the horizontal and vertical as well as other movements in the area. By measuring it was concluded that the horizontal movements are of primary and vertical of the secondary origin. Accuracy of the measured data is 1 micron. It is to be believed that this data will greatly help in future composition of the neotectonic map of the karst, and in the sesismological researches - becuase ven now it could be indubitably stated that the naotectonic movements are in the direct connection with seismic activities.

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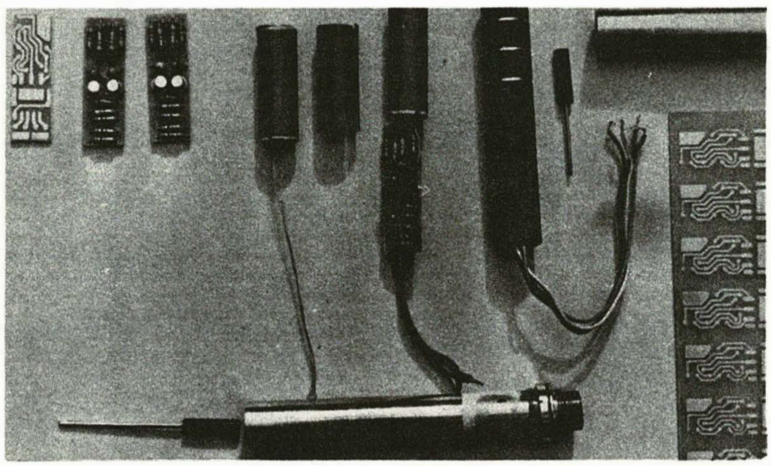

Fig. 1. Digital Microproccessor (inductive) for measuring in caves

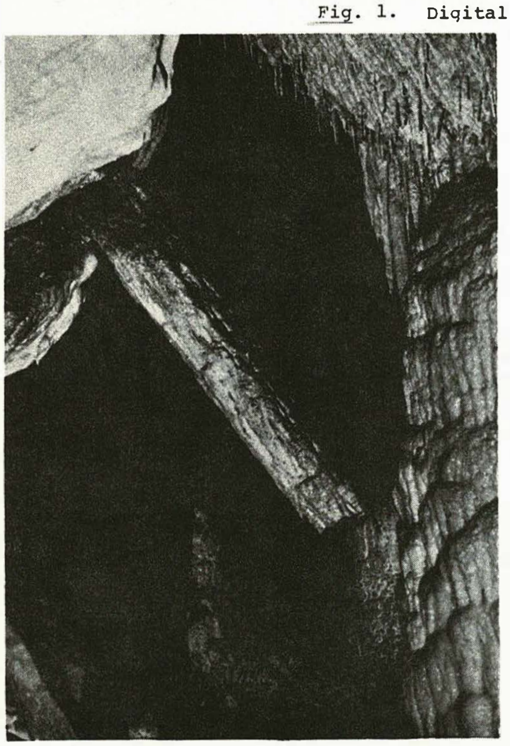

Fig. 2 Result of tectonic and seismio activity in Yugoslav cave

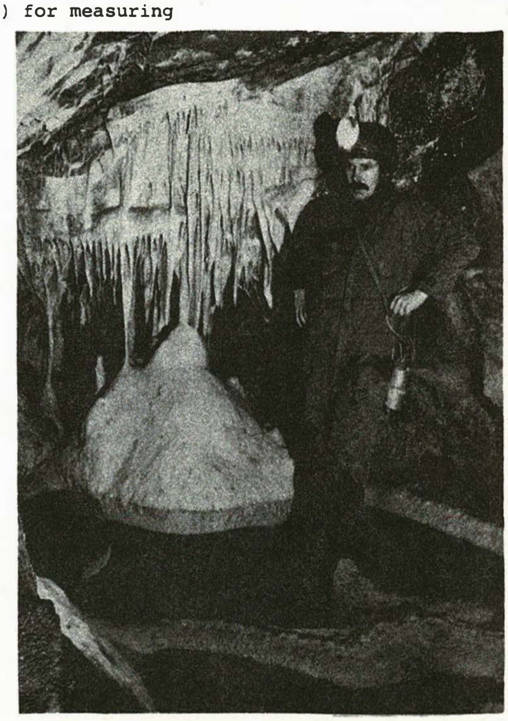

Fig. 3. In this cave much instruments were put for measuring movements (Horvatova Cave; Yugoslavia)

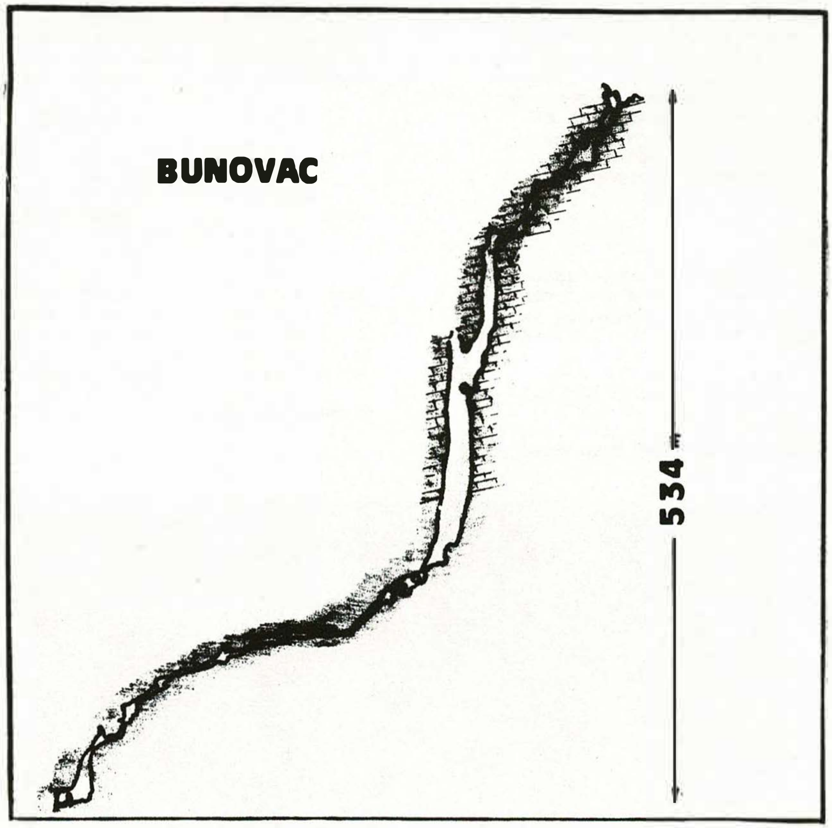

Fig. 4. Profile of Bunovac Ponor.

Multidisciplinary Research for Cave Management: The Waitomo Caves Research Programme, New Zealand

Paul W. Williams
Department of Geography, University of Auckland, Auckland, New Zealand

Abstract

The tourist caves at Waitomo in the North Island of New Zealand, famous for their subterranean glowworm (*Arachnocampa luminosa*) displays, have been the subject of a major interdisciplinary study, designed to provide scientifically sound data for management purposes. Results are available for research on siltation and flooding, geochemistry of the cave atmosphere, cave microclimate, glowworm ecology, plant growth and lighting practice, cave cleaning, and control of lampenflora. Major conclusions are presented.

Résumé

Les grottes touristiques de Waitomo, dans l'île du Nord de la Nouvelle-Zélande, célèbres pour leurs "glowworms", (*Arachnocampa luminosa*) ont été l'objet l'une étude qui entraîne plusieurs disciplines, dans le but de fournir des données scientifiques, afin d'aider l'aménagement des grottes. Des résultats ont été obtenus ~~pour la recherche~~ sur la sédimentation fluviatile et l'inondation, la géochimie de l'atmosphère souterrain, le microlimat des grottes, l'écologie des "glowworms", l'effet de limière sur la présence des plantes; le nettoiement des grottes et le controle de "lampenflora". On présente les conclusions principles.

Paleotemperature, Sea Level and Uplift Data from New Zealand Speleothems

Paul W. Williams
Department of Geography, University of Auckland, Auckland, New Zealand

Abstract

Isotopic analysis of New Zealand speleothems commenced with the work of Hendy and Wilson (1968), when a paleotemperature curve was published. More recent research has investigated the relationship between cave levels and coastal terraces, using uranium series and carbon-14 dating of speleothems. In the northwest of the South Island, at least seven coastal terraces are known up to an altitude of 200 m, with still more (and presumably older) terraces at higher levels. A cave at 225 m above present baselevel has speleothems beyond the range of Th/U dating; while a 60 m coastal terrace is shown to be at least 275,000 years old. Speleothems in cave levels from 10-30 m above baselevel range in age up to 120,000 years. Samples from still lower levels, even in zones commonly inundated by floodwaters near sea level, can be 16,000-19,000 years old. Unequivocal evidence is also presented for invasion of a karst cave by the sea sometime in the interval 120,000-175,000 years ago. Rates of uplift in the northwest of the South Island over approximately the last quarter of a million years have been 0.22-0.36 mm/year.

Résumé

L'analyse isotopique des stalactites néo-zélandais a commencé par le travail de Hendy et Wilson (1968), avec la publication d'une courbe de paléotempérature. Des recherches plus récentes ont examiné le lien entre les niveaux des cavernes et les terrasses littorales, en utilisant la datation par Th/U et C-14 des stalactites. Au nord-ouest de l'île du Sud, on reconnaît au moins sept terrasses littorales jusqu'à une hauteur de 200 m, avec encore des terrasses (vraisemblablement plus vieilles) à des niveaux plus élevés. Dans une caverne à 225 m au-dessus du niveau de bas actuel se trouvent des stalactites au-delà de la porteé de la datation Th/U, tandis qu'une terrasse littorale à 60 m date de 275,000 ans, au moins. Les stalactites dans les étages de grottes de 10 à 30 m au-dessus du niveau de bas peuvent dater de 120,000 ans. Des stalactites des étages encore plus bas, même des zones d'inondation près du niveau de la mer peuvent dater de 16,000-29,000 ans.

On fournit l'evidence sans équivoque de l'invasion d'une caverne karstique par la mer à une époque il y a 120,000-175,000 ans. Les taux de soulèvement au nord-ouest de l'île du Sud dans les derniers 250 mille ans sont etablis à 0.22-0.36 mm par an.

Introduction

Pioneering research on the interpretation of paleoclimatic data from speleothems was published in 1968 by Hendy and Wilson for a series of New Zealand sites. Further detail was presented in subsequent publications (Hendy, 1969, 1971). A difficulty with this early work was that absolute dating was only possible to 40,000 years B.P. using carbon-14; thus beyond that limit the paleotemperature curves could only be fitted to a nominal time scale based on speleothem growth rates. Nevertheless, as Harmon et al. (1978) also concluded for North American speleothem data, good general overall agreement was displayed between the speleothem record and foraminiferal paleoclimatic interpretations.

With the advent of uranium series dating of speleothems, the opportunity exists to extend and provide better time control for the New Zealand speleothem paleoclimate record, and this research is underway. However, current attention is being focused mainly on another problem that of dating coastal terraces and deriving uplift rates, which forms the main subject of this paper.

Marine Terraces in New Zealand

As a tectonically active country, New Zealand has many areas of rapid uplift. The rates of uplift (and subsidence) are of considerable interest to those studying the origin of the Southern Alps and crustal deformation near the Indian/Pacific plate boundary (e.g. Walcott and Cresswell, 1979; Yoshikawa et al., 1980), as well as to students of paleosea levels (e.g. Chappell, 1974, 1975). The lower marine terraces and beach ridges have often been dated using carbon-14 techniques, while in the North Island where volcanic activity is widespread tephrachronology has been applied very successfully. Ash layers over terrace deposits have been dated by carbon-14 on included organic materials and by fission-track methods; thus yielding minimum ages for the terraces. However, in regions where ash fall deposits are not available and where terraces are beyond the range of carbon-14 considerable problems arise in dating terraces. This applies to much of the South Island and to sizeable portions of the North. Nevertheless, opportunities arise to such terraces where they cut across limestone lithologies with caves and speleothems suitable for isotopic analysis.

An area of particular interest is the northern half of the west coast of the South Island (Figure 1). It lies to the west of the Alpine Fault, a major transcurrent dislocation with 600 km offset. An important series of coastal terraces has been described in the area by Suggate (1965), Bishop (1971) and Nathan (1975), at least seven terraces having been recognised up to 200 m with others at still higher elevations, but their ages are speculative. In the Westport area, Suggate has assigned a last interglacial (Oturian in terminology) age to two terraces between 34 and 45 m and an interglacial before last (Terangian) age to a 65-72 m terrace. A major terrace at 55-60 m in the Paturau area has also been tentatively assigned to the Terangian (Bishop, 1971). Limestone caves run beneath or close to some of these terraces and the record from them provides the only known means of dating the terrace sequences.

Cave Levels and Sea Levels

Dating terrace levels using speleothems has a number of problems. Firstly, it is assumed that, unless there are any deposits or re-solution effects that might indicate otherwise, a cave is contemporaneous with or younger than the terrace which it lies beneath. Hence its oldest speleothems will provide a minimum age for the terrace. Secondly, it is assumed that the geochemical and analytical assumptions and techniques for isotopic dating are valid. In the ideal case, an approximately horizontal phreatic passage is genetically related to a coastal water-table and thus to sea-level. Upon uplift the passage drains and speleothems immediately commence to form. Thus they would be only slightly younger than the sea-level, the true age of which could lie within the standard deviation of the speleothem data.

A. The Paturau District

Paturau is located in the northwest corner of the South Island (Figure 1). The karst of the area has been briefly described elsewhere (Williams, 1978; in press). An important characteristic of the region is that a 30-50 m zone of Tertiary limestones dips gently to the WNW, with the result that these rocks descend from 260 at the summit of coastal hills in the northeast to below sea-level in the southwest and, in so doing, obliquely cut across a set of emerged coastal terraces. Thus caves are associated with higher altitude terraces in the northeast than in the southwest.

The most well developed coastal terrace at Paturau extends inland, usually for 400-600 m, to a height of approximately 60 m at the foot of a degraded cliffline. A site of particular interest is Cascade Cave, a phreatic passage which extends just beneath the level of the 60 m terrace at its inland end. The passage is essentially horizontal, meanders slightly and has a narrow, deep slot in its floor descending to a lower, active level. The passage has very little fill of any kind except for a few speleothems, one of which was sampled and dated by $^{230}Th/^{234}U$ methods as 275,000 ± 70,000 years old. The implication, therefore, is that the 60 m terrace at Paturau dates from at least the interglacial before last, being more than a quarter of a million years old.

A few kilometres northeast is Wet Neck Cave, a site of considerable significance because it was in existence prior to the 60 m sea which invaded it, filling it to the level of the terrace (Figure 2) with well rounded boulders, cobbles, and pebbles of igneous and metamorphic origin identical to those found on the modern beach. It is significant that the small cave stream has a catchment entirely in sedimentary rocks; thus could not have been responsible for introducing the gravelly fill. A speleothem sample collected from a site at the top of the fill (but not actually on the fill) was dated three times, the replicate assays yielding ages of 108,000 and 125,000, indicating that the sample was growing in the last interglacial. The marine deposits were therefore introduced before the last interglacial and presumably by the 60 m sea about 275,000 years ago. However, they are being re-excavated by the present cave stream, which has incised through and beyond them into underlying clastic rocks beneath the limestones.

B. Metro Cave and the Westport Terraces

Approximately 170 km to the southwest of Paturau along the same coastline is a superb set of at least seven terraces cut mainly in emerged deltaic sediments and in underlying Tertiary rocks at the mouth of the Buller River near Westport (Suggate, 1965; Nathan, 1975) (Figures 1 and 3). These terraces extend southwestwards against a rugged, rainforest covered plateau of polygonal karst (Williams, 1978; in press) that is occasionally traversed by rivers set in gorges over 200 m deep. Numerous caves exist in the area and one of them, Metro Cave, is of particular importance because of its association with a coastal terrace assumed to date from the interglacial before last (Terangian).

Metro Cave is a floodwater maze cave developed in the basin of Ananui Creek, which drains to the Nile, one of the main rivers cutting through the karst plateau (Figure 3). The cave is situated 5.5 km upstream from the coast and its stream resurges at the level of the trunk river about 30 m above sea-level. The entire cave is developed below the level of, and is set into, the Terangian terrace, which is cut across mudstones that stratigraphically overlie gently dipping Oligocene limestones. Metro Cave could only develop when Ananui Creek incised and breached tne mustone caprock and the limestones became exposed. Thus the oldest levels of the cave are significantly younger than the terrace. Furthermore, as the Southern Alps were uplifted, so the main trunk river through the karst plateau cut a still deeper gorge and the cave stream, its tributary, migrated to lower levels. Several former resurgences now remain abandoned in the sides of the gorge up to 37 m above the level of the modern Nile River (Figure 3).

Eight speleothem samples from various passages in Metro Cave have been dated. These range in age from 16,000 ± 140 years for a sample taken within the modern flooding zone to 120,000 ± 4,500 years for a sample from an older gallery at a level about 30 m higher. The ages of three of the youngest samples were cross-checked by carbon-14 dating.

The implications of these dates are, firstly, that Metro Cave is older than 120,000 years and consequently will have started to form before the last interglacial, since extensive older passages overlie those from which samples have been dated; hence the overlying surface terrace is at least that old. And, secondly, that the cave stream had cut down virtually to its present level by 16,000 years ago, close to the peak of the last major glaciation in New Zealand.

Conclusions

Recent isotopic work on New Zealand speleothems is yielding valuable information on the ages of coastal terraces that otherwise could not be dated. From preliminary evidence, uplift on the coast of northwest Nelson near Paturau has been at an average rate of 0.22 mm/year, while near Westport it appears to be about 0.25 mm/year. Uplift rates of similar order are found in the Takaka Valley (Figure 1), where a speleothem from Irvine's Cave near the top of a 70 m terrace was found to be >195,000 years old, indicating an uplift rate of up to 0.36 mm/y. In neighbouring Manson's Cave, 225 m above local baselevel, speleothems occur beyond the range of $^{234}Th/^{230}U$ dating. These uplift rates are greater than those proposed by Wellman (1979) for the same areas, based on an assumed age of a summit erosion surface, and provides the first quantitative data for the region.

Acknowledgement

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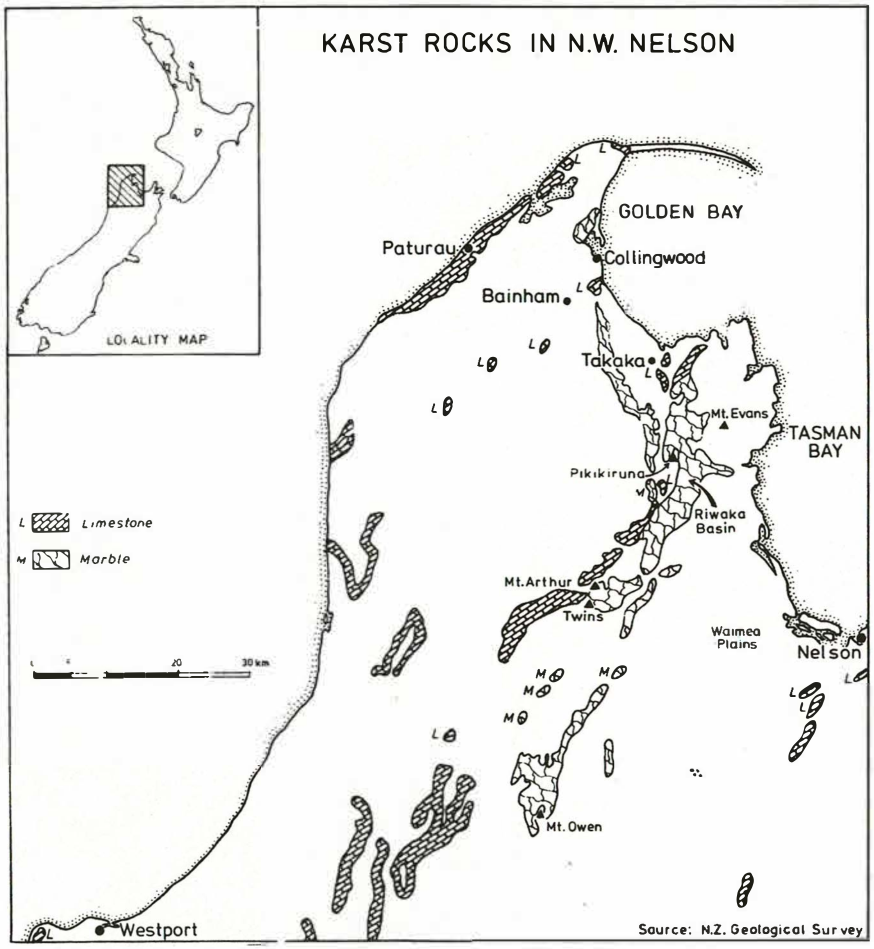

Figure 1. Karst Rocks in NW Nelson

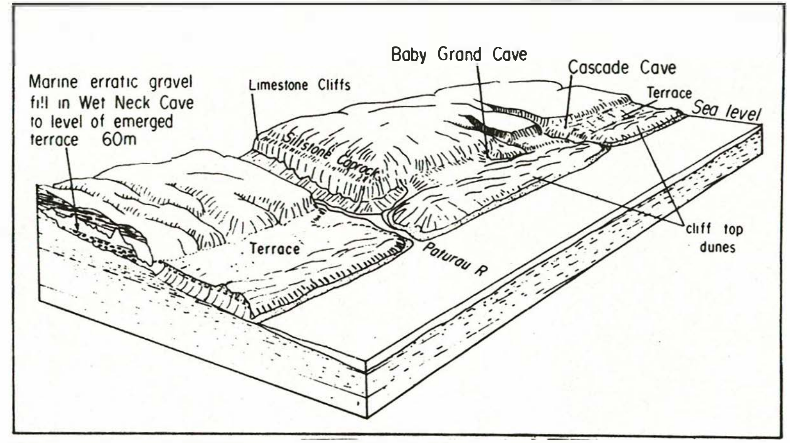

Figure 2. Relationship of caves to emerged marine terrace, Paturau

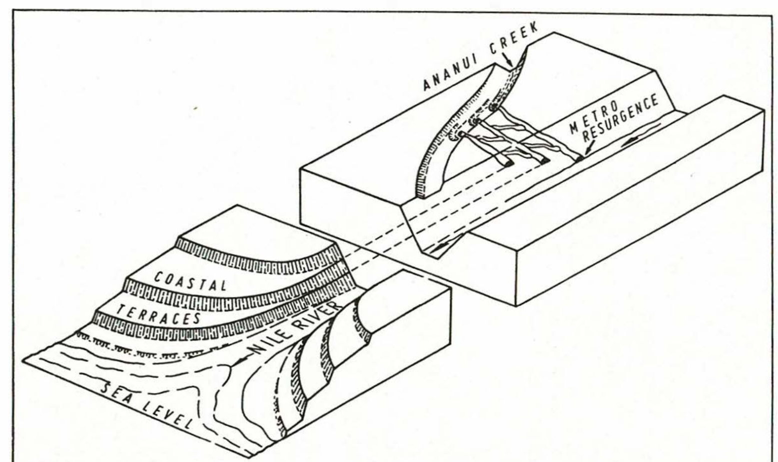

Figure 3. Relationship between Metro Cave and the Westport terraces

Desert Gypsum Karst in Bir al Ghanam, Libya

Attila Kósa
Budapest, XIV, Kover Lajos U. 46, HUNGARY

Abstract

The outcrop of the upper Triassic to middle Jurassic Bir al Ghanam Gypsum Formation lays West of its namesake town at the foot of the Jabal Nefusa escarpment. The thickness of the dolomite-intercalated formation reaches 400 meters at is main body. According to indices calculated upon meteorological data the local climate is desertic, the annual rainfall does not exceed 150 mm. Authigenic karstification is observable in the typsum hills which appeares - besides underground drainage: caves - in a landform very similar to the well known tropical "cone-karst". The karst of tropical appearence could develop in desertic conditions only due to the high solubility of gypsum. More precipitation would destroy the observed forms and develop a different landscape.

Résumé

Au pied du massif Nefusa en Libie près du village Bir al Ghanam afleure la formation de même nom gypseuse triasique superieure-a meso-jurassique.

L'épaisseur de la formation émaillée d'intercalaires dolomitiques s'élève à 400 mètres par endroit.

Selon les indices calculé des données météorologiques, le climat local est désertique; la quantité annuelle de la précipitation n'excede pas les 150 mm. Au collines gypseuses on peut observer une karstification autogène, qui apparait - en outre de l'écoulement souterrain: les cavernes - en formes très similaire au "Karst conique" bien connu dans les regions tropiques.

Le karst tropique n'est developpé parmi des conditions desertiques que grâce a la solubilité extrème du plâtre.

Une plus grande quantité de precipitation aurait résulté une érosion plus forte.

The Tripoli-Nalut /-Ghadames/ road crosses a strange landscape West of the town of Bir al Ghanam. Hills resembling beehives roll South to the foot of the Jabal Navusa escarpment. It is easy to observe in the road-cut that the rock composing the hills is gypsum. The gypsum outcrop is known as the Bir al Ghanam gypsum Formation. The age of the Formation is from upper Triassic to middle Jurassic, its thickness at its namesake town and West reaches 400 meters. The most recent parts of the outcrop are positioned between Bir al Ghanam and Bir Ayyad. These parts are the highest, 300-500 m of altitude. The rest of the Formation extends to the Tunisian border and is intensively weathered, almost level with the Jeffara Plain. /Fig. 1/

Geological knowledge is scarse about the Formation, detailed description is nonexistant. Some boreholes were drilled at its lower part along the highway, but the stratigraphy of the upper 300 m thick part of the Formation is practically unknown. According to what had been published /Ref. No. 5/ and the Author's field investigations it is known that algunal gypsum, dolomite, dolomitic-limestone and clay layers vary at the upper part with anhydrite towards the bottom. Gypsum beds are predominant, their thicknesses reach 30-40 m. Thickness of the dolomite intercalations vary from millimeter to several meters.

The climate of the area can be defined as desertic according to the data of nearby weather stations, the type of scarse vegetation and field observations. The available /discontinuous/ data correlated to the center of the gypsum outcrop /elevation 340 m above sea level/ permits to estimate the following normal data:

Minimal temperature/mean/	10.0°C
Maximal temperature	30.0°C
Mean temperature	20.0°C
Mean annual Rainfall	200 mm
Number of rainy days/annual/	30

Temperature varies between the extremes of -5°C and +55.7°C /Highest ever measured in nearby Aziziya/ Calculation of the de Martonne aridity index classifies the climate of the gypsum area desertic, according to the Emberger index it is arid.

Karstification of soluble rocks is influenced by the quantity of precipitation and runoff conditions. Observations show that in the 1971-72 hydrological year there occured 16 active runoff periods in the Wadi at Tall that bisects the discussed part of the outcrop. The Wadi at Tall collects the runoff of a large area originating on the plateau of the Jabal Nefusa meaning, that the shorter internal valleys of the gypsum area flood less frequently. Observations of the author prove that some caves flooded three times in the winter 1978-79. On of these floods was observed directly with extreme luck. The flood was preceded by a 12 houres varying intensity rain. Than a 15 minute shower of extreme intensity followed in the fifth minute of which surface runoff started instantly flooding the cave. The flood was about two houres of duration. The value of the observation is that it can be said now under what conditions and with what a duration the runoff occures in the gypsum area. Thus for any runoff extreme conditions are necessary and the valleys that originate within the gypsum hills do not flood more than several houres annually in the rainy winter season.

The relief of the Bir al Ghanam gypsum outcrop is a product of its geological position and structure as well as the prevailing hydrogeological factors. The gypsum formation is a member of the sequence of strata of the Jabal Nefusa and as such its outcropping depends on the recession of the escarpment. Active points of this recession are at the rim of the scarp where streambeds cross it. Because of the high gradient erosion is very energetic, streams cut through the outcropping gypsum beds. In the elongation of the mountain noses between the deeply cut wadis the gypsum outcrop remains intact of the intensive erosion in strips up to 20 km length. Local hydrological systems develope on the gypsum surface during the runoff of local rainfall. At first "sheet flow" starts. As the primary porosity of the gypsum rock is very small, infiltration is negligible at this phase. Sheet flow concentrates to intermittant streams which cut the surface. The corrosion effect of the water in the sheet flow forms a multitude of rounded gypsum hills. /Fig. 2./

Discussing the classification indices for tropical karst surfaces the hills in the Bir al Ghanam Gypsum Karst could be considered Sewu /Java/ type. /Morphogenetical index: diameter /height:3-8, ralative height 30-120 m, occurence 15-30/km^2/ /Ref. No. 1./ In spite of the extreme similarity the karst of Bir al Ghanam cannot be classified as Sewu type since the karstified rock itself is different /limestone in Sewu/ and forms different of the Gunung Sewu karst develope as well. Dolomite and clay beds intercalated in the gypsum mass behave differently against the weathering forces. The weathering of dolomite is slower than that of gypsum, clay weathers quicker. Accordingly dolomite surfaced plateau areas and gypsum capped clay cones develop. After the weathering of the dolomite bed the "cone karst" develops once again at a lower level. The weathering of the dolomite layer is not karstic but mechanical in nature due to the karstification of the underlaying gypsum beds.

Streams accumulated from the sheet flow deeply cut between the cone-hills, intersect "planes of weaknesses" /Ref. No. 6./ i.e. joints, bedding planes, vadose subsurface drainage develop the well know way. Considering that the deposit originally formed as anhydrite and transformed to gypsum only during weathering in the upper layers the Bir al Ghanam Karst is of vadose nature as a whole, a continuous karst water body does not exist in its depth. The Bir al Ghanam gypsum Karst is authigenic, runoff from non-karstic surfaces does not karstify but denudes it without development of karstic phenomena.

There are widely published statements about the two extremes of karst types; the desert and tropical karst such as: "Deserts are typified by the absence of karst phenomena" and "tropical karst can develop beyond the threshold of a mean annual temperature of 17 to 18°C and 1000 to 2000 mm of annual rainfall."

These statements are true concerning the dolomites and limestones in the upper Jabal Nefusa Formations /Ref. No. 7/ but are not applicable in the case of gypsum. The karstification of gypsum occures at relatively low temperatures /only in winter/ at very little rainfall.

The Bir al Ghanam gypsum Karst resembles the tropical karsts in appearance and origin. Still it is not equal with the tropical karsts as it is a desert phenomenon where unfavourable climatic conditions i.e. scarce rainfall are balanced by a petrographic factor namely the high solubility of gypsum.

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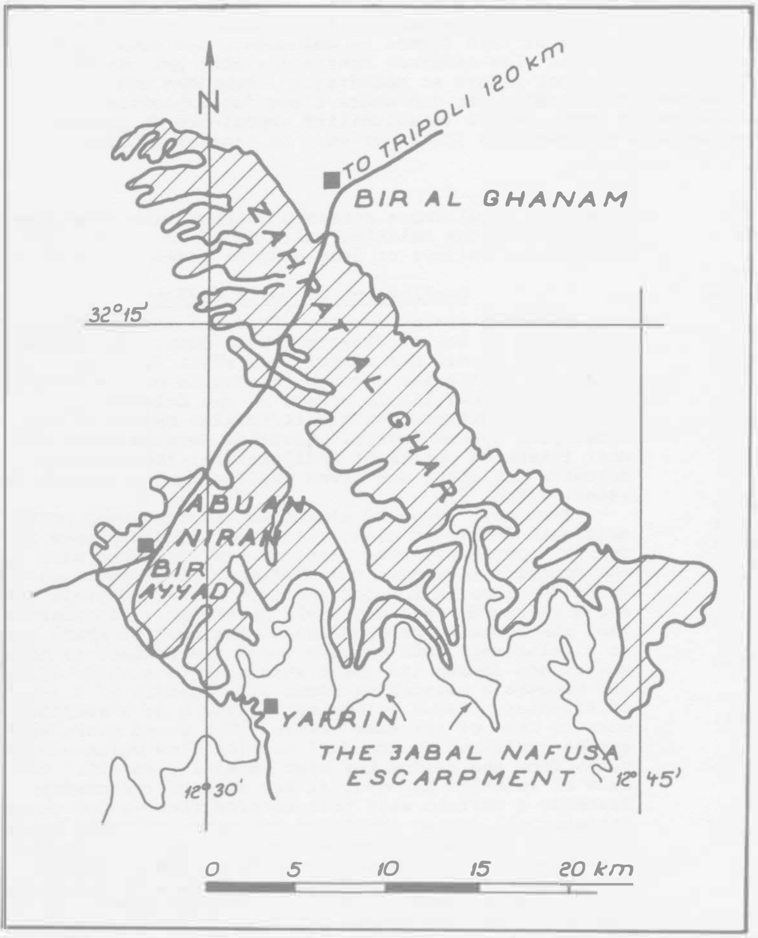

Figure 1. Map of the karstified part of the Bir al Ghanam gypsum karst

Figure 2. Typical gypsum cone-hill area with sinkhole in the foreground

Gypsum Caves in Libya

Attila Kósa
Budapest, XIV, Kover Lajos U. 46, HUNGARY

Abstract

The Bir al Ghanam gypsum karst area lies at the foothils of the Jabal Nefusa escarpment. The karst area which resembles the tropical "cone-karsts" is rich in underground drainage: sinkhole - cave - resurgence systems. Partial exploration showed that two types of sinkholes can be classified. Ones developed on gypsum and ones on dolomite surface. Both are joint oriented at the early stage of development. The continuing caves are mostly oriented by bedding planes of the gypsum beds, blat and meandering, tube-like or composite at later stages. All caves are vadose stream caves. Cave development is presumably slow in spite of the high solubility of the gypsum since the annual pluvial period of the cave systems does not exceed several houres. Length of the longest known system is more than a kilometer.

Résumé

L'aire plâtreuses-karstique de Bir al Ghanam s'étend au pied du massif Jabal Nefusa. L'aire karstique qui ressemble aux formes "cône-karstiques" tropicales est riche en cours souterrains: système de pouor - caverne - résurgence. Une exploitation partielle a prouvé que les pouors peuvent être classifiés en deux types. Notamment ceux qui sont formés sur une surface gypseuse et tels formés en dolomite. Les deux types sont orientés en faille dans la première phase du développement. Les cavernes continuées sont principalement orientées par les jonctions des couches gypseuses, elle sont planes et méandriques, tubulées our hybrides dans les phases postérieures. Toutes cavernes sont formées par des cours d'eau 'alimantation pluviales. Le développement des cavernes est probablement lent, malgré la solubilité supérieure du plâtre, comme la periode pluvieuse du systeme de cavernes ne dure que quelques jours par an. La langeur du plus long système connu est plus qu'un kilomètre.

The Bir al Ghanam Gypsum Karst is situated at the foot of the Jabal Nafusa escarpment between the towns of Bir al Ghanam and Bir Ayyad. The gypsum outcrop which is karstified in the character of tropical "cone karsts" is about 400 km^2 of surface area. Speleological research was started by the author and resulted in the discovery of a number of caves. Study of these caves which originated in various petrographic conditions and represent different stages of development, exploration of swallets and resurgences, survey of these phenomena yielded a new picture about subsurface drainage developed under unusual conditions: dry desert climate and gypsum as soluble rock. All the caves thus far discovered and explored are vadose stream-caves.

The petrographic properties of the karst may be characterised as a several hundred meter thick sequence of gypsum strata intercalated by dolomite beds from one millimeter to several meters of thickness and occasional clay lenses. The beds of the gypsum formation contain other minerals than gypsum and anhydrite. /$CaCo_3$,CaMg/Co_3/$_2$,SiO_2, clay minerals, etc./ The composition basically determines the solubility of the layers. The landscape reflects the stratigraphical conditions. Most of the area is composed of conehills the multitude of which is interrupted at places by dolomite plains which are the outcrops of the dolomite intercalations that are much less destructible than the gypsum layers. At surface conditions of both types sinkhole-cave-resurgence systems develop. The sinkholes discovered can be specified as:

A. Sinkholes /swallets/ on gypsum surface
B. Sinkholes /swallets/ on dolomite surface

The origin and development of the type A sinkholes can be described as follows.

Swallets on Gypsum Surface

A.1.a. The runoff of the rain that falls on the gypsum surface begins as sheet flow. Joints appearing on the surface swallow increasing quantities of sheet flow and due to their enlargement of size they become concentrated swallets of certain areas. The initial type of these primary swallets shows typical joint character. /Fig. 1/

A.1.b. The initial primary type swallets draw increasing quantities of runnoff during their widening and deepening as cuts develop leading to them. The resulting swallets are circular, 5-10 m deep potholes with the original joint tracable on their opposite walls. /Fig. 1/

The A.1. type swallets are classified primary because the primary runoff, the sheet flow is responsible for their development. The swallowed quantity of water is relatively small and the swallet development is possibly slow. Type A.1. swallets are usually positioned between the conical karst-hills.

A.2. Secondary swallets develop at points where joints are crossed by streambeds and by initial infiltration the development of swallets begin. During their development the swallets and continuing caves drain the surface runoff in increasing quantities until taking over the role of the surface valley. Type A.2. swallets are specified secondary because they swallow already concentrated runoff. The streamflows occur relatively oftener and the floods are richer in carried materials resulting a possibly quicker cave development. Depending on the relative position of the joints and the valleys dry valleys or deep canyons develop. /Fig. 1/

Swallets on Dolomite Surface

Dolomite plains develop after the disappearance by weathering of the overlaying gypsum beds. The dolomite plains are almost horizontal, the sheet flow has a good chance to infiltrate through the joints of the dolomite. This process has little effect on the dolomite in desertic conditions but karstification begins in the underlying gypsum layers. Cavities develop under the most intensive points of infiltration, the covering dolomite collapses and gives way for larger amounts of water. /Fig. 2/

From both types of sinkholes karstic water conduits originate developed along joints or bedding planes of the gypsum. Joint oriented passages are characteristic in the conduits that join the shafts of the type A swallets. These develope in the continuation of the original joint along which the swallet itself developed. Considering that the downward development of the swallet-shaft stops at a relatively less soluble layer the passage is horizontal and looses its joint character in a short distance and becomes a meandering, tube-like conduit of 0.3-0.5 m of diameter. Caves belonging to type A or B swallets are more or less of the same nature. The round cross section can be explained by the full section flow which originates from the seldom but high intensity runoff. The rate of solution is equal at any side of the conduit. Reaching a certain size full section flow is not characteristic all during the flood any more, solution at the bottom of the conduit becomes more intensive. Further development of the passage depends on the solubility of the bottom layer. Relatively low solubility results in a side-way enlargement to 6-8 m at extreme cases. In the case of thick pure gypsum layers high narrow passages develop. Both cases were found in clear forms but composite sections also often occur. /Fig. 3/

Caves originating from type B swallets develop more or less the same way as type A-s do. The important difference is that while development and positioning of type A caves is independent of the surface topography and the overburden can be thicker than the height of the cone hills, rock covering of type B caves is thin as they develop parallel to the dolomite surface. It is another difference that in the vicinity of the thicker dolomite layers the sequence of strata is disturbed, clayey, marly beds also occur. The nature of passages is rather flat, instead of deeper cuts development along the bedding planes is characteristic, even multiple levels develop. The thin rock covering and the wide-flat passages result in cave-ins which enlarge the cave or open it up finally resulting in the destruction of the caves and thus the dolomite plains.

According to the above description caves belonging to type A or B swallets can be specified as type A or B caves. Meaning: type A caves make systems with type A swallets where the main agent of cave development is solution while type B caves make systems with type B swallets where beside solution mechanical agents also play a significant role in cave-space enlargement and swallet development. Because of the mechanical agents caves of B type are less stabile their destruction is relatively quicker. This fact is verified by a number of "cave-wrecks" discovered.

The foregoing speleo-genetic description is a result of the exploration and survey of a number of caves discovered in a rather small part of the gypsum karst. Information about the karstic phenomena in the rest of the area is sporadic but there does not seem to be much difference in cave types and development in the whole of the area.

The longest and most intricate known system thus far is the Abu an Niran Cave system which consists of two sizable caves with interconnecting passages that are mostly unprooved because of their flat difficult nature. Seven sinkholes belong to the system. /Fig. 4/

Continued research in 1981 will throw light on many other detailes, speleological as well as biological, archeological and others.

/See References at the end of the paper titled Desert Gypsum Karst in Bir al Ghanam, Libya by the same author in this volume./

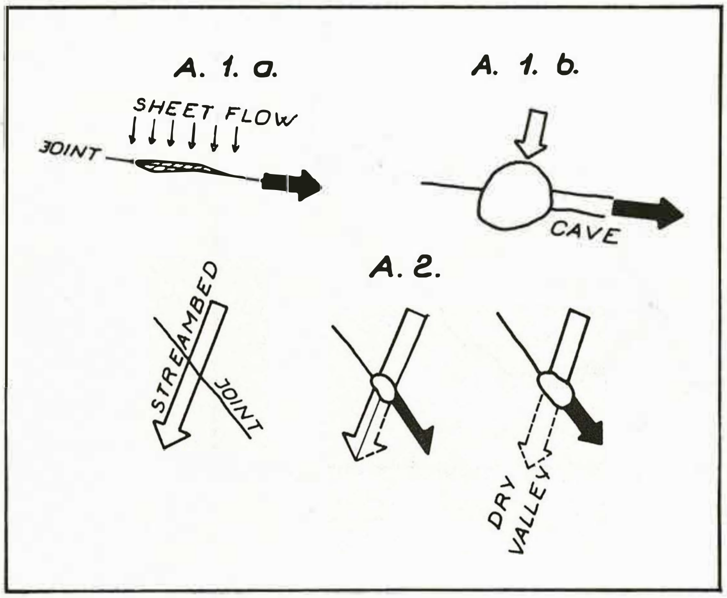

Figure 1. Development of type A sinkholes

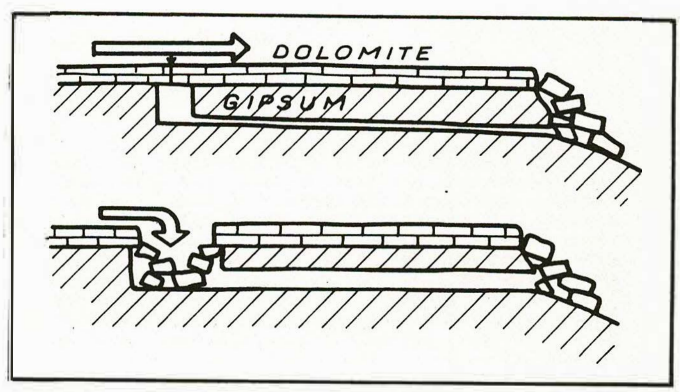

Figure 2. Development of type B sinkholes

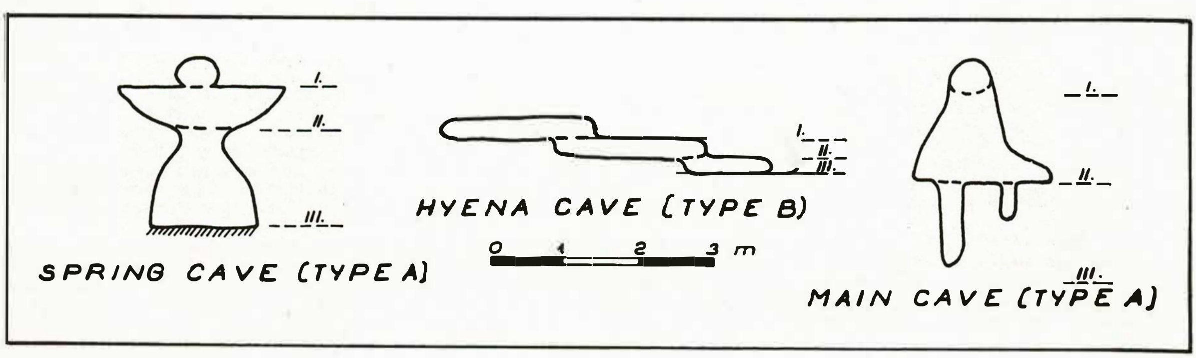

Figure 3. Various composite cave sections

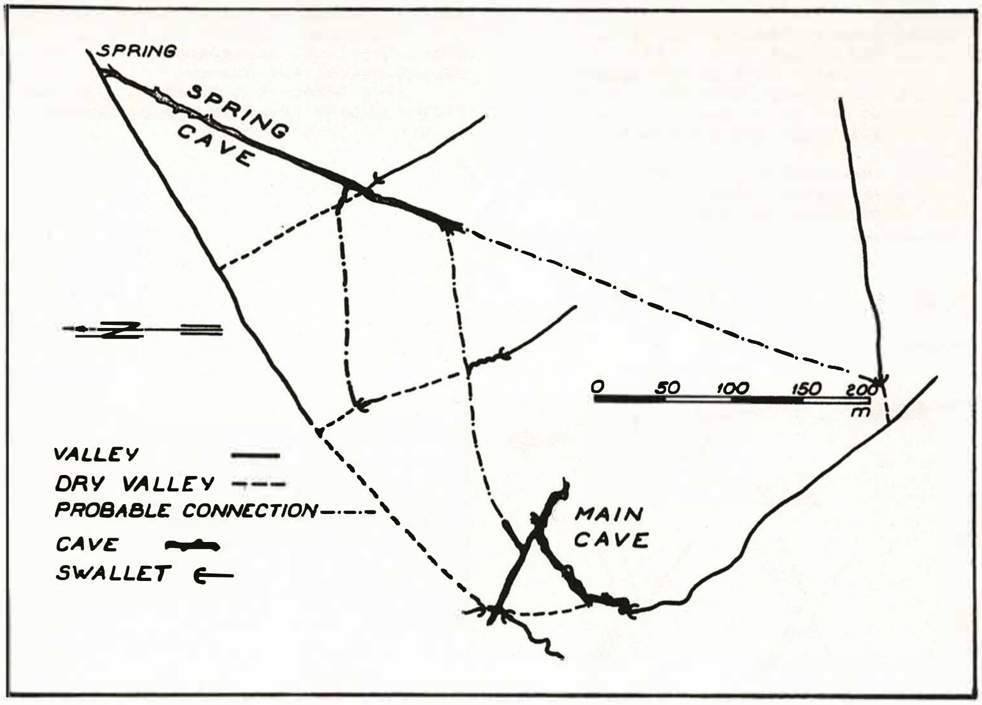

Figure 4. The Abu an Niran Cave System

A General Model of Karst Specific Erosion Rates

John J. Drake
Department of Geography, McMaster University, Hamilton, Ontario, Canada L8S 4K1

Abstract

The concentration of ions in waters in a karst terrain is equivalent to the specific erosion rate - i.e. the erosion per unit of water per unit time. Variations in specific erosion rates in regional karst terrains throughout the world have been analysed by a General Linear Model which divides variation in mean values into variations associated with the level or absence of controlling attributes, and with the value of controlling variables. In the karst context, parameters such as soil porosity, geologic homogeneity and recharge timing are extremely difficult to quantify for regional aquifers worldwide, many of which have not been studied extensively. Nevertheless, it is usually possible to estimate the general level of such parameters (for example, soil texture as sandy, intermediate or clayey) from published information and theoretical work has suggested that such a division is sufficient. Other parameters, such as temperature, are easily quantified for most parts of the world and are incorporated as controlling variables.

Results show that regional mean annual temperature has a significant effect, but that attributes such as the presence/absence of overburden carbonates determine the nature of the temperature effect. The model allows the estimation of probably changes in specific erosion rates due to anthropogenic factors such as agricultural liming and acidic precipitation or to natural factors such as climatic change.

Résumé

Dans un terrain karstique, la concentration des ions en solution est équivalente à l'érosion spécifique, c.-à-d. l'érosion par unité d'eau par unité de temps. Les variations des taux d'érosion spécifique furent analysées pour des terrains karstiques régionaux situés à travers le monde, à l'aide d'un modèle général linéaire. Le modèle sépare la variation dans les valuers moyennes en deux groupes: d'une part, les variations associées au niveau ou à l'absence d'attributs exerçant un contrôle et d'autre part, les variations associées à la valeur de variables exerçant un contrôle. Dans le contexte karstique, la qunatification de paramètres tels la porosité du sol, l'homogénéité géologique et la distribution temporelle de la recharge s'avère extrêmement difficile dans le cas d'aquifères régionaux à travers le monde et qui, dans plusieurs cas, n'ont pas été étudiés en profondeur. Néammoins, il est ordinairement possible d'estimer le niveau général de ces paramètres (par example, la texture du sol comme étant sablonneuse, intermédiaire au argilleuse) à partir de renseignements publiés; des travaux théoriques ont suggérè qu'une telle distinction suffit. D'autres paramètres, comme la température, sont facilement quantifiables pour la plupart des régions du monde et sont incorporés en tant que variables exerçant un contrôle.

Les résultats démontrent que la température annuelle régionale moyenne exerce un effet significatif, mais que certains attributs tels que la présense/absence de carbonates dans le sol détermine la nature de l'effet de la température. Le modèle permet l'évaluation de changements probables des taux d'érosion spécifique causés par des facteurs anthropogéniques tels que le chaulage agricole et les précipitations acides, ou par des facteurs naturels tels que les changements climatiques.

The Mammalian Fossils of Muskox Cave, Eddy County, New Mexico

Lloyd E. Logan
Assistant Curator, Museum of Natural History, Unviersity of Georgia, Athens, Georgia, U.S.A.

Abstract

Muskox Cave is located on the eastern face of the Guadalupe Mountains, within the boundaries of Carlsbad Caverns National Park, Eddy County, New Mexico. The sinkhole entrance, at an elevation of 1600 meters, trapped both montane and grassland mammals from the surrounding area. Forty-six percent of the mammals identified from these deposits are either extinct or no longer occur in the area. Extinct forms include Canis dirus, Acinonyx trumani, Felis atrox, Camelops sp., Equus sp., Tetrameryx onusrosagris, Stockoceros conklingi, Preptoceros sinclairi and an undescribed bovid closely related to the modern Oreamnos americanus. Extant species recovered from the deposit, but no longer occurring in the area, include Sorex cinereus, S. vagrans, S. palustris, S. merriami, Cryptotis parva, Tamiasciurus hudsonicus, Marmota flaviventris, Neotoma cinerea, Microtus pennsylvanicus, and M. ochrogaster. Both paleomammalian and paleobotanical evidence from the area indicate a spruce-fir forest with open grassy meadows, probably with a small permanent stream along the valley floor, instead of the desert shrub community that exists in the vicinity of the cave today. This drastic habitat change probably explains the local extinction of extant forms. Radiocarbon dates on bone collegen indicate an age of 25,500 ± 1,100 YBP to 18,140 ± 200 YBP for much of the deposit.

Résumé

La Caverne Muskox est localisée sur le flanc est des Montagnes Guadalupe, dans les limites de Carlsbad National Park dans le comté d'Eddy, Nouveau Mexique, L'entrée de la abîme qui se trouvent à 1600 mètres d'altitude, a attraqué les mammifères vivant dans les montagnes et les prairies environnantes de la région. Quarante-six pourcent des mammifères identifiés dans ces couches sont éteintes ou ne vivent plus dans le secteur. Parmi les espèces éteintes sont Canis dirus, Acinonyx trumani, Felis atrox, Camelops sp., Equus sp., Tetrameryx onusrosagris, Stockoceros conklingi, Preptoceros sinclairi, et un bovidé dont les traits n'ont pas été définis qui est apparenté au Oreamnos americanus moderne. Les espèces qui n'existent plus dans le secteur mais qui ont été dans les couches sont Sorex cincereus, S. vangrans, S. palustris, S. merriami, Cryptotis parva, Tamiasciurus hudsonicus, Marmota flaviventris, Neotoma cinerea, Microtus pennsylvanicus, and M. ochrogaster. Les indices paléomammifères et paléobotaniques indiquent que la region comportait autrefois une foret d'épicéas avec de riches prairies et probablement un petit cours d'eau au fond de la vallée, alors que maintenant dans evirons de la cave, elle ne reste qu'une région désertique avec une végétation d'arbustes. Ce changement radical de milieu explique le fait que les espèces encore vivantes n'habitent plus dans la région. La datation au carbon des os de collagen indique qu'ils ont un âge variant de 25,000 ± 110 YBP à 18,140 ± 200 YBP pour la plupart des couches.

Introduction

Muskox Cave is located at an elevation of approximately 1600 meters on a southwesterly facing slope of the eastern face of the Guadalupe Mountains, within the boundaries of Carlsbad Caverns National Park, Eddy County, New Mexico. The present entrance is a small, partially boulder-choked shaft which flares with depth to a moderately large, joint-controlled room with the present floor approximately thirty-five meters below the surface. The primary Pleistocene entrance, which was a sinkhole approximately 20 meters in diameter, is now filled to within five to ten meters of the surface with breakdown block and debris.

The Peistocene entrance must have been an effective trap as evidenced by the presence of numerous herbivores (Camelops, Tetrameryx, Stockoceros, Preptoceros, Equus, and an undescribed bovid similar to the modern Oreamnos) and carnivores (Felis, Acinonyx, Lynx, Canis, and several smaller carnivores). The fall, possibly as much as 75-80 meters, must have been fatal or at least disabling for most large animals since there is very little evidence of carnivore gnawing on the bones recovered. Many of the large bones recovered show evidence of rodent gnawing, most probably Neotoma sp., which are common fossils in the site.

Botany

The present flora near Muskox Cave can be characterized as a complex Chilhuahuan desert scrub community mixed with chaparral and grassland species, including Agave sp. (Century plant), Cercocarpus montanus (Mountain Mahogany), Dasylirion sp. (sotol), Echinocerus sp. (hedgehog cactus), Ephedra sp. (Morman tea), Lesquerella sp. (bladder pod), Oenothera sp. (Evening primrose), Opuntia imbricata (cane cholla), Opuntia sp. (prickly pear), Quercus sp. (oak), and Yucca sp. (yucca).

While the only plant macrofossils recovered from Muskox Cave are seeds which ~~represent~~ Celtis reticulata (hackberry) and Opuntia sp. (cholla or prickly pear cactus), the faunal assemblage indicates a sub-alpine forest with open glades similar to the area near Upper Sloth Cave (Logan and Black, 1979), Lower Sloth Cave (Logan, 1977), and Dust Cave on the west face of the Guadalupe Mountains during the late Pleistocene. Since Muskox Cave is over 300 meters lower in elevation than the west side caves, it is possible that there was more grassland and less forest. This interpretation is supported by the large numbers and variety of grassland species (antelope, horses, camels, and a cheetah) present in the deposit.

Van Devender et al. (1978 and 1979) characterized the flora near the west side caves in the late Pleistocene as a sub-alpine forest with Picea sp. (spruce), Juniperus sp. (juniper), J. communis (dwarf juniper), Pseudostuga menziesii (douglas fir), Pinus strombiformis (southwestern white pine), P. edulis (Colorado pinyon), Ostrya knowltonii (hop hornbeam), Quercus gambelii (Gambel oak), Arctostaphylos sp. (manzanita), Robina neomexicana (New Mexico locust), and Rubus strigosus (raspberry). This interpretation is based on plant macrofossils and pollen profiles from Upper and Lower Sloth Caves, Dust Cave, and Williams Cave. These four caves are located in Culberson County, Texas which is adjacent to Eddy County, New Mexico on the south.

Conclusions

The mammalian fauna of Muskox Cave represents material from late Sangamon to Recent time. The sediments below the major Pleistocene entrance, including the Muskox Pool Room, Three Muskox Room, and the crawlway and chimney areas above these rooms are filled with vertebrate fossils commonly associated with Pleistocene sediments. The mammalian fossils recovered from below the present entrance represent primarily Recent mammals, with most of these mammals occurring in the immediate vicinity of Muskox Cave today (Findley et al., 1975). It is anticipated that the debris cone below the present entrance could reach a depth of five to six feet and span the gap between the older material (greater than 20,000 YBP) from the Muskox Pool Room and the early Holocene material recovered from below the present entrance.

Extinct mammals make up 18 percent of the fauna of Muskox Cave, and extant, but extralimital, species make up an additional 28 percent to the fauna. Thus 46 percent of the mammals identified from Muskox Cave are no longer found in the area (Table 1).

Nearly all the extant mammals which no longer occur in the area may be found in more mesic habitats in the mountains of northern New Mexico and southern Colorado. The modern ranges of these mammals are primarily to the north or northwest of Muskox Cave, with only Cryptotis parva providing a truly eastern influence to the fauna. Although fossil Cryptotis have previously been reported from several sites in the Guadalupe Mountains (Harris et al., 1973; Logan, 1977; Logan and Black, 1979), the closest modern record is from Lubbock County, Texas, over 325 kilometers to the northeast (Packard and Judd, 1968).

Based on the paleobotanical evidence (Van Devender et al., 1978 and 1979), as well as the habitat preferences of the mammals recovered from Muskox Cave, the area surrounding Muskox Cave was most likely as spruce-fir forest interspersed with grassy glades or meadows. The valley floor probably held a small permanent stream. The flat lands at the base of the Guadalupe Mountains was probably rather open, much as it is today, but undoubtedly with a much richer grassy cover.

Acknowledgements

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Table 1. Fossil mammals of Muskox Cave, Eddy County, New Mexico. Extinct forms are designated by the symbol ** and extant forms which no longer occur in the area are represented by the symbol *.

Order Insectivora	
Family Soricidae	
*Sorex cinereus	Masked Shrew
*Sorex vagrans	Vagrant Shrew
*Sorex palustris	Water Shrew
*Sorex merriami	Merrian's Shrew
*Cryptotis parva	Least Shrew
Notiosorex crawfordi	Desert Shrew
Order Chiroptera	
Family Vespertilionidae	
Myotis velifer	Cave Myotis
Myotis thysanodes	Fringed Myotis
Eptesicus fuscus	Big Brown Bat
Plecotus townsendii	Townsend's Big-eared Bat
Antrozous pallidus	Pallid Bat
Family Molossidae	
Tadarida sp.	Free-tailed Bat
Order Lagomorpha	
Family Leporidae	
Sylvilagus cf. floridanus	Eastern Cottontail
*Sylvilagus cf. nuttalli	Nuttall's Cottontail

Table 1 continued

Order Rodentia	
Family Sciuridae	
Eutamias sp.	Chipmunk
*Marmota flaviventris	Yellow-bellied Marmot
Spermophilus variegatus	Rock Squirrel
*Tamiasciurus hudsonicus	Red Squirrel
Family Geomyidae	
Thomomys cf. bottae	Botta's Pocket Gopher
Family Heteromyidae	
Perognathus merriami	Merriam Pocket Mouse
Family Cricetidae	
cf. Reithrodontomys fulvescens	Fulvous Harvest Mouse
Peromyscus sp.	White-footed Mouse
Onychomys leucogaster	Northern Grasshopper Mouse
Onychomys torridus	Southern Grasshopper Mouse
Neotoma sp.	Woodrat
Neotoma micropus	Southern Plains Woodrat
Neotoma albigula	White-throated Woodrat
Neotoma mexicana	Mexican Woodrat
*Neotoma cinerea	Bushy-tailed Woodrat
*Microtus pennsylvanicus	Meadow Vole
Microtus mexicanus	Mexican Vole
*Microtus ochrogaster	Prairie Vole
*Ondatra zibethicus	Muskrat
Erethizon dorsatum	Procupine
Order Carnivora	
Family Candiae	
Canis sp.	Wolf
**Canis dirus	Dire Wolf
Family Procyonidae	
Bassariscus astutus	Ringtail
Family Mustelidae	
Mustela frenata	Long-tailed Weasel
Spilogale gracilis	Western Spotted Skunk
Conepatus sp.	Hog-nosed Skunk
Family Felidae	
Felis concolor	Mountain Lion
**Felis atrox	American Lion
**Acinonyx trumani	American Cheetah
Lynx refus	Bobcat
Order Perissodactyla	
Family Equidae	
**Equus sp.	Horse
Order Artiodactyla	
Family Camelidae	
**cf. Camelops sp.	Camel
Family Antilocapridae	
cf. Antilocapra americana	Pronghorn
**Stockoceros conklingi	Conkling's Pronghorn
**Tetrameryx onusrosagris	Quentin's Pronghorn
Family Bovidae	
**Preptoceros sinclairi	Bush Ox
**Ovis canadensis	Bighorn Sheep
**Undescribed bovid	Mountain Goat

The Submarine Caves of Bermuda

Thomas M. Iliffe
Am. Con. Gen. BUCH, APO, New York 09757

Abstract

Bermuda consists of a small group of islands situated atop a volcanic seamount in the Northwest Atlantic. The islands themselves are composed of marine and eolian, Pleistocene and Recent limestone completely capping the volcanic pedistal. Three types of submarine limestone cave morphology have so far been identified in Bermuda, with a fourth type suspected. The first type is reef caves which form at the base of the platform's fringing coral reefs in 10-20 m water depths. These caves consist of cavities and roofed fissures within the reef itself. A second type of cave occurs inland and is characterized by fissure entrances and large collapse chambers, both above and below sea level. This type of cave is primarily found on the strip of land between Harrington Sound and Castle Harbour. The third type consists of long, nearly level, anastomosing passages at depths of 18 m connecting Harrington Sound with the North Shore. During glacial periods of low sea level, these caves probably served to transport runoff waters along the surface of the water table from the then enclosed Harrington Sound to outside of the north fringing reefs. A related type of cave may connect both Harrington Sound and Castle Harbour with the South Shore. Since the south reefs are only 1 km distant from these two inshore basins, while the north reefs are 15 km, caves followin the water table to beyond the south reefs would be expected to be large, single, steeply dipping linear passages.

Zusammenfassung

Bermuda besteht aus einer kleinen Inselgruppe, die auf einer vulkanischen Kuppe im Nordwestatlantik liegt. Die Inseln selbst bestehen aus marinem und aeolischem, pleistozaenem und rezentem Kalkstein, der die vulkanische Basis voellig bedeckt. Bisher sind drei Typen submariner Kalkhoehlen identifiziert worden, und ein vierter wird vermutet. Der erste Typ ist die Riffhoehle, die sich in 10-20 m Tiefe an der Basis der Plattform-Saumriffe bildet. Diese Hoehlen bestehen aus Raeumen und gedeckten Rissen innerhalb des Riffs. Ein zweiter Typ findet sich inland und ist durch Riss-Eingaenge und Einsturz-Raeume gekennzeichnet; er kommt hauntsaechlich im Landstreifen zwischen Castle Harbour und Harrington Sound vor. Der dritte Typ besteht aus langen, fast horizontalen, kommunizierenden Passagen, die in 18 m Tiefe Harrington Sound mit der Nordkueste verbinden. Zu Zeiten niedrigen Wasserstandes waehrend der Eiszeiten dienten diese Hoehlen wahrscheinlich dem Abtransport von Grundwasser entlang des Grundwasserspiegels vom damals isolierten Harrington Sound nach aussen, ausserhalb der noerdlichen Saumriffe. Ein verwandter Hoehlentyp verbindet moeglicherweise sowohl Castle Harbour wie Harrington Sound mit der Suedkueste. Nachdem die Suedriffe nur 1 km von diesen beiden Lagunen entfernt sind (im Gegensatz zu 15 km fuer die Nordriffe), kann man erwarten, dass diese dem Grundwasserspiegel folgenden Hoehlen grosse, einzelen, steil abfallende lineare Passagen sind.

* * *

Bermuda is the world's northernmost coral stoll (Garrett & Scoffin, 1977) located near latitude 32°N and longitude 65°W in the Northwest Atlantic Ocean. It consists of a volcanic platform (Pirsson, 1914) completely capped with marine and eolian, Pleistocene and Recent limestones (Land et al., 1967). The major physiographic provinces of the Bermuda Platform are an 18 m deep main terrace, a shallow rim consisting of fringing reefs, a central lagood containing patch reefs, and a series of over 150 islands and islets composed of Pleistocene eolianites interbedded with terra-rosa paleosols (Fig. 1A).

Although considerable attention had been given to the terrestrial caves of Bermuda (Verrill, 1980; Swinnerton, 1929; Forney, 1973; Harmon, 1974; Palmer et al., 1977; Iliffe, 1979), little was known of th extensive submarine portions of these caves. In 1979, systematic exploration and mapping of the underwater caves of Bermuda was initiated utilizing advanced cave diving equipment and methodology (Exley, 1979). Dives have since been conducted in 27 different inland cave pools as well as numerous reef caves. From these explorations, three distinct types of submarine cave morphology have so far been identified.

Reef Caves

Numerous submarine caves are found along the seaward base of the platform's fringing reefs in 10-20 m water depths (Fig. 1A). These reefs are locally referred to as boiler or breaker reefs since they extend to the sea surface and have waves breaking over them. The reefs consist primarily of encrusting coralline red algae, encrusting vermetid gastropods and Millepora corals with few or no other corals. Reef caves are generally tens of meters in length and consist of cavities or roofed vertical fissures within the reef itself. Stanley and Swift (1967) have proposed a solutional origin under subserial conditions for these caves stating that reef caves resemble partially collapsed caves from the interior of the island. However, there are at least three significant differences between reef caves and inland collapse caves. First, speleothems are completely absent from the reef caves, while they are very common in the inland caves - both above and below sea level. Second, the collapse features observed in reef caves cannot compare in magnitude or character with that found in inland caves. Reef caves contain only limited numbers of well rounded boulders, while extensive angular collapse blocks are prominent features of inland caves. Third, reef caves are generally composed of small irregular rooms or roofed vertical fissures, contrasting with the inclined fissures and large collapse rooms of inland caves. Thus it is unlikely that reef and inland caves were formed by similar means. The most likely origin of reef caves is that of a constructional void within the reef being enlarged and shaped by wave and surge erosion.

Collapse Caves (Walsingham Area)

The inland caves of Bermuda were probably formed during periods of continental glaciation when sea level was as much as 100 m below its present level. Consequently, Bermuda was a much larger island since the entire top of the platform was emergent and thus, unlike today, substantial bodies of fresh ground water were present. Cave formation probably occurred primarily in the phreatic zone along the surface of this paleo water table (Palmer et al., 1977). Collapse of roof rock and deposition of secondary dripstone contributed to the isolation of the caves. As interflacial sea levels rose, substantial portions of the caves were drowned in sea water. Today, most of Bermuda's inland caves contain deep tidal sea level pools, indicating that the terrestrial sections may only represent a small portion of Bermuda's cave systems with the majority of cave passages, including the original phreatic passages lying deep below present sea level.

The Walsingham area, located between Harrington Sound and Castle Harbour (Fig. 1B), contains the largest known concentration of caves in Bermuda - approximately 100-150 caves. These caves are characterized by fissure entrances and large collapse chambers (Palmer et al., 1977). Divers in these caves have reached depths of -24 m where the traversable cave terminated in collapse. It is possible that these large chambers have resulted from collapse into deeper passages lying at the limestone-basalt interface. This interface may be as shallow as -35 m in the Walsingham area (Newman, 1959). During periods of lower sea level, ground water would penetrate the very porous eolianite limestone until reaching the impermeable basalts. At the interface, horizontal transport of the ground water would likely have formed large solutional cave passages. The underwater portions of the Walsingham caves closely resemble the terrestrial morphology found in the same caves, even to the variety of large speleothems found at all depths within the caves.

Passage Caves (Shelly Bay Area)

Dives in inland caves in the Shelly Bay area of Bermuda (Fig. 1B) have revealed very extensive caves with long, nearly level, anastomosing passages reaching from Harrington Sound to the North Lagoon (Iliffe & Warner, 1980). The largest of these caves, and also the longest cave in Bermuda - terrestrial or marine - is the 1.5 km long, totally underwater Green Bay Cave System (Fig. 2). This cave and other caves in the Shelly Bay area probably acted to transport water between the nearly enclosed Harrington Sound and the North Lagoon or possibly even the North Rim, 15 km distant. The 18 m average depth of these caves corresponds with the depth of the main reef terrace indicating that both features may have formed during a stationary stand of sea level at this position.

Devil's Hole Caves

A fourth type of submarine cave, as yet still theoretical, may exist in the area of Devil's Hole, located between Harrington Sound and the South Shore (Fig. 1B). Four caves containing sea water pools are known from this area. However, only a few preliminary dives have been made in these caves without any significant discoveries. Since the distance between Harrington Sound and the South Rim is only one km, it is possible that caves from the Devil's Hole area may consist of large, single, steeply dipping linear passages transporting water from the then totally enclosed Harrington Sound during low stands of sea level. Even today, approximately 50% of the tidal exchange in Harrington Sound in through caves.

Summary

Diving explorations in Bermuda have so far identified three different types of submarine cave morphology. Reef caves are probably of constructional origin, modified by erosion. Caves in the Walsingham area are probably the product of collapse into deeper solutional voids. Caves at Shelly Bay, and possibly at Devil's Hole, probably formed in response to water transport into and out of the nearly enclosed Harrington Sound.

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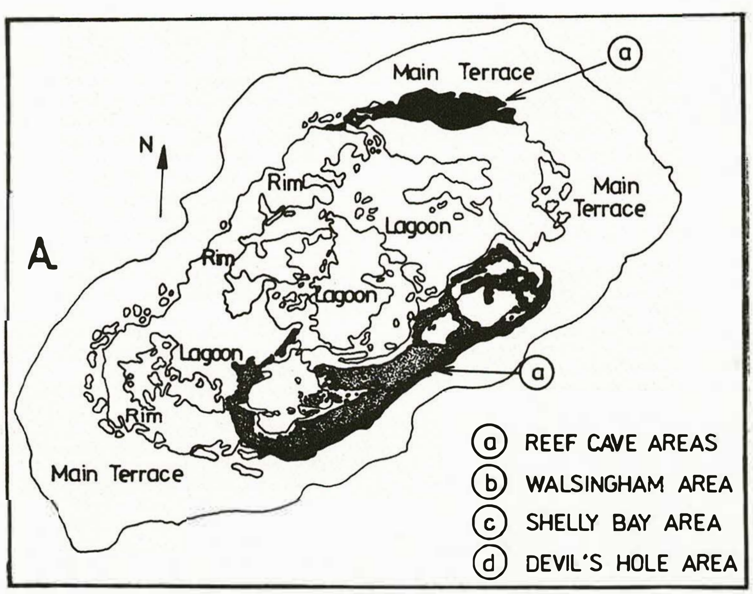

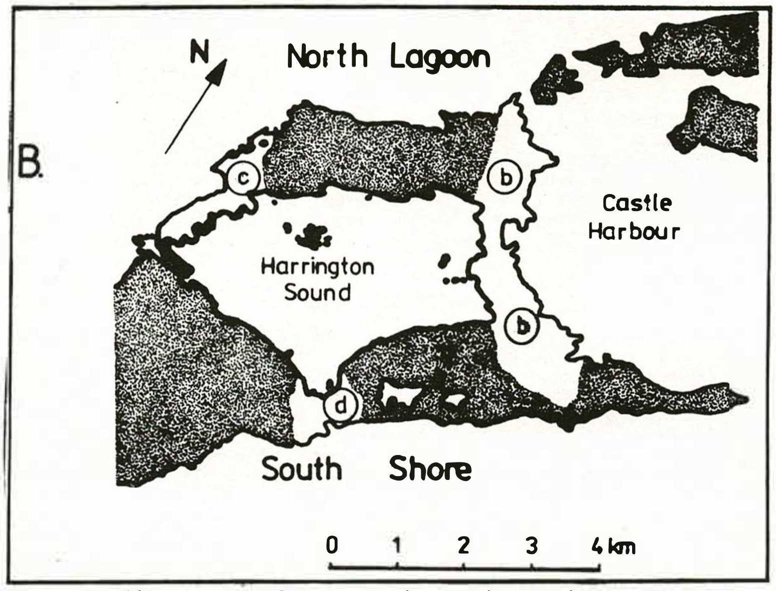

Figures 1A and 1B: Physiographic Provinces and Cave Areas in Bermuda

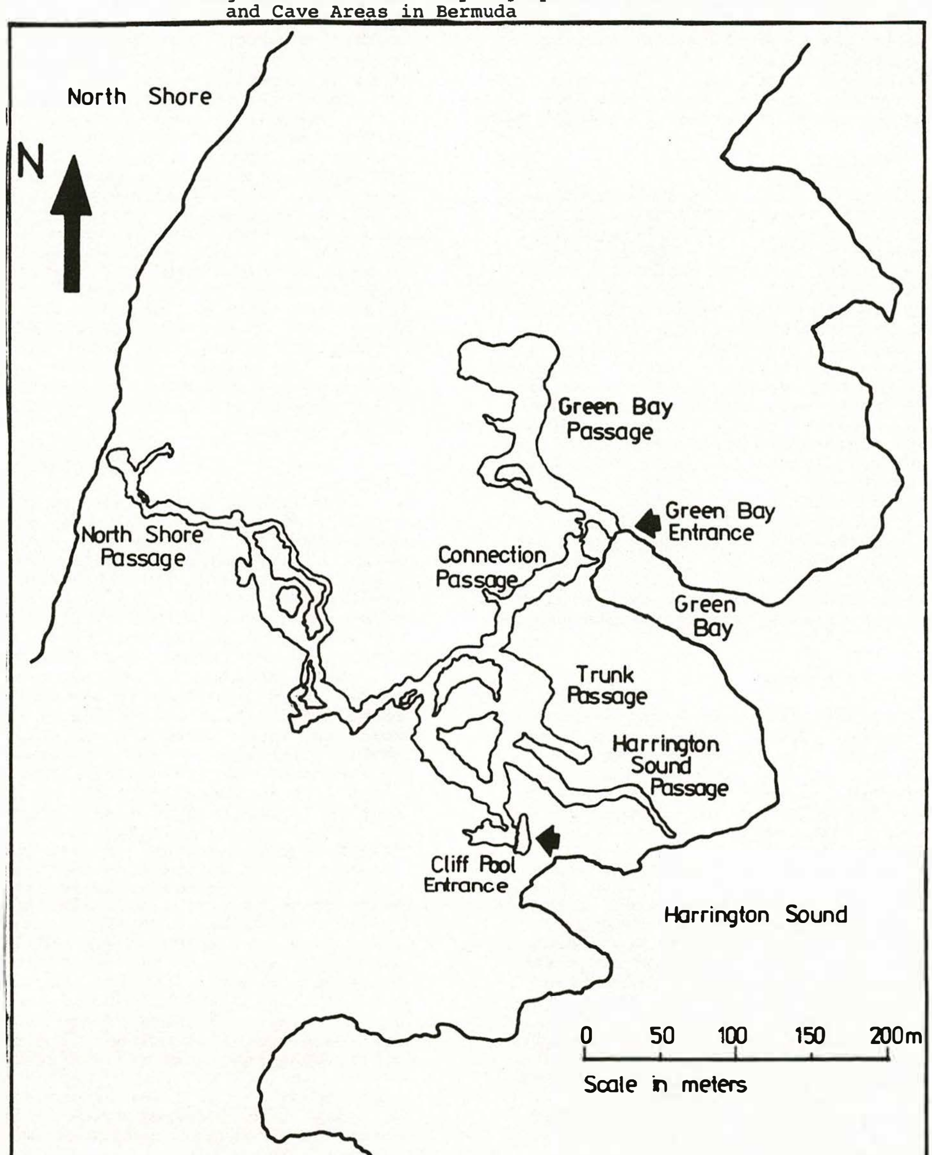

Figure 2: Map of Green Bay Cave System

The Lower Cretaceous Paleokarst in the Moravian Karst (Czechoslovakia)

Pavel Bosak
P.O. Box 8, CS 14500 Praha 4, Post Office 045,
(Czechoslovakia)

Abstract

Relatively large Lower Cretaceous (pre-Cenomanian) paleokarst forms are known. If not exhumed and destroyed, they are filled by sediments of the Rudice-Formation (kaolin-laterite weathering products of tropics and subtropics). The formation of the paleokarst passed in the period from the Middle Malmian to the Cenomanian along the paleolatitude approximately 30°N. Morphologically diversified paleokarst forms were developed which represent the cockpit-type of the tropical karst. Filling of depressions was synchronous with their deepening. Only minor forms were formed before the sedimentation. The deposition took place in environments of rivers, alluvial cones, lakes and by mudflows, as indicated by analysis of granulometrical curves.

Zusammenfussung

Der unterkreide Paleokarst in den Mährischen Karst (Tschechoslowakei). Die relativ grossen unterkreide (vor-Cenomanische) paleokarstischen Formen sind bekannt. Wenn sie nich exhumiert und vernichtet sind, so sind sie mit Sedimente der Formation Rudice (kaloinisch-lateritischen Verwitterungen der Tropen and Subtropen) gefüllt. Die Bildung des paleokarstes ging im Zeitabschnit von den mittleren Malm bis zum Cenoman in dem Niveau der Paleobreite approximately 30°N. Die morphologisch gegliederten paleokarstischen Formen entwickleten sich die den Typus Cockpit representieren. Die Ausfüllung der Depresionen verlief gleichzeitig mit ihrer Vertiefung, nur eine Minderheit der Formen entstand vor der Sedimentation. Die Sedimentation ging in der Umgebung von Flüssen, alluvialischen Kegeln, Seen und Schlammströmen vor sich, vie uns die Analysen der granulometrischen Kurven indizieren.

Introduction

The Moravian Karst represent the largest karst area in Czech countries. Morphologically depression form wide several kilometres and long several tens of kilometres (Fig. 1C) lies to north from Brno. Paleokarst forms have been investigated by many authors and more than 40 publications deal with the Lower Cretaceous paleokarst (see Bosak 1978). The main interest is paid to occurrences of the Rudice Formationk sands of which are exploited as moulding sands.

Geology

The Moravian Karst is built by Middle Devonian (Givetian) to Lower Carboniferous (Tournaisian) shelf carbonate sequence to 1000 m thick with irregular layer of basal clastics at the base. The basement of the Paleozoic is formed by Upper Proterozic magmatites (both acid and basic) of the Brno Eruptive Massif. Lower Carboniferous limestones transtitionally pass to flysh shales, greywackes and conglomerates (Visean). So called Nemcice belt of the Devonian is the continuation of the Moravian Karst to the north. Carbonate rocks of this belt are only several hundreds meters wide (Fig. 1C). Devonian carbonate sequence of the Moravian Karst was uncovered to weathering already during the Permian. Intermontane depression had originated since the Triassic (Panos 1962-63). This broad and relatively shallow form with the axis N-S was filled during the ingression of The Jurassic epicontinental sea (Callovian to Kimmeridgian) by sandy and pure carbonate rocks (Hanzlikova and Bosak 1977). Intensive weathering in the Lower Cretaceous caused rich development of karst and nearly whole Jurassic sediments were destroyed. The evolution of karst relief was interrupted by the Cenomanina transgression.

Karst Phenomena

Relicts of the Lower Cretaceous karst are concentrated in the norther part of the Moravian Karst and in the Nemcice Karst. Their occurrences are dependent on the course of main sunkened zones parallel to Saxonian tectonic grabens of NNW-NW - SSE-SE direction. Regions in vicinities of village Rudice and Nemcice represent such zones, i.e. the Rudice sunkened block parallel with the Blansko Graben (Burkhardt 1974) and sunkened zone along the Valchov Graben between viallages Nemcice and Vratikov (Fig. 1C). Southern parts and also certain zones in the northern part of the Moravian Karst had rather elevation character and therefore Lower Cretaceous karst phenomena have been fully destroyed since the uppermost Cretaceous. Morphologically diversified relief is preserved, where it is covered by weathering products or/and by younger sediments.

The levelled surface of corrosioanl origin with cupola-shaped elevations and isolated inselberges was originated during the Lower Cretaceous. According to Panos (1962-63) it represents the basic planation surface in the Moravian Karst. Marginal zones of the Moravian Karst in neighbourhood of nonkarstic relief (magmatites, flysh clastics) were modelled by gradually arranged outwash pediments (Panos l.c.). The evolution of karst phenomena was characteristic for the centre of large intermontane depression rimed by relatively high relief on nonkarstic rocks. Tropical karst relief was developed and contemporaraneously filled by redeposited weathering products of crystalline and sedimentary rocks.

Depressions of old karst have various shape and size. Uvales, dolines, complex and double sinkholes, shafts, geological organs and valley-like forms were originated. These forms were formed only partly before the beginning of the sedimentation for the discussion (see Bosak 1978). Certain horizons of fossil scree and fossil soils prove the origin of inicial depressions or in certain cases of whole karst forms. Depressions were separated by richly modelled elevations of the character of mogotes, karst tower and spires (?assegais), inselbergs and short ridges. Walls of elevations and depressions are steep and in many cases even overhanging. Mean values of the total height of the relief are 30-50 m, but maximal values reach more than 140 m in the Rudice region. The morphology and the concentration of depressions are structurally controlled, what is proved by their directions parallel with main joints systems and faults (Fig. 1B).

Fillings

The base of depressions is uneven. Limestones are strongly corroded, dissected by widened fissures and/or bedding planes. Relatively large quantity of small cavities occur shallowly below the surface. All these forms are filled by limonite iron ores. Limonite minearlization reached relaitvely deep horizons (first tens of metres). Origin of limonite is connected with the seepage of weathering solutions which attacked limestones and caused their cold metasomatism.

Basal horizons of sedimentary fillings differ in single areas according to the character of weathered rocks. The oldest weathering products are kaolinic weathered Lower Carboniferous shales for the region of Nemcice-Vratikov. Shortly redeposited coloured clayey sediments of the halloysite nature with overlaying ochre clays from weathered Jurassic rocks are present additionally in the Valchov area (Panos 1963).

Basal horizons in the Rudice region are built by fossil screey and fossil soils, ochre clays and sandy to clayey chert conglomerates in total thickness to 15 m. The basal horizon is formed in places by in situ weathering products of Jurassic limestones represented by kaolinic sands to sandy kaoline clays with abundant relicts of Sponge spicules (Wankel 1882). The main thickness of fillings are represented by redeposited kaoline-laterite weathering crusts. Old karst relief in surroundings of Nemcice and Valchov was covered by redeposited basal horizons of these crusts and fillings have still the character of laterites. The situation in other parts of the Moravian Karst was different. All forms were covered and filled by continental sediments of the Rudice-type (Bosak et al. 1979) as indicated by in situ occuring fillings or by indirect evidence from redeposited Rudice Formation in younger sequences (mainly Upper Cretaceous and Tertiary).

The Rudice Formation is built by alteration of clays, kaolines, kaoline clays, sandy clasy, clayey sands, quartz sands, quartz and chert conglomerates. The distribution of single lithological type is very irregular. Part of sandy and sandy-clayey deposits is coloured to yellow, ochre, red, reddish-brown and purple colours. This phenomenon indicates in situ lateritization of freshly deposited filling (Pelisek 1976). Such process probably existed as proved by complete colouring of all structures and textures of sediments and by larger extent of colouring along subsidence fractures in the Rudice Formation. Certain horizons of sands were cemented by silica cement as a result of the seepage of weathering solution from lateritization enriched with the SiO_2.

Mineralogy and chemistry of sediments of the Rudice Formation prove intensive weathering of source deposits. The amount of unstable minerals is limited both in heavy fraction (association disthene-tourmaline-zircon with staurolithe, i.e. chemostable association, Burkhardt 1974, Krystek 1966) and in light fraction (mainly quartz, with muscovite, chert, quartzite, kaolinite, halloysite, montmorillonite, Fe and Al oxydes and hydroxides, Bosak 1978). Chemistry show nearly total decalcification, impoverishing in Na, K and strong presence of amphoteric elements (Fe, Al, Mn, Burkhardt 1974).

The nature of fillings and the result of evaluation of granulometrical curves in log-probability chart clearly indicate that fillings are sediments (Bosak 1978) and not weathering products of Jurassic rocks in situ (opinion of Panos 1963). Sediments were brought from the south by intermittent streams and deposited in environment of river channel, alluvial cones and periodic lakes. Additional transport of sediments occured from W and # by mudflows and outwashes (from pedimented borders of central karst depression).

The age of fillings is clearly limited by the Kimmeridgian and by the Cenamanian. The Jurassic regression took place during the Kimmeridgian. Paleontologically dated Cenomanian fresh water and also marine deposits in places cover sediments of the Rudice Formation, or Cenomanian deposits are built by redeposited Rudice Formation (Valchov Graben).

Discussion

Certain forms were also deepened during the uppermost Cretaceous and later as indicted Upper Cretaceous sunkened in depressions and covered by Tertiary and Quaternary deposits. The evolution of depressions (the deepening) probably continue even in the Recent. That is why the term paleokarst and not fossil karst is used (for terminology see Bosak and Horacek, in print). The Rudice Formation have been described as Upper Cretaceous (Cenomanian) in age (see Krystek and others 1966). The opinion of these authors was led by the sinking of Upper Cretaceous sediments into the old relief. But it was clearly shown that the Rudice Formation is pre-Cenomanina and the later sinking even post-Turonian (or Santonian, see Bosak 1978).

The morphology of elevation and depression karst forms show similarilty with the recent cockpit-type of tropical karst. Mineralogy and geochemistry of sediments prove the weathering in prevailing tropical and partly maybe also in subtropical clima (Burkhardt 1974, Bosak 1978). These results are in the agreement with palinspastic reconstructions, which indicate the position of the Rudice-Nemcice region along the 30°N paleolatitude (See Bosak, in print).

Old karst surfaces with rich and diversified morphology were not limited only to the area of the Moravian Karst and to areas in its closest proximity. Lower Cretaceous karstification left some relicts in nearly all terrains with soluble rocks in whole Bohemian Massif (Fig. 1A No. 1 - the Moravian Karst, 2-Nemcice-Valchov-Vratikov, 3-the Tisnov Karst = Cebin, 4-Kunstat, 5-Olesnice, 8-The Bohemian Karst = surroundings of Praha and Beroun. Nos. 6 and 7 represent parts of eastern margins of Boehmian Massif now incorporated in "Outer Klippen Belt" of Outer Carpathians, 6-Turold Klippe, 7-Kotouc Klippe. No. 9 represents the locality Kadov with sediments in karst pocket ekvivalent to the Rudice Formation, Burkhardt 1962).

Conclusions

Morphologically diversified Lower Cretaceous karst surface of the cockpit-type is known from larger remains from the Moravian and Nemcice Karsts. Karstification took place in the tropical clima. Thick kaoline-laterite weathering crusts were the source of fillings of contemporarily deepened depressions. Fillings were deposited by mudflows, outwashes and by intermittent streams in alluvial cones and periodical lakes. Only part of filling represent in situ weathered older rocks.

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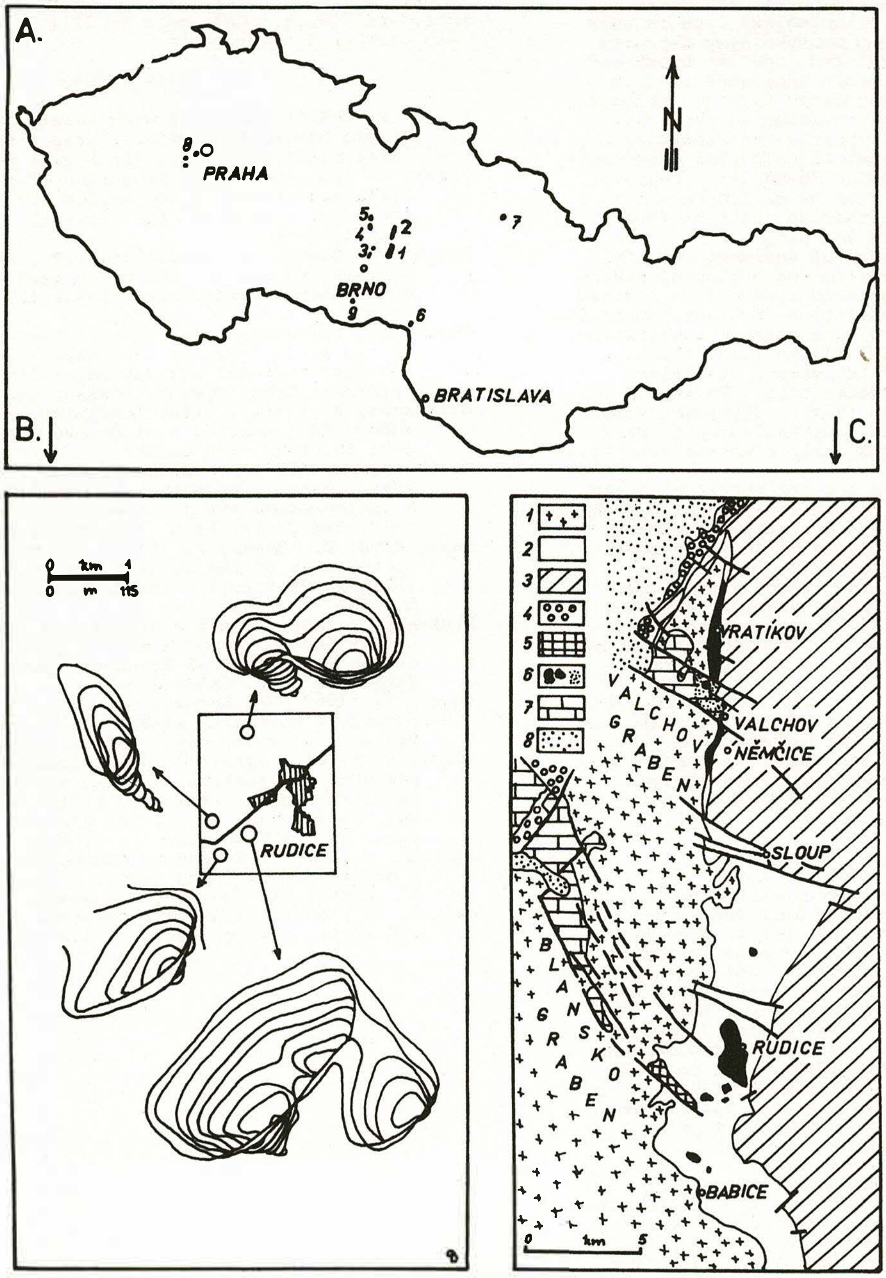

Figure 1. Distribution of Lower Cretaceous karst phenomena on the Bohemian Massif (A), for explanation see the text. The representation of the shape of old depressions in the Rudice region as resulted from boring data (B). General geological schema of the Moravian Karst and surrounding areas with representation of occurrences of remains of the Lower Cretaceous karst. 1-Brno Massif, 2-Devonian to lowermost Carboniferous carbonate sequence and basal clastics, 3-Lower Carboniferous flysh, 4-Permian mollasse, 5-Jurassic rocks, 6-remains of Lower Cretaceous karst, a. uncovered, b. covered, 7-Upper Cretaceous rocks, 8-Lower Badenian sediments.

The Investigation of Old Karst Phenomena of the Bohemian Massif in Czechoslovakia: A Preliminary Regional Evaluation

Pavel Bosak and Ivan Horacek
P.O. Box 8, CS-14500 Praha 4, Post Office 045, Czechoslovakia

Abstract

Rich development of morphologically diversified karst phenomena in the geologic history of the Bohemian Massif has been conditioned by its geological evolution. The oldest known karst phenomena are fo the Lower Givetian, Lower Carboniferous and Permian ages. The Lopies. The development of the karst during the Tertiary was very intense with the maximum Miocene-Late Pliocene. The development of karst phenomena during the Quaternary was influenced by the alteration of climatic cycles.

Zusammenfassung

Die Erforschung des altes Karstformen der Böhmische Masse in Tschechoslowakei: Die Vorläufige regionale Bewertung.

Die reichliche Entwicklung der morphologisch vielförmigen karstischen Erscheinungen in dem Gebiet der Böhmischen Masse war hauptzächlich durch seine geologische Entwicklung bedingt. Die älteste bekannte Erscheinungen des Karstes waren während des Untergivets, Untercarbon und Perm geformt. Die Unterkreide war eine sehr ausdrucksfolle Phase der Verkasrstung in den Tropen. Die Entwicklung des Karstes während des Tertiärs war sehr intesiv, mit dem Maximum von Miozän bis der ober Pliozän. Die Entwicklung der Karsterscheinungen während der Quartars war durch der Wechseln des klimatischen Zyklen beeinflust.

Introduction

This paper does not represent complete description of old karst phenomena, the discussion of their age and origin, but it brings the general review of the succession of karstifications in the Bohemian Massif. The review cannot be detailed owing to the complex distribution and geological evolution of single bigger and small karst areas.

The tectonic development of the Boehmian Massif (in which the pre-Cambrian,(Caledonian and Variscian orogeneses participated) culminated in the forming of the Variscian mountain chain during the Late Paleozoic. The Bohemian Massif was turned into cratogen, latter coqered by continental Permo-Carboniferous, marine Upper Jurassic, Upper Cretaceous and continental Tertiary. All these younger depositions combined with the effect of long-lasting planation led to the formation of leveled surface on the Bohemian Massif during the pre-Cenomanian and Paleogene. The Neogene tectonic movements of radial character (horsts, grabens), the general uplife of the Bohemian Massif (with the continuation into Pleistocene) and volcanic activity in the Neogene led to the geomorphological rejuvenation of the Bohemian Massif and from it resulted accelerated karstification appeared. No part of the Bohemian Massif was directly glaciated during the Quaternary. The whole area was a part of periglacial European province.

The extend of karst areas of the Bohemian Massif is rather small, but occurrences of soluable rocks are numerous (Fig. 1). Karst phenomena are developed mainly in Silurian to Lower Carboniferous limestones, in lesser extend in Upper Proterozoic carbonate rocks.

Terminology

The terms fossil karst and paleokarst have not been distinguished in the Czechoslovak literature until now. All these phenomena were described rather as old karst forms (see der Urkarst of Panos 1964). Fully fossilized and latter not developed karst forms will be described as the fossil karst. Paleokarst forms are those, which were by any way rejuvenated and which are still in the development. The term -old karst phenomena - include all these forms and forms with the indistinct origin - it is the general term. Terminological problems appear alos if the term - phase of karstification - is used. We propose to use this term only for shorter time periods and if clear upper and lower limits are distinguishable. Long-lasting karstification, active through several groups of periods and without distinct limit/limits must be designated only as the karstification - for example the pre-Cenomanian karstification.

Methods

Old karst phenomena in Czechoslovakia are investigated by classical methods of the geological and geomorphological research based on detailed documentation in the field and laboratory evaluation of data and material. Where possible, dating of fillings is made paleontologically (with the use of molluscs and small vertebrata). Paleontologically sterile localities are dated on the basis of detailed lithostratigraphical correlations with dated profiles. Additionally, paleomagnetic data were obtained from several localities. Whole complex of propsecting geophysical methods is adopted in several last years, mainly in areas with occurrences of raw materials.

Development of Old Karst Forms: An Outline

Only two long-lasting periods of karstification we can distinguish in general for the Bohemian Massif. The boundary between them is the Cenomanian to Santonian break - i.e. period of mass marine sedimentationin nearly whole area of the Bohemian Massif. The first period was pre-Cenomanian. We can delimitate several phases in the frame of the pre-Cenomanian karstification only in eastern parts of the Massif, where the geological development - successions of transgressions, regressions and ingressions - was more complicated. The second period of karstification passed in post-Santonian periods in the dependence on unregular wobbling movement of single geological blocks during the impact of the Alpine folding.

The oldest phases of karstification passed in the area of present central and eastern Moravia and their effects are relatively small. Karstification took place in Lower Givetian (Fig. 1-1) and during the Upper Devonian to Lower Carboniferous and Uppermost Carboniferous to Permian in the Moravian Karst (Fig. 1-1) and in the Tisnov area (Fig. 1-2, Dvorak 1978, Bosak 1980). Only smaller karst forms were originated - coastal lapies, sinkholes, karst wells. Some hydrothermal cavities were formed in the Tisnov area during the Permian (Fig. 1-2, Bosak l.c.). Old karst forms were filled by marine and continental sediments, which are paleontologically dated.

The intensity of the karstification in the frame of the pre-Cenomanian period strongly increased during the uppermost Jurassic and Loer Cretaceous, when favourable climatic conditions appeared. The effect of this karstification was equivalent both in the area of central Bohemia (Fig. 1-2) and in Moravia (Fig. 1-1,2-4). Basic planation surface of the Bohemian Massif was originated in the course of the Lower Cretaceous intensive weathering. The planation of nonkarstic regions was accompanied by intensive karst denudation of soluable rocks. The systems of cupola-shaped elevation surfaces and karst pediments were developed in the Bohemian and Moravian Karsts (Fig. 1-3, resp. 1-1). Surfaces were morphologically very diversified with deep depressions (dolines, uvalas, complex sinkholes, shafts, karst wells, geological organs) and steep elevations (karst towers, conical and cupola shaped elevations, etc.). Depressions were synchronously deepened with their filling by redeposited weathering products. Fillings are formed by kaolines, red and reddish-brown clays, laterites and by sediments of the Rudice type (Panos 1963, Bosak et al. 1979). Some forms were partly filled by fossil cemented scree and by younger Cenomanian to Turonian marine deposits.

The complex karst relief was also formed in nearshore maritime areas, which belonged to the platform cover of the easter marginal area of the Bohemian Massif. The relicts of this cover were later incorporated into the nappe structure of the "Outer Klippen Belt" of Outer Carpathians. Relicts of developed caves with flowstone or inner sediment fillings and of coastal karst forms (lapies, relicts of karst towers, depressions, etc.) are described by Housa (1976) from the Kotouc Hill near Stramberk (Fig. 1-4). These forms were covered by the Albian and younger sediments.

A little is known on the karst development during the Paleogene, because of lack of correctly dated localities. There is supposed, generally, that tropical weathering of the Cretaceous platform cover occured. Weathering was connected by fluvio-lacustrine erosion/accumulation activity resulted in total covering of the relief and creating the levelled surface in the Oligocene. Following this Rassmuss's (1913) hypothesis, more authors have considered the Paleogene karstification was limited into local vertical corrosive processes related to the incidentally appeared tectonic dislocations. Consequently, the creating of the contemporary caves (and majority of the older karst phenomena) have been interpretted in most cases to be of the Late Cenozoic or even only of the Quaternary age (cf. e.g. Kukla and Lozek 1958). Considering the evidence recently available, we tend to asses the course of the Late Cenozoic karstification in a slightly corrected way.

It appears, anyhow, to be without any doubt that the Late Cenozoic period represents one of the most important stages of karstification in the Bohemian Massif. It was particularly the general uplift of the Massif appeared since the beginning of the Noegene (cf. Malkovsky 1979), which impacted the karst development in the most considerable degree. It caused: (1) disappearing of the Paratethys sea (covering the southern areas - the Moravian Karst including - as late as in the Badenian). (2) increase of the land/sea declivity resulting in a considerable increase of the river erosion rate, which caused exhumation of old surfaces and then rejuvenisation of the older karst phenomena, (3) a continual fall down of the lower erosion basis connected with the stabilisation of the river systems during the Pliocene. It produced conspicuous horizontal levelling in some bigger karst areas. Hence, the dating of the horizontal cave systems is usually made by means of a direct comparision of their current altitude positions with that of appropriate river terrace accumulations. Sometimes, however, this treatment may result in a strong misinterpretation. For example, in the Bohemian Karst, two karst localities of a river deposits paleontologically dated back to the Miocene differs in their vertical position of about 150 m, though they are only approximatley 5 km distant (Tetin, Suchomasty 3, Fig. 2B). Analysing this situation we have concluded that the neotectonic relief inversion had to appear during the Late Cenoxoic history of that area. Hence, also a considerable differences among either parts of it might occured as to the course of the exhumation/deposition a.o. processes, which situation may influence our first-look view of the karst development of the area. Of course, such a local pecularities in a neotectonic activity (and related karstification conditions) may be supposed to occur in some other karst areas.

Based on contemporary knowledge one can not exclude that majority of the karst phenomena in the Bohemian Karst - but not only in it (e.g. caves, planation surfaces, etc.) - have been rather older than is obviously thought (at least of the Miocene age). Moreover, is most instances a general modelation of them appears to be fossil since the Pliocene (comp. finding of an Upper Miocene bat fauna in the pulver-like sedimentary falling of a wall niche in the top part of the Nova propast Cave in the Koneprusy area - Fig. 1-3, or that of the Middle Pliocene fauna in the bottom sinter in Javoricko Caves - Fig. 1-5, cf. Horacek, in print and Musil, unpub. MS).

An intensive karstificiation modelled only the active water karst during the Pleistocene (e.g. the Moravian Karst, Fig. 1-1). The modelation could be influenced by the Pleistocene climate-dependent changes in a water balance in a considerable way. Relatively short interglacial periods (manifested in the sinter growth, intracave dejection of surface soils, etc.) might influenced the karst forms only by inextended cosmetic retouches, but not by and expressive karstification events. The relatively frequently evidenced Pleistocene exhumation/deposition activity (about 20 paleontologically dated localities of the Early or Middle Pleistocene age, a mass of the younger ones, Fig. 1-1, 3,6,7,8, etc.) represents itself the msot conspicous process of the karst fossilization in that period. It could be summarized as follows: (a) exhumation of vertical communications and/or collabing in spacious cavities at the end of a glacial and (b) deposition-particularly sedimentary filling of the vertical cavities, chimneys, etc. during the following glacial cycle (cf. Kukla and Lozek, 1958). Partly it (the "a" especially) might be connected with the phases of increasing neotectonic activity (e.g. 0.8-0.7 M.Y. in the Bohemian Karst).

Conclusions

Considering all above presented data one may postulate that the main and (or the most expressive phases or periods of karstification were in the Bohemian Massif associated with the humit and war tropical climate of the Lower Cretaceous, Early and Middle Miocene (probably up to the Pliocene, when climatic conditions changed), while the younger karstification participated in creating contemporary karst phenomena only in several areas (e.g. the Moravian Karst) an in lesser degree. Consequently, the majority of karst phenomena in the Boehmian Massif are to be denoted as the paleokarst and a considerable part of them appears to be fossil in the recent time.

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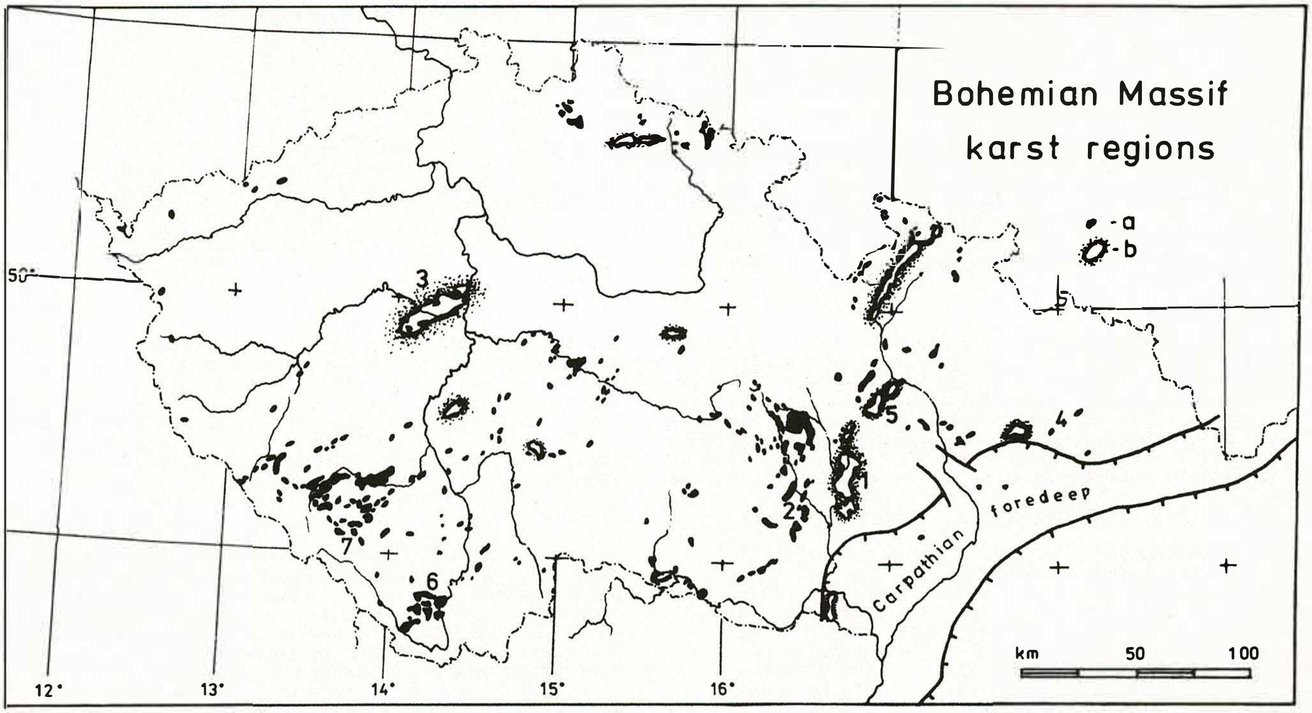

Figure 1: A slightly simplified survey of the karst regions in the Bohemian Massif (adapted after Stelcl and Vodicka (1966). Regions with a little developed karst phenomena (a) and considerably karstified regions with significant old karst forms are designated.

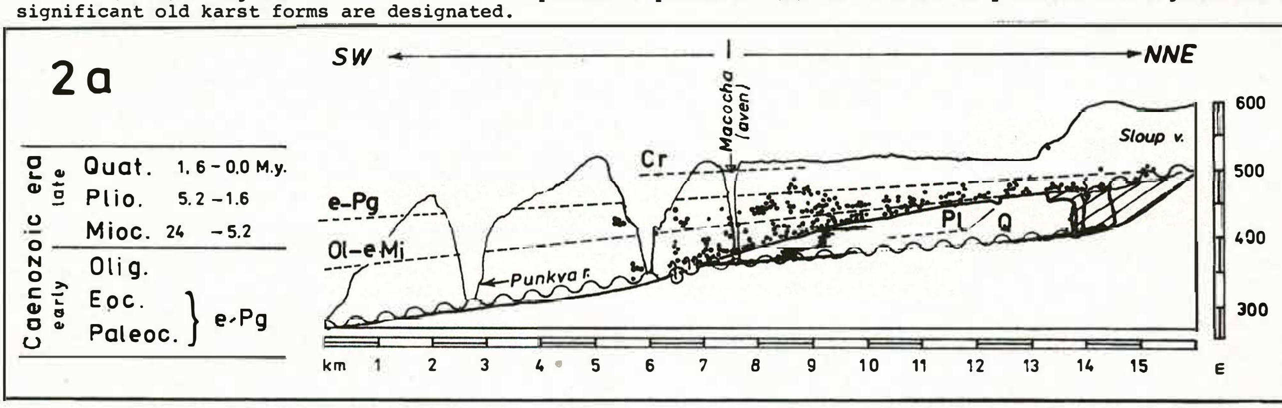

Figure 2A: Schematized section through the northern part of the Moravian Karst (in the direction of the riverbed of the Punkva River - after Panos in Vahala et al. 1963, completed and modified) and an outline of the Lat Cenozoic concept as used in the presented paper. Dots - cave openings, wavy line-active river bed of the Punkva River, dashed line - lower erosion basis in the respective periods.

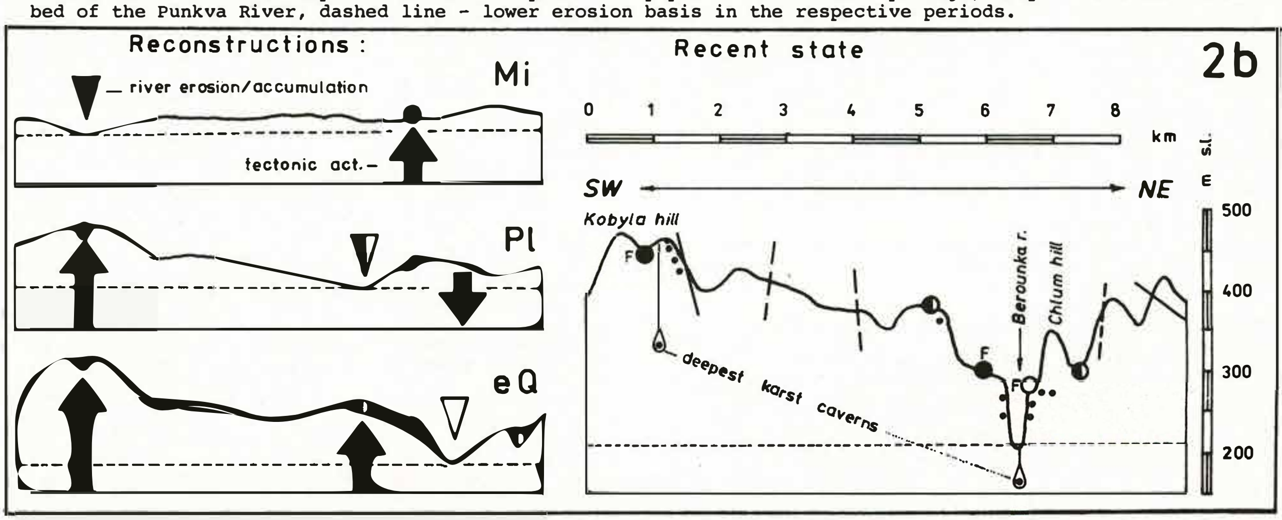

Figure 2B: Longitudinal section through the central part of the Bohemian Karst (after Horacek in print, modified). Large circles - terrace accumulations with a direct relation to karst processes, dots - major horizontal caves, thick solid line - longitudinal faults (overthrusts), thick dashed line - radial faults, thin dashed line - niveau of the lower erosion basis, f - direct faunal evidence of the age of a terrace deposit.

The Development of the Lower Cretaceous Karst: A Comparision With the Plate Tectonics

Pavel Bosak
P.O. Box 8, CS-14500 Praha 4, Post Office 045, Czechoslovakia

Abstract

The most important karst phenomena of the Lower Cretaceous age are situated along the northern border of the Tethys and on emerged areas within it. Favourable positions of lithspheric plates and smaller blocks along the paleo-Equator influenced the development of karst. Paleomagnetic data show the position of main karst forms in the area limited by the paleolatitude 30-35°N and by the paleo-Equator. Certain forms occured even to the paleolatitude 60°N. Paleoclimatic zonality, which was different in the comparison with the Recent, is reflected by sedimentary fillings of old karst forms. The morphology of karst phenomena resulted from regional geological development.

Zusammenfassung

Die Entwicklung des Unterkreidekarst` Vergleich mit der Platentektonik. Die bedeutsamsten Vorkommen des Unterkreidekarstes sind entlang der nördlichen Abgrenzung der Tethys und in den enporgehobenen Gebieten im Inneren situiert. Die günstige Lage der litosphärischen Platten und der kleineren Blöcke entlange des Paläo-Äquator beinfluste die Entwicklung des Karstes. Die paleomagnetische Daten zeigen uns die Lage der wichtigsten Erscheinungen des Karstes in dem Gebiet beschrankt durch den Paleo-Äquator und der Paleo-Breite 30-35°N. Bestimte Formen kamen sogar in der Paleo-Breite 60°N vor. Die plaeoklimatische Zonalität, die in Vergleich mit dem Rezent unterschiedlich war, sind in den sedimentaren Ausfüllungen des Urkarstes abebildet. Die Morphologie der urkarst Formen resultieren von den regionalen geologischen Entwicklung.

Introduction

The development of the plate tectonics model of the Earth's crust evolution brings many new questions to nearly all branches of geological sciences. The evaluation of old karst phenomena is one example. All reconstructions of old karst forms must take into consideration changing positions of different parts of continents in the geological history. Many problems exist mainly if old karst of orogenic belts is studied. In such case, karst forms originated in different climatic provinces may be latter situated in the closest proximity. The solability of this problem with the use of classic geotectonic models was limited. But better results appear if plat tectonics model is accpeted. The application of plate tectonics in the evaluation of old karst forms will be demonstrated on the example of the Lower Cretaceous of Eurasia.

Palinspastic and Paleogeographical Reconstructions

The abundance of Lower Cretaceous karst phenomena is known mainly from the area of European Cretaceous Tethys and from its maritime areas. That is why the necessity of palinspastic reconstruction of young European orogenic belts appeared. Reconstructions are based on data of Roth (1980) for the Insurbric-Carpathian block syste-, of Cohen (1980) for the Iberian Messeta, of Burchfield (1980) for the Moesian and Rhodopian fragments and of Hsu (1977) for southern and southeastern Mediterranean. There are differences as compared with older reconstructions. It resulted from the new view on palinspastic reconstructions of the Isubric-Carpathian system (see Roth, 1980). The reconstruction presented on Figure 2 (based on the situation in Albian) is only hypothetic. It was based on up-to-date data and was constructed linary without modifications of shape and size of blocks which moved to the south. Therefore the southeastern Mediterranean (Northern Africa, southern Turkey, Italy and Greece) is smaller in comparisions with used geographical projections of northern parts of Europe.

The distribution and the extend of land and sea were collected from many sources (more than 40), which cannot be presented here. Paleogeographical situation on Figure 2 encompass all areas which were emerged at any time during the Lower Cretaceous. Such areas are designated as the land. Position of paleolatitude 30°N is reconstructed after Creer (1973), the position of paleo-Equator agree with paleomagnetic data of El Shazly and Krs (1973).

Lower Cretaceous Karst Forms and Their Fillings

Only minor quantity of primary existed Lower Cretaceous karst phenomena has been presented until now. Available data on them are missing from many parts of the world. The distribution of data on such forms is dependent on detailed knowledge of geological structure and geomorphological development, on the stage of uncovering and on the human factor. That is why prevailing majority of data have their source in areas known in detail, i.e. from regions with deposits of raw materials.

Reconstructions of the positions of paleo-Equator and other paleolatitudes show, that majority of Lower Cretaceous karst forms were originated within the area limited by the paleo-Equator and paleolatitude 30°N (Fig. 1,2). Several forms occured even to the paleolatitude 60°N and only one example is known beyond this limit (northern Canada). Favourable position of emerged areas along the paleo-Equator influenced the rapid and rich formation of karst phenomena and thick weathering crusts of different composition and type.

There are difficulties with the determination if karstification antecedent to the filling by sediments or if karstification is developed under the sedimentary cover. Two opinions concerning bauzities are occurring. Bardossy (1970) and Bushinskiy (1975) prefer karstification which is followed by the deposition of bauxities. French authors (for example Combes, 1970) think the karstification is synchronous with the postdepositional process of the bauxitization. It seems, from other areas, that karstification took place in two steps (1) before filling and (2) contemporarily with filling as a result of the action of seeped solutions (see Bosak 1979, Valeton 1972). Both these in origin different types of karst phenomena are taken into consideration in this paper.

The morphological variety of known Lower Cretaceous karst forms is wide and embraces nearly all recently occurring karst forms. Large karst planation surfaces were described from Czechoslovakia, Hungary, USSR and Western Germany. Big depressions (pojes, marginal poljes, etc.) are known from Western Germany, Hungary, Rumania and USSR. Fluviokarstic relief is presented from Kazachstan (USSR). Karst surfaces of the conical karst and/or cockpit-type were developed in Western Germany, Yugoslavia, Hungary, Czechoslovakia and positive karst forms (Mogotes, karst towers etc.) in USSR, Hungary etc. Equivalents of karst plateau are present in the Transural area (USSR). Relicts of caves were uncovered in Belgium, France, Bulgary, Italy, USSR and Czechoslovakia. Shafts as well as old karst valleys are known in Italy and USSR. Developed Lower Cretaceous relief with whole variety of karst makro, meso and microforms are presented for example from Bolskoy Kavkas (Skalistyy Range, Popov et al. 1972), Transural area (Sverdlovsk region, Gevirc 1964), Kazachstan (Turgay depression, Sokolov et al 1967), Moravian Karst (Czechoslovakia, Bosak 1981).

The rate of the karstification and from it resulted the rate of development of karst relief depended on the length of karstification and on climatic conditions. Short-lasting emergence of carbonate terrains in the tropical climate may be sufficient for the origin of morphologically diversified karst relief as occured for example in southern Italy. On the other hand the karstification in less favourable climatic conditions may resulted also in developed karst relief, but in longer time space (for example in the Transural area, USSR).

Old karst forms are preserved if buried. Fillings of Lower Cretaceous karst forms are built by various types of weathering products, continental and marine sediments. The composition of old weathering products which occur as redeposited fillings of karst forms show certain zonality owing to paleolatitudes. The rate of weathering depends also on the length of this process, which can a little modify the general situation. Different types of bauxites were originated within the paleo-Equator and paleolatitude 30-35°N. Bauxites become of the worse quality, more bauxitic clays occur and some kaoline fillings appear close to the upper limit of this zone. Typical mature continental sediments of the Rudice-type (i.e. kaoline, kaolin clays, quartz sands, etc., Bosak et al. 1979) were developed along 25-30°N paleolatitudes. The situation becomes more complicated toward the north. Several bauxite deposits in old karst forms are known even from paleolatitude approximately 50°N as well as of kaolines, kaolinic clays, ochres and fireclays. Bauxite are of worse quality in many places and together with kaolines may represent redeposited older weathering crusts or products of longer weathering or may indicate different climatic zonality during the Lower Cretaceous as compared with the Recent time.

General climatic schema of the Cretaceous, published by Markov (1960), shows broad zones of tropics, neartropics maximum and warm polar zone. Transitions between single zones were inexpressive. Hot tropics reached high paleoatitudes. It could be an explanation for the northern occurrences of bauxites and kaolines. Clima within the tropical zone indicate us some paleotemperature data from USSR (Crimea, Transcaucasus), Bulgary, Germany and France. Lower Cretaceous paleotemperatures obtained from measurements of ΔO^{18} in belemnite remains reach 33.8-14.8°C. Data show that differences in annual mean values for whole Lower Cretaceous were in the range of 6°C, if certain single anomalous data are excluded (see Teis et al. 1975). It indicates that very favourable conditions lasted through the Lower Cretaceous, what resulted in rich development of karst phenomena. Paleotemperatures for northern territories reach the value approximately 15°C along paleolatitudes 50-70°N (Siberia). Paleoclimatological data obtained from the measurement of ΔO^{18} better illustrate the indirect evidence form the interpretation of fillings of old karst forms.

Lower Cretaceous karst forms are filled not only by redeposited weathering products, but by normal marine or continental sediments. Such occurrences are abundant (Fig. 2) and yield in most cases perfect paleontological delimitation of the length of the karstification.

Conclusions

The evaluation of old karst phenomena yields more plausible results when the plate tectonics model is used in the reconstruction of paleogeography (mainly of orogenic belts). Space relations accord better with primary situation of the development of karst phenomena in larger evaluated regions.

Acknowledgements

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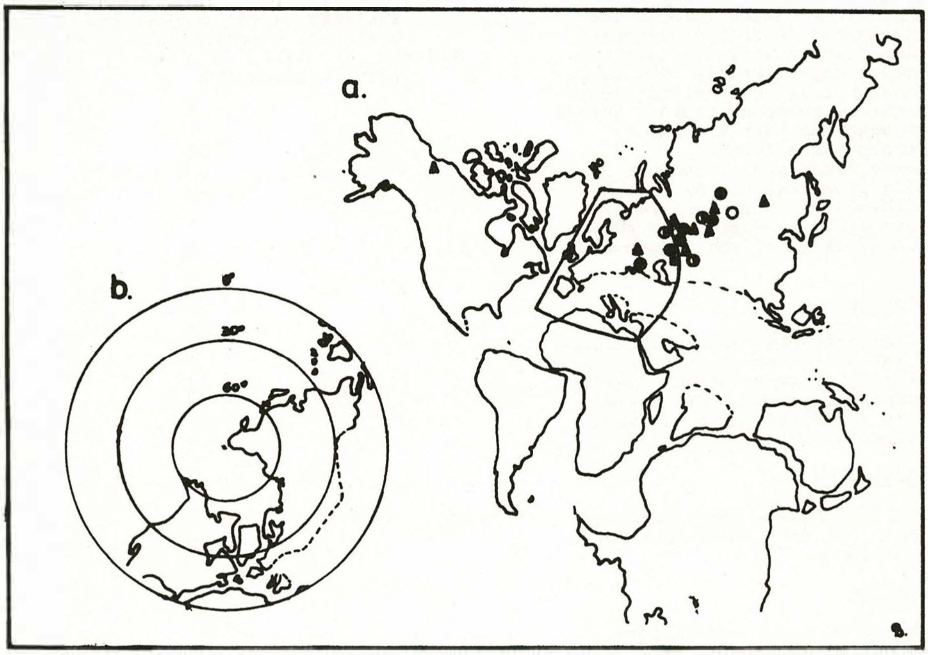

Figure 1: Lower Cretaceous palinspastic continental reconstructions. A Representation of Lower Cretaceous old karst forms. For framed area and explanations see Figure 2. Continental reconstructions modified aft Jenkyns (1980), B. Paleolatitutdes after Creer (1973).

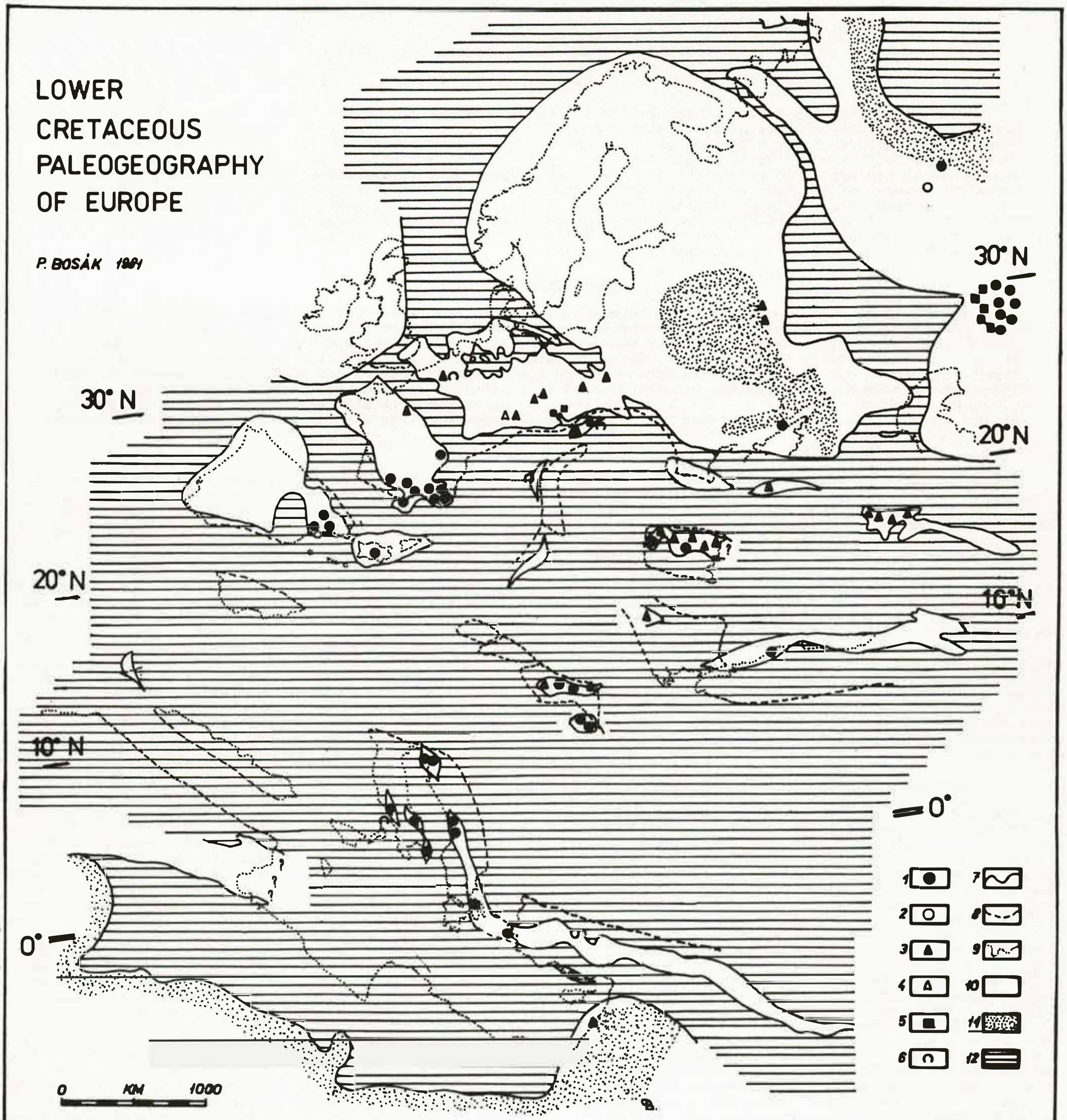

Figure 2: Lower Cretaceous paleogeography of Europe. The course of 30°N paleolatitude after Creer (1973). Positions of Lower Cretaceous karst occurrences are marked and type of their fillings is represented: 1. bauxite, bauxitic clay, terra rossa like deposits, 2. kaoline, kaoline clays, 3. younger continental and marine sediments, 4. laterites, 5. sediments of the Rudice-type. Other symbols: 6. caves, 7. land/sea boundary, 8. boundaries of tectonic blocks, 9. representation of Recent topography in single tectonic blocks, 10. land, 11. thick continental deposits, 12. Sea. For other explanations see the text.

Impact of 1980 Eruptions on the Mount St. Helens Caves

William R. Halliday
117 36th Ave. East, Seattle, Washington 98112 (U.S.A.)

Abstract

During the first six months of the recent eruptions of Mount St. Helens, complex access regulations and passive obstructionism by administrators of the Gifford Pinchot National Forest greatly hindered study of the effects of the eruptions on the caves nearby. Nevertheless, Wester Speleological Survey parties were able to visit vital parts of certain caves in June and in September 1980. Little or no damage due to the actual eruptions was observed, but subsequent mudflows became an increasingly grave threat to several of the most important caves. Direct negotions for less restricted studies of the caves and the mudflows were initiated with the Forest Supervisor in September 1980. Little or no damage due to the actual eruptions was observed, but subsequent mudflows became an increasingly grave thread to several of the most important caves. Direct negotions for less studies of the caves and the mudflows were initiated with the Forest Supervisor in September 1980.

Zusammenfassung

Während der ersten sechs Monate der erneuten Vulkanausbrüche von Mount St. Helens wurden die Studien über die Auswirkungen dieser Vulkanausbrüche an den dortigen Höhlen enimal durch komplizierte Zugangs - Verordnungen erschwert, zum anderen durch passive Hindernisse der Verwaltung des "Gifford Pinchot National Forest." Trotzdem gelang es WSS Gruppen, Teile gewisser Höhlen in Juni als auch im September 1980 su besichtigen. Geringer, oder nahezu garkein Schaden durch die Vulkanausbrüche wurde vorgefunden, jedoch die nachfolgenden Erdrutsche, (aus Schlamm bestehend) sind eine ständig wachsende Bedrohung für einige der allerwichtigsten Höhlen. Direkte Verhandlungen, welche sich um verringerte Einschränkungen in den Studien der Höhlen sowohl als auch der Erdrutsche bemühen, wurde im September 198+ mit dem Forest Supervisor aufgenommen.

Introduction

The national significance of the Mount St. Helens caves has long been recognized. Ape Cave formerly was the worldäs longest lava tube cave, and remains the longest on either of the American continents. It is a very popular public attraction even though almost completely undeveloped. Several other caves in the area are world-class, and several smaller ones have major biological, geological, historical, recreational, wilderness, and other values. In 1962 I urged creation of a Lava Caves National Monument here. In 1972 the NSS formalized a Mount St. Helens Caves Conservation Task Force, with Charlie Larson and myself as initial co-chairman. In 1973 the NSS Board of Governors formally urged inclusion of these caves in a Mount St. Helens National Monument and reasserted this proposal in 198+. Over the years, this NSS task force and other northwestern speleologists have urged a maximum of protection for the caves and for the cave area.

Geographic and Administrative Situation

The crater and the "Devastation Area" of Mount St. Helens are on the north sideof the mountain' the cave area is on the south. Thus it is protected by the ner-vertical crater walls which are almost 1 km high. The caves are in the Recent (ca. 1900 B.P.) Cave Basalt Lava Flow, a single geologic unit. The location of its vent is not known. Aside from its southern fringe, which is owned by the state of Washington, this flow entirely within the Gifford Pinchot National Forest. However, ownership of the flow and its caves is complicated by checker-boarding of lands owned by the Burlington Northern Railroad Company and the Weyerhaeuser Corporation within the boundaries of the national forest. Gremlin Cave and some other especially important caves thus are on private land. The U.S. Forest Service has pursued a policy of acquiring such inholdings, and northwestern speleologists and other conversationists have supported such acquisitions to simply management of the caves area. Over the years, the NSS task force and individual northwestern speleologists repeatedly urged Gifford Pinchot National Forest administrators to prepare appropriate management plans for each significant cave and for the cave area as a whole, recognizing and protecting their unique values and resources. This has not happened. These administrators seem to consider the presence and national significance of the caves as an annoying complication of forest management, to be ignored as much as possible. This attitude is reflected in present severe restrictions on speleological research here.

History of Post-Eruptive Studies

After some minor preliminary volcanism, an earthquake triggered landslides, than a hugh lateral eruption of the north side of Mount St. Helens on May 18, 198+ - actually in full view of the glaciospeleological group of the Cascade Grotto of the NSS on Mount Rainier. Property damage was heavy and lives were lost outside the area of supposed hazard. Administrators of the national forest belatedly closed virtually its total extent, including mucn that many considered to be at very low risk. This was true of the low-risk cave area, which was treated exactly the same as the crater itself. Scientific research on the effects of the eruption supposedly was encouraged. But except for that of the U.S. Geological Survey, administrative obstructionism and dealy of research became something of a scandal, picked up by the national scientific press. A "Catch-22" permit system was established. All research (apparently except that of the U.S. Geological Survey) had to be done within 15 minutes of an "escape vehicle," and in constant radio contact with a base station. Further, research was prohibited in cloudy or rainy weather. Our initial application was promptly approved by Dr. John Eliot Allen, who then served as the scientific screener of such applications, but was never acted upon by the administrators of the Gifford Pinchot National Forest. Its effective date was to be May 17, 1980. All early permits were cancelled after the May 18 eruption, whether or not they had been acted upon. Our reapplication again was promptly approved by the "Allen Committee" and I inquired about waivers of the excessive restrictions. On July 30, 1980 the "gatekeeper," Mr. Warren Winters of the Gifford Pinchot National Forest told me by telephone, in the presence of a state administrator, that no such waivers would be forthcoming for speleological studies and that our requests would receive even more "stringent consideration" than those of other researchers. He expressed doubt that it was possible to use radio communications in caves (even though we previously had communicated more than 1 km in Ape Cave with hand-held 4 or 5 watt CB units). Further, he expressed doubt that there was any scientific validity in our studies even they they had been approved by the "Allen Committee." When asked to confirm this in writing, he failed to respond. Subsequently another spokesman for the forest administrators told the press that radio communications were not possible underground. Nevertheless, with the assistance of the staff of Senator Warren Magnuson, we were able to place WSS field parties in the cave area on June 22 and August 23-24, 1980. All participants were experienced members of the Cascade or Oregon Grottos of the NSS.

Initially we found that the caves received little or no damage from the eruptions and concommitant earthquakes. Those with vertically tapering entrances underwent funnelling of tephra but this was of little consequence in comparison with out principal discovery. To our surprise and dismay, extensive mudflows were developing and enlarging downhill where the tephra became lubricated with rainfall or other sources of water. Between these visits, Hopeless Cave was entirely engulfed in mud and in August, Ape Cave was beginning to receive mud through several small orifices. Gremlin Cave appeared in immediate danger from a particularly active mudflow then fed by aberrant glacier runoff, and several others were in the paths of other flows. And it was obvious that other flows would be greatly enlarged by autumn and winter rains. Equally, it was obvious that past mismanagement of both private and Forest Service lands (including inappropriate road-building and clear-cutting, devegetation, and stripmining of cinders) aggravated the mudflow problem and caused part of the threat to the caves.

The Western Speleological Survey published four bulletins on our findings, in July, August, and early September (others now are in press). Besides supplying copies to administrators of the Gifford Pinchot National Forest, I attempted to bring the urgency of the situation to the Forest Supervisor himself. My letter of August 31 stressed that there was no time to be lost, and asked for a meeting "very soon", to "bury the hatchet" and save the caves while they might be saved. Nothing happened. On September 21, I wrote again, in more vigorous language. Finally I obtained a face-to-face meeting with the Forest Supervisor on September 30, 1980. In part, I urged an immediate and on-going inventory of mudflow threats to all the major caves. In view of his obvious distaste for speleology, I suggested that it be by speleologically trained U.S. geologists like Jim Moore if not by our own teams. In any event, I told him, it should be performed in order to determine what protective measures may be necessary and desirable. Further, I informed him that such an inventory would require wiavers of the prohibition on research more than 15 minutes from a car and in cloudy and rainy weather. He promised to make appropriate enquiries and contact me in return, beginning two days later when I was to be in Vancouver again. In never heard from him again, and no such inventory has been instituted.

Even before the eruption, certain actions of these administrators clearly were arbitrary, capricious, insensitive, and deceptive in matters relevant to these nationally significant caves. Its regulations on access to the cave areas similarly are arbitrary and capricious. Supposedly the reason for their restrictiveness is hazard to researchers. On October 14, 1980, I requested the data base for the risk assessment under the risk assessment under the Freedom of Information Act. This request was ignored until I pointed out that the Forest Supervisor had violated the Freedom of Information Act - and brought this to the attention of Congress. Subsequently, Rob Stitt and I received a large number of documents in response to this request and two subsequent ones, none of it indicating that the administrators had followed standard techniques of scientific risk evaluation.

Unexpectedly, I received new access permit application forms and procedural information, mailed on October 27, 1980, without comment on any other matter. The new procedures proved even more obstructionistic than the previous ones. Not until January 10 and 11, 1981 could we place another WSS party in the study area.

However, the U.S. Forest Service did invite Clyde Senger and me to serve as consultants to a field task force of November 10, 1980, on protection of the caves. Some observations were possible during our four hours in the caves area. Also, I conducted an aerial reconnaissance of the area on December 28, 1980. Gifford Pinchot National Forest administrators including Forest Supervisor Robert Tokarczyk himself turned away one additional WSS field party with an approved permit, at the last moment on 1-3-81 even though a U.S. Geological Survey field party was allowed to be in the crater at the time. This action supposedly was because the "Red Zone" was closed to us but not to the U.S. Geological Survey party. The "Red Zone" was technically reopened on Friday January 9, 1981, the weather report was favorable, our party began to comply with administrative requirements in Vancouver at 0830 next morning and reached the study area at 1145. We were required to leave the "Red Zone" by 1618, and most of that day was spent in demonstrating the range of radio communications in Ape Cave to protect our permit!

Findings

At the time of writing (January 25, 1981), most of the caves of Mount St. Helens have received no study since the eruption. Those effects which we have discovered in the locations we have been permitted to visit are as follows:

1) Utterstrom's Caves area:

These are the closest caves to the volcano, being 5-8 km from the new summit. They also are the least affected of those studied to date. No evidence of nuee activity is present, but tephra was found to be as much as 7 cm thick in June 1980. Most of these caves have small vertical or sloping entrances. Rainwater and gravity sliding had transported some entrance tephra into the caves, but had not significantly affected any of them. Immediately east of the caves is a fascinating area with huge new leveed gullies, mudplains, and other features of alluvial fans, changing markedly after each storm. This has not affected these caves. One tongue of mud extended from this area toward Breakdown Cave where the U.S. Geological Survey has placed instruments. Its entrance sink, however has a raised rim about 2 meters high, and this has diverted the mud southward, away from the cave.

2) The Upper Caves - (Little Red River Cave, Gremlin Cave, Spider Cave, Flow Cave, Little Peoples Cave).

This is a group of more or less parallel caves with entrances located 1/4 to 1 km south of road N818, about 10 km from the new summit. Only small portions of most of these caves can be examined under the "15-minute rule." We have observed initial invasion of some of these caves by local mud tongues, followed by peripheral tongues of mud-flows which aggrade further with rainfall and glacier runoff. Studies in the lower entrance room of Gremlin Cave (which is the only part of the cave we were allowed to visit) show that it and the distal crawlway serve as a major conduit transporting floodwater and waterborne tephra. Headward erosion by a gully along road N818, however, captured many of the feeders of the Gremlin Cave Mudflow between the August and November trips. However its western lobe is enlarging and looms higher and higher above this entrance sink. Further, this lobe extended several hundred meters directly toward Spider Cave between the November and January trips. Spider Cave is an important hibernaculum for *Plecotus townsendi*, a bat uncommon in this area. This cave other wise is unaffected by the eruption. The speed and topographic orientation of the Gremlin Cave Mudflow is strongly influenced by past clearcutting of vegetation during logging operations in this area, and by inappropriate location of logging roads which direct its tongue toward Gremlin and Spider Caves. Flow and Little Peoples Caves are amid peripheral tongues of the western part of a very large mudflow, presently aggrading into a wide, gently sloping plain across road N818. To date, this and Little Peoples Cave have received only a small amount of mud from local tongues, but parts of the aggrading plane are higher than their entrance sinks. Much of this material is from an old cinder quarry north of N818. As early as June 1980 extensive headward erosion was in progress here, with the material washing across N818. And because of the restrictions, essentially nothing is known about the present status of Little Red River Cave.

3) Ape and Hopeless Cave

The N818 Mudflow drains southwestward to the west edge of the lava flow. There its waters join local runoff which forms a seasonal creek flowing along the edge of the lava, toward the main entrance of Ape Cave. About 3 km of the Ape Cave road (N816) and the parking lot were built in the gully of this stream, beginning about 1 km north of the main Ape Cave entrance. Several years ago I found that this roadbuilding had diverted part of this seasonal creek into Hopeless Cave, but this did not appear to be a problem. On June 22, 1980 we found several small mud ponds in this general area. All appeared to be the result of coalecence of very finegrained tephra particles moistened by scant summer rain. One of these ponds was in the Hopeless Cave sink, half-filling its crawlway entrance. The largest was dammed by N816 at its northermost curve. On August 24, some of the smaller ponds had coalesced, and only about 5 cm of the highest point of the Hopeless Cave sink now was visible. Peripheral tongues of a much larger mudflow were entering the area from the northwest, following the seasonal creek where it had been diverted by N816. By January 1981 this mudflow had aggraded into a wide mudplain about 2 meters thick at the site of Hopeless Cave and had engulfed much of N816 between Hopeless Cave and Ape Cave.

The Hopeless Cave Mudflow crosses diagnoally over a considerable section of Ape Cave. On January 10, 1981 we finally were able to visit this part of the cave. Considerable fine-grained tephra has seeped into Ape Cave through many small orifices here, but the maximum depth was only 8.5 cm. Lesser amounts have entered this at other points. The plain continues to aggrade, and it appears that a protective sandbag barricade has been built in the wrong place.

Conclusions

Administrators of the Gifford Pinchot National Forest have prevented systematic studies of the effects of the 1980 eruptions on the caves of Mount St. Helens. Less than half of Ape Cave has been visited since the eruption, for example, because of inappropriate regulations. Quick visits to some of the caves have shown that ponding and flow of lubricated tephra and other mudflow material have caused almost all the spelean changes to date. A sequence has been demarcated beginning with local mudponds and tongues formed by coalescence of very fine-grained particles of tephra moistened by rain. In some cases, these local ponds and tongues have been enlarged by invasion by peripheral tongues of larger mudflows carrying coarser materials. The third stage is the development of broad, actively aggrading mudplains fed by processes commonly active in alluvial fans. Each stage is capable of producing specific impacts on caves as described. Further studies are essential. Too much remains unknown about the effects of the eruptions on these important caves. And the continued existence of some of the most important is uncertain.

History and Contributions of the Western Speleological Survey

William R. Halliday
117 36th Ave. East, Seattle, Wash., 98112 (U.S.A.)

Abstract

The Western Speleological Survey is a small, informal organization whose operations deliberately are low profile except in the field of conservation in which it is vigorously outspoken. It was chartered in the state of California in 1955 and now is incorporated in the state of Washington. Currently it has units in several western states, and has initiated or assisted in speleological studies in Vancouver Island (Canada), Belize, and Okinawa. It has had an especially active role in preservatin of caves and karst and their features, such as inclusion of the Mineral King caves in Sequoia National Park, protection of underground wilderness in Mammoth Cave national park and the Guadalupe Mountains, opposition to the use of certain caves as fallout shelters, protection of the Karst from overindustrialization, and assurance of safety in siting of nuclear plants in karstic terrains. Most recently, it has been very active in attempts to protect the caves of Mount St. Helens from post-eruptive mudflows. To date, more than 60 WSS bulletins have been published, and two monographs. On July 31, a fundamental change will occur in the WSS.

Zusammenfassung

Der "Western Speleological Survey" ist eine kleine, zwanglose Organisation, deren Arbeitspensum absichtlich mit "Arbeit in der Stille" bezeichnet werden kann. Eine Ausnahme besteht jedoch, wenn es sich um das Gebiet der Naturerhaltung handelt, dann äussert man sehr kräftig seine Meinung. Gegründet wurde der WSS in Jahre 1955 im Staate Kalifornia und besteht nun auch im Staate Washington. Zur Zeit bestehen Verbände der WSS in verschiedenen westlichen Staaten der USA und man hat mit folgenden Höhlenforschungen entweder begonnen oder dabei assistierti` Vancouver Island (Canada), Belize, und Okinawa. Der WSS spielte eine besonders aktive Rolle in der Erhaltung von Höhlen und Karst und deren Charakter, wie zum Beispiel die Einschlüsse in den Mineral King. Höhlen im Sequoia National Park and Schutz der unterirdischen Wildnis im Mammoth Cave National Park und in dem Guadalupe Mountains. Eine entscheidende Rolle spielte Opposition zum Gebrauch von einigen westlichen H-hlen als Fallout-Deckungs-schutz, Schutz des Karst von Überindustriegebrauch, Erforschung und Zusicherung von Sicherheit, sollten nucleare Anlagen im Gelände des Karst erbant werden. Gerade jetzt war der WSS ungeheuer tätig, um die Höhlen des Mount St. Helens von Erdrutschen, welche noch nach dem Vulkanausbruch stattfanden, zu schutzen. Mehr als 6+ WSS Bulletins sind bis heute veröffentlicht worden und ausserdem noch zwei international anerkannte Monographs. Am Ende dieser Aufseichnungen soll eine specielle Ankündigung stehen, sie ist von sehr grosser Bedeutung für den weiteren Weg der WSS.

* * *

The Western Speleological Survey is a small, low-profile group of western NSS members dedicated to systematic exploration, study, and preservation of caves of the western United States and elsewhere. Informality is its keynote. Often we do not know how many members we have and for many years the WSS existed entirely without funds or even a treasurer. Yet its contributions to world speleology have been significant.

The WSS Constitution was dated July 11, 1955 and it was chartered by the state of California on December 9 of that year. Its roots, however, are several years older. The late 1940's saw a sudden mushrooming of speleological activity in California. Three new NSS grottos -- the only ones in the western half of the United States -- were vigorously hunting for caves. In late 1948 or early 1949 NSS Bulletin Ten - The Caves of Texas - reached the membership. In California, we reasoned that a similar bulletin on the caves of California would greatly advance California speleology. In 1950 the California grottos jointly proposed such a publication, and the idea was favorably received "back East", where the rest of the NSS was located. Various individuals and teams undertook feature articles and systematic regional reports. Teams engaged in the latter increasingly formalized as a Clifornia Speleological Survey. The results soon exceeded the ability of the NSS to publish them. The California Division of Mines took over the project and for several years it considered publishing the report. Having been appointed coordinator of the Caves of California project by the NSS Board, I became Director of the California Speleological Survey and continued in that position until 1974 when Dell Quick was appointed. Beginning in 1955, in the later stages of the Caves of California project, some of its units began to publish, mostly in the form of field trip reports or preliminary drafts of their sections of the report. These were the first WSS publications even though most of them bore no WSS serial number. To date, its Mojave Division has published 5 bulletins, its Mother Lode Division 2 bulletins, its Santa Cruz-Monterey Division 7 bulletins and its Southern Sierra Division 4 bulletins. Its Shasta-Siskiyou Division never has been activated. In 1962 Caves of California (Halliday, 1962) was published as the first special publication of the WSS. Although it is long out of print, it remains the definitive study and is greatly sought by today's speleologists.

Charter members of the WSS included members of the Salt Lake and San Jaquin Valley grottos of the NSS as well as myself. Our initial plans were for units like the CSS in all the western states, but our studies soon trended more and more to its western part. Initial WSS compilations on New Mexico were transferred to the Texas Cave Survey which published an initial review of this and other data in 1958 (Widener, 1958).

The Washington Speleological Survey began almost as early as the California survey, and even more informally. It preceded and helped create the Cascade Grotto of the NSS, first in the entire northwestern quarter of the United States. All other NSS grottos in Washington and Oregon are second or third generation offspring of the Cascade Grotto. Initially, few caves could be found in Washington state. Enthusiasm waned. The grotto became inactive for several years, and only the Washington survey continued speleological activity here. Nineteen fifty-six to 1959, however, saw tremendous breakthroughs in knowledge of caves at Mount St. Helens, Cave Ridge, and elsewhere. Much of this was the result of WSS field parties. The Washington survey has published 15 bulletins to date (1-26-81). The last four issues have dealt with posteruptive studies of Mt. St. Helens caves; the WSS is the only organization which has received a permit for such studies. Other reports are in preparation. Other topics include two bibliographies, spelean fallout shelter studies (which were effective in preventing inappropriate designation of some of this state's caves as fallout shelters), the first published call for a national mounument to protect the Mount St. Helens caves, and reports on several unusual glacier caves. I served as Director until 1979 when Jim Nieland was appointed. In 1963, Caves of Washington (Halliday, 1963) was published by the state's Division of Mines and Geology, as a result of the survey's activiites. Among its effects was the recruitment of a president-to-be of the NSS: Charles V. larson, who first learned about speleology from Caves of Washington.

The Oregon Speleological Survey has had the most complex and controversial history of any WSS unit (Halliday, 1978). Its existence was announced in 1956 (Halliday, 1956), but it continued mostly as a one-man survey (myself) until 1958 when Portland and Bend cavers formed OSS units. I continued as Director until 1969 when Steve Knudson briefly served as Acting Director but soon abandoned his appointment. I took over again until 1975 when Charles V. Larson was appointed Director. Late in 1977, three friends of the former acting director incorporated another OSS and another WSS in the state of Oregon. As far as has been determined, these organizations exist in name only. The OSS has published six bulletins to date, a monograph should appear in 1981.

The history of the Idaho unit also is complex. It formally began in 1956 with M.W. Echo as Director (Echo, 1956), but he subsequently moved away and the ISS became inactive. Subsequently the Idaho Bureau of Mines developed its own statewide cave survey, leading to the publication of Introduction to Idaho Caves and Caving (Ross, 1969). A year earlier, The Gem State Grotto of the NSS had published Caves of the Gem State (Thornton, 1969), also based in part on WSS and ISS data. Unfortunately, its title page erroneously stated that it was "Publication #1 of the Idaho Speleological Survey." This was not authorized and would nothave been authorized because of the report's inclusion of overexact, potentially harmful location data, contrary to WSS policy (Halliday, 1960). The ISS actually was not reactivated until 1977, when Frank Ireton became Director. To date, ISS studies have appeared in the WSS Miscellaneous Series.

The Utah Speleological Survey began in 1952 (Halliday, 1952). Dale Green became Director in 1957. It has waxed and waned, functioning mostly as an arm of the Salt Lake Grotto of the NSS. Because of that grotto's Technical Note Series, there has been no need for USS bulletins.

The caves and some cavers of Arizona presented special problems. One problem was the potential initials of an Arizona Speleological Survey. In 1958, John Shaydak, its director, therefore named the first Arizona survey the Arizona Thunderbird Speleological Survey. After his transfer to Kansas in 1959, the ATSS became simple the Arizona unit of WSS, and its contributors remain anonymous.

No Nevada Speleological Survey has been organized. A so-called California-Nevada Speleological Survey was merely a summer-long field trip by members of the former Sanford Grotto of the NSS in 1952. Alvin McLane has served well as an unoffical on-man survey in this state, publishing A Bibliography of Nevada Caves (McLane, 1974) and other reports. His work is independent of the WSS but correlated with it.

In 1959 Howard McDonald became Director of the Montana Speleological Survey. He collected and systematized much data and in 1960 he published two MSS bulletins. After 1963 his owrk was continued by the Shining Mountain Grotto of the NSS, eventually leading to the publication of Caves of Montana (Campbell, 1978) by that state's Bureau of Mines and Geology. Caves of Wyoming (Hill et al, 1976) and Caves of Colorado (Parris, 1973), however were entirely independent of WSS work.

Outside the United States, the Vancouver Island Speleological Survey formally arose out of a meeting between Derek Ford and myself at Glacier, B.C. on July 3, 1966. But its roots informally date to 1962. Dave Dunnet and I served as initial co-directors. Its field work and publications formed one of the two initial mainstreams of the Vancouver Island Cave Exploration Group. By 1970 the success of VICEG ended the need for a VISS, from 1963 to 1967 it published three bulletins.

In the Pacific, I began to study and collect data on Okinawan caves in 1955, and subsequently maintained a repository for what became the Okinawa Cave Society. In 1979 this material was transferred to Shigeru Ohde at the University of Ryukyus. For a time, these efforts were called the Okinawa unit of the WSS.

Also in 1955 I published an initial report on caves of Hawaii as a Bulletin of the Miscellaneous Series of the WSS. Subsequently it was reprinted in the NSS Bulletin. No Hawaii unit of the WSS has existed.

In central America, Barbara MacLeod conducted systematic speleological studies in Belize from 1971 through 1975. These and other's subsequent work have been termed the Belize Speleological Survey (MacLeod, 1972). WSS personnel assisted and participated in some of these studies, but the relationship was extremely informal and no one seems quite sure whether these should be considered WSS activities.

Informality and lack of funds were not wholly without problems, however. In 1977 it was decided to reorganize the WSS, the Washington survey, and the Oregon survey as tax-exempt corporations. This was done on January 9, 1978, under the laws of the state of Washington. Immediately prior to this action was its publication of the Proceedings of the International Symposium on Vulcanospeleology and its Extraterrestrail Applications as a WSS Special Publication when the NSS was unable to finance it.

In addition to the two Special Publications and the bulletins of the component state surveys, the WSS also has published 19 Miscellaneous Series bulletins including the Hawaii report, various speleogenetic, speleomineralogical, and speleobiological reports, additional spelean fallout shelter studies, bibliographies, and conservation analyses (primarily on underground wilderness in Mammoth Cave National Park, and protection of Rainbow Bridge from the Glen Canyon reservoir). To date, WSS publications total 64.

The WSS has played an especially important part in preservation of caves and karst and pseudokarst and has been vigorously outspoken in many conservation actions. As its Director, I have written many letters, articles, reports, and other writings for this purpose. I have participated in formal and informal meetings and conferences from Washington, D.C. to Washington state, and was the NSS representative at the First World Congress on National Parks. The WSS has been particularly active in preservation of the Mount St. Helens cave area, the Mineral King and Stanislaus River caves in California, Rainbow Bridge National Monument, the proposed Great Basin National Park in Nevada, the Guadalupe Mountains, the karst of Lost River, Germany Valley, and the Meramec River, underground wilderness in Mammoth Cave, and, recently, the preservation of karstic areas from unsafe nuclear plants. In 1980 it was my special honor to be a speaker at the International Symposium on Uses of Karstic Areas, in Trieste, to help save The Karst from inappropriate industrialization.

At the January 1980 meeting of the WSS Board of Trustees, I informed the WSS Board that I wished to retire as Director, effecgive July 11, 1980 when I officially would have completed 25 years in that position. The Board accepted my retirement and appointed Charles V. Larson as the second Director of WSS. However it proved impractical for him to assume the Directorship until July 31, 1981. My presentation of this paper, therefore at the 8th International Congress of Speleology should be my last formal action as Director of the Western Speleological Survey. I wish to express my thanks to all those who have assisted its work through the years, and my best wishes to its new Director.

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Development of Relevant Testing Procedures Leading Toward Establishing Standards For Caving and Static Loaded Rescue Ropes

Kyle Isenhart
Rt. 2, Box 168, Little Hocking, Ohio 45742

Abstract

This paper is devoted to a discussion of tope testing methods in the United States and the progress toward establishing U.S. standards for caving and static loaded rescue ropes. Test methods in current use and other tests under development, as well as their relationship to end use situations are examined. Specific tests such as tensile strength, elongation, flexibility, abrasion, and sheath slippage on kernmantle ropes are discussed in detail.

The design criteria, materials, and construction methods used in manufacturing ropes specifically for caving and static loaded rescue use are reviewed.

Zusammenfassung

Dieser artikel befasst sich mit seil-testmethoden in den USA und der Entwicklung au einem US standard fur gruben-und andere tests, die sich noch in entwicklung befinden, als auch ihre brouchbarheit werden beurteilt. Reissfestigkeit, dehuung, biegsaukeit, arieb, und mantel-schlupf werden eingeheud behandelt.

Die berechuungskriterien, materialien und kroustruktions-fur methoden die fur die scilfabrickion fur gruben-und bergungsarbeiten augewandt werden, werden besprochen.

* * *

At the present time there are no national standards for caving or static loaded rescue ropes in the United States. There are some written guidelines for fire services ropes but non for caving ropes. The combinations of high strength, low elongation, good abrasion resistance, and anti-spin characteristics of these ropes are desirable in a rescue rope. Additional characteristics desirable for search and rescue ropes are; high visability, shock load absorption capacity, good chemical and U V light resistance, and flexibility.

Numerous agencies throughout the world have developed test procedures and specifications for ropes to be used for a specific purpose. One of thee agencies is the U. I. A. A., which has developed standards and test procedures for mountain climbing ropes. Many of their tests are quite applicable to caving and rescue ropes. Other agencies such as B.S.A., A.S.T.M., C.S.A., U.S. military, N.F.P.A., and numerous industrial organizations have standard tests or guidelines for textile products which are applicable to caving and rescue ropes. Currently work is being done with N.I.O.S.H., O.S.H.A., and several large city fire departments such as New York, Chicago, and Los Angeles to develop standard tests and specifications for search and rescue ropes in the United States. It is hoped that caving ropes will also meet most of these specifications as a means of assuring safety and quality control.

Some of the standard tests such as tensile strength, elongation, and flexability we will examine in detail.

Tensile strength tests are normally run on a machine that applies the load to the rope by pulling on it at a constant rate. Usually 50 to 150 mm/min. The slower speeds are used for the stronger ropes. The fixtures which hold the ends of the ropes are drums 100 to 150 mm in diameter. The ropes are either eye spliced or wrapped around the drums and then secured. Tensile strength specifications vary but for 11mm nylong ropes the minimum should be 2500kg.

Elongation tests are of two types. The usual type is that run simultaneously with the tensile test. The other is one similar to the U.I.A.A. low load elongation test. The standard elongation test run during the tensile test is quite simple. After placing the rope to be tested in the machine two marks are made on the rope with an ink marker. These generally 30 to 60cm apart. Then as the rope is stretched during the tensile test a ruler is used to measure the increasing distance between the marks and the elongation is calculated in percent. For 11mm nylong ropes the elongation at failure should be at least 15%. The other elongation test usually follows very closely the U.I.A.A. method which will be described here. The length of rope tested must be such that the clamps supporting the rope and weights can be at least 1.2m apart. When adding weights it should be done carefully to avoid shock loading the rope.

Step 1. Load the rope to 80kg. and maintain for 10 minutes.
Step 2. Unload the rope and let it relax for 10 minutes.
Step 3. Load the rope with 5kg and mark 2 reference points 1m apart.
Step 4. Load the rope to a total of 80kg.
Step 5. After being at 80kg load for 60±5 seconds measure the distance between the 2 reference points and calculate the percent elongation.

For a 10-12mm static rope the elongation should not exceed 3%.

Flexibility tests are run to determine the knotability of ropes, how well they will conform when bent around fixtures, and their general ease of handling. Ropes which are too stiff will not hold knots and they can be difficult to catch and hold in an emergency. Most flexibility tests are very similar with their major differences being the amount of weight applied to the rope which depends on its diameter. For ropes between 9 and 13mm weights such as those used for the U.I.A.A. knotability test are common. The test is quite simple to perform. A single overhand knot is loosley tied in the middle of a piece of rope. One end of the rope is secured and the other end is left hanging free so weights can be hung on it. The knotted rope is weighted with 10kg for 1 minute and then the weight is reduced to 1kg and maintained at that level for approximately 5 mintues. As long as the 1kg tension is on the rope it must not be possible to insert a rod equal to the rope diameter into any part of the knot from either direction.

Tests such as shrinkage, shock load strength, load absorption, abrasion, sheath slippage on kermantle ropes, and UV resistance are not as standardized nor as commonly run on ropes in the United States as the previously discussed tests.

Shrinkage tests on nylong ropes are run in various manners. Some in boiling water and some in hot air ovens. Shrinkage results in the 6% range are common.

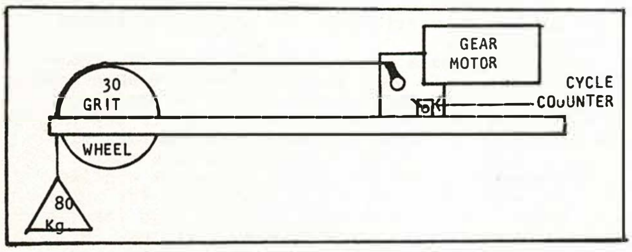
Shock load strength and load absorption tests are run on a test tower like that specified by the U.I.A.A. for dynamic rope testing. In that test 80kg is dropped 5 m on a fixed piece of rope and the force transmitted through the rope is measured. For static ropes this force would far exceed the U.I.A.A. specification for dynamic ropes, but this type of test can be used to calculate the load absorptio- capacity of a rope. Also any tope used for rescue should withstand at least two drops of this type of tower without breaking.

Sheath slippers on kernmantle ropes is tested in various ways. One method is to cut the sheath completely at least 3 m from the lower end of a vertically suspended test speciment and place a "Jumar" type rope ascender on the rope 10mm below the cut. Then place a 80kg load on the ascender and measure the distance the sheath slips. Another method is to cut one end of a 5m test speciman cleanly so the sheath and core can move independently and then pull the test speciman through a rappel rack device and measure the distance the sheath slips past the end of the core. The sheath slippage should not exceed 5%.

Chemical resistance is rarely tested on rope specimens. This type of testing is usually done on the polymer from which the rope yarn is made by the polymer producer. Nylon, polyesters, and polypropylene all have excellent chemical resistance.

Ultraviolent light resistance is being tested more now than in the past. Caving ropes do not need as much UV resistance as mountain climbing ropes but they should still have some resistance. Rescue ropes, on the other hand, should have good UV resistance. A common test for UV resistance is to expose a sample in an Atlas "Fadeometer" with 6500 watt xenon arc light source for 200 hours, then test tensile strength. Strength loss should not exceed 25%.

Abrasion resistance is an important area in which there is very little standardization. Most testing is of the reciprocating type where the rope specimen is weighted and is then moved back and forth across the abrasive surface until failure. The variation from test to test is mainly in the abrasive surface used and the amount of weight applied to the test speciman. Abrasive mediums such as bricks, granit and limestone slabs, concrete blocks and curbstones, have been used but have poor reproducibility. Other items such as brass or steel octagons and angles, metal cutting saw blades, and files have also been used. It appears that the best abrasive medium is a grinding wheel such as the ones used on large pedestal grinders. A wheel of appx. 30 grit, 250mm in diameter and 50mm wide gives good results. A weight of 80kg is suspended from the rope and the rope is pulled back and forth over the stone in a reciprocating motion. A machine similar to the one in the accompanying sketch is recommended. On 10-13mm diameter kernmantle ropes the sheath should withstand at least 50 cycles, each of which is two 50mm strokes, before complete failure. Total rope failure, regardless of the construction type, in these diameters should require at least 200 cycles on this machine.



Other types of testing are also performed on ropes such as color, hardness, number of twists per meter, % of broken filaments per yarn, etc. To discuss all the current and proposed tests available is beyond the scope and purpose of this paper.

When specialty topes are designed it is important to know as much as possible about their end use so proper materials can be selected and construction methods used to ensure satisfactory performance. For caving and rescue ropes the end use conditions are well known. Most of the materials and construction methods that have been used to manufacture these ropes are briefly discussed here.

Aliphatic nylon, eg. type 6, type 6,6 etc., are the best. They have high strength, high abrasion resistance, good elongation which results in high load absorption capacity, and good resistance to strength loss from flexing.

Polyesters are also good materials but not as good as the previously mentioned nylons. They usually have lower strength, less abrasion resistance, and less stretch. The lower stretch can be good but results in lower load absorption.

Polypropylene is sometimes used but is not a good choice because it has low strength and poor abrasion resistance.

Aromatic nylons such as Kevlar are not good choices either because of poor abrasion resistance, high flex loss in flexing situations, poor load absorption, and they are very heavy. On the plus side they have high strengths, and low stretch.

The construction methods used for caving and static loaded rescue ropes are three popular rope construction types. The best ropes are of kernmantle construction. They have no spin, low stretch, and high abrasion resistance. The other ropes are eighter braid over braid, or laid (twisted) construction. The popular laid type ropes have several drawbacks. They have high stretch, they spin when suspended free, and because their load bearing strands are not protected they have low abrasion resistance. The braid over braid ropes have high stretch, the sheath slips very easily, and because of the braid type they have poor abrasion resistance.

The constructing of a good rope with all the desirable characteristics of strength, elongation, flexibility, abrasion resistance, etc., is very difficult. If too much emphasis is placed on one particular characteristics another one must be sacrificed. The rope manufacturing companies are constantly working to improve their products and develop new and better ropes. It is hoped that in the near future not only will betther ropes be available but that standards will be set so the consumer will know immediately if the product meets safety specifications.

Jointing as an Index of Sulphate Massif Karstification

I.A. Pechorkin, A.I. Pechorkin, G.B. Bolotov
U.S.S.R.

Abstract

The higher, in comparison with carbonates, solubility of gypsum and anhydrite rocks conditions the peculiarities of sulphate massifs karstification. Because of rapid saturation of water filtrating through joints into the massif, the development of surface karst forms prevails. The subsurface cavities on the considerable depth are rare. According to the data obtained by the authors up to the 95% of the total volume of the dissolved $CaSO_4$ are washed out of the upper subsurface zone from the depth of not more than 10-15 m.

The tectonic jointing of the rock, taken together with the hydrogeological and hydrochemical situations, is the main factor of sulphate karst development. The authors' emphasis lies on the fact that distribution of joints in the massif is not uniform and the influence of jointing on the character of karst manifestation is significant: much more rock is washed out from the highly-dissected zones than from slightly dissected. This fact should be taken into account when estimating the velocity of karst denudation. To calculate the quantity of gypsum washed out per time unit from the square unit of the massif, the authors propose formula taking into consideration the degree of tectonic jointing.

Résumé

La haute, en comparaison avec les roches de carbonate solubilité du gypse et de l'anhydrite conditions les particularités du développement du karst des massifs sulfatés. En rapport avec la saturation rapide de l'eau, qui se filtre par les fissures dans le massif, se développent principalement les formes karstiques. Les cavités souterraines sont rares sur la grande profondeur. Conformément aux explorations des auteurs, de la zone supérieure souterraine dont la profondeur ne dépasse pas 10-15 m, se lave jusau'à 95% de tout le volume de dissous $CaSO_4$.

La fissuration des roches joue rôle dirigent dans le développement du karst sulfaté à côté des situations hydrogéologique et hydrochemique. Les auteurs marquent le morcellement fissuré inégal des massifs et son influence sur le caractère des manifestation du karst des zones morecellées fortement se lave beaucoup plus de roche dissoute que des zones morecellées faiblement. Il est nécessaire de prendre tout cela en considération à l'appréciation de la vitesse de la dénudation karstique. Pour les calculs de la quantité du gypse lavé en unité de temps de l'unité de surface, on propose la formule qui tient compte du degré la fissuration du terrain.

The majority of the present-day methods of estimating the velocity of karst denudation (methods developed by J. Corbel, D. Smith, M. Pulina) takes into account the total volume of the run-off from the surface of the massif and the content of the dissolved component in these waters. When karsting rocks are covered by rocky unsoluble ones the dissolved rock is washed out not from the karsting rock surface but from the walls of the joints crossing it. As a rule, jointing distribution in the massif is not uniform: there are highly and slightly jointed zones. Other things being equal, the quantity of the dissolved component washed out of highly jointed zones is much greater than that of slightly jointed ones. When estimating karst massif denudation, the jointing of the massif, sulphate in particular, should be taken into consideration.

According to I.A. Pechorkin's investigations (1969) the solubility of gypsum through joints depends mainly on their width and the character and velocity of the water moving through joints. At low velocities, the length of the water routes equals several dozens centimeters, at high velocities, water saturation takes place when water has already covered the distance of dozens and hundreds meters. At a given velocity the increase of the width of the joints results in increase of the route and saturation of the water and vice versa.

The authors propose formula for calculation the quantity of gypsum washed out by infiltrating water from the massif covered by jointed unsoluble rocky thickness:

$$m = V\,[C_H - (\exp \frac{2k^x h}{-nv}) C_H]\,N \qquad (1)$$

where: m - the quantity of gypsum removed from the hectare of the massif surface (gr); V - the volume of the water (l) infiltrating per hectare of the massif surface; C_H - gypsum solubility (gr/l); k^x - the velocity constant of gypsum solubility (cm/min); h - the depth of infiltrating water sulphate calcium saturation zone (cm); n - the average width of joints in the area (cm); v - the velocity of water filtration through joints into the massif (cm/min); N - the quantity of joints per hectare of the karsted massif.

The velocity constant of gypsum solubility can be calculated by the empirical formula:

$$k^x = k^x_o + \alpha t \qquad (2)$$

where: k^x_o - the velocity constant of gypsum solubility at 0°C (k^x = 0,0015 cm/min); α - the empirical coefficient (α = 0,00007 cm/geg·min); t - filtrating water temperature in degrees Centigrate.

The depth of calcium sulphate saturation zone (h cm) under water filtration through joints should be determined by experimental methods, taking into consideration the average width of the joints in the massif, the velocity and chemical composition of the infiltrating waters.

The conditions of washing out dissolved calcium sulphate can be illustrated by those of Polaznenskyi gypsum massif (Preduralje) characterized by various degree of tectonic jointing dissection. The karsting gypsum and anhydrite rocks (P_1) are covered here by marls (P_2) and by Quartenary rocks (Figure 1). The overall joint measuring in the massif followed by statistic analysis shows three types of zones with various degree of dissection (Figure 2): 1) slightly-dissected zones (N < 60); 2) medium-dissected zones (N = 60 + 120); 3) highly-dissected zones (N > 120). Using formula (1) one can calculate that the quantity of gypsum washed out from slightly-dissected zone equals 300 t/year·hectare; for medium-dissected zone - 600 t/year·hc; for highly-dissected - 1200 t/year·hc. Thus the quantity of gypsum washed out in dissolved state from highly-dissected zones is 4 times greater than that from slightly-dissected.

Big subsurface cavities are encountered not only in the upper subsurface zone of the gypsum massif but also on the considerable depth of about 50-100 m. It seems to be in contradiction with rapid calcium sulphate saturation of the water moving through joints deeply into the massif. However when considering the conditions of karst process development in the depth, the strain in the massif should be given primary importance.

High pressures from all directions owing to the weight of the overburden rocks lead to increasing calcium sulphate solubility. According to experimental data by V.I. Manikhin (1966) the pressure rise of 1000 kg/cm^2 results in 4 times greater solubility. At the depth of 50 m in a gypsum massif the average pressure is 12,5 kg/cm^2, while at 100 m it is 23 kg/cm^2, which brings about 0,5 and 0,1 times increase in gypsum solubility, respectively.

The deficiet of water saturation with $CaSO_4$, therefore, is 0,9 gr/l greater for the depth of 50 m and 0,9 gr/l for the depth of 100 m. At the expense of this in areas of 500 mm/year precipitation up to 300 kg of gypsum are dissolved yearly on a hectare of a gypsum massif at the depth in 50-100 m interval, under condition of free air access.

Water aggressiveness in relation to $CaSO_4$ will increase when two non-agresssive saturated flows with different temperatures mix with each other. For instance, infiltrating water (t=10°C) is mixed up with the underground waters (t=5°C) in equal quantities, the phenomenon is possible in localities with intensive infiltrating water inflow, their resulting temperature is 7,5°C. The plot of Figure 3 shows that at temperature of 10°C $CaSO_4$ solubility is 1,90 gr/l, at temperature of 5°C - 1,823 and at temperature of 7,5°C it is 1,80 gr/l. Simple calculations show that at temperature of 7,5°C the deficiet of water saturation with gypsum in this case is 0,0615 gr/l. Though this value is somewhat lower than that in the case of increasing the solubility under all-sided compression, its influence on the karst development process is considerable.

Consequently, cavity formation in sulphate massif at considerable depth is conditioned by: 1) increasing the rock solubility under the all-sided compression; 2) increasing the ground water agressiveness when mixing up flows with different temperatures. According to the given calculations, the deficiet of water saturation with calcium sulphate, conditioned by these two factors will be 0,15-0,16 gr/l, when water infiltration takes place at the depth of 50-100 m. In the geological scale of time it is quite sufficient for the formation of extensive karst cavities. Increasing the water agressiveness when two factor with different chemical composition are mixed may be considered as the third factor.

In conclusion it should be mentioned that the difference between sulphate and carbonate massifs lies in a lower depth of karstification of the former. According to a number of authors (L. Jakučs et al., 1977) this fact can be accounted for by a low degree of gypsum dissection by tectonic jointing and by the non-spreading of jointing to the considerable depth owing to the high elasticity of the rock. Our investigations in Preduralye, Prikarpatye and Povolzhye show that on the depth of 50-70 m tectonic jointing in gypsum is quite vividly expressed. Slight karstification of sulphate massifs occurring at considerable depth is conditioned by rapid water saturation with $CaSO_4$, when it is moving deep into the massif. Our investigations show that in gypsum and sulphate massifs up to the 95% of calcium sulphate are washed out from the upper subsurface zone (10-15 m deep) and only 5-10% of the rock are dissolved and washed out from the deep)lying parts of the massif.

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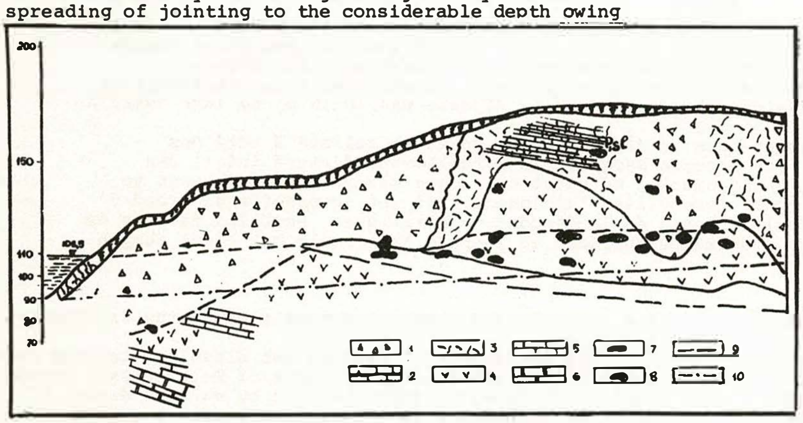

Figure 1. Geological section of Polazna area. 1. Karst-caving deposits (N-Q); carbonate rocks (P_2): unfaulted (2); faulted (3); 4 - gypsum (P_1); 5 - limestone (P_1); 6 - dolomite (P_1). Karst cavities filled with: sand-and-clay material (7); water or air (8). Level of the water table: in 1969 (9); before the reservoir creation (10).

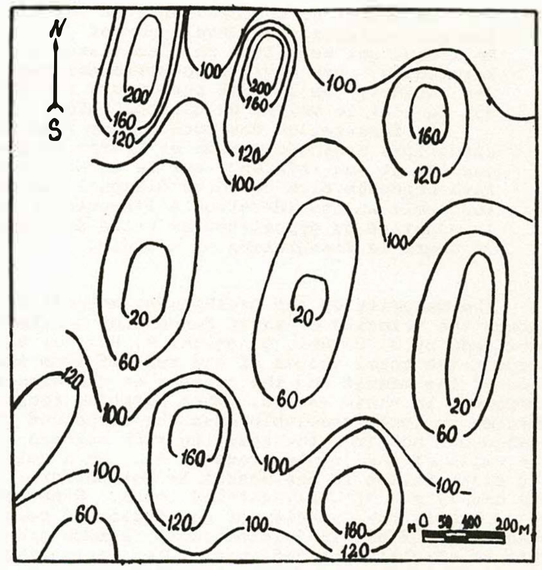

Figure 2. Scheme of the joints quantity isolines (N) per hectare of the Polaznenskyi gypsum massif.

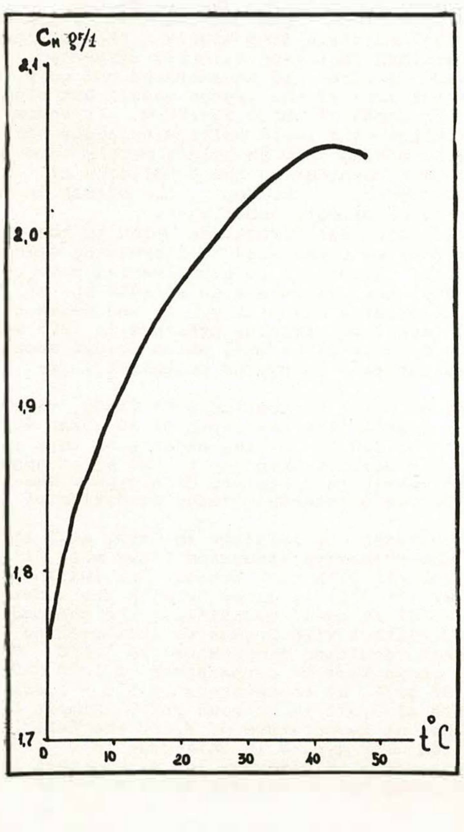

Figure 3. Interdependence between the gypsum solubility in distilled water ($C_H$gr/l) and water temperature (t°C).

Early American Speleological Writings

Jack H. Speece
711 E. Atlantic Ave., Altoona, PA., 16602, U.S.A.

Abstract

Prior to 1750 the only mention of caves in America was contained in the journals of the early explorers and specific names and locations were omitted. Later, caves were mentioned as landmarks and curiosities. Thomas Jefferson was one of the first to recognize and write about the scientific aspects of caves in this country.

Although America is in its youth, little has been done to organize its early speleological writings. Caves have played an important role in the country's history and progress and have been the subject of great legends and folklore, but little has been written about them and the few writings which do exist are widely scattered.

Résumé

Avant 1750, la seule mention des cavernes en Amérique se trouva dans les publications de premiers explorateurs. Les déscriptions précises, les noms et les locations furent omis.

Plus tard, les cavernes furent mentionnees comme bornes et curiosités. Thomas Jefferson fut un des premiers à reconnaître et écrire au sujet des aspects scientifiques des cavernes dans ce pays.

Quoique l'Amerique soit jeune, on fit peu pour organiser des documents spéléologiques. Les cavernes jouerent un rôle important à l'histoire et au progrés de ce pays; et furent le sujet des légendes et des superstitions populaires, mais il y en eut peu ecrit les rares documents éxistants sont bien éparpillés.

Long before modern white man ever landed on the shores of the American continent, caverns were being used by the natives for various unique purposes. Archaeologists have been studying the remains of these people for more than 100 years. Caves have helped to preserve these pieces of historic data by preventing them from being destroyed by the elements. Russell Cave, Alabama, is a good example of such a site. A chronological order has been uncovered here which traces man for 8,000 years. Radiocarbon dating of charcoal remains associated with lithic remains at Meadowcraft Rockshelter, Pennsylvania, show that man has existed in these parts since 17,000 B. C. and is among the oldest discoveries in America.

The only ancient written reference to caves in America is found in the Book of Ether, Chapter 13. This was originally written by Ether in approximately 400 A. D. These translations describe how the author dwelled "in the cavity of the rock" during great battles between the Jaredites under King Coriantumr and the Nephites under King Skiz somewhere in northeastern United States (Ohio, Pennsylvania or New York).

The Northmen were believed to have visited North America about 1,000 A. D. It is highly unlikely that Eirik the Red, the Greenlanders, Bjarni Herjolfsson and other Vikings ever found any caves during their visits. Columbus, however, probably did view a few caves in 1492-1493 while on the islands of Bahama, Cuba and Hispaniola. The Spanish explorers who followed: Balboa (1513) in Panama, Ponce de Leon (1513) in Florida, Diego Velazquez de Cuellar (1516) in Cuba, Hernan Cortez (1519) in Mexico, Panfilo de Narvaez (1528) in Florida, Hernando de Soto (1539) to the Mississippi, and Francisco Vazquez do Coronada (1540) in southwestern United States and Mexico, all should have seen great caverns. No records have ever been reported from their reports or journals.

In 1566 Diego de Landa, a Spanish Priest, wrote on his travels through the Yucatan andincluded references to several caves. His writings are presently on file at the Franciscan Convent at Merida, Mexico. Antonio Vazquez de Espinosa in 1629 wrote descriptions of the karstic ebb-and-flow springs near Chiapas, Mexico. His works are found in Seville Archives of the Indies, Spain. Athanasius Kircher started to publish a series of encyclclopaedic works in 1655 entitled Mundus Subterranens. Another description of a Mexican cave which was covered with a kind of leaf-gold was written in the Philosophical Transactions, Vol. 3, No. 41, dated November 16, 1668.

Not only were early records made in Mexico but also of the islands which Columbus discovered. The underworld of Bermuda was recorded by Captain John Smith in 1624 while searching for fresh water, mentioning that in some places there were "verye strange darke and cumbersome Cause". The island of Madeira was described by Sloane in 1707. Barbados was mentioned by Hughes in 1750 and Long wrote a history of Jamaica in 1774.

The early explorers of the United States also left a few journal references. Friar Rodrigo de la Barreda in 1674 visited an impressive cavern in Florida "with three apertures buttressed by stonework of unusual natural architecture". Reports on the expeditions of such men as Hernando De Soto in southeastern United States, Jacques Marquette and Louis Jolliet up the Mississippi, Dulhut and Viele would be interesting to the speleohistorian.

In September of 1700, Le Sueur ascended the Mississippi River into the Meramec River and recorded in his Journal that he viewed several lead mines and small saltpetre caves in Minnesota. This area was explored earlier that year by Father James Gravier from Illinois and later by Father Jacques Marquette whom some give credit for discovering the Meramec Caverns. This distinction is shared by Philip Renault and dated somtime in the early 1920's. None of these claims, however, have been substantiated by actual written accounts. Le Sueur's journal has been reported to exist but its location is unknown. The first known written reference to a Minnesota cave was made by Jonathan Carver in November 1766 when he explored a cave which was named after himself.

An early landmark along the Ohio River is Cave-in-Rock, Illinois, which has quite an impressive entrance. This feature was noted on maps as early as 1764. Some reports state that M. de Lery observed the site as early as 1729 and referred to it as "Caverne dans le Roc". Charlevoix also recorded its existence in The History of New France (1744) which includes Bellin's Map of Louisiana. The cave's reputation for being a rendezvous for outlaws did not begin until about 1795.

The first American map to show a cave location was produced by W. Scull for Thomas and Richard Penn, Esquires, in 1770. This was a map of Pennsylvania which showed a cave along Maiden Creek about 12 miles north of Reading.

One of the first major settlements in the United States was Jamestown, Virginia, in 1607, but it wasn't until after the turn of the century that many ventured far from the coastal planes. A major trail westward into Kentucky was through the Cumberland Gap, also known as Cave Gap, where Cudjo's Cave and Soldiers Cave are located, which was first blazed in 1750. This brought about more writings on the natural wonders of Kentucky by such men as Filson in 1784 and Fiteroy two years later.

A forerunner in American Speleology was Thomas Jefferson. As early as 1783 he was working with Isaac Zane to verify the uniformity of temperatures within a cave. A year earlier he privately published Notes on Virginia in France. These "notes" contained the first known American cave map, that of Madison's Cave in Virginia, along with several other cave descriptions. Saltpetre caves also became a matter of great concern to Jefferson, along with other wealthy merchants, shortly after the Revolutionary War began. Blowing Cave at Panther Gap, Virginia, and the bones of a giant sloth discovered in a Greenbrier County, West Virginia cave also took his interest. Numerous letters were written to individuals concerning all aspects of speleology. Some have considered Jefferson as the Father of American Speleology but, due to his greater accomplishments as a Statesman, this title has not been imposed.

George Washington also was curious about caves, leaving his name on the wall in a small West Virginia cave named after him in 1748. This cave was later used by Washington and his compeers as a masonic lodge during the Revolution. Washington was the first to survey Natural Bridge and also left his name in Madison's Cave.

In the latter half of the 1700's and early 1800's, Europeans were making tours of North America and Virginia in particular and made extensive reports on their experiences. Most seemed to have viewed the same places, such as Natural Bridge, a cave near Winchester, Virginia, where the water ebbs and flows, Lost River, Madison's Cave and several other caves of minor importance. Some of these better known explorers included Burnaby (1760), Carver (1778), Chastellux (1787), Anburey (1789), and Weld(1799).

By the end of the 1700's Americans were traveling to Europe and making reports on the great caves of the eastern hemisphere. Other foreign cave reports appeared in noted magazines of the day and were written by unknown authors, perhaps of British origin. Men with scientific interests were also discovering bones, fossils and saltpetre in caves and writing articles, making speleology a respectable study.

The search for obscure cave references in the magazines and journals of this country and Europe should still contain a wealth of information. It is interesting to see how our forefathers felt about this science which we consider so precious. A keen eye will observe speleological passages in the historical material one reads and only by publishing its existence can the bibliography of American Speleological Literature become more complete.

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Underground Wilderness A Conservation principle and a Management Tool

Robert R. Stitt
1417 9th Ave. West, Seattle, Washington 98119 USA

Abstract

With the passage of the Wilderness Act in 1964, the Congress of the United States of America established the National Wilderness Preservation System for the protection of natural lands in the U.S.A. Cave Conservationists have argued for many years that caves, because of their unique nature, could and should be included in the National Wilderness Preservation System without further statutory authority. They have introduced the concept of "underground wilderness" to describe what many consider to be the world's last true wilderness--completely untouched, in many cases, by the hand of man. Although to date no caves have been included in the System on their own merits, some Federal agencies have accepted the validity of the concept, but have declined to ask Congress to implement it.

This paper presents a working and legal definition of underground wilderness, the application of the concept to cave preservation, and a discussion of the prospects for obtaining such application in the future.

Résumé

Avec l'adoption de l'Acte des Régions Inexplorées de 1964, le Congrès des Etats-Unis d'Amérique a établi le Système National de Préservation des Régions Inexplorées afin de protéger les terres naturelles aux Etats-Unis. Les partisans de la conservation des cavernes se sont disputés des années durant au sujet des cavernes, qui, en raison de leur nature unique, pourraient et devraient être comprises dan le Système National de Préservation des Régions Inexplorées, sans autre autorisation réglémentaire. Ces conservationistes ont introduit le concept d'une "région inexplorée souterraine" pour décrire ce qui est souvent considéré comme la dernière région vraiment inexplorée du monde - souvent complètement protégée de la main de l'homme. Bien qu'il n'y ait pas de cavernes inclues dans le Système actuellement à cause de leurs propres merites, quelques-unes des agences Fédérales ont accepté la validité de ce concept, mais elles refusent toujours de demander au Congrès son exécution.

L'auteur de ce document présente une définition légale et générale des régions inexplorées souterraines, l'application du concept de la préservation des cavernes, et un discours sur la possibilité d'obtenir une telle application dans l'avenir.

In the United States of America, particularly in the western part of the country, there are large areas of land which are both owned by the Federal government and still in a relatively natural state, mostly untouched by the effects of human habitation or use. Many of these lands contain caves and karst features.

Although these lands had been managed under administrative regulations as "wilderness" for many years, in 1964 the United States Congress passed formal legislation, known as the "Wilderness Act of 1964," which formally recognized the existence of these lands and provides for their permanent preservation in a "National Wilderness Preservation System" (NWPS). Subsequent legislation also included in the NWPS some lands in the eastern part of the U.S.A., which had shown signs of human use, but which had through wise management returned to a "Natural" state, with most of the human effects no longer visible. Although the Wilderness Act has primarily been used for the preservation of "lands," cave conservationists have long argued that it can and should be used for the protection of caves and cave systems as well. The most isgnificant example of a cave system which could be protected by the Wilderness Act is the world's longest cave, the Mammoth Cave System in Kentucky.

The Wilderness Act of 1964 (1) defines wilderness as "an area where the earth and its community of life are untrammeled by man, where man himself is a visitor and does not remain . . . retaining its primevel character and influence, without permanent improvements or human habitation . . . and which generally appears to have been affected primarily by the forces of nature with the imprint of man's work substantially unnoticable, . . . has outstanding opportunities for solitude or a primitive and unconfined type of recreation, . . . and may also contain ecological, geological, or other features of scientific, educational, scenic, or historical value."

Clearly, this definition can apply to lands containing caves. But many lands which contain caves cannot meet the test of this definition because of the presence of human artifacts or habitations on the surface, even though the underlying subsurface portions of the land containing caves are substantially without signs of human influence.

In American jurisprudence, the usual practice is of separating ownership by horizontal boundaries, normally defined upon the land surface, but extending ownership "from the sky to the depths," unless there has been division by vertical boundaries. The concept of vertical division is also quite clearly established, although it is less common for it to be applied except in the case of mineral rights. There are instances of the separation of "cave rights," however (2).

American cave conservationists have introduced the concept of "underground wilderness," wilderness lying below the surface of the earth. Although primarily aimed at including caves, other subsurface features could also be included in an underground wilderness area. The presence of human effects upon the surface need not necessarily interfere with the wilderness status of the subsurface.

The preservation of caves as underground wilderness has several values to society: for wilderness-type recreation, for scientific research, and as a management baseline for the management of other caves. Although there is a place for non-wilderness caves--for developed recreation and education, and for industrial uses--an important value of caves is as a wilderness resource and nature preserve, not only for the benefit of cavers and scientists, but for the benefit of the larger society. Caves are an important component of our natural heritage, worthy of preservation.

Although the concept of underground wilderness was first introduced in the 1960's (3), Federal land management agencies have continued to oppose the designation of underground wilderness areas and to date none have been added to the National Wilderness Preservation System.

Such inclusion would require a high standard of management on the part of the administrating agency. Many cave conservationists feel that all caves should be managed as wilderness unless they have been specifically dedicated to another use, such as tourism or other forms of developed recreation. A cave can be managed as wilderness even though it is not provided statutory protection. But formal designation as wilderness by Congress sets long term management goals and assures that land managers keep the wilderness concept foremost in mind in managing the cave (4).

It is in Mammoth Cave National Park where the underground wilderness concept is most applicable. Most of the surface lands in the Park were farmed at one time, and the surface forests, in spite of more than 40 years of wise management, have not yet returned to a completely natural state. The cave systems are generally protected by a sandstone cap rock, so that the detrimental effects of agricultural surface use did not occur, or have mostly disappeared. So the cave system, except for those portions which have been intensively developed for tourist visitation, is largely a <u>de facto</u> wilderness area.

Over the years, however, several problems have occurred which have threatened the wilderness quality of parts of the cave system. In the 1960's a Job Corps Center was constructed on Flint Ridge, within the Park. Improper design of sewage lagoons led to high coliform counts in cave waters and some effects of this pollution were very obvious within the cave system. A nationwide protest by speleologists led to the eventual correction of the problems, but the continued existence of the Center has led many to fear that additional problems would occur. Finally in 1981 the Center is being moved to a new location of the periphery of the Park.

For many years the Park obtained its water supply by capping springs within the Park and diverting the water to human use. This reduced water flow through the caves and upset the ecological balance.

Finally, the most significantly, improper disposal of sewage outside of the Park, on the Sinkhole Plain, has led to massive destruction of cave life, particularly in the Hawkins River area of Joppa Ridge. This area was only recently discovered and entered, so it is not known how many times such destruction has occurred in the past.

Clearly the designation of all or part of the Park as wilderness would not have magnically halted these problems. But if the subsurface areas of the Park had been statutory underground wilderness for the past twenty years, it is much less likely that these problems would have occurred. If wilderness preservation had been an acknowledged goal of management during this period, the following effects probably would have occurred:

1. The Job Corps Center would not have been located in an area where it had a potential for reducing the wilderness quality of the caves.
2. Sources outside the Park would have been sought for water supplies, thus reducing the adverse effects on the cave hydrology and ecology.
3. There would have been earlier support for, and pressure to provide adequate means of sewage treatment for areas on the Sinkhole Plain. Thus the likelihood of massive ecological upsets would have been much reduced.

The fact is, though, that none of Mammoth Cave National Park has yet been designated as underground wilderness. The concept seems to have been a casualty of a difficult political situation coupled with the inability of the cave conservationists to deliver widespread public support for the concept. Local residents, still mindful of the process which transferred the Park lands to government control and deprived many of their parents and grandparents of the farms, resist anything which they feel might "lock up the park." Wilderness is a dirty word in central Kentucky. And powerful commercial interests have opposed enlightened planning in the Park because the plans proposed might shift the economic balance away from the status quo. The result has been that in order to assure the acceptance of the Master Plan, which would help to assure wise Park management, the Park Service and the conservationists have been forced to place a lower priority on the fight for wilderness at Mammoth Cave National Park. Although there are hopeful signs that Kentuckians as a whole are more interested in supporting wilderness, it will still be a long drawn out political battle before the objective is achieved.

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Cave Conservation in the United States of America An Overview in 1981

Robert R. Stitt
1417 9th Ave. West, Seattle, Washington 98119 USA

Abstract

Growing out of a rising environmental awareness in Amerca in the 1960's, cave conservation activists have worked hard to obtain protection for caves during the 1970's. Efforts have concentrated in several areas: education of cavers, cooperation with government ladn management agencies, identification of and fighting against environmentally unsound projects affecting caves and karst, inclusion of caves in the National Wilderness Preservation System, ownership and management of caves by cavers, obtaining passage of state cave preservation laws, and in one case an official State Cave Commission, and protection of endangered species of cave life. American speleologists have chosen a low-profile path, avoiding that public media and shunning contact with the general public. This ostrich-style approach may have reduced the effectiveness of cave protection attempts, but has certainly preventing caving from becoming a widely popular sport which might result in the destruction of many, if not most, caves. Organizations most active in cave conservation efforts have been the National Speleological Society and its many local chapters, and the Cave Research Foundation with its close relationships with Federal agencies. The efforts of thousands of individual cavers, working on the local level, are probably responsible for the successes that have resulted, in spite of a lack of strong direction from the national level after 1975.

Résumé

Par suite d'une conscience élévée des environs aux Etats-Unis dans les années 1960, les activistes de la conservation des cavernes ont beaucoup travaillé d'obtenir la protection des cavernes pendant les années 1970. Les efforts ont été concentrés dans plusieurs domaines: l'éducation des explorateurs des cavernes; la cooperation avec les agences du gouvernement de l'administration des terres; l'effort d'identifier et de lutter contre des projets qui nuisent aux caves et au karst; l'inclusion des cavernes dans le Systême National de Préservation des Régions Inexplorées; la possession et l'administration des cavernes par les explorateurs des cavernes; le passage des lois de preservation des cavernes au niveau des etats; et la protection des espêces de vie aux cavernes en danger. Les spéléologues americains ont choisi une voie qui évite la presse et qui fuit le contact avec le public general. Cette attitude a pu diminuer l'efficacité des efforts de protection des cavernes, mais elle a certainement empêché que la spéléologie devienne un sport en vogue, ce qui pourrait aboutir â la destruction de beaucoup de cavernes. Les organisations les plus actives dans les efforts de préserver les cavernes ont été la Société Nationale de Spéléologie et son grand nombre de groupes locaux, et la Fondation de Recherche des Cavernes avec ses proches relations avec les agences Fédérales. Les efforts des milliers des spéléologues individuels, travallant au niveau local, sont sans doute responsables des success qui en ont resulté, malgré la manaue d'une direction claire provenant du niveau national agrês l'année 1975.

In 1966, Victor A. Schmidt, who was at that time Chairman of the Committee on Conservation of the National Speleological Society, outlined the status of American efforts at cave conservation in an article in Studies in Speleology (1). In that article, Schmidt listed several problems of importance: both professional and casual vandalism, the over collection of biota, pollution of groundwater, and unexplained decreases in bat populations. He noted a trend towards increasing destruction of caves by public works projects, such as dams and highways, and finally he predicted that the major problems or protecting caves were yet to be faced.

When Schmidt wrote in 1966, the National Speleological Society (NSS) had about 2500 members, representing, it was supposed, about half the cavers in the U.S. The world's longest cave was still in bits and pieces awaiting connection. In spite of 25 years of attempts to convince the American public that caves were important and deserved protection--the message still hadn't gotten across.

Into this world of 1966 emerged the American and worldwide environmental movement. Laws were passed to protect the environment. Conservation activists within the NSS began pushing for more action. Cavers started putting their efforts into fighting conservation battles and attempting to save caves from the outside world. Up until this time, American cavers had probably been most concerned and occupied with saving caves from themselves. The adoption of the NSS Conservation Policy, in 1960, presented a strong conservation ethic as the accepted mode of caving. But putting into practice what the Conservation Committee preached was a slow process, almost depending on a complete turnover of the membership and constant exposure to the message. But by the beginning of the 1970's, the battle had been won--at least within the NSS. Almost all NSS cavers accepted and practiced the high standards of the NSS Conservation Policy (2). In those instances where the policy was broken or misinterpreted, peer group pressure led to acceptance of the attitudes.

In the late 1960's, however, cave conservationists began to realize that too many people caving would eventually lead to destruction of many, if not most, caves. With the growing self-awareness of conservation came a growing sense that if the public didn't know about caves, it would limit the potential for damage from groups outside organized caving. So in the early 1970's it became official NSS policy to seek no new members--and especially to do nothing to encourage the general public to go caving. The result of this policy was that the general public did not recognize caves as being valuable, and thus the problem of obtaining protection for them became that much harder. As many people pointed out the problem did not go away, it just went underground.

Coupled with the environmental movement in the U.S. was an increasing awareness of outdoor recreational activities, and an increasing participation in such sports as mountain climbing, hiking, and in spite of the efforts of organized cavers to keep it under cover--caving. Especially in areas containing many caves, hordes of young people--ranging from Boy Scouts to school groups--ventured under the ground. Caves that they knew about were vandalized extensively.

A growing awareness of this problem has led the NSS in the last few years to modify its membership recruitment policies, but not without some controversy. In spite of the protestations of the radical secrecy advocates, the NSS now is attempting to recruit all "existing cavers" into the organization--not only to gain their support for cave protection--but to expose them to high standards and ideals of caving and cave protection.

While lowering their public profile, cave conservationists raised their private one. Since, in the western part of the country in particular, the majority of caves are owned by various government agencies, cave conservationists began to work closely with public agencies to influence policy and encourage good cave management practices--include limitation of access, gating of significant caves, and in some cases commercialization. The efforts of many local groups led to progressive policies on the local level, and it was soon recognized that there was a need for communication among cave managers and the caving public. This led to the first National Cave Management Symposium at Albuquerque, NM in 1975--since followed by annual symposia throughout the nation. These symposia have produced much communication and the publication of several volumes of proceedings (3). The dialogue has finally moved from considering whether we should save caves to how to go about it.

Although the bulk of the work on the Interstate Highway System was completed in the 1960's (at least in rural areas), continuing efforts at control of the nation's waterways by various federal agencies have continued. Cave conservationists have met these projects with varying responses.

In the case of New Melones Dam and reservoir in California, cavers decided to attempt the path of cooperation. By working with the U.S. Army Corps of Engineers to identify caves which would be adversely affected by the reservoir, and helping to mitigate the potential loss of caves and endangered species, members of the New Melones Conservation Task Force were able to obtain the creation of several cave preserves and the relocation of an endemic species of spider to another locale. Thus the loss of some caves will be offset, hopefully, by the preservation of others which might not have ever been protected without the presence of the dam.

At the other end of the spectrum the Meramec Conservation Task Force fought successfully to stop the Meramec Dam project in Missouri, which would have inundated over 100 caves. Other conservation battles have involved strip mines, uranium mines, and the continuing battle for wilderness protection.

With the passage of the Wilderness Act in 1964 (4), the American Congress committed federal land management agencies to a review, within ten years, of all existing wilderness to determine if it should be preserved by statute permanently. Cavers had worked hard for passage of the Wilderness Act and now were faced with the monumental task of identifying which potential wilderness areas contained caves and which should be supported for inclusion in the National Wilderness Preservation System (NWPS). Efforts were in particular concentrated on the two most important cave National Parks--Mammoth in Kentucky and Carlsbad in New Mexico.

Although the Wilderness Act does not specifically mention caves, it was soon concluded (by conservationists at least) that it did not exclude them. And a new concept was developed--underground wilderness. The ideas was first proposed formally at a preliminary wilderness planning meeting at Mammoth Cave National Park in 1967 by the NSS. Although the surface lands in Mammoth Cave National Park are not considered suitable for inclusion in the NWPS because they have been recently farmed, the underground portions of the park are still of wilderness quality. Why not include just the underground part of the park in tne NWPS? This would provide additional protection for the caves, raise the standards of care, and assure that the world's longest cave (as it became five years later) was adequately protected and managed. Unfortunately the federal agencies have fought against this concept at every opportunity. Alghough they have been forced to acknowledge the legality and practicality of the idea, they have not yet created any underground wilderness areas. Thus the battle still goes on. At Carlsbad Caverns National Park, however, where the surface areas are of wilderness quality, large portions of the Park have been included in the NWPS, and thus many of the caves have been protected as wilderness.

In the Eastern part of the country most of the land is in private ownership, and cavers have worked with private landowners to assure continued access and in some cases have actually taken over management of caves, installing gates and attempting to limit access by peer-group pressure. But this has not been completely effective. Thus many cavers and organizations have acquired caves which they are managing themselves as cave preserves. The NSS owns two caves--Shelta Cave in Alabama and McFails Cave in New York. The Butler Cave Conservation Society was formed in the 1960's to own and manage the longest cave in Virginia (5). The Northeastern Cave Conservancy has recently acquired Knox Cave in New York. Many other groups of cavers have pooled their resources to purchase and manage other caves and cave systems.

There are no specific Federal cave protection laws, although caves and cave features are protected under statutes aimed at other problems, such as the Water Pollution, Endangered Species, and Antiquities Acts. However, many states have enacted cave protection legislation since the late 19th Century, when Wyoming and Colorado enacted laws to protect caves. Until the 1960's such laws were usually applied specifically to show caves. Beginning in the 1960's cavers, speleologists, and cave conservationists became more active in seeking cave protection laws, and by the end of the 1970's almost of the important cave states have adequate laws--Kentucky being the major exception. These laws usually go beyond merely prohibiting vandalism and also protect caves from pollution and protect cave life. Whether they are truly effective, of course, is another question, since there is little public pressure for their enforcement and unless a vandal is caught in the act it is difficult to obtain a conviction in the courts. The passage of adequate protection legislation remains high on the list of priorities for cave conservationists in the U.S., however (6).

Cavers in the state of Virginia have accomplished the most. The Virginia cave protection law passed in the early 1960's was the first of the more comprehensive laws and became the model for many others. In the late 1970's, cavers worked hard for the establishment of a State Cave Commission to review this law, and this Commission eventually recommended, and the legislature passed, a more comprehensive law. Although there has been little funding by the State, the life of the Commission has been extended and it continues to monitor the status of caves in Virginia and work for their protection (7).

Many states have laws protecting endangered species, but the most important means of protection is through the Federal act. Several species of bats and cave invertebrates and fish are currently so protected, and others are in the process of designation. Speleologists have continued to work with the office of Endangered Species to identify and obtain designation for endangered and threatened species of cave life. Currently, efforts are continuing to obtain listing for the Kentucky Cave Shrimp, Palaemonias ganteri, which is found in limited numbers only in Mammoth Cave National Park, and is threatened by pollution from the nearby sinkhole plain.

In spite of the efforts of Jum Quinlan at Mammoth Cave National Park, Tom Aley at the Ozark underground laboratory, and many others, the public still has little knowledge of the complexities of karst environmental problems. Land planners in karst areas still overlook what seems to speleologists to be most elementary--that just putting something underground will not necessarily get rid of it. Changing public attitudes by education has been a slow and frustrating process. But when the U.S. Environmental Protection Agency, in 1981, treats karst terrain and its special and difficult problems as a trivial case in developing its Proposed Ground Water Protection Strategy (8), one wonders just how much progress has been made in informing the very people who should be educating the public.

In working for protection of caves and related features cave conservationists have always faced the misconception on the part of the public that caves are dark places harboring evil and undeserving of public protection. In fact, the caving establishment has promoted this image, because it has been legitimately feared that if the public greatly appreciated caves they would wish to visit them and thus inadvertantly cause their destruction. Because the U.S. has been a relatively affluent country, with a large number of caves, there has been a relatively large number of show caves that have provided some opportunity for public visits. With the exception of a few government-owned show caves which have accented environmental education, until recently the show cave experience has usually been more of an entertainment experience and has lacked an education orientation.

Published cave books have tended to be the "Guide" type, which has made them controversial in the eyes of the caving community and has usually caused them to be of high circulation but limited value in promoting cave conservation. Most high-quality "cave appreciation" books that have circulated in the U.S.A. have originated in Europe.

Organizations active in cave conservation efforts have included the NSS, with its many local chapters, the Cave Research Foundation, principally involved in research and education but also concerned about conservation, and a variety of general conservation organizations including the Sierra Club, the Audubon Society, the Friends of th eEarth, the National Parks and the Conservation Association, and the Wilderness Society.

The NSS, with its over five thousand members and many local chapters, has probably contributed the most to the cause of cave conservation through its attempts to support and encourage local activists in their battles and via the communications afforded by its national publications and local chapter newsletters.

The Cave Research Foundation has worked hard to develop close ties with various Federal agencies in furtherance of its research goals, particularly at Mammoth Cave National Park in Kentucky. At the same time CRF leaders have realized that without preservation of the resource that they would be unable to study it. Alghouth CRF took a relatively low profile until recently, within the last three years it has vocally spoken out with respect to important issues at Mammoth Cave and in other areas. Other conservation organizations have generally tended to give support to cave related conservation issues when requested, but have generally not taken the initiative. The Nature Conservancy, however, has purchased and preserved many caves. Most conservation success that have occurred have been due to the hard-working efforts of local cavers who have become convinced that without their efforts to intervene in an issue that the caves would suffer.

Although the pronouncements of various cave conservationists (including myself) have tended to view the future with apprehension, I feel cautiously hopeful that an increasing number of caves will be preserved and protected. The trend in recent years for increasing caver control of caves through ownership is one hopeful sign. Increased awareness and activity on the part of Federal and State land managers has resulted in a more enlightened management of government owned caves. And there is a large body of concerned cavers who will continue to be vigilant and to deal with issues as they come up. The combination of improved state laws, self regulation on the part of cavers and scientists, and an effort to halt public sales of speleothems via economic boycott and peer group pressure has succeeded to a certain extent in reducing the vandalism problems. A very conservative attitude towards collection prevails, especially with regard to bats. Although population declines continue, the increased awareness on the part of the cavers, scientists, and the Federal government have been hopeful signs.

Ultimately, however, the real conservation of American caves depends not only on continued vigilance on the part of cave conservationists, but an improvement of the public image of caves and cave related features, which will require increased public education about the need for cave conservation and protection.

As cavers are able to take management of caves into their own hands, they will be better able to control that management. Even though this control will represent only a few of the more than 20,000 caves in the U.S., at least some of them will be preserved. The rest of the caves may survive also, in varying degrees. Most of the traffic is to those caves which are well known, and although these caves will certainly be subject to destruction and degradation, others that are less well known will be relatively protected. But this puts the responsibility even more strongly on those who own and protect, and presumably manage well, those caves which cavers do control. Only by increased vigilance and efforts on the part of the conservation community will we assure that there are some relatively undamaged, wilderness caves existing in the next century.

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North Carolina's Bat Caves: A Significant Region of Tectonokarst

Cato O. Holler, Jr.
P.O. Box 100, Old Fort, North Carolina 28762

Abstract

In the Blue Ridge Mountains of Western North Carolina lies the community of Bat Cave, the name of which arose from a nearby series of fissure or tectonic caves. The caves are formed in the Henderson Granite-Gneiss Formation along a system of enlarged joints which run through the mountainside. Though local residents have known of the caves for well over a century, it has only been within the last decade that systematic exploration by the North Carolina Cave Survey has begun to reveal the extensive nature of these fissures. The main Bat Cave system has over a half-mile of passages and offers the potential of yielding considerable more. Thus it has become one of the longest tectonic caves of its type of which we are aware. On the same mountain another cave has over a thousand feet of surveyed passages, and numerous smaller caves abound. Adding to the interest of the caves are the presence of various opal speleothems and a number of unique cave organisms as well.

Zusammenfassung

In den Westlichen Bergen, Blauen Hohen Rücken genannt, liegt ein Ort, und hat den Namen, Fleder-Maus Höhle.

Der Name kommt von den Spalten in diesen Hohen-Rücken. Die Höhlen sind geformt von Granit in der Henderson-Granit-Gneiss Formation.

Neben bei sind verschiedene grössere Höhlen, welche sind durch den Hohen-Rücken Entlanf siehen.

Jedoch dic Bevölkerung, haben diese Höhlen schon fur uber 1++ Jahre gekannt, es ist erst in den letzten 100 Jahre gekannt, es ist erst in den letzten 10 jahren eine systematische erforschung von der Nord Carolina Höhlen unternommen worden.

Welche sich herausstellte dass viele Natürliche Formationen von diesen Spalten vorhanden sind.

Die grösste Fleder-Maur Höhlen system hat uber 1/2 Meile Durchgänge, und bringt noch viele andere austehende Höhlen. Damit bekommt diese die längste Tectonic Höhlen auf solcher Naturorscheinung. In den selben Gebirge ist noche eine Höhle und hat über 1000 fuss erforschten Gänge mit vielen kleineren Höhlen herum.

Es ist von grosser Wichtigkeit dass diese Höhlen verschiedene Opale Specimen und viele interessante Höhlen Organissmus aufweisen.

* * *

In the foothills of the Blue Ridge Mountains of western North Carolina lies the small community of Bat Cave. Hundreds of people pass through here each year totally unaware of the unique natural phenomena to be found high above on the sides of neighboring Blue Rock Mountain. Sometime in the distant geological past rremendous forces left this augen-gneiss mountain scarred with extensive fractures or joints. These, in time, were modified by other natural processes such as frost action and weathering to produce a series of fissure or tectonic caves which are among the most extensive of their type in the country, and perhaps even of the world.

Through extensive explorations by the North Carolina Cave Survey, several of the Bat Caves which were originally believed to be separate entities have been integrated into the half-mile long Bat Cave System. Also well over a dozen other smaller caves have been discovered on the mountain, and some of these of scientific importance as well.

Little Bat Cave is one of the most frequented caves on the mountain. Its entrance is the first large fissure one reaches at the head of the trail, and its passages, though relatively narrow, are fairly easy to negotiate.

Just a short distance away stands the entrance to Big Bat. Through this massive cleft in the rocks, entrance is made into the largest cavern room in the state of North Carolina. This chamber is longer than a football field, and the ceiling rises to a height of eighty-four feet in places. High on one wall 160 feet in from the entrance lies a difficult climb known as Gibb's Fingernail Traverse. It was through this crevice that Big Bat Cave was eventually connected to the passages of Little Bat.

Lesser knoen, due to its obscure entrance, is Frigid Bat Cave. The name was derived from the fact that the cave serves as a cold air trap, and nearly every explorer that has entered it declaires it as being one of the coldest caves on the mountain. This particular cave has been connected through several hundred feet of tight passage to a highly fractured cave known as Cracked Bat. It is hoped that someday a connection will be found between these caves and the main Bat Cave System which they underlie.

Located further to the west on the mountain is the Campbell-Amazing Bat System with over 1000 feet of passage. On the lowermost level of this cave is a small underground stream in which a new species of troglobitic amphipod is found.[1]

Most geologists will tell you that granite fissure caves don't contain the stalactite and stalagmite formations as found in limestone caves. Yet in several of the more remote passages within Blue Rock Mountain, these deposits do occur. Small brown and sometimes brilliant yellow and orange stalactites and draperies adorn some areas. What makes these speleothems interesting outside of aesthetics is their composition. X-ray analysis of similar appearing specimens from nearby caves show them to be composed primarily of silica in the form of cristobolite or opal with possible traces of cordierite.[2] Siliceous flowstone with microgour surfaces and several varieties of cave coral are found here as well.

The largest of the Bat Caves have been known for well over a century by the natives of the region, but few people dared to venture very far within them due to superstitions attached to the bats which dwelled there. In recent years no large bat colonies have beeen seen in the caves. However, the occasional appearance of at least four different species have been documented in the past, including that of Myotis sodalis, the endangered Indiana Bat.[3]

The caves were first brought to the attention of the caving community back in 1940. At this time several members of the newly formed National Speleological Society were called upon to investigate the fissure caves on nearby Rumbling Bald Mountain, a few miles east of Bat Cave. Legible dates on the walls of this cave go back as far as 1878, which was one year before the Bat Cave community received its current name. It is interesting to note that the caves at Rumbling Bald and the Bat Caves were sometimes confused. This is well illustrated by an old post car once sold in the area which sported the caption, "One of the natives exploring Bat Cave," yet the picture was made within a few feet of the entrance of one of the Rumbling Bald Mountain Caves instead. Upon completing their study at Rumbling Bald, several of the 1940 explorers made a quick visit to Bat Cave but lacking time for a proper study later mistakenly reported it as being "merely a small duplicate of Rumbling Bald Cave."[4]

Some years later, Bill Cuddington, who is regarded as the "Father of Vertical Caving" in the U.S., did some further exploring in the system and made what was probably the first descent of what the locals called the "Bottomless Pit," an upper entrance which drops the explorer down 135 feet into the heart of the Bat Caves.

It has only been within the past decade that really systematic exploration and mapping by the North Carolina Cave Survey has begun to reveal the true nature and complexity of the caves. In fact, when the preliminary surveys of Littl and Big Bat Caves were completed in January of 1971, no one was really aware of the maze of passages which were later to allow the two caves to be connected. The fact that sheets of glare ice covered many of the rock surfaces in the caves proved to be a definite deterrent to any real pushing on these winter trips. Littl Bat ended up with only

174 feet and Big Bat with 372 feet of surveyed passages at that time.

Though icy conditions made exploring more difficult, the caves were found to take on a magical quality during the winter months. Ice stalagmites and icicle draperies adorned the Big Room while unusual ice helictites were found in other passages.

Later as more suitable weather conditions allowed, more and more fissures were discovered and other caves were integrated into the system with the resulting passage total exceeding teh half-mile mark. This was practically unheard of for this type of cave. Even now, some years later, we are still finding more cave within the mountain.

It may be that we have only scratched the surface toward understanding the magnitude and complexities of the Bat Caves. The area presents a myriad of natural mysteries, and for every scientific question answered about this region of tectonokarst, a dozen new ones pop up in its place. For example, just what is the speleogenesis of these caves? How were they formed exactly, and how long ago? What methods could be used in dating the caves? How long did it take for the strange secondary mineral deposits of opal to occur, and could these be of any use in dating the fissures? What is the source of the small underground stream in Campbell-Amazing Bat Cave, and where does it eventually end up? So far, stream tracing studies have been inconclusive. Also of note are two narrow "blow-holes" lower on the mountain which alternately suck in and breathe out large quantitites of air depending on the seasons. Is there extensive unexplored passage between them and the upper caves, or do they remain narrow fissures throughout their length? Meteorological investigations are needed in this area.

Then there is the possibility of archaeological and paleontological studies. Were any of the Bat Caves used as shelters for primitive man as were other fissures not too far away?

The biological field is also wide open. Already several undescribed species of cave-dwelling organisms have been discovered in the system and are currently under study by specialists. It appears that we may be looking at what will prove to be an important part of an entirely new and unsuspected regional cave fauna.

Most of these cave sciences depend heavily on an understanding of passage locations and configurations. With the recent discoveries of new passages within the mountain, members of the North Carolina Cave Survey have begun a new, more accurate map of the three dimensional maze of fissures which comprise the Bat Cave System.

Many of the passageways are quite narrow and tight, and gear often has to be relayed from one person to the next. Claustrophobics would do well to shy away from much of this cave, and in several instances only the smallest cavers have been able to push the exploration.

Occasionally vertical caving expertise is required to explore some of these granitic fissures. Cable ladders are used on some of the shorter pitches, while single rope techniques are the standard for most of the drops.

Due to the very nature of these tectonic caves, unstable areas of breakdown are sometimes encountered. Engineering skills are then called upon to assure safe access. Once a large, precariously balanced rock was found to be blocking a significant passage. In order to remove it, an expansion bolt and hanger were placed into the rock, and a portable come-a-long winch was used to lift away the dangerous boulder. This allowed the cavers access to a virgin chamber deep within the mountainside.

Another hazard to be considered in these caves is the presence of numerous knife-edged flakes of the granite-gneiss which must often be traversed. Any carelessness in these areas woulc result in severe cuts and other injuries, so extreme care is needed by the explorers at all times.

Despite these and other problems, literally hundreds of volunteer man hours have been poured into ridgewalking, exploration, and surveying North Carolina's Bat Caves over the past several years. Much work still remains.

Except for scientific studies and surveying, the caves are currently closed to all other traffic. The North Carolina Nature Conservancy is now engaged in plans with the owner in hopes of providing further protection to this outstanding area of tectonokarst.

It is hoped that future generations, too, may then be able to enjoy this unique laboratory situated in a wilderness setting whose beauty is unsurpassed by few other areas of the country.

Acknowledgements

The author wishes to thank the members of the Flittermouse Grotto and the N.S.S. and the North Carolina Cave Survey without whose help this work could not have been conducted. Special thanks are due Pete Kirchner, Suzanne Kielbasa, Joel Stevenson, and Cathy Topping for the use of their slides.

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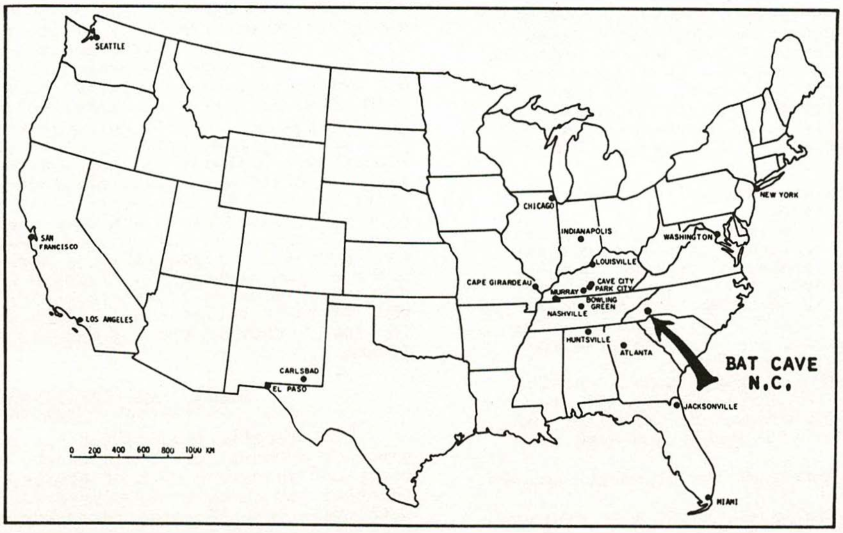

Figure 1. Location map of Bat Cave, North Carolina

Specific Dissolution in the Mediterranean Karstic Areas of France

Guilhem Fabre
Docteur d'Etat Géomorphologie, E.T.A. 282, National Scientific Research Center (C.N.R.S.), Institute of Geography, Aix-en-Provence, France. 21, rue Colbert, 30000 NIMES, FRANCE

Abstract

All rates presently calculated, concerning actual specific dissolution in the mediterranean karstic areas of France are presented for the first time. They have been got with several means: J. Corbel's formula and others, discharge-total hardness at springs, etc... The values obtained range from 10 to more than 50 mm/1000 years. They roughly can be grouped in three zones:

- Coastal karsts of Provence, Languedoc and Roussillon: less than 10 mm;
- Median karsts of the Garrigues du Languedoc-Roussillon-lower Provence: 25-30 mm;
- Upper karsts of the Grands Causses, Alpes Maritimes, Pyrénées Orientales: 25 mm and much more.

A rough map illustrates this classification which shows a typical altitudinal graduation from the Méditerranée sea up to the back mountains. With the exposure of these rates, critical appreciations about their geomorphological signification are exposed.

However the 25 mm/1000 years mean rate got for the whole region agrees correctly with the morphogenetics studies produced by many authors who think that post-Miocene karstification has been very important, especially in the canyonlands.

Résumé

Tous les taux bruts, présentement connus, concernant la dissolution spécifique actuelle dans les karsts du Sud méditerranéen français sont présentés ici. Ils ont été calculés à partir de plusieurs façons: formule de J. Corbel, rapport débit-teneurs en $CaCO_3$ aux exutoires et sur les karsts etc... Les valeurs se calent entre 10 et plus de 50 mm/1000 ans. Elles peuvent être groupées en trois zones:

- Karsts littoraux: moins de 10 mm en moyenne;
- Karsts médians (Garrigues du Languedoc et de Basse-Provence): de 10 à 23-30 mm en moyenne;
- Karsts supérieurs (Grands Causses, Alpes-Maritimes, Pyrénées Orientales montagneuses...): de 25 à plus de 50 mm.

Une carte schématique illustre cela. On y observe une croissance des taux en fonction de l'altitude. L'exposé de ces chiffres bruts est accompagné de leur critique.

Au total les 25 mm/1000 moyens obtenus pour toute cette zone "méditerranéenne" se corrèlent correctement avec les résultats de nombreuses études morphologiques. Il apparaît en effet que la karstification post-Miocène a été particulièrement important. Le paysage actuel en relève largement, surtout au niveau des karsts de canyons.

The quantification problem of the present times karstic erosion in the southern mediterranean part of France, always and necessarily very much argued about, has been studied rather completely in Provence and in the subalpine meridional edge (East of Rhône), and more erratically in the Languedoc-Roussillon and on the Grand Causses (West of Rhône). Recently an essay of synthesis has been presented (G. Fabre, 1979, 1980 b) on the latter areas. The purpose of this up to date communication is to under line all the known gross rates of specific dissolution and a few brief aspects of their morphogenetic implications on the scale of:

-a karstic area which has been analysed in details: the Languedoc Oriental;

-all the southern mediterranean part of France.

Languedoc Oriental
(Plate 1 - Figure 1 and 2)

1-1- Introduction

The karsts we are interested in are to be found in limestone formation of the APTIAN-BEDOULIAN age, of URGONIAN facies (mainly 300 m) and at a lesser degree in the HAUTERIVIAN limestone-maris group (200 m), and in the middle-superior jurassic limestone (200/300 m).

The local karstification showed itself right from the withdrawal of the cretaceous seas, mainly during the Pyreneo-Provencale tectogenesis (inferior paleogene) and alpine (superior paleogene, miocene) and particularly from the marine recession of the superior miocene, till our days (pliocene - holocene). In summary, the Eastern Languedoc is a karst made up of folds and faults with a long morphologic evolution marked by the permanent swing of the uprising of the Mediterranea between which it places itself as a median step. (G. Fabre, 1980 b).

1-2- Method of calculation and critical analyses of specific dissolution rates

The values obtained, have been reached by several means, of unequal precision, taking into consideration the numerous uncertainties linked to certain quantitatif parameters which are characteristic of the exo-endor-karst. In all cases, the datas taken into consideration correspond to averages duly calculated, with occasionnal extropolations and modulations depending on other precise datas. Whic is to say mainly from:

- the state of the surface (bare, under deposits either thick or not, under vegetal cover or not etc...);
- the importance of the exo-endokarstic gaps and of their more or less advanced chimical and others deposits state;
- the surfaces and volumes of the carbonate masses and springs impluvia;
- the effective rain falls (30 to 45 % in average);
- the chimical componants of the water and in particular of the binomath (Ca^{2+} + Mg^{2+}) - TAC (very often HCO_3^{2-}) when the TA equal zero;
- the discharge of springs;

From our experience, of all these quantitative datas, the least one subject to error, taking everything into consideration, is the water chimical componants.

The specific dissolution rates registered are as follows:

- calculation with J. Corbel's classic formula (1957):

  $X = \frac{4\ ET}{100}$ ou X = theoritical specific dissolution (m3 / km2 : year or mm/1000 years), E = available water and T = chimical concentration. Here the TH;
- calculation at springs level by means of evaluation of the joint discharge - Ca Co3 exported;
- calculation with reference to the exported volume of the Ca Co3 at the srpings and surfaces of the impluvia.

The values obtained are shown in the plate, figure 1. They very clearly present an increasing progression in the South-North way linked with the altitude and the effective rain falls. They go indeed from less 10 m3 / km2 / year to plus 25. These potential and relative rates are far from been without meaning. With 25 m / 1000 years, it appears that a 100 m thickness of limestone can be exported in 4 millions years.

Of course, this value assumes an invariability of climatic conditions and others, wrong in the absolute but quite feasable in relativity. In any case and even with modulation it coroborates validly with essais done in the regional karstic morphogenesis. They all underline the fact that major typical karstic forms active or sub-active, actually in place, were principally formed right from the withdrawal of miocene seas, 5/6 millions years ago). It is in particular the case of the karsts of canyons less than 250 m deep where allogene rivers flow and where the majority of superposed important caving systems are essentially of phreatic origin. Nevertheless, the given rates indicate an action of the "physical" erosion ("catastrophic") more efficient than the purely "karstic" one; besides the two of them are combined. That is true of the whole South-East of France.

South - Mediterranean France
(Plate 1 - Figure 2)

The specific dissolution has been analysed by numerous authors (cf. bibliography and plate) in the south-mediterranean part of France, in ways relatively identical to those we have used in the Languedoc. In total more than 50 rates described at length allow us to offer a covering cartographic essay from which 3 principal uniformity factors appear:

- Uniformity where the specific dissolution is less than 10 mm / 1000 years.

The areas concerned are: in Provence, the coastal limestone strip (and in particular the Calanques); in the Languedoc, the southern Garrigues of Nîmes and of Montpellier, and the mountains of La Gardiole and La Clape.

- Uniformity where the specific dissolution is included between 10 and 15/30 mm / 1000 years.

The regions concerned are broader and are: in Provence, the carbonate littoral area situated at the West of Nice, the low plateaux of the Var, the Aix en Provence massifs - in Languedoc all the eastern and central Garrigues situated between the Rhône and the Hérault, the karsts of the southern border of the Montagnes Noires (St Pons, St Chinian ...) and the eastern Corbières.

- Uniformity where the specific dissolution is over 25/30 mm / 1000 years.

The regions concerned, very broad, are: in Provence, the whole subalpine limestone strip, from the Italian border up the Rhône Valley, Marguareis, Plans de Gnasso, the Verdon area, the plateaux of the Vaucluse... - in Languedoc, the Ardèche sub-cèvenol area, all the Grands Causses, the Hautes Garrigues of the Gard and the Hèrault, the eastern and central Corbières, the Ariège, the small karsts of the eastern and northen Piemont of the Canigou in French Catalogne.

Remarks and Conclusion

As a theoritical essay of quantification, to be considered with all the necessary caution, these gross rates represent interesting reference values of the sub-actual karstic erosion. Their increase is a perfect copy of the hypsometric and pluviometric stages, and vice versa. The general average of 29.8 mm / 1000 years for the whole south-mediterranean part of France is superior to the karsts situated at the West of the Rhône and slightly inferior to the Provencal and subalpine unities. In total, they show no less than the present times north-mediterranean morphoclimatic conditions and the conclusions of most morphogenetic analyses of karsts where the plio-pleistocene karstogenesis is signaled as been greatly responsable for the setting of actual karstic landscapes.

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Tableau 1

Epaisseur et volume théoriques de calcaires érodés actuellement par dissolution spécifique dans les karsts du Sud méditerranéen de la France.
(Theoretical thickness and volume of limestones at present being eroded by specific dissolution in the karstic areas of mediterranean South of France.)

Synthèse par Builhem FABRE, Docteur d'Etat en géographie
Chargé de Recherche au C.N.R.S.

Karsts	Altitude (m)	Author	X (*)
KARSTS SITUES A L'EST DU RHONE (East Rhône karstic areas)			
I - Alpes Maritimes			
1. Massif de Marguareis	2000	(7)	40
2. Plans de Grasse	500-900	(7)	45,2
2.1. Siagne		(7)	62,6
2.2. Loup Supérieur		(7)	49,2
2.3. Esteron		(7)	35
2.4. Plateaux des Baous		(7)	35
3. Littoral à l'Est de Nice	<500	(7)	20-40
II - Provence		(9)	41
4. Plans du Verdon, impluvium de Fontaine l'Evêque		(4)	20
" "	410-1100	(9)	38
" "		(10)	46,3-56,7
5. Plateaux varois, région Nord de Toulon			
5.1. Agnis	320-900	(10)	38,7
5.2. Selves	300-600	(10)	37,2
5.3. Impluvium de la source de la Bresque	400-690	(6)	9-30,1
5.4. Impluvium de la source d'Argens	300-600	(10,6)	4,7-37,2
6. Impluvium de la Fontaine de Vaucluse	230-1920	(3)	66
7. Calanques de Marseille-Cassis	0-600	(2)	10
KARSTS SITUES A L'OUEST DU RHONE (West Rhône karstic areas)			
I - Bas Vivarais et bordure sous cévenole			
8. Plateaux des Bras et canyon de l'Ardèche	200-500	(5)	15-25
9. Karsts barrés sous cévenols	200-600	(5)	26,3
II - Garrigues du Languedoc oriental (axe Nord-Sud)	50-300	(5)	20-25
10. Massif de Lussan	100-300	(5)	15,4
10.1. Impluvium de la source d'Arlinde		(5)	15,2
10.2. Impluvium de la source de Goudargues		(5)	14,4
10.3. Impluvium de la source de la Bastide		(5)	11,5
11. Garrigues d'Uzès	100-200	(5)	14,5
11.1. Impluvium de la Fontaine d'Eure		(5)	34,8-61
11.2. Impluvium de la source du Moulin des Fontaines		(5)	31,9
12. Garrigues de Nîmes	50-200	(5)	6,8-15
12.1. Impluvium de la Fontaine de Nîmes		(5)	3,5-6,3
III - Garrigues de la région de Montpellier			
13. Région Nord	100-700	(9)	31
13.1. Impluvium de la source du Lez	200-360	(8)	34
13.2. Impluvium de la source de Saugras	215	(4)	50
14. Région Sud: montagne de la Gardiole	80-220	(5)	6
IV - Grands Causses et bordure Sud de la montagne Noire			
15. Grands Causses	600-1200	(5)	48,2
16. Minervois	200-700	(5)	14-18
17. Région de Saint Pons	200-800	(9)	26
V - Bas Languedoc occidental			
18. Montagne de la Clape	0-200	(5)	5
19. Corbières orientales	200-700	(5)	18,2
VI - Ariège			
20. Impluvium de la source du Baget	920	(1)	48-89

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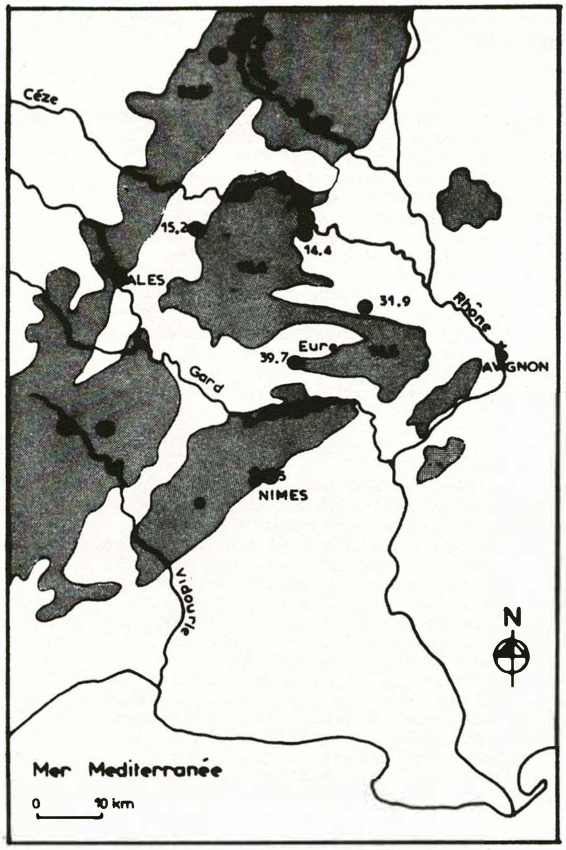
(*): dissolution spécifique théorique actuelle (present theoritical specific dissolution); valeurs exprimées en (rates in): mm/1000 ans (years) ou m^3/km^2/an (year).



Zones karstiques
Karstic areas

● Source karstique perenne importante.
Important perennial karstic spring.

Figure 1. Taux bruts de dissolution spécifique actuelle en Languedoc oriental (G. Fabre, 1980)

Actual specific dissolution rates in the eastern Languedoc (G. Fabre, 1980)
(mm/1000 ans - $m^3/km^2/an$)

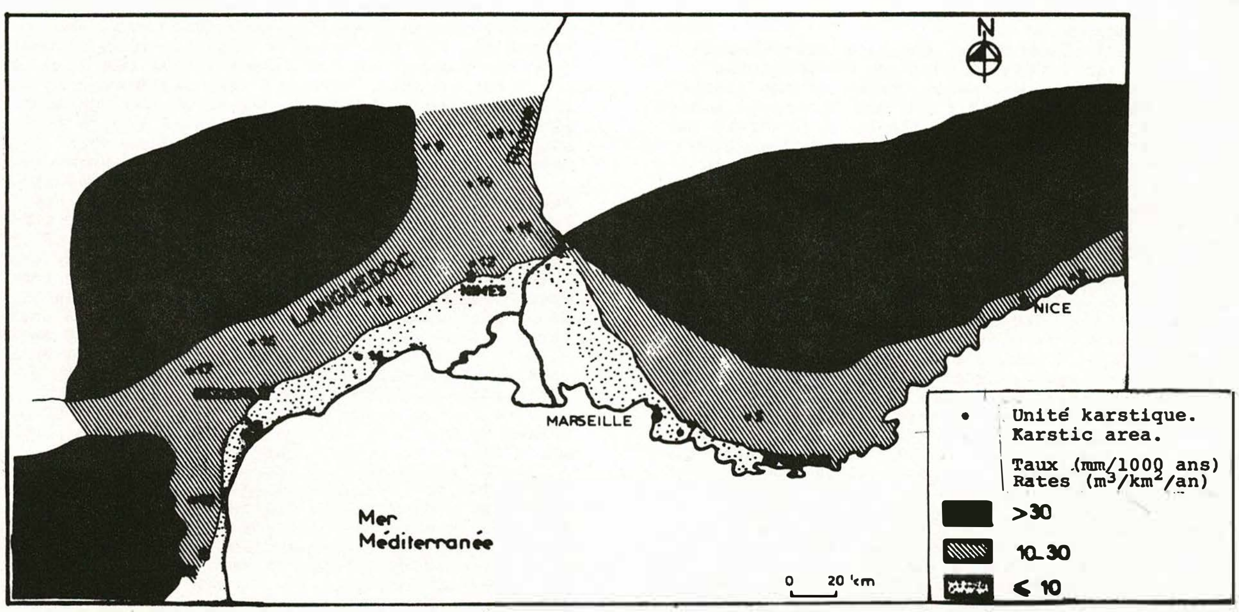


Figure 2. Taux bruts de dissolution spécifique théorique actuelle dans les karsts du sud méditerranéen de la France (G. Fabre, 1980)

Actual specific dissolution rates in the south mediterranean karstic areas of France (G. Fabre, 1980)

Subterranean Stream Piracy in the Garrision Chapel Karst Valley, Indiana, U. S. A.

David J. Des Marais
1015 Woodland Avenue, Menlo Park, California 94025 U.S.A.

Abstract

The Garrision Chapel karst area, in western Monroe County, Indiana, is about 6 km long from north to south and 4 km wide and contains several springs and more than 25 km of mapped cave passages. The caves describe in remarkable detail the underground piracy of a southward -draining surface stream by four westward-draining karst spring systems. The history of this drainage network has been revealed both by several dye tracing experiments and by studying cave passage morphology. The karstification of the Garrision Chapel valley was cuased by the entrenchment of Richland Creek, located west of Garrision Chapel, to a level which is presently more than 50 m below the karst valley floor. Upper-level cave passage orientation indicate that the earliest westward subsurface drainage was shared approximately equally by the following three spring systems, which are listed from north to south: the Garrison Chapel Cave System (which includes a sizable sinking stream and 5 known caves), the Big Blair Cave System (with 4 known caves), and the South Blair Spring System (with 6 known caves). Subsequently, the flow patterns were altered by several events, most notably the deepening of Richland Creek to the northwest, and the extensive capture by Big Blair Springs of the drainage from the eastern flank of the karst valley. The headwaters of the Garrison Chapel Cave System were then pirated northwestward to Richland Springs, on Richland Creek, and the Big Blair Spring System's watershed expanded at the expense of the South Blair System.

Zusammenfassung

Die kalksteinumgebung von Garrison Chapel im westlichen Teil des Landkreises Monroe im Staat von Indiana, is ungefähr 6 km lang von Norden nach Süden und 4 km breit und enthält mehrere Quellen und mehr als 25 km von kartographierten Höhlengangen. Die Höhlen beschreiben sehr ausfürlich den unterirdischen Raub eines Oberflächenstroms, der nach Süden fliesst, durch 4 kalksteinhaltige Quellensysteme, die nach Westen strömen. Die Geschichte dieses Abflussnetzwerkes is durch Farbspuruntersuchungen und durch das Studium der Höhlengangmorphologie aufgedeckt geworden. Die Kalksteininformation des Garrison-Chapel-Tals is durch das Tiefsinken des Richland-Bachs, der westlich von Garrison Chapel verlauft, und sich jetzt mehr als 5+ m unter dem Kalkstein-Talboden befindet, verursacht worden. Die Richtungen der Höhlengange an höheren Niveau deuten darauf hin, dass fer früeste westliche Untergrundabfluss ungefähr gleich geteilt war zwischen den folgenden drei Quellensystemen, von Norden nach Süden aufgezahlt` das Garrison Chapel H-hlensystem (einschliesslich eines grösseren, versinkenden Stroms und 5 bekannten Höhlen), das Big Blair Quellensystem (mit 4 bekannten Höhlen), das Big Blair Quellensystem (mit 4 bekannten Höhlen), und das South Blair Quellensystem (mit 6 bekannten Höhlen). Späterhin wurden die Flussverlüufe durch mehere Ereignisse verändert, vor allem das Vertiefern des Richland-Bachs im Nordwesten und der weitreichende Einfang des abflusses von der Ostflanke des Kalksteintals durch die Bib-Blair-Quellen. Der Vorlauf des Garrison Chapel Höhlensystems wurde dann nach Nordwesten, zu den Richland Quellen am Richland-Bach hin geraubt, und die Wasserscheide von dem.Big Blair Quellensystem weitete sich auf Kosten des South Blair Qullensystem aus.

Introduction

The Garrision Chapel karst area, in western Monroe County, Indiana, U.S.A., is an unusually excellent example of subterranean stream piracy. This report presents the history of this are using three lines of evidence, as follows: 1) a study of surface karst features, 2) dye tracing of subsurface passages, and 3) examination of cave passage orientation and morphology.

As Figure 1 illustrates, the Garrision Chapel valley once drained from north to south to Indian Creek (located at the southeast corner of the figure). The valley has become karstified (see Figure 1, location R), due to the subsurface piracy of water to the deep valleys located along the northern and western margins of the karst area. These deep valleys are tributaries of the area's major surface drainage, Richland Creek, which flows from northeast to southwest to the west of the study area. The Garrison Chapel karst area is strinkingly similar in several ways to the Mammoth Cave area in Kentucky. The ridges in both localities are capped by Mississippian-age shale and sandstones which overlie soluable Mississippian carbonates. The bedrock dips in the general direction of the subsurface water flow (a Garrison Chapel, this dip is 5m/km to the southwest). The recharge areas contain abundant limestone outcrops which are riddled with sinkholes, and the areas wherein the cave streams resurge are deep limestone-floored valleys surrounded by sandstone-capped ridges. The history of the Garrison Chapel karst has been generally described by Beede (1911), Malott (1922), Wayne (1950) and Powell (1965). These investigators discussed, in addition to the piracy, the development of both the thick mantle of reddish soil ("terra rossa") within the karst valley and the terraces which line the deep valleys to the west. The relatively recen observations dicussed below reveal that the subsurface drainage in relatively recent observations discussed below reveal that the subsurface drainage in the Garrison Chapel valley has occupied several distinct configurations during its history.

Tracing and Cave Passage Studies

The relationships between the accessible caves in the valley were elucidated using a combination of water dye and air odor tracing techniques, In all cases except one, the stream waters were traced using the disodium salt of fluorescein. This dye was absorbed using activated charcoal placed in the stream resurgences. The dye was visually detected after its release from the charcoal which was immersed in a solution of 5 percent potassium hydroxide in ethanol. Congo Red dye was used in one trace (between locations T and S in Figure 1), and was detected visually when it emerged from the spring. Where a cave stream was inaccessible for water tracing, passages were delineated by utilizing subsurface air flows driven by the "chimney effect." On a cold day, ethanethiol vapors sucked into the cave were subsequently smelled when they exited elsewhere from higher elevation entrances.

The karst features whose interrelationships were illustrated by the tracing experiments are labelled in Table 1 and Figure 1 by letters, which are defined in Tabl 1's footnote. For some of the stream tracing experiments, Table 1 lists the dye's transit time and the approximate gradient of the cave stream examined. Based upon examination of upper level passages, the form subsurface flows of these streams were reconstructed on Figure 2. The water flow of these cave streams is generally from east to west; and the following discussion will begin at the north end of the karst area.

As Figure 1 shows, the sinking stream (B) was traced to Richland Spring (A). Although the stream, which flows through Salamander (G), Turtle (F), Shaft (E) and Grotto (D) Caves and resurges in the spring (C) in Coon Hollow, has a much smaller base flow than does Richland Spring, this smaller stream can rapidly attain very large discharges during heavy rains. Sections of large diameter (6m wide by 9m high) cave passages in Salamander (G), Shaft (E) and Grotto (D) Caves are remnants of a large conduit which formerly carried all of the sinking stream's (B) discharge to the head of Coon Hollow near the site of the present spring (C). The appreciable depth and width of the head of Coon Hollow was excavated by the once large stream whose spring discharged the sinking stream's (B) headwaters. Eventually, the southeastward development of a surface tributary of Richland Creek, located northwest of the area in the figures, created a steeper gradient (above 12m/km) than did the cave stream to Coon Hollow (about 11m/km). An abandoned segment of the pirating conduit can be seen in I.U. Cave, located west of point B. Salamander Cave sustained extensive silt deposition, which could have been caused by the damming of silty floodwaters behind breakdown collapses in the western end of the abaondoned system. Active siltation of this type is observed in Binkley's Cave, Indiana, as well as in other Indiana caves.

The history of the Big Blair Springs (O) cave system is easily the most complex in the area. The drainage through Eller (M), Saltpeter (L), and Queen Blair (P) Caves is likely joined by the Baugh Swallowhole (K) stream. This stream may pass through Him's Hole (Q). The Buckner Cave (U) stream flows to Big Blair Spring (O). At least two air-filled passages connect Buckner and Queen Blair Caves. The east stream (J) in Wayne Cave behaves like an overflow route for the Big Blair system. Tne entire flow of Saltpeter Cave and the other eastern headwaters of Big Blair once flowed through Wayne and discharged at Wayne Springs (N and points between N and O). That this stream had a substantial discharge is evidenced by the sizable main passages in Wayne cave (4m high by 6m wide, where downcutting is not evident). The combined flow of this once large spring and South Blair Spring (S) developed Blair Hollow into a deep, flat-bottomed and low-gradient tributary of Richland Creek, which lies to the west. The base flow of the Wayne Cave stream (J) eventually abandoned Wayne Springs and resurged at the Big Blair Spring site (O). Wayne cave's west stream (I) still carries local drainage to Wayne Springs (N). Big Blair (O) captured more drainage on the east side of the Garrison Chapel valley, including that of Eller Cave (M). Big Blair's growth caused it to capture Buckner Cave's (U) headwaters, which formerly flowed to South Blair Spring (S). The much smaller presnet stream in Buckner carries only local drainage to Big Blair (O). The base flow of Big Blair's northeastern headwaters entirely abandoned Wayne Cave (J), and now flows along a more direct route between Saltpeter (L) and Queen Blair (P) Caves. Unlike Buckner Cave (U), Wayne (J) still receives occasional floodwaters, suggesting Wayne's abaondonment by base flow was more recent than was Buckner's abandonment.

The South Blair Spring System's extent was firs elucidated using air tracing (Sperka, 1969). Ethanethiol was introduced into King Blair Cave (T), and its odor was later smelled at the entrances to Brinegar (W), Trap Door (X) and Bee Tree (Y) Caves, and at a shallow sinkhole (Z). Later discoveries linked all of these features together into a 5.0km long system. Streams flowing from locations X, Y and Z join and then flow to location T, which was stream dye traced to South Blair Spring (S). Despite the close proximity of Big Blair (O) and South Blair (S) Springs, no leakage of water occurs between them. South Blair Spring once carried the drainage of both Buckner Cave (U) and the South Blair system. That this drainage was sizable is evidenced by the large main passages in these caves (4m high by 6m wide). As mentioned above, the Blair Hollow springs deepened the eastern end of the hollow, which caused most of the Wayne Spring stream to relocate to the Big Blair (O) site. By steepening the gradient of the Big Blair Spring system, this relocation contributed to the piracy of Buckner Cave's (U) headwaters to Big Blair Spring (O). Before this piracy, South Blair Spring drained perhaps the southern 40 percent of the Garrison Chapel karst valley. The South Balir Sytem's present share of this drainage is now much less, and is essentially confined to the area south of the road (see figures) which runs east-west along the southern extent of Buckner Cave (U).

A number of interesting general observations can be made abou the Garrision Chapel karst area. Even where piracy was not a factor, the older cave stream conduits are, on average, markedly larger in cross section than are the presently active stream passages. Perhaps a wetter earlier climate caused larger stream discharges. Secondly, the cave stream gradient in the Big Blair system is much steeper between Jim's Hole (Q) and the spring (O) than it is between Eller Cave (M) and Jim's Hole. Perhpas this steepening of the gradient is a consequence of the stream piracy which abandoned Wayne Cave (J). Third, the underground stream gradients are steeper in the southern end of the karst area than they are in the northern end (see Table 1). This trend is perhaps explained by the great depth of spring-fed Blair and Coon Hollows, a situation which reflects the long history of westward karstic drainage which has converged radially upon these hollows.

The Garrision Chapel valley deserves further investigation, including a quantitative water budget of the spring systems which will help to establish the maximum eastern extent of the karst drainage basins. Water budget and water quality studies are urgently needed, because this area is threatened by groundwater pollution (Gardiner, 1971; Hoye, 1976).

The author wishes to acknowledge the efforts both by the workers listed in Table 1 and by countless others, whose contributions made this report possible.

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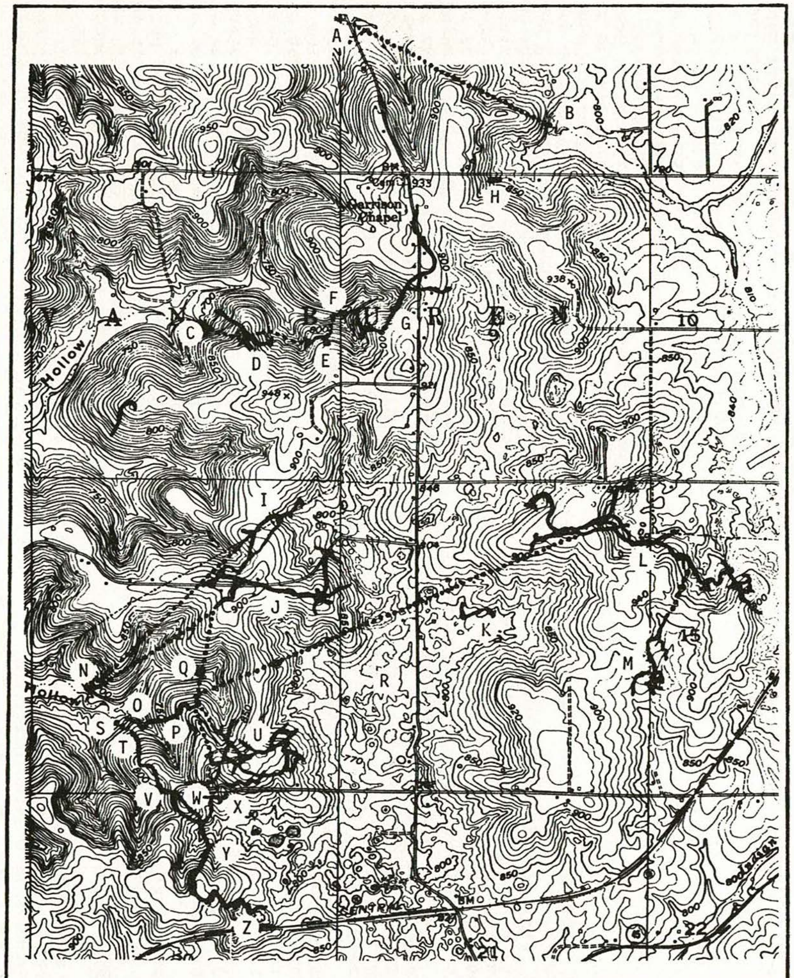

Figure 1. Topographic map representation of the Garrision Chapel karst area, with the cave systems and the dye traces indicated. North is at the top of the map. Known cave systems are represented by the heavy black lines; traced streams, etc. are represented by dotted lines. The lettered karst features are defined in the footnotes (a) in Table 1. Area shown is 4.0 km wide.

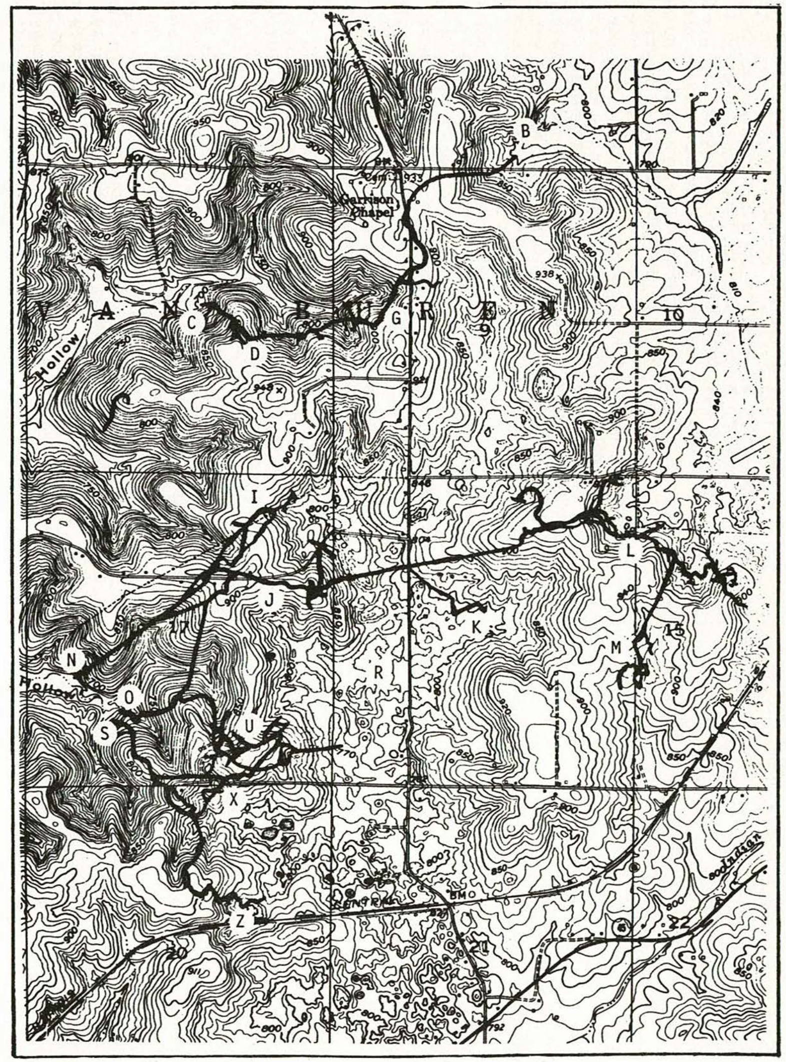

Figure 2. Topographic map representation of the Garrison Chapel karst area, with the ancient cave systems indicated by heavy black lines.

Table 1
Results of Tracing Experiments
(Letters in parentheses indicate footnotes.)

Water Traces (a) (stream gradient)	Flow Times Minimum	Maximum	Worker
B to A (7.5m/km) (b)	(c)	(c)	(d)
G to F to E to D to C (15m/km) (b)	(c)	(c)	(e)
I to N	(c)	(c)	(f)
J to O and points west of O	stormwater pulse		(g)
L to O	4 days	5 days	(h)
M to L to O (13m/km) (b)	5 days	6 days	(i)
U to O	(c)	20 hrs.	(j)
T to S	9 min.	10 min.	(j)

Air Traces (a) (stream gradient	Flow Traces Minimum	Maximum	Worker
O to P	3.7 hr.	4.3 hr	(k)
O to U's north entrance	4.3 hr.	4.8 hr.	(k)
O to U's stream	(c)	21 hr.	(k)
S to W, X, Y and U south entrance	(c)	7 hr	(l)
S to Z (28m/km) (b)	(c)	20 hr.	(l)

Footnotes to Table 1. (a) letters denote karst features whose names, including cave lengths (km) are as follows: A - Richland Springs; B - sinking creek; C - spring in Coon Hollow; D - Grotto Cave (0.8km); E - Shaft Cave (0.7km); F - Turtle Cave (connects to G); G - Salamander Cave (>1.0km); H - Mederis Cave (connects to G); I - Wayne Cave (7.3km), Keyhole River; J - Wayne Cave, Camp I stream; K - Baugh Swallowhole (0.3km); L - Saltpeter Cave (5.6km); M - Eller Cave (2.0km); N - Wayne Springs; O - Big Blair Spring; P - Queen Blair Cave (0.8km); Q - Jim's Hole; R - Garrision Chapel karst valley sinkholes; S - South Blair Springs; T,W,X,Y,Z - Respectively, the King Blair, Brinegar, Trap Door, Bee Tree and Triple J entrances to the Blair Spring System (5.0km); U - Buckner Cave.
(b) Stream gradients are approximate, undertainity is ± 30 percent. (c) Information not available. (d) R.L. Powell, date unknown. (3) Nicoll (1963). (f) Windy City Grotto of NSS, 1964. (g) T. Cox, 1971. (h) J. McIntosh, 1968. (i) T. Cox, 1970. (j) R. Sperka, 1968. (k) Des Marais (1971). (l) Sperka (1969).

Molecular Isotopic Analyses of Bat Guano Hydrocarbons and the Ecology of the Insectivorous Bats in the Region of Carlsbad, New Mexico, U.S.A.

David J. Des Marais, J. M. Mitchell, W.G. Meinschein and J.M. Hayes
NASA - Ames Research Center, Moffett Field, CA 94035

Abstract

The structure and ^{13}C contents of individual alkanes extracted from recent bat guano found in the Carlsbad region of New Mexico can be related to both the photosynthetic pathways of the local plants and the feeding habits of the insects that support the bats. Carbon isotopic analyses show that equivalent numbers of C3 and C4 native plant species occupy the Pecos River Valley, a very significant feeding area for the Carlsbad bats. During the seasons when bats frequent the area, the agricultural corps consist principally of alfalfa and cotton, both C3 plants. The molecular composition of the bat guano hydrocargons is fully consistent with an insect origin. Two groups of alkanes derived from two chemotaxonamically distince populations incests possessing distinctly different feeding habits. It is possible that one population grazes predominantly on crops whereas the other population prefers native vegetation. This and other isotopic evidence suggests that crop pests constitute a major percentage of the bats' diet. Future studies of more ancient auano deposits should reveal a measurable influence of both natural and man-induced vegetative changes with time upon the ^{13}C content of the bat guano hydrocarbons.

Zusammenfassung

Die Strukturen und der Gehald an Kohlenstoff-13 der einzelnen Alkan von Fledermauseguano in der Gegend von Carlsbad, New Mexico, sin mit der photosynthetischen Reaktionsbahn der örtlichen Pflanzen und der Nahrungsgewohnheit der Insekten, die die Fledermäuse unterstützen, verbunden. Durch isotopische Analysen des Kohlenstoffes wurde festgestellt, dass die Dreikohlenstoff- (C3) und Vierkohlenstoff- (C4) Arten den einheimischen Pflazensorten im Tal des Pecosflusses, ein sehr wichtiges Nahrungsgebiet fur die Fledermäuse von Carlsbad, zahlenmässig äquivalent sind. Während der Jahreszeit wenn die Fledermäuse im Gebiet zahlreich auftreten, besteht die Ernte hauptsächlich aus Alfalfa und Baumwolle, die beide C3 Pflanzen sind. Die Molekularkomposition der Kohlenwasserstoffe von Fledermausguano ist mit einem Ursprung von Insekten hervöllig vereinbar. Zwei isotopisch verschiedene Gruppen von verzweigten Alkanen wurden bei den Insekten erkannt. Die beiden Alkangruppen stammen von chemotaxonomisch unterscheidbaren Völkern von Insekten, die auch ganz verschiedene Nahrungsweisen haben. Es ist möglich, dass eine Gruppe hauptsächlich Kulturpflanzen befallt, während die andere Gruppe den wilden Pflanzenwuchs bevorzugt. Dieses und auch andere isotopische Beweise scheinen anzudeuten, dass Erntenplage den grössten Prozentsatz der Ernähungder Fledermause ausmacht. Künftige Untersuchungen viel älterer Guano-Ablagerungen dürften einen messbaren, zeitabhängigen Einfluss - sowohl natürlich wie auch von Menschen verursacht - auf den ^{13}C-Gehalt der Kohlenwasserstoffe von Fledermausguano ethüllen.

Introduction

Biogeochemical investigations and techniques can contribute to the delineation of the flows of carbon and other nutrients in ecosystems. Often, these details are inaccessible to other methods (e.g. direct observation, morphometric analysis). Such biogeochemical work is facilitated by the observation that herbivores reflect the carbon isotopic composition of their food source (DeNiro and Epstein, 1978). In addition, the observation that C4, CAM and C3 plants can differ significantly in their ^{13}C contents (Smith and Epstein, 1971) provides biogeochemists with a natural spectrum of ^{13}C abundances within which the different dietary preferences of herbivores may be resolved.

The present study involves the flow of carbon from plants through insects to bats in the Carlsbad region of New Mexico. A more detailed report of this sutdy has appeared elsewhere (Des Marais, et al., 1980). At the beginning of the food chain, the photosynthetic fixation of carbon sustains, among other things, a diverse and seasonally variable insect population. Various species of migratory bats feed on the insects; they then take shelter in the local caves where they leave substantial guano deposits. A limited suite of structureal and isotopic analyses of the easily sampled inputs (plant material) and outputs (guano) would appear to offer significant opportunities. First, isotopic analyses of the plants provide information regarding the phtosynthetically derived isotopic labelling of the input carbon flow. Second, investigations of the guano provide directly an appropriate time averaging of the conditions and populations involved. Finally, the resolution and analysis of individual alkanes in the guano allow characterization of details of the carbon flow far upstream from the final metabolic steps. This ability to retrace the steps of carbon flow arises because alkanes, once formed, are not likely to be modified in subsequent metabolic steps (Oro et al., 1965; Mitchell, 1972). Thus, for example, alkanes produced by the insects can pass unchanged through the bats to the guano, remaining there to provide evidence (through their structure) regarding the species of insects involved and (through their isotopic compositions) the plants eaten by the insects.

Results and Discussion

The bat guano was obtained from a cave in the Carlsbad region in Eddy County, New Mexico (Meinschein, 1963). The experimental procedures are described by Mitchell (1972) and Des Marais et al. (1980).

Carlsbad area prefer to forage for their prey principally along the Pecos River valley (Barbour and Davis, 1969), because the relatively abundant vegetation of this area supports a larger population of insects than do the adjacent uplands. Accordingly, the carbon isotopic compositions of the plant species in this valley were determined (Fig. 1). Among the 58 nonagricultural plant species, there is a bimodal ^{13}C distribution with 31 isotopically 'heavy' species (in the range -10 to -20 permil versus PDB) and 27 isotopically 'light' species (in the range -20 to -35 permil), reflecting the plant population with C3, Cr and CAM photosynthetic pathways (for a discussion, see Smith and Brown, 1973). Grasses dominate the ^{13}C-enriched plant population in this ecosystem. Of the four principal summer season crops in Eddy County, the two dominant crops, alfalfa and cotton (New Mexico Agricultural Statistics, 1977), are C3 plants. Therefore, the biomass consumed by the population of insects feeding on crops in this region is ^{13}C-depleted relative to the native plant biomass.

Concerning the bat guano, a radiocarbon analysis of a portion of the guano alkanes revealed that the guano is less than 40 years old. The normal alkane series extends from molecules with 15 carbon atoms (C_{15}) to those with 43 carbon atoms (C_{43}). The branched hydrocarbons consisted of internally branched monomethylalkanes having even numbers of carbon atoms ('even carbon numbers') from C_{26} to C_{36}, and internally branched dimethyl substituted alkanes occurring at each of the odd carbon numbers from C_{35} to C_{51}.

Most bats in the area inhabit the caves only during the spring, summer and fall seasons. The insectivorous bats Tadarida brasiliensis and Myotis velifer are dominant in the Carlsbad area. No hydrocarbon analyses have been reported for the prey of Tadarida and Myotis, but published analysis of hydrocarbons in insects indicate an appreciable structural overlap among alkanes isolated from various insect species (see Jackson and Blomquist, 1976). These distinctive insect patterns closely match those found in the guano sample. No other known natural source produces such an abundant array of high-molecular-weight branched hydrocarbons (Kolattukudy, 1976). Therefore, insects consumed by the bats produced essentially all the branched hydircarbons found in the guano.

The isotopic composition of the insect remains in the guano should reflect the isotopic compsition of the plants in the Carlsbad area which consituted the insects' diets (De Niro and Epstein, 1978). It is necessary first to evaluate any isotopic discrimination that may occur as carbon flows from the plants to the guano. The steps in this process are schematically represented in Figure 2, which in oder to establish a basis for discussion of the present results, represents the expected (not actually measured) sequence of carbon isotopic fractionations in a high simplified system involving a single plant and a single insect (see Des Marais et al., 1980, for the derivation of Fig. 2). An interpretation of the results of the present study, which involves a complicated natural system containing many species at each trophic level, can be based onthe expected fractionations outlined in Figure 2. In this case, it is necessary to begin with the observed isotopic compositions of the guano alkanes and to work backward through the carbon pathway to reach a satisfactory accomodation with the known isotopic compsitions of the plants that must have furnished the input carbon. The data indicate that these branched hydrocarbons derive from a variety of insects with a variety of dietary preferences. Given the wide variety of flying insect species available to the bats during the summer season, it is no surprise that a complex hydrocarbon pattern is observed. It is surprising, however, that a plot of numbers of branched alkanes versus their ^{13}C content (Fig. 1c) yields a pronounced bimodal distribution. This distribution must describe two insect populations that differ both in their diets and in the molecular composition of their branched hydrocarbons. The relationships between the isotopic compositions of the branched alkanes and the dietary preferences of the two insect populations are summarized in Figure 3. The heaverier branched alkanes ('branched alkanes I', $\delta^{13}C$ = 20.2 permil must relate to a net plant dietary input of -21.2 permil ('I in the 'inferred diet' column of Fig. 3). The insects responsible for the production of the lighter branched alkanes must have preferred plants with a weighted average isotopic composition of -24.7 permil ('II' in the 'inferred diet' column, Fig. 3), which is very near the avera $\delta^{13}C$ value (-26.0 permil) for the C3 plants in this locality. Calculations show that insect population I derived roughly 40 percent of its diet from C4 or CAM plants and that insect population II derives roughly only 10 percnet of its diet from those sources.

A number of explanations could be offered for the appearance of two populations of insect alkanes that differ both in their carbon isotopic contents and in their molecular compositions. First, these populatios could represent the output of two or more species of bats. One might speculate that different bat species selectively consume different species of insects, that in turn, show different preferences for C3, C4 and CAM plants. Insect species can specialize in C3 or C4 plans. However, plants apparently consume flying insects, insects of a given order without much selectivity for even the insects' genus affiliation (Ross, 1967). Another explanation for the presence of two distinct insect populations is that a single bat species grazes upon two insect groups which consume varying proportions of C3, C4 and CAM plants. This explanation leads to the clearly wrong implication that the grasses in this ecosystem play a relatively minor role in the sustenance of the native insects eaten by the bats (Des Marais et al., 1980). A third explanation for the presence of two distict insect populations is that one population consists of native insects consuming predominantly native vegetataion and that the other population consists of native species and species imported to the Carlsbad area by man, the latter two groups of species preferring the crops to the native vegetation. The crop biomass contains a substantially greater percentage of C^3 plants (over 90 percent) than does the nonagricultural plant biomass (below 50 percent). Given this contrast, the insects consuming mainly crops would be istopically lighter than the insects that select native vegetation, and these two groups can be tentatively identified with insect populations II and I in Figure 3, respectively, and the lighter and heavier peaks in Figure 1c, respectively.

One test of the hypothesis that crop cultivation has produced an isotopically distinct population of branched alkanes would be to examine guano that had been deposited prior to the advent of agriculture in the Pecos River Valley. A solitary hydrocarbon peak in a diagram such as Figure 1c, with a mean $\delta^{13}C$ value in the vicinity of the mean value for the native vegetation, would support the notion that the secon, isotopically lighter peak in Figure 1c dervies from crop pests.

Estimates of the feeding habits of bats and their populations in the southwestern U.S. indicate that these mammals consume prodigious amounts of flying insects (see Constantine, 1970). If, as proposed in the previous section, the remains of such insects produced the isotopically lighter group of branched alkanes, then these pests constitute approximately half of the bats' diet.

Acknowledgements

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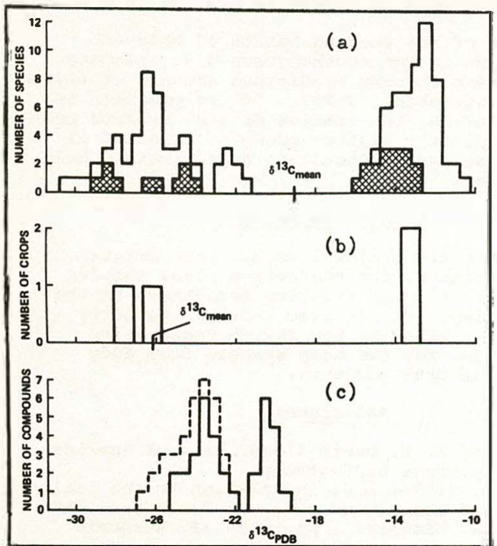

Figure 1. Plots of abundances of plant species or insect alkanes versus their ^{13}C values. Abundances were determined by grouping ^{13}C values within ± 0.5 permil of -10 permil, -10.5 permil, -11.0 permil, and so forth. It should be noted that each ^{13}C value is ounted twice in this procedure. (a) Abundances of nonagricultural plants in the Pecos River valley, New Mexico, versus their ^{13}C values. Mean ^{13}C for all plants is indicated as a vertical black bar on the horizontal values. Mean ^{13}C for all plants is indicated as a vertical black bar on the horizontal axis. Shaded portions of the histogram depict the distribution of the most abundant plants in the ecosystem. (b) Abundances of dominant agricultural plants in the Pecos River valley versus their ^{13}C values. Mean ^{13}C for 1977 biomass is indicated as a vertical black bar on the horizontal axis. (c) Abundances of guano alkanes vs their ^{13}C values. Branched alkanes are represented by the solid lines; the normal alkanes are represented by the dashed lines. $^{13}C_{PDB}$ is defined as equal to $(^{13}C/^{12}C)_{sample}$ $(^{13}C/^{12}C_{PDB}$ - 1 1000, where PDB is the Pee Dee Belemnite fossil carbonate standard.

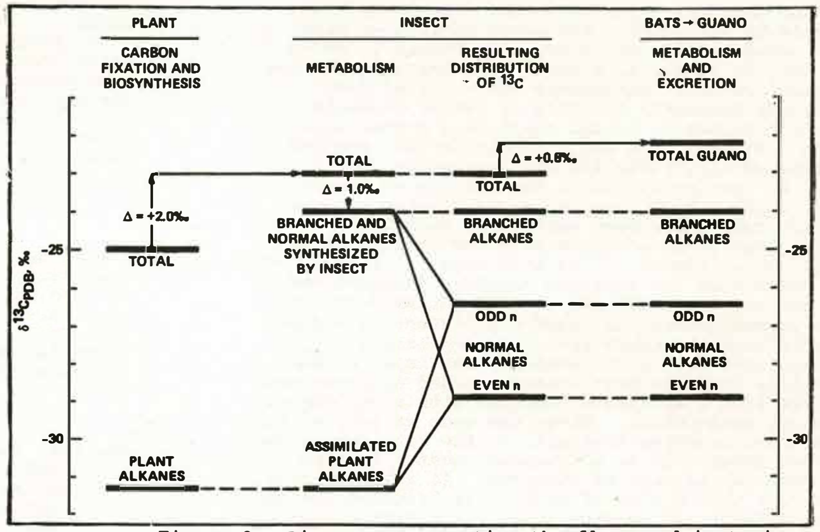

Figure 2. Diagram representing the flows and isotopic compositions of carbon in a simplified ecosystem including only one plant species and one insect species. The term 'branched alkanes' refers specifically to the branched structures made selectively by insects.

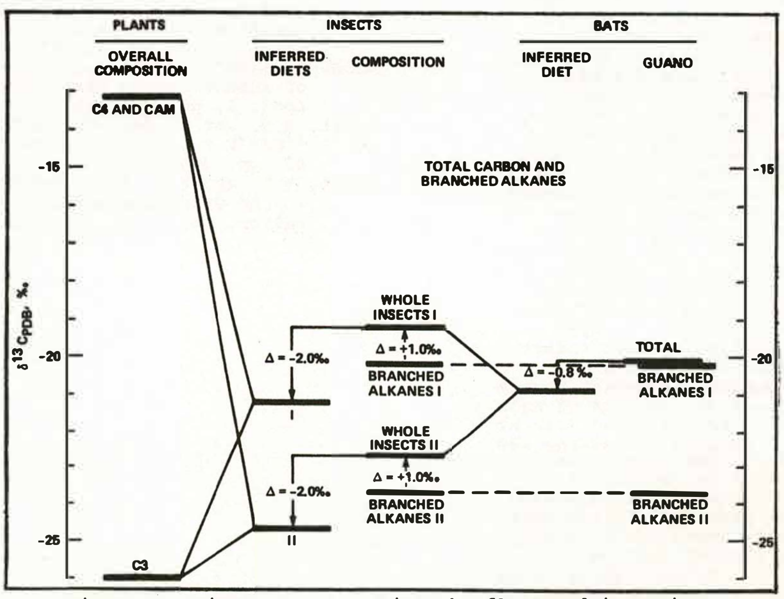

Figure 3. Diagram representing the flows and isotopic compositions of bulk carbon and of branched alkanes in the plant-insect-bat ecosystem studied here. The existence of two isotopically distinct families of branched alkanes is used to infer the existence of two isotopically distinct insect populations that must have isotopically distinct diest derived from different proportions of C3 and C4 plants.

Ecological and Biological Implications of the Existence of a "Superficial Underground Compartment"

C. Juberthei and B. Delay
Laboratoire souterrain du CNRS Moulis 09200 Saint-Girons, FRANCE

Abstract

In three countries of the European temperate zones, the Central Pyrenees, the french Alpes, the Carpates in Romania, we have found a new underground environment, that have named "milieu souterrain superficiel" or "underground superficial compartment".

One of its main features lies in the fact that it is very enlarged in non-limestone rocks, such as shales and granite; it is also present in some part of limestone countries.

It is directly situated under the last layer of the soil. It consists of cracks in the superficial part of rocks and interconnected spaces in the screes. Superficial spaces are connected with deep fissures of shale or granite whose fauna can be studied in artificial tunnels of mines, and with limestone caves. Deep cracks and caves represente the deep underground compartment. Its moisture is similar to caves. An other main feature lies in the large change in annual temperature: about 10°C.

The same species of cave beetles, Bathysciinae and Trechniae, are found in limestone caves and in this superficial compartment in shale organite. In the Pyrenees all the species of Speonomus and three species of Aphaenops have been found in this new environment. At the present the biocenose is partly known; it consist of troglobitic beetles, Diplopoda Typhloblaniulus and Collembola.

This superficial compartment extend the geographical area of many cave terrestrial Arthropods; its study will permit a more comprehensive knowledge of the underground ecosystem, and will give a more complete basis to study origin and genesis of the troglobitic terrestrial species.

Résumé

Dans trois régions de la zone tempérée européenne, les Pyrénées centrales, les Alpes françaises, les Carpates en Roumanie, nous avons trouvé un nouveau milieu souterrain, que nous avons appelé "milieu souterrain superficiel" ou "underground superficial compartment". L'une de ses principales caractéristiques réside dans le fait qu'il est très étendu dans les roches non carbonatées, telles que les schistes et les granites; il est aussi présent dans certaines zones des régions calcaires. Il est directement situé sous le dernier horizon du sol. Il consiste en fissure de la zone superficielle de dégradation de la roche-mère, et en espaces intercommunicants des éboulis de pentes. Les espaces de ce milieu sont en communication avec les fissures profondes des schistes et des granites dont la faune peut être étudiée dans les tunnels artificiels, et avec les grottes calcaires. Fissures profondes et grottes constituent le compartiment profond du limieu souterrain.

Son humidité est identique à celles des grottes. Un autre de ses traits importants réside dans l'importance des variations annuelles de la température: 10°C.

Les mêmes espèces de Coléoptères Bathysciinae and Trechinae sont récoltés dans les grottes calcaires et le milieu dans les schistes et les granites. Dans les Pyrénées ariégeoises toutes les espèces de Speonomus et trois expèces d'Aphaenops ont été trouvées dans ce nouveau milieu. Actuellement la biocénose est partiellement connue; elle est composée de Coléoptères, Diplopodes et Collemboles troglobies.

Ce compartiment superficiel étend la répartition géographique de beaucoup d'Arthropodes terrestres connues des grottes. Son étude devrait aboutir à une connaissance exhaustive de l'écosystème souterrain, et permettre de poser sur des bases exactes, l'étude de l'origine et de la genèse des espèces troglobies terrestres.

In three countries of the european temperate zone we have found a new underground environment that we have named "superficial underground compartment". We have first discovered it in the french Pyrenees (Juberthie et al., 1980) then in the french Alps and also in carpathian. Mountains in Romania, in the latter with the collaboration of V. Decu and G. Racovitza.

Methods

In this environment the samplings of beetles and other Arthropods were performed with two methods (Fig. 1).

First glass round-shaped traps, 6 cm in diameter and 8 to 10 cm in height were used. The bottom of the container was filled with water and salt (NaCl) to preserve the animals which fell down and died. Old odoriferous cheese was put on a support in the trap and on the rim of this one, beetles and other terrestrial Arthropods were attracted.

Secondly, old cheese or marine shrimps were put on several small stones directly; this method allowed to catch alive animals.

Traps and stones with attractive products were placed into the bottom of a hole, burrowed in screes or in cracks of the superficial part of the rock covered with soil. The holes, 40 to 90 cm deep, were filled above the trap with small stones taken from the superficial underground compartment; the holes were plugged up with earth, that is important to prevent the draughts. The Arthropods were collected one to four weeks later. These methods are very efficient for beetles and Diplopoda.

Situation, Structure and Characteristics of the Superficial Underground Compartment (S. U. C.)

One of the main features of the superficial underground environment lies in the fact that it is very spread in non-limestone rocks, such as shales; it is also present in granite and in some region of limestone countries. It is directly situated (Fig. 2) under the last layer of the soil in mountains and hills. It consists of cracks and fissures in the superficial part of the rock, and interconnected spaces in the screes. These empty spaces or cracks are 1 mm to several cm wide.

In the shale countries in Pyrenees, under the soil forest with a compact B layer, the S. U. C. lies on large spreads where screes and rocks with many are present. In this situation, the screes and correlately the S. U. C., represent a new layer between the last soil layer, commonly the B layer, and the rock, that we have numbered C1 (Fig. 3).

In the limestone area the S. U. C. is commonly represented by screes on the mountain sides and at the bottom of the hills.

The empty spaces of the S. U. C. are connected with deep fissures in shales, granite or limestone, the fauna of which can be studied in artificial tunnels of mines and in limestone caves. The caves and deep cracks represent the deep underground compartment.

The most conclusive example (Fig. 4) of connections between the S. U. C. and a limestone cave is given by the Laboratory cave system of Moulis. In this case the S. U. C. lies near the entrance of the cave, and it consists of a scree, on the mountain side, covered with trees and a soil 60 cm deep. Under this latter appears a moisted layer made of small dolomitic stones covered with "monmilch", with empty spaces between them. In these spaces we have collected four Bathysciinae species, inhabiting the cave of Moulis. Two out of four, Speonomus hydrophilus and Troglodromus bucheti represent imported species in the laboratory cave, some twenty years ago; these species, escaped from the rearings, have colonized the cave (Christiansen, 1970) and the S. U. C. This settling experimentally demonstrates that the cave is connected with the S. U. C. which appears to be like a part of the underground system.

Some climatic characteristics of the S. U. C. are very similar to caves: its moisture is always high and the small stones which demarcate the spaces are usually covered with moisted clay (except in one station where Aphaenops have been found). An other characteristic parameter is however different: it is the large range of annual temperature variations which is about 10 to 20 ° C in Pyrenees, between 400 and 1000 m in altitude.

Fauna in the S. U. C.

In Pyrenees the same species of cave beetles, Bathysciinae and Trechinae, and Diplopoda were found in limestone caves and in the superficial compartment.

The figure 5 summarizes the data on Speonomus hydrophilus, a troglobitic Bathysciinae with a contracted life-cycle. It clearly demonstrates the importance of the S. U. C. in the distribution of this species; at the present its area is twice larger than the original distribution in limesonte caves. In Pyrenees, 11 troglobitic cave species of Bathysciinae (Speonomus abeilli, carrerei, delarouzeei, diecki, hydrophilus, longicornis, monticola, pyrenaeus, stygius, sophosinus, Troglophyes aubryi), two species of Trechinae (Aphaenops), and two species of Diplopoda (Typhloblaniulus lorifer, T. mayeti) some species of Collembola have been found also in the S. U. C. In contrast, very few new species have been collected in the superficial compartment: one Aphaenops sp. and presumably one Troglophyes sp. In the french Alps (Vercors) a cave beetle species, Royarella tarissani has been collected.

In Romania three types of species have been found in the S. U. C.:

- troglobitic species (Isopoda, Araneida, Coleoptera) numerous in the caves and collected in the S. U. C. either in great number, or only in a few exemplars,
- troglophilic species very numerous in the S. U. C. (Isoposa, Diplopoda, Coleoptera) or scarce (Opilionida, Pseudoscorpionida and some Coleoptera),
- rare species in the caves and in the soil, on the contrary very abundant in the S. U. C. which may represent their true habitat.

Conclusions

The superficial underground compartment is well represented under the soil in orogenic countries of the european temperate zone, specially in non-limestone areas. These data represent a new stage in the knowledge of the terrestrial underground habitat. The existence of the S. U. C. enlarges the geographical areas of the most cave terrestrial species, so that the insulated distributions of species in limestone countries, of island type, is presumably not always right. Indeed the areas of two cave species, may come in contact or almost in contact in shale or granitic parts which lie between the limestones.

Nowaday, we must consider that the underground habitat consists of two compartments:

- a superficial compartment
- a deep compartment made of cracks and fissures with caves in limestone and get at able by mean of artificial tunnels in the other rocks.

The S. U. C. is clearly distinct from the deep soil habitat; it differs by its structure and porosity. The last soil layer (the B layer) is characterized by a low porosity related to the small size of the spaces; it is an interstitial habitat. In contrast, the S. U. C. possesses larger empty spaces, fissures or interconnected spaces between the stones. In the first the edaphic fauna inhabits; it is composed of a majority of small, narrow, short-legged, blind species. In the second, a troglobitic fauna inhabits. Generally the boundary between the two habitats is clean and it is easy to see that the transition is only a few centimeters thick. Sometimes there is not a definite boundary and the B or A soil layers are locally mixed with the screes (C1) and so their fauna do.

In the S. U. C. 3 types of species have been collected troglobitic species, rare species and a few number of new species.

The troglobitic species, well known in the limestone caves, such as Speonomus hydrophilus have the same representation in the S. U. C.

The rare species, previously known by one or a few animals in caves, such as Sp. zophosinus, are much better represented in the S. U. C.

The range of annual thermic variations is higher in S. U. C. than in caves, so that it is sufficient to induce seasonal rythms in the reproductive cycle of beetles according to the observations of L. Juberthie-Jupeau reported in this Congress. These data suggest that troglobitic Bathysciinae of the genus Speonomus are not restricted in an habitat with constant temperature by contrast to the classical concept.

The underground habitat and ecosystem cannot be limited henceforth to the karstic system.

A difference probably persists between the amount of passive and active food transport according to the compartment examined; in the limestone deep compartment the passive transport by water prevails, while in the S. U. C. soil and underground fauna are in contact, so that active transport presumably plays an important part.

The present available data suggest that the colonization of the underground environment has proceeded not only in limestone areas, but still in all the countries where the hypogeous fauna was able to use empty spaces in screes under the soil or cracks of the rocks. The S. U. C. appears to be as a way for the species "en route" to the caves, but also presumably as a stage for the species which stopped or are stopping in in (Juberthie, Delay, Decou, Racovitza, in press).

To conclude the terrestrial underground habitat is independent from the geological nature of the rock; it is characterized by:

- interconnected spaces, cracks or fissures wider than about a mm, larger in caves, - a relative air humidity very hight, - a low or middle range of annual temperature variations without extreme temperatures, - a constant darkness and a lack of photoperiod, - alimentary chains based on detritivorous animals, - biocenosis compound of few number of species, - and a primary productivity originating from other ecosystems situated on the earth surface.
- the data of this work on superficial underground compartment lead to a more comprehensive knowledge of the underground system and will give a better base to study the origin and the genesis of troglobitic terrestrial species.

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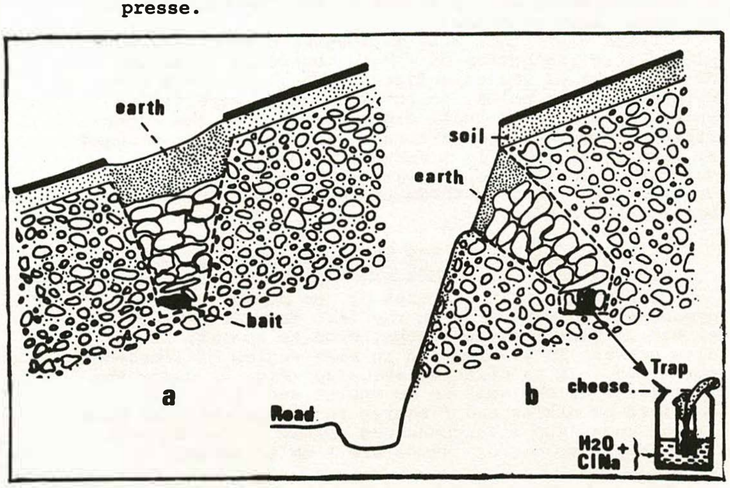

Figure 1. Shetchs showing the methods used to collect terrestrial troglobitic Arthropoda under the soil, in the superficial underground compartment.

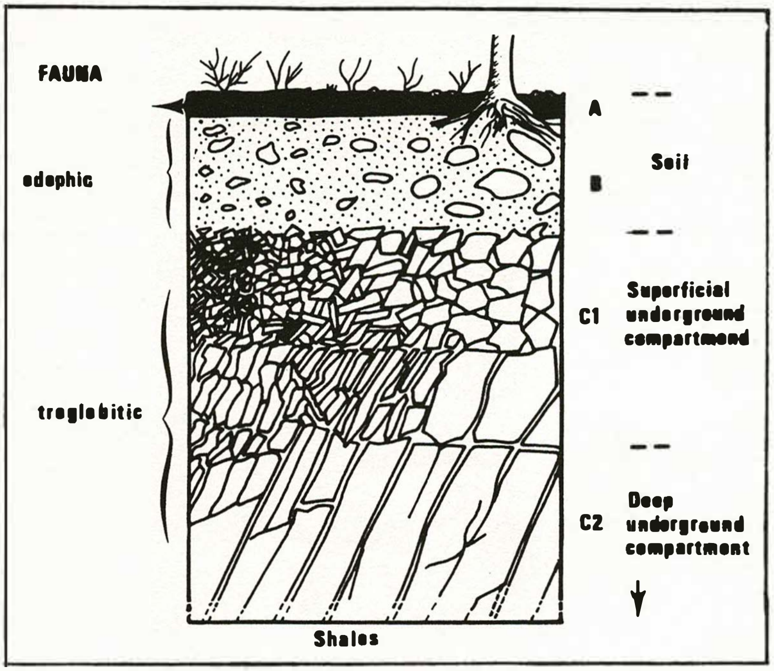

Figure 2. Shetch of the situation and the structure of the superficial underground compartment in shales, and its connections with cracks and fissures of the rocks. Different sizes of the stones have been represented.

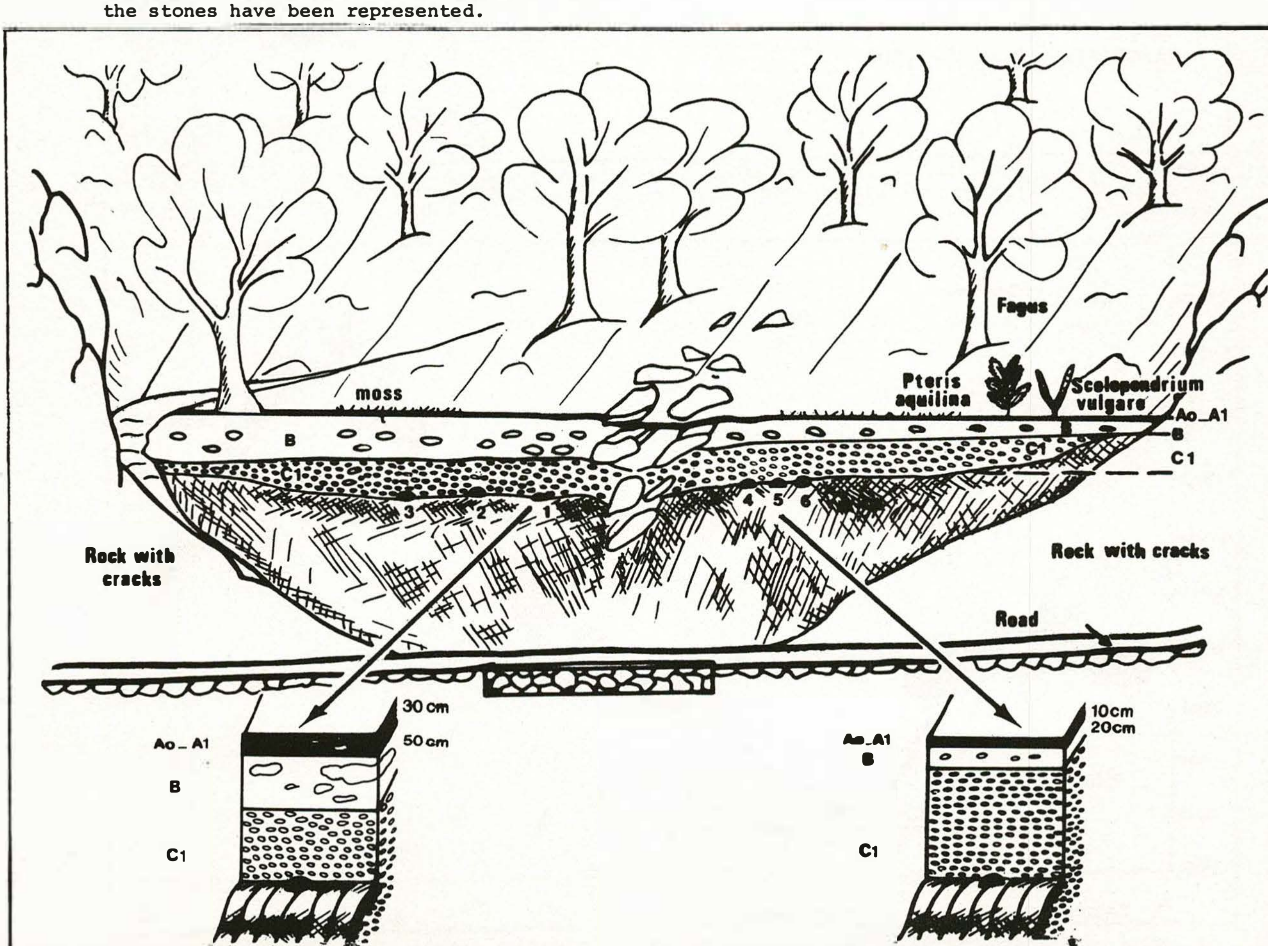

Figure 3. Shetch of a scree under a forest soil in a valley, W exposed in Pyrenees, 710 m in altitude (S 7, Les Embaousses). In the superficial underground compartment, the troglobitic beetle Speonomus hydrophilus were found.

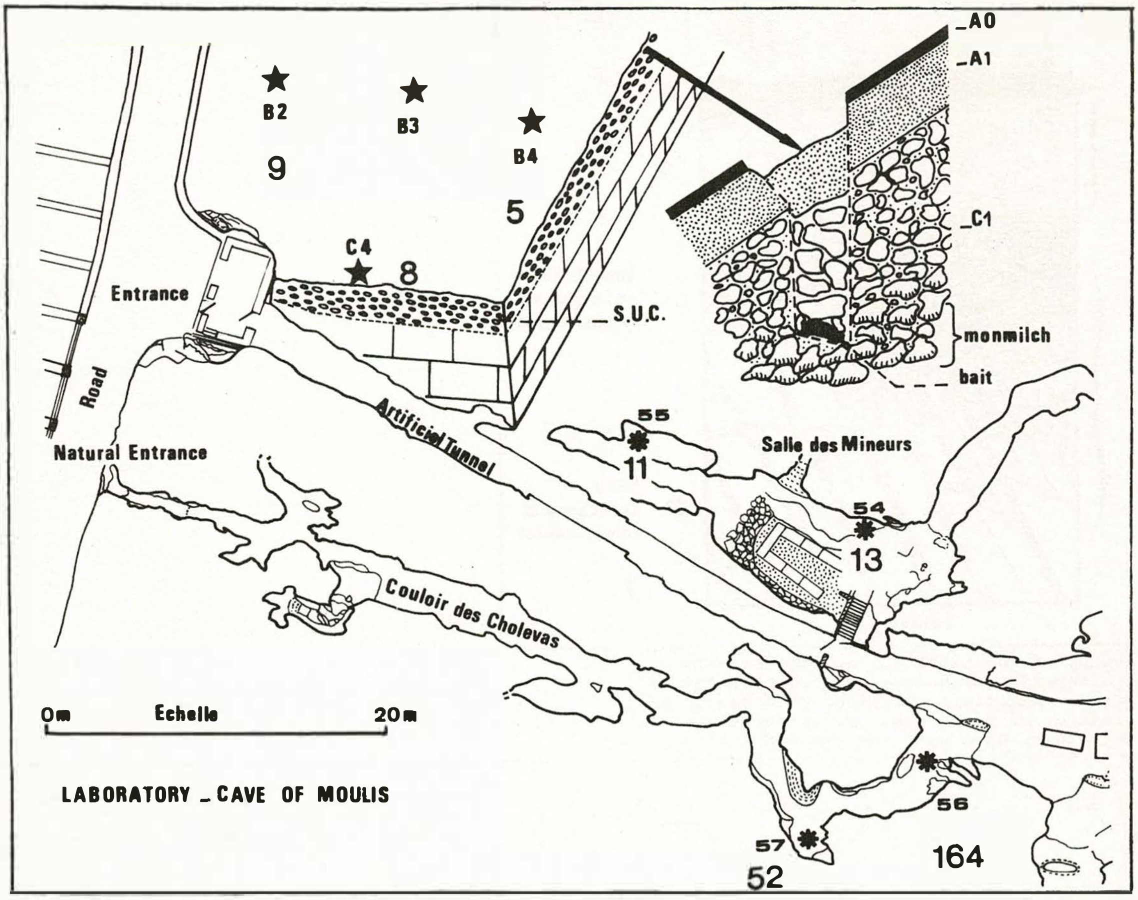

Figure 4. Shetch of the distribution of the troglobite Bathysciinae Speonomus hydrophilus in different underground environments: limestone with its caves and mines; shales with stations of superficial underground compartment.

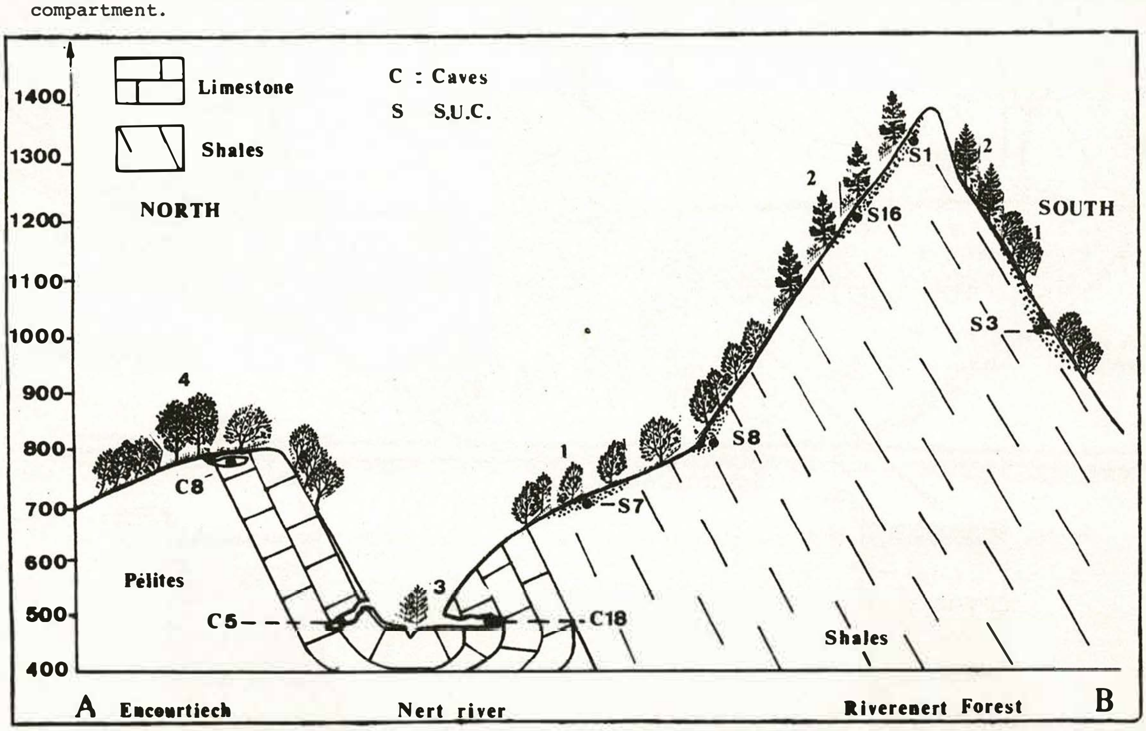

Figure 5. Situation of the superficial underground compartment (limestone scree) connected to the cave system of the laboratory cave of Moulis, near the entrance, under the soil of the mountain side. The same troglobitic beetles inhabite the S. U. C. and the cave. The stations are noted with a small size number in the cave and with B_2, B_3, B_4, C_4 in the S. U. C., the number of Sp. hydrophilus are noted with collected the 20 of June 1980 a large size number.

The Effect of Competition on Species Composition of Some Cave Communities

David C. Culver
Department of Ecology and Evolutionary Biology, Northwestern University, Evanston, Illinois, U.S.A. 60201

Abstract

Competition coefficients for a community of one amphipod (Crangonyx antennatus) and two isopods (Caecidotea recurvatus and Lirceus usdagalun) were calculated from laboratory of their interactions. Using these data it was possible to predict (1) sub-communities of one or two species resistant to invasion by other species, and (2) unstable species pairs that should not exist in nature. Analysis of successful invasions, failed invasions, and species composition in seven cave streams in Lee County, Virginia, indicated complete agreement of field data with the predictions.

Résumé

Les coefficients de compétition pour une communanté d'un amphipode (Crangonyx antennatus) et de deux isopodes (Caecidotea recurvatus et Lirceus usdagalun) ont été calculés d'après l'étude en laboratoire de leurs interactions. En utilisant ces résultats, il a été possible de prédire (1) des communantés d'une ou deux espèces résistantes à l'invasion par d'autres espèces et (2) des paires instaples qui ne devraient pas exister dans la nature. L'analyse des invasions qui ont réussi, des invasions qui ont raté et de la composition des espèces dans sept grottes dan Lee County, Virginie, indique une concordance complète des résultats expérimentaux avec les prédictions.

Introduction

It is the purpose of this paper to examine the extent to which competition sets constraints on community structure, constraints in the form of a set of rules about which combinations of species can co-occur and what species can successfully invade a particular community. The basis for these constraints is that the stable co-existence of N interacting species does not mean that every subset of this community with N-1 species can also stably coexist.

The best known examples of this come from predator-prey systems in the marine intertidal studied by Robert Paine and his students. Paine showed that the removal of the starfish Pisaster from rocky intertidal communities caused a reduction by half or more in the number of prey species present, as a result of intense competition among the prey species. Predation by Pisaster prevented the complete exclusion of weak competitors. Clearly the sub-community with Pisaster absent was unstable and rapidly reduced to one with a smaller number of species that was stable.

This phenomenon can also occur in purely competitive communities. Consider three competing species, A, B, and C. Species A affects species B in two very different ways. First, there is a direct negative effect on species B; and second, there is an indirect positive effect on species B because species A reduces the population size of species C, thus reducing its negative effect on species B. It is possible to have the situation where species A drives species B to extinction when species C is absent, but when species C is present the indirect effects are strong enough to allow the stable co-existence of the three species together. This example in fact corresponds to the cave stream organisms analyzed in the remainder of the paper.

It may come as a surprise to some that the standard Lotka-Volterra competition equations are sufficient to describe the above phenomenon. In particular, the following equations provide a sufficient theoretical basis:

$$\frac{dN_1}{dt} = \frac{r_1N_1}{K_1}(K_1-N_1-\alpha_{12}N_2-\alpha_{13}N_3) \qquad (1a)$$

$$\frac{dN_2}{dt} = \frac{r_2N_2}{nK_2}(K_2-\alpha_{21}N_1-N_2-\alpha_{23}N_3) \qquad (1b)$$

$$\frac{dN_3}{dt} = \frac{r_3N_3}{K_3}(K_3-\alpha_{31}N_1-\alpha_{32}N_2-N_3) \qquad (1c)$$

where N_i is the population size of species i, r_i the intrinsic rate of increase of species i, K_i the carrying capacity of species i, and α_{ij} the effect of an individual of species j on an individual of species i. The change from competition between 2 species to competition between more than two species results in a shift from a planar representation of the dynamics to a representation in a volume of hypervolume. This shift creates a quantum increase in possible dynamics.

Using the above equations, allowable and non-allowable communities and sub-communities will be predicted. For our purposes an allowable community (or sub-community) has two characteristics. First, the equilibrium population sizes of all species must be positive. Second, the equilibrium must be stable in the sense that after a small displacement from equilibrium, population sizes return to the equilibrium. The mathematical details of these criteria are not especially illuminating by themselves and are not repeated here. Interested readers can consult Strobeck (1973) for details.

Allowable and non-allowable invasions can also be predicted. An invasion by species i into a subcommunity of species j and species k if

$$\frac{dN_i}{dt} = \frac{r_iN_i}{K_i}(K_i-\alpha_{ij}\hat{N}_j-\alpha_{ik}\hat{N}_k)>0 \qquad (2)$$

where $\hat{N}_j$ and $\hat{N}_k$ are the equilibrium population sizes of species i and j in the absence of species K. In words, species K can invade if it can increase when rare.

Methods and Materials

In the central part of the Powell River Valley in Lee County, Virginia, various combinations of the isopods Caecidotea recurvatus and Lirceus usdagalun, and the amphipod Crangonyx antennatus, comprise the macroscopic fauna of gravel bottom cave streams. As described previously (Culver, 1973, 1976), all of the species prefer the underside of gravels in shallows (riffles) and compete for these hiding places to avoid the brunt of the current. Since the result of competition in this system is the washing out of individuals from a riffle, it is possible to measure both competition coefficients and carrying capacities in an artificial stream in the laboratory. To a first approximation

$$\alpha_{ij} \approx \frac{e_{ij}}{e_{ii}}$$

$$K_i \approx \frac{a}{e_{ii}}$$

where e_{ij} is the effect of an individual of species j on the washout rate of an individual of species i, and a is a constant.

To have a fair test of the effect of competition on species composition, all caves considered must be within the range of all three species. The limiting factor is the small range of Lirceus usdagalun (Holsinger and Bowman, 1973). To minimize faunal differences due to historical reasons rather than competitive reasons, only cave streams within 1 km of a known locality of L. usdagalun.

Several invasions were noted by repeated visits to the same cave stream. An invasion was considered successful if the number of invaders increased.

Results

The competition coefficients (α_{ij}'s) were calculated as follows:

Crangonyx antennatus	1.00	0.99	1.32	=	1 α_{12} α_{13}
Caecidotea recurvata	0.32	1.00	1.29		α_{21} 1 α_{23}
Lirceus usdagalun	1.16	0.49	1.00		α_{31} α_{32} 1

and the carrying capacities (K_i's) are

$K_1 = 1.4K$ $K_3 = K$

$K_2 = 1.3K$

where K is an unknown constant. From these values, allowable and non-allowable species combinations can be predicted. Obviously, each species living by itself should be stable. The 2- and 3- species combinations are shown in Figure 1. As indicated in the figure, there are two allowable combinations: all three species together, and C. recurvata and C. antennatus. Table 1 summarizes the observed species combinations. Due to the small number of caves within the range of L. usdagalun, the results are only marginally significant, but no caves had "forbidden" communities. Especially impressive is the distribution pattern of species in Thompson-Cedar Cave (Fig. 2). In the three physically distinct sections of the cave stream, all three species occur in the downstream section, C. recurvatus and C. antennatus occur in the upstream section, and L. usdagalun occurs alone in the middle section. No non-allowed combinations occur even with the species in very close proximity.

One successful invasion has been reported. Estes (1978) followed the results of an invasion by L. usdagalun into the C. antennatus - C. recurvata community in Gallohan Cave No. 2. Substituting values into equation (2) indicates this should be a successful invasion. From the distribution pattern of amphipods and isopods in Thompson - Cedar Cave, it is likely that both C. antennatus and C. recurvata have invaded the section of the stream with only L. usdagalun, albeit unsuccessfully. For both these species, equation (2) indicates invasion is possible, but the rate of increase of the invader is very close to zero. Small changes in carrying capacities would cause the rate of increase to be negative, which is apparently the case in the cave streams.

Acknowledgments

Dr. John R. Holsinger accompanied me on many field trips to the area, and provided much useful advice.

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Table 1. Observed communities and sub-communities of Caecidotea recurvatus (Cr), Crangonyx antennatus (Ca), and Lirceus usdagalun (Lu) in cave streams within the geographic range of all three. Expected numbers were generated by assuming species were distributed at random.

Stable Combinations			Unstable Combinations		
Species	Observed	Expected	Species	Observed	Expected
None	0	0.16	Lu-Cr	0	1.02
Lu	2	0.41	Lu-Ca	0	1.02
Cr	0	0.41			
Ca	0	0.41			
Cr-Ca	2	1.02			
Cr-Ca-Lu	3	2.55			
$\chi_1^2 = 2.80$, $P > 0.90$					

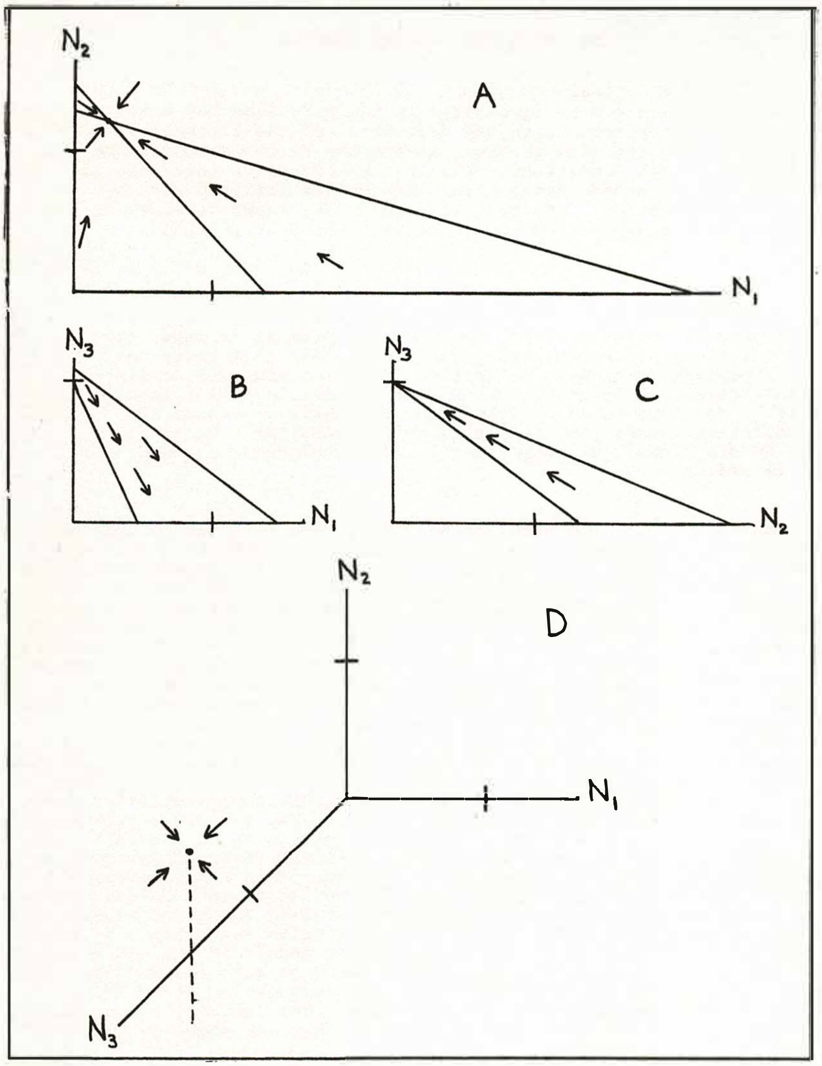

Figure 1. Predicted results of competition. A. C. recurvata and C. antennatus; B. C. antennatus and L. usdagalun; C. C. recurvata and L. usdagalun; D. all three species.

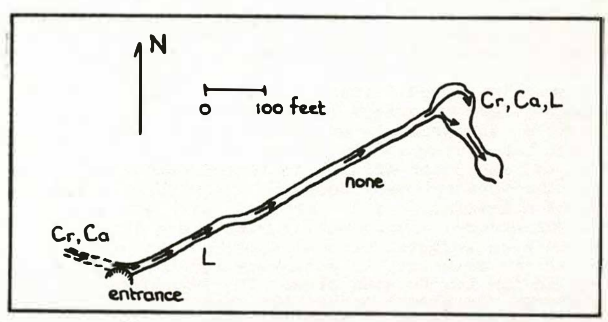

Figure 2. Distribution of species in Thompson Cedar Cave. Map is from Holsinger (1975). Ca = Crangonyx antennatus, Cr = Caecidotea recurvata, Lu = Lirceus usdagalun.

The Pre-Quaternary Palaeokarst of the Morecambe Bay Area, Northwest England

Stephen J. Gale
University College of Wales, Aberystwyth, Dyfed SY23 3DB, United Kingdom

Abstract

At least three phases of pre-Quaternary karstification can be recognised in the Morecambe Bay area. The earliest, intra-Carboniferous, phase was pene-contemporaneous with the deposition of the limestone. It is characterised by intermittent karst surfaces within the rock record. During the Permo-Carboniferous, a now-buried karst landscape developed under tropical humid conditions. Finally, an extensive interstratal karst developed at some stage after the Triassic. Caves formed during this phase became infilled both by the collapse of overlying beds and by haematite mineralisation. The resultant features, known as sops, have been cautiously assigned to the Oligo-Miocene on the grounds of their relations with structural features of the area.

Résumé

Dans la région de Morecambe Bay, on peut distinguer au moins trois périodes de karstification pré-quaternaire. La première periode, qui eut lieu pendant le Carbonifère, se produisit pendant la déposition du calcaire et se caractérise par des surfaces karstiques intermittents qu'on trouve dans l'histoire des couches. Puis, pendant le Permo-Carbonifère, un paysage maintenant enterré se développa sous des conditions d'humidité tropicale. Enfin, un karst interstratal d'étendue considérable se développa plus tard, agrès le Trias. Les cavités formées pendant cette dernière phase se remplirent de débris provenant de l'effondrement des couches supérieures et de matériaux formés par la minéralisation hématite. On avance l'hypothèse suivante: ces cavités, qu'on appelle des "sops", se rapportent à l'Oligo-Miocène, à cause de leur relation avec les formes structurales de la région.

The Morecambe Bay karst consists of an almost continuous belt of Lower Carboniferous Limestone fringing the southern edge of the Lake District in northwest England (Fig. 1). At least three phases of pre-Quaternary karstification can be recognised in the area. The earliest, Lower Carboniferous, phase is indicated by the presence of palaeokarst surfaces within the rock record. The surfaces are of Chadian-Arundian age (Nicholas, 1968) and Arundian age (Gale, 1981), suggesting a relative fall in sea level and exposure of the limestone to subaerial processes during these times.

At the end of the Carboniferous, the area was subjected to the increasingly violent tectonic effects of the Hercynian Orogeny. This seems to have initiated a phase of considerable erosion, as evidenced by the almost total absence of Upper Carboniferous beds in the area. Consequently, the succeeding Permo-Triassic deposits were laid down both in Low Furness and probably elsewhere in the area on an eroded Carboniferous surface (Binne, 1847; Dunham and Rose, 1949; Rose and Dunham, 1977).

During the Permo-Carboniferous transition, the environment of Britain changed from the tropical conditions of the Westphalian to the hot, dry conditions of the Permian. At this time the area would have been adjoined to the north, south and southeast by topographically higher, impermeable beds; whilst borehole records (Institute of Geological Sciences) show that within the area the higher ground would have been capped by relatively impermeable Namurian Sandstone. Thus, at least during the early part of the period, both climatic and hydrological conditions were favourable for karstification of the eroded Carboniferous surface.

Unfortunately, little evidence of such a phase of karstification exists in the Morecambe Bay area. Remnants of the pre-Permian surface survive only where they have remained buried by Permo-Triassic beds. In a few areas, the buried pre-Permian surface has been unaffected by subsequent fault movements and may give an indication of the Permo-Carboniferous landscape. One such area is around Sandscale (Fig. 2) where the eroded Carboniferous surface has a relative relief of at least 80 m, and probably even more once allowance is made for the southwesterly dip of the rock.

With the exception of unconsolidated Quaternary deposits, the youngest beds found in the Morecambe Bay area are of mid-Triassic age. Between this time and the Late Quaternary, environmental conditions in the area can only be inferred with difficulty. At some stage after the Triassic, an extensive karst landscape developed in the Low Furness area. The remnants of this landscape are almost invariably associated with deposits of haematite which have infolled solutionally-eroded features in the Lower Carboniferous Limestone, known locally as sops. The sops are basin-like forms containing a sedimentary sequence of basal limestone breccia, a thin layer of bright red clay, and the ore, which often includes a central core of Permo-Triassic Sandstone blocks (Dunham and Rose, 1940; Rose and Dunham, 1977; Smith, 1924). Where they remain buried, sops and other haematite deposits, both in the Morecambe Bay area and in west Cumbria, are restricted to areas where permeable beds rest directly on the limestone (Trotter et al., 1937; Dunham and Rose, 1949, 1949), suggesting that the ore was deposited from downward-moving mineralising fluids.

The stratigraphy of the sop fill can be best explained in terms of the model proposed by Dunham and Rose (1949) whereby karstic voids are mineralised prior to the formation of the limestone basal breccia. The subsequent brecciation of the limestone may have been either of the concentration of groundwater flow through the ore body or of effluent mineralising waters, though neither process is made explicit. Finally, as a consequence of this brecciation, collapse let down the haematite and provided a void for the ultimate collapse of the overlying Permo-Triassic Sandstone.

From a study of fluid inclusions within the ores, it is clear that the mineralising waters must have been hot, hypersaline fluids (Rose and Dunham, 1977). On geochemical and geophysical grounds, Shephard (1974) and Brown et al. (1980) considered the mineralisation to be the result of hydrothermal convection of mineralising fluids from the granitic basement rocks of the region. Rose and Dunham (1977), on the other hand, favoured a mechanism whereby hypersaline fluids were driven up-dip along the permeable Permo-Triassic Sandstone beds from a heat source in the northeast Irish Sea basin. It may be possible to reconcile the two models if the hot mineralising waters can be considered to have leached iron from the Permo-Triassic beds and redeposited it by downward movement into the limestone. The convective heat source might have been the same as that envisaged by Rose and Dunham.

The hydrological conditions under which interstratal karsts develop are little known. Even presuming the sops to have been formed by the solutional action of hot mineralising waters, a low-level hydrological outlet must have existed within the limestone. Without that, groundwater movement would have been slow, waters would have become rapidly saturated and karstification would not have occurred on the same scale. That an outflow level did exist at considerable depth is supported by the vertical range of mineralisation. Most of the ore bodies either terminate, or show conclusive signs of so doing, at around -180 m O.D., even where structural and lithological controls appear favourable to further development (Rose and Dunham, 1977). An outflow level at a depth of perhapds -200 m O.D. implies a considerable relief during the period of sop formation. It also suggests the existence of a relatively low sea level, perhaps associated with contemporaneous tectonic uplift.

It is likely that the phases of sop mineralisation and karstification were roughly contemporaneous; or at least that mineralisation re-initiated karstic development. The mineralisation post-dates the period of post-Triassic faulting. Furthermore, the infilling of the sops must have pre-dated the removal of the Permo-Triassic cover from the area. In central and northern England, a mid-Tertiary age is usually assigned to faults that can be shown to displace Mesozoic strata. This coincides approximately with the culmination of Alpine tectonic activity in Miocene times. However, the possibility of earlier fracturing must not be ignored, for there is a continuous history of pulsed tectonism in northern England from Hercynian times to the present day.

It does not appear unreasonable to suggest that the karstification which initiated the sops was the result of this tectonic activity. Fracturing could have provided fissures for groundwater movement, uplift could have resulted in greater hydraulic gradients, and increased denudation could have enabled the circulation of meteoric waters through the limestone. Furthermore, tectonic pressures could have driven ferriferous formation waters up-dip from the Irish Sea to the Morecambe Bay area, as proposed by Rose and Dunham's (1977) model. Thus, if a provisional Oligocene-Miocene age is accepted for the faulting, along with a similar age for sop formation, a Late Palaeogene-Early Neogene data can be cautiously assigned to the Morecambe Bay interstratal karst.

A further phase of karstification may be indicated by deposits found in Grizedale Wood Drainage Level, Silverdale (SD 48257409). A natural karst cavity in the level is infilled by unlithified, laminated, red and grey silty beds. Analysis of the clay content of the beds by X-ray diffraction showed both the red and grey materials to be almost exclusively composed of quartz. The only local source of quartz in isolation from other minerals is the Permo-Triassic Sandstone. This directly overlies the Lower Carboniferous Limestone in Low Furness and it is reasonable to assume that this was once also the case throughout most of the rest of the area.

Assuming, therefore, a Permo-Triassic source for the deposits, it is difficult to establish a date for their deposition, and hence a minimum date for the karst feature which they infill. However, samples of the deposits subjected to palaeomagnetic analysis suggest that it was laid down during a period of reversed polarity (Fig. 3). For most of the last 0.69 m.y. the earth's magnetic field has been normal, although there is evidence of a small number of polarity excursions lasting perhaps 10^2 to 10^3 years. The oldest of these, the Blake, occurred ∿ 0.11 m.y. ago, i.e. during the last interglacial in Britain. If Permo-Triassic beds had still capped the limestone of the Silverdale area at that time, then Permo-Triassic erratics would have certainly been found in the till of the last glaciation in the area. Since they are not, the age of the deposits in Grizedale Wood Drainage Level may be reasonably assumed to be >0.69 m.y.

Thus, at least three phases of pre-Quaternary karstification may be recognised in the Morecambe Bay area: intra-Carboniferous, Permo-Carboniferous and ? Oligo-Miocene. A further phase of at least Middle Pleistocene age may also be recognised but no more accurate estimation of the age of this phase may be made at present.

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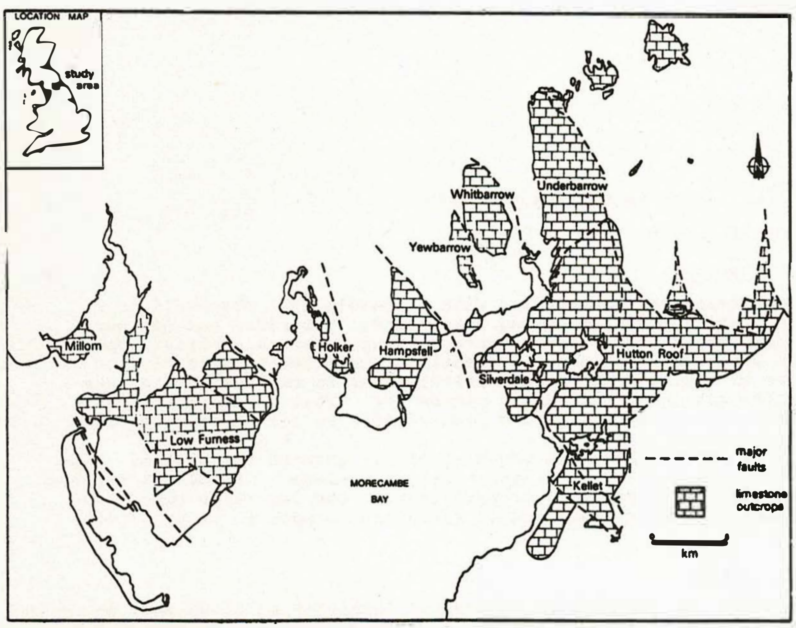

Figure 1. The Morecambe Bay karst.

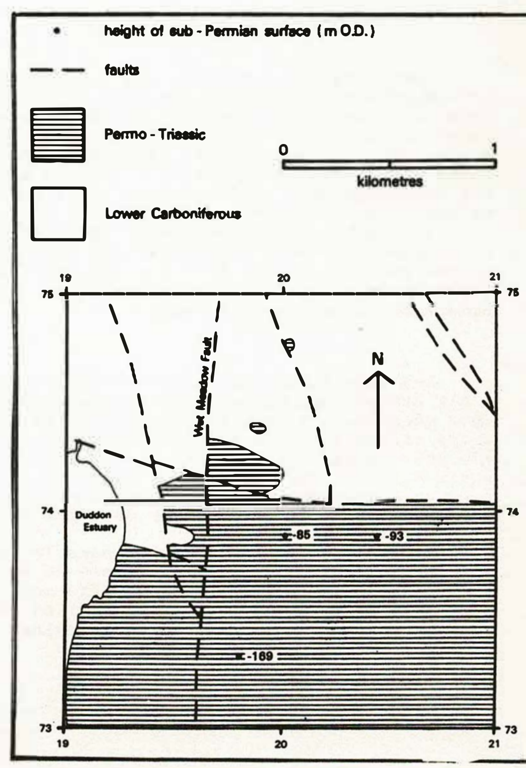

Figure 2. The sub-Permian surface in Low Furness.

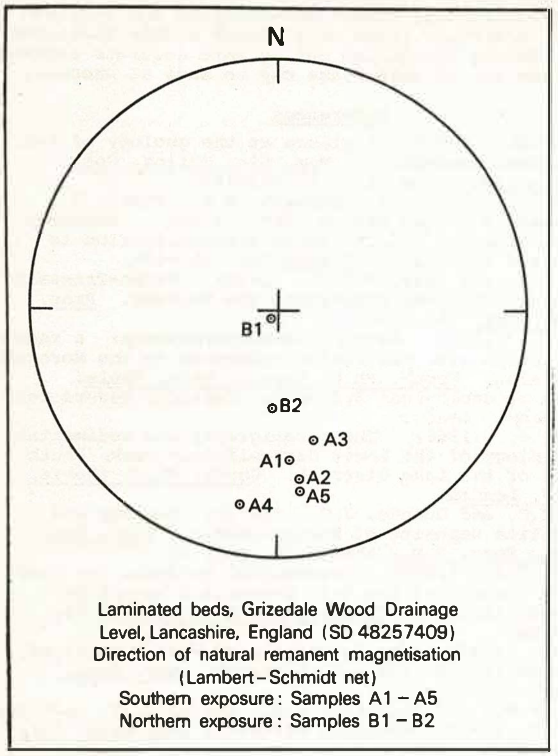

Figure 3. The direction of natural remanent magnetisation: laminated beds, Grizedale Wood Drainage Level, Lancashire, England.

Radon Sources and Distribution in Castleguard Cave

P. L. Smart

Abstract

Concentrations of radom gas in air were determined in conjunction with meteorological observations of air temperature, humidity and wind velocity in Castleguard Cave during April 1980. Two radon methods were used; firstly alpha particle activities were determined after air filtration using a portable battery operated scintillation counter (EDA RDA 200 Radon Detector). Secondly a plastic track detector sensitive to alpha radiation (CR-39) was exposed in the cave air using Whatman GF/A filter paper to exclude particulate radon daughters. After etching the track density was measured under a microscope. This novel method has the advantage that it integrates radon variations caused by short term fluctuations in air which occur in response to the diurnal variations of surface temperature.

The radon concentrations in the cave are low due to the rapid movement of air through the system. Concentrations increases progressively downwind, but are highest in stagnant branch passages. Little difference in the emmanation rate from wet and dry zones could be determined, probably due to the low radon concentrations in drip waters entering the cave. The main source of radon gas is therefore thought to be by direct emmanation from the wall rock.

Résumé

Les concentrations du Radon (^{222}Rn) dans l'air, la temperature de l'air, l'humidité et la vitesse de l'air étaient determinés dans Castleguard Cave pendant le mois de Avril 1980. Le radon était determiné par deux méthodes: L'activité des particles alpha était determiné avec un compteur de scintillation en piles, aprés filtration (EDA RDA 200 Radon Detector). En outre, un détecteur de la traj ctoire plastique, sensible pour la radiation alpha (CR-39) était exposé dans la grotte derriére un papier filtre Whatman GF/A pour exclure les filles du radon en particules. Aprés la gravure, la densité des trajectoires était déterminée avec un microscope. Cette nouvelle méthod a l'avantage d'integer les variations du radon provoqués par les fluctuations de la circulation de l'air dans le systéme souterrain en response de variations de la température sur terre.

Les Concentrations du radon dans la grotte sont basses par rapport à la vitesse de la circulation d'air. Les concentrations augment à travers le systéme, mes elles sont le plus hautes dans les passages sécoundaires sans circulation d'air. Peu de différence était déterminé dans l'émanation des zones sêches et humides, peut être parce que l'eau d'infiltration contiens peu du radon. La source majeure du radon est l'émmanation directe des murs des passages souterrains.

The Palaeohydraulics of Karst Dainage Systems: Fluvial Cave-Sediment Studies

Stephen J. Gale
University College of Wales, Aberystwyth, Dyfed SY23 3DB, United Kingdom

Abstract

Simple grain-size statistics are used to establish the flow competency of streams within now-abandoned cave systems. For those sediments interpreted as channel deposits, flow depth is estimated from the thickness of the sediment body and its structural characteristics. Analysis of the grain-size distribution curves of such channel deposits enables the size boundary between bedload and intermittent suspension load to be determined, and from this the bed shear velocity (u*) may be calculated.

Having obtained these values, other palaeohydraulic parameters are extrapolated, including the Froude (F) and Reynolds (Re) numbers, the Chézy (C) and Darcy-Weisbach (f) friction factors, mean boundary shear stress (τ), and stream power (P).

Résumé

L'emploi d'une statistique élémentaire de dimensions de grain permet d'établir la compétence d'un cours d'eau et la manière de dépôt des sédiments qui ont été transportés hydrauliquement dans une caverne. Pour les sédiments qui se montrent sédiments de chenal, on peut calculer la profondeur du courant d'après l'épaisseur du dépôt sédimentaire et ses traits structuraux. L'analyse des courbes de distribution granulométrique de tels dépôts de chenal permet de déterminer la division entre les deux classes de charge solide: les matériaux roulés au fond du lit et ceux qui sont transportés en suspension intermittent; d'où on peut calculer la vitesse de frottement (u*).

Après avoir calculé ces valeurs, on peut extrapoler d'autres paramètres paléohydrauliques, y compris les valeurs de Froude (F) et de Reynolds (Re), les facteurs de friction Chézy (C) et Darcy-Weisbach (f), la tension tangentielle sur le fond du fleuve (τ), et la force du cours d'eau (P).

Although numerous studies have been made of the history of development of karst drainage systems (e.g. Droppa, 1966; Waltham, 1970), relatively few of these have made any attempt to quantify karst palaeohydrology. Yet caves, in particular, contain much evidence of the hydraulic conditions under which former flows occurred. Thus, scallops, flutes and cave meanders may all be used, with caution, to infer past conditions of flow (Gale, 1981). Similarly, hydraulically transported cave sediments may provide a useful record of palaeohydraulic conditions. Yet only a few preliminary studies have attempted to decipher this record (Burkhardt, 1958; Collier and Flint, 1964; Renault, 1968; White and White, 1968). It was therefore decided to make a detailed study of the deposits of a single cave in an effort to investigate the potential of fluvial sediments for palaeohydraulic reconstruction.

Fissure Cave (SD 45557560) consists of a short vadose passage located within the Lower Carboniferous Limestone of the Morecambe Bay area, northwest England (Fig. 1). The passage is now abandoned, but it contains complex sedimentological sequences exposed in five main sections in the cave. Samples of all the clastic beds from four of these sections were taken and their grain-size distribution investigated by sieving at ½ ø intervals and by the pipette method of sedimentation analysis.

Using the QDa-Md approach of Buller and McManus (1972), all the samples, with the exception of those from the basal component of the depositional sequences, were characterised as hydraulically transported on the basis of their grain-size distribution. Since rather more palaeohydraulic information may be derived from those sediments dominated by bedload materials (i.e. Allen's (1965) channel deposits), it was necessary to establish which of the sediments were bedload deposits. In the first instance, this was done by considering only those sediments of median grain-size (D_{50}) $> \sim 0.2$ mm, since, according to Sundborg (1967), particles of smaller than this tend to go immediately into suspension once eroded.

The grain-size frequency curves of bedload sediments tend to be characterised by two log-normal sub-populations, one consisting of bedload and the other of intermittent suspension load (Middleton, 1976). Having established the break point between the two sub-populations, the size of the coarsest particle in suspension is known and it is possible to estimate bed shear velocity (u*) using the relationships established by Bagnold (1973) and Middleton (1976). In all cases it was found that u* fell within the range 20.0 - 1.4 cm s^{-1} regarded by Middleton (1976) as necessary for the bedload transport of sand (Table 1).

Following the approach of Friend and Moody-Stuart (1972), channel depth (d) may be estimated on the basis of the mean thickness of coarse-member beds (Table 1). An independent indicator of channel depth is provided by sedimentary structures within the beds. By using Southard's (1971) depth-velocity-bedform relationships, derived for a range of particle sizes, an approximate measure of flow depth may also be found.

The critical velocity of each of the deposits was estimated using Jopling's (1966) modification of Sundborg's (1956) method to take account of the relatively poorly-sorted nature of many of the **sediments.** The surface velocity given by this method may be converted to an approximate mean velocity ($\bar{u}$) by multiplying by 0.8 (Saunderson and Jopling, 1980). Although flow velocity is, at best, an indirect indicator of erosional competence, it has been adopted for two reasons: firstly, velocity is of more relevance in palaeohydrological studies, and secondly, it is difficult to apply conventional bedload transport equations to the relatively poorly-sorted sediments typical of Fissure Cave.

Having established u*, d and $\bar{u}$ for each sediment, and assuming the eroding fluid to be pure water at 10°C, it is possible to estimate a variety of other palaeohydraulic parameters. Considerable caution must be exercised in this, for it is clear that the errors which exist in the original parameters can only be compounded by using them to derive further values. Nevertheless, it was considered that the values so obtained were of at least the correct order of magnitude and, furthermore, since so little is known of either karst or small-stream hydraulics, that the data provide a basis for comparison with further work.

The following parameters were derived (Table 1):

(i) The Chézy coefficient (C)

$$C = \sqrt{g}\,(\bar{u}/u^*)$$

(ii) The Darcy-Weisbach resistance coefficient (f)

$$f = 8/(\bar{u}/u^*)^2$$

(iii) Discharge per unit channel width (Q_{unit})

$$Q_{unit} = d\,\bar{u}$$

(iv) Reynolds number (Re)

$$Re = (\rho_f\,\bar{u}\,d)/\mu$$

(v) Froude number (F)

$$F = \bar{u}/\sqrt{g\,d}$$

(vi) Mean boundary shear stress (τ)

$$\tau = (u^*)^2 \rho_f$$

(vii) Power of stream flow per unit area of bed (P)

$$P = \bar{u}\,\tau$$

ρ_f = fluid density
ρ_s = particle density = 2.65 g cm^{-3}
g = acceleration due to gravity
μ = fluid dynamic viscosity

Very few measurements have been made even of the basic hydraulic parameters of cave streams. Observations by White and White (1970) suggest that velocities of < 30 cm s^{-1} and flow depths of the order of "tenths of meters" are typical. These values are similar to those derived from the Fissure Cave sediments, although it might be expected that flows of greater magnitude would be found in larger caves.

Friction factors, such as those of Chézy and Darcy-Weisbach, express the resistance to flow of a fluid by a solid boundary. The Darcy-Weisbach friction factor is recommended by the Task Force on Friction Factors in Open Channels (1963) in slight preference to the Chézy coefficient. Considering, therefore, only f, it can be shown that a strong relationship exists between frictional resistance and the grain-size of the sediments (characterised by their D_{50} value) in Fissure Cave (Fig. 2). It should be pointed out, however, that f and D_{50} are not entirely independent, both being derived from the initial grain-size distribution of the sediment.

Bagnold (1966) has published a list of friction factors for present day rivers. These show that 95% of f-values lie between 0.01 and 0.15, whilst the results of flume studies by Guy, Simons and Richardson (1966) indicate that all friction factors lie between these values. With the exception of samples 11 and 14, the results from Fissure Cave all fall within this range.

The Reynolds number expresses the dimensionless ratio of intertrial to viscous forces in the stream and serves as a criterion to distinguish between laminar and turbulent flow. As expected, calculated values of Re are all in excess of 2000, indicating that all the sediments were laid down by fully turbulent flows.

The Froude number indicates the ratio between flow velocity and the velocity with which waves can move over the water surface, i.e. the ratio between inertial and gravity forces in the fluid. Thus, the Froude number distinguishes supercritical and subcritical flow according to whether F is greater or less than unity. In all cases, the sediments in the cave were transported by subcritical flows, indicating transport under a subcritical-turbulent flow regime. This is in accord with the general observations of White and White (1970) that most cave streams are characterised by lower-turbulent flow regimes.

The boundary shear stress is the retarding resistance at the channel bed acting against the direction of flow. In open channels this stress tends to be non-uniform on account of the shape of the channel cross-section and the presence of secondary flows within the channel. Thus, the boundary resistance may be written in terms of mean shear stress, even though the shear stress distribution is unknown (Henderson, 1966).

To compare τ with values obtained from other rivers, shear stress may be recalculated as a dimensionless parameter (θ):

$$\theta = \tau/(\rho_s - \rho_f)\ g\ D_{50} \quad \text{(Bagnold, 1966)}$$

Values of for 115 rivers, mainly large alluvial streams, are listed by Bagnold (1966). Mean θ is 2.24 ($\sigma' = 4.58$) but the range of values lies between 0.14 and 30. As expected, the calculated values of for Fissure Cave lie at the bottom end of this range. Saunderson and Jopling (1980) studied a similar-scale environment to that of Fissure Cave, a micro-delta within an esker. They obtained values more comparable to those in Fissure Cave: $\tau = 4.50$ N m^{-2}, giving $\theta = 1.33$.

Stream power can be defined as the rate at which a stream loses energy. It is equal to the product of the weight of water in a reach and the loss of energy head per unit time (Colby, 1964). On the basis of the stream power categories devised by Friend and Moody-Stuart (1972), the Fissure Cave sediments fall below the sand rivers class (median power ~ 2 W m^{-2}).

Thus, the derived palaeohydraulic values fall generally within the expected ranges of a system of this scale, suggesting that the errors resulting from the initial assumptions and simplifications of the method are not significantly high. The results form an addition to our knowledge of the behavior of small-scale natural hydraulic systems and indicate the potential of the method as a means of quantifying the study of karst palaeohydrology.

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Table 1. Fissure Cave fluvial channel deposits: palaeohydraulic parameters.

Section	Sample bed	Sample Number	Break point (mm)	ω (cm s^{-1})	u* (cm s^{-1})	D_{50} (mm)	Mean bed thickness = flow depth (d) (cm)	$\bar{u}$ (cm s^{-1})	$C/\sqrt{g}$	f	Re	R	P (W m^{-2})	τ (N m^{-2})	θ	Q_{unit} (m^3 s^{-1})
A	Sand 1	8	0.18	1.7	1.7	0.54	6	29	17.1	0.027	13385	0.38	0.08	0.29	0.03	0.017
A	Sand 3	24	0.20	2.1	2.1	0.22	35	31	14.8	0.037	83462	0.17	0.14	0.44	0.12	0.109
A	Sand 4	42	0.27	3.2	3.2	0.33	10	29	9.1	0.097	22308	0.29	0.30	1.02	0.19	0.029
B	Sand 2	10	0.16	1.4	1.4	0.22	10	29	20.7	0.019	22308	0.29	0.06	0.20	0.06	0.029
B	Sand 3	6	0.23	2.6	2.6	0.38	10	30	11.5	0.060	23077	0.30	0.20	0.68	0.11	0.030
B	Sand 3	35	0.29	3.6	3.6	0.38	10	30	8.3	0.115	23077	0.30	0.39	1.30	0.21	0.030
B	Sand 4	37	0.22	2.4	2.4	0.31	5	26	10.8	0.068	10000	0.37	0.15	0.58	0.12	0.013
D	Sand 1	26	0.18	1.7	1.7	0.19	15	31	18.2	0.024	35769	0.26	0.09	0.29	0.09	0.047
D	Sand 2	11	0.50	7.2	7.2	0.57	15	35	4.9	0.339	40385	0.29	1.81	5.18	0.56	0.053
D	Sand 3	14	0.57	8.3	8.3	0.50	7	29	3.5	0.655	15615	0.35	2.00	6.89	0.85	0.020
D	Sand 4	9	0.18	1.7	1.7	0.22	10	29	17.1	0.027	22308	0.29	0.08	0.29	0.08	0.029
E	Sand 3	28	0.16	1.4	1.4	0.27	2	24	17.1	0.027	3692	0.54	0.05	0.20	0.05	0.005

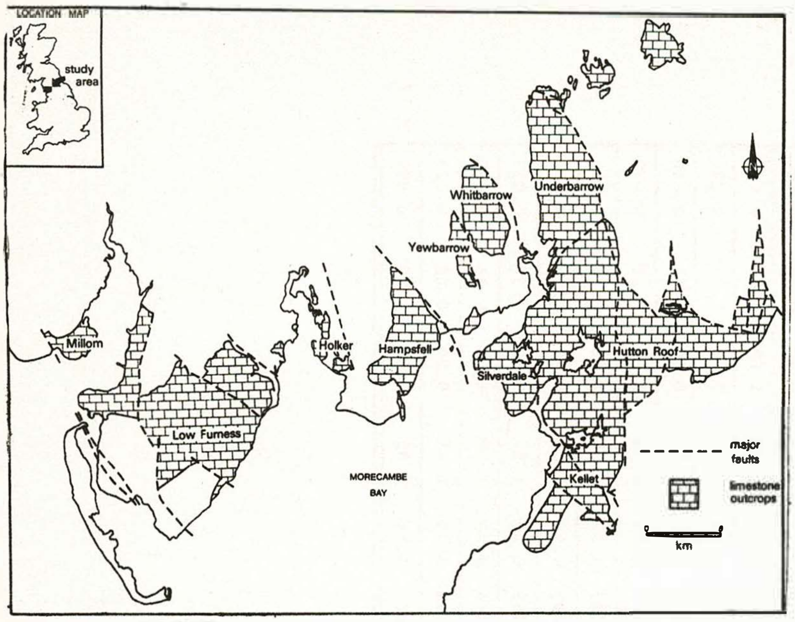

Figure 1. The Morecambe Bay karst.

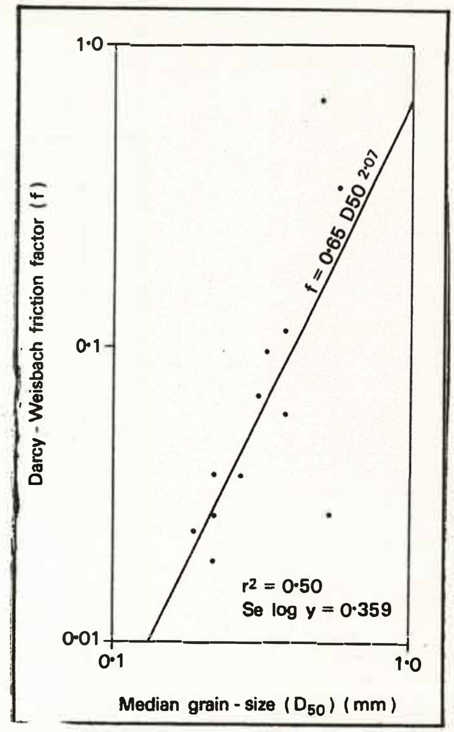

Figure 2. The relationship between the Darcy-Weisbach friction factor and median grain-size for fluvial channel deposits in Fissure cave.

Geomorphic Adjustments of Fluvial Systems to Groundwater Hydrology in Semiarid and Humid Karst

Steve G. Wells and Alberto A. Gutierrez
Radian Corporation, Suite 600, Lancaster Bld., 7927 Jones Branch Dr., McLean, VA 22102

Abstract

Low relief karst, which is characterized by integrated surface and subsurface drainage systems, occurs on Mississippian, carbonate bedrock in central Kentucky and on Permian, evaporite bedrock in southeastern New Mexico. In these two study areas, sinking streams recharge karst aquifers at the terminus of blind valleys. Temporal and spatial adjustments of these fluvial systems are complicated by groundwater responses to recent precipitation-runoff events and to Pleistocene climatic fluctuations.

The surface-runoff and groundwater-recharge relationship differ between fluviokarst systems in semiarid and humid climates. In humid karst of Kentucky, sinking streams provide continuous recharge to karst aquifers; whereas, flashfloods in semiarid karst of New Mexico provide discontinuous recharge to the aquifers. Hydrograph analyses of runoff events in humid fluviokarst sytems indicate groundwater recovery times ranging from 10 to 20 days and sinking stream recovery times ranging from 3 to 5 days. Flow data obtained from field measurements and solutional-scallop studies in semiarid karst illustrate groundwater recovery times of 9 to 24 hours and sinking stream recovery times of t to 8 hours after a single precipitation event. Limited volume of the karst aquifers and rapid recharge from sinking streams increase the hydraulic head in the distal reaches of blind valleys. This ponding of groundwater increases the magnitude and frequency of overbank stage on sinking streams. Overbank sedimentation in humid karst develops wide alluvial valleys near sinking streams' termini. In semiarid karst, minor overbank sedimentation occurs, in part, because the rapid transmission of floodwaters prevents extensive ponding of water in blind valleys. The rapid increase in hydraulic head in semiarid fluviokarst produces groundwater flow velocities exceeding 1 m/sec. Alluviated surface drainages in semiarid karst display discontinuous runoff throughout a watershed for a given precipitation event.

Late Quaternary geomorphic history of both study areas involves successive lowering of base level. Periods of base-level stability are recorded as strath terraces on base-level rivers ans as large, integrated cave systems sloping toward base-level rivers. Pleistocene base-level lowering resulted in capture of surface-subsurface drainages, shifts in groundwater and subaerial drainage divides, and abandonment of topographically higher groundwater levels.

Preservation of these geomorphic adjustments is not common in alluvial-fill sequences of blind valleys in humid karst; rather, the longitudinal profiles of sinking streams record these late Quaternary changes. Longitudinal profiles of sinking streams can be described mathematically and extrapolated beyond their terminus. The sinking streams grade to both active and abandoned groundwater levels beneath the present karst surface. Sinking streams near the base-level rivers have regraded their longitudinal profiles to the active groundwater level. Sinking streams farthest from base-level rivers have not adjusted and remain graded to an abadnoned, Pleistocene groundwater level.

In semiarid karst, arroyo incision and terrace development result from base-level lowering and subterranean capture. Sinking streams above blind valleys' termini are characterized by single, paired terraces, but below the spring outlets, fluvial systems are characterized by several unpaired terraces. Correlation of terraces in semiarid karst is complicated by the interdependence of surface and subsurface drainage.

The Guacharo Cave

Dr. Eugenio de Bellard-Pietri
Apartado 80210 - Prados Del Este, Caracas - Venezuela 108

Abstract

Guácharo Cave is Venezuela's largest cavern (10,200 meters explored). The tourist sector (about 1,200 meters) harbors the largest known colony of oil birds in the world (about 19,000) and has an interesting fauna (rodents, bats, spiders, centipedes, and miriads of insects). Due to the fact that the birds bring seeds in their crops and regurgitate them, the cavern's Humboldt Hall (759 m. long) holds a number of seedling forests during the breeding season. The tourist sector can be divided in three successive sections: a) Humboldt's Hall, b) the Hall of Silence (240 m. long), c) the Precious Hall (100 m. long).

The beautiful cavern has been developed for tourism having in mind two parameters: (1) keep the cave as wild and as natural as possible, (2) give the visitors minimum adequate facilities. For this, a rock slab walkway 1,500 m. long with four well spaced and ample areas and a number of natural rock bridges were constructed. All possible effort was put in camouflaging as best and as safely as possible the full walkway. No railings of any sort appear and steps only when necessary. Due to the birds, no electric light has been installed. The results have been rewarding: 65,471 visitors saw the cave during 1979. No accidents have been reported and wheelchairs for disabled can reach 400 m. in Humboldt Hall. A visitor with two artificial legs managed with reasonable ease the full tourist development. Guides with gasoline lanterns lead the tourists.

Résumé

La Grotte du Guacharo est la plus grande du Vénézuéla (10.200 metres explorés). Le secteur touristique (1.200 metres) abrite la plus nombreuse (19.000) colonie de guacharos conneu dans le monde et présente une faune interessante (rongeurs, chauve-souris, araignées, mille-pattes et miles d'insectes). Du fait que les guacharos transportent des fruits dans leurs gosiers et les regurgitent, le Salon Humboldt de la grotte (759 metres de long) est partiellement recouvert de végétation durant l'époque de l'élevage. Le secteur touristique peut se diviser en trois sections successives: a) le Salon Humboldt, b) le Salon du Silence (240 metres de long), c) le Salon Précieux (100 metres de long).

Cette belle caverne a été developpée pour le tourisme en prenant compte de deux parametres: (1) maintenir la grotte dans un état le plus primitif et naturel possible, (2) donner aux visiteurs les facilités minimums adéquates. Dans ce but, un chemin de 1.500 metres a été construit avec quatre petites plateformes suffisamment espaceés et unies par plusieurs ponts de roche. Le maximum a été fait pour disimuler tout le chemin en restant dans les marges acceptables de sécurité. Il n'y a pas de passerelles ni de marches sauf la ou c'est absolument nécéssaire. Du fait de la présence des guacharos, la lumiere électrique n'a pas été installée. Les resultats ont été excellents: 65.471 personnes ont visité la grotte en 1979. Il n'y a pas eu d'accidents et les chaises roulantes pour handicapés peuvent entrer jusqu'a 400 metres dans le Salon Humboldt. Une visiteuse, avec deux jambes orthopédiques a pu voir sans trop de difficultés tout le secteur touristique. Des guides avec lampes à essence conduisent les touristes.

Resumen

La Cueva del Guácharo es la mayor caverna de Venezuela (10.200 metros explorados). El sector turístico (unos 1.200 metros) alberga la mayor colonia de guácharos conocida en el mundo (unos 19.000) y presenta una fauna interesante (roedores, murciélagos, arañas, ciempies y miles de insectos). Debido a que los guácharos traen semillas en sus buches y las regurgitan, el Salón de Humboldt de la caverna (759 m. de longitud) presenta unos pequeños y precarios bosques durante la época de la cría. El sector turístico puede subdividirse en tres secciones sucesivas: a) el Salón de Humboldt, b) el Saló del Silencio (240 m. de longitud), c) el Salón Precioso (100 m. de longitud).

Esta bella caverna ha sido desarrollada para el turismo teniendo en cuenta dos parámetros: (1) mantener a la cueva tan primitiva y natural como fuera posible, (2) darle a los visitantes las mínimas facilidades que fueran adecuadas. Para ello se construyó una caminería de 1.500 m. con cuatro - plazoletas bien espaciadas y varios puentes de roca. Se puso todo empeño en disimular lo mejor posible dentro de márgenes aceptables de seguridad, la caminerí entera. No existen barandas de ninguna especie y escalones solo donde eran imprescindibles. Debido a los guácharos, no se ha instalado luz - eléctrica. Los resultados han sido generosos: en 1.979, - - 65.471 personas visitaron la cueva. No han habido accidentes, y sillas de rueda para lisiados pueden llegar en el Salón de Humboldt hasta los 400 m. Una visitante con las dos piernas ortopédicas pudo ver sin excesivas dificultades todo el sector turístico. Guías con lámparas de gasolina conducen a los turistas.

Introduction

The Guacharo Cave, by far the largest so far explored in Venezuela (10,200 meters known so far) and, without question, one of the most complete caverns to be seen anywhere in the world, was first seen by europeans in 1657 (de Bellard, 1960). Explored by Humboldt in 1799 (Humboldt, 1956), Codazzi in 1835 (Codazzi, 1835) and by the Speleological Group of the Venezuelan Society of Natural Sciences in a methodical and systematic way starting in 1951 (de Bellard, 1968), the cave's first sector now called "the tourist sector" has been vandalised since 1900, perhaps earlier.

Besides its spetacular crystals, speleothemes of every variety and color, gypsum river, etc., the Guacharo Cave is an incredible fauna and flora sanctuary. And its colony of some 19,000 guacharo birds (oil birds, Steatornis caripensis Humb.) living in the first hall and fully protected since 1949 is, without question, one of the paramount attractions offered by nature to the visiting tourists (de Bellard, 1979).

Both in 1953 and 1974, absurd plans to illuminate the cavern with powerful lights were prepared and engineered. The 1953 project was rapidly stopped after the birds left by hundreds their nests and began to abandon the cavern. The 1974 project, disregarding the previous experience, included the construction of a massive concrete walkway all through the tourist sector (some 1,500 meters).

Alarmed by the information received, the Venezuelan Government's Ministry of the Ambient and Renewable Natural Resources and the Speleological Group of the Venezuelan Society of Natural Sciences, working in a joint team, stopped altogether the irresponsible project which would have probably wiped out the guacharo colony there, so far the largest colony of Steatornis known in the world, and severely affected the troglobites and troglophiles of the cave (Ad Honorem Commission, 1975).

The experience never the less helped to point out that the very large numbers of visitors entering the cave then (40,264 in 1974; 46,241 in 1975) would welcome and aplaud any reasonable tourist development made in the cave. This view was jointly appreciated by the above mentioned Ministry and by the speleologists and conservationists of the Venezuelan Society of Natural Sciences. So both institutions planned and developed a master project aimed at the detterment of the wild conditions still to be faced by all visitors entering the cavern.

The Project

The principal aims of the new project were:

(a) to keep the cavern as wild, natural and unspoiled as physically possible;

(b) to give the visitors of the cave the minimum adequate facilities and safety.

With these two parameters in mind, the Government project was carried out and executed as follows by the already mentioned Ministry of the Ambient, the Ministry of Agriculture and Livestock and, principally, by the National Parks Institute (Instituto Nacional de Parques 1980).

During July 1976 a specially designed limestone slabs walkway was constructed without railings, banisters or lights of any sort, and the use of bridges (over the cavern rivulet) and stone steps was reduced to the absolute minimum.

The first lap, easily covered even in wheelchairs, permits the visitor to enter Humboldt's Hall (759 meters long) up to the horizontal depth of 400 meters. Thousands of guacharo birds live in the nooks, crevices and balconies of this sector right up to the ceiling, some 40 to 45 meters above the rivulet. The walkway is 2 meters wide but widens considerably to form small plazas in six selected sites. Four somewhat camouflaged bridges span the cavern rivulet. Although easily identifiable, the walkways and plazas made of limestone slabs match very well the surrounding rockfall and therefore fit in perfectly with the natural structure seen all around. A well hidden water line allows the cleaning of the walkway for the full initial 400 meters, thus simplifying the maintenance. This first span required the handling of 3,026 cubic meters of rock, guano and earth at the cost of U.S. $42,000 (at 1976 rates).

The second lap, 600 meters long and 2 meters wide, covers the second half of Humboldt's Hall right up to the small crevice which connects with the second hall of the cave, known as the Hall of Silence (some 240 meters long). In this sector, limestone gravel was used and compacted for a better footholding. Two bridges span the rivulet in this part and 253 cubic meters of rock, guano, earth and gravel had to be handled. Footsteps were made in site with the original rocks found and a large plaza was erected at the point where Humboldt turned back finalising his visit of September 18th, 1799. A simple marble slab with a brief inscription marks the place and constitutes the only non-natural item in the cavern. The cost of this second lap mounted to U.S. $59,000 (1977 rates).

The third and last lap was developed from the entrance crevice to the Hall of Silence up to the Hall of the Breasts, the very extreme corner of the tourist sector, itself the final room of the Precious Hall (some 100 meters long). This span is 800 meters long, has seven bridges and the walkway somewhat reduced in comparison with the previous sections. 48 cubic meters of rock, gravel and earth had to be handled in this part, and the cost of the third lap mounted to U.S. $22,000 (at 1977 rates).

The total cost of the full works developed in the cave mounted to U.S. $123,000. The complete walkway is 1,800 meters long and occupies an area of some 4,500 square meters.

The Results

This magnificently designed walkway has given immediate and most unexpected dividends.

Before, since the cavern floor was uneven and irregular and visitors were not limited to a certain trail, the latter walked all over the open areas, got extremely dirty with the mud to be found, wet to the knees in the rivulet, and killed inadvertently thousands of all sorts of troglobites, troglophiles, guanobies and plants growing from the seeds dropped by the guacharo birds after feeding. The so called "cave rats" (*Heteromys anomalus* and *Proechimys guyannensis*) were scarce and fishes were rarely seen in the rivulet.

Nowadays the cavern reminds those who entered thirty or more years ago, the very scenes they saw back in the late 1950's: millions of insects live all over Humboldts Hall; spiders, centipedes, millipedes and rodents have multiplied; fishes of the cavern stream are no longer a rare sight and beautiful dense little seedling forests of laurels and palms greet the visitors with their pale yellow leaves and palid stems, a most unforgetable sight for those who visit the cave during the breeding season of the guacharo birds.

Visitors are conducted by guides using Coleman 300 candlepower gasoline lamps (which eventually will be substituted by adequate and sturdy electric lamps) and are instructed to stay at all times on the walkway and plazas. During 1979, visitors came to see this spectacular cavern from all over Venezuela and from overseas, and their number summed 65,471. Although the walkway and plazas are extremely simple and somewhat camouflaged, no accidents have been reported so far and a visitor with two artificial legs managed with acceptable discomforts to walk the full tourist sector, that is, 1,800 meters.

We feel that this philosophy of trying to keep this magnificent cavern as wild looking as it possibly was back in 1657, gives the visitors the additional thrilling experience of a visit to a very large natural and untouched, semivirgin cave, a nowadays rare sight if we consider the tourist caverns open all over the world. If we add to the previous statement the fact that visitors to the Guacharo Cave arrive all the way from Caracas city on an asphalted road that allows the finest cars to park within 80 meters of the huge cave entrance, we feel we have managed to give a most unusual experience to any caver and naturalist that comes to this grandiose cavern.

If only the indispensable artificial elements are incorporated into nature so as to guarantee a very safe visit to prudent and averagely careful visitors, the two principles can be kept and exercised to the benefit of Nature and man's unbending desire to know more.

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Radioactivity in Venezuelan Caves

Dr. Eugenio de Bellard-Pietri
Apartado 80210 - Prados del Este, Caracas - Venezuela 108

Abstract

Radiation detectable in Venezuelan caves has been and continues to be the object of our consideration. A number of caves have been checked so far in this respect and we plan to continue such an investigation until all the different regions of the country have been fairly well covered.

"Background" gamma readings as a reasonable yardstick for comparison were:

a) In Caracas City, open air garden: 100 cps
b) In Caracas City, indoors, in our closed office: 110-130 cps

For the readings we used a Scintrex Scintillometer Model 801013 and in the near future a Model GSM - 5 High Range Survey Meter (Geigercounter) will also be used.

Readings in caves were done holding the gamma sensitive "eye" of the scintillometer at waist level and moving it slowly in all directions in order to get sound average readings. The future readings with the GSM - 5 will be done the same way.

We have registered so far inside the caves readings ranging from 3 cps in a Caracas Mountain range minor cave to 440 cps in a vertical shaft cave not more than 3 kilometers from it.

Work has just been initiated and will now be extended to caves in every accessible region of Venezuela.

Résumé

La quantité de radiations présente dans les grottes Vénézuéliennes a été et est l'objet de notre étude. La radioactivité de plusieurs cavernes a été déjà mesurée et nous continuerons nos investigations jusqu'à ce que toutes les règions du pays soient couvertes.

Les lectures de radiations gamma, employées comme "témoins" raisonables pour établir des comparaisons, furent les suivantes:

a) dans la ville de Caracas à l'air libre dans un jardin: 100 cps
b) dans la ville de Caracas, dans un studio fermé: 110 à 130 cps

Pour les lectures nous avons employé un scintillomètre scintrex modèle 801013 et dans l'avenir nous utiliserons aussi un compteur geiger modèle GSM-5 high range survey.

Les lectures dans les grottes ont été faites en maintenant l'oeil sensible du scintillomètre au niveau de la ceinture alfin d'obtenir des rèsultats confiables.

Nous avons enregistré jusqu'à présent des lectures qui varient entre 3 cps, dans une petite caverne des montagnes au nord de Caracas, et 440 cps dans une autre a moins de 3 kilomètres de la première.

L'étude est à peine commencée et sera étendue à toutes les grottes accessibles du Vénézuéla.

Resumen

El monto de radiaciones presente en las cuevas de Venezuela ha sido y sigue siendo objeto de nuestro estudio. Varias - cavernas han sido estudiadas y continuaremos estas investigaciones hasta que todas las regiones del pais hayan sido bien cubiertas.

Las lecturas de radiaciones gamma usadas como "testigos" razonables para establecer comparaciones fueron:

a) En la Ciudad de Caracas, en jardín al aire libre: 100 cps.
b) En la Ciudad de Caracas, en nuestro estudio cerrado: 110 a 130 cps.

Para las lecturas hemos usado un cintilómetro Scintrex Modelo 801013 y en el futuro usaremos también un contador Geiger Modelo GSM-5 High Range Survey.

Las lecturas en las grutas se hicieron manteniendo el ojo sensitivo del cintilómetro a nivel de la cintura y moviéndolo lentamente en todas las direcciones a los fines de obtener lecturas confiables. Las lecturas futuras con el Contador Geiger se harán iguales.

Hemos registrado hasta el presente dentro de las cuevas - lecturas que varían entre 3 cps en una gruta pequeña de las montañas al norte de Caracas, hasta 440 cps en una sima que no - dista más de 3 kilómetros de la anterior.

El estudio apenas ha sido iniciado y ahora será extendido a todas las cuevas accesibles de Venezuela.

Introduction

Ever since we began exploring caves in Venezuela, we always wondered on what their radioactivity level would be.

Towards the end of 1979 we made acquaintance with Dr. Jean Pasquali Z., of the Venezuelan "National Council for the Development of the Nuclear Industry" (CONAN). Through his kindness and collaboration, we finally managed to secure, on a loan basis, a BGS - 1SL Broadband Gamma Ray Scintrex Scintillometer (Model 801013). This apparatus is a portable, lightweight, transistorized instrument, capable of detecting with high sensitivity any gamma-ray emitting material. Incorporated in the instrument is a rugged crystal-photomultiplier assembly which is shock mounted and which includes a Thallium-activated NaI crystal. Integrated with the system is an audio output circuit which gives an aural indication of the presence of radiation. This circuit complements the meter readout of the same radiation levels, and does this by a pitch change proportional to the radiation level. A Threshold control allows the operator to adjust the level above background at which the "squealer" is activated. For energy, four "D" sized batteries are used.

This scintillometer has the following ratemeter ranges: 10,000, 3,000, 1,000, 300, 100 and 30 c.p.s. with an accuracy of $\pm 5\%$ of full scale and is, therefore, a precision instrument. It is sensitive to gamma ray energies from approximately 80 KeV to greater than 3 MeV (cosmic).

Well aware that we could only register the gamma count and had no way of measuring the amount of α and β radiations independantly one from another, we proceeded to visit a number of caves in different regions of the country with this simple and magnificent instrument. We have so far visited 12 caves, mines, artificial underground tunnels and ancient colonial wells with the purpose of determining the different levels of gamma radiation present in the same and checking these readings carefully against the corresponding "background readings" of the areas. These background readings proved to be quite different from one part of the country to another (see below).

We now give on a very simple table our findings, rudimentary as they are, which we trust will serve as a basis for future more technical studies.

Gamma Readings

Name of cave or "background readings" in area	Identification No. of cave in the Speleological Atlas of Venezuela of the author	gamma ray: counts per second: c.p.s.	Altitude of cave in meters
1. Central Venezuela			
Caracas City open air garden:		85 - 105	915
Authors library (indoors):		100 - 130	915
Control readings (for checking purposes):			
Uranium metal, nuclear grade (Merck)		1400-1500	
Thorium metal (K&K)		2700-2800	

Gamma Readings (continued)

Name of cave or "background readings" in area	Identification No. of cave in the Speleological Atlas of Venezuela of the author	gamma ray: counts per second c.p.s.	Altitude of cave in meters
Caves:			
El Indio No. 1:	MI - 63	120 - 140	1020
background reading outside:		80 - 120	
El Indio No. 2:	MI - 64	60	±1000
El Pio:	MI - 76	280 - 340	910
background reading in thalweg:		90 - 130	± 880
Gruta del Castillo Negro:	DF - 10	3 - 6	1460
background of former:		13 - 16	
Tunel del Castillo de San Joaquin:	DF - 8	150 - 160	1420
Ancient Well of above fort:	DF - 9	120 - 140	±1450
background in said fort:		190 - 230	±1450
Hoyo de la Cumbre:	DF - 11	440	1260
background of former:		220 - 240	1260
Tunel No. 1 Alta Florida:	DF - 5	160 - 210	
Tunel No. 2 Alta Florida:	DF - 75	190 - 210	
background of former:		170 - 200	
Alfredo Jahn Cave:	MI - 1	80 - 100	210
2. Eastern Venezuela			
Caripe Hotel patio:		58 - 63	870
Plaza in front of the Guacharo cave (open air):		60 - 75	1066
Guacharo Cave:	MO - 1		1066
at 400 meters from entrance:		58 - 72	
at 500 meters from entrance:		60 - 76	
at 600 meters from entrance:		110 - 135	
at 825 meters from entrance:		140 - 150	
at 960 meters from entrance:		110 - 130	
3. Western Venezuela			
Gruta de Gañango:	CA - 9	50 - 60	5
background of former:		50 - 70	5

The readings were all done holding the gamma sensitive "eye" of the scintillometer at waist level and moving it slowly in all directions in order to get the full scope of readings possible at one given station.

As can be easily appreciated, the variety of the readings is tremendous and goes from as low down as 3 to 6 γ c.p.s. (Gruta del Castillo Negro) to as high as 440 γ c.p.s. (Hoyo de la Cumbre). These two readings were made in caves just about 3 kilometers apart one from the other..!

As for the Guacharo Cave, it is interesting to note how the readings increase as one penetrates farther into the cavern (58 to 72 at 400 meters; 140 to 150 at 825 meters from the entrance), though the rule drops as one enters The Precious Hall (110 to 130 c.p.s. at 960 meters from the entrance of the cave). These differences are hard to explain, by any standards. The differences evidently respond to variable concentrations of radioactive elements throughout the whole rock masses surrounding the cavernous structures in a most arbitrary way.

Similar Investigations Carried Out Elsewhere

Reading literature published by the National Speleological Society, the British Cave Research Association and Energia Nuclear of Spain, we have excellent articles dealing with the subject with considerable detail and using knowledges and techniques that far surpass those of the author (see Bibliography at end of this paper).

A two year study of airborne radioactivity in caves of the Carlsbad Caverns area has indicated that tour guides spending most of their time in underground caverns can be exposed to as much radiation as uranium miners (!). However, in announcing the findings, Dr. Marvin W. Wilkening of New Mexico Tech emphasized the caves contain no unusual quantities of U, Th, and K40. Wilkening said the radioactivity found in the cavern air originates from extremely small amounts of U and Ra present in all rocks and soils (Radioactivity in Caves - July 1976). This, evidently, is the explanation to what the author has found in the Venezuelan caves considered in this paper.

Scientists in the Southwest Region of the National Park Service have been investigating radiation produced by the radioactive decay, of Rn 222 and 220 at caves in the National Park Service system. Comparative studies have been made at the following caves: Carlsbad Caverns, New Cave, Crystal Cave, Marble Cave, Timpanogos Cave, Oregon Cave, four lava tubes at Lava Beds National Monument, Lehman Cave, Round Spring Cave, Wind Cave, Jewel Cave and Mammoth Cave. This study was begun at Carlsbad Caverns in August 1975, after Wilkening and his associates found measurable amounts of Rn in air sampled at Carlsbad Caverns, Cottonwood Cave and Jurnigan Cave (Keith A. Yarborough, G. Ahlstrand & M. Fletcher-August, 1976).

In short, minute amounts of Ra and Th in the bedrock produce, through radioactive decay, Rn 222 and 220. Thus the two Rn isotopes are produced throughout bedrock and since they are gases, they are carried into the cavern ducts and halls with the normal air movement always present underground. But, and this must be stressed, Rn presents little hazard to cavers of ordinary activity and career, even considering the most decided and enthusiastic of the lot (Steve Knutson - 1977).

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Stalactite Growth in the Tropics Under Artificial Conditions

Dr. Eugenio de Bellard-Pietri
Apartado 80210 - Prados Del Este, Caracas - Venezuela 108

Abstract

The paper discusses the development and growth of isotubular stalactites ("straws") in the building of the Venezuelan Society of Natural Sciences, in Caracas. After giving due consideration to the fact that over eighty caves can be found in the vicinity of Caracas City, and that a number of these present isotubular stalactites, it was thought worthwhile to study in some detail these unusual artificial ones which have grown with a very similar rainfall pattern as that one governing the growth of natural ones in caves not exceedingly far away.

The case: Eight isotubular stalactites have appeared in the ceiling of a small protected foom of the Society (constructed in November, 1973). The longest stalactite is already 20.4 centimeters long. The general appearance is identical in every way to the natural isotubulars. Rainfall during the period: an average of 801 milimeters per year in the Caracas Valley. The longest isotubular of the eight has grown an average of 2.9854 centimeters per year (2.4878 milimeters per month). We shall continue checking its growth.

The cement powder which was used in the construction has a 63.8% to 64.4% CaO content before being mixed. Once mixed with sand, rock (usually $CaCO_3$ and SiO_2) and the water, the final hardened concrete presents a composition of insoluble silicates, aluminates and ferroaluminates. We therefore conclude that the isotubular stalactite originated from the natural limestone contained in the concrete used in the construction.

Résumé

Ce travail Consiste a étudier le développement des stalactites isotubulaires dans l'immeuble de la Société Vénézuélienne des Sciences Naturelles; à Caracas.

Considérant qui' aux alentours de Caracas il y a plus de 80 grottes et que dans quelques unes s'est manifestée la présence de stalactites isotubulaires, nous avons cru intérèssant d'étudier, dans ses details, ces curieux exemplaires qui se sont developpés sous un règime de pluies très semblable a celui qui a permis la crois - sance de spéléotèmes similaires, éxistant dans des cavernes proches.

Sujet de l'étude: Huit stalactites isotubulaires ont apparu au plafond d'une petite chambre protegée des intempéries de l'immeuble de la société, laquelle fut construite en Novembre 1973. La plus grande de ces stalactites mesure 20.4 centimètres. L'aspect génèral est identique à tous points de vue aux éxemplaires naturels. Les precipitations durant la période de croissance a été en moyenne de 801 milimètres par an dans la vallée de Caracas. La plus grande des huit stalactites a grandi en moyenne de 2.9854 centimètres par an (2.4878 milimètres par mois).

Le ciment en poudre qui a été employé pour la construction de l'immeuble avant d'être melangé, a entre 63.8% et 64.4% de CaO, une fois melangé avec du sable, de la pierre (généralement Ca CO3 et Si O2) et de l'eau, le béton une fois durci présente une composition de silicates insolubles, d'aluminates et de ferroaluminates. De ces faits, nous concluyons que les stalactites isotubulaires se sont formée grâce a la présence de la pierre calcaire contenue dans le béton employé pour la construction de l'immeuble.

Resumen

El trabajo estudia el desarrollo de estalactitas isotubulares en el edificio de la Sociedad Venezolana de Ciencias Naturales, en Caracas.

Habida consideración de que en las vecindades de Caracas existen más de 80 cuevas y de que algunas de ellas presentan estalactitas isotubulares, se ha creido apropiado el estudiar en algún detalle estos curiosos ejemplares que han crecido - con un régimen de lluvias muy parecido al que ha gobernado el crecimiento de espeleotemas similares existentes en cuevas no muy distantes.

El caso: Ocho estalactitas isotubulares han aparecido en el techo de un cuarto pequeño y protegido de la Sociedad (la cual fué construída en noviembre de 1.973). La más larga ya mide 20,4 centímetros. La apariencia general es idéntica en todo sentido a los ejemplares naturales. Precipitación durante el período: un promedio de 801 milímetros por año en el Valle de Caracas, La más larga de las ocho ha credico un promedio de 2,9854 centímetros por año (2,4878 milímetros por - mes). Continuaremos controlando su crecimiento.

El cemento en polvo que se usó en la construcción del - edificio tiene entre 63,8% y 64,4% de Ca O antes de ser mezclado. Mexclado ya con arena, piedra (usualmente Ca CO_3 y Si O_2) y agua, el concreto final endurecido presenta una composición de silicatos insolubles, aluminatos y ferroaluminatos. En razón de ello concluimos que las estalactitas isotubulares seoriginaron por la presencia de la piedra caliza natural contenida en el concreto usado en la construcción.

Introduction

Some eighty caves of all sizes (largest: Cueva Ricardo Zuloaga, about 500 meters development) dot the hills and mountains surrounding Caracas City valley. Since some of these caves present isotubular stalactites ("straws"), the author was very pleased to notice that within the very same building of the Venezuelan Society of Natural Sciences, parent society of the Speleological Group, some minute stalactites were growing in the great lecture hall and, also, in the projection room alongside. In view of this unique event, the author instructed immediately the administrative personnel so that such artificial "speleothemes" would not be disturbed in the least.

The Sociedad Venezolana de Ciencias Naturales, though founded 50 years ago, only inaugurated its new building on November 14th 1973, that is, seven years ago. The complete structure (5 stories high, plus basement) was constructed with the usual engineering techniques current in Venezuela, that is to say, cement, steel rods and bricks.

The original cement powder used in construction (roughly classified as a Portland type cement) has a 63.8% to 64.4% CaO content before being mixed. Once mixed with sand, rocks (usually $CaCO_3$ and SiO_2) and water, the final hardened concrete presents a composition of insoluble silicates, aluminates and ferroaluminates, plus variable amounts of unaltered $CaCO_3$ and SiO_2.

One cubic meter of this type of concrete may weigh between 2,400 and 2,500 kilograms, or more, and has this usual final composition:

Cement	between	250	and	410	kilograms
Sand	"	1200	"	850	"
$CaCO_3/SiO_2$ (in lumps)	"	800	"	1300	"
Water	"	150	"	200	"

(plus chemical additives in minor amounts)

The Curious Growth

It is now impossible to say just when the artificial "speleothemes" began their growth but we distintively recall seeing a chalk white stain in the roof of the great lecture hall of the Society years ago and such roof has not received any maintenance since the inauguration date (November 14th, 1973).

During early 1979 the author noticed that, besides the "straws" growing in the lecture hall, the projection room of said hall (also under the same concrete roof and therefore receiving the same rainfall) presented eight similar ones, only longer, surrounding a circular ventilation window in the ceiling. Since the projection room was not liable to critiques from "non-cave-lovers" members of the Society, we decided to protect it from the usual roof cleaning procedures and issued terminant orders to that effect.

On July 20th 1979 we made the first measurements of these artificial straws. The lengths and diameter follow:

			Status on	
Nº 1	length:	204 mm	July 20, 1979:	dripping
2	"	50	"	apparently dry
3	"	70	"	dripping
4	"	65	"	"
5	"	67	"	apparently dry
6	"	69	"	"
7	"	32	"	"
8	"	46	"	"

The diameter of all eight were identical in all respects to the diameters of similar natural isotubulars found in natural caves in Venezuela: 2.5 to 3.0 mm.

On December 15th, 1980, we made a second measurement of the longest of the speleothemes, Specimen Nº 1, and found it to be 290 mm long, that is to say, 86 mm. longer than the previous opportunity (July 20th, 1979). We can therefore validly conclude that Specimen Nº 1:

a) Is by far the longest of these artificial speleothemes and is the one that displays the most rapid growth;

b) It evidently has a richer water flow than the other seven "straws", a fact impossible to verify physically without destroying the very vase of said isotubular;

c) Its average growth rate would seem to have been:

(1) 0.09582 mm per day during the first period (November 1973 to July 1979);

(2) 0.1676 mm per day during the second period (July 1979 to December 1980).

It must be mentioned that no visible cracks or crevices can be seen anywhere on the roof of the projection room and if they do exist, they have now been covered by the calcium carbonate layer which serves as a base for the speleothemes.

The Rainfall

It has not been possible to obtain up to now the complete and up to date rainfall data of the Caracas Valley, trigger of the isotubular stalactites development, so we have had to use average figures for the years of 1978, 1979 and 1980 in order to arrive to reasonable numbers.

Rainfall in the Valley of Caracas, in milimeters

1973	288 mm.	(September to December)
1974	950	
1975	975	
1976	690	
1977	737	
1978	801	(average of 1973 to 1977)
1979	801	"
1980	801	"
TOTAL:	6,043 mm.	

We therefore conclude in a most general way that the isotubulars in the Venezuelan Society of Natural Sciences developed thanks to this total rainfall on the area (estimated for the full period of growth of the speleothemes at 6,043 mm.) during a period of roughly 7 years and 3 months.

Comments

It is obviously impossible and most unwise to try to jump to any sort of firm conclusions with such an isolated, minute and marginal case, but we feel that we have at least set some sort of very general rates of growth for these speleothemes (isotubular stalactites) in the Caracas area: about 0.1676 mm per day once the straw has started to develop.

But two fundamental unsolved problems have remained:

(1) We admit that the different rates of growth noticed for the periods November 1973 / July 1979 (0.09582 mm. per day, average) and July 1979 / December 1980 (0.1676 mm. per day, average) cannot be easily explained;

(2) We cannot understand the reason for the different rates of growth of the eight "straws", since all are located in identical positions around the same opening in the roof of the projection room. Unless proven otherwise, the water access to all these eight speleothemes is identical and they are separated one from another by just a few centimeters or decimeters. It must be mentioned that three were dripping at a uniform rate while the other five seemed to lack water totally.

We conclude that the isotubular stalactites originated mainly from the chemical solution by the H_2CO_3 of the natural limestone contained as free rock in the cement, and not from the CaO combined in the hardened cement as calcium silicate, aluminate or ferroaluminate.

Needless to say, we will continue new experiments along this line in the near future.

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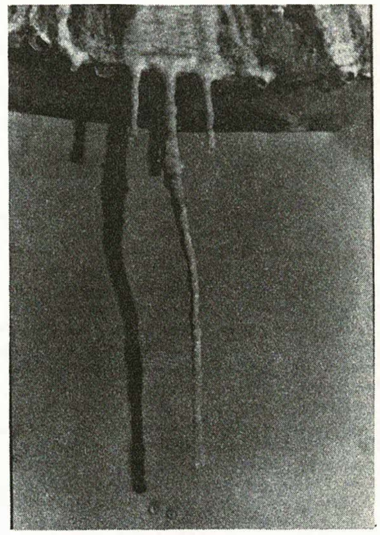


Foto Nº 1. Specimen Nº 1, the longest "straw", between Specimen Nº 8 (on the right) and Specimen Nº 2 (on the left).

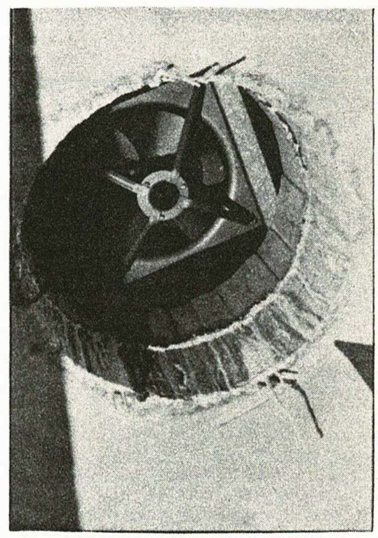


Foto Nº 2. The circular ventilation window in the ceiling of the projection room, alongside the major lecture hall of the Society, showing its cement structure and the "straws". The largest specimen appears clearly on the lower right corner (plus its shadow to the right).

A Karst Ecosystem the Dorvan Massif (Ain, France). V - Drift of Invertebrates, Organic Matter and Minerals out of the Massif.

Janine Gibert

Université Claude Bernard LYON I, Hydrobiologie et Ecologie Souterraine; Départment de Biologie Animale; E.R.A. n° 849 - Ecologie des eaux douces; 43 Bd du 11 novembre 1918, 69622 VILLEURBANNE CEDEX, FRANCE.

Abstract

A series of filterings has been undertaken at two important water exits of the DORVAN Massif: in the upper part of the massif at the exsurgence of the CORMORAN Cave and at the base of the massif at the resurgence of the PISSOIR Cave. The observations are relative to three periods during 1978-1979 (January, March, June) made during flood decline when water flow was similar.

The matter retained in the filters (300µ) is composed in part by live drift (aquatic and terrestrial animals) and in part by non-living drift (particulate organic matter and minerals). The drift is always more abundant in the upper part of the massif. The terrestrial fauna is composed predominant by Collembola. The respective percentages for these insects of the drift are as follows: 2.5%, 0.9%, 15.9% for the PISSOIR and 74.4%, 52.2%, 72.5% for the CORMORAN. Over 90% of the invertebrate ejected are of epigeous origin: this fact is discussed.

The amounts of organic and mineral matter collected are extremely variable and do not show daily fluctuations. The quantities are generally more important at the upper part of the massif where the flow is less intense.

Résumé

Des filtrages ont été réalisés au niveau de deux sorties importantes du massif karstique de DORVAN: dans sa partie supérieure à l'exsurgence du CORMORAN et à son niveau de base, à la résurgence du PISSOIR. L'étude a porté sur 3 périodes du cycle hydrologique 1978-1979 (janiver, mars, juin) en phase de décrue et pour des débits comparables.

Le matériel retenu par filtrage (300µ) est composé d'éléments de dérive vivante (animaux aquatiques, terrestres et émergents) et de dérive inerte (matiére organique particulaire et minérale). La dérive de la faune aquatique est constituée principalement de larves d'insectes et de crustacés. Sa densité est plus importante dans la zone supérieure du massif. La faune terrestre essentiellement représentée par les Collemboles constitue respectivement pour janvier, mars et juin 1979: 2.5%, 0.9%, 15.9% (PISSOIR) et 74.5%, 52.2%, 72.5% (CORMORAN) des animaux dérivants. Plus de 90% des invertébrés entrainés à l'extérieur du massif sont d'origine épigée. Ce phénoméne est discuté.

Les quantités de matiéres organiques et minérales sont trés variables au cours des prélévements successifs et ne montrent pas de périodicité journaliére. Ces quantités sont d'une façon générale plus importantes au niveau supérieur du massif où le courant est le plus faible.

Introduction

A recent study has shown that an important and diversified fauna can be found in the DORVAN Massif (GIBERT et al., 1978). Among this community the drift of Amphipoda and Gastropoda has already been studied (GIBERT, in press). These first results seem to show that large populations of hypogean macrofauna live in the saturated zone. So it was interesting to find out what was globally rejected at different periods of a hydrological cycle by the two water exits situated respectively in the upper part of the massif (exsurgence of the CORMORAN cave) and at the base of the massif (resurgence of the PISSOIR cave).

1) MATERIALS AND METHODS

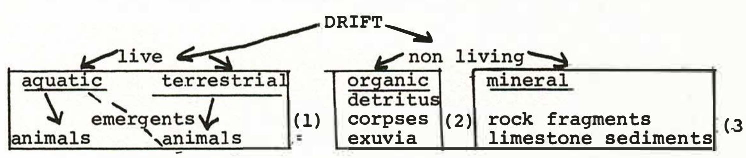
The observations are relative to 3 periods of the 1978-79 hydrological cycle (January, March and June 1979) during flood decline and when water flow was similar (fig. 1, table 1).

date of samplings	CORMORAN Exsurgence			PISSOIR resurgence		
	M	J	QM	M	J	QM
31 Jan 79 to 1 Feb 79	40 l/s on 27 Jan (8h)	4	1.3	498.3 l/s on 27 Jan (8h)	4	150.8
15 Mar 79 to 16 Mar 79	37.5 l/s on 11 Mar (12h)	4	1.7	824.3 l/3(*) on 11 Mar (12h)	4	181.7
6 Jun 79 to 7 Jun 79	207.5 l/s on 5 Jun (2h)	1.5	2.3	547.6 l/s on 4 Jun (24h)	1.5	148.3

Table 1: Hydrological characteristics of the two outflows. M: Maximum flow recorded in the CORMORAN cave and at the PISSOIR resurgence (*) Estimated flow (too intense for the enregistrement). J: Number od days elapsed between maximum flow and the samplings. QM: average flows recorded during sampling (in liters per second).

The massif is almost exclusively fed by atmospheric water. As there are no epigeous streams on the DORVAN Plateau, the flows recorded in the CORMORAN cave are directly related to the penetration of seepage water. This also applies to the PISSOIR resurgence but it can be fed by the underflow of the BIEF RAVINET (GIBERT et al., 1978). However for a given amount of rainfall on the massif the two outflows behave in a different and probably independent way. Thus, while similar discharges were recorded at the PISSOIR on 1 February (498.3 l/s) and on 6 June (547.6 l/s) the quantity of water recorded at the CORMORAN on 6 June was 5 times as important as on 27 February (table 1).

At the PISSOIR site samples were taken every 2 hours during 24 hours for each period (due to low flow). The techniques used for filtering and for measuring the stream flow are given in GIBERT et al. (1978) and in GIBERT (in press). The matter retained in the filters (mesh : 300µ) includes the following elements:



Group 1 was removed and groups 2 and 3 were weighed together after evaporation at 70°C (dry residue at 75° in g) then weighed again after calcination at 550°. The second residue constitutes the mineral matter collected. The difference between the two dry residues represents approximately the amount of organic matter retained and which was destroyed during calcination.

2) RESULTS

a) Invertegrates collected

Figure 2 shows that 10 main groups have been identified:

- aquatic animals: Plecoptera, Ephemera, Diptera, Trichoptera (insect larvae), Coleoptera, Crustacea, Gastropoda, Annelida;
- terrestrial animals (exogenous): Arachnids, Myriapoda, Collembola and other Pterygota.
- emergents (nymphs and insect imagos drowned during the last period of nymphosis).

Very few hypogeous species were collected. These included Crustaceans: Niphargus rhenorhodanensis (Amphipoda), Proasellus cavaticus (Isopoda), Graeteriella unisetigera (Cyclopoda); Gastropod Mollusca: Hauffenia minuta, Bythiospeum diaphanum diaphanum, B. d. d. bourgouignati; Oligocheta: Peloscolex turquini; Coleoptera (terrestrial): Trichaphaenops cerdonicus. These hypogeous species represent less than 10 per cent of the drifting animals.

--Aquatic fauna drift

Crustaceans and insect larvae (particularly Plecoptera) are predominant. The density of the drifting aquatic fauna increases during the hydrological cycle: it amounts to 12 speciments per 100 m^3 in January, 13 speciments per 100 m3 in February, 17 specimens per 100 m3 in June at the PISSOIR resurgence and respectively 21, 22, 50 per 100 m3 at the CORMORAN exsurgence (table 2). So the density is always higher in the upper part of the massif.

The difference samples taken at the PISSOIR were fairly constant, since their variation coefficients were 0.22, 0.25 and 0.32. They did not reveal an increase in the number of aquatic insects drifting during the night, however different groups were studied globally, and only Crustaceans were analysed more precisely (fig. 3). They include: the hypogeous Amphipoda (Niphargus rhenorhodanensis), the epigeous Amphipoda (Gammarus pulex), the hypogeous Isopoda (Proasellus cavaticus) and the Cyclopoda (Paracyclops fimbriatus, Diacyclops languidoides s. l., D. l. languidoides, D. l. clandestinus, Graeteriella unisetigera). A higher noctural drift was observed for Niphargus only, resulting from a behavioural pattern (GIBERT, in press).

--Drift of terrestrial fauna and of emergents

The terrestrial fauna represents respectively for January, March and June 1979: 2.5%, 0.9% and 15.9% at the PISSOIR and 74.4, 52.2 and 72.2% at the CORMORAN of the drifting animals. It is composed mainly of Collembola at the upper water exit. It is always superior to the density of aquatic animals. The location of the CORMORAN cave may well account for this fact. As it has its entrance into the forest of oak-trees and yoke-elms of the DORVAN Plateau. A construction was placed at the CORMORAN exsurgence to canalize the water and fill in the exits in order to collect the fauna of the underground stream only, and to prevent epigeous aquatic and terrestrial animals from entering the cave. In spite of the precautions taken, a lot of animals of the surface fauna, mainly Collembola enter the karst and are carried out again by the underground stream.

The number of emergents is higer at the end of the hydrological cycle, that is to say at the end of springs. At that time emergence mainly occurs during the day (fig. 2).

b) Organic matter

Only the amounts of particulate matter have been measured. They vary considerably during a full period of one night and one day (variation coefficient very close to 1, table 2). They are negligible in March and June at the PISSOIR resurgence (about 10g for 24h). It is to be noted that the drift is always more abundant in the upper part of the massif.

c) Mineral matter

At the PISSOIR site during the full 24 hour period the mineral matter, like the particulate organic matter is carried out of the massif in a haphazard way without following any paatern. On the other hand at the CORMORAN site the quantity of sediment collected during the 3 periods considered is related to the intensity of the flow: flow 40 l/s or 37.5 l/s, density 0.2 and 0.3, flow 207.5 l/s density 2.8.

The results in table 2 show that during flood decline, the stream whose flow is more important at the PISSOIR, does not carry more sediments than the other (CORMORAN).

Discussion and Conclusion

This study reveals two important facts concerning:

a) The density of drifting matter at the two water exits of the DORVAN Massif. The density of total live drift at the PISSOIR resurgence is relatively low (a maximum of 26 organisms per 100 m^3 on 5-6 June 1979) compared to the density at the CORMORAN exsurgence (a mamimum of 120 organisms per 100 m^3 on 5-6 June 1979). This value is very close to the value recorded by most authors in permanent pollution free streams (BROOKER and HEMSWORTH, 1978); CHAVANON, 1979); HYNES, 1975; LEGIER, 1979 have found an average of 100 specimens per 100 m3). DECAMPS and ROUCH (1974) have shown at the LAS HOUNTAS (BAGET) that the density varied from 2.8 to 283.2 specimens per 100 m3, however during a period of flood.

At the DORVAN Massif water exits, the amounts of non live drift is extremely variable during successive samplings. It is low and the quantity of particulate organic matter is always inferior to 1 mg/l (value observed by DECAMPS and LAVILLE, 1975) in the BAGET. In the same way during flood decline, the streams carry very little sediment (maximum value: 2.9 g/100 m3).

b) Upstream movement of epigeous aquatic animals in the karst

DECAMPS and ROUCH (1973) and DECAMPS and LAVILLE (1975) have shown that floods result in an important depopulation of surface stream for the benefit of the karst and that large numbers of epigeous organisms enter the underground world alive. Their estimation made at the entrance and the exit of the BAGET karst system reveal that over 90% of the invertebrates carried inside remain trapped in the Karst.

The DORVAN Massif is different from the above mentioned system in as much as it is almost exlclusively fed by rain water. So obviously only terrestrial soil fauna can enter the underground environment and not the aquatic fauna typical of surface streams. However important amounts of these epigeous animals collected at the two outflows were studied. This fact can only be due to their upstream movement in the cracks existing between the epigeous part of the stream and the Karst. Filterings taken inside the CORMORAN cave and observations made in the PISSoir cave never revealed the presence of surface aquatic insect larvae and/or Gammarus and epigeous Coleoptera; which would occur for short distances (a few meters to a hundred meters or so inside the karst).

This process of upstream movements are a common phenomenon in epigean streams (BISHOP and HYNES, 1969; ELLIOTT, 1971; HUGUES, 1970; KURECK, 1967; MEIJERING, 1962). In the case of springs, the number of animals concerned seems to the more important: as in karst the conditions of temperature and environment are far more stable and the inter-specific competition far less severe during flood decline than in epigeous streams.

Acknowledgements

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		PISSOIR resurgence			CORMORAN exsurgence		
Dates		3I.I. to I.2.79	I5.3 to I6.3.79	6.6 to 7.6.79	3I.I. to I.2.79	I5.3 to I6.3.79	6.6 to 7.6.79
Number of sampling		14	14	12	I	I	I
Aquatic Animal Drift	n	1852	2920	2200	23	33	100
	$\bar{x}_2$ (2 hours) S C.V.	132.3 817.5 0.22	208.6 2771.5 0.25	183.3 3497.2 0.32			
	N 24h	1588	2503	2200	23	33	86
	d n/I00m3	12.2	13.2	17.2	20.6	22	50.3
Terrestrial Animals and Emergents Drift	n	49	26	1104	67	36	138
	$\bar{x}_2$ (2 hours) S2 C.V.	3.5 4.7 0.62	2.3 8.2 1.25	92 2913.1 0.59			
	N 24h	42	22	1104	67	36	119
	d n/100m3	0.3	0.1	8.6	60	24	69.5
Total live Drift	d n/100ms	12.5	13.4	25.8	80.6	46	119.8
Organic Matter Drift	mI (g)	44.2	14.4	9.2	0.3	0.2	0.8
	$\bar{x}$ (2 hours) S2 C.V.	3.2 24.2 1.55	I I I.04	0.7 0.5 0.73			
	MI (24 h)	37.9	11.5	8.5	0.3	0.2	0.7
	d g/I00m3	0.3	0.08	0.07	0.3	0.1	0.4
Inorganic Sediment Drift	m2 (g)	321.6	20.9	14.1	2.4	0.5	4.8
	$\bar{x}$ (2 hours) S2 C.V.	23 351.4 0.82	1.4 1.7 I.22	I.I I.4 I.09			
	M2 (24 h)	275.6	16.8	13	2.4	0.5	4.1
	d g/100m3	2.1	0.1	0.1	0.2	0.3	2.4
Total non-living drift	d g/100m3	2.3	0.2	0.2	0.5	0.5	2.8

Table 2 Living and non-living Drift during the investigation period at the PISSOIR resurgenceand the CORMORAN exsurgence.

n: total number of animals captured during the period under study

$\bar{x}$: mean for a 2 hour sampling

S2: variance; C.V. : variation coefficient

d: drift density number of animals per 100m3
quantity of matter per 100m3

mI: dry weight of organic matter (g)

m2: dry weight of mineral matter (g)

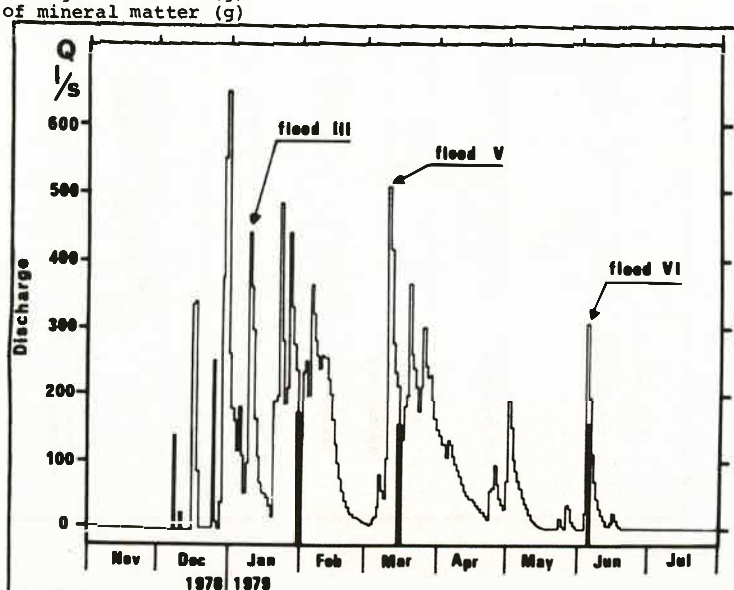


Fig. 1 Evolution of daily mean discharges at the PISSOIR resurgence during the hydrological cycle 1978-79. Situation of studied periods (floods III, V, VI)

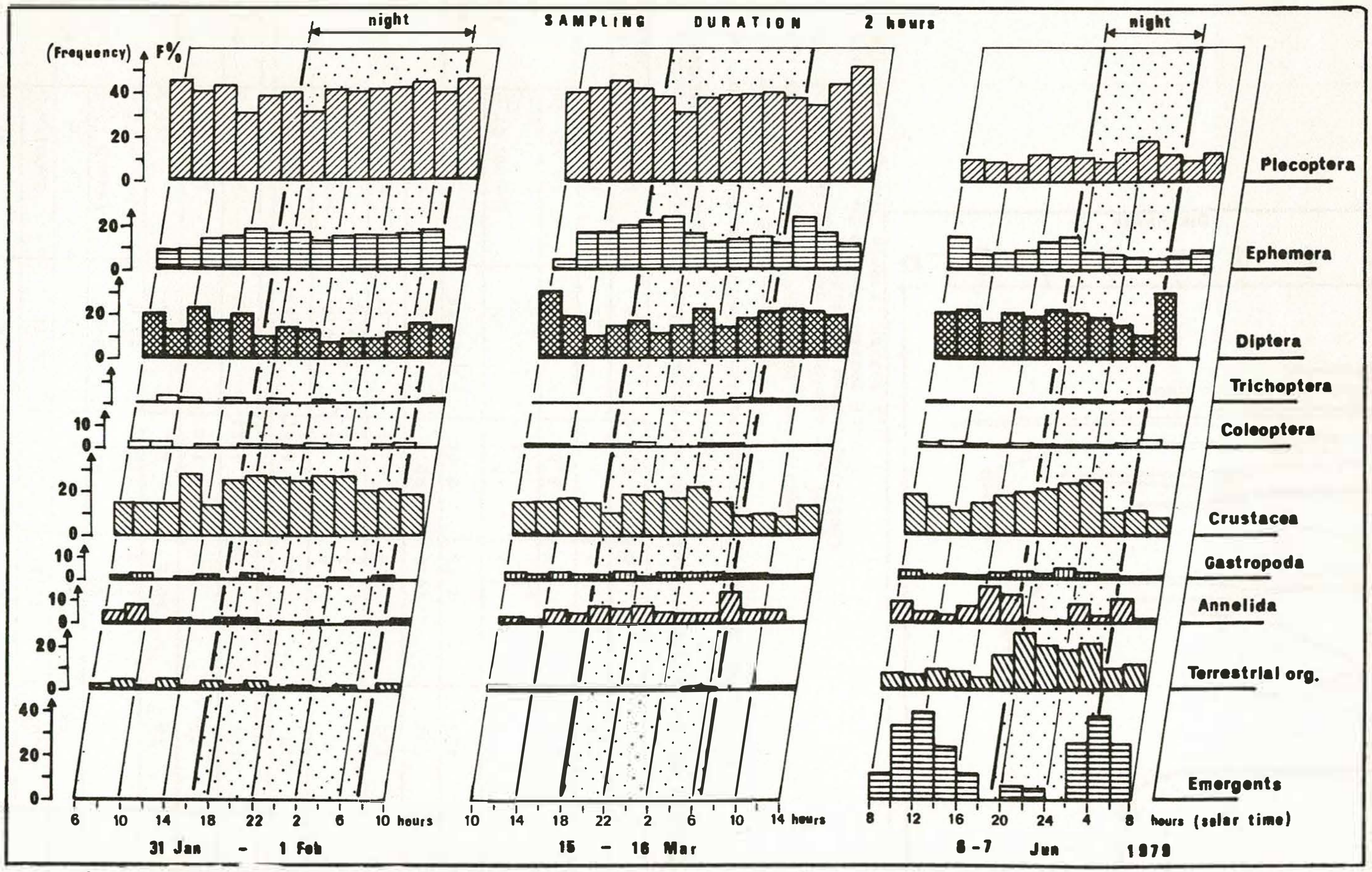
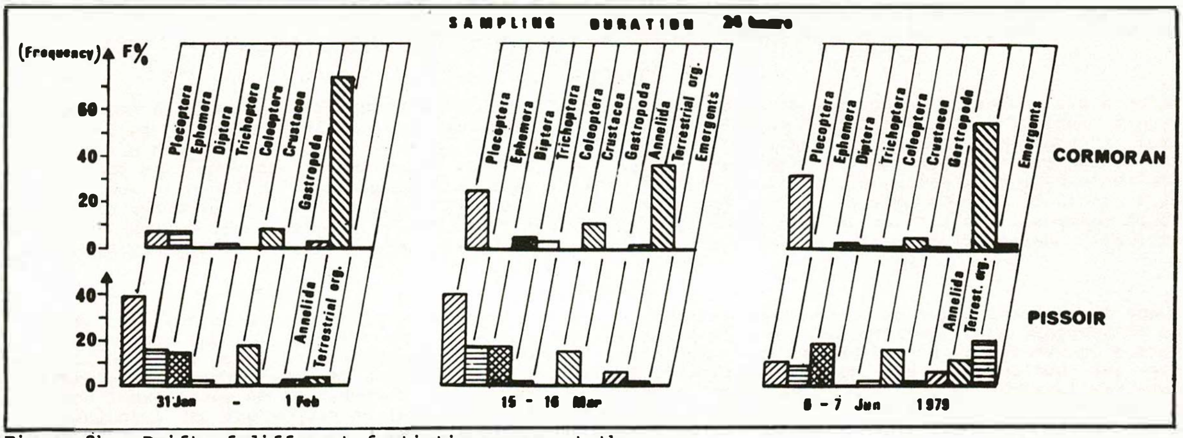


Figure 2a. Daily fluctuations of different fautistic groups at the resurgence of PISSOIR in January, March & June 1979 (one sampling takes 2 hours).



'Figure 2b. Drift of different fautistic groups at the PISSOIR resurgence and the Cormoran exsurgence during a period of 24 hours in January, March and June 1979.
F: frequency in per 100 of the total numbers of specimens in each sampling.

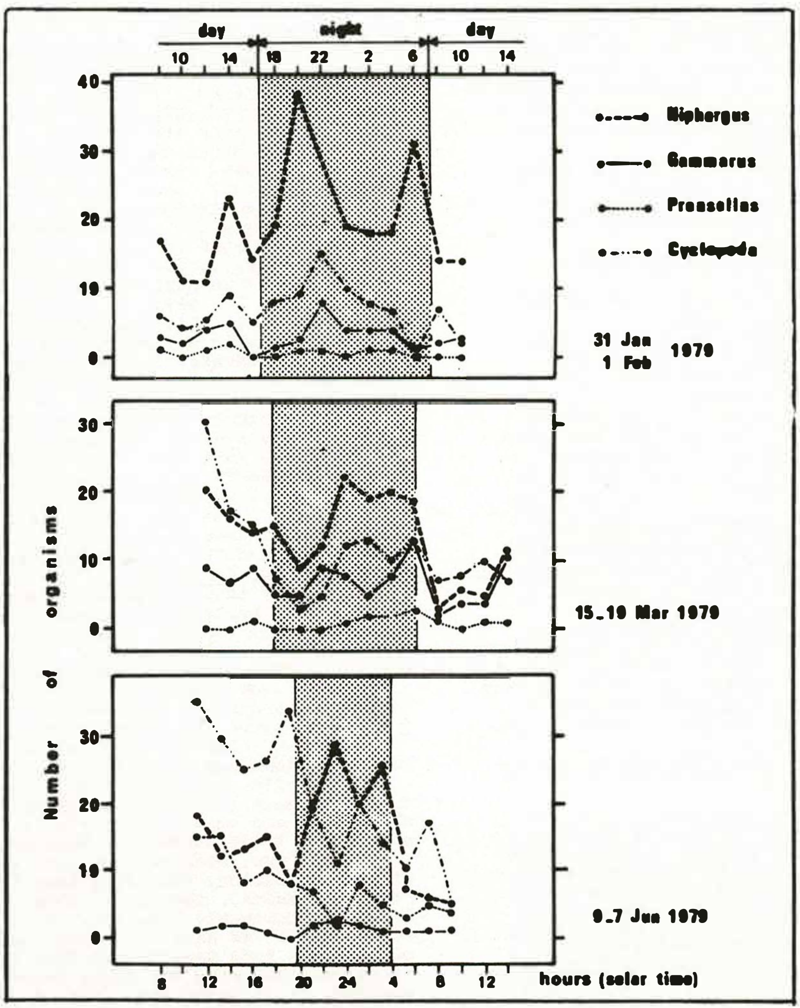


Fig. 3 Daily variation of Crustaceans drift at the PISSOIR resurgence in January, March and June 1979.

Ecological Studies of Openings Into Underground Karst. - I - The Shaft Wall Fauna of An Entrance Pit (Gouffre de Lent, Ain, France) First Results.

J. Gibert, R. Laurent, J. Mathieu, J. L. Reygrobellet
Université Claude Bernard Lyon I, Hydrobiologie et Ecologie Souterraine; Department de Biologie Animale et Ecologie; E.R.A. CNRS n° 849 Ecologie des eaux douces; 43 Bd du 11 novembre 1918; 69622 CILLEURBANNE cedex, France.

Abstract

Within the context of a general study of energy transfers between epigeous and hypogeous ecosystems, the shaft-wall fauna of an entrance pitch was studied (for the first time systematically) during nearly 2 years. For this, it was indispensable to construct a scaffolding enabling precise observation of the pitch wall. By the use of two complementary methods (quadrate analysis and pitfall trapping), the communities populating this vertical wall have been described. They are varied, with a well defined seasonal periodicity and comprise a parietal association comparable to that of the twilight zone in horizontal caves. The presence of this important subtroglophile association and the quantity of permanent troglophiles are due to the morphological and microclimatic characteristics of the wall and also to the particulär characteristics of the whole shaft.

Résumé

Dans le contexte d'une étude générale entreprise sur les transferts d'énergie entre les écosystémes épigés et hypogés, nous avons étudié (pour la premiére fois de façon systématique) pendant prés de deux ans, la faune d'entrée de la paroi d'un gouffre. Pur cela, il a été indispensable d'utiliser un dispositif (échaffaudage) qui nous permette une observation fine de la paroi. L'utilisation de deux méthodes d'estimation complémentaires (analyse de quadrats et piégeage) a permis de decrire les communautés de cette paroi verticale. Elles sont diversifiées avec des périodicités saisonniéres bien définies, et comportent une association pariétale comparable à celle de la zone d'entrée des grottes horizontales. La présence de cette association subtroglophile importante et la quantité des troglophiles permanents de cette paroi sont dues à ses caractéres morphologiques et microclimatiques, mais aussi aux caractéristiques particuliéres du gouffre tout entier.

Introduction

Much works were already been done on the fauna living in caves entrances, but it is only in the past ten years that attention has been turned to quantitative aspects of this community (in PECK, 1976 and in BOURNE, 1977 a). Moreover, data concerning the fauna of entrance pitches is very scant and mainly results from brief observations made during the descent. In fact, because of technical difficulties, the authors consider mainly the screes and shelves at the bottom of the first pitches (GINET, 1955; TURQUIN et BOUVET, 1977). Most of time, they describe the shaft walls of entrances as disappointing environments, because of scarcity of the resident fauna.

Therefore, it seemed useful to perfect a method by which a systematic study of the populations of dynamic of these walls could be made. For this, we sought a representative pit of "Green Karst", which fulfilled the following conditions:

-it must have a large opening on the epigean milieu

-it must open into a well-lighted forested area, with a relatively thick pedologic layer

-it must cut across a faulted karstic network (at the surface and underneath)

-it must be uninteresting to sportsment (to avoid being perturbated by spelunkers)

Out of all the cavities studied by the Laboratory in the "Jura Méridional" over the last ten years, the pit "Gouffre de Lent" (Lambert coordinates 839,33 x 106, 91 x 625; s^t. RAMBERT n° 5) seemed best to fit this description. Moreover, this pit is situated in the karstic area of TORCIEU ___________, where five horizontal cavities and two vertical ones are well known. Several works have already demonstrated that the whole massif is populated by an abundant and varied terrestrial underground fauna (GIBERT et al, 1975 a, 1975 b; ___________ BOURNE, 1977, 1978 a-b).

This publication is the first anlaysis of our studies in the whole pit "Gouffre de Lent", where we have indexed over 50.000 organisms since 1975. Our many results are still being treated, but it is already possible to give some informations about the populations colonizing the shaft wall of the entrance pitch.

Presentation of the Pit; Estimating Methods in the Entrance Pitch

The pit "Gouffre de Lent" is a cavity of structural origin hollowed out from a bundle of joints, oriented in a south-westerly direction (decompression cracks bordering the anticline of CERNAY-CLEYZIEU). The slightly overhanging entrance pitch can be subdivided into three well distinct zones. (Fig. 1):

-1- From 0 to -3m, a frost breaking funnel gives access to the pit; it is a 45° cone, collecting material originating from the plant cover and beyond which the proper wall begins.

-2- From -3m to -10m, (Fig. 1, G to E) the nodulous limestone favours the formation of a multitude of coalescent horizontal cusps, sketching out some waves in the rock (especially at the stratification limits). These micro-reliefs favour the accumulation of detritic material, masking the few existing concretions.

-3- From -10m to -18 m (Fig. 1, D to A), corrosion by rain-wash has been predominating; there are many vertical furrows, now crossed by calcite concretions where the stratification forms slightly overhanging rims. Except for these reliefs, the rock is bare in this part of the pitch, or covered by a thin film of calcite with no detritic deposit.

The properly so called shaft wall (zones 2 and 3) is saturated in moisture, but not sufficiently to produce continuous streams. The bottom of the entrance pitch (-18m) is covered with scree, dogged up by humus and litter fallen from the surface.

Figure 1 shows the maxima of luminosity that the wall can receive. These measurements are made in winter (no plant - cover, snow, sunshine).

To make a serious study of the fauna of this wall, it was necessary to know and observe all its nooks and crannies. Because of this, classical exploration material (cabble ladders, etc...) were replaced by a fixed scaffolding with 7 landing stages at 2 meters intervals, as shown in fig. 1. Owing to this original set up, two methods of estimating could be used simultaneously:

- Systematic observation of all the fauna present in the 2x2 m. quadrates limited by the scaffolding landings (this method is the same as this described by BOURNE, 1977 b).

- Continuous capture by pitfall trapping at points fixed at each side of the zones reserved for observation, at each level (the traps used are the same as those described by GIBERT et al, 1975 a).

The complementarity of these two methodsgives a better picture of the real composition and evolution of this particular entrance. Effectively, there is a great difference between the populations caught in the traps and those observed "in situ":

-by their presence or absence on the one hand (Harvestmen, Spiders for example are trapped very rarely, while they are commonly seen on the rock surface.

-by their frequence (relative abundance) on the other hand, because the attractive power of the traps is more or less selective. Some faunistic groups may therefore be over-or under-estimated in relation to their real place in the wall-community. In these cases, the "in-situ" observations are the most strict. On the contrary, some small individuals (Collembola, Acarida) or very mobile ones (Araneida, Diptera active within the cave) are certainly under-estimated by direct observation, while they are easily quantified in the traps. (POULSON and CULVER 1969; CULVER and POULSON, 1970).

Therefore, both methods give relatively false ideas of the population, but using them together overcomes most of their faults. They must, however, be considered together to correctly integrate the dynamic of the entrance communities. We have therefore coupled these two types of readings from Nov 1977 to June 1979, changing the traps and observing the fauna every two months. The species, or at least the genus of each systematic group, captured or observed directly, was determined in most cases. The complete systematic list will be published later, the object of the present paper being simply to bring out the principal components of this shaft wall community.

First Remarks About the Shaft Wall Community

a. Results obtained by trapping

Firstly, we noticed that the traps were more or less "profitable" depending on their position on the wall. Traps B_2 (bottom right) and G_1 (top left) caught most animals (fig. 2I). They correspond to shelves where litter and organic detritus are accumulating. The other traps, more closely associated with the wall were clearly less productive. When all the levels are considered, the total population of the wall show a seasonal variation with maxima at the end of spring and beginning of autumn and minima in winter (fig. 2, II). In fact, these total spatial or temporal changes reflect the variations of the predominant groups. So, the variations of smaller systematic units can be masked. For these reason, the Collembola which are very dominant in the community captured by the traps, have been separated from the macrofauna in figure 2. However, the two groups seem to have similar evolution in time:

The Collembola show a maximum in Spring and in Summer at all the levels (fig. 2, III). According to Gruia (1976), they ar accidental units in caves entrances, foreign to the parietal association, and "their presence is closely tied to the existence of organic substances". In the pitch, their permanent colonization and their particular dominance in the most earthy regions of the wall would seem to confirm this remark.

The macrofauna is composed by the principal groups colonizing the twilight zone of regional caves (Bourne, 1977 a). The most abundant are Diptera, Coleoptera, Myriapoda, Diploura, Araneida and terrestrial Isopoda. The summer and Autumn maxima are quite synchrone with those of the Collembola and are mostly due to the Diptera, espeically the Phoridae (Triphleba aptina) which at these moments are distributed all over the wall. This is in good agreement with most of the observations carried out in the horizontal caves of the whole massif (Gibert et al, 1975 a et b).

b. Results from the quadrate analysis

The total evaluation of the wall clearly shows two zones of particularly abundant populations (A and especially E: fig. 3, I). A seasonal cycle is easily detected (fig. 3, II), and the periods of maxima (summer) and minima (winter) are very similar of those of the trapped populations.

However, when we pass to the analysis of the systematic groups which are responsible for the observed peaks, the differences become apparent. In fact, contrary to the observations made by trapping, the peaks are caused mainly by the so called parietal subtroglophilic species (Motas et al, 1967) as they form temporary groups (Bourne, 1977b) of important number, which follow in time..Thus, when they are present in the pitch, they are clearly dominant within the population. Some examples are particularly demonstrative:

-Limonia nubeculosa is a Diptera which spends the summer in caves entrances. The figure 3 (V) shows that it appeared in the pitch in June 1977. It stayed there in August and the beginning of September, and then, was totally absent from October 1977 until June 1978. As soon as it enters in the pitch, the population is dense at level E, which has many cusps (as described in §I), sheltered by a slight overhang (see measures of lumiuosity, fig. 1).

-Another Diptera (___________troglophile) is also concentrated in this zone E with its particular microclimatic conditions. This is Speolepta whose larve and nymphs are fairly dependent on the high condensation in this type of relief. After the nymphosis which seems to occur in April in this pitch, the adults are more spread out over the pitchwall.

-Amilenus aurantiacus is a subtroglophile Opilionid spending the winter in __________caves. It has been closely observed in the "Gouffre de Lent". The arrows in figure 3 (VII) show its appearance in the subterranean environment in October and its departure in April (results found over 2 cycles). Therefore, it seems really to behave in this pitch as in all horizontal caves. Apart from these transit periods, our observations in the deeper part of the pitch have shown that the population is fairly large, compared to that of the Cormoran cave situated in the same area and described by Bourne (1978) as rich in this specie of Opilionids.

-Other groups do not show such striking peaks as they constitute the permanent element of the pitchwall community. This is the case for Araneids (fig. 3, VI) which are very varied. They are mostly Tetragnathidae (Meta), Nesticidae (Nesticus), Agelenidae (Tegenaria), Clubionidae (Clubiona), Linyphiidae)_________Leptyphantes). They are found all year round especially at the bottom of the pitchwall, and in Summer, in the zone E where they can easily live on the seasonal subtroglophilic fauna mentioned above (Bourne, 1978).

Finally, the particular case of the Phoridae, especially Triphleba alpina, shall be considered. Contrary to the preceding organisms, they populate the whole pitch, even in the deeper part, and are the "troglophile-troglobite association" of the :Jura méridional". Figure 3 (IV) shows that they were observed all along the entrance pitch, only during the warm season (June to October). This coincides with the maxima shown by the pitfall trapping estimating. Examination of our contemporaneous pitfall traps in the deep part of the pitch would no doubt bring out important complementary informations about the migration of this Diptera in the whole cavity.

Our deep pitfall trappings could also indicate certain migrations of real troglobionts such as the Coleoptera Trichaphaenops cerdonicus which have been found on the entrance pitch wall as far as the zone C.

General Discussion

Following these first results, two remarks must be made:

-the shaft wall of the entrance pitch of the "Gouffre de Lent" shelters a rich and varied community at all the levels. This community is so diversified because of the seasonal visits of numerous subtroglophiles among the resident troglophiles and sporadic trogloxens. Before 1976 this was not obvious for us, in spite of our many descents through this pitch. It is only by the construction of a scaffolding that the inhabitants could be quanitifed in such a way that the results were really comparable to those found in horizontal caves.

-the faunistical structure mentioned above is due to the particular morphological and climatic conditions of this pitchwall. Moreover the whole pitch itself and the karstic massif characteristics have also a great responsibility on this structure.

Therefore, we may conclude that, in our further studies, the shaft walls should be not dissociated from the rest of any cavity, because the imbrications between the different biocenoses are yet far from clear.

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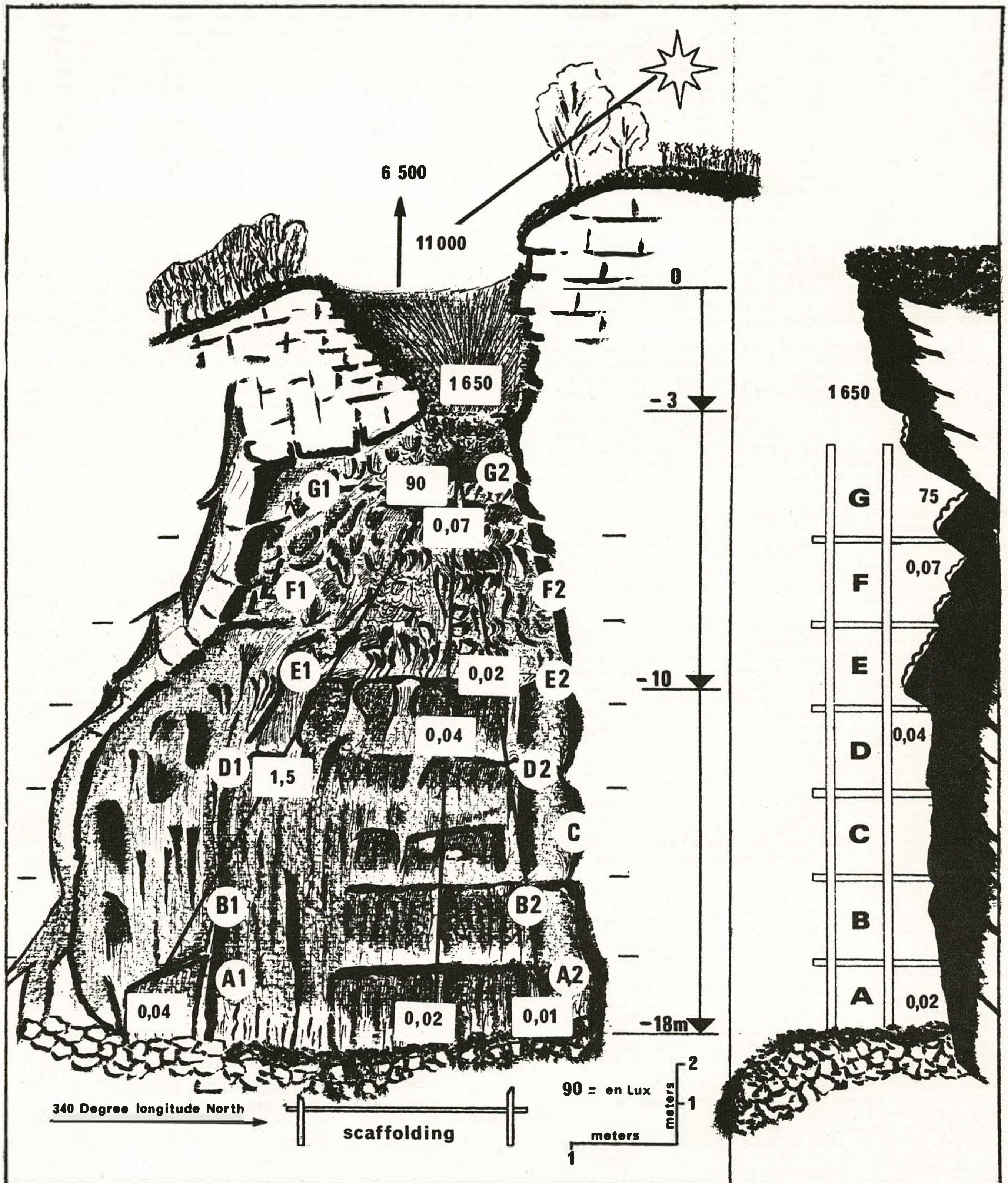

Figure 1: Plan and coupe of the entrance pitch (Gouffre de Lent) showing:
1- the fixed scaffolding
2- the relief features of the wall
3- the trap and quadrate sites
4- the values of luminosity (in lux)

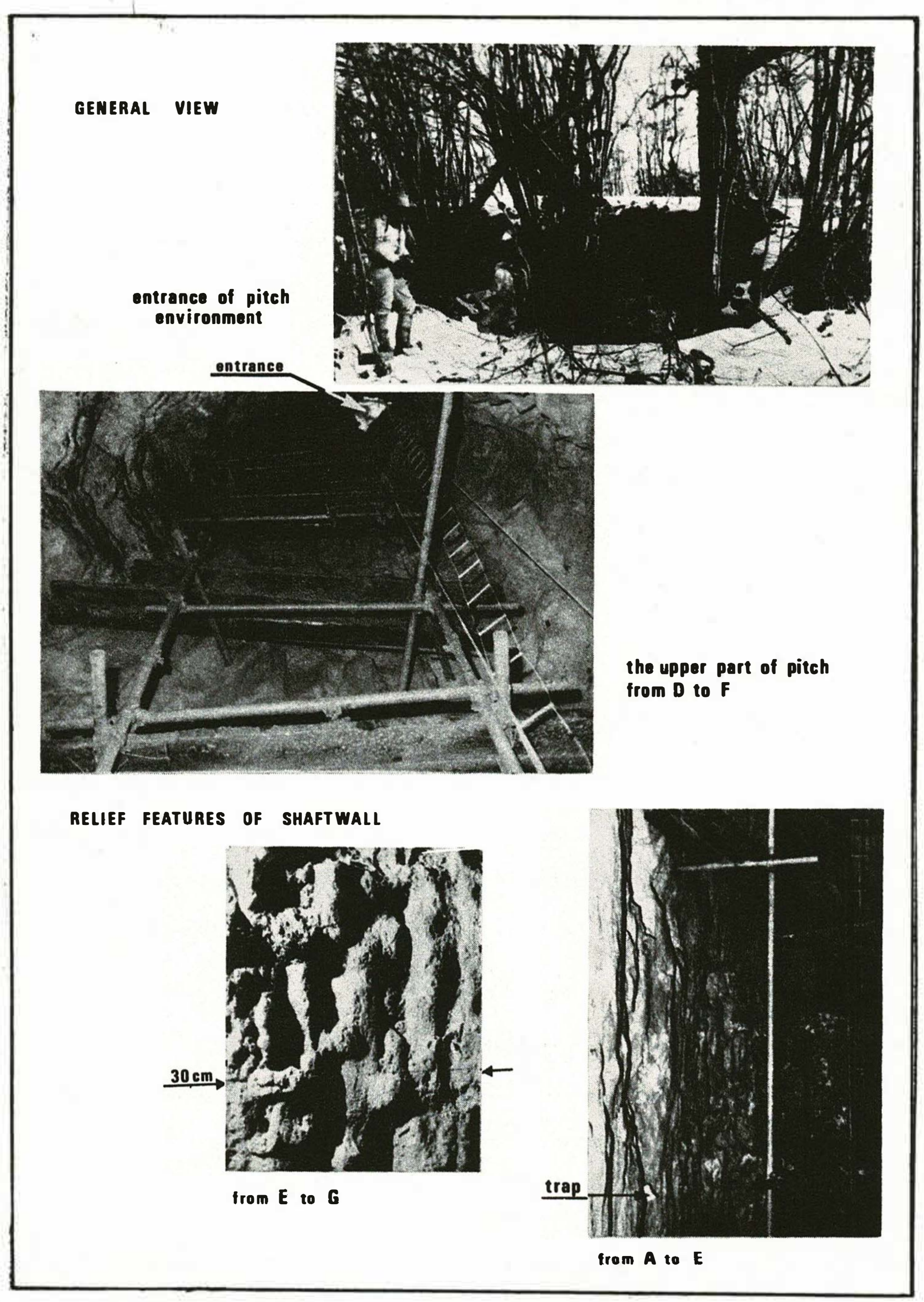

Figure 1b. General view of the entrance pitch (Gouffre de Lent). Letters are keyed to Figure 1.

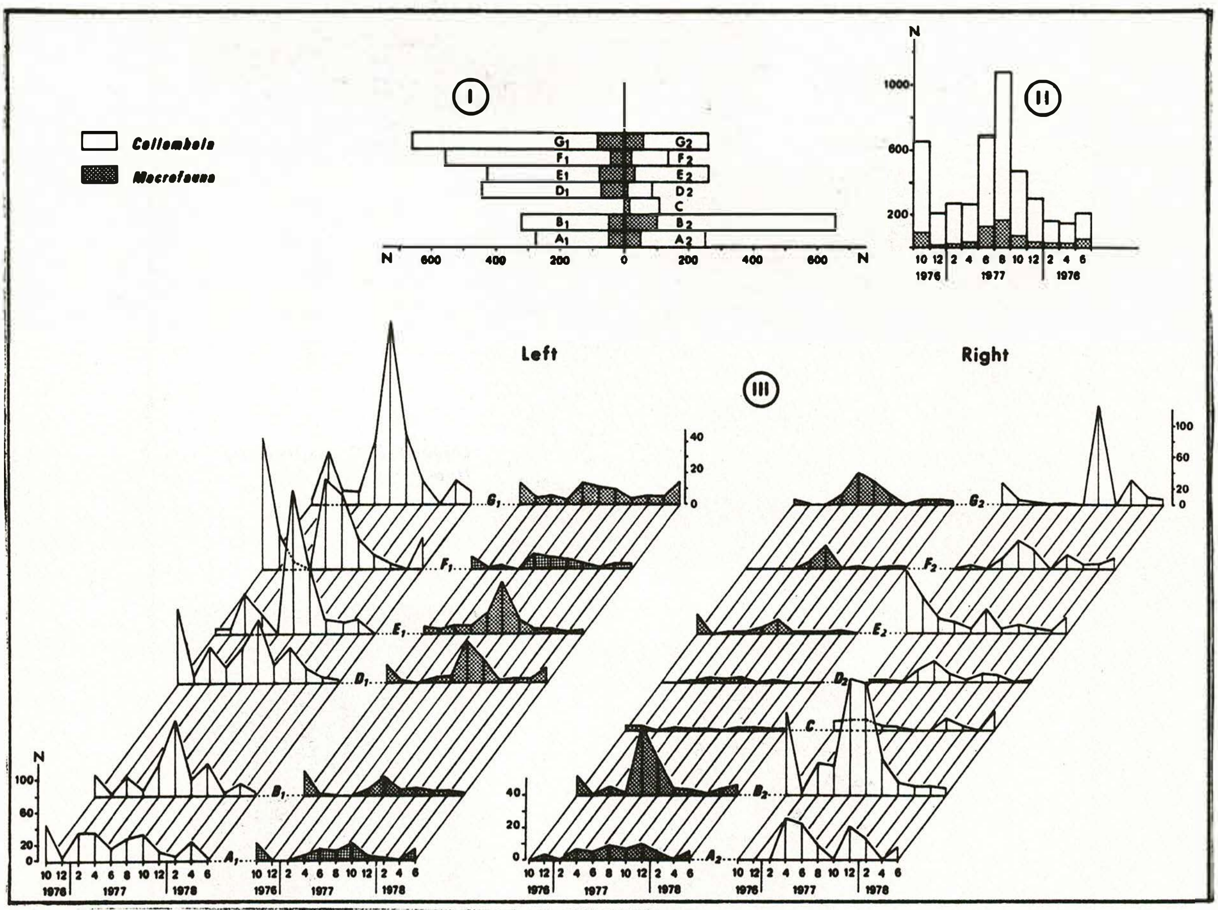

Figure 2: Fauna collected in the pitfall trappings.
I- Number of individuals collected during the whole study at the different levels of the pitch; on the left (A_1, B_1, ...) and on the right (A_2, B_2, ...).
II- Total evolution in time of the number of individuals (N) collected in the pitfall trappings.
III- Evolution in time of the number of individuals (N) collected in each pitfall trapping.
For all the figures, dotted surfaces = macrofauna; white surfaces = Collembola.

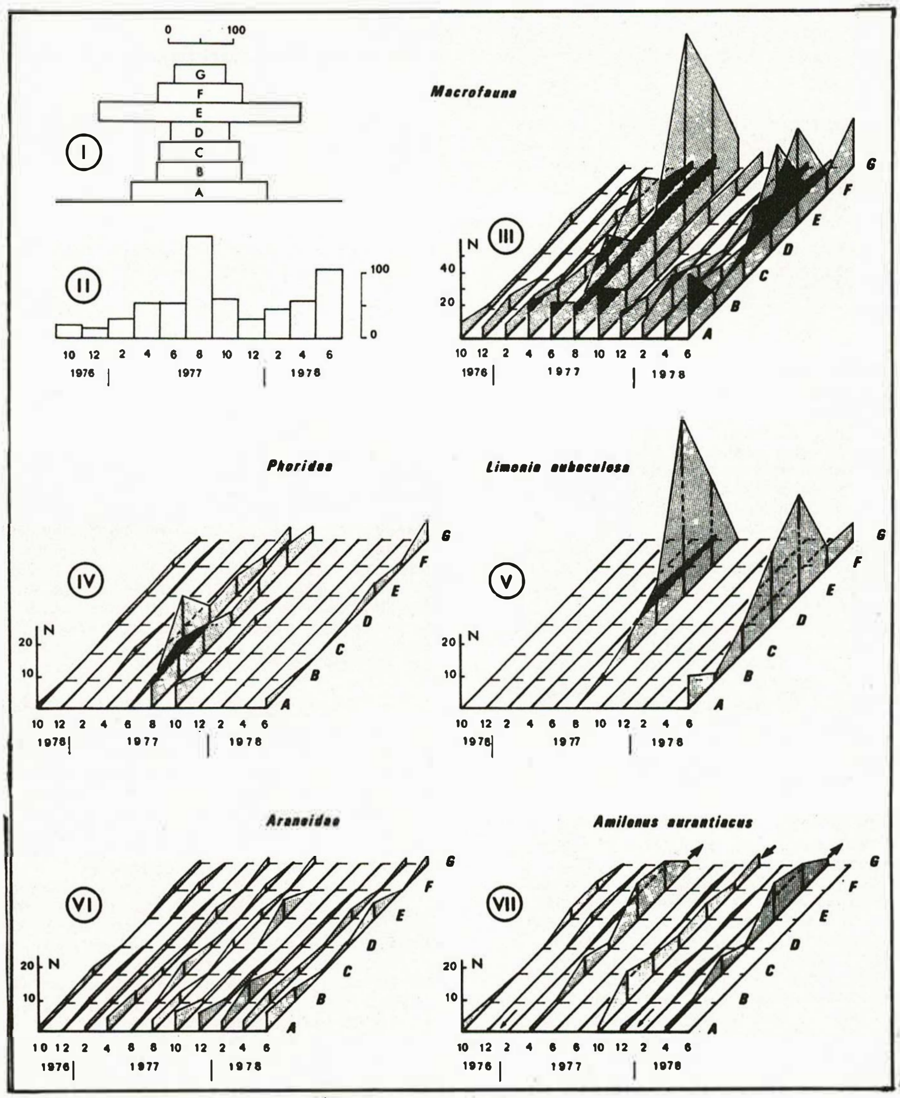

Figure 3: Fauna observed by quadrate analysis.
I- Total numbers of individuals observed at each level of quadrates.
II- Evolution in time of the degree of colonization on the wall.
III- Evolution in time of the number of animals observed in each quadrate (A,B,C, ...).
IV- Variations in space and time of the number of Diptera Phoridae.
V- Idem for Limonia nubeculosa (Diptera).
VI- Idem for spiders.
VII- Idem for Amilenus aurantiacus (Opiliones). Arrows indicate the passages of this specie; big arrows: entrance to or exit from the pitch; little arrows: Amilenus goes to the deeper part of the cave.

The Subterranean Caecidotea of the Interior Low Plateaus

Julian J. Lewis
Water Resources Laboratory and Department of Biology, University of Louisville, Louisville, KY 40292

Abstract

Six subterranean species of Caecidotea inhabit the Interior Low Plateaus: Caecidotea stygia, C. barri, C. jordani, C. bicrenata, C. sp. 1 and C. sp. 3. These species are members of the stygia group. The most interesting situation from a ecological or zoogeographical point of view exists in Mammoth Cave National Park, where Caecidotea stygia and C. sp. 1 both occur together.

Résumé

Six espèces souterraines des Caecidotea habitent les Plateaux Bas de l'Intérieur: Caecidotea stygia, C. barri, C. jordani, C. bicrenata, C. 1, et C. 3. Ces espèces appartiennent au groupe stygia. La situation la plus intéressant du point de vue ecologique et zoogeographique existe à la Mammoth Cave au Parc National (Kentucky, E-U), ou et la Caecidotea stygia et la Caecidotea 1 se présentent ensemble.

Introduction

The Interior Low Plateaus (ILP) comprise an area of the southeastern United States, from northern Alabama to central Indiana, and west into southern Illinois. The entire region, lying south of the limit of glaciation, was formed on part of a broad north-south anticline known as the Cincinnatti Arch. In much of the ILP limestones lie at or near the surface and thousands of caves have been recorded from the area, including the largest cave system known, the Flint-Mammoth Cave of central Kentucky. The caves lie in relatively undisturbed, flat-bedded limestones, which provide few physical barriers to the dispersal of aquatic troglobites.

When compared to other U.S. cave areas, the diversity of the subterranean isopod fauna in the Interior Low Plateaus is poor, with only six species known from the area (Figure 1): Caecidotea stygia Packard, C. bicrenata (Steeves), C. barri (Steeves), C. jordani (Eberly), and two undescribed species, Caecidotea sp. 1 and C. sp. 3 (following the designations of Peck and Lewis, 1978). All of these species belong to the stygia group, an assemblage of perhaps a dozen subterranean species.

Zoogeography

The zoogeography of subterranean asellids inhabiting the Interior Low Plateaus has been difficult to accurately interpret, because the taxonomy of the group has been confused. The morphology of the male second pleopod, used to separate the species, is very similar in all six species, and essentially identical in four of them. Caecidotea stygia and C. barri are separable from the group by the morphology of the first and second pleopods. However, the other four species, C. jordani, C. bicrenata, C. sp. 1 and C. sp. 3, are easily confused and other criteria are needed to separate them. To add to the problem, the name Asellus alabamensis has been applied to all of these but C. sp. 3 (Fleming, 1972), although C. alabamensis is authentically known only from a locality on the southern fringe of the Piedmont (Lewis and Bowman, in press).

One method of distinguishing some species of subterranean asellids is to analyze the differences between troglobites and phreatobites. Phreatobites live in quite different habitats from troglobites and are often found in areas where caves do not exist, as is the case with Caecidotea sp. 3. This species, being described from Dixon Springs, in southern Illinois, is also known from several drain tiles in southern and central Illinois. The morphology of phreatobites is also distinctive; in all of the midwestern species, i.e., C. sp. 3, C. kendeighi, C. tridentata and C. spatulata, plus other undescribed species, the body is very slender and elongate, slightly pigmented, and in C. kendeighi vestigial eyes are present. A newly recognized character which has been exclusive to phreatobites is the structure of the fourth pleopod, in which the placement of the false sutures divides the exopod into 3 areas in phreatobites, but only 2 areas in troglobites (Lewis and Bowman, in press).

The three remaining species, C. jordani, C. bicrenata and C. sp. 1 are troglobitic, lacking any vestiges of pigmentation or eyes. Caecidotea jordani endemic to southcentral Indiana, can be separated from the others by its allopatric range and morphological details (Eberly, 1965; Lewis and Bowman, in press).

Distinguishing C. bicrenata and C. sp. 1 has been a formidable task, and the taxonomic details will not be discussed here (Lewis, in prep.). The zoogeography of these two species is interesting, because it appears to be one of the few (if not the only) cases of parapatry among the troglobitic Caecidotea. Caecidotea sp. 1 is found from southern Illinois, through central Kentucky and into northern Tennessee. In northern Tennessee, a narrow band of secondary contact occurs, immediately south of which C. bicrenata is found, ranging into northern Alabama.

Sympatry of troglobitic Caecidotea is common in the northern part of the Interior Low Plateaus. Caecidotea stygia is sympatric with C. sp. 1, C. jordani and C. barri. The ranges of C. stygia and C. sp. 1 are especially interesting, as they overlap in general, but in many places are mutually exclusive. In western Kentucky, C. sp. 1 appears to entirely displace C. stygia, but C. stygia then occurs again in southern Illinois and eastern Missouri. Only in central Kentucky and possibly northern Tennessee do the two species actually occur together, and only in the Flint-Mammoth Cave System of central Kentucky are they syntopic.

Distribution and Ecology in Mammoth Cave

The Flint-Mammoth Cave System in Mammoth Cave National Park is an extremely complex cavern developed on at least five levels, and contains several large base-level streams that drain the sinkhole plain adjacent to the park. In the upper levels, the major habitats are shaft drains, small streams which drain the large pits common in the cave, and breakdown streams, which occur at many of the terminal breakdowns.

To evaluate the distribution of Caecidotea sp. 1 and C. stygia in the Mammoth Cave area, many localities at various levels of Mammoth Cave have been sampled, plus caves on the sinkhole plain and springs on Green River. To study population fluctuations within the cave, detailed censusing is being conducted in Shaler's Brook, a shaft drain stream in Gratz Avenue, and at Lookout Mountain, where a small stream flows down the terminal breakdown of Rafinesque Hall.

The distribution of the two species has for the most part followed a consistent pattern. Caecidotea stygia is the only isopod species found in the two uppermost levels of the cave, in habitats like shaler's Brook and Wandering Willie's Spring. Throughout its range this species is known from an array of habitats, such as cave streams, drip pools, rimstone pools, wells, springs and even intermittent surface streams (Steeves, 1963; Bowman and Beckett, 1978; Lewis and Bowman, in press). Caecidotea stygia is a habitat generalist, an opportunist which will inhabit almost any subterranean habitat within its range if another more specialized species is not present.

As discussed by Barr and Kuehne (1971), the uppermost aquatic habitats in Mammoth Cave are rather ephemeral, and some, e.g., Wandering Willie's Spring, dry up entirely during later summer or autumn, but further down into the system streams become more abundant and permanent. Caecidotea sp. 1 begins to occur in the middle levels of the cave and is in all of the base-level cave rivers. Caecidotea sp. 1 is a habitat specialist, and lives only in such permanent, gravel or breakdown strewn streams at or near base-level. Although it is impossible to tell in the cave which species of isopod one is observing, in all cases studied so far, when the troglobitic crayfish Orconectes pellucidus is present, the isopod found with it will be Caecidotea sp. 1.

An exception to this distribution pattern of these species is found in the Styx, Echo and Roaring rivers. In this part of the cave, water backfloods from the Green River because of Green River Lock and Dam 6, located downstream from the cave, near Brownsville. The backflooding has caused a rise in the level of the cave rivers, reduced stream velocities, and heavy siltation in the downstream parts of the rivers. The biological consequence of the siltation has been reduced habitat diversity.

In the disturbed area the optimum habitat of Caecidotea sp. 1 is almost entirely absent. With the absence of C. sp. 1, C. stygia has taken over the silted parts of the streams, but even this species is rare due to the lack of suitable habitats. Moving upstream from the effects of the backflooding, an interface, where both species occur, is present in the Styx and Roaring rivers. In the upstream extension of the park's base-level cave streams, at Mill Hole, Gray's Water Cave and Parker Cave (all on the sinkhole plain), only *Caecidotea* sp. 1 has been found.

Studies conducted in Shaler's Brook have shown that *C. stygia* uses gravel riffle habitats and silt bottomed areas very differently. During the peak of the spring reproductive period, population densities of this species rise to about 70 individuals /15 cm^2 in the gravel riffle areas, then gradually fall to about 10 /15 cm^2 by the end of the year. The silt bottomed areas of the stream have a maximum population density of 0-1 /15 cm^2 during the entire year. The isopods congregate in the gravel areas, where cover is available, and cling to the undersides of stones, or in spaces between the gravel. *Caecidotea stygia* also uses the riffle areas to reproduce, and population densities may be higher there because the young can hide from predators in the gravel.

In the silted areas of Echo and Styx rivers the population has become greatly reduced because of the uniformity of the substrate. Censusing in the silted parts of the rivers has revealed a population density of nearly zero, and seasonal replenishment does not occur, since the isopods seem to avoid congregating, much less reproducing, where cover is not available. The absence of isopods in large expanses of the river passages has also deprived other species, such as the crayfish *Orconectes pellucidus*, of one of their primary food sources. The crayfish reported as common by Hay (1902) before the construction of the dam, are now rare in the silted areas.

Some hope, however, exists for the restoration of the natural habitat in the Styx and Echo rivers. Green River Lock and Dam 4 collapsed in 1965, leaving dams 5 and 6 stranded upstream. Commercial navigation is thus restricted to the part of Green River ponded by Dam 3. The Cave Research Foundation has recommended removal of the structures at Lock and Dam 6, which would reinstate free flow conditions in the silted parts of the cave, with a gradual increase in habitat diversity, and restoration of the natural cave community (Duchon and Lisowski, 1980).

Acknowledgements

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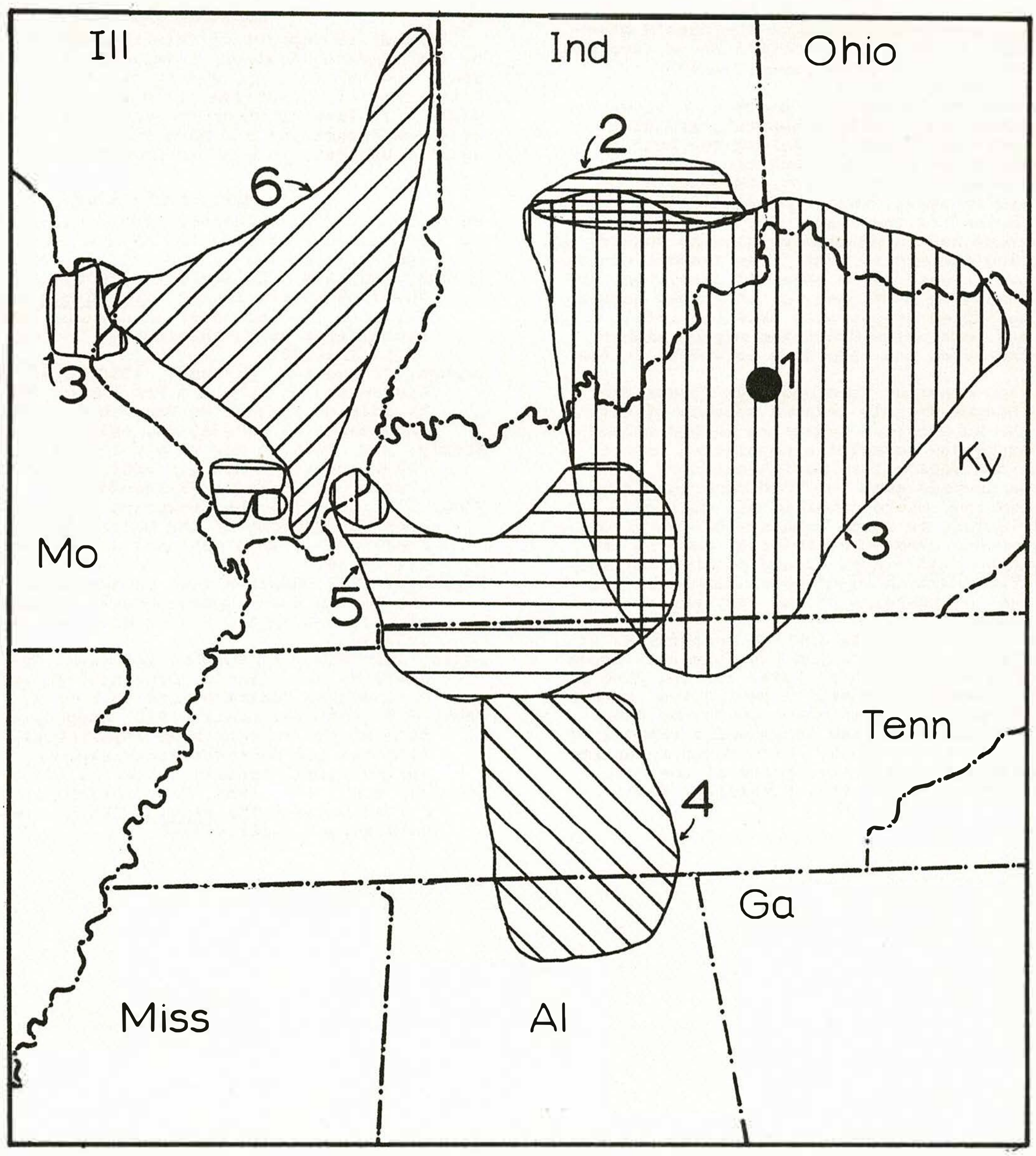

Figure 1. The distribution of subterranean asellids inhabiting the Interior Low Plateaus: (1) Caecidotea barri, (2) C. jordani, (3) C. stygia, (4) C. bicrenata, (5) C. sp. 1, (6) C. sp. 3. Much of the range of Caecidotea sp. 3 lies north of the Interior Low Plateaus and parts of the ranges of C. stygia and C. jordani also extend outside of the boundaries of the province.

The Relationship Between the Availability of Organic Carbon and Cavern Development in the Phreatic Zone

Julia M. James
Inorganic Chemistry, University of Sydney, N.S.W. 2006, Australia

Abstract

In Bungonia Caves, New South Wales, Australia the distribution of both organic and inorganic carbon has been studied in the phreatic zone. Water chemical analyses of samples from an input pool and an output spring have been made over the last eight years. The water chemical measurements to be discussed are Ca^{2+}, alkalinity, dissolved oxygen and total organic carbon. The water in the system has been both siphoned and pumped out a number of times. During these operations water chemical and tracing studies have been made. The results from the water analyses and associated hydrological studies have enabled a carbon cycle in this system to be constructed and the influence of organic carbon on cavern development assessed.

Résumé

A Bungonia Caves, New South Wales, Australie, les distributions de charbon organique et de charbon anorganique ont été étudiés dans la zône phréatique. On a fait pendant huit années l'analyse chimique des échantillons des eaux de la mare d'entrée et le ruisseau de sortie. On va discuter les mésures chimiques de Ca^{2+}, d'alcalinité, d'oxygène dissourdu et de charbon organique total. L'eau dans la système a été siphonée et pompée plusieurs fois. Pendent ces opérations, des études chimiques de l'eau et des études de trace ont été faits. Les résultats des analyses de l'eau et des études hydrologiques associées ont permis une cycle de charbon de cette système d'être construite et l'influence du charbon organique sur le dévelopment de la grotte d'être estimée.

Introduction

Cavern development in the phreatic region of caves has been the subject of much debate. Limestone corrosion in this submerged region continues even though the waters entering it may be close to saturation with respect to calcium carbonate. A number of theories have been put forward to explain this. Bögli (1964) presented the "mixing corrosion effect", later quantified by Wigley and Plummer (1976) for both open and closed systems. Increased ionic activity by infiltration of saline waters, especially sea water (a special case of the mixing corrosion effect) theoretically would allow significant additional amounts of calcium carbonate to dissolve. This increase in ionic activity appears to have an important role developing the large phreatic tubes found in the caves on the Nullarbor Plain, Australia, and the large chambers in tropical island caves. These are only two of the effects that can contribute to cavern development by apparently saturated waters.

This paper presents evidence for a further contributing factor, the production of carbon dioxide from organic carbon in the phreas by the respiration of microorganisms. Additional evidence can be found in the works of Bray (Picknet et al., 1976) and Atkinson (1975). The production of carbon dioxide in this manner is generally accepted for ground waters.

The analytical data in this paper have been obtained for the system at Bungonia Caves, N.S.W., Australia (James et al., 1978). These caves are unusual because of the considerable quantities of carbon dioxide always present in their atmospheres; the composition of the cave atmospheres indicates that the majority of the carbon dioxide is biologically produced (James, 1977). Water chemical and sediment studies to determine the mechanisms of mineral deposition in the caves have continued for several years. Some of the results from these studies are used in this paper to infer the distribution of organic carbon and to construct a carbon cycle for one of the phreatic sections in the Bungonia Caves area. Pumping and siphoning experiments have also been used to obtain useful chemical data.

Discussion

A. The Phreas (Figure 1)

The phreas to be described lies some 160 m below the surface and is believed to follow a fault line for 360 m from Knockers Cavern to the spring The Efflux (James et al., 1978). The only accessible streams that flow into it are both in Odyssey Cave (Figure 2). The stream which enters at site A is a collection of percolation waters, which flows through the cave, first over argillite and then through deposited sediment to join the phreas in Knockers Cavern. The second stream enters the cave at site B, The Sirens; its source is in the other deep foul air caves in the area. Its course cannot be followed between The Sirens and the Beauty Parlour (site C) where it enters Knockers Cavern. Evidence from quantitative dye traces, flow measurements and siphoning and pumping experiments (James and Martin, in preparation) indicates that the volume of water contained in the phreas is at least 2000 m^3, with only a small surface area exposed to the cave atmosphere. The amount of water observed entering the phreas at Odyssey Cave is only 15% of that emerging at The Efflux.

Excavations since 1955 at The Efflux have lowered the level of the phreas some 5 m (Bonwick, 1972) and this can be lowered a further 5 m by siphoning and pumping. When the water level is lowered, the cave at both ends can be examined. The passage at the spring has dynamic phreatic character, with scalloping on the rock walls. Knockers Cavern is largely nothephreatic, with rock pendants. The Beauty Parlour is usually submerged and has little water flow. There are vast sediment deposits at both ends of the system. Water takes 16 days to reach The Efflux from Odyssey Cave in average flow conditions.

B. Forms and Distribution of Carbon In and Around the Phreas

Production of carbon dioxide by microorganisms requires a source of organic carbon. In order to establish possible sources it was necessary to consider the carbon cycle in the cave. Figure 3 shows the postulated carbon cycle, and indicates the forms of carbon present. The arrows indicate directions of movement of carbon and the double circle encompassing all of these represents the importance of the biosphere on these movements.

There are two major sources of organic carbon for the phreas, the streams flowing into it and the sediments associated with it. There are normally no surface streams in the Bungonia Caves catchment, so that only percolation waters reach the phreas. The percolation waters collect into small streams which flow through foul air caves and then into the phreas. These waters contain a considerable amount of organic matter, for example, the stream flowing into the pool in Knockers Cavern contains an average of 30 mg ℓ^{-1} total organic carbon (TOC) from 56 measurements over 5 years, and the Efflux water contains an average of 16 mg ℓ^{-1}.

The sediments are a much richer source of organic material. After flood rains, streams flow into the cave entrances, carrying solid organic materials, some of which accumulate in the restricted sections of the caves. Considerable amounts pile up in the chambers at the bottoms of the caves. This material may then be buried under clastic sediment as the floods subside. The banded sediments in Knockers Cavern contain many different layers of material (James, 1972). Carbon analyses in a core sample taken in Knockers Cavern are presented in Table 1.

Table 1

Sediment type	%C (various bands)
sands	0, 1.1, 1.2
clays	3, 9, 12, 18
red bands	10, 11, 11, 14
black bands	26, 32

Muds collected in Knockers Cavern gave 5-14% carbon for seven samples, and at The Efflux 4-8% for six samples.

No analyses for carbon are available for the Bungonia Limestones. The bedrock as a source of organic material should be considered, since it is part of the phreatic system, but its contribution will be small.

C. Production of Carbon Dioxide from Organic Carbon

Organic carbon is oxidised to carbon dioxide by biological processes on the bedrock surface, in the sediments and in the waters of the phreas. In the phreatic levels of Bungonia Caves there is no shortage of suitable microorganisms. Both aerobic and anaerobic types can migrate freely through the phreas (Dyson and James, 1973). Aerobic organisms require dissolved oxygen (dO_2). Many of them also require a source of organic carbon. The cave waters throughout the phreas contain sufficient organic carbon, and considerable quantities emerge from the system at the spring. The supply of dO_2 is more limited. Water surfaces in the phreas exposed to cave atmospheres are believed to be small, so equilibration with them will only be a minor way of replenishing the dO_2 after microbial action. A second source of dO_2 is the streams which flow into the phreas, some of which already have reduced dO_2 because their courses lie in the foul air caves. During the years of measurement the cave waters leaving the spring have consistently had lower dO_2 than the cave streams.

The waters leaving the system contain microorganisms, organic material and dO_2, so that the process of CO_2 production can continue. This is demonstrated by the behaviour of water samples in the aggressiveness test of Stenner (1969). This "latent aggressiveness" has been observed in other systems (Brook, 1976; James, 1980).

The sediments in the phreas are also important in the production of CO_2 in the system. It has been estimated that some 30-50% of the carbon deposited in new sediments will be liberated as CO_2 or CH_4 (Bordovski, 1965). While oxygen is present the aerobic microorganisms will produce CO_2. When the oxygen is depleted the anaerobic bacteria become active, producing CH_4 as well as CO_2. At this stage the muds and sediments smell of hydrogen sulphide, indicating that they are anoxic.

D. Reaction of Carbon Dioxide with the Bedrock

The majority of the carbon dioxide produced is available for cavern development. The extent to which the extra solution is occurring is estimated from measurements of Ca^{2+} and alkalinity.

Examination of the chemical data obtained from Odyssey Cave and The Efflux show an increase of Ca^{2+} and alkalinity between the cave and the spring. The same waters show a decrease in dO_2 and TOC. Any jubilation arising from these results showing the expected trends is short-lived, because, with only 15% of the source water characterised, no significant calculations of erosion rates can be made. The siphoning and pumping experiments give more reliable data, and no assumptions need to be made in the calculations about the unknown water sources. There is a direct relationship between the dO_2 and the volume of water withdrawn from the phreas, and an inverse relationship between Ca^{2+} and volume removed. This indicates a dO_2 gradient through the phreas, high at the source and low at the spring, indicating that microbiological activity is occurring throughout the phreas. The CO_2 produced by this activity has caused solution of the bedrock, giving a Ca^{2+} gradient in the opposite sense.

E. Erosion in the Phreas

Preliminary calculations (James, in preparation) on the data in the siphoning and pumping experiments indicate that the erosion rates are less than 10 $m^3 km^{-2} yr^{-1}$ and that they remain fairly constant through the various experiments despite the range of base flows. The erosion occurring in the phreatic zone is some 10% of the total erosion in the Bungonia Limestone. The other 90% of the erosion is distributed between the surface and foul air regions of the caves. This remaining erosion has a distribution that is highly variable with as much as 50% of it occurring in the foul air regions of the caves. Variations in the distribution pattern of this erosion can be related to events outside the caves, such as bushfires and floodrains. The figure of 10% of the total erotion for the phreatic zone is higher than anticipated and it is believed that this, like the high percentages of carbon dioxide in the cave atmosphere, is probably another special feature of Bungonia Caves.

Conclusion

Carbon dioxide is produced in the phreas. It is produced by microorganisms from the always available organic carbon in the cave waters and sediments. Dissolved oxygen is required in some of these processes and there is sufficient present in the cave waters to maintain activity by aerobic microorganisms from streamsink to spring. In cavern development in the phreatic zone at Bungonia, both the carbon dioxide produced in the cave waters, and that produced in the sediments are important. The supply of food and oxygen is generous so that considerable carbon dioxide is produced and the resulting corrosion leads to a significant increase in passage size. Microorganisms appear to be more numerous at rock or sediment/water interfaces and much of the solution occurs at these.

The mechanism proposed in this paper for cavern development can explain many if not all of the geomorphic observations in the drained phreatic passages. A classical phreatic passage with uniform cross section and extending for kilometres is easiest to explain by continuous microbial activity and difficult using the other theories. However, it is not the purpose of this paper to present an alternative theory to those proposed by Bögli and others, but an additional one.

Acknowledgements

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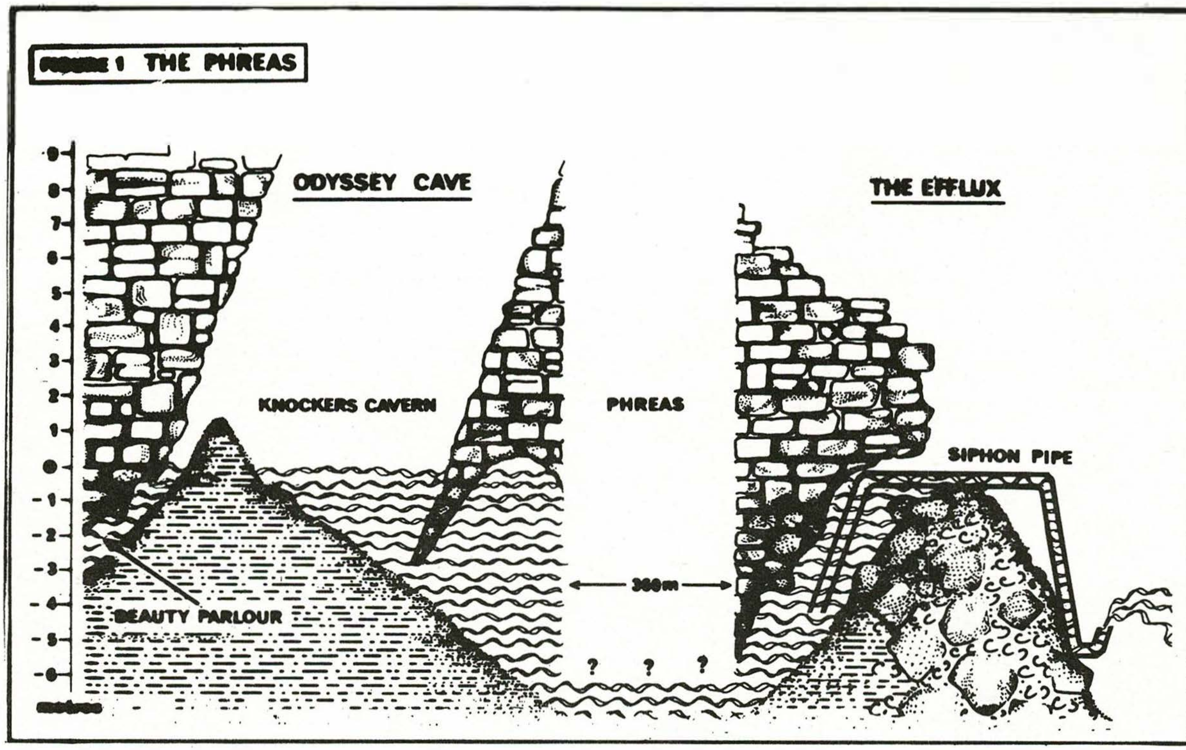

FIGURE 1 THE PHREAS

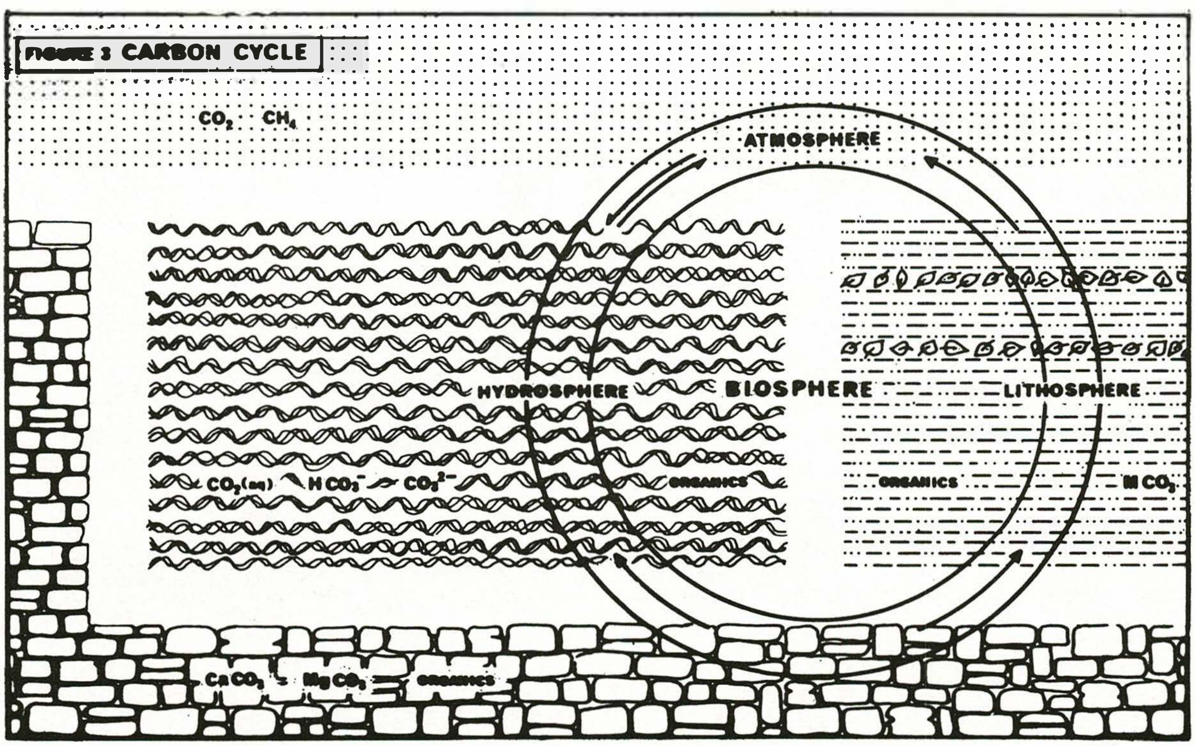

FIGURE 3 CARBON CYCLE

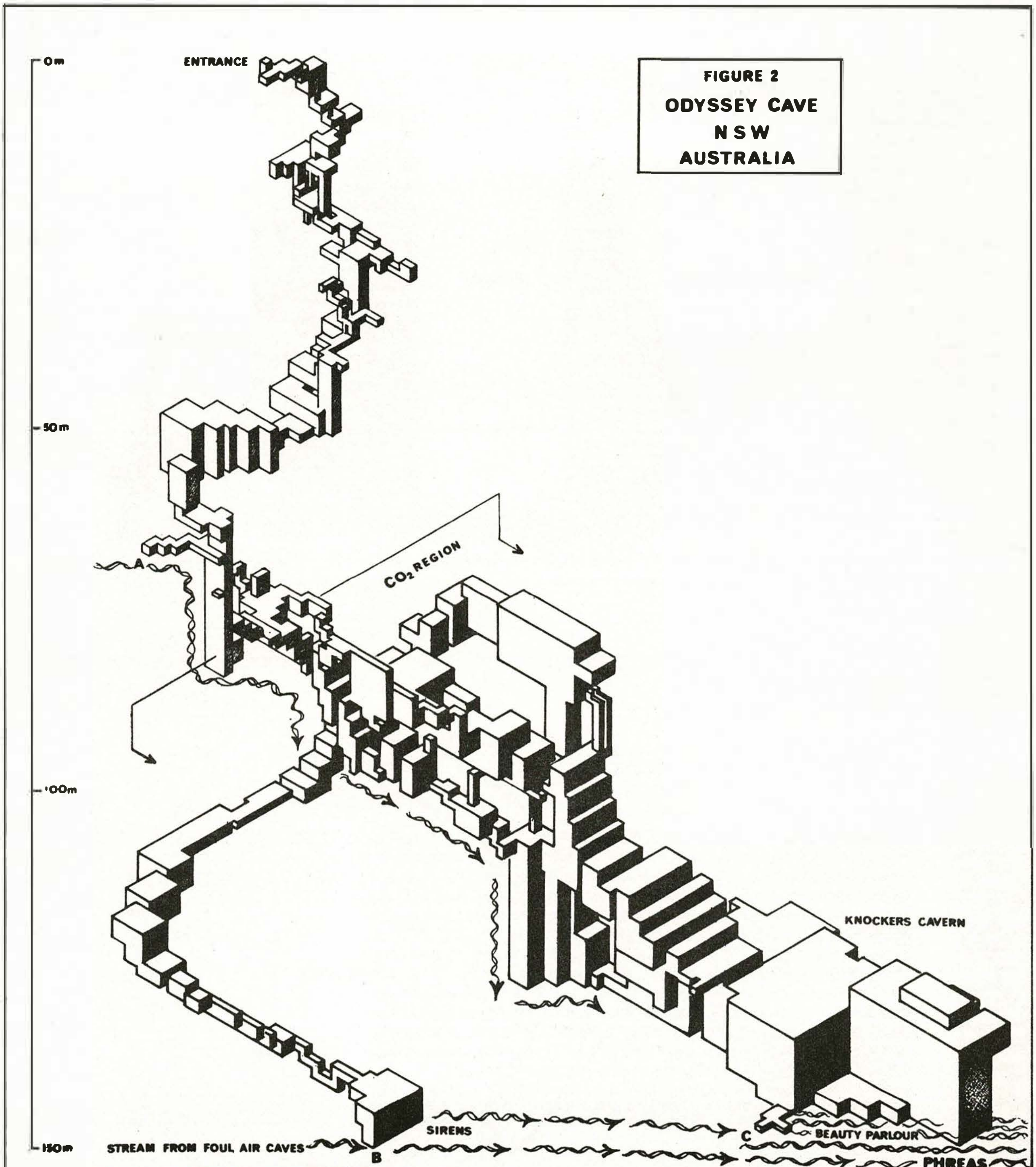
FIGURE 2
ODYSSEY CAVE
N S W
AUSTRALIA
0m
50m
100m
150m
ENTRANCE
CO_2 REGION
A
KNOCKERS CAVERN
SIRENS
STREAM FROM FOUL AIR CAVES
B
C
BEAUTY PARLOUR
PHREAS

Experimental Breeding of the U.S. Cavernicolous Crustacean Caecidotea Recurvata (Steeves, 1963)

Guy J. Magniez
Université de Dijon, Biologie Animale et Générale, 6, Bd. Gabriel, 21100 Dijon, France

Abstract

Thanks to Prof. Dr. John R. Holsinger, we brought back to France some living adults of this large species, captured in the brook of Buis Saltpetre Cave, Clairborne County, Tennessee (sept. 19th, 1978).

Using the same breeding methods as for European Stenasellids, we kept a single pair of C.r. in an aquarium at 12° C in an isothermic chamber, for 2 years. They can grow and reproduce, feeding indefinitely on elm-tree dead leaves and Cerophyl. In spite of the enormous size of ♂ propodites 1, they showed no predatory behaviour and did not burrow cave clay. The ♂ reached 18 mm and the ♀ 14 mm.

As for European cavernicolous Asellids, the intermolts last several months and the intramolt is long (3-4 days). The regeneration of an antenna or uropod needs at least 2 intermolts.

The ♀ is very prolific, being able to lay twice a year. Brood size was about 40 living youngs. Intramarsupial life exceeds slightly 2 months. The young leaving the brood-pouch have a normal juvenile aspect and the hypertrophic size of adult gnathopods and uropods seems to result from later allometric growth.

One year after leaving the marsupium, the young have reached some 6-9 mm; the genital-rest oostegites of the larger young females began to develop and their first generation of ovocytes began to grow inside their ovaries.

Résumé

Grâce au Prof. Dr. John R. Holsinger, nous avons pu rapporter en France quelques exemplaires adultes vivants de ce grand Asellide, capturés dans le ruissear de Buis Saltpetre Cave, Comté de Clairborne, Tennessee, le 19 septembre 1978.

En utilisant les mêmes techniques d'élevage que pour les Sténasellides européens, nous avons conservé un couple de C.r. durant 2 ans dans un aquarium à 12°C de nos chambres isothermes. Les Crustacés croissent et se reproduisent, nourris uniquement de feuilles mortes macérées d'Orme et de Cérophyl. Malgré la taille énorme du propodite du péréiopode 1 ♂, ilsn'ont montré aucun comportement prédateur et ne creusent pas de terriers dans l'argile. Le ♂ a atteint 18 mm et la ♀ 14 mm.

Comme pour les Asellides cavernicoles d'Europe, les intermues durent plusieurs mois et les intramues 3-4 jours. La régénération d'une antenne ou d'un uropode exige au moins 2 intermues.

La ♀ est très féconde, ayant donné 2 pontes par an. Les portées sont d'environ 40 pulli vivants et la vie intramarsupiale dépasse légèrement 2 mois. Les jeunes qui quittent la poche incubatrice ont un aspect normal d'Asellides juvéniles: ainsi, l'hypertrophie des gnathopodes et uropodes de l'adulte semble résulter d'une croissance allométrique tardive.

Un an après avoir quitté le marsupium, les jeunes ont atteint 6-9 mm. Chez les plus grandes des jeunes femelles, les oostégites de repos génital commencent à se développer et la première génération d'ovocytes s'accroît dans les ovaires.

Introduction

The Asellids studied here have been captured during a field trip (sept. 17-19th, 1978) in the caves of Powell Valley (see Steeves, 1969; Holsinger, 1975), after the International Symposium on Groundwater Biology in Blacksburg, Va. The trip was led by our friends Prof. Dr. John R. Holsinger and David C. Culver. We thank them very much for all their help and advices.

Capture, Transportation and Rearing

The specimens of Caecidotea recurvata were captured with a large plastic spoon and a thin brush and placed in a small expanded polystyren box with some mosses twigs. These boxes are suitable for Isopods transportations as the animals can cling to the soft walls and avoid to be tossed from side to side during the travels. Inside, we add only a little amount of water, to facilitate oxygenation. This first box is put into a larger one of the same isolating material and, between the two walls, we add, from time to time, some ice cubes, to prevent heating. This this simple system, the Asellids can be kept alive during several days and these which were not injured have been reared in an isotherm chamber at 11-12° C, at the University of Dijon, after our travel back to France.

We used the same rearing methods as for the cavernicolous Asellota Stenasellus virei Dollfus, kept at our laboratory since 1960 (Magniez, 1975). The aquariums are always very shallow rectangular glass vessels or plastic photo-processing basins. The bottom is smeared with fine grain clay, collected in an underground river 60 km N-W of Dijon and a part of the surface is provided with calcareous gravels from a karstic exsurgence. The water used is a bottled mineral one, that proved to be suitable for rearing of youngs and larvae of Stenasellus (main ions: HCO_3^- : 357mg/l ; Ca^{++}: 78; Mg^{++} : 24; dry content : 309 mg/l ; pH : 7.2). In all our aquariums, we used to put only a very little height of water (1-2 cm), that proved to be sufficient for walking Isopods and gives a better oxygenation. Nevertheless, it was necessary to close the aquariums with glass panes: C. recurvata, as well as our Stenasellus species is able to leave water and climb up to the walls of the vessels. The smaller aquariums are simply kept in larger plastic boxes, with some water at their bottoms, to collect escaping specimens.

Feeding and Behaviour

The European cavernicolous Asellid Proasellus cavaticus (Leydig) and its related species have been reared at our laboratory during the last two decades (Henry, 1976). They have been mainly fed on elm-tree (Ulmus campestris) dead leaves and we found this diet very suitable for the Amercan Asellid (see Dickson, 1979). The fallen leaves are collected, strongly boiled and kept in a flask of bacteria and fongus-free mineral water. C. recurvata are well attracted by these leaves. They rest under them and cling to the surface, eating progressively all the parenchyma and leaving only the nerves nets. Old mine timber pieces are also very attractive and they devour the superficial soft layers of this material. Once a month, we add small pieces of Cerophyl lozenges in the medium. The Asellids eat them quickly and this food colours in green their guts and enteric caeca.

I never observed a predatory behaviour in this large species, never between adults, nor against the youngs, even though the adults, especially the males have gnathopods with enormous propodites. The species behaves as a vegetarian, contrary to Stenasellids that can be partly predators, sometimes against their own youngs (Magniez, 1975). These Stenasellids dig more and more ramified nets of galleries in the clay bottoms of their vessels, as they do in their biotopes, but I never observed any burrowing activity in the American Asellid. On the other hand, newly hatched C. recurvata often shelter between gravels and we can suppose that this interstitial life gives them a better protection against their predators in the natural biotopes (see Holsinger and Dickson, 1977), as we observed the same behaviour in the young Stenasellus virei hussoni of a Pyrenean cave (Magniez, 1974).

Growth and Molts

Among the 10 specimens captured on sept. 17th 1978, only 3 C.r. were kept alive. A male died dec. 12th 1979 nad only a pair remained. The growth of the female had been rather weak as, at the end of 1980, it reached only 13.5 mm. The male of the pair was killed 23rd aug. 1980, after an excessive sequence of photo-flashlights, but its growth had been more vigorous after the capture: the body size reaches 18.3 mm, that is larger than the size (17 mm) given by Steeves (1963, p. 478) in the original description of the species. The antennae reach 17 mm the uropods 12.2 mm (protopodites: 6.7 mm; endopodites: 5.5 mm; exopodites: 1.5 mm). In this large male, the propodites of the 1st pereopods become enormous. It is clear that these organs, as well as the uropods, are subject to a very late positive allometric growth, as their sizes in the young and juveniles are moderate relatively to the sizes of the bodies.

From nov. 13th 1978 to dec. 20th 1980, the female molted 12 times. The mean time of the 11 corresponding intermolts is 70 days. Yet, this average value hides important differences, as the reproductive intermolts last at least 90-100 days, whereas the genital-rest ones can be as showt as only one month.

Once, we observed an uropod of the female broken proximally and lost after a reproductive molt and copulation. The lacking appendage regenerated during the two following intermolts, with a half-size step. The same phenomenon was observed for the flagellum of an antenna which regenerated also in two steps.

Rythm of Reproduction and Fecundity

The adult female captured in Buis Saltpetre Cave was still alive at the end of 1980. It has been observed permanently and reproduced 5 times. The dates of these layings are: nov. 18th 1978; jul. 4th 1979; oct. 25th 1979; mar. 26th 1980 and sept. 23rd 1980 (this last reproduction obtained by mating with its sons of the second litter, born sept. 10th 1979). So, we can say that the species is able to reproduce twice a year. Note that between the layings III-IV and IV-V, we find respective intervals of 5 and 6 months, whereas the cycle had been more irregular during the first year of the breeding: the first laying in France seems to have been delayed, perhaps as a consequence of the trouble caused by capture, travels and acclimatization to the artificial environment. The female, examined on dec. 1980, showed a new generation of ovocytes (some 50-55, as in each of the previous cycles) growing in its ovaries: a 6th laying can be expected during the first half-year 1981. So, we can say that a single female can give birth to about a hundred youngs per year and more than 300 during its life, as the studied specimen was already a large adult, having certainly reproduced in the natural biotope before its capture.

As in other Asellids, the reproduction occurs during a particular molt of the female: the parturial molt. The first time is an ecdysis of the posterior half of the body (the last 3 pereonites and the pleon). This causes the formation of wide and soft-rimed genital openings, suitable for copulation and laying. Then occurs mating, that seems to be very short, as in our European underground Asellids. We have not observed in C.r. any precopulation of "nuptial ride" stage, as in epigean Asellids (Magniez, 1978). The anterior ecdysis (cephalon and the 4 anterior pereonites) occurs some 4 days (3-5) after the posterior one: the functional oostegites develop and form the brood pouch. The laying occurs during the 1-2 days following the end of the ecdysis. When the female is in a parturial intromolt, the males are very active, running in zigzags and exploring the bottom with their antennae. After layings, I used to take the males off, as long as the female bore.

Development, Juvenile Life and Puberty

Intramarsupial development includes, as in other Asellota, all the embryonic stages and the first larval stages. In the five reproductions cited, the total time between laying and the end of marsupial life of the litter was 70-80 days (at 11° C). Then, the young leave actively the brood-pouch, one by one, and the total release of the group lasts one week or sometimes more. After, the mother keeps its empty pouch some 15-20 days more and finally, the regressive molt occurs, causing the reduction of the oostegites to non-functional type.

The young just released are very similar to those of other species of Asellids (length: a little more than 1 mm; gnathopods slender; 1st pleopods lacking; 2nd ones with female aspect in every specimens; uropods normal-sized; last pereonite half-developed and lacking pereopods = manca stage).

In a given litter, a part of the young die during the first months of free life. So, in the 4th litter (young released 10-16th june 1980), initially composed of more than 50 individuals, a chekcing made dec. 27th 1980 (age: 6 months and 20 days) points the presence of only 43 specimens. Their size was very similar and about 4 mm; the 1st and 2nd pleopods of future males began to differentiate. During the following months, a severe competition for food exists in the aquariums (see Culver, 1976) so, the 2nd litter (about 50 young released sept. 10th 1979) is reduced to 38 specimens on aug. 25th 1980 (age: 11.5 months). The composition of this litter at this date gives:

- 18 males, general size: 6-9 mm, but some reached only 4 mm,
- 20 females, general size: 6-8 mm, but some of only 4-5 mm.

In the aquarium, the weaker individuals stood generally far from food, in gravels, and their guts were often empty.

This second litter permitted some observations on the occurence of puberty in the species. Among the 20 females alive on aug. 25th 1980, the 3 larger (7-8 mm) had already formed non-functional oostegites (so, they were nulliparous young adults), whereas their 17 sisters, without oostegites were still large juveniles.

Between sept. 10th and dec. 10th 1980, 6 of these females underwent their first parturial molts and first layings. In *C. recurvata*, we can say that the females begin to reproduce at 12-15 months, whereas the males are already able to mate at 12 months, in our laboratory conditions.

Conclusions

These succinct observations on *Caecidotea recurvata* point out the similarity of the data with these given by Henry (1976) for the European *Proasellus cavaticus*. For instance, the reproductive molts last 4 days in the two species, gestation lasts 70-80 days in each, the reproductive intermolt 80-90 days in *P.c.*, 90-100 days in *C.r.*, etc...whereas these respective periods last only 1 day, 19 days and 21 days in the epigean species *Asellus aquaticus*. Speciation occuring in epigean genera of Asellids gave underground forms, morphologically different in the American and European faunae, but showing the same adaptative characters in the same biological processes.

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Ecology of Bat Guano in Tamana Cave, Trinidad, W.I.

Stuart B. Hill
Department of Entomology, Macdonald College of McGill University, Ste Anne de Bellevue, P.Q., Canada H9X 1C0

Abstract

Decomposition of insectivorous and frugivorous bat guano was studied quantitatively and qualitatively over a two year period. Relationships are established between the chemical, physical and energy properties of the guanos, their microflora and fauna, and the climate both inside and outside the cave. The decomposition of bat guano and forest litter are compared. The study emphasised the behavioural extraction of guano arthropod fauna, particularly Acarina.

Résumé

La décomposition du guano de chauve-souris insectivores et frugivores a été étudiée quantitativement et qualitativement durant une période de deux ans. Des relations ont été établies entre les propriétés, physiques et énergétiques de ces excréments, leur microflore et microfaune et le climat interne et externe de la caverne. La décomposition du guano des chauves-souris est comparée à celle de la litière forestière. Cette étude porte surtout sur l'extraction comportementale des arthropodes du guano, particulièrement des Acariens.

Introduction

During 1966 and 1967 a biospeleological study was conducted in Tamana Cave, Trinidad, as part of a Ph.D. program at the St Augustine Campus of the University of the West Indies. Some of the aims of the study were to describe the physical, chemical, microbiological and faunal properties of the bat guanos in the Cave and to analyse the biological processes taking place within them. The guano was treated as an organic - rich soil and the work was zoologically biased. This work comprised the first comprehensive ecological study of bat guano in a tropical cave.

Tamana Cave is located on the N.E. face of Mt. Tamana, 253 m above sea level at lat. 10°27'57"N and long. 61°11'27"W. The mapped part of the cave is 122 m long. It is in Guaracara or Tamana limestone of Miocene age, a buff massive, impure limestone with few well preserved fossils that is used for cement production. A small stream runs through the cave, which is either entered by a "Walk-In Chamber" and through a "Crawl-Hole" or by means of the "Main Chimney". The cave was mapped by Dr. J.S. Kenney and students from the University of the West Indies in 1966.

The work reported here was conducted upstream from the "Main Chimney" in the "Round Chamber", which is about 6.7 m in diameter and 5.5 m high. This chamber was chosen because it was level and had a large area of undisturbed guano. The guano adjacent to the N.W. wall of the cave was deposited uniformly over the area by the insectivorous bat Natalus tumidirostrias haymani Goodwin, which roost individually. The other bat in this chamber, Phyllostomus hastatus hastatus (Pallas) is frugivorous and roosts collectively in domes in the roof. Its guano is deposited in piles that are subsequently dispersed laterally by the burrowing activities of the dominant cockroach Eublabarus distanti (Kirby). While these bats were the only two species in the "Round Chamber" eleven species were recorded in the whole cave. No bats roosted between the domes, hence the guano below this part of the roof was referred to as the "Non-Deposition Area". A faunal analysis of the "Round Chamber" is given in Figure 1.

Methods

Standard methods were used to measure the climate of the cave and of the surrounding forest environment, the "soil" and "food" properties of the bat guanos, carbon dioxide evolution from the guanos and their microbiological and faunal properties.

Qualitative and quantitative examinations of the microarthropod populations of the guanos were conducted monthly between November 1966 and June 1967 using a modified Kempson, Lloyd and Ghelardi (1963) behavioural extractor. Full details of the techniques are given in Hill (1969).

Results and Discussion

While detailed results are given in Hill (1969) these will be summarized here by following what happens to the insectivorous and frugivorous bat guanos after they are deposited.

A. Insectivorous Bat Guano

The small colony of the insectivorous bat, Natalus tumidirostris haymani Goodwin, which roosts in the Round Chamber leaves the cave at night to feed. Most of their guano is deposited between 3 am and 7 am soon after they return to the cave. The guano, which consists of discrete, oblong pellets approximately 7 mm long, is fairly dry. It consists of fragments of insect cuticle from which some of the protein, probably the unbound protein, has been removed in the bat gut. During the period of guano deposition the nymphs and adults of the cockroach, Eublabarus distanti (Kirby), which until then have been below the surface of the guano with their antennae reaching to the ~~surface,~~ come onto the surface and feed on the fresh guano. They are probably responsible for the removal of most of the fat and a third of the protein during their digestion of the fresh guano and for its 12% drop in energy content. Certain other guanophages, such as the tineid moth, Phereoeca sp., may also feed on the fresh guano but for most of the guano community the incoming supply of energy is in the form of cockroach faeces. The subsequent decomposition of the guano and the composition of the decomposer-based community are mainly limited by the fact that the guano consists predominantly of chitin and that its pH is very low (3.5). The former has the effect of making the guano selective for organisms able to digest chitin, and the latter for organisms able to tolerate acid conditions.

An examination of the microflora revealed that it contains only three species of bacteria and three species of fungi, one species, Penicillium janthinellum Biourge, dominating the community. P. janthinellum is probably able to digest chitin. Its habit of producing bactericides combined with the low pH of the guano is responsible for the low number of species and low density of bacteria. In fact, bacteria were estimated to be responsible for less than 3% of the carbon dioxide evolution from the guano, fungi being responsible for most of the production. One of the fungi present in this guano is a yeast, Torulopsis famata (Harrison), Lodder and Kreger--Van Rij, which is thought to have entered the cave via the bat ~~guano~~ as yeasts are commonly found in high densities both on and in insects. Some of the variations in the physical and chemical properties of the guano with increase in depth can be traced to fungal activity, i.e., the increase in particle size, the decrease in the amount of crude fibre (chitin) and the increase in the amounts of protein and nitrate. Other changes with depth include an increase in the density of the guano, this being due to the weight of the overlying material increasing with increases in depth; and certain inorganic materials are redistributed in the guano by the movement of water, which is predominantly upwards as the water lost by evaporation at the surface is replaced by capillarity from the stream, there being no gravitational water. At the base of the profile (25 cm deep) the guano grades into the eroded limestone floor of the cave. This region is characterised by a drop in the calorific value and in the organic fractions and by an increase in the pH and in the inorganic fractions.

The fauna of the guano can be divided into those animals that live in the water film (water fauna), such as Protozoa and nematodes, and those that live in the air spaces (air fauna), such as mites and insects. True burrowing organisms, such as earthworms, were not encountered. The water fauna was not examined, although it is unlikely to be of great importance as the food chains of soil Protozoa and nematodes are usually based on bacteria and, as has been mentioned above, they occur in very low densities. The air fauna is dominated by mites although only seven species occur in medium to very high densities, one of these, Rostrozetes foveolatus Sellnick, comprised over 80% of the mite population. As most of the mite species are likely to be feeding on fungi the low number of fungal species are probably responsible for the low number of mite species, although the low pH of the guano could be inhibitory to certain species. The other six mite species comprise three species of fungal-feeding uropodines, two predatory gamasids and an astigmatid mite that may be coprophagus.

In addition to the mites, a fungal-feeding ptiliid beetle also occurs in this guano in medium densities. The main food chains in the guano probably include the above species, the arrangement shown in Figure 2 being the most likely.

As the respiration rate of the guano decreases with the depth the biomass of fungal hyphae is also likely to decrease as are the densities of fungal feeders. Thus, most of the fungal-feeding uropodines and their predators decrease in density with depth. However, out of 30 species (stages or sexes) 14 reach their peak density some way below the surface. This could be due to their being unable to compete with the species that decrease in density with depth, especially with the cockroach, E. distanti. Some of them may find the younger surface guano and its microflora unattractive and others probably live deep in the guano due to their small size or ability to tolerate a low oxygen concentration.

The energy released at each level is not limited by the amount of energy that is present because although energy content per volume increases with depth, rate of carbon dioxide evolution decreases. However, the energy released from the total profile is limited by the rate of guano deposition as the guano is in equilibrium, i.e., neither accumulating or declining.

B. Frugivorous Bat Guano

The frugivorous bat, Phyllostomus hastatus hastatus (Pallas), roosts collectively in domes that have been partly formed by their sharp claws as they scrabble to find a place in the colony. Like the insectivorous bats they leave the cave at night to feed and return between 3 am and 7 am. The appearance of their guano varies depending on the fruits on which they have been feeding, although it is always wet and made up of undigested fragments of fruit and of any seeds that have been taken in with the fruit. In fact, the only seeds that were found are Cercopia peltata L., however, it was noted that in other caves the guano of Phyllostomus contained different seeds. Thus, it is the colonies in a cave rather than the species as a whole that have characteristic food preferences. The reason for Cercopia being a favourite food of the Tamana Cave colony could be related to the fact that Cercopia trees are very common around Tamana Hill. The Cercopia seeds do not germinate in the cave, although they do germinate when placed in the light. In addition to dropping guano the bats drop the remains of insects, which they sometimes carry back to the cave to eat. One reason why the fresh guano is so wet is that the bats urinate onto it, this not being the case in the Insectivorous Bat Area as Natalus roosts on a side wall of the chamber and urinates against this. The concentration of the bats in domes has resulted in their guano accumulating as raised areas, here called Frugivorous Bat Piles, above the level of the surrounding area, which is referred to as the Non-deposition Area.

The fresh, wet guano supports a dense population of nematodes that are probably feeding on bacteria, which are also likely to occur in high densities, particularly as the pH of this guano (8) favours bacteria rather than fungi. Only 1% of the arthropods in the total profile live in the fresh bat guano whereas between 1.9 and 3.8 cm deep there occur 24% of the number in the total profile. The fresh Frugivorous Bat Guano, unlike the fresh Insectivorous Bat Guano, is not eaten by the cockroach, E. distanti although cockroaches do tunnel in and out of the Piles lower down and in doing so distribute the guano to the surrounding Non-deposition Area.

Bacteria and nematodes are presumably responsible for the 7% drop in energy content between the fresh guano and that at depth of 2 cm. The species of arthropods that occur in medium to very high densities below the fresh guano, comprise 24 species of mite, one collembolan and one pseudoscorpion. The arthropod community is dominated by three of the mites, Eohypochthonius gracilis (Jacot), Centrouropoda rhombogyna Berl. and Caloglyphus nr. mycophagus (Megnin), and by the collembolan, Lepidocyrtus nr. lanuginosus (Gmelin). Most of the mites are likely to be fungal feeders. The main food chains in this guano are shown in Figure 3.

The respiration rate of the guano decreases with increase in depth much as it does in the Insectivorous Bat Area. The decomposition of the Frugivorous Bat Guano was not followed any further in the Piles although it was followed in the Non-deposition Area.

As mentioned above, the guano in the Non-deposition Area has been moved there from the Piles due to the tunnelling activity of the cockroach, E. distanti. It consists of the small seeds (2 mm long) of Cercopia peltata and represents that fraction of the fresh bat guano that is most resistant to decomposition. Although organic analyses of this guano revealed that it contains over 20% crude protein, 20% nitrogen-free extract and 3 to 4% fat, most of these fractions are contained within the seed coats, which comprise over 40% of the guano. As the seed coats resist decomposition they make the above decomposable material unavailable to the decomposers. However, the guano is able to support a dense population of bacteria, of at least eight species, which are probably responsible for much of the decomposition. The pH of the guano in this region, unlike that in the Insectivorous Bat Area, is not low enough to inhibit bacterial growth. The fungal-feeding arthropods occur in very low densitives, which suggests that fungi also occur in low densities, although it could be that most mycelial growth occurs within the seeds. Nine species of fungi were recorded from this guano, Mucor hiemalis Whemer being dominant at the surface and species of Aspergillus, Cylindrocarpon and Triochoderma dominating deeper down. The incidence of seed penetration increases sharply at a depth of 17 cm, as seen by the decrease in the density of the guano and in its fat content after this depth, and by the fact that very few seeds from below this depth germinate, whereas most above this depth are able to do so.

Microfloral activity is presumably responsible for the slight decrease in protein and for the slight decrease in nitrogen-free extract with increase in depth. The nitrates, which are released as a result of protein decomposition, are carried upwards in the water film as there is an upwards movement of water just as there is in the Insectivorous Bat Area.

The high density of bacteria in the Non-deposition Area presumably supports a dense population of bacterial feeders and their predators. Only ten species of arthropod, nine mites and one collembolan, occur in medium to high densities in this area and none of these is conspicuously dominant. Three of the mite species are predators and the rest either feed on fungi or on the faeces of other arthropods. The main food chains in this guano are shown in Figure 4.

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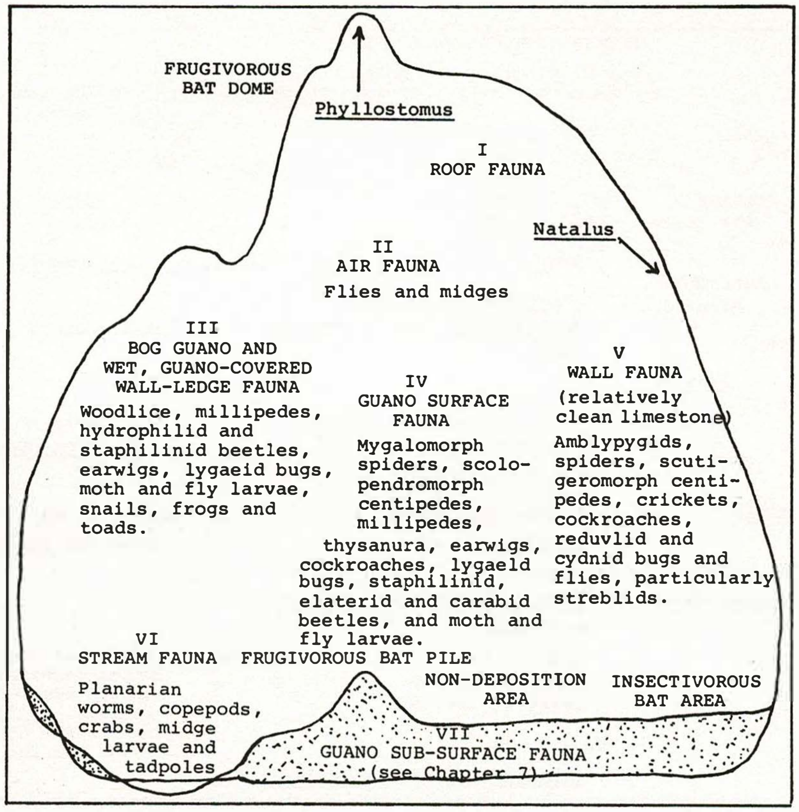

Figure 1. A diagramatic cross-section of the Round Chamber showing the faunal groups

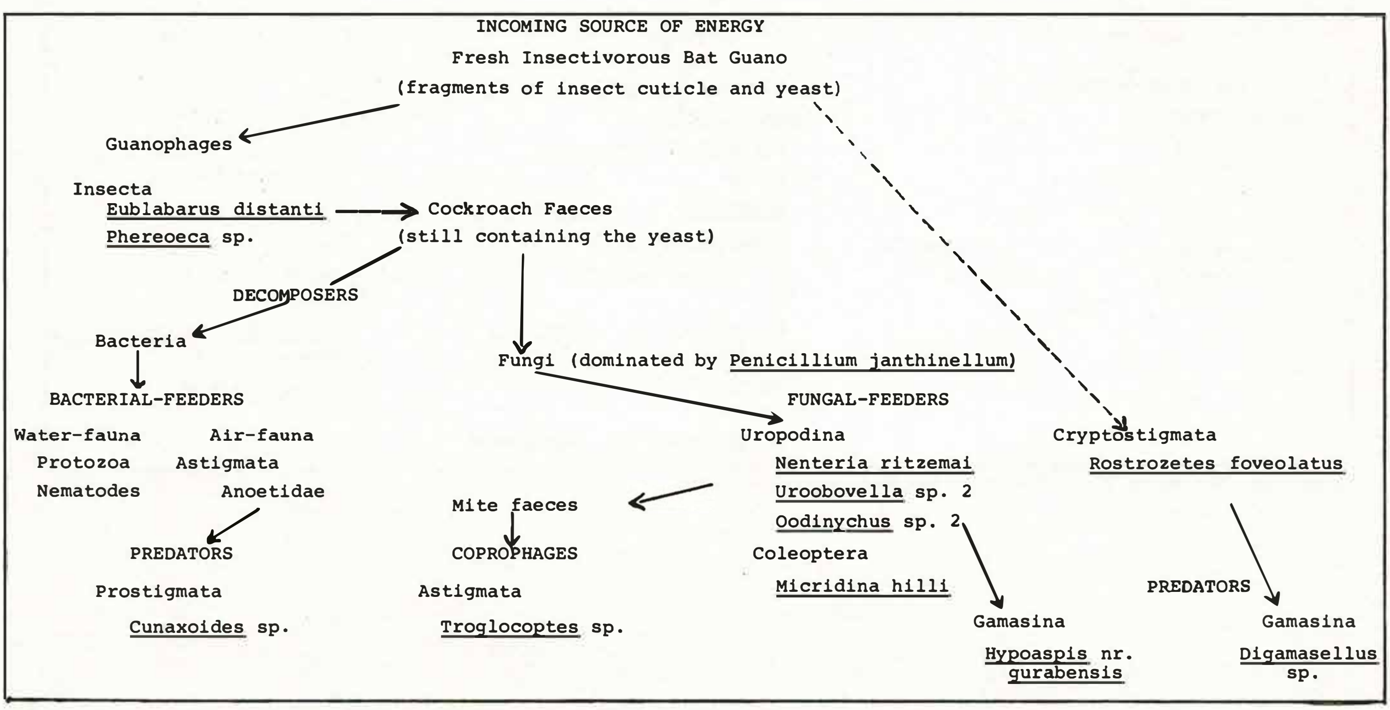

Figure 2. The major food-chains in the Insectivorous Bat Area

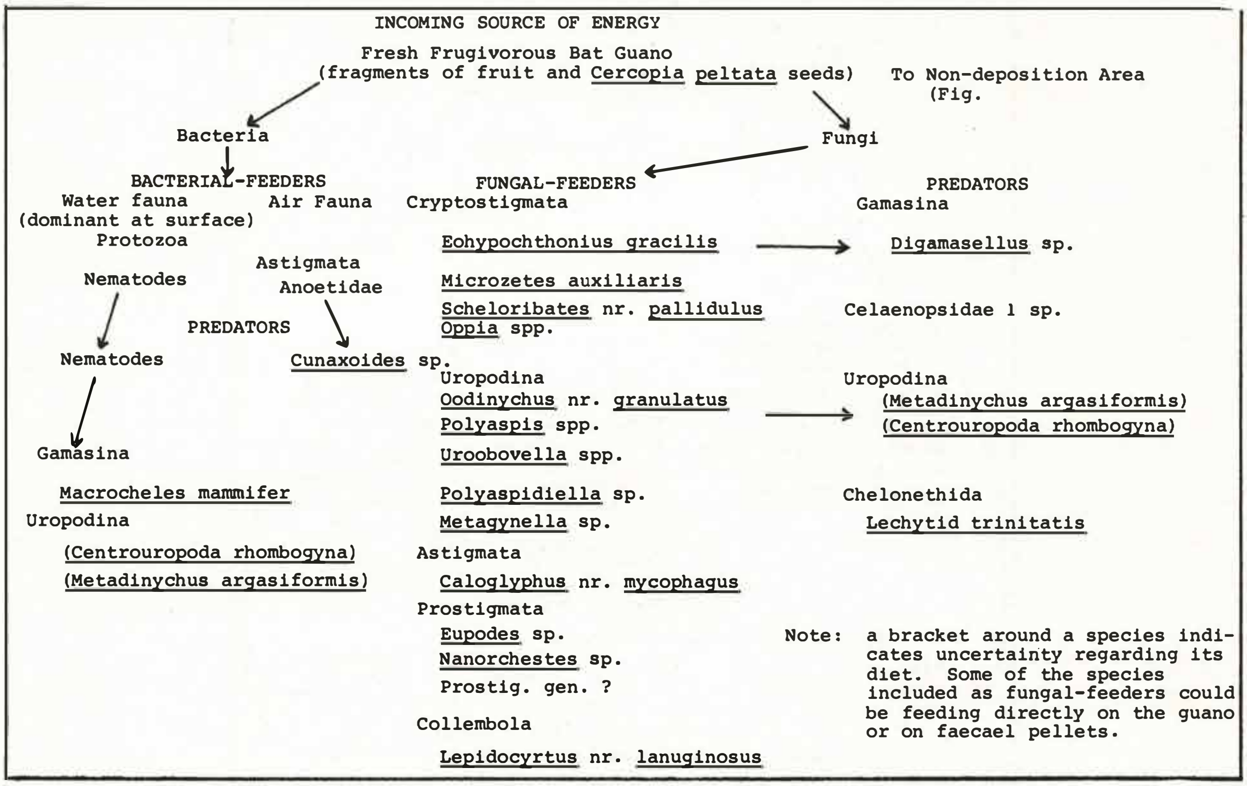

Figure 3. The major food-chains in a Frugivorous Bat Pile

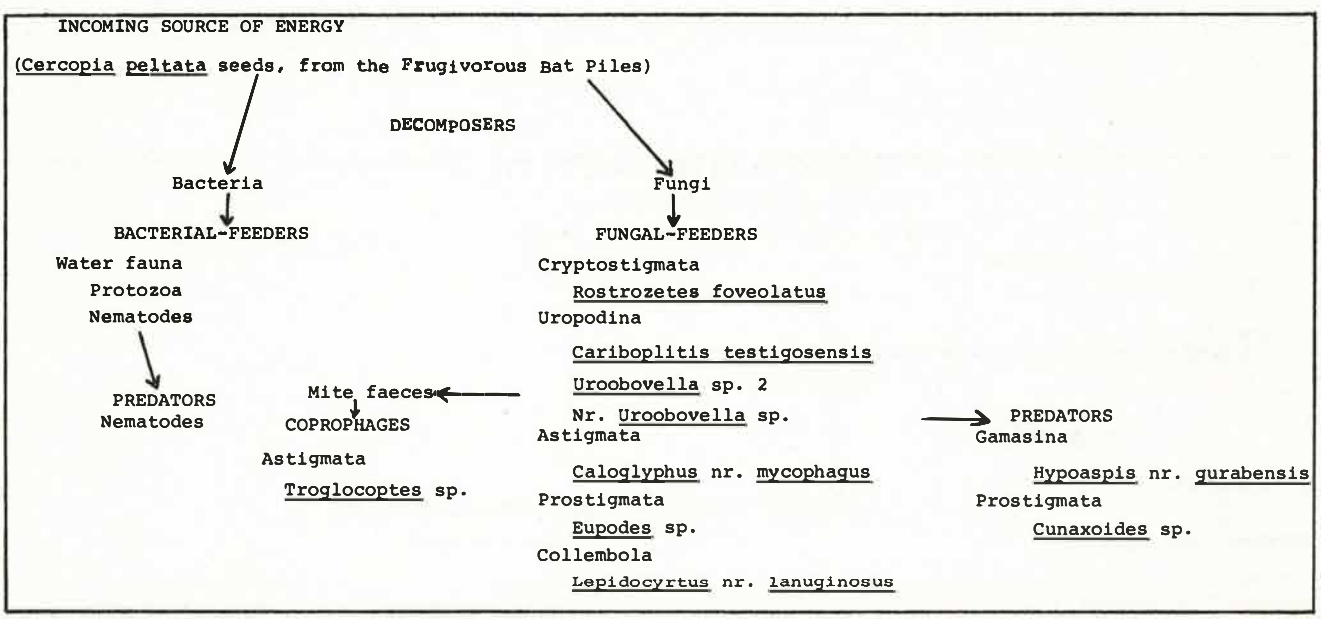

Figure 4. The major food-chains in the Non-deposition Area

Pioneers of North American Cave and Karst Science Prior to 1930

Ernst H. Kastning
Department of Geosciences, Murray State University, Murray, Kentucky 42071 U.S.A.

Abstract

Fifty years ago William Morris Davis published his celebrated study, "Origin of Limestone Caverns." Within twelve years, no less than four other benchmark papers on speleogenesis appeared in prominent American geological journals; some of these embellishedvis' ideas while others proposed alternative theories. This flourish of conceptualism provided in impetus for subsequent regional cave studies in many states, including Pennyslvania, Virginia, Tennessee, Alabama, Indiana, Kentuck, and Missouri. Ultimately, many of these simplistic theories were refined and synthesized into modern views that now treat caves as products of multiple or complex interactions among diverse factors such as bedrock lithology, geologic structure, chemical kinetics, hydrodynamics, and topographic evolution.

Physical speleology in North America did not have its beginnings in the deductive works of Davis and his contemporaries, but was founded instead in a host of descriptive studies concerning selected cave areas in the easter United States and Canada. Many of these works are well known today because they address the classic karst regions of the United States, notably central Kentucky, Indiana, and Tennessee. However, some of the earliest literature, published during the interval 1820 to 1930, is relatively obscure and rarely cited because it concerns less spectacular karst regions, such as those of New York and New England. Among the unsung pioneers of American speleology are Amos Eaton, Ebenezer Emmons, Charles U. Shepard, Edward Hitchcock, William W. Mather, Lewis C. Beck, James Eights, Amadeus W. Grabau, John H. Cook, George B. Shattuck, George H. Hudson, and Herdman F. Cleland.

Zussammenfassung

Vor 50 Jahren veröffentlichte William Morris Davis seine berühmte Studie "Entstehung der Kalksteinhöhlen." Innerhalb von 12 Jahren erschienen vier weitere bahnbrechende Artikel über Speläologenesis in führenden amerikanischen geologischen Zeitschriften´ einige dieser Artikel bauten auf den Ideen von Davis auf, während andere Artikel wiederum alternative Theorien vorschlugen. Dieses plötzliche Interesse war ein Antrieb für spätere regionale Höhlenforschungen in vielen Staaten der USA, einschliesslich Pennsylvania, Virginia, Tennessee, Alabama, Indiana, Kentucky und Missouri. Schliesslich wurden viele der einfachen Theorien weiterentwickelt und ausgebaut bis hin zu den modernen Ansichten, in deren Rahmen Höhlen heutzutage als Ergebnisse von vielfachen und kmoplizierten Wechselwirkungen verschiedener Faktoren wie Grundgestein, Lithologie, geologische Strukturen, chemikalische Kinetik, Hydrodynamik und topographische Evolution behandelt werden.

Die physikalische Speläologie (Höhlenforschung) in Nord-Amerika hatte ihre Anfänge keineswegs in den aufschlussreichen Werken von Davis und seinen Zeitgenossen, sondern wurde vielmehr durch eine Reihe anschaulicher Studien über auserwählte Höhlengebiete im Osten der USA und in Canada begründet. Viele dieser Werke sind heutzutage wohlbekannt, weil sie sich insbesondere mit den klassischen Karstgebieten in den USA befassen, nämlich hauptsächlich in Kentucky, Indiana und Tennessee. Ein Teil der ursprünglichen Literatur, die zwischen 1820 und 1930 veröffentlicht wurde, ist jedoch verhältnismässig unklar und wird kaum zitiert, weil sie sich mit den weniger spektakulären Karstgebieten befasst, wie zie z.B. in Staate New York und in Neu-England vorhanden sind. Unter den weniger bekannten Pionieren der amerikanischen Speläologie finden wir Amos Eaton, Ebenezer Emmons, Charles U. Shepard, John H. Cook, George B. Shattuck, George H. Budson, und Herdman F. Cleland.

Introduction

The onset of contemporary cave science in North America is usually ascribed to William Morris Davis' celbrated deductive study, "Origin of Limestone Caverns" (Davis, 1930). In the ensuing years, several other benchmark papers on speleogenesis appeared in American geological journals, offering support or alternatives for Davis' theories, and fueling a debate on cave origin that continues today (White, 1959; Halliday, 1960; Warwick, 1962; Powell, 1975; Ford and Ewers, 1978). Regional cave studies prior to 1930 are sparse in the geologic literature. The best known concerned cave development in Pennsylvania, Virginia, Tennessee, Alabama, Indiana, Kentucky, and Missouri (See Davies, 1966 and Powell, 1975 for selected references).

The origin of caves is but one aspect of karst science, and North American contributions on karst are scant, at best, when compared to the vast world literature (Davies, 1966; Quinlan, 1968, 1978; Shaw, 1979). Physical speleology in North America began as isolated and relatively obscure descriptive studies in the eastern United States and Canada. A few works are well known today because they address the classic karst of Kentucky, Indiana, and Tennessee. However, much of the early literature (1820-1930) is rarely cited because it concerns lesser karst areas. This paper focuses on geologists from the northern U.S. who have contributed to North American speleology, and briefly serves to introduce early American cave geologists to the international speleological community, establish the role of the northeastern U.S. in North American cave and karst science, and credit some heretofore unsung pioneers of American speleology.

Pioneers of North American Speleology

The earliest reported writings on northeastern caves concern caves in Albany and Schoharie Counties, New York (Hanor, 1950; Kastning, 1971, 1975, 1978, 1979; Engle, 1979). The prolific works of Horace C. Hovey (1833-1914) and Edwin S. Balch (1856-1927) greatly advanced speleology in the northeast, but because these contributions are discussed in detail elsewhere (Halliday, 1970a, b), and are internationally well recognized, they are omitted herein.

Amos Eaton (1776-1842) was a pioneer of North American geology, taught at Williams College in Massachusetts and founded the Rennsselaer school of geology at Troy, New York in 1824. Two of his earliest work (Eaton, 1818, 1820a, b) metnions caves in the Helderberg Limestone units of Albany County.

Ebenezer Emmos (1779-1863, geologist of the Second District, New York State Survey and noted mineralogist, identified the first occurrence of strontianite in the U.S. (from Ball's Cave, Schoharie County)(Emmons, 1835). His work on carbonate cave minerals, in conjunction with that of Shepard and Beck (below), represents one of the earliest cave-mineral studies in north America.

Charles Upham Shepard (1804-1886), State Mineralogist of Connecticut, examined strontianite and other calcareous spar from Ball's Cave (Shepard, 1835). He brought to the attention of the scientific community a previously published, but obscure description of Ball's Cave (anonymous,1832). This account, along with the published discovery of Howe's Cave (Squier, 1842),led to later scientific cave studied by Beck, Mather, Grabau, and Cook (below).

Edward Hitchcock (1793-1864), Professor of Chemistry and Natural History at Amherst College, Massachusetts, and later State Geologist of Massachusetts and Vermont, published a volume on the geology of Massachusetts (Hitchcock, 1835), containing some of the earliest geologic material on New England caves, which included natural marble bridges near North Adams, pseudokarstic cave at Sunderland and limestone caves near West Stockbridge, Lanesborough, and Adams. He also described Spouting Cave, a sea cave at Newport, Rhonde Island.

William Williams Mather (1804-1859) served as Geologist of the First District, New York Geological Survey; and in the final report for that work (Mather, 1843), he described Ball's Cave (with a profile drawing) and Clarksville Cave, noting the hydrogeology of both. An announcement of the discovery of Howe's Cave and plate illustrating it entrance were included as well.

Lewis Caleb Beck (1798-1853), noted chemist and mineralogist and author of the mineralogy volume of the Natural History of New York (Beck, 1842), described carbonate minerals from several caves in Albany and Schoharie Counties, extending the work of Emmons and Shepard. The volume included a profile of Ball's Cave

Cave and a crude map of Knox Cave, one of the earliest maps of a northeastern cave.

James Eights (1798-1882), the noted Antarctic explorer and geologist, wrote several geological reports on New York State. His only known sepleological paper (Eights, 1848) is an exacting description of Mitchell's Cave, Montgomery County, for some time the deepest known cave in the northeast. Eights explored the cave to its lowest point in an unsuccessful quest for vertebrate fossils.

Amadeus William Crabau (1870-1946) was one of America's most noted and controversial stratigraphers. During his tenure with the New York State Museum, he studied the geology and paleontology of the Schoharie Valley (Crabau, 1906), the most cavernous area in the northeast. Grabu's mongraph includes brief descriptions of Howe's, Ball's, Clark's, Becker's, and Strontium Mine Caves, the first photographs of northeast caves in the geologic literature, and a profile and map of Ball's Cave modified from Knoepfel (1853), Beck (1842), and Mather (1843).

John Hawley Cooks was employed by the State Museum of New York in the early 1900's to investigate the Quaternary and glacial geology in east-central New York. During this interval, he was instructed to explore, survey, and geologically examine all accessable caves in the Helderberg Plateau of Schoharie and Albany Counties. His report (Cook, 1907) is a landmark paper in northeastern speleology that describes 18 caves (with maps of 6), and discusses in detail the role of stratigraphy, structure, and hydrogeology on speleogenesis.

George Brubank Shattuck (1869-1934), Professor of Geology at Vassar College, wrote a small geological guidebook to southeastern New YOrk (Shattuck, 1907). He described Eighmyville and Stone Church Caves, Dutchess County, and briefly discussed the origin of limestone caves and speleothems.

George Henry Hudson (1855-1934), teacher of science at the State Normal School at Plattsburg, New York, spent twenty years studying the geology of the Lake Champlain region near Plattsburgh. His meticulous work on solution phenomena of Valcour Island included joint-controlled caves, dolines, karren, pitting, and scallops (Hudson, 1909, 1910, 1912). Hudson's lucid discussion of solution scallops is the first to appear in the North American literature, and accurately attributes their origin to turbulent flow.

Herdman Fitzgerald Cleland (1869-1935), Professor of Geology at Williams College, investigated the morphology and origin of natural bridges, including those of solutional origin (Cleland, 1905, 1910, 1911a). Later, his interests turned to dolines and karst springs (Cleland, 1911b). He was the first to relate Thompsons Lake, Albany County, to underground piracy of surface streams and to nearby Pitcher Farm Spring. He explained the role of solution processes and glaciation in the development of the Helderberg Escarpment (Cleland, 1930).

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Preliminary Report of the Cave Minerals in China, South Korea and Japan

Naruhiko Kashima
Department of Geology, Faculty of General Education, Ehime University,
Matsuyama, Ehime 790, Japan

Abstract

For a number of years, speleological and mineralogical investigations have been carried out some of the karst regions of southern parts of China, middle eastern part of south Korea and Japanese islands.

The purposes of this preliminary report are to give an overview of these karst regions and to describe cave minerals.

X-ray, chemical and scanning microscopic analyses revealed that seventeen cave minerals account for the speleothems: Oxides (goethite, birnessite), Carbonates (aragonite, calcite, magnesian calcite, dolomite, protodolomite, hydromagnesite), Sulfates (gypsum), Phosphates (brushite, crandallite, hydroxyapatite, strengite, taranakite, variscite), Silica minerals (quartz) and Silicates (mullite).

Zusammenfassung

Seit einige Jahren, mit speläologischen und mineralogischen Untersuchungen über mehrere Karst Gebietes waren in das Süd-China, das Mitte-östlichsten Südkorea und die Japanische Inselkette geausführenet.

Ziels dieser Arbeit sind sie, der eine wird über der Überblick von diese Karst Gebietes erwähnt, die andere über die beschreibende Mineralienkunde von Höhleninhaltes.

Röntgenostrahlenisch, chemisch und rasterelektronenmikroskopisch Analysen über Höhleninhaltes sich in siebzehn Mineralien durchschauen; Oxide (Goethit, Birnessit), Carbonate (Aragonit, Calcit, Magnesiocalcit, Dolomit, Protodolomit, Hydromagnesit), Sulfate (Gips), Phosphate (Brushit, Crandallit, Hydroxyapatit, Strengit, Taranakit, Variscit), Silika Mineral (Quartz) und Silikate (Mullit).

Introduction

More recently, much biological, geomorphological and palaeontological studies have been done of the karst regions in Asian countries. Nevertheless, there have been less information on mineralogy of the cave minterals.

This paper presents the brief results of mineralogical studies on the cave minerals in China and South Korea that were collected during the short investigative trips and of the systematical investigations in Japanese Islands.

China, which is the largest karst region in the world, covering thirteen percent (an area about 2,000,000 square kilometers) of the whole country by the carbonate rocks. The largest karstland cropping out of southern China in the provinces of Yunnan Sheng, Sichaun Sheng, Guizhou Sheng and Guangxi Zhuangzu Zizhigu. The writer visited the some of southern karst regions in Yunnan Sheng, Guangxi Zhuangzu Zizhigu and Guangdong Sheng a couple of trips in 1979 and 1980. Total fifteen limestone caves were explored and investigated.

The most important karstland in South Korea occupies the middle eastern part of Korean Peninsula which lies in Gang Weon-Do and Chung Buk-Do. The formations affected by karstification belong to the Palaeozoic (Cambro-Ordovician) limestones in the Josen Supergroup. The total numbers of limestone caves in South Korea were estimated at 5,250 caves (S.M.SUH, 1977). Since 1973, the writer visited four times in South Korea and made an investigation of about thirty caves.

In 1971, the Scientific Exploration Group of Ehime University compiled a list of 1,222 caves in Japanese Islands. The main parts of the karst regions in Honshu, Kyushu and Shikoku Islands occur on the Palaeozoic (Permo-Carboniferous) and the Mesozoic (mainly Triassic) limestone plateaux. On the other hand, a large number of caves are developed in the Quarternary reefal Ryukyu limestones.

The writer briefly describes to the seventeen cave minerals and should serve to the mineralogical data from above Asian countries.

Methods

The mineralogical identification of all cave minerals was made by X-ray powder diffraction analysis on hand-picked samples using a Shimazu Electric X-D unit equipped with a copper tube and nickel filter. In addition, the very fine powdery samples were observed by scanning microscope techniques for their microcrystal morphology. The chemical analysis were carried out for the selected samples of phosphate minerals.

Results

This study has resulted in the identification of cave minerals heretofore undescribed for Asian karst regions as follows: oxides, carbonates, sulfates, phosphates, silica minerals and silicate minerals.

The iron and manganese oxides known in the caves of China and Japan. Goethite ($HFeO_2$) has been found from the Hoshino-no-ana Cave in Minamidaitojima Island, Okinawa Prefecture, Japan. Birnessite ($(Na,Ca)Mn_7O_{14}.3H_2O$) has been discovered from the Dushu-yan Cave, Guangzi Zhuangzu Zizhigu in China. These two minerals occur as wad-minerals whose apper black powdery substances in the caves.

Naturally, the carbonate minerals are the most common class in cave minerals. On the six carbonate minerals have been recognized; calcite, magnesian calcite, aragonite ($CaCO_3$), dolomite, protodolomite ($CaMg(CO_3)_2$), and hydromagnesite ($Mg_5(CO_3)_4(OH)_2.4H_2O$). The carbonate mineralization of the Seoghwa-gul Cave in South Korea deserve special mention. This cave is well known for its abundance of carbonate cave minerals (calcite, magnesian calcite, aragonite, dolomite, protodolomite and hydromagnesite) and gypsum.

The class of sulfate minerals is very rare in these countries. It has been known the beautiful gypsum flower from the Hwaan-gul Cave, Gang Weon-Do, South Korea (S.Ueno et al., 1966). In the Seeoghwa-gul Cave, gypsum ($CaSO_4.2H_2O$) occur as small crystals on the aragonite trostwork and were associated with hydromagnesite.

The phosphate minerals have commonly been in the limestone caves usually occur as fine, soft earthy and powdery texture aggregates or massive microcrystalline crust. Described phosphate minerals are brushite ($CaHPO_4.2H_2O$), crandallite ($CaAL_3(PO_4)_2(OH)_5.H_2O$), hydroxyapatite ($Ca_5(PO_4)_3OH$), strengite ($FePO_4.2H_2O$), taranakite ($H_6K_3Al_5(PO_4)_8.18H_2$)) and variscite ($AlPO_4.2H_2O$). Hydroxyapatite is found first time at the Todoroki-go Cave in Okinawa-jima, Japan (N.Kashima, 1968). After a time, it has been made clear that hydroxyapatite is widely distributed throughout Japanese Islands. To give a few instances, the Kyusen-do Cave and the Taishi-ga-Iwaya Cave in Kyushu Island contain exceptionally well phosphotized cave minerals. Chemical compositions of four phosphate minerals from the Kyusen-do Cave are presented in Table 1, chemical composition of brushite and the other sulfate mineral. In this case, it is noteworthy that according to the observation of scanning microscope, sulfate mineral was identified as gypsum. On the other hand, chemical composition of taranakite showed acceptable values except water content. The taranakite from the Kyusen-do Cave is identified by means of its chemical data as $H_{5.59}K_{2.64}(Al,Fe)_{4.68}(PO_4)_{8.00}11.18H_2O$. Crandallite and strengite have recently been discovered from the Shuangyuan-dong Cave in Guangdong Sheng, China. Strengite is a new mineral found in the limestone cave and the first finding of cave minerals from Asian countries.

As is well known, silica mineral (quarts (SiO_2) from the limestone cave is very rare mineral, however, sometimes quartz was found by X-ray powder diffraction method. The presence of microcrystalline quartz in the Fuji-ana Cave, Gunma Prefecture, Honshu Island, probably represents that the input source of silica can be proposed to the underground water.

The problematical silicates, mullite ($Al_6Si_2O_{13}$) has been found in the Qixing-yan Cave, Guangzi Zhuangzu Zizhigu, China.

Table 1
Analysis of Phosphate Minerals from the Kyusen-do Cave (in weight percent)

	brushite	hydroxyapatite	taranakite	variscite
SiO_2	tr.	3.30	tr.	0.25
Al_2O_3	—	1.45	17.00	22.90
Fe_2O_3	—	0.86	1.43	1.12
MgO	1.97	tr.	tr.	tr.
CaO	27.76	41.49	tr.	tr.
Na_2O	0.04	tr.	tr.	tr.
K_2O	0.08	0.03	9.14	0.01
P_2O_5	8.70	41.82	41.71	37.46
SO_3	35.20	tr.	tr.	tr.
NO_3	2.86	—	—	—
H_2O	—	2.21	7.40	21.10
Ig.Loss	—	8.85	24.95	12.59
Insol. Residue	23.39	1.20	tr.	3.40
Total	101.00	101.21	101.63	98.83

Analyst: T. Maki.

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Matching Cave Gear to Cave Hazards

David R. McClung
2318 Jane Lane, Mountain View, California 94040, U.S.A.

Abstract

What kind of equipment should I bring on the this trip? How cold is the cave? Will we be doing any vertical work? Do I need a wet suit? How long will we be underground?

These and questions like them are fundamental to preparing for any cave trip. To help cavers, trip leaders, and cave managers answer these questions, we have set up three categories of caves based on the techniques and equipment needed to explore them. Superimposed over these categories are two additional hazards: vertical extent and water. This categorization is based on difficult and not on beauty or natural values. (Even so, you must never forget that any visit to a cave can cause damage, so your environmental impact must always be considered.) Our goal with this classification scheme is to give some general guidelines that will tell you what to expect and what we recommend in the way of equipment for each class of cave.

Zussammenfassung

Was für einen Höhlenausrustung soll ich mitbringen? Wie Kalt ist es in der Höhle? Muss ich eine Taucherausrüstung haben? Wie lange bleiben wir unten?

Diese und ähnliche Fragen sind grundlegend für der Verbereitung fur eine Höhlenbefahrung. Um Höhlenforschern, Höhlenführern, und Höhlenbehandlungsleitern behilflich zu sein, haben wir die drei, Klassen der Höhlen dargelegt. Die Klassen sind auf die Methoden und Ausrüstung pasiert, die mann haben mus um diese Höhlen zu forshen. Dazu hingefügend sind zwei weitere Geführlichkeiten, nähmlich: die Grösse der Vertikalstrecke und Wasser. Diese Klassifizierung hängst von der Schwerigkeit ab, und nicht von der Schönheit oder geologischen Wert. (Jedenfalls, mussen mir nie vergessen dass irgend einer Besuch eine Höhle beschädigen kann. Also, ist die Umweltverschützung immer zu berücksichtigen.)

Es ist hier unser Zeil, einige allgemeine Anhaltspunkte anzudeuten die erklären, was zu erwarten ist, und unsere Empfehlungen, um die richtige Ausrüstung fur jede Höhleklasse zu wahlen.

* * *

This paper categorizes caves into three classes according to the equipment and techniques needed to explore them. Overlaying the general classification are two special dangers, vertical extent and water. By vertical, we mean unclimbable pits which require ladder climbing or rappelling and prusiking. By water hazards, was mean streams, lakes, and flooding which require woolen clothing at a minimum and in extreme cases, wet suits.

Class 1. Beginner Caves: Horizontal Passages.

Beginner cavers are caves with essentially flat passages and no pits. The floor may be rubble filled or rough. Passages may incline up or down like the ramps in a sports stadium or even have broad steps less than one meter high. Some crawling on hands, knees, or belly is required. Getting from one level to another (if multileveled) is done by walking or, at most, by easy scrambling over boulders or small breakdown blocks with less than three meter drops.

The major hazard is water in streams or lakes. In lava tubes the main hazard is loose, jagged breakdown, and in lava tubes with ice, freezing temperatures and year-around ice floors.

Class 1 caves can extend for one to two kilometers (half a mile to a mile and a half) but more commonly 150 to 500 meters (a few hundred to a few thousand feet). Average trip length is two to three hours, with up to five or six maximum.

Equipment required is full caving gear including helmet, three sources of light, lug-soled boots, warm clothes if the cave is cold (including perhaps woolen unders), coveralls if it's to be an extended stay or is a cold cave, and a cave pack with pares, including food if necessary. Vertical gear as such is not needed. However, a simple sling such as four meters of 25 mm (one-ince) webbing and a locking carabiner should be carried.

Class 2. Intermediate Caves: Horizontal with Climbable Pitches.
Class 2V. Intermediate Caves Vertical: Horizontal with 1 or 2 Small 5 to 10 Meter Pits (15 to 30 feet).

This category of cave is still loosely called horizontal, but now the levels are connected by one or more pits, steep slopes, or large breakdown blocks. Skills required for the climbable pitches may extend from beginning to nearly advanced, but the number of them is small enough to still consider the cave as intermediate. Handlines and belays are required for the climbing. If there are non-climbable pits, they should be easy enough to provide good training in technical vertical caving. Many caves and multilevel lava tubes fall into this category.

Hazards include active streams, lakes, vertical pitches, and crawlways one half meter (18 inches) or less with some twisting and turning over. Length averages one to five kilometers (one-half mile to several miles) long. Trip duration is usually five to ten hours. A typical maximum is 12 to 16 hours, except in Class 2 Vertical when rigging and derigging are necessary.

Equipment required is full caving gear, plus food for one meal and several snacks. Vertical equipment: four-meter caving sling with locking carabiner plus one 15 meter long 9 mm handline. If Class 3 Vertical, seat harness, Figure 8 Ring or Longhorn, safety loop (a 1 2/3 meter length of 7 or 8 mm Perlon tied into a 500 mm or 20 inch loop), plus ladders or prusik gear.

Class 3. Advanced Caves: Complex Multilevel or Multimile Cave Systems.
Class 3V. Advanced Caves Vertical: Large Systems with Technical Vertical Pitches.

Class 3 caves are often called caver's caves because they require considerable experience and a wide range of skills. They can be more difficult than purely vertical shafts (even though the latter may be deeper), because a shaft may only require technical rope work to yo-yo up and down.

Hazards are active streams, lakes, tight squeezes, slippery slopes, deep pits. Cave length is several miles or kilometers. Trip length is at least ten hours and at most 20 to 24 hours. An average trip is 12 to 14 hours.

Equipment required is full caving gear with plenty of spares and food for two meals and two to four snacks. In Class 3 (non-vertical), the pitches are by definition climbable but you still should have a basic sling and locking carabiner, perhaps a set of prusik slings or Jumars (for new pits or emergencies), a rappel device, two safety loops, and a 15 or 20 meter long 9mm hand line. For Class 3 vertical, which could include short, medium, or long drops, your complete vertical pack is required, including full rappel and prusik rigs.

Vertical Classifications

Three vertical and three water categories overlay the cave classifications. Both Vertical Short and Vertical Medium can apply to any class. But if a cave has Vertical Long pits (over 50 meters or 150 feet) it automatically drops into the Class 3 slot.

Vertical Short. 5 to 15 meters (15 to 50 feet) pits. For this class of pit, if there are only one or two short pits (under 10 meters), we recommend you rappel in, then climb the ladder back out. (Rappelling is easier than climbing down a ladder, and more fun.) With a large sized group, climbint out of a short pit on a ladder is faster and cuts down the vertical gear everyone has to bring. If more than two short pits or deeper than 10 meters, rappelling in and prusiking out are called for.

Equipment for 5 to 15 meter pits: For rappelling, a minimum of a Longhorn or Figure 8 Ring attached with a locking carabiner to a diaper sling backed up with a waist loop, or to a swami seat. A sewn seat harness would be better. For prusiking, knots, Texas sit-stand system with Jumars, Mitchell ropewalker system with Jumars, or three Gibbs ropewalker system.

Vertical Medium: 15 to 50 meters (50 to 150 feet). This category is more of a step up than many cavers realize. For rappelling, the multi-brake-bar rack is used much more, but the others will work, too. For prusiking, however, a full resting position with a comfortable seat harness is mandatory. Up towards the top of this category at 50 meters, the Texas or similar sit-stand systems may be too strenous. If used, it will require another ascender and chest sling for safety. The Mitchell ropewalker system with chest box and third ascender, or the three Gibbs ropewalker with a floating knee cam are both excellent.

Vertical Long: 50 to 300+ meters (150 to 1000+ feet). For the really big ones, a rappel rack is standard. For prusiking, both Jumar and Gibbs rope-walking rigs are used. With a Gibbs setup, you may prefer to float both the foot and knee ascenders with flexible (shock) cord. You should always carry one spare ascender plus two or three safety loops for emergencies.

Water Hazards

The difficulties that water can add to caves are more subtle than vertical hazards, but no less dangerous. If you were writing a set of specifications for conditions to produce hypothermia, the wet, muddy environment of many caves would be ideal. Flooding, too, is an ever present dager in caves with active streams or a steeply sloping sinkhole entrance. In threatening weather, it's best to stay out of such caves.

Water 1. Shallow streams.

Shallow streams (50 to 200 mm deep -- 2 to 8 inches) are common in caves. Usually, they can be avoided by walking on the bank or breakdown. If not, their shallow depth usually presents no real hazard beyond wet feet.

Clothing required: Woolen socks will probably save the day if the trip isn't too long and the cave is not too cold. Wet suit booties worn inside a size larger boot are also an excellent choice. If there is any possibility of falling in and getting wet or if you have to crawl in the water for any distance, woolen unders and perhaps a change of clothes would be called for. If you're to be in water more than this, you'll need a wet suit.

Water 2. Accidentlly getting soaked.

In this class of caves, the danger is increased by the possibility of falling into the water and getting soaked. Here there are pools or lakes deep enough for you to get your whole body immersed, and depth is often over your head. The exact depth is less important than the size and how easy it would be to accidentlly fall in and become an immersion hypothermia victim. Make no mistake about it, if you get soaked in frigid water, your life is in real danger unless immediate treatment is begun.

Clothing required: Several layers of clothing starting with woolen underwear (tops and bottoms), woolen pants and shirt, topped with a woolen sweater if the cave is wet and cold, plus coveralls over the whole thing. A change of clothing in a plastic bag may be a good idea. In extreme cases, nothing less than a full wet suit will do. The important thing is to keep dry and out of the breeze. Be prepared! Hypothermia is the killer of the unprepared.

Water 3. Getting wet on purpose.

In some caves you can't avoid getting wet. To explore the cave, you have to wade through waist or chest deep water, slosh through low crawlways with 200 mm or more of water (eight inches plus), or rappel right in the middle of a waterfall.

In Water 3, a wet suite is mandatory.

Summary of Vertical Equipment Required

This is a run-down on the vertical gear we take along on cave trips. For caves where we know we'll be doing vertical work, we carry a separate pack for vertical gear in addition to our cave pack.

Class 1 Caves -- No pits expected. Caver's sling (4 meters of 25 mm --one inch--webbing), and locking carabiner. This sling is always carried.

Class 2 Caves -- Small drops (5 to 10 meters) or a new cave with unknown but expected vertical extent.

15 meter 9 mm handline. MSR Longhorn or Figure 8 descender. Caver's sling and locking carabiner. Prusik slings (6 mm Tenstron). 12 mm (9/16) mini-etrier (attach with Prusik knot or Jumar to line). Safety loop (500 mm or 20 inch diameter) 7 mm perlon. Two carabiners. Rigging knife.

Class 2V Caves -- Vertical Short Medium pits (5 to 50 meters).

MSR Longhortn or rappel roack. Spelean Shunt. Chest sling, homemade two-inch with loop for Biggs cam. Seat sling, REI, attached to chest sling. Three Gibbs ascenders. Safety loop on line for fourth point. Shock cord for knee Gibbs (left knee). 25 mm (one-inch) etrier with Jumar, plus 12 mm (9/16) mini-etrier. Two extra safety loops, with long carabiners. Rigging knife. Spare Gibbs (part of Shunt).

Really Big Ones -- Vertical Long (50 to 300+ meters)

Rappel rack. Spelean Shunt. Chest and seat slings as above. Gibbs as above except float both knee and foot Gibbs. Spare Gibbs (part of Shunt). Jumar and 25 mm (one-inch) etrier, 12 mm (9/16 inch) mini-etrier. Three extra safety loops, four carabiners. Rigging knife.

Self Tests for Conservation Awareness and Caving Skills*

David R. McClung
2318 Jane Lane, Mountain View, California 94040 U.S.A.

Abstract

Here are four self tests than any caver, beginning or advanced, can use to compare his or her progress toward becoming a conservationally aware and competent cave explorer. Each item in the test contains specific details and dimensions, such as size of crawlways to be negotiated or pits to be dropped.

The tests are (1) Conservation Awareness Skills: crawling and walking through obstacle courses with loose, easily disturbed objects. (2) Basic Skills: knots, lamp operation, crawling, scrambling, climbing slopes and slots. (3) Intermediate and Advanced Skills: tight squeezes, verbal climbing signals, rigging, static belaying, chimneying, traversing, free climbin. (4) Technical Vertical Skills: ladder climbing, rappelling and pursiking (including pits of over 500 meters), changing over between rappelling and prusiking, passing knots.

Zusammenfassung

Hier gibt vier Selberproben die jeder Höhlenforscher gut gebrauchen kann, Anfänger oder Fortgeschrittener, um sich zu einem unweltschutzenden und fähigen Höhlenforscher zu messen. Jeder Punct der Proben enthält genaue Einzelheiten und Dimensionen´ zum Beispiel, die Grösse der Schlüfen, die mann begehen muss, oder die Grösse der Grube, die mann abseilen muss.

Die Proben sind: (1) das Unweltschutzbewusstsein: Bewegung einem Wege mit Hindernisse und mit losenhängenden, leicht gestörten Sachen. (2) grundlegende Fähigkeiten: Knoten, Lampewirkung, Kriechen, Abhangklettern und andrere Arten der Höhlenbewegung. (3) Mittel-und Fortgeschrittener fähigkeiten: Bewegung in engen Schlüfen, Rufzeichen, Seilbefestigung, Sicherung, Bewegung in Klufstrecken, Bewegung das Klettern. (4) Spezialle Vertikalabstieg-fähigkeiten: Drahtseilleitern, Abseilen und Prusiken (Grube grösser als 50 m eingeschlossen), die swischen abseilen, prusiken, und anderen Seilen wechselen, und das über Knoten steigen.

* * *

How good a caver are you? Do you know how easy it is to damage a cave just by being there? Do you consider yourself a beginner or an advanced caver?

To the best of my knowledge, there are no generally accpeted national or international standards for juding how aware cavers are of the damage that careless cave exploration can cause or how well they have mastered the essential caving skills. Thus, they are unable to compare their achievement in these areas with any recognized norms or to take steps to improve their performance to an acceptable level.

The following self tests are intended to fill this gap. They will give both beginning and advanced cavers a way to check their progress toward becoming conservationally responsible and competent in cave craft.

Conservation Awareness Self Test

Avoiding Careless or Destructive Exploration

To help develop an awareness of how your movement in a cave can unintentionally damage formations, hwere are two tests to be conducted above ground in full caving gear. These tests should be repeated several times until you are able to pass through the maze without disturbing anything at all. At club meetings or regional meets, a contest can be run to see who gets the lowest score. Here again contestants can try several times in order to perfect their skills and cause zero potential damage to the caves.

1. Walk across a floor densely strewn with easily disturbed objects such as plastic packing material chips or ping pong balls without touching or disturbing any of time.
2. Make up an obstacle course or maze of chairs, other furniture covered with loose objects that are easily dislodged, or tin cans that are easily knocked over. Crawl through this course without touching or knocking anything off.
3. Demonstrate a knowledge of sound conservation rules and practices, such as the NSS Conservation Policy.

Basic Skills Self Test

1. Knots: Tie these basic caving knots blindfolded or in complete darkness, including backup overhand knots where required: (1) bowline, (2) bowline-on-a-coil, (3) water knot (overhand bend, tape knot), (4) grapevine knot, (5) figure-of-eight loop, (6) Prusik knot.
2. Carbind Lamp: If using a carbine lamp, extinguish it in total darkness and immediately find and light your secondary source of illumination. Then, determine the cause of the following troubles and correct them. (Another caver could introduce some of these troubles in the lamp or another lamp.) This test assumes you are carrying extra water, carbide, and a spare parts kit at all times in the cave, plus the normal two other sources of light.

   Lamp won't light -- No water or carbide, clogged tip, wet felt, bad gasket, loose bottom. Refill the lamp with water and carbide, and put the used carbide in a suitable container for removal from the cave.

   Lamp burns irregularly -- Same causes as above, but dismantle lamp and actually replace felt and tip.

   Flame around gasket -- Bad gasket or thread seat, loose bottom.

   Flame around tip -- Bad or loose tip, bad tip seat.

   Water spurts from top, bubbles out of water filler cap, or flame is several inches long -- Too much water; decrease flow and wait before lighting. Felt may also have been soaked and needs replacement.
3. Electric Lamp: Turn the lamp out. Find and light secondary source of illumination. Then determine the cause and repair the following troubles. It is assumed that you have spare bulbs and batteries at all times, as well as your two other sources of light.

   No light -- Bad Bulb, dead batteries, loos connection. Take lamp apart and tighten or replace bulb and batteries.

   Irregular light -- symptoms as above.

   Dim Light -- check batteries for crroded or loose connections.

   Cable catches on obstructions -- Rerout cable from battery to lamp. Also demonstrate ability to remove lamp from helmet or ~~disconnect cable~~ quickly when it snags in a tight spot.
4. Crawling: Crawl through a low passage, ½ meter (18 inches) or less in height, 2/3 meter (two feet) or less in width, and 3 meters (10 feet) or more in length.
5. Scrambling: In a breakdown area scramble up and down over some good sized blocks (3 x 3 x 7 meters or 10 x 10 x 20 feet), using walls and ceilings, if available.
6. Slopes and Slots: Slide downward on a slope (using walls and ceiling if possible), a semi-vertical passage (less than 45°), a fissure, or between breakdown blocks, for at least 3 meters (ten feet) in total depth. (This assumes the landing below has been previously explored and is known to be a safe stopping place.)
7. Slopes and Slots (up): Similarly, climb, crawl, or chimney back up this or a similar passage.
8. Tilted Slots (down): Slid down a titled slot, fissure, or breakdown of similar dimensions as above, so that you must slide not straight down but at an angle.
9. Tilted Slots (up): Similarly, climb or clamber back through this or a similar slanting passage.

Intermediate and Advanced Skills Self Test

1. Tight Crawling: Crawl through a tight passage 300 mm (12 inches) or less in height with at least one "S" curve that requires turning over or crawling on your side, with one shoulder ahead of you, and pushing hard-hat and gear ahead of you.
2. Verbal Climbing Signals: Demonstrate the proper verbal signals and use them in each test.
3. Rigging: Find and rig a satisfactory anchor and backup anchor and use them in a cave.

4. Static Belaying: Belay a 40 to 90 kg (150 to 200 lb) caver on both an ascent and a descent in a cave, using the sitting hip position. Successfully hold an unannounced fall by both an ascending and a descending climber.

5. Chimneying Down: Chimney down a vertical or semi-vertical pit (more than 45°), that is wider than 2/3 meter (two feet) on the average, and at least 5 meters (15 feet) deep. Use a belay if the chimney bells out, is slippery, or is otherwise dangerous.

6. Chimneying Up: Similarly, chimney up the same or a similar pit.

7. Traversing: Make a horizontal traverse, while on belay, using three-point rock climbing skills and if the walls are close.

8. Free Climbing: Using three-point climbing technique, climb up and down while on belay, 7 to 10 meter (20 to 30 feet) vertical pit or wall that is too wide for chimneying and too steep for scrambling, using hand and footholds.

9. Demonstrate a knowledge of the proper climbing calls and responses.

Technical Vertical Self Test

To check your vertical competency, this is a self test for technical caving skills. These skills are in addition to those tested in the previous test that apply to vertical caving such as knots, verbal climbing signals, rigging, and belaying. As a review, they should be done in conjunction with the following tests.

1. Ladder Climbing--Find and rig a satisfactory anchor and backup anchor for a cable ladder.

2,3. Climb down and up at least a 10 metere (30 foot) cable ladder with a proper static belay from a separate belayer.

4,5. Climb up and down a 10 meter (30 foot) ladder using a self belay on a fixed line with a Prusik knot or Gibbs ascender.

6. Rappelling--Find and rig a satisfactory rappel anchor and backup anchor in a cave.

7. Rappel into a tight fissure or pit where you are against the wall most of the way. The drop must be at least 12 to 15 meters (40 to 50 feet).

8. Rappel into a medium width fissure or pit where you have contactand free rappelling. The drop should be at least 12 to 15 meters (40 to 50 feet).

9. Rappel into a wide fissure or room where you are mostly free from the wall. Drop must be at least 12 to 15 meters (40 to 50 feet).

10. Rappel down into one of these pits, perform a changeover from rappel to prusik, then ascend back to the top.

11. Rappel down a long drop in a cave or outdoors at least 50 meters (150 feet) and preferably 60 meters (200 feet) or more. Demonstrate your ability to handle the weight of the free hanging rope--from 22 to 66 kg (10 to 30 lbs) or more, by adding and removing bars from your rack, locking off and unlocking the rack, and securing and freeing your spelean shunt or other dynamic safety device. (A Prusik knot is not recommended for this purpose because of the difficulty of freeing it under load.)

12. Rappel down a line with two knots and successfully pass them both. Then continue on down.

13. Rappel down a line to a knot or obstruction. Then transfer to an adjacent line and continue down.

14. Prusiking--Find and rig a satisfactory anchor in a cave for a prusik line. (This could be the same anchor used in No. 6).

15,16,17. Prusik up the three separate types of drops required for the rappel test (in the same or different cave).

18. Prusik up in one of these drops and perform a changeover to rappel. Then rappel back down.

19. Prusik up to a knot or obstruction, then transfer to an adjacent line and continue up.

20. Prusik up a line that has two knots and successfully pass them. Continue on up.

21. Prusik up a pit at least 50 meters deep (150 feet) of any type, using a three ascender system and a seat sling resting position.

22. Be familiar with and follow the safety rules of your local or national caving group.

Systematik Der Mineral Paragenesen In Österreichischen Höhlen

Dr. Robert Seemann
Naturhistorisches Museum Wien, Mineralogisch-Petrographische Abteilung, Burgring 7, A-1+14 Wien, Österreich

Zussammenfassung

Je nach Entstehung und Herkunft wird unterschieden swischen "Mineralien in Höhlen" als allgemeiner Überbegriff und "Höhlenmineralien" im eigentlichen Sinn. Höhlenmineralien sind kristalline Körper, die unter den physikalisch-chemischen Bedingungen im Höhlenraum gebildet werden. Das dafür notwendige Elementangebot stammt entweder direkt aus dem anstehenden Gesteinsverband oder aus geologischen Nachbarformationen. Eine Systematik der Höhlenmineralien muß somit sowohl das Ausgangsmaterial als auch die speziellen lokalen chemisch-physikalischen Bedinqungen in der Höhle berücksichtigen.

Zur Einengung der in Frage kommenden Ausgangsmaterialien erfolgt eine Gliederung Österreichs in geologische Hauptzonen mit Berücksichtigung der verkarstungsfähigen Carbonatgesteine (Abb.2). Die mineralsystematik erfolgt nach`

1. Geographischer, geologischer und petrologischer Zuordnung des betroffenen Karstgebietes
2. Reihung der Mineralien nach Strunz (1970)
3. Trennung nach chemischer oder physikalischer Bildung der Ausbildungsformen (Speleothems) der mineralien
4. Trennung der Herkunft der Mineralien bzw. der Ausgangsstoffe für die Mineralbildung
   a. ortsgebundenes Karstmaterial und Nicht-Karstmaterial ("autochthon")
   b. ortsfremdes Nicht-Karstmaterial ("allochthon")

Abschließend wird ein kurzer Überlick über den Mineralinhalt österreichischer Höhlen am Beispiel des repräsentativen Karstkomplexes der Nördlichen Kalkapen mit ausgewählten Beispielen aus der Dachstein-Mammuthöhle (Abb.2) gegeben.

Der überwiegende Teil des "festen Höhleninhaltes" (Trimmel, 1968) besteht aus Mineralien und Gesteinen. Entsprechend kommt der Behandlung dieses Themas in Hinblick auf Klärung der Genese und Entwicklungsgeschichte der Höhlen und Karstlandschaften große Bedeutung zu.

Grundlegend muß zwischen "Mineralien in Höhlen" als Überbegriff und den eigentlichen Höhlenmineralien unterschieden werden. Als "Mineralien in Höhlen" können ohne Rücksicht auf Herkunft und Genese alle in Höhlen aufgefundenen Mineralien bezeichnet werden.

Höhlenmineralien im engeren Sinn sind sekundäre, d.h. nach, bzw, frühestens während der Höhlenbildung entstandene kristalline Körper, die unter den charakteristischen physikalisch-chemischen Bedingungen im Höhlenraum neugebildet werden. Damit sich ein Mineral bilden kann, ist ein Angebot von bestimmten chemischen Elementen in bestimmten Konzentrationen oder schon vorhandene andere, primäre Mineralien oder Mineralgemenge notwendig. Entscheidenden Einfluß auf Ausscheidungsgeschwindigkeit, auf Ausbildungsform, Farbe, etc., nehmen auch Elemente oder organische Komponenten, ohne am eigentlichen Aufbau des Minerals beteiligt zu sein. Ein weiterer Variationsfaktor kann auch durch die physikalische Beschaffenheit (Oberfläche, Ladung, etc.) und dem chemischen Zustand angrenzender Gesteinskörper (Fels, Sediment) gegeben sein.

Entsprechend ist für die Bildung oder Umbildung eines Minerals in Höhlen neben dem Einfluß der Atmo-, Hydro- und Biosphäre die Beschaffenheit der unmittelbar und mittelbar umgebenden Gesteinskörper von größter Bedeutung.

Zur Definition und Gruppierung des mineralogischen Höhleninhaltes gehört somit neuben der Feststellung der physikalisch-chemischen Entstehungsbedingungen auch die geologische und patrologische Erfassung des anstehenden Karstgesteins, wie auch der im Einzugsbereich befindlichen geologischen Nachbarformationen.

Für ein besseres Verständnis der Karst - und Höhlensituation in Österreich in Hinblick auf die Verteiling des mineralogisch-petrologischen Höhleninhaltes, erfolgt ein Gliederung in geologische Hauptzonen mit Berücksichtigung der verkarstungsfähigen Carbonatgesteine (Abb.1).

Unter Berücksichtigung der geologischen Situation läßt sich folgende Gliederung der Mineralien in österreichischen Höhlen durchführen´ zur besseren Verständlichmachung wird das Beispiel der Dachstein-Mammuthöhle herausgegriffen (Abb.2):

1. Feststellung der Lokalität, Umgrenzung des Karstgebietes (Dachstein-Massiv), geologische Zuordnung (N-rdliche Kalkalpen), petrologische Zuordnung (Kalkkarstgebiet).
2. Reihung der registrierten Mineralien nach Strunz (1970) beginnend mit den Elementen über die Sulfide, Oxide, Hydroxide, Carbonate, Sulfate, Phosphate bis zy den Silikaten.
3. Feststellung der Auzbildungsformen des Minerals ("Speleothems" nach Moore (1952)). Dabei wird unterschieden zwischen chemischer Bildung ("echteHöhlenmineralien") und physikalischer oder klastischer Bildung bzw. Transport und Sedimentation in der Höhle. Bei den zwei Gruppen erfolgt eine Einteilung nach Kristallinität und/oder Korngröße (Abb.2: Ziffer 1-3 und 4-6).
4. Feststellung der Herkunft des Minerals bzw. dessen Ausgangsmaterialien, wobei in erster Linie unterschieden wird zwischen ortsgebundenem und ortsfremden Material.

a. Unter ortsgebunden versteht man als Erweiterung des Begriffes "autochton" Material aus dem engeren Karstkomplex, wobei neuerlich getrennt wird zwischen ortsgebundenem Karstmaterial und ortsgebundenem Nicht-Karstmaterial.

In erster Linie handelt es sich bei ortsgebundenem Karstmaterial um das anstehende Karstgestein, dazu zu zählen sind aber auch auf chemischem Weg in Höhlen new entstandene Mineralien.

Ortsgebundene Nicht-Karstmaterialien sind einerseits eng begrenzte, bis mikroskopisch kleine Einschlüsse oder Zwischenlagen ("Xenolithe") im verkarstungsfähigen Gestein´ andereseits auch anstehende geologische Nachbarformationen dis fähigen Gestein; andererseits auch anstehende geologische Nachbarformationen die durch Weglösen des Karstgesteines zum höhlenraumbegrenzenden Material werden.

b. Unter ortsfremd ("allochthon") versteht man Material (meist Nicht-Karstmaterial), das von Bereichen außerhalb des engeren Karstkomplexes aus geologischen Nachbarformationen stammt. Der Transport kann auf chemischem oder physikalischen Weg erfolgen.

Auf Grund der erstellten Systematik für Mineralien in Höhlen und der Zuordnung zu den geologischen Großeinheiten ergibt sich zum heutigen Zeitpunkt für Österreich, eingeschränkt auf die Nördlichen Kalkalpen als repräsentativster und umfangreichster Karstkomplex, folgende Aufstellung von Mineralien in Höhlen.

Elemente:

Kohlenstoff*: dünne amorphe Überzüge an Höhlenwänden und auf Höhlensedimenten. Es handelt sich meist um inkohlte organische Schwebstoffe, die auf den eiszeitlichen bis subrezenten Gletscherarealen angereichert und durch Schmelzwässer in die Karstsystems eingebracht wurden; ^{14}C-Altersbestimmungen ergaben Werte zwischen 2000 und 7000 Jahren bP (Seemann, 1979a). (*Elementarer Kohlenstoff (amorph) ist hier nicht zum mineralogischen sondern zum chemischen Höhleninhalt oder zy den organischen Sedimenten zy zählen).

Sulfide:

Pyrit und Markasit: die Bildung fand unter charakteristischen pH- und Eh-Bedingungen unter Mitwirkung anaerober Bakterien in den ältesten, meist paläogenen bis neogenen Karstsedimenten statt (Seeman, 1979a). Eisen stammt als Verwitterungsprodukt größtenteils aus ortsfremden Schotterkörpen ("Augensteine"); Schwefel aus Evaporitlagerstätten permisch-triadischer Nachbarformationen. Als Folgeprodukt zeigen sich sekundärer Gips und Limonit (Pyrit: siehe auch Abb.2).

Oxide und Hydroxide:

Eis: als "Höhleneis" und als "Rauhreif" in temporär oder permanent tieftemperierten Höhlenteilen (kein eigentliches Höhlenmineral, da es nicht auf chemischem Weg in der Höhle entstanden ist).
Magnetit: als chemische Neubildung durch teilweise Reduktion von Fe-Oxiden und -Hydroxiden in Höhlensedimenten.

Ortsfremdes Material als Relikt aus den fluviatilen Schotterkörpern aus den Zentralalpen.
Hämatit: als chemische Neubildung durch Oxydation der Höhlenpyrite und Markasite, sowie als Relikt der kristallinen Augensteinschotter.
Maghemit: durch Ozydation von primärem und sekundärem Magnetit und als Neubildung durch teilweise Reduktion von Fe-Oxiden und Hydroxiden (Schwertmann, 1969).
Quarz: zum überwiegenden Teil als Quarzrestschotter aus den kristallinen Augensteinmaterialien (siehe auch Abb. 2).
Opal: lokale Neubildungen in Höhlensedimenten, die temporär durch Thermalwässer beeinflußt wurden (Niedermayr & Seemann, 1974).
Hornstein, Jaspis: als Lösungsrückstände anstehender oder benachbarter Karstgesteine ("ortsgebundenes Nicht Karstmaterial").
Manganogel: als wasserreiches, röntgenamorphes Manganoxid-Hydrat. Vorkommen in Form geringmächtiger Überzüge, als Lösungsrückstände meist anstehender Gesteine, angereichert über den biologischen Kreislauf in den Böden.
Gibbsit und Böhmit: als abgerolltes Transportgut aus benachbarten, z.T. ehemals überlagernden bauxitreichen Sedimentfolgen (Oberkreide bis Paläogen).
Goethit, Lepidokrokit: als Oxydationsprodukt der Höhlensulfide, sowie anstehender oder ortsfremder Karst- und Nicht-Karstgesteine. Hauptbestandteil der Limonit-Pseudomorphosen nach Pyrit und Markasit sowie der "Pseudobohnerze" und "Bohnerze" (Seeman, 1979a) (Goethit: siehe auch Abb.2).
Alumogel ("Kliachit") und Siderogel: als röntgenamorphe Zersetzungsprodukte aluminium- und eisenreicher Sediments.

Carbonate:

Calcit: als häufigstes Höhlenmineral in Form der diversen Tropfsteine, Excentriques und Sinter. Als Ausblühung in Form der "Bergmilch" und "Bergmilchwatte". Als Neubildung von Kristallindividuen in Lösungen und Sedimenten (siehe auch Abb.2).
Dolomit: entsprechend dem Mg-Anteil in der Lösung als Ausblühung und Neubildung in Sedimenten (zusammen mit Calcit, Aragonit und Hydromagnesit (Fischbeck, 1976). Zum Teil als Lösungs- und Zersetzungsrückstand dolomitreicher Kalke.
Aragonit: als Ausblühung oder Sinter.
Malachit: als Zersetzungsprodukt Cu-haltiger Zwischenlagen oder Nebengesteinsformationen.
Thermonatrit: als Zersetzungsprodukt von Soda.
Soda: als Ausblühung und Auskristallisation aus Lösungen aus eingeschalteten permischen oder triadischen Evaporithorizonten (Seeman, 1979b).
Hydromagnesit: als Ausblühung, zusammen mit Calcit, Dolomit und Aragonit in Abhängigkeit von Mg-Gehalt der Höhlenwässer (Fischbeck, 1976, Teitz, 1978).

Sulfate:

Thenardit: als Ausblühung, als Zersetzungsprodukt von Mirabilit.
Hexahydrit: meist als Ausblühung in Mg- und sulfatreichen Grenzzonen zy permischen Nebengesteinsformationen.
Mirabilit: als Ausblühung und Auskristallisation in Zusammenhang mit permischen oder triadischen, evaporitischen Horizonten (Seeman, 1979b)
Gips: als häufigstes Kalkkarst-Sulfatmineral` einerseits primär durch zirkulierende Wässer aus benachbarten oder anstehenden permischen Evaporithorizonten, andererseits sekundär durch Zersetzung der Höhlensulfide. Entsprechende Beziehungen konnten durch S-Istopenuntersuchungen nachgewiesen werden (Seeman, 1979a) (siehe auch Abb.2).

Phosphate:

Carbonat-Apatit: als neugebildete Konkretionen in knochenreichen Sedimenten (Niedermayr & Seeman, 1974).
Brushit: als Ausblühung aus knochenreichen Sedimenten.

Silikate:

Tonmineralien (Illit, Kaolinit, Chlorit): als Zersetzungsprodukt der kristallinen Fremdgesteine, sowie als Lösungsrückstand unreiner Karstgesteine (Illit: siehe auch Abb.2).
Granat, Glimmer, Feldspäte und diverse Schwermineralien: als Rückstandsmaterialien der Augensteinsediments (Seeman, 1979a).

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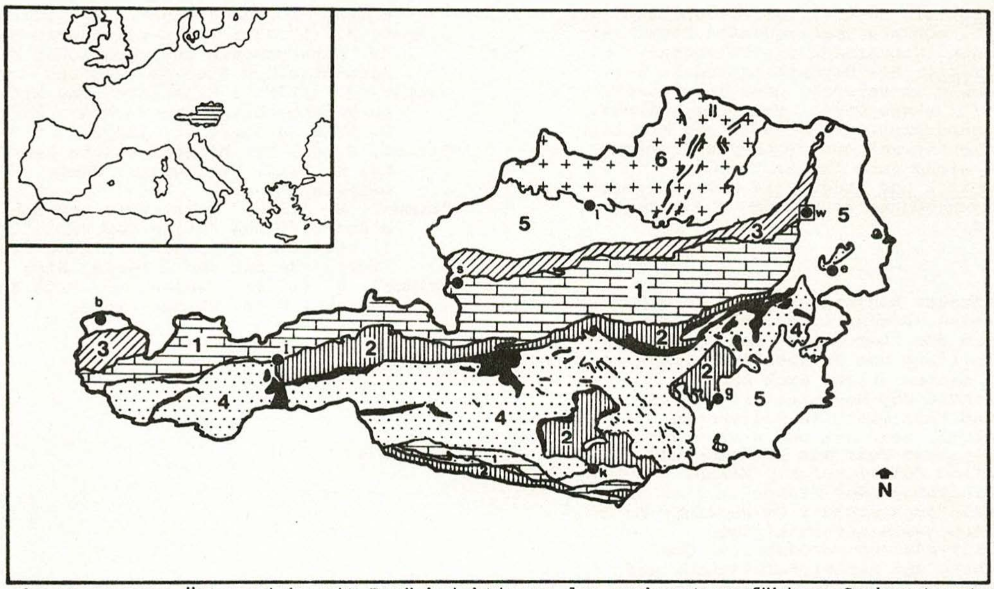

Abb.1: Geologische Hauptzonen Österreichs mit Berücksichtigung der verkarstungsfähigen Carbonatgesteine:

(A) Vorwiegend reich an Carbonatgesteinsserien`
<u>1</u>: Mesozoikum der Nördlichen und Sudlichen Kalkalpen: - sehr reich an Verkarstungserscheinungen: Nörliche Kalkalpen (i.e.S.): - durchschnittlich: Drauzung (Lienzer Dolomiten, Gailtaler Alpen, Nordkarawanken), Mesozoikum der Südalpen.

(B) Lokal reich an Carbonatgesteinsserien:
<u>2</u>: niedrig metamorphe altpaläozoische Serien: - reich an Verkarstungserscheinungen: Grazer Paläozoikum: durchschnittlich: Karnische Alpen: - arm: Grauwackenzone, sowie das Murauer Paläozoikum, Teile der Gurktaler Alpen und Anteile der Saualpe.
<u>3</u>: Helvetikum und Kliopenzone (reich an Verkarstungserscheinungen) und Flyschozone (arm).

(C) Mit geringen Anteilen an Carbonatgesteinsserien:
<u>4</u>: metamorphes Altkristallin und Pennin mit zentralalpinem Mesozoikum (schwarze Flächensignatur): geringmächtige metamorphe Carbonatgesteinsserien mit entsprechenden Verkarstungserscheinungen.
<u>5</u>: Neogene Ablagerungen der Molasse und der inneralpinen Becken mit einigen kalkreichen, karstanfälligen Beckenrandentwicklungen des Wiener und Steirischen Teriärbeckens.
<u>6</u>: Außeralpines Kristallin der Böhmischen Masse mit sehr geringmächtigen metamorphen Carbonatgesteinsserien (schwarze Flächensignatur) mit schwachen Karsterscheinungen.
(Landeshauptstädte: b = Bregenz, e = Eisenstadt, g = Graz, i = Innsbruck, k = Klagenfurt, l = Linz, s = Salsburg, w = Wien)
(zusammengestellt nach Trimmel (1965), Lein (1979) und Beck-Mannagetta & Matura (1980)).

DACHSTEIN-MAMMUTHOELE(Kat.Nr.1547/9)				Kalk-Karstgebiet der NOERDLICHEN KALKALPEN				(1)
MINERAL	Ausbildungsform in der Höhle (Speleothems)			Herkunft des Minerals, bzw. der Ausgangsmaterialien				Anmerkung
				ortsgebunden			ortsfremd	
				Karst-material	Nicht - Karstmaterial			
	Bildung	Anteil			aus d. Karstgest.	aus dem Nebengest.		
(Sulfide)	chem.	⬤	1		•	⬤	●	
PYRIT		•	2		•	⬤	●	Karstpyrit
FeS_2		●	3		•	⬤	●	
	klast. (phys.)		4					
kub.		+	5			+		
			6					
(Oxide)	chem.		1					
QUARZ			2					
SiO_2		+	3			+	+	Neubildung im Sed.
	klast. (phys.)		4					
trig.		⬤	5				⬤	Augensteine
		•	6		•		⬤	
(Hydroxide)	chem.	⬤	1	⬤	•	•	•	Pseudomorphosen
GOETHIT			2					
FeOOH		●	3	⬤	•	•	●	Bohnerze
	klast. (phys.)	•	4	●	⬤			Derberze
rh.		●	5	●	●	•	⬤	Pseudobohnerze
		•	6	●	•	•	●	
(Carbonate)	chem.	●	1	⬤		•		Sinter i.A.
CALCIT		•	2	⬤				Krist.
$CaCO_3$		•	3	⬤		•		Ausblühungen
	klast. (phys.)	⬤	4	⬤			+	
trig.		•	5	⬤			+	
		●	6	⬤			+	Höhlenton
(Sulfate)	chem.		1					
GIPS		⬤	2	⬤		●		Krist.
$CaSO_4 \cdot 2H_2O$		●	3	⬤		●		Ausblühungen
	klast. (phys.)		4					
mon.		+	5	+		+		
			6					
(Silikate)	chem.		1					
ILLIT			2					
$-(K,)(Al,Mg,)_2-$ $-(Al,Si)_4O_{10}$-aq.		+	3		+	+	+	Neubildungen
	klast. (phys.)		4					
mon.			5					
		⬤	6		•	•	⬤	Höhlenton

Abb.2: Aufstellung der in österreichischen Höhlen vorkommenden Mineralien am Beispiel der "Dachstein-Mammuthöhle", Oberösterreich (Kataster-Nr.1547/9) aus dem Kalkkarstgebiet der Nördlichen Kalkalpen mit einer kleinen Auswahl von 6 Mineralien aus 6 verschiedenen chemischen Mineralgruppen.

Die Einteilung der Ausbildungsformen ("Speleothems") erfolgt bei chemische Bildung (Transport/Sedimentation)
(1) makroskopische kristalline Massen
(2) makroskopische Einzelkristalle
(3) makroskopische und submikroskopische Kristalle und kristalline Massen; und bei klastischer oder physikalischer Bildung (Transport/Sedimentation) nach
(4) Schutt (locker + verfestigt)
(5) Geröll, Sand (locker + verfestigt)

Der prozentuelle Anteil der Ausbildungsformen und der Ausgangsmaterialien, bzw. Ausgangsmineralien ist größenordnungsmäßig festgelegt nach:

⬤ = 50 - 100%

● = 10 - 50%

• = unter 10%

\+ = lokale Einzelfälle

Der Hypsometrische Höhlen-Übersichtsplan

Günter Stummer
Institut für Hohlenforschung am Naturhist, Museum Wien, A-1010 Wien, Burgring 7

Zusammenfassung

Die Methode, zur Darstellung der Höhenunterschiede bei topographischen Karten die Isohypsen weitgehend durch farbige Höhenstufen zu ersetzen, kann auch für die Ausarbeitung von Höhlenplanen herangezogen werden.
Der Autor empfiehlt und beschreibt diese hyposometrische Methode unter Benützung des Prinzipes, höhere Höhlenteile heller, tiefere Höhlenteile jedoch dünkler darzustellen.

Summary

The method of using for the graphic representation of difference in altitude of maps not isohypses but coloured vertical intervals can also be adapted for cave mapping.
The author recommends and describes this hypsometric method using bright colours for high, but dark colours for deep cave parts.

Zur exakten Darstellung eines dreidimensionalen Höhlenobjektes ist die Projektion auf zwei senkrecht zueinander stehenden Ebenen erforderlich. Es ergibt sich daraus die Darstellung einer Höhle in Grundriß (Projektion auf eine vertikale Ebene). Erst die gemeinsame Betrachtung und Integration beider Risse vermittelt eine räumlich Vorstellung vom Verlauf und der Ausdehnung der dargestellten Höhlenräume.

Dieses optische Zusammenführen von Grund- und Aufriß gestaltet sich bei großen Höhlensystemen bereits überaus schwierig. Es bedarf dazu meist eines sehr großen räumlichen Vorstellungsvermögens, sehr großer Übung im Planlesen und oft auch eine besondere Kenntnis der Höhle selbst. Es hat daher, unabhängig von den Versuchen einer räumlichen Darstellung oder der Erstellung von Modellen, ständig Bemühungen gegeben, die vertikale Komponente optimal in den Grundriß einzuarbeiten. In enger Anlehnung an die Kartographie wurds dazu auch in der Speläokartographie die Isohypsendarstellung herangezogen. Vor allem seit dem Jahr 1945 wurde diese Methode für großmaßstäbige Höhlenpläne immer häufiger verwendet und etwa von Stummer (1980) für die 35 km lange Dachstein-Mammuthhöhle bereits konsequent eingesetzt. Die Verwendung von Isohypsen zur Darstellung der Höhenunterschiede ist jedoch ebenfalls begrenzt. Es wurde daher ständig nach weiteren Darstellungmöglichkeiten für die Vertikaldimensions im Grundriß gesucht. Götzinger (1956) hat zum Beispiel die Darstellung der Höhlendecke durch eine Kombination von Isohypsen und Isohypsenschummerung versucht und Leja (1962) verwendet zur Darstellung von Etagenhöhlen verschiedene Flächenraster, um die H-henunterschiede der einzelnen Etagen im Grundriß deutlich zu differenzieren (Abb. 2b). Trimmel (1956) benützt dagegen zur Grundrißdarstellung von Schächten verschiedene Raumbegrenzungssignaturen für die einzelnen "Teifenstufen" (Abb.2a).

Auf diesen Gedanken aufbauend läßt sich nun auch jene kartographische Technik in die Höhlenplandarstellung einführen, die überall dort, wo die Isohypsendarstellung aus Maßstabsgründen versagt, die Methode der Hypsometrie zur Darstellung der Reliefenergie verwendet.

In topographischen Karten mit Maßstäben von 1: 100 000 und kleinr sowie vor allem in der Atlaskartographie werden zur Darstellung verschiedener Höhenlagen fabige H-henstufen verwendet. Für die Farbauswahl wurden dabei verschiedene Prinzipien entwickelt und erprobt. So wird etwa der natürliche Farbaspekt einer Landschaft, der durch die Farbe der Vegetation oder durch ihr Fehlen charakterisiert wird, herangezogen oder as wird die Technik, höhere Landschaftsteile heller, tieferliegende Landschaftsteile dünkler darzustellen, verwendet.

Gerade das letztere Prinzip scheint für die Anwendung in der Höhlenplandarstellung besonders geeignet zu sein. So können Höhlen-Übersichtspläne mit Maßstäben kleiner als 1:1000, in die schon aus Maßstabsgründen keine Höhleninhalte mehr eingetragen werden können, nach der hypsometrischen Methode überaus eindrucksvoll gestaltet werden. Durch die exakte Zuordnung eines Flächenrasters oder einer Farbe zu einer bestimmten Höhen- oder Tiefenstufe kann der vertikale Unterschied einzelner Höhlenteile auch im Brundriß deutlich sichtbar gemacht werden. Dabei kommt das Prinzip "Je höher, desto heller" auch dem natürlichen Empfinden des Höhlenforschers entgegen (Abb.1).

Vor der Ausarbeitung eines hypsometrischen Höhlenübersichtsplanes sind jedoch individuell für jebe Höhle eine Reihe von grundsätzlichen Überlegungen anzustellen. So ist etwa die Frage zu klären, ob für den vorgesehenen Maßstab die Fläche zwischen den Raumbegrenzungen zur Auftragung eines Flächenrasters oder einer Farbe ausreicht. Sehr wesentlich ist auch die Festlegung der Äquidistanz der Höhenstufen selbst. Diese wird sehr weitgehend von der gesamten Niveaudifferenz der darzutellenden Höhle und von der Anzahl der zur Verfügung stehenden, klar zu unterscheidenden Raster oder Farben abhängen. Grundsätzlich wird festzulegen sein, ob die hypsometrische Darstellung etwa aus reproduktionstechnischen Überlegungen mit Raster oder für Ausstellungszwecke mit Farben ausgeführt wird. Im ersten Fall wird der Vertikalmaßstab als visuell erkennbare Tonwertstufenskala erstellt, bei der jedoch der Übergang zwischen den Stufen so kontinuirlich erfolgen soll, daß nicht der Eindruck von Abbrüchen vorgetäuscht wird. Bei der Darstellung mittels Farbskala ist bei der Farbauswahl besondere Sorgfalt erforderlich. Hier bietet sich etwa die Farbwahl nach dem Prinzip der Farbgewichte an, bei dem etwa die Farbskala von Gelb über Grün, Blau, Blauviolett zu Schwarz ginge. Denkbar wäre auch die Erstellung der Farbskala nach dem Empfindungswert der Farben, wobei etwa höhere Höhlenteile in "warmen Farben" (Gelb,Rot), tiefere Höhlenteile jedoch in "kalten Farben" (Blau,Grün) dargestellt werden könnten. Eine erstellte Farbskala ist jedoch hinsichtlich des Farbempfindens der Höhlenforscher genauestens zy Überprüfen, um Fehlinterpretationenzu vermeiden. So könnte etwa die Farbe Gelb-Brau-Braun den Eindruck von sedimenterfüllten Höhlenteilen, die Farbe Blau von wassererfüllten Höhlenteilen erwicken.

Der Übergang zwischen den Höhenö oder Teifenstufen stellt gleichzeitig eine Höhenlinie mit der durch die Stufe vorgegebenen Äquidistanz dar. Mehrere Höhenstufen zusammen können darüberhinaus durch Zähllinien vermerkt werden, was die Aussagekraft des hypsometrischen Planes wesentlich verbessert.

Bei der praktischen Anwendung dieser Methode in der Speläokartographie werden sicherlich noch weiters Darstellungsmöglichkeiten entwickelt werden und zahlreiche Schwierigkeiten, vor allem bei der Erstellung des Vertikalmaßstabes, zu lösen sein. Es wäre etwa denkbar, das Eingangsniveau einer Höhle besonders hervorzyheben, indem man für Stufen über dem Eingang Strichraster, darunter jedoch Punktraster verwendet. Bei den Schwierigkeiten sei zum Beispiel nur erwähnt, daß die Grundlage des hypsometrischen Planes der Polygonzug ist, die jeweilige Bezugsfläche jedoch die Höhlensohle. Ist der Polygozug nicht annährend ident mit der Höhlensohle, wie dies vor allem bei der Vermessung von Canyons der Fall ist, können Fehlinterpretationen auftreten.

Neben dem Horizontalmaßstab ist für die Lesbarkeit eines hypsometrischen Planes auch ein exakter Vertikalmaßstab erforderlich, der die Zuordnung einer gewissen Raster- oder Frabintensität zu einer dazugehörenden Stufe ermöglicht.

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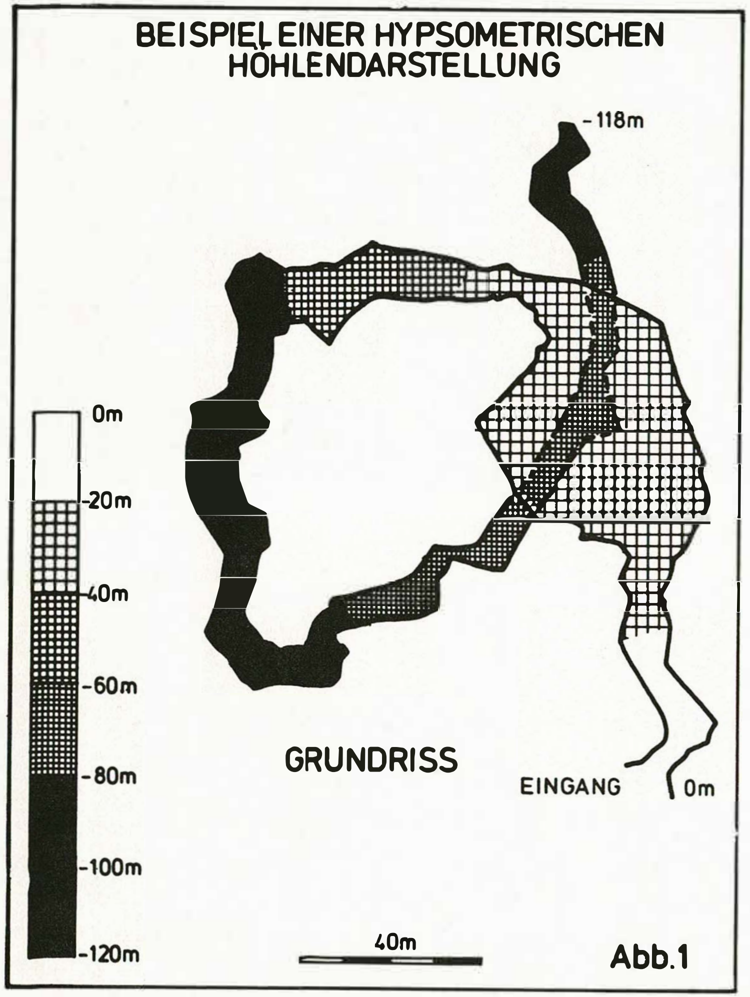
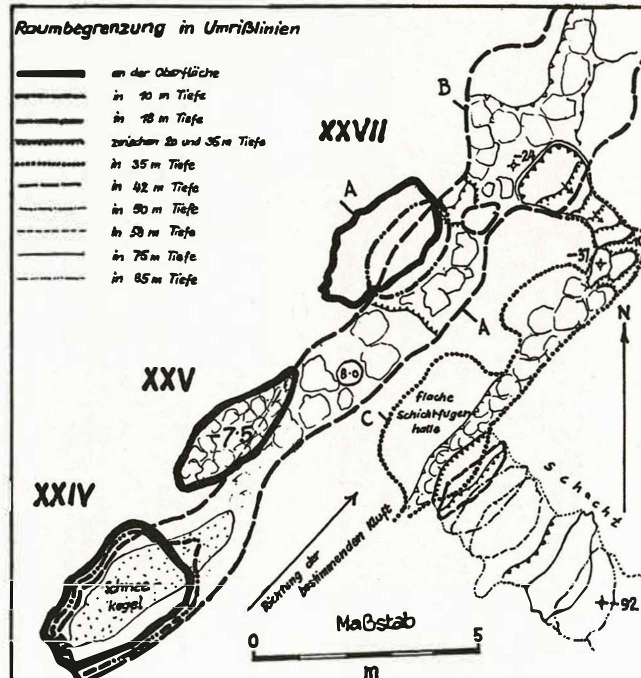


Abb.1



Trimmel 1956

Abb. 2a

Leja 1962

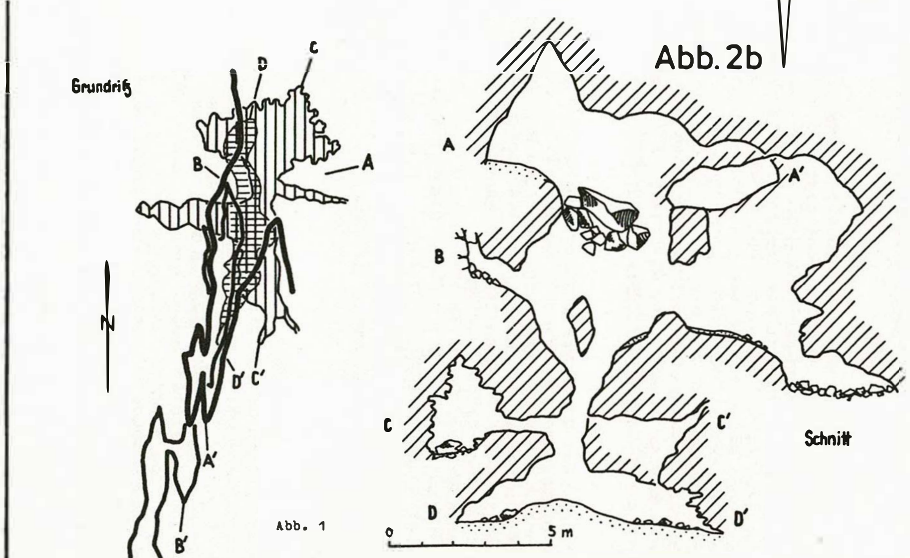


Abb. 2b

Beispiel einer schachtartigen Kluft (A25 Bismarckgrotte, Keller) mit 4 Etagen:
1. oberste Etage A-A' — 1,6 mm, 2. obere Etage B-B' — 1,0 mm
3. mittlere Etage C-C' IIII 0,5 mm, Strichabstand 3 mm
4. untere Etage D-D' 0,3 mm, Strichabstand 2 mm

Abiotic Effects on the Successional Decomposition of Dung

Kathleen Hoey Lavoie
Department of Biological Sciences, University of Illinois at Chicago Circle, Box 4348, Chicago, Illinois 60680, U.S.A.

Abstract

The influence of several abiotic factors on the successional changes in invertebrate and microbial species during the decomposition of cave rat dung was studied. Ground-up fecal pellets from Neotoma cave rats were formed to resemble the size, shape, and consistency of three naturally occurring fecal types found in caves --- rat pellets, raccoon scats, and cricket guano veneer. The amount of material in each form, the nutritional value, fungal inoculum, and moisture content were constant.

Deep cave and entrance areas showed similar patterns of microbial succession when invertebrates were excluded. Shape was the most important determinant of fungal succession.

Invertebrates did not select the three dung shapes and two consistencies equally, preferring the intermediate imitation rat pellet shape and the finer consistency dung. The abiotically variable entrance area had a higher density and diversity of fly species while the constant deep cave area had higher densities of scavenging Ptomaphagus hirtus beetles.

Résumé

L'influence de divers facteurs abiotiques sur la succession de changements des invertébrés et des expèces microbiennes pendant la décomposition de la bouse de rats cavernicoles a été étudié. Les fientes de Neotoma sp. ont été arrangées de façon à ressembler en grosseur, en forme, et en consistance à trois types fécaux naturels trouvés dans les grottes - les fientes de rat, de raton laveur et de grillion (guano en couche mince). La quantité dans chaque forms, la valeur nutritive, l'inoculum de mycètes, et la humidité étaient tenus constants.

L'endroit profond de la grotte et l'endroit à l'entrée ont démontré des successions microbiennes semblables lorsque les invertébrés étainet absents. La forme était le facteur le plus important pour déterminer la succession de mycètes.

Les invertébrés n'ont pas chaisi également les trois formes de bouse et les deux consistances. Ils ont préféré la forme intermédiaire de rat at la bouse à consistance plus fine. L'entrée de la grotte (variable en abiotique) avait une densité et une diversité plus grandes des espèces de diptères, alors que l'endroit profond de la grotte (constant) avait une densité plus grande du coléoptère coprophage, Ptomaphagus hirtus.

Introduction

The decomposition of detrital material results in recycling and mineralization of nutrients essential for growth. Detritus and decomposer organisms form the food base for many systems, including soil, streams, dung, the rumen, artificial sewage systems, and - of course - caves. The heterotrophic decomposition is successional; the changes in species are regular and predictable over time, but differences are found in the species involved and the timing of the succession on different materials such as dung and litter (Swift et al., 1979).

Many factors influence the succession on detrital material including the physical and chemical nature of the resource and the local environment (Richardson, 1972; Swift et al., 1979). The effect of biological interactions are discussed by Lavoie, elsewhere in these Proceedings. Richardson (1972) suggested the use of experimental manipulations of dung to study the effects of these factors on the succession.

One aspect of my research has been the study of the influence of abiotic factors on the successional decomposition of dung. This report deals with the effects of shape and consistency of the dung and the microclimate at the site of deposition. The availability of colonizing species in affecting the succession is also discussed.

Methods

The cave ecosystem is optimally suited to my research due to the simplified community structure, moderate physiochemical conditions, reduced seasonal and weather effects, and lack of plant interactions (Poulson and White, 1969). In the Mammoth Cave area of Kentucky where my field work is done, the communities are based on detrital input from washed in litter and silt with lesser inputs from facultative cave species which feed outside the cave (Barr and Keuhne, 1971). All three of the dung types used in my research are from facultative cave species (rat, raccoon, and cricket). The animals are found near cave entrance areas where their dung is seasonally renewed and subject to abiotic rigor through winter drying. These conditions result in a seasonal cycle of availability (Kane and Poulson, 1976). The natural rat fecal types differ in the size and shape of individual fecal units, energy availability, and their predictability in time and space (Poulson, 1972) as discussed by Poulson, elsewhere in these Proceedings.

The basic field experiment consists of grinding up fecal pellets from Neotoma cave rats which are kept in the lab and fed rat chow (Purina) and vegetables with an added fungal inoculum from naturally occurring rat latrines. The dung is ground in a Willey Mill to coarse (20 mesh) and fine (60 mesh) consistencies and formed by hand to resemble the size and shape of the three fecal types; rat pellets, raccoon scats, and cricket guano veneer. The amount of material (5 g dry weight), nutritional value, and moisture content (60% water) is constant in each manipulation (approximately 150 rat pellets, one raccoon scat, and 100 cm^2 of 1 mm thick cricket veneer). Duplicate samples are field incubated in a variable entrance area (Little Beauty Cave) and a constant deep cave area (Columbian Avenue, Flint-Mammoth Cave). In each area one group of samples is exposed to all invertebrates and microbes in a wood and chicken wire cage to exclude rats, and a second group of samples exposed only to microbes and microfauna such as mites and enchaetryid worms in metal and cloth cones.

All samples are censused on each field trip, and one replicate of each manipulated type is collected and returned to the lab. Each sample is weighed in total and the percent moisture determined by drying a portion in a 100 C oven for two days. One to 1.5 g of dung is diluted 1:100 in sterile water with a Waring Blender. Slides for Gram stains and direct bacterial and fungal spore counts are made from the diluted sample.

Samples collected after one week of exposure in the field were wet incubated in moisture chambers under cave conditions and examined every 1 to 3 weeks for fungal fruiting bodies and invertebrates.

Results and Discussion

The fungal succession on manipulated dung in both study areas are similar. A generalized sequence of appearance of the fungal groups on exposed and within-cone imitation rat pellets is shown in Figure 1A. The sequence followed the classic pattern (Webster, 1970) with Phycomycetes coming in early, then Ascomycetes and Basidiomycetes later. Fungi imperfecti and asexual Ascomycetes appeared throughout the succession.

The early fungi (6-8 species of Phycomycetes) appear in four days on within cone and exposed dung and quickly develop a dense hyphal mat. Most species persist only within the cones in the basence of invertebrates. Rhizopus persists for several weeks, possibly because it moves out from the dung pile and fruits directly on the soil. The species encountered have a ubiquitous distribution and I see little evidence of antagonism among species.

Based on observations within-cones and in lab wet incubations, the rat dung supports a very low diversity of higher fungal species.

The next group to appear are the Ascomycetes, including the plectomycetes and pyrenomycetes. Only three species have been seen: Chaetomium (a pyrenomycete), a plectomycete, and Ascobolus (an ascomycete). The Chaetomium may be a contaminant from the lab since I do not see it on naturally occurring rat dung.

Only one Basidiomycete (Coprinus sp.) grew on one within-cone manipulation in the field and on two lab-incubated samples. It has not been seen on dung exposed to invertebrates or on natural dung, possibly due to the extensive comminution and mixing by invertebrates, or it may be especially palatable to the animals. The mushroom is very transient on lab-incubated material. It might also be a contaminant from the lab.

The variable distribution of occurrence of these "contaminants" suggests that the fungal succession on cave rat dung is not ecologically saturated. Any of several species can appear without affecting the sequence of the "natural" fungi.

Fungi imperfecti (3-5 species) and asexual members of the Ascomycete (3-4) form-genera Penicillium and Aspergillus appeared throughout the sequence.

The colonization of dung by fungi is restricted by their relative immobility and the need for stimulation before the spores of some species can germinate (Webster, 1970). Bacteria face similar problems. However, colonization by microorganisms is not usually a problem due to their ubiquitous distribution (Swift et al., 1979). My experiments with colonization of sterilized dung shows that most species of Phycomycetes are inhabitants of the cave and can colonize directly from the substrate, and to a lesser extent from the air. Some of the same species can also be brought in on the bodies of animals or in their guts, as demonstrated for litter invertebrates by Phearson and Beattie (1979). Later fungi either colonize from other sources or grow from spores already present in the dung. No differences in fungal species between the two cave sites has been noted on the manipulated dung.

The invertebrate succession followed the typical pattern (Swift et al., 1979) with specialists coming in early and more generalist species later. A simplified sequence for both study sites is shown in Figure 1B based on observations of imitation rat (60 mesh) exposed in the rat-proof cages. The succession was influenced by the local species pool and the mobility of colonizers. Cave rat dung is normally found in the abiotically variable entrance area while it is a few hundred meters from the nearest natural rat latrine to the constant deep cave study site. The entrance had a higher density and diversity of fly species (sciarid, phorid, borborid, and psychodid) and Collembola (Folsomia, Arrhopalites, Tomocerus, and Hypogastrura) than the deep cave (sciarid, phorid; Arrhopalites, Folsomia). The deep cave had higher densities of scavenging Ptomaphagus hirtus beetles (Catopidae).

Predators drastically modified the succession. Staphylinid beetles entered the entrance dung piles and caused a rapid drop in the number of large invertebrates. No predators capable of eating the large fly and beetle larvae have been seen on or in the dung piles at the deep cave site.

The physical nature of the dung and the site of deposition influence both the microbial and invertebrate successions to different extents.

The surface area to volume ratios of the three dung shapes result in different densities of early fungal hyphae on the surface as shown by simply clipping the mat off and weighing it (0.50 g on rat vs 0.023 g on cricket). Shape affects where the fungi develop, to some extent; the nooks and crannies of the pile of imitation rat dung supports more fruiting bodies of Chaetomium and Ascobolus than the single smooth lump of imitation raccoon. The thinly spread imitation cricket veneer showed only limited growth of Phycomycetes and Fungi imperfecti; higher fungi (Ascomycetes and Basidiomycetes) never developed on the veneer. Weight loss data from the within-cone dung show that even in the absence of large invertebrates, the dung still loses a great deal of mass, with the rat pellet shaped dung losing more weight than the raccoon (Table 1). No clear effect of consistency was noted.

The number of fungal spores per gram of dry weight generally supports the field observations; the raccoon and cricket shaped dung showed less fungal fruiting than the rat pellets.

The bacterial counts showed cell numbers staying high during the first week, dropping dramatically by the third week, and rising again by the sixth week. Numbers peaked in the twelfth week at only slightly higher levels. There is no obvious difference in the proportion of Gram-positive and Gram-negative cells over time. This observation may not be relevant, since many Gram-positive species become Gram-negative as they age. The number of short forms and replicating cells is greater in the early weeks. Bacterial spores greatly increase in the older manipulations.

Shape and consistency of the dung modify its appeal to invertebrate colonizers. The invertebrates preferred the raccoon-shaped manipulation over the rat shape and used the imitation cricket veneer very little; only an occasional Ptomophagus adult or fly adult were ever observed on the veneer, and only a few (1-3) Ptomaphagus larvae used the veneer. In all cases the finer consistency dung was preferred. Data to support these field observations are given in Table 1 as weight loss of each type over twelve weeks. The finer particles may be easier to eat directly or may support more bacterial or fungal growth, or the increased smell may attract the invertebrates as suggested by more frequent "breaking and entering" of cones with the finer material.

The nature of the local deposition site affects both the microbial and invertebrate successions. Dung deposited on rock retains more moisture and leachate, making it more attractive to specialized animals and prolonging the dominance of early fungal species. Sandy and muddy substrates appear little different in influencing the succession. In lab studies using the smae amount and percent moisture of the three manipulated forms the rate of drying was cricket $\gg$ rat $\geq$ raccoon.

The microclimate can be modified by the amount of deposition. Winter sampling of a natural rat latrine in Rat Cave, Indiana, showed that the piling of pellets did not affect temperature within the pile, but piling did help to retain moisture in the interior (outer pellets, 19.8% moisture; interior pellets, 29.5% moisture). The deep pile was less rigorous to organisms as indicated by the fungal hyphae and Collembola found there, but not among the outer pellets.

In summary, the successional decomposition of rat dung is strongly influenced by the shape and consistency of the material and the nature of the deposition site; nutritional value is less important in controlling the succession. Invertebrate colonization was affected by the local species pool while the microbes showed a more ubiquitous distribution.

Acknowledgements

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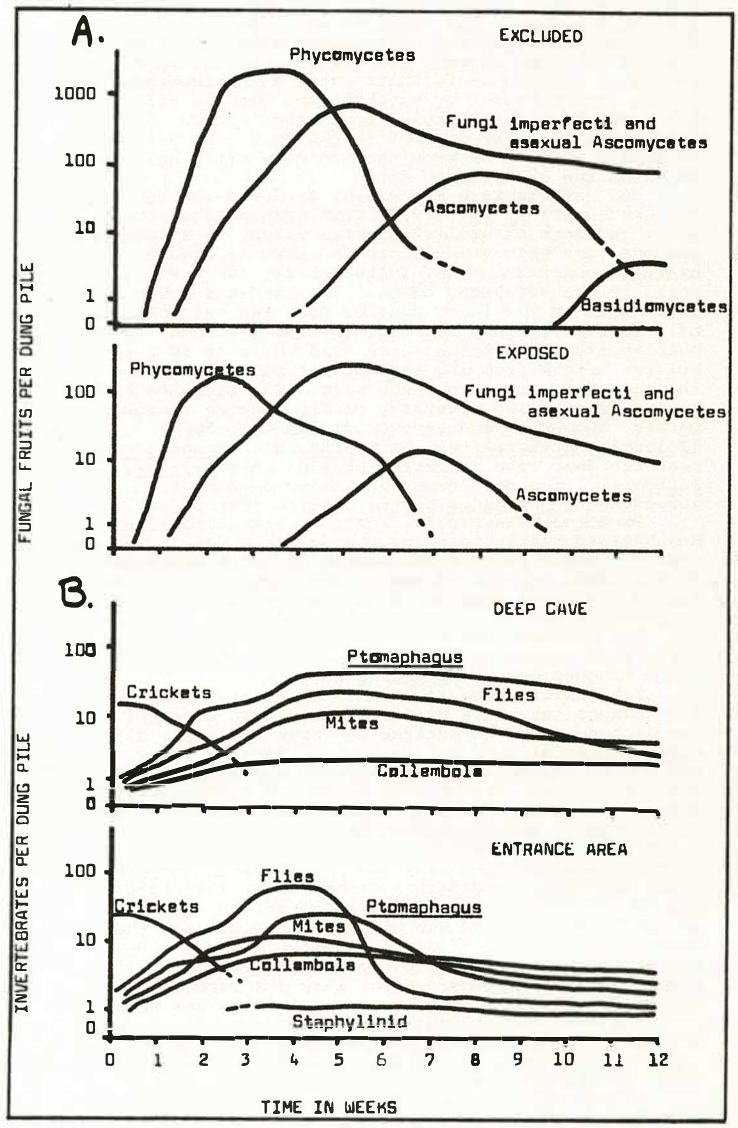
Table 1. Changes in dry weight of manipulated dung in the deep cave and entrance areas. Duplicate samples were exposed to all invertebrates or only to microinvertebrates. Time given in weeks from the start of the field exposure. Imitation rat and imitation raccoon of two consistencies were used (20 = coarse; 60 = fine). Data for real rat pellets are also given.

Sample	Start	W1	W3	W6	W12
WITHIN-CONE					
Deep Cave					
Real Rat	5.0	3.8	3.5	3.0	2.4
ImRat 20	5.0	3.8	--	3.1	--
ImRat 60	5.0	3.8	3.2	2.8	2.7
ImCoon 20	5.0	3.9	--	3.3	--
ImCoon 60	5.0	3.8	3.9	3.6	3.7
Entrance Area					
Real Rat	5.0	4.5	--	--	--
ImRat 20	5.0	5.0	--	3.6	--
ImRat 60	5.0	4.5	--	--	--
ImCoon 20	5.0	4.2	--	4.2	--
ImCoon 60	5.0	4.4	--	--	--
EXPOSED					
Deep Cave					
Real Rat	5.0	3.7	2.8	2.2	1.7
ImRat 20	5.0	3.4	--	2.3	--
ImRat 60	5.0	2.9	3.1	2.0	1.8
ImCoon 20	5.0	3.4	--	2.6	--
ImCoon 60	5.0	2.5	2.6	1.6	--
Entrance Area					
Real Rat	5.0	3.1	3.2	3.4	2.8
ImRat 20	5.0	4.5	--	3.3	--
ImRat 60	5.0	4.1	3.0	2.4	2.9
ImCoon 20	5.0	3.9	--	3.5	--
ImCoon 60	5.0	2.6	2.1	2.0	1.2

Figure 1. A. Generalizations of the number of fruiting structures in each major fungal group over time on exposed and within-cone manipulated dung in both study areas. Figures for Phycomycetes and Fungi imperfecti are only estimates.
B. Average number of invertebrates over time per pile of exposed imitation rat pellets (60 mesh) in the deep cave and entrance areas. Mites are totals for all species. Collembola include Arrhopalites and Folsomia in both areas, and Hypogastrura and Tomocerus in the entrance area. Fly species are a sciarid and a phorid in both areas, plus borborid and psychodid in the entrance area.



Invertebrate Interactions with Microbes During the Successional Decomposition of Dung

Kathleen Hoey Lavoie
Department of Biological Sciences, University of Illinois at Chicago Circle, Box 4348, Chicago, Illinois 60680, U.S.A.

Abstract

In caves, where nutrient input is limiting, there is a direct competition between scavenging invertebrates and microbes for ephemeral food resources such as dung. Field and laboratory studies using standardized manipulated cave rat dung have shown that whichever group establishes dominance first limits the use of the resource by the other group. The early dominance of invertebrates, especially the scavenging beetle *Ptomaphagus hirtus* and the larvae of the fly *Sciara,* eliminates any succession of fungi. This inhibition of the fungi persists after the invertebrates have abandoned the dung pile. An early dominance of fungi and/or bacteria reduces the reproductive success of the invertebrates, but does not eliminate them, presumably since the microbes themselves can serve as a source of food for the scavenging invertebrates. Laboratory experiments with *Ptomaphagus* have shown that their reproductive success and survival on fresh dung is high with very rapid growth while their reproduction, survival, and growth on old dung is poor. Reproductive success is intermediate on fresh dung if fungi are established before the beetles colonize.

Résumé

Dans les grottes, où l'énergie nutritive mise en oeuvre est limitée, il y a une concurrence directs entre les invertébrés coprophages et les microbes pour les ressources éphémères de nourriture, telle que la bouse. Des études sur les lieux ou en laboratoire sur la bouse de rat cavernicole manipulée et standardisée ont démontré que, peu importe le groupe qui devient dominant le premier, il limite les ressources utilisées par l'autre groupe. La première predominance des invertébrés, surtout le coléoptère coprophage, *Ptomaphagus hirtus,* et les larves du diptère, *Sciara* sp., élimine toute suite de mycètes. Cette défense des mycètes persiste après que les invertébrés ont abandonné l'amoncellement de bouse. Une première prédominance des mycètes et (ou) des bactéries réduit le succès de reproduction des invertébrés, mais ne l'élimine pas, probalement parce queles microbes eux-mêmes peuvent se servir d'une source de nourriture pour les invertébrés coprophages. Les essais en laboratoire avec *Ptomaphagus* ont démonté que leur succès reproductif et leur survivance en bouse fraîche est élévé et le taux de croissance est très rapide tandis que leur reproduction, leur survivance et leur croissance en vieille bouse est réduit. Le succès reproductif est intermediaire en bouse fraîche si les mycètes sont établis avant la colonisation des coléoptères.

Introduction

In caves, where nutrient input is limiting, there is a competition between invertebrates and microbes for ephemeral resources such as dung. The detritus base of the food web in caves varies from area to area, but the resources are usually predictable in time and space. Terrestrial cave communities in the Central Kentucky Karst are usually based on input from troglophilic and trogloxenic species. Cave rats input plant material and feces; beetles provide feces; cave crickets provide eggs and guano; and all eventually contribute their dead bodies. The two largest resources in Kentucky caves are the mud (clay-silt) substrate and washed in litter which primarily enters the caves during spring flooding (Poulson, 1972). For a discussion of these resources see Poulson, elsewhere in these Proceedings. Bats, which are very important sources of food input in many caves through extensive guano deposition and carrion, are not of major importance in Central Kentucky caves since most species of bats in these caves use them only for overwintering; their nutrient input is minimal.

This varied detrital input is converted into usable food by the action of decomposer microorganisms, both bacteria and fungi. Higher organisms eat the microbes and/or feed directly on the detritus. On ephemeral resources the process is successional, with regular changes in the microbial and invertebrate populations at different times. A stable or regularly renewed resource supports a relatively constant climax community.

This study was done to determine how interactions between microbes and invertegrates influence the successional decomposition of dung.

Materials and Methods

Dung from *Neotoma* cave rats kept in the lab was collected, dried, and ground up in a Willey Mill. The animals were fed vegetables and rat chow (Purina) with an added fungal inoculum from natural rat latrines. The ground-up dung was moistened and formed by hand to resemble the size and shape of three naturally occurring fecal types found in caves; rat pellets, raccoon scats, and cricket guano veneer.

These manipulated dungs were field incubated in a variable entrance area (Little Beauty Cave, Kentucky) and a constant deep cave area (Columbian Avenue, Flint-Mammoth Cave, Kentucky). Duplicate samples of the manipulated dungs were exposed to all invertebrates in wire and wood cages to exclude rats, and the other exposed only to microbes and microfauna in metal and cloth cones.

The manipulations were examined and censused over twenty weeks of field exposure.

Laboratory experiments are discussed in the next section.

For a more detailed description of the field experiment, see Lavoie, elsewhere in these Proceedings.

Results and Discussion

The successions on decomposing rat dung show the classic patterns (Webster, 1970; Swift *et al.,* 1979). Invertebrate specialists appear early in the succession followed by more generalist species. The appeal of the dung for colonization is affected by the shape and consistency, and the sequence is modified by the availability of invertebrate colonizers, as discussed by Lavoie, elsewhere in these Proceedings.

Phycomycetes appeared early in the fungal succession, followed by Ascomycetes and Basidiomycetes. Fungi imperfecti and asexual forms of Ascomycetes appeared throughout the sequence.

The effect of interactions between microbes and invertebrates on the successions is complicated. My field and laboratory studies have shown that either microbes or invertebrates establishing dominance first in the pile limits the use of the resource by the other group. These interactions could be due to either interference or exploitation competition. With interference competition, the mixing and grazing activity of invertebrates would keep the fungi depressed, while the thick hyphal mat of early fungal colonists would physically prevent invertebrates from reaching the dung. With exploitation competition one group would simply use up or modify the resource before the other group could.

The early dominance of large invertebrates, especially larvae of *Sciara* flies and *Ptomaphagus* beetles, virtually eliminated the succession of later fungi. Only one type of Fungi imperfecti was found on most of the older dung piles at very low densities. This reduction in the fungi could be due to either an inhibitory effect or depletion of nutrients. In the entrance area the staphylinid beetle predator entered the piles after week three and ate most of the larger invertebrate inhabitants. Fruiting bodies of fungi appeared shortly thereafter, and persisted in the absence of the large invertebrates. Old dung, either previously exposed to invertebrates or microbes, will quickly develop fungal hyphae if a solution of 5% glucose is added to the dung. These observations suggest that the type of competition switches from interference early in the succession, to an exploitation competition.

Microfauna, including enchaetryid worms and mites, were able to establish themselves on the within-cone dung in the absence of large invertebrates. These small animals are normally restricted to the dung/soil interface. The worms caused the formation of a thick (0.5-2.5 mm) slurry on the surface of the dung. Fungi were reduced on dung with the slurry, and the slurry also reduced the attractiveness of the dung to larger invertebrates. The mites (Stigmaeidae) are probably predators on the worms.

An early dominance of fungi reduced or slowed down the reproductive success of the invertebrates, but did not eliminate them, presumably since the microbes themselves serve as a course of food for the invertebrates.

The dense hyphal mat of the early fungi effectively blocks colonization by flies by trapping them. Ptomaphagus are able to eat their way through the mat, opening up the dung resource for themselves and other invertebrates. The early microbial effect on the invertebrates is one of interference.

Dung protected from large invertebrates shows little fungal succession after twenty weeks of field exposure. Flies (Sciara) entered the cones after the twelfth week and showed high reproductive success on the old dung. Ptomaphagus is less able to use older, microbially conditioned dung, as shown by Poulson (1976).

Lab studies to quantify the competition between microbes and invertebrates are now being done. Data from these experiments will be presented at the Congress. I am making the three forms of dung and incubating them on mud under cave conditions in the lab for 0, 2, 6, and 10 weeks to obtain dung which has been "conditioned" by microbial activity. The same number of sexed Ptomaphagus beetles are added to each bowl and their survival and reproductive success on the differently aged dung used as a measure of resource use. This experiment also eliminates any artifact caused by different colonization rates of dung piles in the field, since the animals have no other option for food.

In a second and related experiment, dung several weeks old with a thick mycelial mat is clipped to remove external hyphae, exposing the dung surface. The hyphae are left in the container. Unclipped dung is used as a control. Ptomaphagus beetles are added to the bowls and their survival and reproductive success used as a measure of resource use. Based on previous observations, I believe the beetles will readily use the clipped dung, but show delayed use of the unclipped dung. To support this expected outcome of physical interference, I will wrap fresh dung in a thin layer of inert glass wool to simulate fungal hypahe to show if the hyphae alone can effectively block invertebrate colonization.

I am also doing an identical set of experiments with Sciara flies. Based on field observations, I expect they will show greater reproductive success on old dung than Ptomaphagus, but be totally unable to use unclipped dung.

Competition between Ptomaphagus and Sciara did not seem to be important in the field; the flies tended to use the center of the pile while the beetles worked on the surface. In the field, Ptomaphagus ate through the hyphal mat which effectively opened up the pile for colonization by flies. Repeating the above experiments with both animals together will show if interactions between them reduce or enhance their reproduction.

In conclusion, interactions between microbes and invertebrates influence the process of successional decomposition of dung. Whichever group establishes dominance first, limits the use of the resource by the other group. This competition has aspects of both interference and exploitation, and the importance of each can change during the course of the succession.

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Cryospeleology

Garry D. McKenzie
Ohio State University, Columbus, OH 43210, and National Science Foundation, Washington, DC 20550

Abstract

The study of caves and cavities that exist in or contain frozen materials, or are formed by periglacial processes, is here termed cryospeleology. The two most familiar types of caves in this area are glacier cave and ice caves, although the widespread acceptance of glacier caves as legitimate speleologic features has occurred only in the last decade. Study of caves in cold regions is not limited to these two varieties, but includes caves formed in all types of ice, firn, frozen regolith and bedrock. A classification matrix of these caves has been developed based upon the nature of the enclosing material and the mechanisms of formation which include weathering and deformation processes. Although carbonate speleothems which formed during warmer periods occur in some of these caves, most speleothems consist of ice.

The Impact of the Agricultural Land-Use Cycle on Flood Surges and Runoff in a Kentucky Karst Region

Percy H. Dougherty
Geography Department, University of Cincinnati, Cincinnati, Ohio 45221

Abstract

Sinking Valley, Pulaski County, Kentucky is a typical karst area on the Cumberland Plateau. Thus, it was chosen as the site in which to study the hydrological regime of an area which has gone through a multiple land-use change. The early settlement pattern of the region resulted in a shift from an oak-maple forest to an economy based on clean tilled crops such as corn and tobacco. Today, another shift of the land-use is occurring for grazing is becoming the dominant activity. The area has therefore gone through a cycle of intensification of land-use in the clean tillage stage, and is now retrograding to its former nature as indicated by the greater vegetative cover and the large number of abandoned farms.

The study used historic data from maps and air photos to reconstruct past landscapes, and field work to assess present conditions. These landscapes were then analyzed by a modified Thornthwaite-Mather water budget in order to determine the hydrological impact at selected temporal stages. Verification of the resulting data was accomplished by field observations and interviews with local farmers.

It has been shown that the period of clean tilled agriculture was responsible for disasterous valley floods known locally as "valley tides." The floods were caused by increased runoff from the large bare soil areas where poor agricultural techniques were practised. and were aggravated by the increased sediment load in the runoff which blocked the already insufficient subterranean drainage channels. Recent land-use regression to a more vegetated landscape has resulted in reduced sedimentation and less runoff. This is verified by the water budget model as well as field work which shows that sediment deposits laid down in the previous period are now being aggressively eroded.

Zusammenfassung

Sinking Valley im Bezirk Pulaski in Kentucky ist ein typisches Karstgebiet in der Cumberland Ebene. Deshalb wurde es als der Ort ausgewählt, an dem die hydrologische Beschaffenheit eines Gebietes studiert werden sollte, das durch einen mehrfachen Wechsel der Landnutzung gegangen ist. Die erste Besiedlung des Gebietes resultierte in einer Verschiebung von einem Eichen-Ahorn Waldbestand zu einer Wirtschaft, die auf gänzlich umgepflügten Früchten wie Mais und Tabak aufbaut. Heute sehen wir wieder einen Wandel der Landnutzung, da die Begrasung sich zur vorherrschenden Nutzung entwickelt. Das Gebiet ist so durch einen intensivierenden Zyklus der Landnutzung auf der Stufe der Bewirtschaftung durch gänzliche Umpfügung gegangen und entwicklet sich jetzt zurück zu seinem früheren Charakter, was sich auch in dem verstärkten vegetativen Bestand und der großen Zahl verlassener Höfe zeigt.

Die Studie stützte sich auf Daten von historischen Lankarten und Luftaufnahmen, um die frühere Landschaft zu rekonstruieren, sowie auf Arbeit vor Ort, um die gegenwärtigė Situation zu analysieren. Diese Landschaft wurde anhand eines modifizierten Thronthwaite-Mather-Wasserhaushaltmodells analysiert, um den hydrologischen Einfluß auf verschiedenen zeitliche Ebenen zu ermitteln. Die resultierenden Daten wurden anhand von Beobachtungen vor Ort und Interviews mit ansässigen Farmern verifiziert.

Es hat sich gezeight, daß die Periode einer Landwirtschaft mit gänzlicher Umpflügung für katastrophale Talflutungen, die örtlich als "Tal-Gezeiten" bekannt sind, verantwortlich ist. Die Fluten wurden durch den gesteigerten (Wasser-) Ablauf von den großen Gebieten brachliegender Erde verursacht, wo schlechte landwirtschaftliche Techniken angewendet wurden, und sie wurden verschlimmert durch den gesteigerten Sediment-Anteil im Ablauf, durch den die schon unzureichenden unterirdischen Drainage-Kanäle verwtopft wurden. In letzter Zeit hat der Rückgang der Landnutzung zu einer ursprünglicher bepflanzten Landschaft zu verringerter Sedimentation und wniger Ablauf geführt. Dies wird verifiziert durch das Wasserhaushaltmodell sowie durch Studien vor Ort, die zeigen, daß Sediment-Ablagerungen, die in der früheren Periode entstanden sind, nun aggressiv abgebaut werden.

* * *

The Cumberland Plateau of Kentucky exhibits a land-use change referred to in this paper as the agricultural land-use cycle. It is characterized by a transition from a pre-settlement oak-maple forest, to a period of expanding clean tillage of tobacco and corn, to the present in which there is a regression of the landscape from clean tillage to pasture and pasture to forest. It is interesting to speculate on the impact of these changes in land-use on runoff and sediemntation rates. Few studies have investigated the influence of land-use change in karst regions, although the physical characteristics of the terrain and the responses to environmental stimuli vary considerably from normal fluvial landscapes. It is therefore the purpose of this paper to investigate the results of agricultural land-use change on the hydrologic regime of a karst region.

Sinking Valley, Pulaski County, Kentucky (Fig. 1) was chosen as the study area. It is located in South-central Kentucky on the western edge of the Cumberland Plateau where Buck Creek has become entrenched in Upper Mississippian and Lower Pennsylvanian sediments which dip 5-8 m/km to the southeast. The deposits include hilltop basal Pennsylvanian clastics of the Lee Formation ranging from cross-bedded conglomerates to siltstones, shales and coal, whie the lowlands are composed of Newman and Borden Formationlimestones (Hatch, 1964). The area is characterized by numerous dolines and solution valleys of which Sinking Valley is a good example. Sinking Valley, a structurally controlled valley oriented north to sotuh, is roughly 13 km long and 6.5 km wide. It drains an area in excess of 88 km^2. Fluorescein tracing has verified the areal extent of the drainage basin which culminates in a karst window known as Short Creek from which the water diffuses through bedding plane anastomoses to Buck Creek (Dougherty, 1981). Few surface streams exist within the basin since most drainage is through underground channels, several miles of which have been mapped.

Excessive sediementation in the cave system underlying Sinking Valley has resulted in a serious impact on the surface-flooding. Local floods known as "valley tides" has been responsible for the loss of crops, damage to roads and buildings, and severe erosion of the land. What has caused these floods? It is hypothesized that the flooding is a function of increased sedimentation resulting from the greater runoff caused by the cultivation of clean tilled crops. This has important ramifications for Sinking Valley and is representative of many other valleys in the plateau karst of Kentucky and Tennessee. A better understanding of these processes will enable farmers, land-use planners and government officials to minimize the threat of flooding and the resulting property damage by insituting proper conservation techniques.

In order to show that surface flooding was caused by changes in land-use, three periods were studied. The first was the pre-settlement era with its forest cover. Such landscapes have a small runoff and sediment load compared to the second category, agricultural land which is typified by the land use of the 1930's when corn and tobacco were the primary cash crops of the region. The third period is the present, a time of change in which many clean tilled fields are reverting to pasture and many pastures of the 1930's have returend to forest. It is assumed that a forest cover contributes a smaller amount of runoff and sediment, and clean tilled fields contribute a larger runoff and accompanying sediment load as has been shown in previous studies (Cook & Doornkamp, 1974; Gregory & Walling, 1973). Since the land use has progressed through periods of increased and decreased utilization, analysis of the hydrologic regime should reflect a subsequent increase and decrease in runoff and sedimentation. To prove this, the amount of land in each land-use in the three aforementioned periods was computed and a Thornthwaite-Mather water budget was used to estimate potential runoff. In addition field checks of cave sediments were used to verify the results of the water budget analysis.

Table 1 shows the land-use in Sinking Valley for the three periods of this study. It is assumed that the area was covered by a contiguous forest in the pre-settlement period. In addition, a stratefied random sample from air photos was used to compute the land-use of each category in the clean tillage period and the present. Examination of Table 1 shows the previously mentioned trend of land changing from cultivation to pasture and pasture reverting to forest. This can also be seen in the field in the form of abaondoned farmstead, overgrown roadways, and the common occurrence of stone walls, that once separated fields, winding through secondary forest growth. The results for the clean tillage category in Table 1 are conservative since the period preceding the earliest available air photos undoubtedly had more clean tillage agriculture, as indicated by abandoned fields, second growth, and reports by local farmers.

A monthly water budget with declining availability was computed for each period. The amount of water storage for each land-use was determined by examining the rooting depths of the dominant vegetation and the runoff figures were calculated by using values for similar areas in the hydrologic literature (Gregory & Walling, 1973; Thornthwaite & Mather, 1957; Chorley, 1969). A runoff factor of .30 was selected for forest, .50 for pasture and .70 for clean tilled crops, the remainder staying in the decreasing availability water budget as base flow. This was well within the range of .15 for forests found by Gregory and Walling (1973) and .75 for clean tilled areas studied by Chorley (1969). The monthly water budget was computed in proportion to the amount of land use in each period, the reuslts of which are presented in Table 2.

It is apparent that there is a difference in the total runoff totals between the three groups. As expected the forest runoff is the least of the three categories because of a greater rooting depth, interception of precipitation by the leaves and other factors. The greatest runoff occurs in the clean tilled stage since there is less soil moisture utilization by the shallower rooted plants. Although this small variance could result in a 16 m^3dy^{-1} difference in stream flow, it is not statistically significant.

A closer examination of the water budget table shows that rather than a great change in the amount of runoff, there was instead a change in its temporal distirbution. With increasing tillage of the land, there was an increase in the peak flows and a decrease of the low flows in both the clean tillage and present stages compared to the forest stage. The clean tillage era shows an excess of runoff over the present of nearly $100m^3dy^{-1}$ during the peak surplus months of January, February and March. It is assumed that this increased runoff also resulted in omre erosion and sedimentation since the soil was retained by forest or vegetation. Statistics in Cooke and Doornkamp (1974) show sediment yields of 861 kg x 10^2/ha for continuous maize with rows up and down the slope and only 86 kg/ha for continuous blue grass cover. There are numerous other studies substantiating the magnitude of sediment transport from clean tilled fields. The added runoff caused by the land-use change in the study area undoubtedly resulted in the removal of sediment which entered the cave system. In addition tree trunks, branches and other debris entered the system because of flooding caused by the greater runoff. The debris became wedged in cave conduits and caused a damming action which resulted in the slowing of the water velocity and a subsequent increase in aggradation. Cave passages became blocked and surface runoff backed up and spewed out onto the surface in flooding episodes known locally as "valley tides."

Interviews with local farmers and field inspections indicate that the agricultural peak period experienced a greater frequency of flooding, larger floods, more erosion, and greater property damage. Reports from the 1920's and 1930's of water gushing from wells that were 50 meters deep show that blockage of the subterranean system caused a backup of water by hydrostatic pressure. Another indicator of the blockage are the "Boiling Pots," karst springs in the southern part of the valley where water used to frequently well up in large lenses after a storm because of blockage of the cave system by debris and sediment. Both the reverse flow of wells and the "Boiling Pots" have become less frequent in recent times. There is no report of shooting wells in recent decades and the "Boiling Pots" have become less frequent in recent times. There is no report of shooting wells in recent decades and the "Boiling Pots" only flow after heavy storms during the spring thaw/runoff. This indicates that the change in ladn-use to a less tilled condition is not only resulting in less runoff and sediment deposition, but may also be causing the cleaner water to return the system to a period of degradation.

More evidence of this change in land use on run-off can be seen in cave formation in the area. Most of the formations were deposited in the pre-settlement era when the runoff into the cave system was less; thus stalactites, stalagmites, and other speleothems had a chance to form. With a change in land-use to clean tillage, flooding increased in magnitude and frequency, sediments and debris blocked passages cuasing the formations to be submerged frequently. Flood waters contain less CO_2 then pre-settlement percolating water which deposited the formations, thus erosion occurred. Throughout Sinking Valley, caves exhibit speleothems which show evidence of resolution which can be attributed to the high water stage caused by debris/sediment backup and flooding.

An inspection of the surface also shows evidence of the flood history of the valley in flood scars. Valley tides in past times severely eroded the valley, often leaving ugly gullies. Although there are still valley scars in the active stage, there are many which are becoming revegetated. Since valley scars are caused by flooding, a reduction in their number also indicates less frequent and serious floods in the study area. Stripped fields and valley scars were common in this area in the 1920's and 1930's, but are less common today.

The amount and disposition of sediment in cave passages also presnets evidence of the impact of the three land-use stages. Preliminary and cursory excavations show that much of the sediments was laid down in a short period of time. Strata in the sediments indicate that catastrophic events deposited much sediment per episode and entrainment of vegetative matter confirms this to be of recent origin. Much of the sediment is also of the size expected to be eroded from agricultural land rather than residual sediments resulting from carbonate corrosion.

In addition, several caves exhibit removal of sediments by recent storm events. Channels are being incised in unindurated sediments indicating degradation has become the dominant erosional process. This is substantiated by interviews with farmers who indicate the water level in the valley is dropping. Druing the 1930's, nobody had entered the cave in what locals call Big Sink for there had always been water blocking the passage. The water has dropped consistently since that period and today the entrance has a metere of air space above the water. In addition, the water flows briskly over rapids today, whereas early explorers found ponded water sumping-out inside the entrance. Several other caves in the valley have similar histories.

In summary it can be said that Sinking Valley is a good example of an area in which land-use change caused a disruption in the hydrologic cycle. Evidence gathered from water budget analysis and field evidence shows that both the amount of water and sediment increased after the area was settled and corn and tobacco were cultivated. Stripped fields, "blowing wells," "boiling pots," sediment analysis, high water levels, flood scars and eroded formations show evidence that the clean tillage era caused general blockage of the subterranean system by debris and sediment. Lowering of the water levels, less flooding, lack of "blowing wells" and boiling pots, incisement of cave streams in their channels, and renewed traverture formation all indicate that the present period of land retrogression to pasture and forest has resulted in a lack of input of new sediment and thus a cleansing of the system by degradational processes.

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Table 1
Land Use Trends Sinking Valley, Kentucky

PERIOD	% Forest	%Pasture	%Crop
Pre-Settlement Forest	100	0	0
Agricultural Peak	37	55	8
Transition Period Today	51	44	4

Table 2
Monthly Water Budget and Runoff for the Land-use Stages

MONTH	FOREST STAGE	AGRICULTURAL PEAK STAGE				PRESENT			
	TOTAL RUNOFF	FOREST (37%)	PASTURE (55%)	CLEAN TILL (08%)	TOTAL RUNOFF	FOREST (51%)	PASTURE (44%)	CLEAN TILL (05%)	TOTAL RUNOFF
J	61*	22.57	47.30	8.48	78.35	31.11	37.84	5.30	74.25
F	76	28.12	54.45	8.88	91.45	38.76	43.56	5.55	87.87
M	85	31.45	56.10	8.48	96.03	43.35	44.88	5.30	93.53
A	74	27.38	41.80	5.28	74.46	37.74	33.44	3.30	74.49
M	54	19.98	22.55	2.00	44.53	27.54	18.04	1.25	46.83
J	38	14.06	11.00	.56	25.62	19.38	8.80	.35	28.53
J	26	9.62	5.50	.16	15.20	13.26	4.40	.10	17.76
A	18	6.66	2.75	.08	9.49	9.18	2.20	.05	11.43
S	13	4.81	1.65	.00	6.46	6.63	1.32	.00	7.95
O	9	3.33	.55	.00	3.88	4.59	.44	.00	5.03
N	9	3.33	3.85	.88	8.06	4.59	3.00	.55	8.14
D	35	12.95	27.50	5.52	45.97	17.85	22.00	3.45	43.30
Yr.	498				499.5				499.11

* all values stated in mm.

Source: Dougherty, 1981

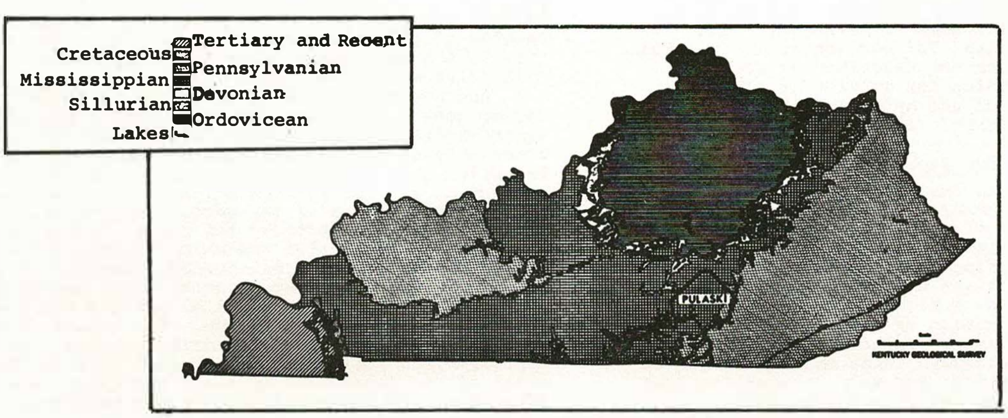

Figure 1. Outline geologic map of Kentucky showing location of Pulaski County.

On Measuring Caves by Volume

P. Jakopin
University Computing Centre, Edvard Kardelj University, Vojkova 69, 61000 Ljubljana, YUGOSLAVIA

Abstract

This paper is devoted to a model for approximation of cave space, where the body of a cave is divided into galleries and gallery into sections, each spreading between two adjacent cross-sections. Every section is illustrated by a multilateral prism, having both cross-sections (approximated by multangles) as an upper and a lower base. The model has been tested on two fossile ponors of the Planinsko polje near Postojna: Skednena jama, volume 8878 m^3, length 225 m (error < 5%) and Mackovica, 38770 m^3 and 650 m (error < 2%).

Résumé

L'objêt principal de cet ouvrage est le modèle pour la présentation de l'espace d'une grotte où le corps de la grotte est divisé en parties, dont chacune s'étend entre deux conjointes sections transversales. Chacune partie est illustrée par un prisme multilatéral ayant pour base inférieure et supérieure les deux sections transversales (approximées par multiangles).

Le modèle était vérifié sur deux grottes, situées au bord septentrional de Planinsko polje près de Postojna: Skednena jama, 8878 m^3 en volume et 225 m en longueur (erreur < 5%), et Mackovica, 38770 m^3 et 650 m (erreur < 2%).

Other Contributors

The work has been made possible by two institutions. Members of the Društvo za raziskovanje jam Ljubljana (Ljubljana Cave Research Society) have helped me with great enthusiasm; the most valuable contribution was given by:

Jože Stražišar,
Marina Brancelj, Jaka Jakofčič, Vanja Janežič,
Marko Krevs, Uroš Kunaver, Andrej Pokorn, Jorg Prestor and Ina Šuklje.

It is Edvard Kardelj University, Computing Centre, where all the results have been computed. Its creative environment has enabled the project to develop and to come to a successful end.

Introduction

Caves as such are three-dimensional structures and it is known for a long time that the intensity of cave-generating processes is at best illustrated by their volume. It would therefore seem quite obvious to have the volume as the first and the most important numerical parameter which describes the cave. It is, however, not so; and there are many good reasons. First of them is the number of points needed. Even the task to get the exact position of a few dozen points of cave body, in order to make a sketch of it, to obtain its length and depth, is in most cases untrivial. And to get a representation, suitable for any serious cave space analysis, not a few dozen, but a few hundred points are necessary. Another good reason was the absence of a suitable method, which would, with reasonable amount of effort, allow to compute the volume from the representation just mentioned.

The challenge is but great and the solution to the problem was only to be expected. When mr. Corbel published his list of 22 top caves, as far as the volume of the rock, in which the cave extends, is concerned (Corbel, 1965), he did not forget to justify the somewhat unusual method by the phrase: à défaut du cubage exact". The next such list, available to the author, was the one published recently by Dubljanski (Dubljanski et al., 1980); here the volume is presented in a modest way, unveiled only after such parameters as length and ~~depth~~. But, nevertheless, it is there, and it is an estimate for the actual volume of cave body. The method, using two formulas, for horizontal and vertical caverns, respectively, is not described as accurate, but "of sufficient precision for solving of all the speleological, geological and hydrogeological tasks, connected to field research" (10-20%).

The Story

Author's interest in the problem began some ten years ago; it is a sad thing if a country that had eight caves on the list of the world's top ten only three generations ago, has to look how its largest cave, Škocjanske jame, has disappeared from the list of top hundred, and how its longest one, Postojnska jama, keeps falling towards the bottom of the same list. The paper "On Numerical Valuation of Karst Objects" was presented at the sixth Yugoslav speleological congress (Jakopin, 1972); to reevaluate these objects by volume was stressed as a difficult, but very interesting task, coming in the future. No method was available at the time but the work started. In 1973 it became clear that a cave shall have to be divided into galleries and each gallery into a set of adjacent sections, each spreading between the two consecutive cross-sections. Every cross-section can be approximated by a multangle, but how to approximate a section?

First Model

An analytical model was chosen first, as it is more elegant and less expensive to compute. The idea was to compute the area of both cross-sections (multangles), delimiting the section and to choose as the base of it the cross-section having the larger area. The section was then approximated by a truncated cone, having as a base a circle with the same area and centre of weight as the basic cross-section; the upper surface was in general an ellipse, having the same centre of weight and the same area as the second cross-section. Both basic surfaces of the truncated cone were, of course, also situated in the same plane as the basic and the second cross-section, respectively. In 1974 the skeleton of the model was derived, the extra-long equations solved and in a small cave, Skednena jama, near Laze (10 km NE from Postojna), 51 cross-sections were measured, composed of 305 points. Only usual cave-surveying equipment was used, combined with three wooden sticks: 1 m, 3 m and 5 m of length. A candle was attached to the top of the last so that the height of inaccessible ceiling points could be estimated.

Yet the model was not implemented, the computer program not written. It was felt that the model would do only as far as the volume of the gallery is concerned, but not in general. In the case of low and wide galleries the boundary area would be much underestimated. The second weak point was the poor graphical representation of the cave, which results from such a model. In 1977 the idea of analytical solution to the problem was definitely abandoned.

Second Model

The new model for approximation of cave space illustrated every section by a multilateral prism, having the delimiting cross-sections as both basic surfaces. Manipulation with such an irregular structure is not particularly elegant, it requires extensive computing and cannot be done without a machine; but the resulting model is very realistic and can approximate the cave with great precision. It also allows better definition of cave gallery length: it can now be defined as the sum of the lengths of all its sections, where the length of a section is the distance between the two centres of weight of delimiting cross-sections.

And how the volume of a section is computed? The method goes as follows: areas of both cross-sections (approximated by multangles), are computed first. The cross-section with larger area is chosen as the basis. The prism that approximates a section is then defined by connecting all the corners of the basic cross-section with proper corners of the second cross-section. It is then cut into two parts by the plane, that is parallel to the basic cross-section and which touches the nearest corner of the second cross-section (nearest to the base). One of the two parts may be empty - the second one if both cross-sections are parallel and the first one if they have some point in common. The volume of each part is then determined by an iterative process: first approximation for the volume of each part is the sum of areas of the lower base (S_o) and the upper base (S_h), divided by two and multiplied by its height (h):

$$V_o = \frac{1}{2}\cdot(S_o + S_h)\cdot h \qquad (1)$$

At the next step, the part is cut at half its height into two slices of equal thickness (h/2) and the next approximation is computed as the sum of the two volumes:

$$V_1 = \frac{1}{2} \cdot (S_o + S_{h/2}) \cdot \frac{h}{2} + \frac{1}{2} \cdot (S_{h/2} + S_h) \cdot \frac{h}{2} =$$

$$\frac{h}{4} \cdot (S_o + 2S_{h/2} + S_h) \qquad (2)$$

At step n, the prism is divided into 2^n slices and the resulting volume given by:

$$V_n = \frac{h}{2^{n+1}} \cdot (S_o + 2S_{h/2^n} + 2S_{2h/2^n} + \dots +$$

$$2S_{(2^n - 1)h/2^n} + S_h) \qquad (3)$$

Such an iteration is usually continued until the relative difference between the two consecutive approximations: $|(V_n - V_{n-1})/V_n|$, falls under prescribed level of accuracy (0.00001 = five decimal digits, for example). In our case it turned out that is is more suitable to stop the iteration when the absolute difference is small enough ($|V_n - V_{n-1}| < 0.005\ m^3$). Volume of the section is then obtained as the sum of the volumes of both parts. Number of slices necessary varies from section to section but, as it showed up later, usually ranges from 16 - 128 for the first part and from 32 - 4096 for the second, more complicated one. The area of the sections coat, which adds into the area of the body surface, can be computed directly.

All that remained was to implement the idea. In 1978 several circumstances, not exactly favorable for the author, gave necessary push to the project. Old measurements, made in 1974 in Skednena jama, were used as the testing ground. The cave, in fossile ponor of the Planinsko polje, is composed of simple main gallery to which several small side tunnels are connected. In the beginning of 1979 the model was implemented and the results which followed, were these: volume 8878 m^3, area of the body surface 6455 m^2, length 225 m, depth 31 m, 7 galleries, 44 sections, 51 cross-sections, all derived from 305 measured points (6 per section). The estimated error, due mostly to primitive technique for the measuring of inaccessible (ceiling) points, was below 5%.

Mačkovica

A better technique was necessary if one was to attack some larger cave. Therefore two equal prototypes of a special inclinometer were constructed and completed. Both consist of a wooden rod (1.2 m long), to which a school inclinometer (0.5 m long) is attached. The rod is furnished on the top with a narrow, battery operated light beam. Inclinometer's pointer is equipped with a water level, for greater accuracy and comfort. To get a proper representation of a vertical cross-section (which are most common) the ground points are measured first, in usual way (at best all from the same central point). Then each chosen ceiling point is determined by illuminating it from two measured ground points (narrow light beams just mentioned) and putting down the angles on both inclinometers. The equipment described was tested in another fossile ponor of the Planinsko polje, cave Mačkovica (pronounced muchcovytsa), which is also situated near the village Laze. Eastern Gallery and the Great Hall were measured: the largest cross-section was 55.7 m wide, 24.4 m high, had an area of 516 m^2 and was represented by 14 points (6 inaccessible). The results were published in spring 1979, together with an article "On Some Terms Concerning Cave Space" (Jakopin, 1979), that has explained author's view on several widely used, but often differently defined terms (as an example: depth was defined as difference in above sea level altitude of two such points of cave boundary, that one has the biggest and the other the smallest altitude).

Author's plans to move with the work fron an amateur to professional environment have in spring 1979 definitely failed and so the project discontinued for a while. But, strange as it may seem, it has shown up later, that the project even benefited from this. In the fall of 1980 the work started again with full power, the supporting software being switched from one large scale computer (CDC CYBER 172) to another (DEC 1091). The set of routines has been much improved, it is now more convenient to use and some important features have been added. To define a section, for example, all the corners of one delimiting cross-section have to be connected to proper corners of the second cross-section. Up to now this had to be done explicitly, which is a time consuming and not very pleasant task. It is now typically determined by an algorithm.

In January 1981 four more excursions were made into Mackovica cave. The measuring of vertical cross-sections has been brought to the level of routine (the last excursion achieved a record of 40 cross-sections) and the survey is practically completed. 725 points were measured and 709 were included in a model of the cave body (105 inaccessible). The cave was divided into 10 galleries, composed of 106 sections, which were delimited by 116 vertical cross-sections (again 6 points per section). The net results, which can be seen in more detail on Figure 1, were these: volume 38770 m^3, area of the body surface 20821 m^2, length 650 m and depth 57 m (the error was estimated as less than 2%).

Conclusion

Mackovica is not a large cave but may be it has opened the way up. For the real giants.

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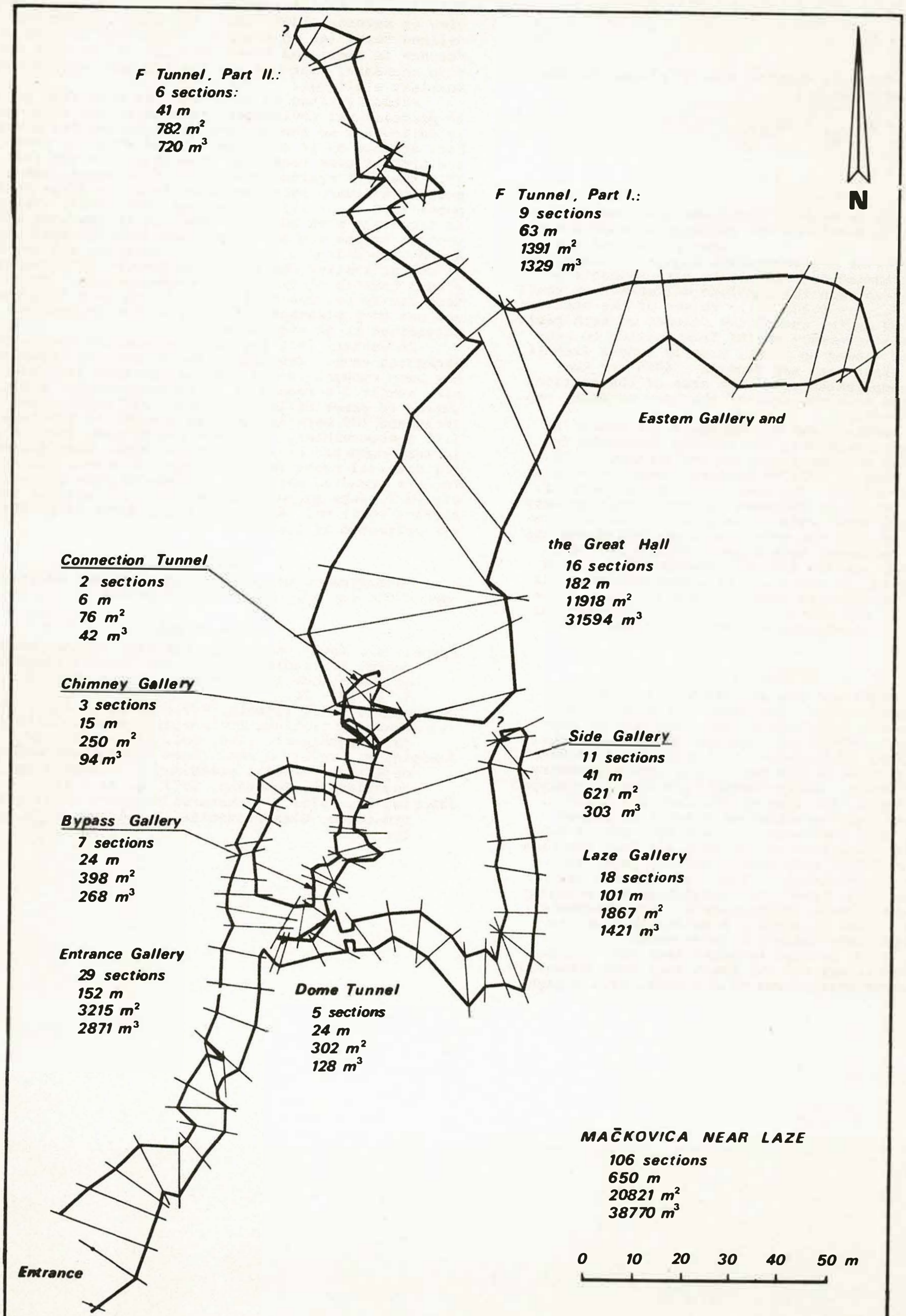

Figure 1. Map of Mackovica Cave.

Comparative Research of Limestone Solution by Means of Standard Tablets
(Second preliminary report of the Commission of Karst Denudation ISU)

Ivan Gams
Ljubljana, Yugoslavia

Zusammenfassung

Die Kommission für die Karstdenudation ISU hat 1977 in Sheffield beschlossen, im Jahre 1978 in Zusammenarbeit mit Mitgliedern aus allen Kontinenten mit der Forschung der Lösung mittels Kalktabletten, exponiert auf der Karstoberfläche, in und über dem Boden, in verschiedenen Umweltverhältnissen zu beginnen. Gegeben werden einige Ergebnisse der 1 - 2-jährigen Messungen des Gewichtverlustes und einige Faktoren, die die Lösung beeinflussen.

Introduction

The session of the Commission of Karst Denudation during the 7th International Speleological Congress in Sheffield 1977 decided to carry out the joint research of solution in different environments in the world in cooperations with all who wish to cooperate. The work is a continuation of research done by individual karstologists who have proved the limestone tablets as a method for quantification of solution (between other Chevallier, 1953; Gams, 1959; Rebek, 1964; Trudgill, 1975, 1977; Jennings, 1977). Using standard tablets built of the same limestone from the series of the factors which affect the corrosion the lithological factor is eliminated and the rest can be better evaluated.

Our field work was planned in that way to recogize:

1. the effect of different climates by means of tablets hung in the open air above surface,
2. the rate of solution of bare limestone ground by means of tablets left on the rocky surface or on grass cover,
3. the corrosion rate in the soil by means of limestone tablets exposed in different soil types and in different depths,
4. the differentiate corrosion in different sites in one karst form, in the different soil types, in the different vegetational types, etc.

Limestone from which the tablets were built and send abroad, derived from the region where the notion karst came from: (Triestiner) Karst (NW Dinaric Karst, Yugoslavia, quarry near of the village Lipica). It is of upper Cretaceous (Senonian) age composed nearly of pure limestone with less than 0,1% SiO_2, 0,007% F_2O_3, less than 0,05% Al_2O_3, less than 0,05% S. Microfossils are composed mostly of fragments of moluscs (50-2000 um) and of single plates of shells of moluscs. Alochems are represented by micritic intraclasts (up to 400 um) and micritic pellets. Cement (mass, 30-40%) is micritic slightly recrystallized limestone with grains of 10 um. The rock is classified as recrystallized biopelmicritic limestone. Some tablets built of the same limestone are slightly different in color (grey) and with less cement (mass, 10%).

The standard tablets have their diameter of 41 mm and are 2.5-3.5 mm thick (weight 8-12 mg mostly). One to four holes were drilled near the edge for attachment to plastic insulated horizontal wire. Before distribution tablets were treated with acid to diminish the unnatural smoothness. More than 1500 tablets have been distributed to about 30-40 collaborators from China and Australia to U.S.A. and instruction for uniform treatment have been sent to them. A sketch of the typical site as it was arranged in Australia is reproduced here from the report of Mr. K. B. Grimes.

A series of tablets was exposed horizontally nearly 1.5 m above the surface in the open air, the second one on the bottom (grass, stony) and the third one in the soil in the depth where greatest solution is expected. In regions with high winter snow higher position than 1.5 m is reasonable. Tablets were weighed before placement and re-weighed each year (or in two years) for the duration of the experiment. The tablet loss was calculated in mg $.10^{-3}$/d/cm^2.

Primarily the experiment was planned until the 8th International Speleological Congress in summer of 1981 but the distribution of tablets and their placement were later than planned and the report was needed earlier for this publication. Therefore only some cooperators succeeded in sending their results before the end of January 1981 when this report was finished. They are named in the Table 1 as authors of the report (column 1). The list of collaborators until September 1979 is shown in the first preliminary report given on the symposium of our Commission at Aix en Provence-Marseille-Nimes 1978 (Gams, in print)

In the column 4 of the diagram the data for the position of tablets series means: plus (+) is above surface (ground), 0 means on the surface, minus (-) depths in the soil. Also climatical, soil, vegetational and microbiological data are collected and will be analyzed in the final report. Here only some essential data are given.

In the middle of the experiment it is too early to come to the conclusions. Here are mentioned some indications (significances) which will be quantitatively analyzed in the final report.

In arid climates loss in weight of tablets exposed above the surface is seldom the same and often higher than that of the tablets left on the surface. In humid regions it is reversed (exception: Vercors). It seems that the rate of solution of tablets above surface is influenced by direct sun radiation and heating. At the same site (Smartno in the table) the corrosion of tablets in the dense forest is significantly less than that in the open air. There in the open air (+ 140 cm) the tablets built of limestone with less pelets and microfossils and with more micritic cement have shown less solution than the standard limestone. Solution is probably reduced by the same effect also at the tablets in grass which in the temperate climate offers shadow.

In Slovenian Alps and partly in Vercors the solution of tablets on surface is less than that in the lower karst regions. High precipation in form of snow in the mountain seems to have no positive effect (see Mt. Kanin with nearly 10 m of winter snow precipitation.

Loss in weight of the tablets above the surface and those on the surface is less than expected. The proable partial reason is only one side of the tablets exposed directly to the precipitation and radiation. Some tablets have shown after one or two years some powder redeposit on the underside adjacent to their drip point.

Loss of tablets exposed in the soil shows a clear dependence from climate: the primar factor is run-off as difference between precipitation and evaporation.

The former cultivated and now for grass abandoned soil shows less solution. High alpine dark rendzina has shown until now a feeble corrosion activity.

In comparison to the solution rate calculated on basis of run-off in the drainage area and total hardness of river water, the solution of the tablets exposed above the surface takes in Slovenia in low karst regions less than 1/3. That percent for the tablets on the surface is less than one tenth, and for the tablets in the soil nearly one quarter to one third (exceptional results are here eliminated, also the cultivated soil). In the higher (alpine) karst this percentage is reduced for one half.

Solution amount determined with our experiment can be used for comparison of further local measurements by means of limestone tablets.

At the commission session at Bowling Green in July 1981 the proposal will be given for the continuation of the experiment as some results achieved to now are not in accordance with the prevailing theory of solution.

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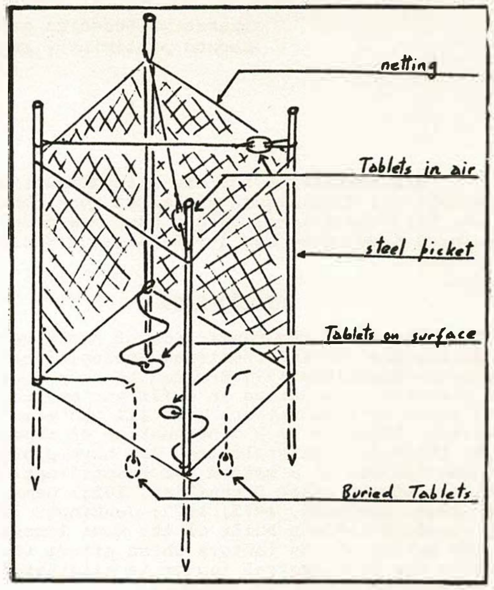

Figure 1. Typical Site Layout.

Table 1

Location, Author, Station, Altitude, Years	Days of Exposure	Nature of Tablets	Position cm	Loss mg. 10^{-3} day/cm^2	Precipitation in exposure cm	Long term Precipi- tation cm	Remarks
1	2	3	4	5	6	7	8
USA							
W.C. Sinclair, Tampa	371	3	+150	3.25	1721		Exposure time: 22.1°C
~~Florida~~, 17m, 1978/80		3	0	2.05			grass and sow-palmetto
		2	- 60	31.44			quartz sand below organic pan
Gainesville,Fla.	214	3	+150	3.03	555		
27m, 1979/80		2	0	1.54			wiregrass and blackberry
		3	-15	4.98			quartz sand below plastic clay
ENGLAND							
M.M.Sweeting,	441	2	+125	3.8			
Church Enstone,		2	0	0.55			stony bare soil
1978/79							
K. Paterson,	345	2	+150	9.864	708		
N. Oxfordshire,		2	- 5	2.02			thin calcareous loam
1978-79		2	- 10	2.37			-20 cm: 0.24% CO_2
	344	2	+150	9.06			
		1	- 5	9.76			thin stony calcareous soil
		1	- 10	1.45			thin stony calcareous soil
	344	2	+100	11.366			
		2	0	2.567			
	344	2	- 2	1.453			thin flinty calcareous rendz.
		2	- 10	0.939			thin flinty calcareous rendz.
	344	2	+150	4.709			below a tree canopy
		2	0	1.172			
		2	- 5	1.075			thin flinty rendzina on chalk
		2	- 10	0.891			thin flinty rendzina on chalk
ITALY							
U.Sauro, Monti	370	4	- 10	8.715		1600	soil under moss and grass
Lessini, 1400m							
1979/80							
YUGOSLAVIA	319	4	- 10	3.281		3415	rocky limestone surface
J. Kunaver,		1	- 10	1.170			
Mt. Kanin, 2050m		3	0	1.968			slope of a stony doline
1979/80		1	0	12.560			stony bottom of the same doline
		1	0	4.263			rock elevation, stony surface
FRANCE							
Vercor, T. Muxart	722	2	+80-100	1.93	1332		Nat.veg.:Buxo-Quercetum
Prestles, 850m		2	0	3.43			on the soil
1978/80		3	-3-4	10.83			brown calcaresous soil
Foret de Coulmes,	721	2	+80-100	2.29	1200	1200-1470	Fagetum sylvaticae tip.
1060m		2	0	1.70			below branch
		2	-12-15	13.51			brown calcaresous s-rough humus
Correncon en	721	2	+100	1.98			Abieti faetum + piceetum
Vercores, 1200m		2	0	7.32			
1978/80		2	-3-6	20.16			calcareous soil, humus

Location,Author, Station,Altitude, Years	Days of Exposure	Nature of Tablets	Position cm	Loss mg.10^{-3} day/cm^2	Precipitation in exposure cm	Long term Precipi- tation cm	Remarks
1	2	3	4	5	6	7	8
Fontaine de	722	1	+100	1.28			Nardus stricta+Pinus mont.
Garland 1520m		2	0	2.82			
1978/80		-1-2	-4-15	18.90			acid brown soil, subalpin
CZECHOSLOVAKIA							
A. Droppa	336	2	+100	4.694	1081		6.7°C (time of exposure)
Demanova, 1978/79		2	0	2.532			stony soil, grass
YUGOSLAVIA							
Serbia,E.	777	1	0	1.969			on stony surface
D.Gavrilovic,		2	- 20	7.564			moss turf, grass
Kucaj,1140m 1978/80		1	- 20	2.689			between B/C hor., in the scrub ('macchia')
Slovenia,I.Gams,	404	4	- 2	0.943		1350	long term ann. 11.5°C
1978/80, Littoral,		3	- 10	0.617			mediterranean brown soil
Sepule, 347m							
Postojna, 533m	404	4	+246	12.26		1298	long term 8.5°C
1978/80		4	- 10	5.348			brown loamy clay
Ljubljana, 286m,	789	3-4+	70	15.632		1387	long term 8.5°C
1978/80		3-4	0	5.90			grass (between)
		3-4	- 2	2.242			rendzina, former field
Smarto, 430m	755	2-5	+142	12.86		1160	
1978/80	725	1-4	+300	4.99			between pine trees, 7.6°C
		2-3	0	2.79			on moss, below canopy
		3-4	- 20	28.50			grey below moss, moist
		3-4	- 35	29.34			grey below moss, moist
Mt. Urslja,	754	3	+246	9.06			
1700m 1978/80		3-4	0	1.72			dark alpine calcarous rendzina
		3-4	- 13	10.67			below alpine grass
Kredarica (Mt.	758	3-4	+245	9.17		2143	long term ann. 1-6°C
Triglav, 2515m,		3-4	0	1.42			on limestone rubble
1978/80	388	5	-3-5	2.63			moss turf, alpine grass, calc.
Vrhnika, 420m in the doline, 1978/80,							
sunny side, upper	751	3-4	- 2	10.32		1535	thin brown loam to rendzina
		4	- 13	2.21			
shaddy side	751	4	- 2	14.43			moist drak brown loam
		4	- 12	14.55			below moss + grass
bottom	751	4	- 2	0.75			former field, loam
		4	- 50	0.76			grass
Logatec, 520m in the doline, 1978/80							
sunny side, upper	746	2	- 3	6.37		1734	grey soil, humus
		4	- 13	9.25			under grass
lower	746	2	- 2	8.98			
		4	- 13	9.21			
shaddy side, upper	746	2	- 3	10.88			
		2-4	- 13	16.57			
lower	746	2	- 3	11.34			
		4	- 13	11.09			
bottom	746	2	- 3	22.40			grey humus loam
		3-4	- 14	18.01			
		4	- 50	9.99			
AUSTRALIA S.							
J.J. Jennings,	751	3	+150	1.70	1200		Mean annual temp. 7.5°C
A.P. Spate		3	2	1.52			grass
Cooleman Plain		3	0	3.06			bare rock
1290m 1978/80		3	- 15	4.19			grassland soil
		3	- 15	5.42			forest soil
Yarrangobilly Caves,	751	3	+150	2.09			
1100 m 1978/80		3	0	3.02			bare rock
		3	+ 2	2.04			grass
		3	- 15	4.81			grassland soil
		3	- 15	4.64			forest soil
Queensland,	389	1	+100	1.2	163	387	Mean annual 25.6°C, Tussock
K.B. Grimes,		1	0	1.5			grassland+savannah woodlands
Camooweal 1979/80		2	- 20	1.6			brown loam with chert
		1	+100	1.6			Tussock grass+savannah wood.
		2	0	1.9			
		2	- 20	3.0			red loamy fine sand, pH 6.0
Chillagoe, 1979/80	364	2	+100	1.0	689	845	savannah woodland+bare lmst.
		2	0	2.1			long term tem. 23.3°C
		2	- 34	9.7			dark chocolate to red soil
Rockhampton, Central	364	2	+100	2.5		943	Eucalypt.forest,lg.term.22.1°C
Queensland, 1979/80		2	0	7.5			brown heavy loam (2,5Yr 4/4)

Contribution to Morphometrics of Stalagmites

Ivan Gams
Ljubljana, Yugoslavia

Zusammenfassung

Auf Grund von Messungen der Stalagmitenformen in einigen slowenischen Höhlen (Dinarischer Karst, Yugoslavia) wurde der Einfluss der Deckenhöhe, Verschiebung und Oszillation des Wasserzuflusses auf die Stalagmiten- für die Sedimentation des Sinters und der Messungen des Stalagmitenumfangs wurde die Tropfsteinkonzentration in einigen Teilen der Höhle von Postojna erörtert.

Introduction

For a better evaluation of age measurements (by means of ^{14}C, Uranimum-Thorium a.s.o.) of secondary chemical cave deposits, for a better understanding of cave and karst in general, the further scientific development of morphometrics is necessary. National terms for cave formations are difficult to compare as they have different meanings, so also for the general cave formations built of chemical deposits (cave formation and speleothem in English, Sinterformen in German, concretions in France). If the root of the word stalagmite and stalactite is Greek stalagma (drop), names as dripstone, Tropfstein, kapelnie obrazovania (Russian) are usually too broadly understood (for example stalactites grow by flowing and not by dripping water). The kind of water supply (dripping, flowing, sliding, penetrating, hanging, attached in water film (s.Gams, 1955, Sweeting, 1972), the kind of cristallisation and recristallisation (Cabrol, 1978), mineralogical composition, are decisive for dripstone form under further terminological differentiation in this sense is necessary.

This article deals with the stalagmite forms which are shaped by mostly dripping and (or) occasionally trickling water. All are basically controlled by gravitation of flowing water. Basis for this study are morphometrical measurements and observations and analyses of cut stalagmites.

Basic Rules for Stalagmite Forms

They were formulated by W.H. Franke (1961,1963). According to him the stalagmite width is a function of water inflow (in term of liter/minute = Q in the sketch 1). As Q oscillates according to weather in span of 1: 1000 and more and inflow even on stalagmite heaps (cocks) ceases in fully draught, the equations has to be completed in: $2r = f(Q_{max})$. Q_{max} means middle maximal water in the year and in the years with maximal Q_s in the period of stalagmite age.

In the Gay-coloured (Pisani) Channel of the Cave of Postojna the heights of the measured stalagmites are in span of 3: 150 and their volume in span of 1: 400 (Gams, 1980). Franke-Gey (1971, s. also Gospodarič, 1972, 1976) have by means of ^{14}c there determined the age of general caving-in. According to this the measured stalagmites are presumable all of Holocene age. Reason for this difference in growth is mostly frequence of Q. Franke's equation for the height of stalagmite $h = f(t)$, t = time or age, is for practice more adequate in form: $h = f(tF_q)$. F means frequence of different Q. In every longer cave the frequence observed on dripstone is in span of 1: 365 in a year of more. Maximal flow on a stalagmite heap in Tartarus in the Cave of Postojna (0.36 l/sec) ceases sometimes completely (Gams, 1967).

A stalagmite can be on its top flat of more or less conical. The inclination of the top part (in sketch 1) is a function of inflow (Q) oscillation and of frequence of different Q, as at low water supply in a thinner and at high inflow in a wider circle around the dripping point the secondary calcite is deposited.

Some stalagmite show on their top some mm to some cm wide and deep hollow. It is the point where the dripping water touch the stone. These hollows are signs of the insignificant dislocation of points of falling water (ß in the sketch 1) at low water level and when it is dripping. High oscillation of Q in general increases the dislocation.

Franke (1963) has attributed the 1-8 cm vide shelves on the stalagmite or stalagmate side-surface to the climatical changes. In his view the warmer and wetter climate produces with higher water hardness fatness in stalagmite growth. But these shelves are generally found and, what is more important, as a rule, they do not incircle the full stalagmite circumference (Gams, 1979a). Closer analyses have shown the change of point where the dripping or sprinkling water touch the stalagmite top as a very important factor for stalagmite form and for these shelves too. Changes (dislocations) occur if stalagmite is dislocated together with the basis or, what is more often, due to alterations on the cave ceiling. Less changes occur when drop is falling directly from rock to ceiling, if Q oscillation is small and where the ceiling is not high. As stalactites grow mostly unsymetrically they increase the dislocations. A shifting for one half of the drop diamter (1-3mm) is enough that the water flows mostly on one side of stalagmite if the top is conical.

Beside this the shelves are caused by many other factors (slower water flow on less inclined surface and therefore more deposition there, different strengths of crystal net, penetration of water from the stalagmite mass to its surface (Gams, 1979b, 1981 in print).

Modificators of Stalagmite Forms (Sketch 2)

They in many cases obscure the basic rules of morphometrics. The most imporant modificator in the Slovenian Caves found till now is connected with the formation of crust built of secondary calcite on the ceiling. It reduces the Q_{max} in the primary water channel and activates the side channels in the ceiling. Percolation through the new crust is more and more diffused. Instead of one wider stalagmite many thinner stalagmites nearby began to grow (Sketch 2, 2a,2b,2c). Water falling from a high ceiling sprinkles on the stalagmites. In the Cave of Postojna the following relationship of distance from stalagmite top to ceiling to stalagmite diameter was found in case of dropping and not trickling water (Gams, 1968, 1979b):

height of ceiling(m): 2-3 -diameter of stalagmite(cm): 8
height of ceiling(m): 4-6 -diameter of stalagmite(cm):11
height of ceiling(m): 10-15 -diameter of stalagmite(cm):15

With diminishing distance between the growing stalactite and stalagmite the last one is getting therefore thinner (3a,3b). On a growing stalactite the surface where the flowing water is aerated is getting larger and the deposition of secondary carbonate on stalagmite is by this reduced. If the stalactite breaks and falls down, dislocation of dripping point is wider, the primary stalagmite is retting thinner and larger the new one which gets more water through the side channel. After a stalagmate (column) is formed widening of it downwards began (3c,3d).

Some cut wider and lower stalagmites show that their width has changed sometimes during the dripstone growth by dislocation of dripping point and by differences between the Q_{max} and Q_{min}. At the same water supply diminishing Q_{min} means widening of the dripstone. Transformation of a conical stalagmite by increasing water supply in a cylindrical or reversed conical form takes many hundred of years.

The equation for volume $V = f(QtF_q)$ does not have a comparative value until the water leaving the dripstone has balanced its solution carbonates with the partial pressure of CO_2 in the cave air. After balancing it, it preserves 80-90 mg/$CaCO_3$/l (in the Cave of Postojna - Gams, 1967).

Here are mentioned only some important modifcators. It seems in the Slovene caves that the mentioned modificators produced more irregularity in stalagmite form than the climatic changes.

In one submediterranean cave (Vilenica) dripstone analyses has found the Holocene tendency of diminishing of the Q_{max} through the cave ceiling. In late Pleistocene time wider stalagmites and heaps grew and after that, presumable in Holocene, stalagmites are thinner and thinner. By this fact more secondary calcite is recently deposited on the ceiling than on the bottom. This relationship seems to be in all caves situated in arid and semiarid climates in comparison to wet climates. An international systematic analyse of dripstone forms would bring in my view more evidence to this point of view.

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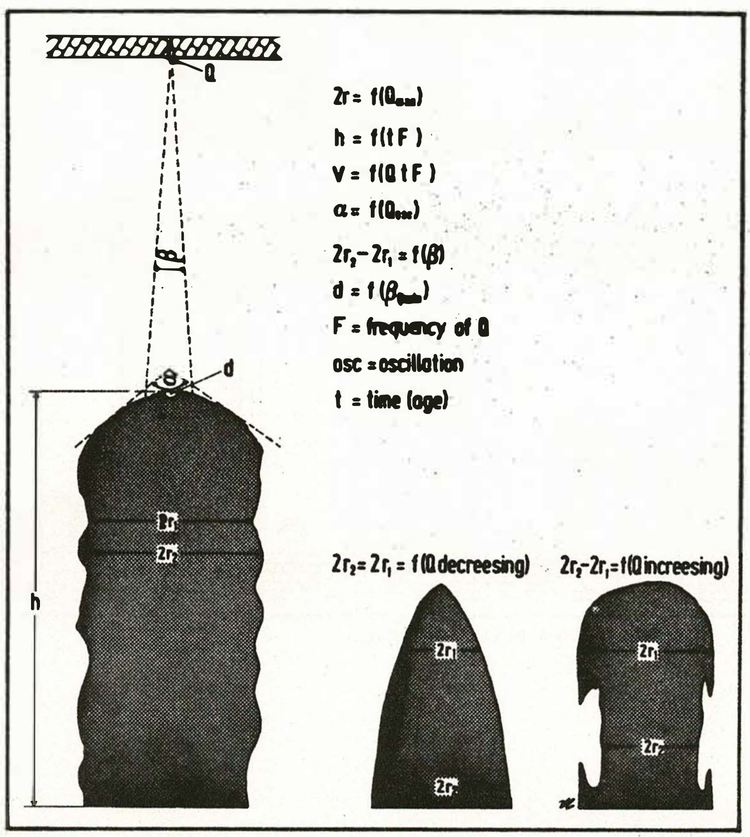

Figure 1. Basic Morphometric Equations.

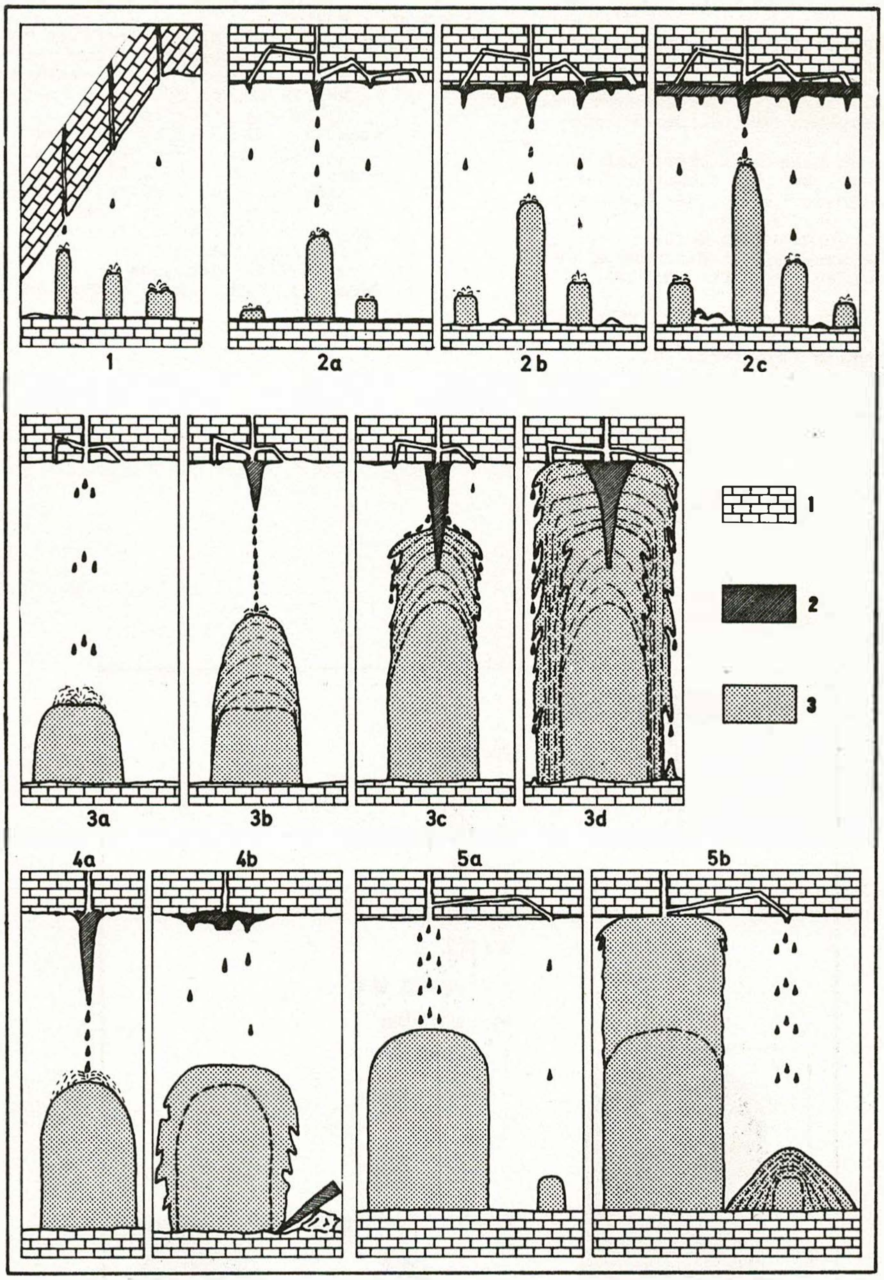

Figure 2. Modificators of Stalagmite Form.

The Collared Lemming Dicrostonyx Hudsonius (Pallas) From a Pleistocene Cave Deposit in West Virginia

Frederick Grady and E. Ray Garton
Dept. of Paleobiology, National Museum of Natural History, Washington, D. C. 20560
Research Associate, Carnegie Museum of Natural History, Pittsburg, Pa. 15213

Abstract

Four teeth of the collared lemming Dicrostonyx hudsonius (Pallas) from New Trout Cave, Pendleton County, West Virginia, demonstrate the presence of this tundra-dwelling rodent in West Virginia during the late Pleistocene. This record is the second for Dicrostonyx hudsonius in the central Appalachians and is ca. 1.5 degrees south of the previous record at New Paris Senkhole No. 4, Pennyslvania. C14 dates of 17,060 + 220, 28,250 + 850, and 29,400 + 1,700, for the levels from which the Dicrostonyx specimens were recovered, bracket the last advance of the Wisconsin glaciation. The older two dates are the earliest for Dicrostonyx in North America, south of Alaska and the Yukon. The fauna associated with the Dicrostonyx specimens is similar to other central Appalachian late Pleistocene faunas.

Zusammenfassung

Vier Zaehne des "Collared Lemmings Dicrostonyz Hudsonius" (Pallas) von der New Trout Hoehle in Pendleton County, West Virginia, zeigt das Vorhandensein des "Tundra-Dwelling Rodent" in West Virginia waehrend des spaeten Pleistocene. Dieser Fund ist der zweite fuer den Dicrostonyx Hudsonius in den Zentral-Appalachen und ist annaehernd 1.5 Grad Sued von dem vorherigen Fund in dem "New Paris Sinkhole No. 4," Pennsylvania. C14 datierend von 17060 + 220, 28250 + 850 und 29400 + 1700 von den Zonen von welchen die Dicrostonyx Muster erschlossen wurden, in der Zeit des letzten Vordringens der Wisconsin Gletscherzeit. Die zwei aelteren Zeitpuntke sind die fruehesten fuer Dicrostonyx in Nord Amerika sued von Alaska und der Yukon. Die Fauna, die mit dem Dicrostonyx auftritt ist gleichartig zu anderen Zentral-Appalachen "Pleistocene Faunas."

* * *

Discovery, in February 1979, of small bones and teeth in New Trout Cave, Pendleton County, West Virginia, led to the collection of a significant fauna of late Pleistocene, Rancholabrean Age vertebrates. The cave is approximately 5.6 kilometers southwest of Franklin, West Virginia, 38°36' 10" N. Latitude, 79°22' 08" W. Longitude (Fig. 1). The entrance is at 548.6 meters altitude. The bone deposit is approximately 305 meters from the entrance, at the far end of the second room (Davies, 1965).

Bone-bearing matrix was collected by 30-centimeter levels, sacked and taken from the cave for processing. The material was wet-screened through 5 mm and 1.5 mm mesh. The concentrate was then picked for bones, teeth, and other organic remains. Samples of unscreened matrix were saved for pollen analysis. Speciments of more than 1000 individual terrestrial mammals and 5000 bats have been recovered to date. Significant numbers of fish, amphibians, reptiles, and birds were recovered. The collection is being deposited in the research collections of the Department of Paleobiology, National Museum of Natural History.

Among the more important remains of small mammals recovered were four teeth of the collared lemming, Dicrostonyx hudsonius (Pallas). One tooth was recovered from each of the first two 30-centimeter levels, and two teeth were recovered from the third level. The specimens represent at least two individuals. These three levels were dated by C14, using bone collagen. 17,060 + 220, 28,250 + 850, and 29,400 + 1700 years BP (Before Present), by the Smithsonian Radiation Biology Laboratory. The third level was also dated on the basis of hackberry (Celtis, sp.) seeds at about 23,000 BP. Dr. Robert Stuckenrath of the Smithsonian Radiation Biology Laboratory (personal communication) has doubts concerning the hackberry date, but is reasonably confident of the bone dates which were done on a suite of fragments from several different taxa.

The Dicrostonyx teeth recovered are two right M1's and one left and one right m1. The M1's are clearly identifiable as Dicrostonyx hudsonius, based on the characteristics discussed in Anderson and Guilday, 1968, and differ from those of Dicrostonyx torquatus in that they lack the small posterior internal cusp that is almost always present in D. torquatus. Also in Dicrostonyx hudsonius (including the teeth from New Trout Cave), the posterior wall of the last alternating triangle of M1's is convex, whereas in D. torquatus it is concave. Each M1 from New Trout Cave measures 2.4 mm in length, well within the range of modern Dicrostonyx hudsonius and close to those from New Paris Sinkhole No. 4 (Anderson and Guilday, 1968; Guilday, et. al., 1964).

The two M1's are Dicrostonyx but are not identifiable to species. Both have seven closed triangles, but differ from each other in the shape of the anterior loop. On USNM 299774, the anterior loop is a simple crescent, while on USNM 299773, it is more in the shape of a trefoil. This character is highly variable in Dicrostonyx, as noted by Guthrie and Matthews, 1971. USNM 299774 is 2.9 mm long referred to Dicrostonyx hudsonius based on the presence of the identifiable upper molars and on geographic probability.

Dicrostonyx lives in the tundra of Holarctica. The modern species are Dicrostonyx torquatus with several subspecies widespread in Eurpoe, Asia, and North America, and Dicrostonyx hudsonius, confined to the Ungava Peninsula of Canada, where D. torquatus does not occur. Dicrostonyx is a common European fossil. The genus is divided into several species, most of which are related to Dicrostonyx torquatus (Janossy, 1954; Anderson and Guilday, 1968).

There are now at least six North American Pleistocene records for Dicrostonyx torquatus south of its present distribution (Fig. 2). These occurrences are late Rancholabrean in age (Martin, et.al., 1979; Guilday and Anderson, 1967; Burns, 1980). The previous most southerly occurrence of D. torquatus in North America is Bell Cave, Albany County, Wyoming (Zeimens and Walker, 1974).

In eastern North America, Dicrostonyx hudsonius have been identified from New Paris Sinkhole No. 4, 40°07' N. Latitude, Bedford County, Pennsylvania (Guilday and Doutt, 1961), and from early Holocene deposits at St. Elzear de Bonaventure Caverne, Gaspe Peninsula, Quebec, Canada (Guilday, personal communication). The presence of Dicrostonyx hudsonius at New Trout Cave ca. 1.5° south of New Paris Sinkhole No. 4 estalishes a new southern distributional record for this tundra rodent during the late Pleistocene. The C14 dates for the two lower levels are the earliest for Dicrostonyx in North America south of Alaska and the Yukon, and indicate that tundra-type vegetation was probably present near New Trout Cave during the interstadial prior to the last advance of the Wisconsin glaciation dated some 20,000 years BP (Wayne, 1967).

The New Trout Cave fauna is extensive and currently under study. The upper three levels contain large numbers of microtine rodents including northern forms such as Microtus xanthognathus, Synaptomys borealis, and Phenacomys intermedius. Dicrostonyx hudsonius represents less than 1% of the combined microtines of the upper three levels. The dominant microtine rodents from these levels are Clethrionomys gapperi, Microtus pennsylvanicus, and Microtus chrotorrhinus, all of which inhabit the local area today.

Microtus xanthognatus at New Trout Cave is rare, representing 2.1% of the microtines from the site. This contrasts strongly with New Paris Sinkhole No. 4, Pennsylvania, and Clark's Cave, Virginia where M. xanthognathus was one of the dominant microtines (Guilday, et.al., 1964; Guilday, et. al., 1977). The overall fossil fauna resembles others of the central Appalachians though percentages of various components vary from site to site.

Acknowledgements

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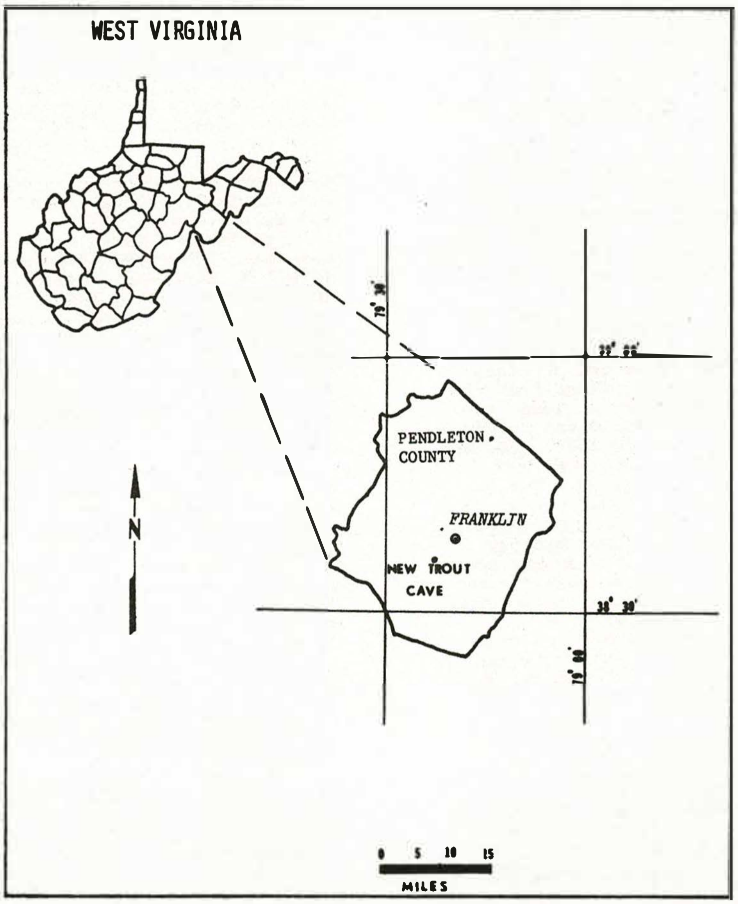

Figure 1. Location Map of New Trout Cave
Pendleton County, West Virginia

Figure 2.

1. January & Eagel Caves, Laberta
2. Jaguar Cave, Idaho
3. Rock Shelter near Natural Trap Cave, Wyoming
4. Roch Shelter near Ten Sleep, Wyoming
5. Little Box Elder Cave, Wyoming
6. Bell Cave, Wyoming
7. St. Elzear de Bonaventure Cave, Quebec
8. New Paris #4, Pennsylvania
9. New Trout Cave, West Virginia

D. hudsonius modern range

D. torquatus modern rnage

Pleistocene Dicrostonyx : D. torquatus 1-6
D. hudsonius 7-9

Modern Ranges from (Guilday 1963)

Speleogenesis of the Castleguard Cave System

D. C. Ford
McMaster University, Hamilton, Ontario, Canada, L8S 4K1

Abstract

At least three major cave systems are identified in the area. "Castleguard I" (Castleguard Cave) is a largely relict system draining down dip to seasonal overflow springs hanging in the north wall of the South Glacier valley. "Castleguard II" is the inaccessible lower storey of this cave, discharging subglacial waters of the central Columbia Icefield to big springs at the base of the wall, 300+ m below the overflow springs. "Castleguard III" is a quasi-independent system underdraining the Meadows strath from a sinkhole karst in the north end southwards aslant-strike to the same big springs plus permanent springs hanging in the wall. It, too, is inaccessible.

Castleguard Cave heads at shallow depth beneath the Icefield in uppermost Cathedral and basal Stephen strata, passes beneath Castleguard Mountain where an additional 400 m of Eldon and Pika strata overly it, and terminates (again at shallow depth) in upper Cathedral strata beneath the southern extremity of the Meadows. There are three principal components of the system: i) the inlet complex, an array of subparallel dip tubes linked by strike-oriented subsequent passages. Form is phreatic with minor vadose entrenchment. Breakdown and glacial injecta fill many parts; the complex is imperfectly understood. ii) a downstream complex of dip tubes, strike links and lifting chimneys initiated by local Meadows drainage. It constituted a targed for iii) the central linking section (the lengthiest) which penetrates the mass of the Mountain. This comprises dip tubes linked by phreatic lifts on faults or sedimentary dykes, with vadose and phreatic components regularly alternating.

Résumé

Au moins trois systémes de cavernes sont identifiés dans la région. "Castleguard I" (caverne de Castleguard) est un systéme largement fossile drainant dans la direction du pendange vers des sources de débordement saisonnier suspendues dans le mur nord de la vallée South Glacier. "Castleguard II" représentee l'étage inférieur inaccessible de cette cave, déversant des laux sub-glaciaires du centre du champ de glace Columbia dans de larges sources au pied du mur, 300+ m sous les sources de débordement. "Castleguard III" est un systéme quasiindépendant sous-drainant la vallée Meadow d'un karst de gouffres à l'extrémité nord de cette strate, vers le sud des mêmes larges sources en plus des sources permanentes suspendues. Cette caverne est aussi inaccessible.

L'origine de la caverne de Castleguard se trouve prés de la surface sous le champ de glace, dans la partie supérieure de la strate Cathedral et dans la partie inférieure de la strate Stephen. La caverne s'étend sous la montagne Castleguard où s'ajoutent au-dessus quelques 400 m de strates Eldon et Pika, et se termine (encore prés de la surface) dans la partie supérieure de la strate Cathedral, sous l'extrémite sud des Meadows. On peut compter trois composantes principales du systéme: i) un complexe d'alimentation, formé d'une gamme de tubes de pendage sub-paralléles reliés par des passages subséquents orientés perpendiculairement au pendage. La forme est phréatique, avec des retranchements vadoses mineurs. Des injections glaciaires et de rupture emplissent plusieurs parties; le complexe n'est pas bien compris. ii) un complexe en aval composé de tubes de pendange, de liens perpendiculaires au pendage et de cheminées d'élevation, initié par le drainage local des Meadows. Ce complexe constitue une cible pour iii) la section c ntrale de liaison (la plus longue section) qui pénétre la masse de la Montagne. Ceci comprend des tubes de pendage joints par des soulévements phréatiques sur des failles ou des dykes sédimentaires; les compsantes vadoses et phréatiques alternent réguliérement.

Cuban Rupestrian Drawings, Techniques, styles and Chronology

Antonio Núñez Jiménez
Sociedad Espeleólgica de Cuba

Abstract

In synthesis, this monograph deals with the results obtained by the study of more than 60 locations of rupestrian art in the Cuban Archipelago.

Such rupestrian manifestations were elaborated with three main techniques: painting, carving and scratching. The colours used in the pictography are red and black.

Generally, the style is abstract and stylized. The figures correspond to geometric patterns. Human and zoological figures are very stylized.

The first Cuban rupestrian drawings can be traced back six thousand years, corresponding to the so called Cultura de Seboruco, of hunters and gatherers, characterized by lithic tools such as big knives or sheets and axes made of silex. The most recent pictographies correspond to the Taína culture, based on agriculture and pottery, of Arawak origin that flourished in the most eastern part of Cuba not long before the discovery of the Island by Christopher Columbus.

Résumé

Cette monographie traite, en synthése, des résultats obtenus de l'étude de l'art rupestre, dans plus de 60 localités de l'Archipel Cubain.

Ces manifestations rupestres ont été élaborées principalement en utilisant trois techniques: peinture, sculpture et "gravure". Les couleur employées pour les pictographies sont le rouge et le noir.

En général le style est abstrait et stylisé. Les figures correspondent à des patrons géométriques et les figures humaines et zoologiques réprésentées sont trés stylisées.

On pourait atribuer à ces premiers dessins rupestres cubains une anicenneté de 6 000 ans. Ils correspondraient alors à la Cultura del Seboruco d'aborigénes s'adonnant à la chasse et à la cueillette. Cette culture se caractérise par un outillage lithique formé par des grands conteaux ou lames et des haches en silex. Les plus récontes pictographies et pétrographies correspondent à la culture "taína", "agro-potiére" et d'origine arawak, qui a fleuri dans la partie la plus orientale de Cuba, pas trés longtemps avant la découverte de l'île par Christophe Colomb.

The Cuban Archipelago has, till the present, more than 60 locations of rupestrian or parietal art, most of which can be found in caves.

The techniques used in these artistic manifestations are of three types: painting or pictography, carving or petroglyphic and scratching. The style of such drawings is closely related to the chronology and culture to which the artists of our rupestrian art belonged.

In Mayarí, Holguín Province, we find the location of Seboruco Caves, with black pictographies in abstract forms, that seem to recall anthropomorphic figures. These rupestrian drawings, in relation to the location, are associated with the most ancient culture discovered in the Greater Antilles. The most characteristic instruments of this culture were sheets of silex some of which were knives, as well as axes and precussors of the same material. They belong to the Cultura de Seboruco, which developed hunting and gathering as a means of living.

Human burials found in this locality are as ancient as 6 thousand years Before the Present (BP), according to the method of the incineration of collagen.

In the North coast of Sancti Spiritus Province, in Caguanes, we have a series of caves with geometric drawings in dagger form, retiform and blade form figures, all of them in an abstract style, as well as some others formed by circles and anthropomorphic and zoomorphic designs, associated with shell instruments.

In that zone there are burials with polished stone spheres that in some other locations were discovered besides lithic daggers. This culture has been called "Cayo Redondo", which belonged to the gathering stage.

In the caves of the Island of Youth, formerly Island of Pines, we have a very definite abstract style, mainly formed by concentric circles, where the red and black colours alternate, sometimes separated by the natural white of the limestone.

This circular geometric style appears associated with tools elaborated with shells of molluscs, mainly from Strombus gigas, popularly known as cobo and with which their menage, such as chisel, picks, plates, hammers, etc. were manufactured. Besides, the Strombus served them as food, therefore the name of Cultura de Caracol that we have given to this group, which archeologically constituted, in its origin, the "Culture ~~de Guayabo~~ Blanco", which belonged to the stage of fishers and gatherers.

Some excavations made in burials in the caves of Punta del Este (Island of Youth) seems to prove that their occupants had been buried for more than 1,100 years B.P., according to radiocarbon analysis. These burial were secondary since the bones appeared to be dyed in red.

The pictographic manifestations of the Isle of Youth, mainly the already mentioned concentric circles, could be associated with astronomic rituals, related to the sun and the moon.

In Sierra de los Organos (Gran Caverna de Santo Tomás) there are some rupestrian manifestations achieved with the scratching technique on a soft rocky surface.

In this location appears a very stylized geometric art with serpentiform and human figures of great simplicity, triangular, cruciform and others.

In that cave was also found the typical menage of the "Guayabo Blanco" culture, formed by plates and picks of Strombus, as well as some small splinters of silex.

In the center of Havana Province (Catalina de Guiñes), in the North of Matanzas Province (Cueva de la Pluma) and in Camagüey Province (Sierra de Cubitas) can be observed some hand prints, as well as horseshoe-like, bannerlike, triangular, anthropomorphic and zoomorphic pictographies in red and black and associated in some cases with pottery, stone percussors and shell objects, traced back some thousand years B.P. They are ascribed to the Siboney Culture, based on agriculture and pottery, very similar to the Taína one.

In the Eastern part of Cuba, mainly in the zone of Maisí, we find the speolologic location of La Patana with petroglyphs mainly anthropomorphic and zoomorphic, associated with pottery of the Taina culture, which inhabited that zone for some 600 years B.P. These cultures, Taína and Siboney, proceed from South American Arawakan migrations.

In Havana Province we have the location of Guara, with numerous pictographic caves in which the main themes are anthropomorphic and zoomorphic, extremely stylized: scenes of hunters and quadrupeds ad big as human beings; the hunters carry sticks, bows and shields (?)

This location has not been studied yet.

There is the possibility that the represented animals as big as human beings, could correspond to species of the fossile or extinguished fauna.

In this location there are also series of concentric circles, Undulating lines and horizontal parallels.

Finally we must add that in Sierra Cubitas (Cueva de los Generales) we have an obvious pre-columbian rupestrian art in which the aborigines represented scenes of the Spanish conquest and colonization of Cuba.

Dye Tracer Studies of the Unsaturated-Zone Recharge of the Carboniferous Limestone Aquifer of the Mendip Hills, England

H. Friederich and P. L. Smart
Department of Geography, University of Bristol, BRISTOL, BS8 1SS, ENGLAND

Abstract

The results of several experiments to trace water movement in the unsaturated-zone of the Carboniferous Limestone aquifer overlying GB Cave in the Mendip Hills are presented. The lateral spread of dye in a direction downslope of the injection site indicates the existence of a sub-cutaneous flow zone or epikarstic aquifer with horizontal flow rates in the order of 100 m per day. Dye recoveries show that the epikarst is preferentially drained by a few open fissures thought to be spaced at about 50 m intervals. Vertical flow rates in these fissures are in excess of 100 m per hour, but much slower rates below 50 m per day are observed for the smaller less open fissure systems, which are much less significant for aquifer recharge. Although dye was still present 10 months after its artificial recharge into the epikarstic aquifer, drip discharge records do not suggest a high storage capacity in this zone. An additional experiment suggests that the rate of vertical infiltration in the soil is less than 30 cm per month and is associated with considerable storage.

Résumé

Pendant plusieurs d'expériments en 1979, la circulation d'eau dans le zone d'infiltration du Karst de Mendip Hills était tracée. Les résultats sont présentés et al signification rélative des parties du systéme d'infiltration est discutée. L'extension laterale de coloration montre l'existence de l'aquifére épikarstique, et la vitesse de circulation horizontale est environ 100 m par jour. Le récouvrement du colorant montre que l'aquifére épikarstique est drainée de préférence par quelques fissures ouvertes qui sont développés aux intervalles de 50 m. Le temps de transit vertical par cettes fissures ouvertes est 100 m ou plus par heure, mais l'infiltration rétardée montre de temps de transit de (ã m par jour. Bien que le colorant est encore détecté dans l'eau d'infiltration 10 mois aprés l'injection, les hydrographes n'apportent pas l'idee d'une sauvitage d'eau étendu. Une traçage d'eau de sol suggére une circulation d'eau verticalle de 30 cm par mois ou moins, apportant la hypothêse d'une vaste saubetage d'eau dans le sol.

Study Area

The Carboniferous Limestone forms an upstanding plateau surface in the Mendip Hills, 35 km south of Bristol, into which an extensive dry valley network is incised (Ford and Stanton, 1968). The work reported was undertaken in GB Cave, which is developed down-dip from the limestone boundary. The cave, described by Ford (1964) is overlain by a fairly level surface with disturbed mined ground to the North and agricultural land in the South. The soils are generally stony and rarely exceed 1 m in depth. A shallow dry valley slopes from East North East to West South East over the central part of the cave, while the swallet complex which is extensively infilled by muddy gravels, is bounded to the South by a buried cliff line.

Methods

Six tracer tests were conducted from sites on the surface above the cave. The first three used water pumped from the active swallet stream to augment natural infiltration. Water was recharged for between 25 and 50 minutes at 80 l/min into depressions at A, B and C (Fig. 1) in February, 1979, using 400 g Fluorescein, 150 g Sulpho Rhodamine B and 400 g Amino G Acid. Site B was retraced under natural recharge conditions in May using 500 g Fluorescein emplaced below the soil, and in December sequential injections were made below the soil cover at site D. Water samples were collected from shaft flows, vadose flows and vadose seeps (defined after Gunn (in press) according to the size of the bedrock opening from m through cm to mm) on a daily or semi-daily basis for 2 weeks after injection, and thereafter irregularly. Discharges were measured by hand and also using previously installed tipping bucket continuous gauges. Dye concentrations were determined using a Turner III filter fluorometer and appropriate filters.

Results

a. Recharge Experiments

Dye recharged at site A was visibly detected 8 minutes after injection in the shaft flow WPAV 80 m underground. Similarly rapid responses were observed at the vadose flows WPOV and BED and the shaft HAV, although the dye concentrations were one thousand time lower than is WPAV. Site B tracer showed a similar rapid response in the OAV shaft, but some 4 hours after injection, had also appeared in the vadose seep UGSL and the flow UGF 27 m below the injection site. Twenty-four hours after injection Site A and B tracers were widely distributed in the central portion of the cave with many vadose seeps positive (Fig. 3). This lateral dispersion continued until nearly all sites sampled were positive 5 days after injection. At shafts and vadose flows adjacent to the input site, dye concentrations peaked on the day of injection and fell thereafter, assuming an exponential decay with time (Fig. 4 WPAV). Similar but more distant sites (OAV) peaked the following day, as did many of the nearer seeps (WP1). More distant sites peaked later, although this pattern was complicated by rainfall which caused multiple peaks at many vadose seeps (MUD).

b. Natural Experiments

Under natural conditions the Site B tracer showed a similar overall dispersion to that observed in the recharge experiments (Fig. 2). Thus this pattern cannot be due to the development of an artificial recharge mound, but occurs under normal recharge. The results of the sequential sampling at Site D proved that the pattern of positive results was reproducible through time, for instance the GCF vadose flow became positive 12 days after the first injection and 15 days after the second. Due to the lower density of cave passage in this area, the exact pattern of dispersion is not well defined, but the more rapid movement appeared to be North towards the axis of the dry valley.

In all the natural experiments, particularly that for site B where there had been no rain for the preceeding 10 days, the first sites to show positive results were the vadose seeps immediately adjacent to the input (Fig. 5). The OAV shaft did not become positive until the flow increased in response to heavy rainfall 11 days after injection. Several sharp peaks in dye concentration were associated with the storm recharge, but it was not until the major rainfall 15 days after injection that concentrations reached high levels. Despite the different discharge response to rainfall, OAV and UGSL had similar dye concentrations, suggesting they are both fed from the same water source.

Discussion

Times of first arrival for dye utilising open shaft flow routes were very short with velocities in excess of 100 m per hour and reaching as high as 600 m per hour. The slowest true vertical flow rates were observed for vaodse seeps (5 to 10 m per day from first arrival times), although many other seeps had rates of the order of 50 m per day. These velocities represent only the most rapid dynamic response of the aquifer. Considerable storrage of dye was observed for periods in excess of 10 months and it is not known if this is isolated and static (indicating void space not directly linked to transmission routes) or dynamic (indicating very slow transit times). The multiple peaks associated with further recharge (e.g. Fig. 4 MUD) suggest the former, with stores emptied only by high flows. However the exponential dye decays observed at other sites (Fig. 4 WPAV) are more suggestive of a perfectly mixed store directly involved in the flow and recharged from it. Some vadose seeps (Fig. 5 ENP) are better modelled as flow-through stores with plug flow (no-mixing), having a single peak followed by undyed water).

The isolated stores suggest the operation of a threshold overflow system, controlled by the rate of recharge and/or storrage state of the fissure system, and this is supported by the observed differences between high and low recharge rate responses in the tests. Under dry antecedent conditions at site B, dye first appeared only in vadose seeps, but as recharge increased vadose flows became positive and there was an associated increase in the spatial dispersion of positive vadose seeps. Finally the discharge and concentration of the OAV shaft flow responded after very intense rainfall 15 days after injection. Similarly under artificial recharge at site A the main shaft WPAV had discharged 100 g (25%) of dye two days after injection; the total recovery at all other sites being only 1 or 2 g. Thus there appears to be a sequence with recharge switching to progressively higher capacity routes as the combined discharges of the smaller fissures are exceeded. This is supported both by the observation of 'overflow' routes discharging only at high flows (Fig. 5 UGF), and by the peaky pattern of response noted in the more open flow paths (Fig. 5 OAV of UGSL).

The surprisingly dispersed pattern observed for the point injections may also be a product of the limited capacity of the vadose seep fissure system. The lateral dispersion occuring at relatively shallow depths in the subcutaneous flow zone, and being most rapid under high recharge conditions. However it may also be due to the ramifying nature of fissure systems in the unsaturated zone. There is no evidence for dip control of the dispersion patterns, thus either the sub-cutaneous flow hypothesis is correct or the North West/South East and South West/North East joints and East/West faults are more significant routes for infiltration. The relatively low surface relief does not appear to affect the pattern, as might be expected if a shallow sub-cutaneous flow was significant, although the site D injections do appear to show more rapid lateral movement towards the axis of the dry valley. There is unfortunately insufficient spatial distribution of sites at a single depth to confirm if the recharge front is actually symetrical or shows more rapid horizontal development near the surface. Apparent horizontal flow rates vary between 100 m per day for vadose flows and 10 m per day for vadose seeps. These are comparable with actual vertical flow rates. The problem is further perturbed by known tributary connections in vadose flows such as the link from OAV to WPAV at a depth of 50 m. Calculations suggest that in the upper part of the cave, where vadose shafts have a spacing of roughly 50 m intervals, the water recharged during a single storm can be almost wholly accounted for by observed discharges entering the cave. Thus it can be concluded that the lateral integration of recharge water is largely complete by depth of 100 m, a factor which would explain the much lower numbers of inflows observed in the deeper parts of the cave.

Conclusions

A hierarchial conceptual model of the unsaturated zone can be formulated from the above discussion. A large number of low discharge tight vadose flows, which have a high storrage to flow ratio, form the lowest level of the heirarchy. They decrease somewhat in number with depth and are tributary to higher numbers of the flow heirarchy. Because the recharge capacity of this level is low, lateral flow develops in the upper more solutionally enlarged parts of the unsaturated zone to guide excess recharge to the higher capacity more open vadose flows which form the next level of the heirarchy. These are much smaller in number, have a much lower storage to flow ratio, and may quite often be inactive during recession periods unless fed by tributary vadose seeps. Segments of isolated storage may well occur in these intermittently active members. With increasing depth the two lower level flow systems may link into the most open routes, the shaft flows which have the highest recharge capacity and the lowest intrinsic storage. These feed directly into conduits in the saturated zone and are responsible for the rapid response to discharge widely observed in karst areas with limited allogenic inflows. A proportion of deep recharge is still, however, via the lower levels of the heirarchy. Present studies aim to test and quantify this model to obtain estimates of total unsaturated zone storrage and the relative amounts of diffuse versus concentrated recharge which occurs.

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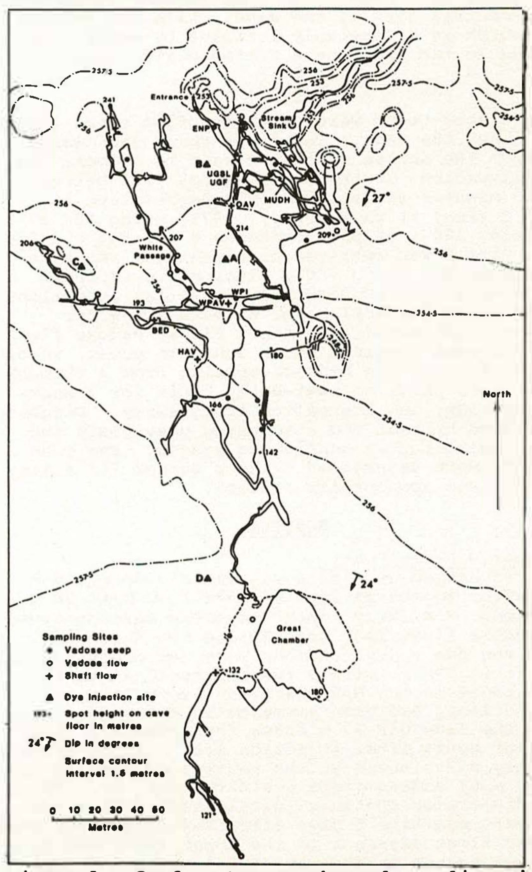

Figure 1. Surface topography and sampling sites G. B. Cave.

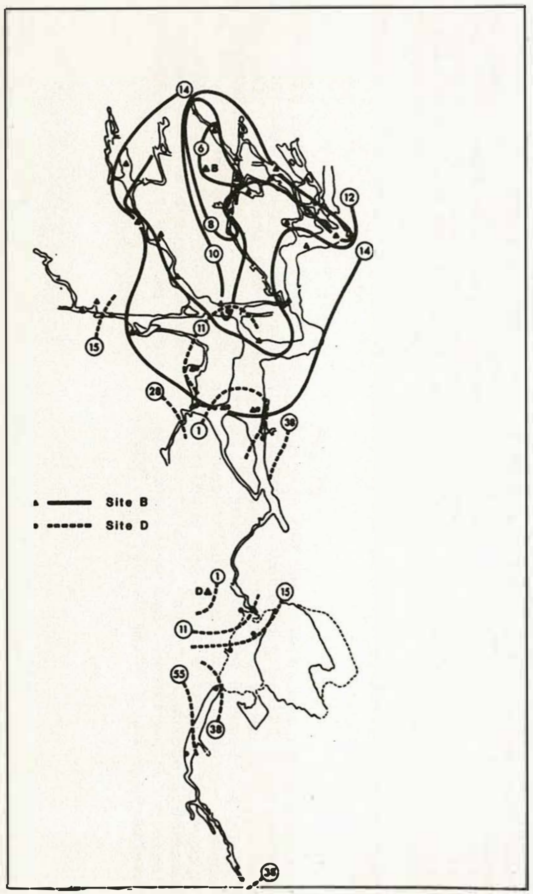

Figure 2. First arrival times in days from injection for natural recharge at sites B and D.

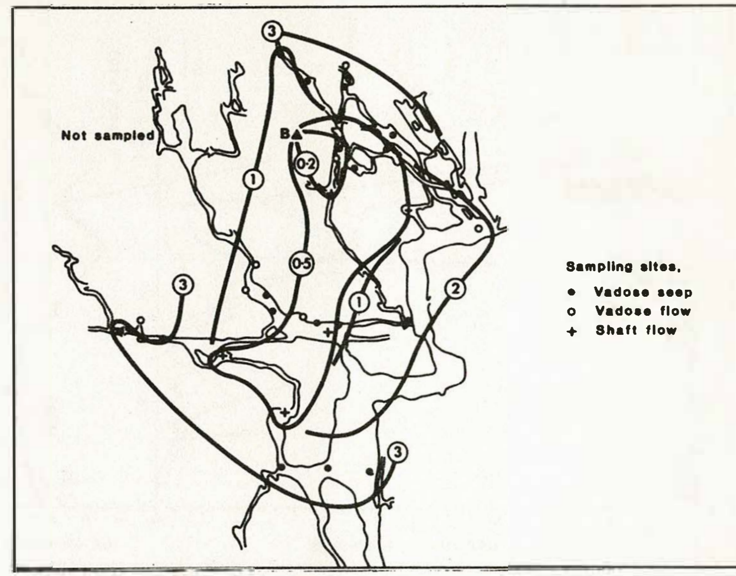

Figure 3a. First arrival times in days from injection for recharge at site B (Rhodamine).

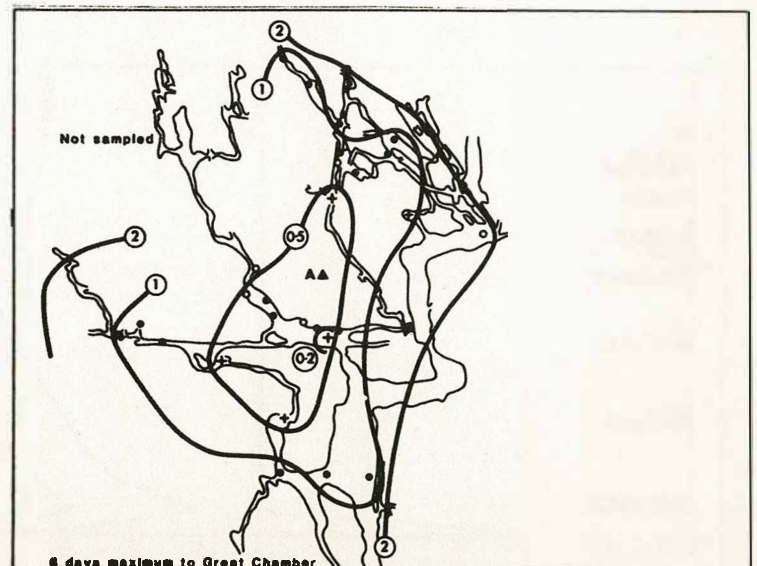

Figure 3b. First arrival times in days from injection for redharge at site A (Fluorescein).

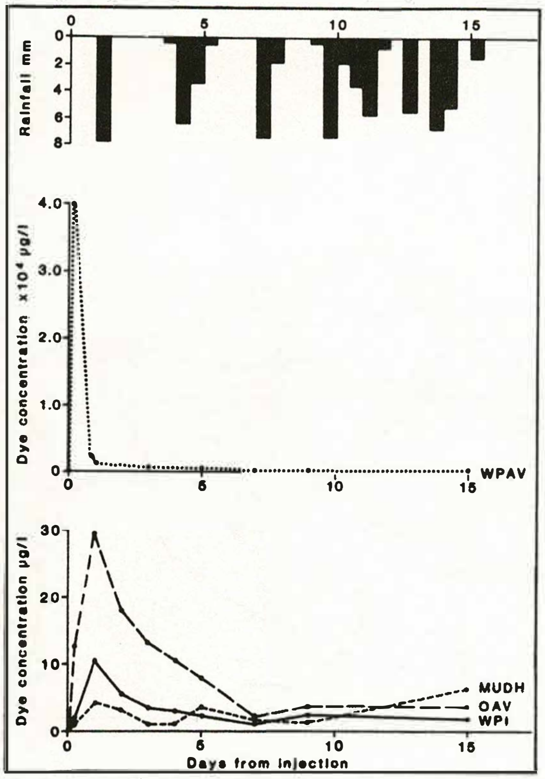

Figure 4. Time/concentration curves for selected sites for dye recharged at site A.

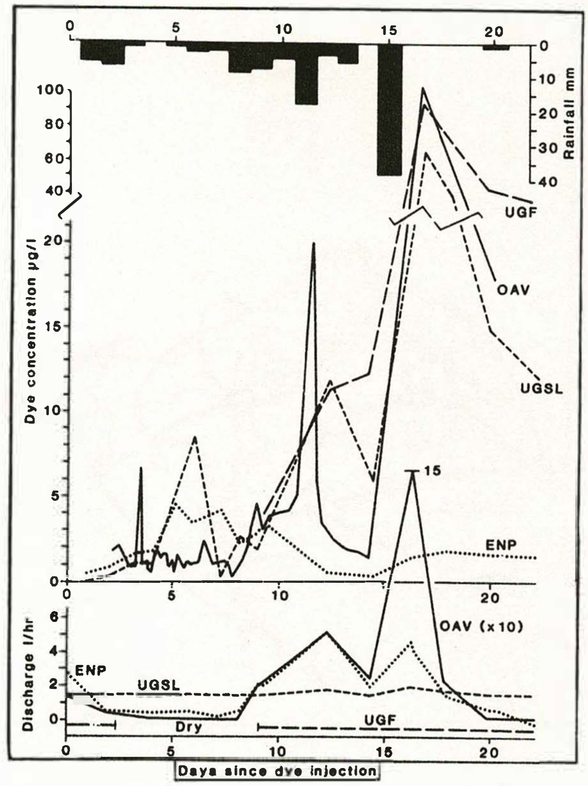

Fig. 5. Time/Concentration Curves and Discharge for Natural Recharge at Site B.

Cave Explorations and Archeaological Discoveries in the Cockpit Karst of Peten, Guatemala

Michel Siffre - Gerard Cappa
34 Rue Trachel, Nice 06000, FRANCE

Abstract

Five speleological expeditions conducted since 1975 have enabled us to explore about 500 wild caves in the Peten, among them about thirty underground rivers at a shallow depth.

The main result is the discovery of a true cave art composed of tens of sculptures carved on a stalagmitic substratum. About 100 sculptures, most of them representing human faces, have been found in caves and shelter rocks. Their principal characteristics are a primitive archaic shape and non-mayan style. Some of the sculptures are masterpieces. I attribute them to the intermediary period between the hunting and gathering peoples and the first pre-maya ceramic settlements, that is to say between 5000 and 3500 B.C.

Parietal engravings, paintings and clay modelings have also been discovered in caves of this Maya Lowland country.

Résumé

Depuis 1975 nous avons exploé environ 500 cavernes dans le karst du Peten et découvert une trentaine de riviéres souterraines à faible profondeur. Toutefois le résultat le plus important est la découverte d'un art des cavernes composé de plusieurs dizaines de sculptures sur stalagmite. Ces sculptures représentent essentiellement des figures humaines. Leur style est non-maya. Quelques sculptures sont de vértiables chefs-d'oeuvre. J'attribute à ces sculptures un âge compris entre 5,000 et 2,500 ans avant Jésus-Christ, à une époque intermédiaire entre les populations des chasseurs-cueilleurs (précéramque) et les premiers établissements agricoles "maya". La découverte de ces sculptures sur stalagmite est un fait nouveau en archéologie précolombienne. Des peintures, des gravures pariétales et des modelages d'argile ont aussi été découverts dans les grottes du bas-pays maya.

Lilburn Cave's Contributions to the Natural History of Sequoia and Kings Canyon National Parks, California, USA

J.C. Tinsley[1], D.J. Des Marais, G. McCoy, B.W. Rogers and S.R. Ulfeldt
[1]1040 Oakland Avenue, Menlo Park, California, 94025

Abstract

Lilburn Cave, a 12 km long maze, is formed in foliated marble by a subsurface stream draining Redwood Canyon. The marble and its associated metasedimentary lithologies comprise the Redwood Mountain pendant in the Sierra Nevada batholith. The U.S. National Park Service manages the cave as a research facility because multidisciplinary research in speleology at Lilburn contributes new perspective to the region's natural history and to the interpretive program of the parks. Bedrock fractures and the regional hydrologic gradient are subparallel and apparently both are responsible for the strongly linear trend (345°) of the cave. However, the orientation of passages seems to be independent of (Ca,Mg)CO_3 variations within the marble. The waters of the Redwood Creek drainage have a resurgence at Big Spring, an ebb-and-flow spring situated at the downslope terminus of the marble at a contact with a schist. Lilburn Cave provides access to the upstream ends of conduits and siphons which cause the flushing action. The cave's sediments indicate an initial period of varve-like clay and silt sedimentation followed by an influx of gravelly granitic detritus. The former phase lasted at least 8 x 10^3 years, indicated by paleomagnetic studies; the latter phase apparently reflects a downcutting Redwood Creek gaining direct access to the central cave system. An unusual mineralogy, locally rich in iron and copper, occurs in the schist, marble, and granite and is shown by the varied speleothemic and petromorphic mineralogy observed in the cave. A study of radon levels and stable isotope concentrations show poor circulation characterizes the present cave atmosphere, which has high concentrations of radon (3.0 Working Levels) and CO_2 (0.2%) gases. Seasonal variations in concentrations of these atmospheric gases reflect a "chimney" effect.

Résumé

La grotte de Lilburn, très complexe réseau à trois dimensions, mesurant environ 12 km, est creusée entirement dans un marbre feuilleté, par le cours d'eau souterrain de Redwood Canyon. Le marbre associe à d'autres roches sédimentaires metamorphisées constituent les roches encaissantes aux batholites de la Sierra Nevada. Le Service du Parcs Nationaux des Etats Unis protège la grotte de Lilburn à fin de recherches parce que l'étude pluridiciplinaire de la spéléologie de la grotte de Lilburn a apporté beaucoup d'informations pertinantes pour la connaissance de l'histoire naturelle de la région. L'orientation des diaclases du marbre et la pente hydrologique de la région sont subparallèles et sont responsables de l'orientation à 345° du réseau karstique. Cependant, l'orientation des chenaux ne correspond pas à des variations de composition en (Ca,Mg) CO_3 du marbre.

Les eaux souterraines ont une résurgence pulsée à Big Spring. Cette résurgence est située dans les roches encaissantes, en aval de Redwood Canyon, au contact du marbre et du schiste. L'exploration de la grotte de Lilburn permet d'accéder, en amont, à la zone de siphons donnant naissance aux écoulements pulsés. Les sédiments detritiques relèvent, d'abord, un episode sedimentaire pendant lequel des argiles limoneuses et des limons argileux se sont déposés. Ensuite, des sediments grossiers et granitiques ont rémpli la caverne. En accord avec les études paléomagnetiques, l'épisode à fins sediments a duré au moins huit au moins huit milles ans. Les dépôts grossiers sont associés avec le creusement de la partie centrale de la grotte par Redwood Creek. Nous n'avons pas d'âge radiometrique pour les sediments.

Une minéralogie particulaire, locallement riche en fer et en cuivre, existe dans le schiste, le marbre et le granite et ceci contrôle la minéralogie des formations karstiques obsérvées dans la grotte. Une étude des gaz et des isotopes stables indique que la ventilation de la grotte est assez mauvaise; l'atmosphére contient de fortes concentrations en radon (3,0 Working Levels et en CO_2 (0,3%). Les variations saisonnières observées dans les concentrations de ces gaz indiquent un effet de cheminée.

The Bedrock of Redwood Canyon

The local geology is similar to much of the southern Sierra Nevada. Cretaceous granitic batholiths described by Ross (1958) intrude and contain the pre-Cretaceous Redwood Mountain pendant. The pendant chiefly consists of foliated biotite quartz schist, pods of metachert and foliated marble. The marble has a distinctive appearance due to a foliation defined by alternating white to light gray bands and dark gray to black bands. Cave development is confined to the marble. The resurgence (Big Spring) occurs at a marble contact with schist. Granite dikes and schist contacts are exposed locally in the cave.

Subtle variations in composition and texture within soluble rock can affect cavern development (Rauch and White, 1970; Des Marais, 1971). Rogers measured Ca:Mg compositions and textures of 56 marble samples collected from surface and subsurface outcrops in Redwood Canyon. Table 1 and Figure 1 indicate the marble is chiefly almost pure calcite. The dolomitic portions tend to be finer-grained, darker and more carbon-rich. The four Ca:Mg compositional ranges appear to be distributed irregularly across the marble (Figure 1). Apparently the cave passages indiscriminantly traverse these broad domains; hence, marble composition does not appear to control the gross location or dimensions of this cave system.

Table 1. Marble compositions and grain sizes in Lilburn Cave.

Marble Type	No. of Samples	Percent Calcite	Grain Size, mm: Mean	Grain Size, mm: Range
Calcite	32	93 - 96	4.3	0.25 - 7
Magnesian Calcite	14	54 - 86	1.9[a]	0.25 - 5[a]
			1.4[b]	0.5 - 3.5[b]
Limy Dolomite	7	36 - 39	---	---
Dolomite	3	>6	2.5	0.25 - 9

[a]Calcite grains only. [b]Dolomite grains only.

Factors Controlling the Development of Lilburn Cave

Chiefly responsible for the distinctive orientation and character of the cave are: the groundwater gradient from north to south, the diversion of surface water via subterranean routes to Big Spring, and the orientations of fractures in the marble. For example, the lowest known levels in the cave are a set of subparallel braided tubes created by the large perennial ground water discharge that flows from north to south. A second set of upper level conduits chiefly consists of subrounded tubes, deep narrow canyons and occasionally pits 10-40 m deep which convey water into the cave from localized sources such as tributary valleys, hillslopes and ravines. The low-level tubes and many of the upper level conduits carry water during spring snowmelts or heavy precipitation. McCoy (these Proceedings) studied the orientation, spacing and extent of fractures in surface outcrops and in six passages selected as representative of the cave. A Rose diagram (Figure 2) illustrates how the dominant orientation (325°) of the subsurface fractures, which corresponds to the local structural grain of the Sierra Nevada, compares to the long dimension of Lilburn Cave (345°) and to the hydrologic gradient (345°-350°). These factors apparently cause the linera trend of the Lilburn system.

The Ebb and Flow of Big Spring

During seasonal rainfall or snowmelt, Big Spring becomes a periodic spring and exhibits intermittent short pulses of very high discharge. Such ebb and flow behavior has been reported elsewhere, including the Ozark region (Bridge, 1923). Inside Lilburn Cave, about 700 m north of the spring and about 10 m above it, we observe water rising slowly in a chamber while the spring discharge increases slowly (Figure 3). At a critical point, the water drains suddenly from the chamber and the spring discharge increases abruptly, sometimes tenfold or more. A decade of water level records reveals that the greater the discharge of Redwood Creek, the more frequently large discharges occur in groups rather than as isolated events. We favor an explanation whereby a system of siphons at different levels is activated by rising water to deliver the surge at Big Spring. The system operates when base flow exceeds the discharge capacity of a lower-level conduit that carries the entire flow during seasons when no surges occur. Observations and models of this hydrologic behavior promise to sharpen our understanding of this spring system.

Sedimentology

Central Lilburn Cave contains a sequence of three distinctive sedimentary deposits which are interpreted to record major changes in the evolution of this karst system (Tinsley, these Proceedings). The stratigraphically lowest sediments are chiefly thinly laminated rhythmites of micaceous silt, clayey silt, silty clay and clay rarely containing laminae of fine to very fine granitic sand. Ulfeldt and Packer (1977) conducted paleomagnetic studies of some of these deposits and concluded that deposition of these fine clastics lasted at least 8×10^3 years. Dissected conglomeratic deposits, composed of a matrix of granitic sand and clasts of stream-rounded gravels, cobbles and boulders, are derived from the Redwood Canyon drainage and overlie the rhythmites. The pervasive cementation, the bleached biotite grains and pervasive stains of iron oxides throughout the matrix distinguish the older coarse clastic unit from the texturally similar but uncemented, unleached young coarse clastics associated with the modern underfit streams.

We ascribe the older coarse clastic deposits to an episode of aggradation which occurred as a downcutting Redwood Creek gained direct access to the cave system. Anastomoses and ceiling channels and related modifications to phreatic passages developed as aggradation directed chemically aggressive water against the ceiling. If the ages of these deposits can be independently determined, we can identify the timing of these fundamental sedimentologic changes.

Mineral Deposits in Lilburn Cave

The close proximity of marble, schist, granite and the metal-bearing tactite has created a noteworthy collection of minerals as identified by B.W. Rogers. Common speleothemic minerals include calcite, aragonite, hydromagnesite and gypsum. Less common speleothemic minterals include azurite, birnessite, goethite, hematite, malachite, and witherite. Petromorphic minerals occur locally in the cave, chiefly in close proximity to the schist or granite and include axinite, azurite, bornite, chalcopyrite, diopside, goethite, hornblende, sepiolite, sphalerite, and tremolite.

Radon and CO_2 in the Cave Atmosphere

Measurements of radon, produced by natural decay of the element radium, and stable isotopes of carbon were performed to assist the NPS studies of the origin and abundance of radioactive substances in Park caves and to study the circulation of the cave's air. Observations made in Lilburn and in other Park caves are summarized below and in Table 2.

Carbon isotopic measurements of CO_2 from cave air ($\delta^{13}C_{PDB}$ = -21.1), soil ($\delta^{13}C_{PDB}$ = -20.8), dissolved bedrock ($\delta^{13}C_{PDB}$ = ~ 0), and cave waters ($\delta^{13}C_{PDB}$ = -12.5) indicate that the CO_2 derives almost exclusively from the biological activity in the forest soil. Measurements of radon levels at selected sites indicate that the cave sediments, the cave stream, and the forest soil are not principal sources of radon gas. The primary source of radon at Lilburn appears to be the decay of redium located in the marble bedrock. Concentrations of radon and CO_2 decrease among in-cave samples taken successively closer to Lilburn's entrances, or from Park caves which are shorter in length than Lilburn Cave. Radon and CO_2 are diluted by the exchange of cave air with surface air, and radon concentrations are especially sensitive to this dilution rate. The concentrations of radon and CO_2 attain their maximum values in late summer and their minimum values in late winter. The generally higher radon levels in Lilburn reflect the relatively weak chimney effect causing the rather slow rate of circulation of forest air through this cave compared to other park caves.

Significance of the Lilburn Cave Studies

Several immediate and practical benefits have accrued from the Lilburn research. For example, the radon measurements offer guidelines for controlling radiation exposure to future cave visitors. More importantly, the cataloging of rare features in Lilburn has heightened concern for the proper management of Lilburn and other park caves. Experienced scientists and laypersons are available and willing to assist the NPS in cave interpretation and in other responsibilities related to cave protection. Des Marais and others (in press) present an earlier, more detailed version of this paper.

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Table 2. Radon and CO_2 concentrations in caves within Sequoia and Kings Canyon National Parks.

Locality	Radon, W. L.[a] Range	Radon, W. L.[a] Median	CO_2 Percent[b] Range	CO_2 Percent[b] Median	$\delta^{13}C_{PDB}$
LILBURN CAVE					
Summer	2.3 - 4.2	3.2	0.17 - 0.30	0.23	-21.1 ± 0.2
Winter	2.1 - 3.2	2.7	0.12 - 0.13	0.13	-18.8 ± 0.2
Cave Sediment[c]	d	e	e	e	------
REDWOOD CANYON					
Air	0	0	0.03 - 0.04	0.035	-10.5 ± 0.2
Forest soil[c]	d	0.1	d	0.8	-20.8 ± 0.2
SOLDIERS CAVE					
Summer	0.9 - 2.2	1.7	0.20 - 0.21	0.21	-20.1 ± 0.2
Winter	e	e	d	0.05	-13.0 ± 0.2

[a] One Working Level is defined as any combination of radon daughters in one liter of air causing the ultimate emission of 1.3×10^5 Mev of alpha radiation energy.
[b] Per cent by volume of cave air.
[c] Prior to sampling, the pits were covered and allowed to equilibrate with the sediments.
[d] Only one locality sampled.
[e] Not measured.
[f] $\delta^{13}C_{PDB} = [(R_x/R_s) - 1]$ (1000) where R_x is the $^{13}C/^{12}C$ for the sample and R_s is the $^{13}C/^{12}C$ isotopic ratio for the PDB standard.

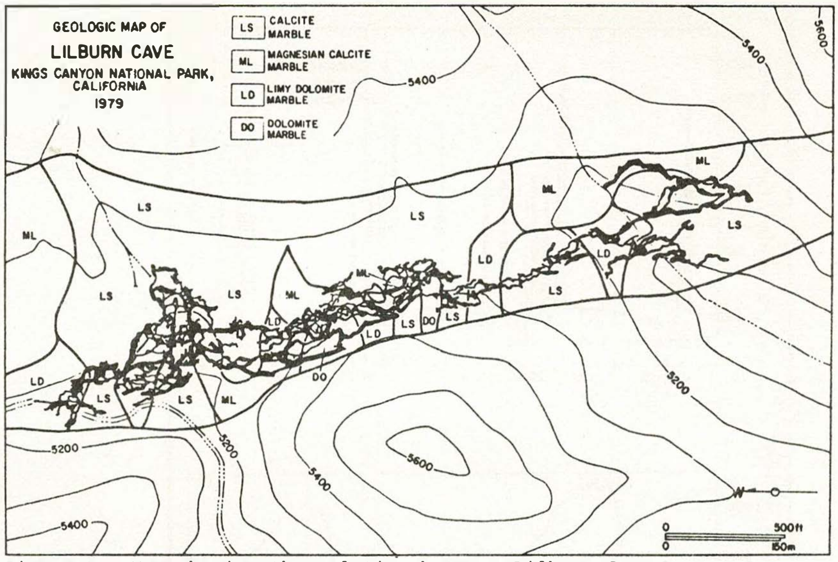

Figure 1. Map showing the relation between Lilburn Cave, the topography and variations in the composition of the marble in Redwood Canyon. The contour interval is 100 feet.

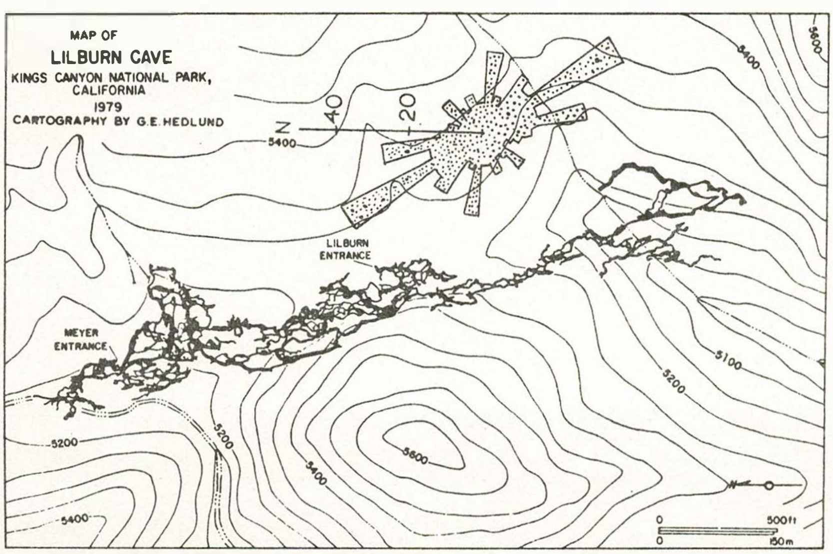

Figure 2. Rose diagram depicting orientations of all fractures measured in selected passages in Lilburn Cave in relation to the cave and the topography of Redwood Canyon. Contour interval is 50 feet. Fracture orientations are grouped in 10-degree increments of arc. The lengths of rays are proportional to the number of fractures per group.

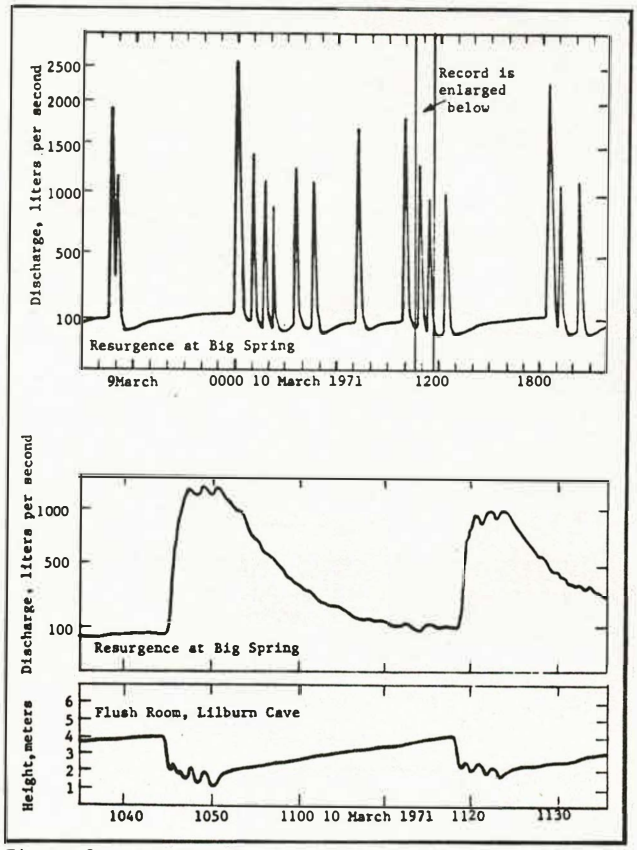

Figure 3. Ebb and flow behavior at Big Spring, Redwood Canyon, and the corresponding fluctuations in water level observed within Lilburn Cave.

Sedimentologic and Speleogenetic Implications of Clastic Deposits in Central Lilburn Cave, Kings Canyon National Parks, California, USA

J.C. Tinsley[1], D.R. Packer[2], and S.R. Ulfeldt[3]
[1]U.S. Geological Survey, 345 Middlefield Road m/s 75, Menlo Park, CA, USA 94025,
[2]Woodward-Clyde Consultants, 3 Embarcadero Center, Suite 700, San Francisco, CA, USA 94111, and
[3]Ulfeldt and Herring, Inc., 780 W. Grand Ave., Oakland, CA, USA 94612

Abstract

Sediments preserved in the central part of Lilburn Cave record at least three episodes of deposition and erosion. During the middle episode, passage morphology was altered substantially as the hydrologic and sedimentologic regimes changed fundamentally. The oldest strata are micaceous clayey silt and silty clay rhythmites that nowhere contain sediment more coarse than a few laminae of fine sand. This fine-grained character contrasts with the overlying second unit. The second unit is composed of coarse granitic sand, gravel, and cobbles, is often cemented with $CaCO_3$, and typically exhibits evidence of post-depositional weathering. The third unit is a younger coarse clastic deposit and is unweathered, uncemented and spatially associated with the modern cave streams.

Paleomagnetic studies indicate at least 8000 years passed during deposition of the rhythmites; on this basis, a sedimentation rate would be 55 mm/1000 years. Accordant elevations of the highest outcrops of the fine-grained strata indicate low-energy subaqueous conditions prevailed formerly in passages which now connect directly with the channel of Redwood Creek via vertical fissures choked with boulders and gravel. Passage geometry indicates these conduits could not have conveyed coarse sediment during deposition of the rhythmites.

The influx of coarse clastics filled many trunk passages and often caused chemically aggressive water and sediment to contact the ceiling. Extensive ceiling channels and anastomoses developed; many of these still contain remnants of the older coarse fill. The deposition of these older coarse clastics is thought to reflect downcutting of Redwood Creek and the breaching of these parts of the cave.

Résumé

Les sédiments détritiques deposés dans la partie centrale de la grotte de Lilburn indiquent au moins trois épisodes de dépôt et d'erosion. Le deuxième épisode a transformé la morphologie des conduits souterrains et a marqué un changement fondamental du régime hydrologique et sédimentologique. Les strates les plus anciennes sont des argiles limoneuses et des silts argileux micasses à fines stratifications containant de rares passées de sables fins. Cette fine texture s'oppose aux couches sus-jacentes, plus grossiers, à sable conglomératique domine par des sables arkosiques, souvent cimentés par $CaCO_3$. Des sediments grossiers plus récents, non climentés et non altérés constituent une troisième unité qui s'associe aux fleuves modernes.

Les études paléomagnetiques indiquent que au moins huit milles ans sont nécessaires pour déposer la sequence à sédiments fins. Le tau de sédimentation est approximent 55 mm/10^3 ans. Les plus hauts affleurements de l'unité fine ont une même altitude et indiquent des conditions de dépôt tranquilles et subaquatiques. Aujourd-hui ces mêmes conduits réunissent directement le cours souterrain avec le lit superficiel du torrent de Redwood Creek par des diaclases verticales. Pendant le dépôt des fines particules, ces conduits ne pouvaient pas fonctionnner commes ils le font aujourd-hui en charriant des débris à gros grain.

Le dépôt des fines sediments est suivi par l'invasion de détritus à gros grain; cet apport a remplit completement les conduits de large diamètres et localement a dirigé les eaux sous-saturees en $CaCO_3$ contre le plafond des conduits et beaucoup d'anastomoses se sont ainsi dévéloppées. Aujourd-hui, ces canaux contiennent encore des sédiments grossiers. Nous pensons que l'invasion des sédiments grossiers les plus anciens est associée au creusement intensif des strates par Redwood Creek, et au remblayage du reseau de la grotte.

Sedimentology and Stratigraphy

The stratigraphically lowest sediments are distinctive, thinly laminated rhythmites, chiefly composed of silt, clayey silt and silty clay, which occasionally contain thin laminae of fine to very fine granitic sand. Each pair of laminae consists of a lower, silty light-toned zone, which over a fraction of a millimeter, fines to an upper, darker, more clay-rich zone. These couplets appear almost varve-like. Remnants of the formerly extensive rhythmites always rest on bedrock--either on floors or on ledges. The rhythmites are overlain unconformably by the older of two coarse clastic deposits.

The old coarse clastic unit (OCC) chiefly consists of isolated conglomeratic deposits, commonly is cemented with $CaCO_3$, and often is encrusted with speleothems. The matrix is quartzo-feldspathic sand; clasts are stream-rounded phaneritic plutonics, quartzites and metacherts typical of the Redwood Creek basin. Eroded remnants of these deposits occur in alcoves and fissures and as fills within ceiling channels and anastomoses. The OCC unit exhibits cut-and-fill relations with, and overlies, the rhythmites. The weathering of lithic clasts, the matrix cementation, the bleached appearance of biotite grains and the pervasive stains of iron oxides throughout the matrix clearly distinguish the OCC unit from the texturally similar younger coarse clastic deposits.

The young coarse clastic deposits (YCC) have the same provenance and textures as the OCC unit. The YCC deposits occur along modern streams and in passages flooded historically. The general absence of cementation, of oxidation, and weathering of clasts and grains and the proximity to the present hydrologic regime distinguish this unit from the others.

Basin Analysis

We have mapped the distribution of the rhythmites. The highest localities at which rhythmites occur have identical elevations (±0.3 m) despite being widely separated in the cave. Sedimentologically similar rhythmites occur about 80 m subsurface in the Lake Room and River Room areas, 22 m below the highest rhythmite outcrops (Figure 1). The rhythmites occur in trunk passages that connect with the surface via vertical fissures through which coarse clastics presently enter the cave. The absence of coarse detritus in the rhythmites and the presence of coarse detritus (OCC) above the rhythmites indicates these major conduits have conveyed coarse detritus at some time after deposition of the rhythmites ensued. Thus we recognize a basin which, when active, included the Lower East Stream and Great Central passages, the Hexadendron Room, the Lake and River Room areas and their connectors (Figure 1).

Paleomagnetics

To investigate the age and stratigraphic relations within the rhythmites, we collected paleomagnetic samples from several cores from deposits throughout the basin. The declination of the earth's geomagnetic field has been shown to exhibit regular east-west fluctuations or swings, the periods of which are approximately 2000 years in the western USA (MacKereth, 1971; Creer, Anderson and Lewis, 1976). As fine-grained sediments accumulate, a record of the earth's magnetic field is produced by a process of detrital remanent magnetization (DRM). During the process of consolidation, magnetic particles which are oriented by the earth's field become fixed and record the direction of the magnetic field present at that time. This paleomagnetic record is read from a series of oriented samples from the sediments. The magnetization of each sample was measured in a 3-axis superconducting rock magnetometer; the samples were "cleaned" of possible subsequent remagnetization by using an alternating field demagnetizer and then remeasuring the sample. The level of demagnetization was increased at each step until the magnetic direction became stable.

Cores G and P from the River Room area, each about 40 cm long, were collected from visually correlatable rhythmites. As expected, these cores are highly correlatable sedimentologically and paleomagnetically and illustrate characteristics we might expect to recognize elsewhere and use as a correlation technique among the rhythmites. Figure 2 shows two swings in declination recorded by more than one sample in both cores G and P (G-28 cm, P-32 cm; G-8 cm, P-10 cm). These swings occur about 20 cm apart and the declinations of the selected DRM levels of these swings are 30°. The general pattern of lesser declination variations also corresponds very well. There are two swings to higher inclinations of approximately 60° (G-25 cm; P-30 cm). Lesser variations in inclination generally are correlatable, but are not as similar between cores as the lesser variations in declination. Intensity of magnetization rarely varies from a relatively strongly magnetized 10^{-4} emu/cm^3.

Visual sedimentological characteristics--grain size and color--are broadly correlative. Other correlative features include the occurrence of sand partings 1 cm thick, a reddish-brown zone about 20 cm thick, and the locations of laminae and the proportions of light to dark laminae in the two cores G and P. The correspondence of the swings in declination and inclination and the distinctive sedimentologic features suggest that these two cores are time correlative within the limits of resolution of the paleomagnetic data. From these results we might expect similar paleomagnetic fingerprints from other rhythmite deposits in the cave.

The upper 2/3's of cores J and N from the Lake Room area show good paleomagnetic and sedimentologic correlations. The lower 1/3's of both these cores are only broadly similar; moreover, the inclination of 65°-75° in the lower 1/3 of core N, is not observed in any of the other cores.

Although none of the swings in declination and inclination are obviously related to slumping, twisting or other potential deformation of these deposits, no site to conduct a fold test or other test have been located to improve our confidence in the correlations of swings discussed above.

There are at least four swings in declination in the paleomagnetic record at Lilburn Cave. If these swings represent continuously deposited sediments, at least 8 x 10^3 years are represented in these cores. With these assumptions a gross mean sedimentation rate would be 55 mm/1000 years. If the paleomagnetic studies are correct, the laminae cannot be annual accumulations, because the number of observed couplets is far less than the number of years implied by the paleomagnetic data.

Conclusions

Mapping has shown that the three depositional units present in central Lilburn Cave can be explained by a basin model. These three units probably reflect at least three episodes of speleogenesis and account for the sequence of breaching and the development of the complex anastomoses in the ceiling of major passages. The paleomagnetic results indicate a good record of magnetic variations in the rhythmites and indicate a complex history spanning at least 8 x 10^3 years. At this stage of our investigation, the observed variations hold promise that we can correlate the various widely separated rhythmite deposits by their paleomagnetic signatures. These signatures hint at a complex history. This history may include multiple depositional episodes, which are not apparent from relative stratigraphic positions, or missing section, which are not apparent from the gross sedimentologic features of the rhythmites. Studies of additional cores may provide records to enable us to evaluate the total amount of time these deposits represent, as well as to correlate amont them. In addition, it may be possible to correlate them with as yet poorly established chronologies of paleomagnetic secular variations in western North America.

Acknowledgements

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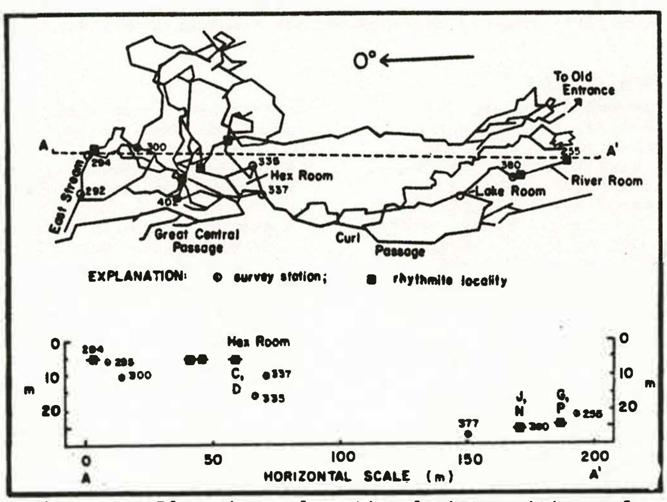

Figure 1. Plan view and section depict positions of selected rhythmite localities and nearby survey stations. Station 292 is assumed to be 0 for the profile; Station 335 is floor of Hex Room.

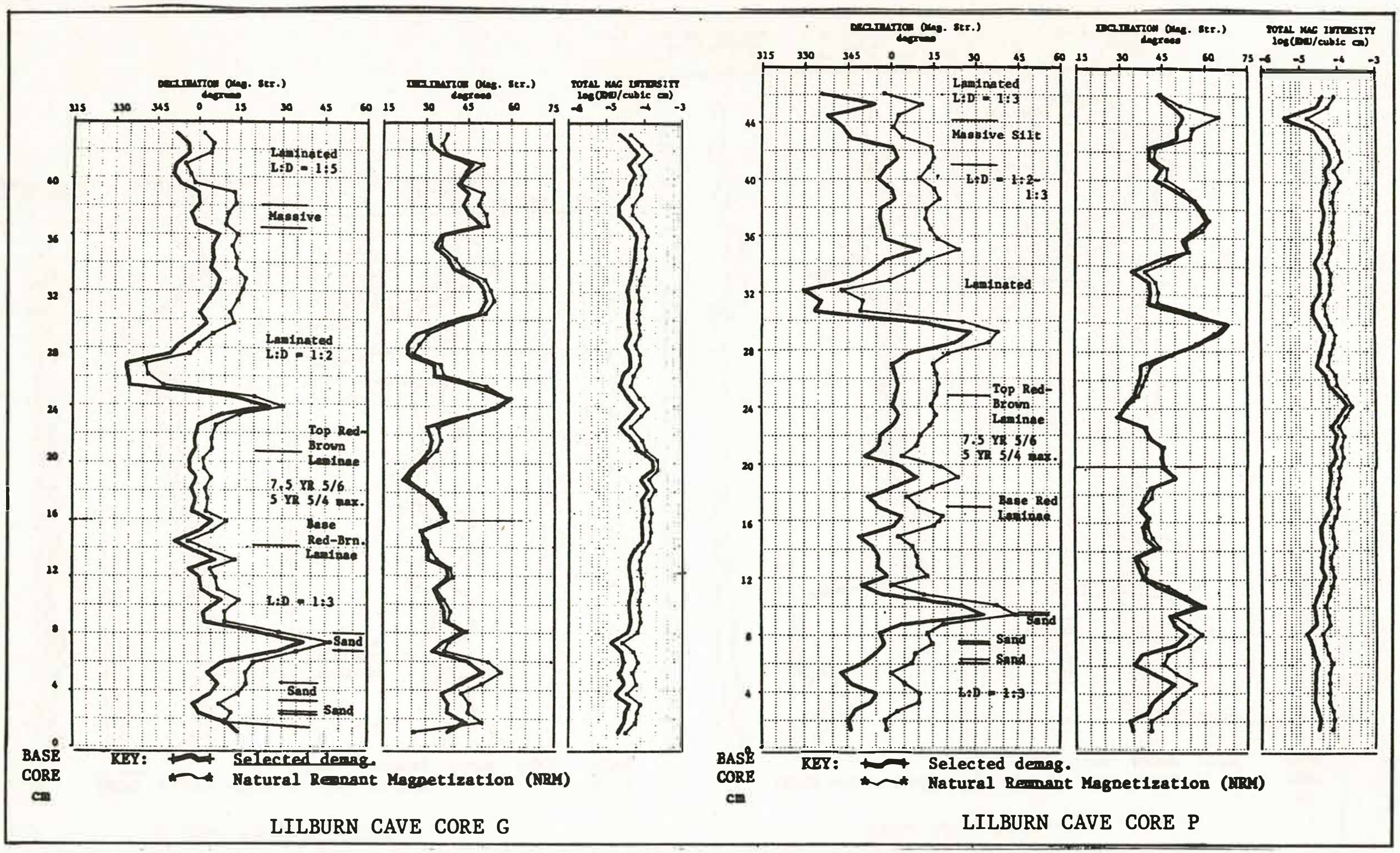

Figure 2. Cores G and P from the River Room show strongly correlatable paleomagnetic measurements. The annotation L:D denotes thickness ration of light (2.5 Y 5/5) laminae to dark (2.5 Y 3/2) laminae. Munsell notation describes moist colors of sediment.

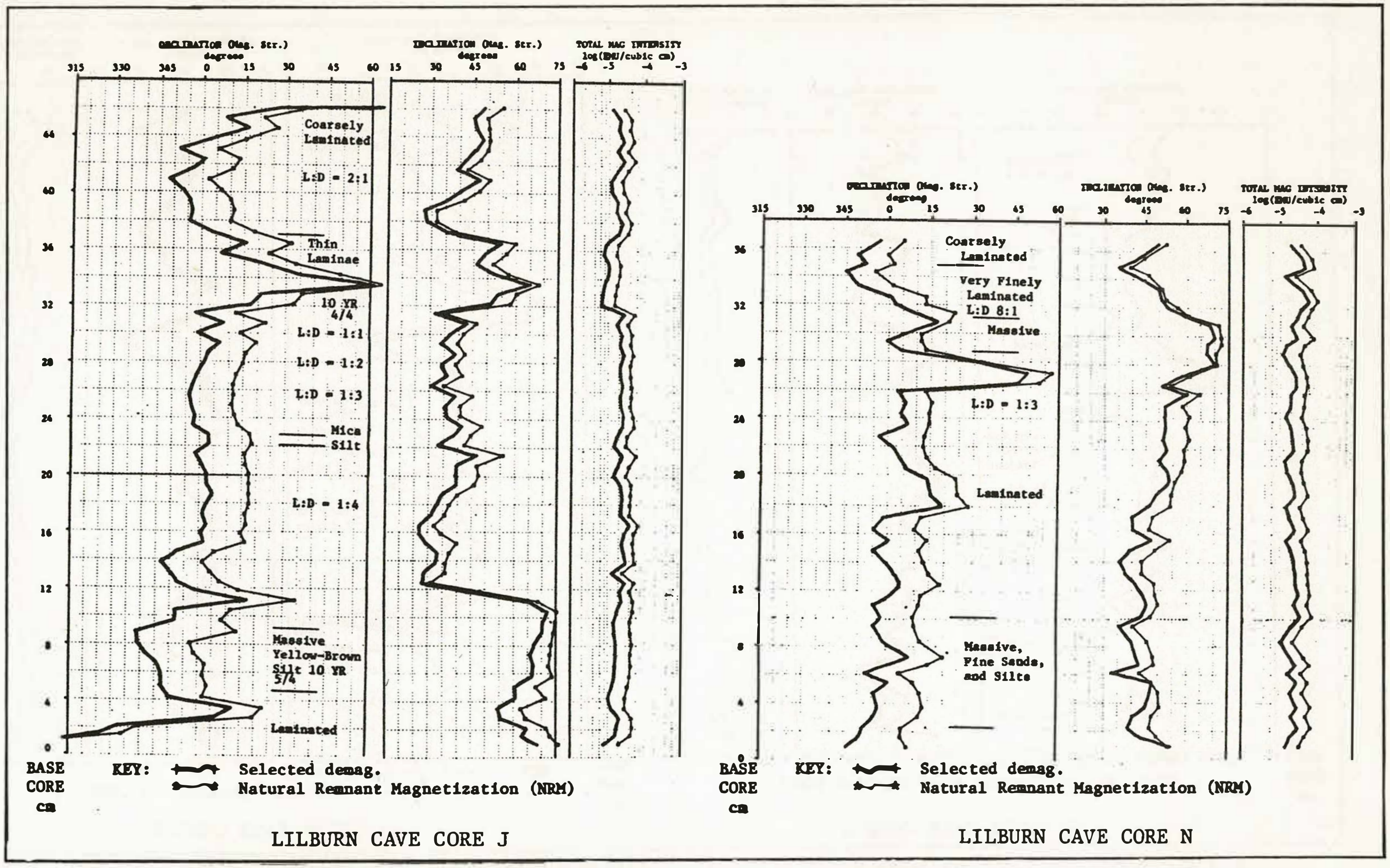

Figure 3. Cores J and N from the Lake Room area correlate well in the upper 2/3's of the section, but do not correlate well in the lower 1/3. The annotation L:D denotes thickness ration of light (2.5 Y 5/5) laminae to dark (2.5 Y 3/2) laminae. Munsell notation describes moist colors of sediment.

A Critique of the Analogy Between Caves and Islands

Rodney L. Crawford
Thomas Burke Memorial Wasington State Museum, University of Washington, Seattle WA 98195

Abstract

Troglobites in caves show few characteristics of island faunas. Caves per se are less favorable envrionments for subterranean fauna than surrounding smaller spaces. Buitable small-space habitats are vastly greater in extend than suitable habitat within caves. It is unlikely that colonists of caves origiante from other caves, as required by the island analogy. Even the largest "troglotites" are able to inhabit the interconnected small spaces between caves and there is evidence that they do so. For obligate subterranean fauna, caves constitute interruptions in the favored environment, which contain smaller, insular habitable patches.

Zusammenfassung

Troglobionten in Höhlen zeigen wenige der Eigenschaften von Inselfauna. Höhlen an sich sind weniger gunstige Umgebungen für unterirdische Fauna als kleinere Räume in der näheren Umgebung. Geeignete Lebensräume mit kleinen Abmessungen sind viel häugfiger und weiter verbreitet als geeignete Lebensräume innerhalb von Höhlen. Es ist unwahrscheinlich dass die Besiedler einer Höhle von den Besiedlern einer anderen Höhle abstammen, wie es von der Insalanalogie postuliert wird. Sogar die grössten "Troglobionten" können die kleinen, in Verbindung stehenden Zwischenräume bewohnen. Es gibt genügend Beweise dass sie dies tatsächlich tun. Für obligate unterirdische Fauna stellen die Höhlen Unterbrechungen in der bevorsugten Umgebung dar, welche kleinere bewochnbare Gebiete mit Inselcharakter beinhalten.

Introduction

Many attempts have been made to apply the dynamic equilibrium theory of island biogeography (McArthur and Wilson 1967) to discontinuous habitats within continents. Vuilleumier (1970), Sepkoski and Rex (1974), and Gottfried (1979), among others, have shown that in some cases the island analogy holds up very well; but Brown (1971), Smith (1979), and Tepedino and Stanton (1976) found continental habitats showing serious divergences from the island model. An island analogy for troglobites in caves was formally proposed by Culver (1970a, 1971b) and Vuilleumier (1973), but such an assumption is implicit in the work of many other authors, particularly those writing on troglobite evolution. The innovation proposed in the paers by Culver and Vuilleumier is application of the MacArthur and Wilson theory to troglobite species diversity. This theory views species numbers on an island as the result of a balance between immigration and extinction. In many cases such a balance could exist in an area with arbitrary boundaries, however, and is thus insufficient in itself to prove an island analogy. The most distinctive features of species numbers on islands as opposed to those on continents are (MacArthur, 1972):

1) Equilibrium number of species on an island is much smaller than that of a similar area on a continent (Faunal Depauperation).

2) While species numbers remain farily stable, species composition on an island may change radically over time (Faunal Instability).

3) Greater distance of an island from sources of colonists lowers the equilibrium number by decreasing immigration (Distance Effect).

4) Greater area of an island increases equilibrium number (at a greater rate than on continent) by both increasing immigration and decreasing extinction (Area Effect).

5) Endemic species tend to evolve on islands due to the effects of isolation, small size of founding populations, and simplified ecosystems (MacAruthur and Wilson, 1967; Uvardy, 1969) (Island Evolution). As such evolution occurs, the species equilibrium number increases (MacArthur, 1972).

Faunal depauperation has been claimed for troglobites in caves (e.g. Culver 1971b, 1976), but I question whether such a statement is meaningful without comparing cave faunas to some continent-like habitat containing troglobites. Such a comparison has not been made. Faunal instability undoubtedly occurs in caves (Culver 1970a, 1973), but may be better explained by the insular character of habitable patches within caves than by insularity of entire caves (see further below). Distance and area effects, essential to the argument, have not been demonstrated for troglobites in caves (Culver, 1970a, 1971b; Vuilleumier, 1973, Culver et al, 1974).

It has been assumed that troglobite evolution is a case of island evolution (e.g. by Barr, 1968). However, little evidence has been presented that troglobites evolution has occurred exclusively or even mainly in caves rather than in the surrounding systems of smaller connected spaces.

Thus, troglobites in caves exhibit few of the phenomena associated with island faunas. To see why thi is so, it will be helpful to consider the nature of an island more explicitly than has been done by most biogeographers (for example MacArthur and Wilson, 1967, under "qualities of islands," simply list small size, barriers to dispersal, and altered climatic variability). The following criteria must apply to any specific taxonomic or ecological group whose distribution is being considered, though not necessarily to other groups in the same habitats:

1) An island is a region (unit) of environment favorable to survival, reproduction, and maintenance or increase of population.

2) Islands are surrounded by an environment which is unfavorable for some or all of the above, and therefore constitutes a barrier to disperal both between islands and from any continent-like source area to islands.

3) Because of (2), all colonists of an island must originate from other islands or mainlands, and cross the entire width of intervening dispersal barrier as individuals.

4) Because of (2) and (3) above, the only significant populations of the organisms in question will be on the mainland or islands.

As I hope to show in the following discussion, troglobitic animals in caves fulfill none of the above four criteria. The arguments refer primarily to aquatic fauna, but some are equally applicable to terrestrial species.

Terminology

A cave is a natural subterranean cavity, large enough for human penetration, with some portion in essentially total darkness (Halliday, 1974). Some lower size limit must be adopted if the concept of "cave" as a discrete entity is to have any meaning, and that of penetration is the one most often accepted or assumed. The terms troglobite, troglophile, referring to animals assumed to be cave-limited, are inappropriate for species populating cavities smaller than caves. For groundwater fauna, the terms stygobiont, stygophile (Thienemann, 1926), referring to all groundwater rather than just that in caves, are preferable. The term interstitial habitat is properly restricted to space between grains of sediments (in hydrological language, the primary porosity). Husmann (1966) introduced the terms petrostygal to refer to habitable spaces in fractured rocks (secondary prorosity). Both types of small-space habitat are available in limestone and lave care areas, the former in overlying, in-cave, and interbedded sediments, the latter in the host rock itself. Limestone aquifers are of two types: free-flow, consisting of integrated conduit drainage newtworks, and diffuse, consisting of water in solution-enlarged joints, bedding planes, anastomoses, and other small spaces, whose flow characteristics are more like those of non-karstic aquifers (White, 1969). Active stream caves are the accessible portions of free-flow aquifers.

Discussion

The following points illustrate the dissimilarity of caves and islands for stygobionts:

1. There are many reasons to believe that caves do not present optimal living conditions for stygobionts, including most if not all of those previsously assumed to be cave-limited. As is well known, most marine interstitial species show specific pore/grain

size preferences and are seldom found in larger, as well as smaller, spaces (Remane, 1940, 1952; Swedmark, 1957; Wieser, 1959). Husmann (1967) discussed the occurence of this phenomenon in continental groundwater, both interstital and petrostygal, and introduced the zonological isolation concept. Simple stated, zonological isolation predicts that small subterranean annimals are partially excluded from cavities much lager than themselves, due to predation and competition by larger organisms. Thus, adjacent habitats with different pore size will have different faunas. Caves *per se* provide no such isolation, and the principle predicts that stygobionts in caves would occur mainly in insular patches of interstital habitat such as gravel beds, and such localities as rimstone pools where they are isolated from other organisms. This is what has been observed. Culver (1970b) showed that there is fierce competition for interstitial niches in cave streams; Lescher-Montoue and Gourbault (1970), studying 14 stogobiont species in a French cave, found that only two occurred significantly outside of interstitial patches.

Zoological isolation remainds to be rigorously tested, many additional factors reduce the habitability of caves to stygogionts. Cave streams are better regarded as extensions of surface streams than as groundwater, both hydologically (White, 1969) and biologically, since surface debris and organisms wash in through stream ponors; the free-flow conditions provide another point of resemblance to surface streams. Thus, highly adapted stygobionts are often out-competed in cave stream habitats by stygophiles which are able to disperse through surface waters and retain some characteristics of their presumptive epigen ancestors. For example, Culber (1970b) showed that the stygophile amphipod *Gammarus minus* competetively excludes stygobiont crustaceans of similar size. A smaller amphipod was not excluded due to its preference for smaller interstitial spaces; a clear case of zonological isolation. Stygobionts in cave streams lack protection against predators originating in surface water. Thus, Briegleb (1962) found that *Proteus* (styobiont salamanders) were excluded from large portions of the Postojna cave streams by the presence of epigen predators. Briegleb also found evidence that juvenile *Proteus* less than 17 cm long were excluded from caves in petrostygal water, possibly due to their sensitivity to bacteria of surface origin, more common in cave streams than in diffuse groundwater. Finally, according to Culver (1971a, 1973), washout due to current is the main cause of mortality in cave streams Crustacea. Living in diffuse groundwater would be the best protective against washout.

2. The medium separating caves does not constitute a less habitable or inhabitable dispersal barrier, as assumed by the "caves as islands" analogy: "Islands are separated by water and caves are separated by limestone" (Culver 1971b). Several aspects of the inter-cave medium must here be considered: its penetrability, the availability of food, and comparative extent of cave and inter-cave habitable spaces. This applies only to caves in different free-flow aquifers; clearly, caves beloning to the same conduit network are not distinct entities for small aquatic animals.

The pentrability of diffuse groundwater throughout cave areas (and in many cases between separate cave areas) is shown by the extensive distribution of many stygobiont animals, even those as large as amblyopsid fish (see discussion in Woods and Inger, 1957). Food chains in diffuse groundwater are probably based on bacterial films living on dissolved exogenous organic matter, and possibly also on the organic component of silt; Jefferson (1976) showed that such food sources can support dense populations of stygobiont Crustacea. The relative volumes of conduit and diffuse groundwater storage is a given karstic spring catchment can be estimated from parameters of the spring discharge. European investigators (Drogue, 1963; Schoeller, 1967; Smith et al., 1976) in seven such determinations found diffuse storage ranging from 49% to 97% of total storage, averaging 76%. In addition, cave areas may contain large diffuse aquifers hydrologically independent from conduits, as reported by Ogden (1978) for the Greenbrier karst, West Virginia. The disparity in habitable space between diffuse and free-flow groundwater is even greater than these figures suggest because less of the conduit storage is in contact with walls or floor, and few styobionts are pelagic.

3. An analogy between caves and islnads implies that immigrants to one cave originated in other caves. Culver (1971b) assumes this explicitly. But if caves are surrounded by stygobiont populations in diffuse groundwater, these are the likeliest source of colonists for habitable patches within caves. Moreover, if the nature of connections between smaller water-filled joints is judged by the maze-like pattern of joint-controlled caves, passage of small animals over inter-cave distances in petrostygal water might take a long time, perhaps several generations. Faults and other discontinuities betweem permeable strata would further lengthen the time required.

4. Finally, it is unlikely that stygobionts have their most significant populations in caves because of the far greater quantity of habitat in diffuse groundwater. Aslo, stygobionts readily colonize rimstone pools and artificial containments in caves via seepts or trickles of vadose water passing through interstitial or petrostygal spaces (Culver, 1970a; Holsinger, 1969); three of the four crustacean species studied by Culver (1970a) were regularly present in rimstone pools, and the exception Gammarus minus, is not a stygobiont. It has been assumed that such colonists were transients through the vadose zone, originating in phreatic groundwater. However, Henry (1979) presented evidence that stygbiont isopods may have dense populations in zones of permanent seepage above the water table, where growth of bacterial fims would be greatest.

Culver (1970a) concluded that stygobiont populations in caves were more significant than those in "non-cave subsurface habitats" because of the low number of immigrants in rimstone pools, compared to the size of populations in cave streams. This, however, simply indicates that noncave vadose populations in cave streams. This, however, simply indicates that non-cave vadose populations are widely spaced and resist dislodgment, and ignores continuous ingress via diffuse groundwater sources of cave streams. The latter is well illustrated in Deadhorse Cave, Washington, where the diffuse sources of the cave stream contribute on the order of the 10 *Salmasellus* sp. (an isopod, the cave's most abundant stygobiont) per day, compared with a cave "population" that probably never exceeds 50 (Crawford, unpublished data).

Despite Vandel's (1965) statement to the contrary, larger stygobiont species are also at home in diffuse groundwater. Vandel himsel (1961) found experimentally that adult *Proteus* salamanders show preference for petrostygal spaces, "being held there by a very marked desire to maintain contact with solid surfaces." The exculsion of immature *Proteus* from open cave waters found by Briegleb (1962) was discussed above. Poulson (1963) also found anomalously low numbers of immatures in cave populations of amblyopsid fish, which suggests a similar exclusion. The Australian stygobiont fish *Milyeringa veritas*, similar in size and shape to the amblyopsids, is found exclusively in petrostygal water, to which it is well adapted (Mees, 1962). Husmann (1967) cites other examples.

Conclusions

Island biogeography may sometimes be applicable to subterranean fauna, but caves are not insular units for such fauna. The concept of "caves as islands" for "troglobites" reflects an anthropomorphic bias, caves being the primary points of human access to the subterranean envioronment. There may be insular karst regions which contain caves (as shown for terrestrial, but is not aquatic, fauna by Culver et al 1974) or insular habitable patches within caves, but caves themselves are local discontinuities in the widespread and interconnected habitat of stygobionts. Caves *per se* may, however, display insular characteristics in relaion to obligate trogloxenes such as certain bats, camel crikets, and grylloblattids, which require the surface access which a cave entrance provides. Vuilleumier (1974) found that total cave faunas did show an area effect, though "troglobites" did not.

Many testable predictions are possible on the basis of the above discussion. For example, cave streams with diffuse sources should have more stygobiont species than swallet caves, and caves in more permeable rock should have more stygobiont species than caves in less permeable rock, regardless of whether there are other caves nearby, Questions of groundwater ecology have been neglected in the United States, though actively pursued in Europe. Elucidation of valid principles of subterranean biogeography will require coordinated research in bioloyg, geology, and hydrology. This paper will have served its purpose if it helps to stimulate such research.

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Preliminary Report On the Biology of Sorcerer's Cave, Texas (U.S.A.)

Rodney L. Crawford
Thomas Burke Memorial Washington State Museum
University of Washington, Seattle WA 98195

and

George Veni
243 Saratoga,
San Antonio, TX 78213

Abstract

Sorcerer's Cave, Terrell County, is the deepest cave known in Texas (depth 170 m). A series of pits and short passages give access to a large underground river explored for 1.8 kn. Environments include dry, moist, and semi-liquid guano; soil, clay, sand, or roch substrates; and standing or running water. A large summer colony of the bat Myotis velifer roosts at unusual depth, 88 m below the entrance. Whipsnakes, Masticophis sp., regularly occupy one site in the dark zone and prey on bats. Twenty-six arthropod species have been collected, including five terrestrial troglobites and one groundwater isopod. Anthropod diversity is highest at two sites, owing to presence of moisture in one case and an ecotone effect in the other.

Zusammenfassung

Sorcerer's Cave in Terrell County is die tiefste bekannte Höhle in Texas (Tiefe 170 m). Eine Reihe von Schachten und kurzen Passagen erlaubt den Zugang su einem grossen unterirdischen Fluss, der auf eine Länge von 1,8 km erforscht ist. Die Umweltbedingungen bieten trockenen, feuchten und halbflüssigen Guano, erdigen, lehmigen, sandigen oder felsigen Untergrund, ferner stehende oder fliessende Gewässer. Eine grosse Sommer-kolonie der fledermaus Myotis velifer nistet in ungewöhnlicher Tiefe, 88 m unterhalb des Eingangs. Exemplare der Peitschenschlange, Masticophis sp., halten sich regelmässig in der dunkeln Zone auf und ernähren sich von Fledermäusen. Sechsundzwanzig Arten von Arthropoden sind gesammelt vorden, darunter fünf terrestrische Troglobionten und ein Grundwasser Isopod. Die Verschiedenartigkeit der Anthropoden ist an zwei Stellen be-sonders ausepgrägt, dan der Anwesenheit von Feuchtigkeit in einem Falle und infolge eines Ökotone Effektes in anderen.

Introduction

Sorcerer's Cave is located in central Terrell County, southwestern Texas, in the Stockton Plateau karst region. The site is in the semi-arid northern fringe of the Chichuahan Desert (Shelford, 1963). Extrapolating from geologic mapping 20 km to the south (Sharps, 1964; revised nomenclature from Smith 1970), the cave is developed under the relatively impermeable Del Rio Clay in the lower Cretaceous Santa Eleno Limestone and possibly the underlying Sue Peaks Formation.

Sorcerer's Cave begins as a sequence of short passages and rooms at successively greater depths connected by pits (see Fig. 1). The final pit leads, via a small tributary, into a large, permanent underground stream, the Sirion River, which has been explored downstream for 1.2 km to a point some 170 m below the entrance, making this the deepest cave presently known in Texas (Veni, 1980).

The following report is based on limited biological collecting and observation during 1978, 1979, and 1980. Field work was done by Veni, assisted by other members of the Texas Speleological Assocation. Taxonomic determinations are by Crawford except where otherwise acknowledged.

Environments Within the Cave

Named passages, rooms, and pits cited below are all indicated in Fig. 1. The upstream portion of the Sirion River and the new "Apprentice" section of the upper cave have not been studied biologically and are not discussed here.

Substrate composition: Bat guano, typically 0.2-0.3 m deep, is present all along the direct flight path between the entrance and the bat roosts in the Sanctum Sanctorum and New Room. Surface alluvium and organic debris occur up to 55 m from the entrance. Guano is absent in the Dragon's Den and Illusion Room, and pathily distributed in the Inner Sanctum and Travertine Tripway. Substrates in these areas include soil, sand, gravel, and clay. The River Pit and Stream Passage are floored with sandy silt up to 0.6 m deep, enriched by suspended guano particles in seepage water from the overlying Sanctum Sanctorum.

Moisture: The upper cave as far as Poltergeist Pit is dry and dusty, except in the Illusion Room and Dragon's Den which are periodically moistened by seepage. From Poltergeist Pit to Demon Drop there is minimal but detectable moisture. The floor of Demon Drop is very moist, and guano floors in the Bubble Passage, New Room, Inner Sanctum, and Sanctum Sanctorum range from very moist to semi-liquid.

Aquatic habitats: Most of the Bubble Passages contains a 1 m deep deposit of semi-liquid guano overlain by 0.2-0.3 m of clear water. There are pools in the Inner Sanctum, Travertine Tripway, and on the floor of the River Pit. The Stream Passage and Sirion River contain permanent streams of clear water, the latter with flow estimated at 190 liters/sec, increasing to 250 liters/sec about 10 days after heavy rainfall. Air and water temperatures near Sump 1 were 24.5^{o} C. in May 1980, in contrast with the annual surface average of 17.8^{o}C. cited by Schmidly (1977).

Vertebrate Fauna

Bats: Sorcerer's Cave houses a large summer colony of the Cave Myotis, Myotis velifer (J.A. Allen) (family Vespertilionidae), roughly estimated at 5,000 individuals. Their primary roosting site, 20 m above the floor of the Sanctum Sanctorum, is the deepest bat roost in Texas at 88 m below the entrance. Bats occasionally roost in the Inner Sanctum (1-4 m above floor) and New Room (7-8 m above floor) and in August 1980 a few were seen at the top of Poltergeist Pit. They feed in the cave's immediate vicinity. Constrictions in their flight path force bats to enter and exit the cave singly or in small groups. Myotis are absent from late November through early March; their hibernation sites are unknown.

Dead Myotis are usually found only below their permanent roost in the Sanctum Sanctorum. However, in August 1980 hundreds of dead individuals were noted in teh upper portion of the cave, chiefly from the floor of Witch's Well to the floor of Poltergeist Pit and in the Dungeon (see Fig. 1). This mortality was correlated with unusually high surface temperatures, which may have affected the bats directly or by depleting their water or insect food resources. At this time 4-5 dead specimens of the Ghost-faced Bat, Mormoops megalophylla (Peters) (family Mormoopidae), were collected in the passage leading from Witch's Well to the Illusion Room. Living Mormoops have not been seen in Sorcerer's Cave; prior to this record the species had not been recorded from Terrell County (Schmidly, 1977).

Snakes: One site, a small natural bridge 5 m up in a high vertical fissure leading into Poltergeist Pit, is frequently occupied by Whipsnakes, Masticophis sp. (family Colubridae). One observed there in October 1978 was killed; at least one other individual occupied the site on three later occasions; in August 1979 and May and August 1980. During two observation periods of nine and seven days the snake was intermittently present and absent. This site, in the dark zone, appears inaccessible and we cannot explain the snakes' apparent ease of access. There is little doubt that the snakes prey on bats, many of which must land on the natural bridge due to congestion while flying in and out of the cave.

Invertebrate Fauna

Twenty-six arthropod species have been collected in Sorcerer's Cave and are listed below in taxonomic order, with notes where appropriate.

Class INSECTA

Order THYSANURA: family NICOLETIIDAE: Texoreddellia texensis (Ulrich). This troglobite occurs in caves throughout central Texas (Reddell, 1966; Wygodzinsky, 1973).

Order COLLEMBOLA: family ENTOMOBRYIDAE: Pseudosinella sp. An apparent troglobite, found associated with guano.

Order ORTHOPTERA: family GRYLLACRIDIDAE: Ceuthophilus sp. An unidentified Ceuthophlius, possibly undescribed, is abundant on walls in the upper portion of the cave; a record from Sump 1 may represent a second species.

Order BLATTARIA: family POLYPHAGIDAE: Arenivaga erratica (Rehn). Sand cockroaches.

Order HEMIPTERA: family VELIIDAE: Microvelia beameri McKinstry. these small water treaders, not previously found in Texan caves, occur only in the Bubble Passage from Demon Drop to the Island.

Order PSOCOPTERA: two undetermined wingless species.

Order COLEOPTERA: family CARABIDAE: Rhadine howdeni (Barr and Lawrence). A characteristic predator of the guano-based community (Reddell, 1966). Tachys sp. Also collected from guano.

Family TENEBRIONIDAE: Xylopinus sp. This large Tenebrionid is abundant on floors in the upper passages.

Family SCARABAEIDAE: Trox sp. One dead specimen found buried in guano.

Family STAPHYLINIDAE: one undetermined species of the subfamily Aleocharinae found associated with guano.

Family HISTERIDAE: one undetermined species of the subfamily Histerinae found associated with guano.

Family MELYRIDAE: one undetermined species of the subfamily Malachiinae.

Order DIPTERA: family PHORIDAE: one undetermined species found associated with guano.

Class ARACHNIDA

Order ACARIDA: family ARGASIDAE: one undetermined tick, probable bat parasite.

Two additional mite species, of undetermined family, have been collected.

Order CHERNETIDA (=PSEUDOSCORPIONES): family CHERNETIDAE: one undetermined pseudoscorpion species was found mainly on or near dry decomposing organic material such as rope, brances, and cardboard.

Order PHALANGIDA (=OPILIONES); family PHALANGODIDAE: Texella, nov. sp. This undescribed troglobite has very limited occurrence within the cave.

Order ARANEIDA: family LEPTONETIDAE: one immature speciment in twilight zone.

Family LOXOSCELIDAE: Loxosceles sp. One immature specimen in twilight zone.

Family PHOLCIDAE: Psysocyclus enaulus Crosby. A common troglophile with webs in small cavities and wall irregularities, usually within 1-5 m of the floor but some high in domepit walls.

Family NESTICIDAE: Nesticus pallidus Emerton. This widespread troglophile has been recorded from under rocks (Reddell, 1965), but in Sorcerer's Cave makes fine webs in irregularities in guano found by slumping or footprints.

Class DIPLOPODA

Order CAMBALIDA: family CAMBALIDAE: Cambala speobia (Chamberlin). The most widespread of Texan troglobites (Reddell, 1965). Usually but not always found associated with guano; some dead individuals found buried in guano.

Class CRUSTACEA

Order ISOPODA: family CIROLANIDAE: Cirolanides texensis Benedict. This stygobiont isopod is widespread in groundwater habitats of central Texas. Specimens have been seen in Sorcerer's Cave only three times: in the River Pit and Stream Passage in October and November 1978, and 300 m downstream in the Sirion River in August 1980.

Discussion

Known occurrence of each species within the cave is summarized by Fig. 2. Lowest arthropod species diversity is found on the semi-liquid guano substrates in the Bubble Passage and portions of the Inner Sanctum and Sanctum Sanctorum. The inhospitable Bubble Passage effectively prevents epigen invertebrates from penetrating further into the cave. Of 20 trogloxenic or trglophillic species, only three have been noted past this barrier. However, three of the five terrestrial troglobites occur on both sides of the Bubble Passage. The floor of Demon Crop forms an ecotone between these two groups, and with twelve species shows the second greatest anthropod diversity in the cave. The greatest diversity, thirteen species in the Illusion Room/Guano Drop area, may be due to the presence of moisture in an otherwise dry area, combined with proximity to the entrance.

Biological research is continuing at Sorcerer's Cave and we anticipate the discovery of many additional species in this rich and diverse subterranean ecosystems.

Acknowledgements

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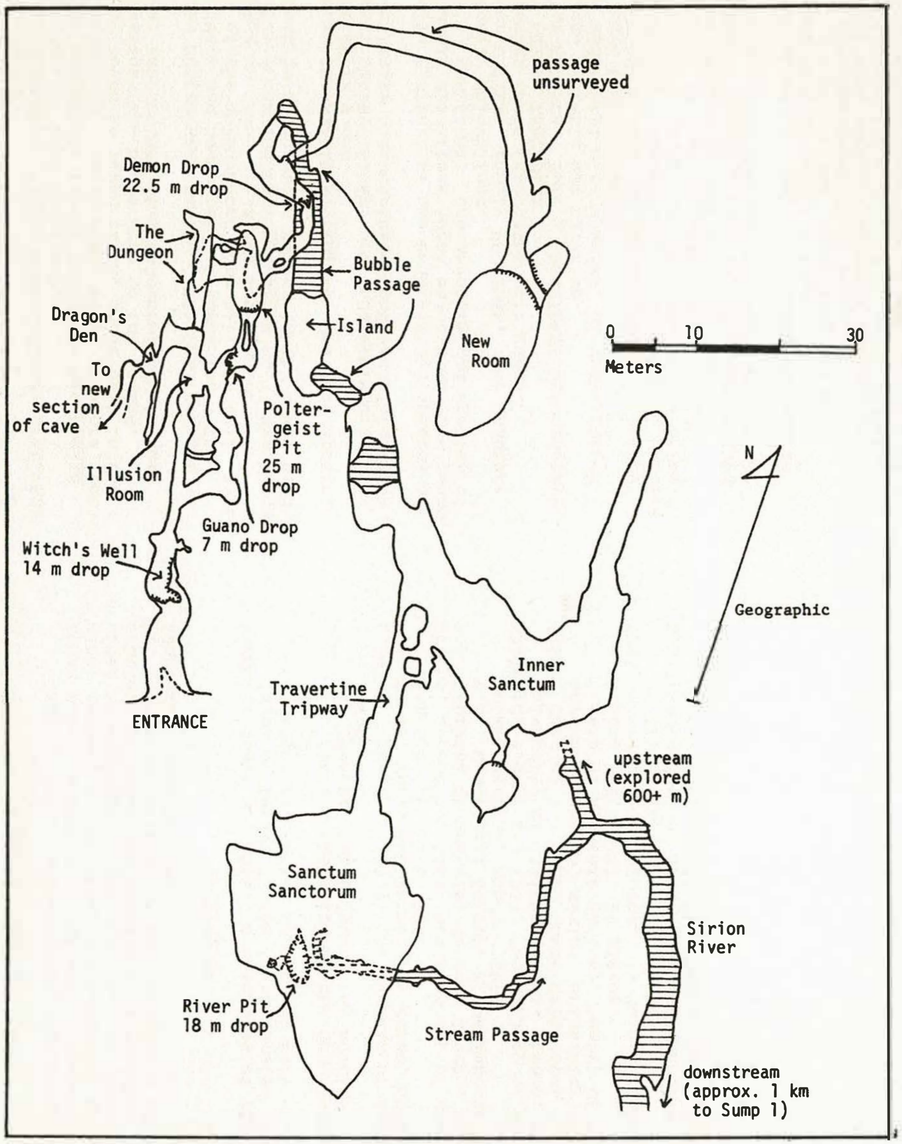

Figure 1. Sorcerer's Cave. Terrell County, Texas, U.S.A. Simplified map of entrance section based on compass and tape survey by Texas Speleological Association.

	Entrance Passage	Witch's Well	Illusion Room/Guano Drop	Dragon's Den	Poltergeist Pit	Demon Drop	New Room and passage	Bubble Passage	Inner Sanctum	Travertine Tripway	Sanctum Sanctorum	River Pit	Sump 1	Species abundance
+ Texoreddellia texensis	X	X	X	X	X	C			C	C		C	C	K
+ ? Pseudosinella sp.	X	X	X	X	X	C			O		O	X	X	A
Ceuthophilus sp.	O	O	O	O	C	C	O	O	C	O	O		O	A
Arenivaga erratica	O	C	C	X	X	X	X	X	X	X	X	X	X	K
Microvelia beameri	X	X	X	X	X	O		C						K
Psocid 1			C											
Psocid 2			C											
Rhadine howdeni			C											I
Tachys sp.	X	X	X	X	X	C								K
Xylopinus sp.	O	C	O	C	C	O		X	X	X	X	X	X	A
Trox sp.			C					X	X	X	X	X	X	I
Staphylinid 1	X	X	X	X	X	C	O							
Histerid 1			C		C									
Melyrid 1			C					X	X	X	X	X	X	
Phorid 1			C								C			
Tick 1									C				X	
Mite 1			C											
Mite 2									C					
Pseudoscorpion 1	X	C	C		O	C		X	X	X	X	X	X	K
+ Texella sp. nov.	X	X	X	X	X	X	X	X	C	C			X	I
+ Leptoneta sp.	X	X	X	X	X	C								
Loxosceles sp.		C						X	X	X	X	X	X	
Physocyclus enaulus	X	C	O	O	C	C		X	X	X	X	X	X	K
Nesticus pallidus	X	X	X	X	X	C			C		C	X	X	K
+ Cambala speobia	X	X	X	X	X	C			C	C		O	O	K
+ Cirolanides texensis	X	X	X	X	X	X	X	X	X	X	X	C	O	I
Masticophis sp.					O	X	X	X	X	X	X	X	X	I
Mormoops megalophylla			C											I
Myotis velifer	F	F	X F	X	O,F	F	O	F	O,F	F	O	X	X	A
Occurrence of guano	■	■	■		■	■	■	■	■	■	■			

Figure 2. Known distribution of fauna within Sorcerer's Cave.
Symbols: + - assumed troglobite/stygobiont; C - collected; O = observed; X = assumed non-occurrence.
Bat symbols: F = normal flight path; X = not on normal flight path; O = normal or extraordinary roosting site (see text).
Abundance symbols: I = infrequent; K = common; A = abundant.

Fluid Inclusions in Speleothem as Paleoclimate Indicators

C.J. Yonge
McMaster University Geology, Hamilton, Ontario, Canada L85 4M1

Abstract

Stable isotope measurements of fluid inclusion and calcite pairs in speleothem have been used to calculate temperatures of deposition. Much of the paleoclimate work until now has been concerned with the interpretation of oxygen isotope profiles in speleothem calcite. Unfortunately, such spectra are complex and subject to a number of climatic variables such as the distribution of weather systems and polar ice volume, in addition to temperature changes. However, fluid inclusions are trapped remnants of the calcite forming groundwaters and as such have been used in conjunction with the calcite phase to determine unique temperatures of deposition. To avoid the possibility that there may have been isotopic exchange between the phases post-depositionally, hydrogen isotopes have been measured in the fluid inclusions and used to infer oxygen values at the time of speleothem formation. The latter is possible because there exists an empirical relationship between hydrogen and oxygen isotopic ratios known as the Craig-Dansgaard meteoric water line.

Discrepant results in previous fluid inclusion studies can be explained because of incomplete extraction of water after crushing the sample under vacuum. For this reason, a heat extraction method has been developed and tested for replication on a number of flowstones. As a definitive test of the paleothermometer, contemporary speleothem isotopic temperatures have been compared to those obtained in the host caves with favourable results.

Résumé

Afin de calculer la temperature de déposition dans un speleothème on a recours au mesurage d'isotope stable d'inclusion fluide et de paire de calcite. Auparavant, les études paleoclimatique de speleothème ont utilises seulements les isotopes d'oxygène de calcite. Malheureusement, ces apectres sont complex et sujet a un nombre climatique variable comme la distribution de systeme de température et volume de glace polaire et ajoute des changements de température. Tout de même les restants de calcite sous forme de inclusions fluides formant de l'eau dure comme ceuxci ont servi en conjunction avec le calcite phase pour determiner l'unique temperature de la déposition. Pour empêcher cette possibilité, il y aurait pu avoir un échange isotopique entre les phases d'avant déposition, isotope hydrogène ont été mesurée dans les inclusions fluides et servi a inserrer les valeur d'oxygène dans le temps de la formation speleotheme. Cette dernière est possible parce-qu'il existe une relation globale entre les proportions d'hydrogène et oxygène connue sous le nom de Craig-Dansgaard ligne d'eau méteorique.

Des résultats discrepants dans les expériences passées au sujet d'inclusions fluide peuvent être expliqués a cause d'extraction incomplète de l'eau après avoir écrasé l'échantillon dans un vacuum. Pour cette raison une méthode d'extraction de la valeur a été trouvé et approuvé pour replication sur un nombre de roches. Comme un test defini du paleothermomètre, les températures des contemporains speleothème isotopique ont été comparé favorablement avec ceux obtenu dans une caverne spéciale.

Introduction

Speleothems are deposits, usually of calcite, which have formed by chemical precipitation from vadose seepage waters entering through the roof or walls of limestone caverns. As these deposits grow, small quantities of seepage water are trapped within them. Since it is possible to date such formations by various means, including U-series disequilibrium methods (1), stable isotope analyses of both calcite and fluid inclusions present complementary data for paleoclimate records at a given site. However, to demonstrate the validity of such records it is necessary to show firstly, that fluid inclusions are equivalent to seepage waters which in turn represent meteoric waters falling at that site, and secondly, that the speleothem calcite formed in isotopic equilibrium with its parent seepage water (2).

Nature of the Samples

Speleothems occur in a variety of morphologies but stalagmites and flowstones are the most useful for analysis. Occurring as regular, continuous sequences of stratigraphic layers, both stalagmites and flowstones have the advantage that their layering has greater lateral extent than in other deposits. This allows tests for isotopic equilibrium and replicate analysse to be made. Flowstones, although exhibiting the greatest lateral growth by far, tend to accrete up to 50 times slower than stalagmites.

The presence of fluid inclusions in speleothem is revealed by a milky tan to white colour. This, at least, is the case for speleothems containing fluid inclusions above a size of 10 μm. However, some of our recent results indicate that even transparent calcite crystals invariably contain some water. How this water is lodged in the structure is under investigation. The range of water content by weight appears to be between 0.05 to 0.50% in all speleothem studied so far.

Extraction of Fluid Inclusions

Care is taken to choose speleothem that is quite pure, avoiding such water-bearing contaminants as clay minerals and natural organic substances. The choice is generally not difficult since most deep-cave deposits are composed of remarkably pure calcite. Structural water, held in other minerals such as hydromagnesite, if present, is not likely to contribute significantly to the total water content since only trace amounts exist in speleothem (3).

Until recently, fluid inclusion water was released by crushing the sample in a stainless steel tube under vacuum (4). The vapour was subsequently frozen onto a cold finger held at liquid nitrogen temperatures (see Figure 1). Recent work now suggests that this procedure, in some cases, may not completely release the trapped water (section on Paleotemperatures deals with this in more detail). As a result, we have adopted the method of heating the sample in a furnace so that CO_2 and H_2O are generated under vacuum at 700°C. The mixture is pumped through a spiral trap held at CO_2/methanol temperatures (-78.5°C) allowing CO_2 to be pumpted from the system whilst the water remains frozen (see Figure 2). The sample is heated until no further CO_2 is liberated and the pressure falls to about 10^{-4} torr. At this point the water is presumed to have been completely released from the sample which by now is converted to CaO. The furnace is then isolated to prevent any back reaction with CaO when the water is transferred to the uranium furnace. Here the water is reduced to hydrogen for mass spectrometric analysis.

The Use of Stable Isotopes in Speleothem

Paleoclimatic records can be obtained from speleothem in a variety of ways. Oxygen isotopic analyses of either calcite or water yield sequences of data open to paleoclimatic interpretation. If coexisting calcite and water phases are analysed then absolute temperatures can be determined (5, 6). A major objection to using the $\delta^{18}O$ of the water arises because of the possibility of isotopic exchange between water and calcite as the deposition site changes temperature with time. Since hydrogen is absent from the calcite phase, a way of avoiding the problem is to measure D/H ratios in the fluid inclusions. Their initial isotope ratio should be preserved as no exchange is possible. The initial oxygen isotope ratios are then inferred from the Craig-Dansgaard meteoric water line (7, 8) or some other established relationship of this kind. Even if such a relationship is not determinable, the δD sequence alone can be used as a measure of variation of meteoric water through time.

Modern Fluid Inclusions and Seepage Water

A good way to test whether fluid inclusions are in fact aliquots of parent seepage water is to examine modern equilibrium deposits of speleothem. At the same time the isotopic thermometer can be tested against present cave temperatures. The results in Table 1 suggest some success in this direction both from crushing and decrepitation experiments. However, in some cases results from the former have hielded anomolously low temperatures.

Analysis of modern deposits does not resolve the problem that fossil fluid inclusion could have altered post-depositionally. The calcite might have recrystallized, some inclusions may have leaked or later seepage water might have penetrated the deposit, exchanging with older waters. Petrological studies made by us and others (9) indicate that fluid inclusions fill isolated and disconnected cavities whose integrity can be recognized in unaltered samples. Decrepitation experiments suggest that water also lies in sites other than these microscopically resolvable fluid inclusions. In spite of this, all speleothems exhibit a fine-structured, isotopic profile displaying variations in δD of considerable magnitude and giving some assurance that post-depositional homogenization has not taken place.

Paleotemperatures

As mentioned in the section on the use of stable isotopes in speleothem, isotopic analyses of coexisting calcite and water allows depositional temperatures to be calculated. Thus, calcite analyses of the samples studied above permit the determination of absolute temperatures. Unfortunately, when this is done some temperatures at the coldest part of glacial stages fall below zero (10); an obvious impossibility since calcite cannot form in a sub-zero environment. A possible way around the dilemma is to ask whether the meteoric water line, generally true for today, held during the past, particularly during the extreme conditions of full glaciations.

The calculation of temperature requires that the $\delta^{18}O$ in the water phase be inferred from δD measurements according to a relationship of the form

$$\delta D = 8\delta^{18}O + d_o \qquad (1)$$

where normally d_o is taken to be +10‰. The relationship does not hold everywhere on the planet even now (for example, 12, 13, 14), so it is perhaps not unreasonable to expect a change in the past. Measurements of glacial ice cores from the Antartic (15, Figure 3) showed that during the Wisconsinan d_o was much smaller; their data can be fitted with a line with the equation

$$\delta D = 7.9\ \delta^{18}O \qquad (2)$$

which corresponds to a δ_o value of 4‰ (assuming a mean $\delta^{18}O$ of -40‰) whereas modern snow at the site gives a d_o value of 10‰. Our work on the Byrd 71SW core suggests similar relationships (Figure 4) for that period. Current studies by Merlivat et al. (16) point to a shift in d_o from 4.1 to 8.8‰ for ice ranging in ages from Holocene to about 29 ka B.P. Merlivat and Jouzel (11) have been given a theoretical argument that the slope of the δD-$\delta^{18}O$ data correlation line should not have been strongly affected by changes in global climate. They show however that changes in humidity over the oceans during the Pleistocene could account for the changing deuterium excess (d_o), while these climatic changes should have little effect on the slope. If a d_o value of +4‰ is assumed in computing paleotemperatures from the data of Harmon et al. (1979), then almost all temperatures become positive (17). It is also possible that crushing of the calcite results in incomplete extraction of fluid inclusion water preferentially releasing isotopic light water, which could also account for some low temperatures. However, where crushing has been found not to yield acceptable data, the data are extremely inconsistent and give paleotemperatures that are clearly anomalously low (Table 2). Unfortunately, at the present time it is not possible to be absolutely sure of the validity of crushing data. A detailed petrological study of samples may resolve the ambiguity as speleothems possessing certain fabrics might lend themselves to crushing in which 100% extraction is achieved. However, if decrepitation by heating can be shown to yield reliable results then it would be a faster, less tedious method for future use.

Paleotemperatures from Decrepitation Experiments

The results of heating modern calcite have been presented in Table 1. They are generally encouraging, with "paleotemperatures" falling within 2°C of the present cave temperatures and hydrogen isotopic compositions of waters falling within 3‰ of the seepage water.

Other temperatures calculated from fossil speleothem, assuming integrity of the inclusions, can be used to check warming and cooling trends as inferred from sequences of $\delta^{18}O_c$ data (section on the use of stable isotopes in speleothem). Note that $\delta^{18}O_c$ may increase or decrease with temperature depending on the relative magnitudes of the temperature dependence of $\delta^{18}O$ of meteoric water and the isotopic fractionation factor between water and calcite. While the latter is constant at about -0.25‰/°C, the former varies from values of about +0.7‰/°C in coastal areas to values around 0.2‰/°C in some continental areas. Furthermore secular changes of $\delta^{18}O$ of sea water and of paths of water vapour masses over continental areas can have affected the secular shift in $\delta^{18}O$ of precipitation, and thus $\delta^{18}O_c$ (13). Some paleoclimatic information can be gotten from such $\delta^{18}O_c$ sequences by comparing them with $\delta^{18}O_c$ of modern calcite at the site providing the record passes through a complete glacial cycle. Relative warming and cooling trends can then be assigned to peaks and troughs in the records as presumably modern or interglacial temperatures are always higher than those during glacial intervals.

The decrepitation data lead to some ambigous results (Table 2). Data from Vancouver Islant (18), show a nice progression downwards of $\delta^{18}O$ (calcite) during the middle of the Wisconsinan, suggesting that $\delta^{18}O_c$ was decreasing with falling temperature. The decrepitation data back this contention, yielding a temperature lower than 4°C for the 50 kA B.P. period and suggesting an appropriate isotopic shift in precipitation at that time to values 15‰ lighter than modern precipitation. Results from Victoria Cave, England, are also encouraging. A sample was taken from the top of a small stalagmite lying inside a massive block of flowstone. Going up the stalagmite axis, $\delta^{18}O$ (calcite) fell steadily to more negative values until growth temporarily ceased at about 150 ka. B.P. Not only does the water show an appropriate isotope shift to values 8‰ lighter than those of modern seepage water (20) but the isotopic temperature gives a value of around zero when growth would be expected to stop.

Less encouraging are the data from Lost John's Cave, England. The top of a stalagmite at 95 ka was thought to have been deposited at a lower temperature than the base at 115 ka according to the $\delta^{18}O_c$ interpretation ($d\delta^{18}O_c/dT < 0$). Fluid inclusion data suggest the reverse with temperatures for the top and base being 4.5°C and 2.7°C respectively. In addition the base contains water indistinguishable from modern precipitation whereas the inclusions in the top of this stalagmite are about 7‰ heavier. The increase in δD may be attributable to the increase in δD of sea water during the transition to a glacial period. However this implies that the temperature effect on δD of precipitation is negligible, which is unlikely. The sample is being studied in more detail as are the others.

The samples from Government Quarry Cave, Bermuda, are from a single layer in a flowstone deposited about 110 ky B.P., during the last interglacial. Temperatures inferred from the D/H measurements are comparable to those observed in the cave today.

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Table 1. Isotopic data and calculated isotopic temperatures from modern deposits

Locality	Isotopic ratios for stalagmite-fluid inclusion-seepage			Isotopic Temperature (°C)		Measured Cave Temp. (°C)	Extraction Procedure
	$\delta^{18}O_{Ct}$	$\delta D_{f.i.}$	δD_{seep}	$T_{f.i.}$	T_{seep}		
Iowa	24.10	-55.6	-52.2	10.6	9.0	8.8	C
W. Virginia	23.64	-60.9	-59.4	10.7	10.0	10.8	C
Missouri	24.78	-47.9	-40.8	10.5	14.0	15.0	C
Pennsylvania	24.06	-50.0	-53.6	11.0	9.3	10.0	D
Iowa	24.58	-54.0	-52.2	7.0	7.9	8.8	D
Jamaica	26.22	-8.8	-	24.0	-	22.0	D
New York State	23.13	-64.5	-67	7.6	8.8	8.5	D

Ct = Speleothem Calcite; f.i. = Fluid Inclusion; seep = Seepage water;
C = Crushing; D = Decrepitation.

Isotopic temperatures calculated from $10^3 \ln \alpha_{C-W} = 2.7\ 10^6\ T^{-2} - 2.89$.

$\delta^{18}O$ (water) calculated from $\delta D = 8\delta^{18}O + 10$.

Table 2. Isotope and paleotemperature data for fluid inclusions compared from two extraction procedures.

Locality	No. of Analyses	$\delta D_{f.i.}$ (‰)	Paleo-Temperature (°C)	Mode of Extraction	Age (Ky)
BERMUDA	11	-8.57 (±2.5)†	+20.3 (±1.5)	D	110
(Government Quarry Cave)	11	-46.5 (±11.3)	-2.4 (±6.0)	C	
IOWA*	1	-54.0 (± ?)	+7.0 (± ?)	D	modern
(Cold Water Cave)	2	-62.1 (±5.1)	+3.2 (±3.0)	C	
VANCOUVER ISLAND	2	-103.2 (±1.5)	+3.6 (±0.9)	D	50
(Cascade Cave)	3	-110.1 (±8.1)	0.0 (±3.2)	C	
U.K.	4	-37.1 (±0.6)	+4.5 (±0.4)	D	95
Lost John's	2	-87.7 (±24.5)	-18.0 (±12.2)	C	

D = Decrepitation; C = Crushing; $\delta D_{f.i.}$ = hydrogen isotope ratios of fluid inclusions (w.r.t. SMOW); † = refer to range of values. * = Data also included in Table 1.

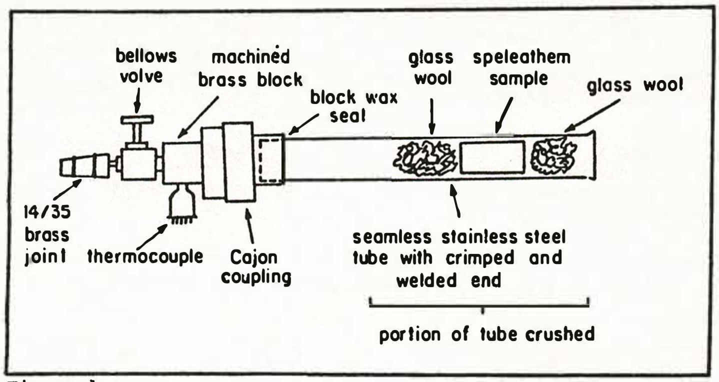

Figure 1

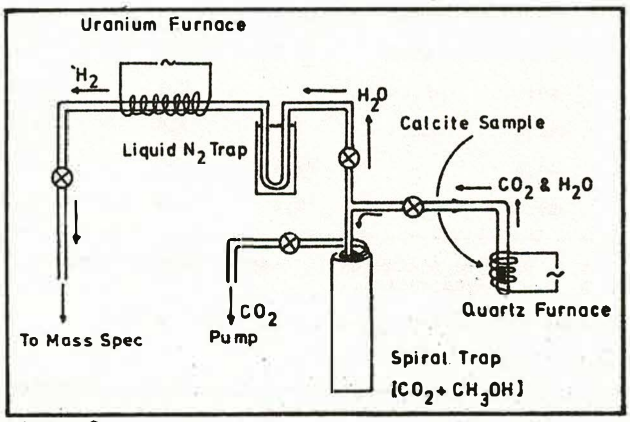

Figure 2

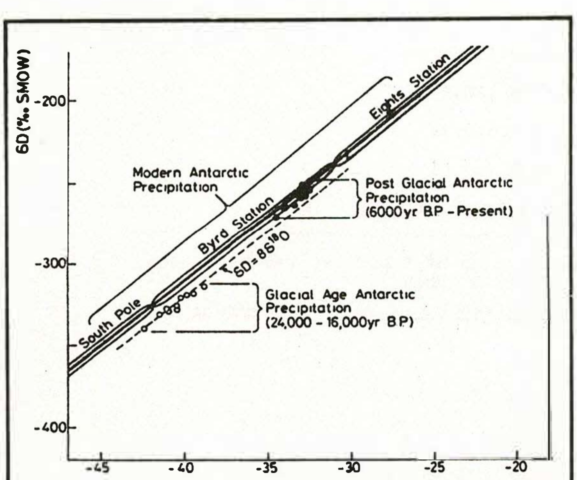

Figure 3

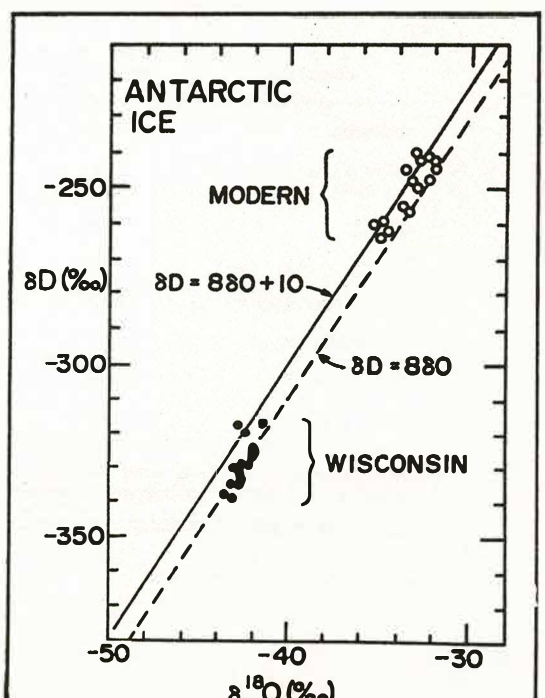

Figure 4

Remarks on Origin and Distribution of Troglobitic Spiders

Christa L. Deeleman-Reinhold
Sparrenlaan 8, 4641 GA OSSENDRECHT, The Netherlands

Abstract

Troglobitic animals are often considered - according to "Jeannelian" and "Vandelian" tradition - to be relicts of ancient hygrophilic faunas, extinct elsewhere. This view has been prompted by their peculiar morphology, which often differs markedly from epigean relatives, and by their patchy distribution, sometimes limited to a small area or a single locality.

In many areas cave spiders are better known than the spider fauna of cryptic habitats on the surface. Better knowledge of these faunas and a taxonomic regrouping based on phylogeny rather than adaptive characters lead to the viewpoint that at least some of the blind cave spiders may not be quite so old as was believed at first. Troglobitic characters, which are predominantly regressive, are an adaptation to a special environment, just like any other adaptation.

The author gives some examples of changed insights of relationships of South European troglobitic spiders which support this view.

Even so, it remains unexplained why troglobites are distributed so unevenly in the world. The author attempts to explain this by arguing that the crucial point is the enormous difference in ecological properties of subterranean environments in different parts of the world. Many factors contribute to the characteristic features of the environment as a habitat and this is reflected in the complexity of the life community it shelters. The more complex the subterranean community and the more isolated from that on the surface, the more chance that adaptational characters develop.

Résumé

Animaux troglobies sont souvent - après les idées de Jeannel et Vandel - considérées comme relictes d'anciennes lignées épigées hygrophiles, éteintes ailleurs. Ces idées sont basées sur leur morphologie souvent très différente de celle de leur parents épigés et sur leur distribution disjointe, souvent limitée même à une seule localité. Cependant, la faune hypogée en général a été mieux exploré que celle des milieux cryptiques superficiels. Une connaissance meillieure de cette dernière et un regroupement taxinomique basé plutôt sur la phylogénie que sur des caractères adaptifs, ont mené à croire qu'au moins quelques unes des araignées troglobies européennes ne soient pas si anciennes que l'on ne les croyait. Il va sans dire que les caractères troglobies (en grande partie regressives) ne sont rien d'autre que des adaptations à un milieu spécial, comme toute autre adaptation.

L'auteur donne quelques exemples d'un changement d'opinion pour ce qui est lesliens de parenté d' araignées cavernicoles européennes qui soutiennent cette idée.

Une autre question touche à la distribution très inégale de troglobies dans le monde. L'auteur présente l'opinion que ça s'explique par la nature écologique actuelle du milieu. L'ensemble de caractères écologiques de ce milieu est très diversifié selon sa situation sur terre, qui se traduit par une différente complexité et richesse de la biocénose. Une grande complexité de celle-ci en isolement avec celle de la surface favorise le développement de caractères troglobies.

In this communication I should like to discuss a few problems in Southeast European cave spiders in view of my own experiences and discoveries, mainly in Yugoslavia. They concern the phylogenetic relationships and age of some blind spiders and I shall make an attempt to relate ecology with the markedly uneven density of troglobites in different karst areas.

Troglobitic animals are often considered - according to Jeannelian and Vandelian traditions - to be relicts of hygrophilic faunas of the Tertiary tropical or subtropical forests, the only survivors of elsewhere extinct lines (Jeannel, 1943; Leleup, 1965; Gueorguiev, 1977; Deeleman-Reinhold, 1978; Deltshev, 1978; Kratochvil, 1978). This view has been prompted by the peculiar morphology, especially in Catopid and Carabid cave beetles, which are sometimes surprisingly different from their nearest relatives, by their patchy distribution, sometimes limited to a small area or a single locality, and by the absence of close relatives on the surface.

In many areas cave spiders are better known than the spider fauna of the surface. Better knowledge of these latter faunas and a taxonomic regrouping based on phylogenetic rather than adaptive characters lead to the viewpoint that at least some of the blind cave spiders may not be quite so old as was believed at first (Brignoli, 1979; Deeleman-Reinhold, 1980). Troglobitic characters, which are predominantly regressive, are an adaptation to a special environment, just like any other adaptation.

Considering cavernicolous spiders from an ecological point of view, they fall into a number of categories, filling various compartments within the hypogean environment. The following classification is based on my experience with Southeast European cave spiders.

1) Entrance spiders ("association pariétale, partim). The "wallé spiders are usually rather large, they are web-makers and find abundant prey among the numerous insects that migrate through cave entrances; examples are Meta menardi (Latreille), Meta merianae (Scopoli), Nesticus cellulanus (Clerck), various Tegenaria and Hoplopholcus species. They are also found in cellars, pits and superficial cavities.

2) Versatile cave spiders; these species lack morphological adaptation like the first category, and they are ecologically rather flexible: they may be found anywhere, from the deepest cave parts to the surface in shaded, moist situations. Their stay in the cave is facultative, although they are perfectly capable of completing their life cycle and reproducing in the cave. Examples in Yugoslavia are Troglohyphantes excavatus Fage and other Troglohyphantes species, Lepthyphantes centromeroides Kulczynski and perhaps some Leptonetidae. These are all web-builders.

3) Endogean (edaphic) spiders, that live in the top meter or so in soil, clay- or rock-particles, only occasionally in caves; they do not appear on the surface and may show some morphological adaptations. They catch prey in various ways, with or without web; it is uncertain what kind of prey they live on. Examples are the Dysderid genera Minotauria and Rhode and certain Harpactea species, also some small spiders like Pseudanapis and certain Centromerus.

4) Obligate cave-dwellers, troglobites that are usually eyeless and live exclusively in the underground channel- and cave system. They hunt actively on the walls and the moist dripstones or build webs in the vicinity of the scarce organic debris. This group includes the majority of the blind Dysderids and Linyphiids (Troglohyphantes and Centromerus) and some Leptonetidae. They are as a rule unrelated to entrance spiders. Their adaptation consists of strongly reduced or absent eyes, pale colouring due to lack of melanin pigement and thinning of the teguments, elongated and thin appendages and hyperdeveloped sensory organs.

It is these last two categories with which the rest of this paper is dealing. Taking into account the fact that troglobites live most often in small populations, in which evolutionary changes can spread rapidly, the mere fact that they look different from epigean relatives does not involve necessarily that they have been separated from them a long time ago. Evidence that their phylogenetic characters are in a more primitive state than they are in their epigean counterparts is unconvincing or lacking, with a few exceptions (Deeleman-Reinhold, 1978, 1).

Does this mean that there are no relicts among troglobitic spiders in Europe? It has to be borne in mind that karst terrain is not one of the most stable environments, as exposed carbonate rock is continuously subject to corrosive destruction. But the very thickest deposits may last long enough to survive through some major climatic revolutions and the possibility should be visualized that the hypogean environment may have similar conservative qualities as for instance deep sea, or islands. Possibly the only witness of this as relicts are the South European troglobitic Telema tenella Simon (Telemidae) and the troglophilic Pseudanapis species

(Symphytognathidae) as representatives of typically tropical families.

An intriguing problem in European spiders is centered around a number of species, some of which with reduced eyes or even blind, that are habitually neither found in caves, neither in leaf litter. They have been found only under special conditions in cave entrances deep down underneath a layer of stones, between sheets of laminate rock, or in spring when wheather is cool and moist they could be obtained in very deep crevices, associated with decaying humus. Their habitat may correspond with what the Moulis workers call "milieu souterrain superficiel" (Juberthie, Delay & Bouillon, 1980). They are related to cave spiders but do not belong to the same species, they have been listed above under the category edaphic spiders; in theory they can also exist on non-carbonate bedrock. In this environment probably a large amount of spiders is still to be discovered, as it is difficult to collect them. Some of the rarer cave spider species probably have their main habitat here. From recent experience in spider collecting in Crete it appears that this habitat is particularly well developed and consists there of a mixture of crumbly, loose clay- and rock particles, and is relatively easily accessible around cave entrances.

The number of spider species or species groups without apparent epigean, "normal" relatives, used as an argument in favour of the theory of troglobites as relicts, has been overestimated as a result of insufficient knowledge of epigean faunas and their phylogenetic relationship with them. In the course of my taxonomic studies on Yugoslav cave spiders I have come across quite a few of such cases. Thus, the apparently isolated taxonomic position of the Dysderid genera of exclusively blind species: Folkia, Stalagtia and Typhlorhode, the troglobitic Roeweriana dibens, dubius and myops (Agelenidae) the Troglohyphantes species of group salax and the singular blind Nesticus absoloni Kratochvil have all been refuted by recent finds by ~~Brignoli, Wunde~~rlich and myself, or by newly established relationships. Still remain to be resolved the relationships of a.o. the blind Yugoslave cave spiders Typhlonyphia reimoseri Kratodhvil, Nesticus parvus Kulczynski, the enigmatic Agelenid Hadites tegenarioides Keyserling, the male of which is still unknown, after 120 years in spite of intensive searching in the few accessible caves of the island of Hvar to which it is endemic, and the Linyphiid genus Icariella (Brignoli, 1979, 1). The distribution patterns of a number of the above mentioned groups are shown in Figures 1-6. (Data a.o. from Brignoli, 1972, 1975, 1976 1 and 1; Deeleman-Reinhold, 1978, 1 and 2; Kratochvil, 1938, 1970.) Troglohyphantes group salax was believed to include at least 13 blind or semiblind species with a remarkable distribution (Figure 6). Recently a new species, epigean and with normal eyes, yet unnamed, was discovered in Turkey. In each of the mentioned cases the bline species were found to be closely associated taxonomically to normally-eyed species, but never from the same area. From these distribution patterns a fascinating trend is distilled: the blind members of each of these units are all centred in approximately the same area in Yugoslavia. Indeed, the absolute number of troglobitic spiders (and also other invertebrates) is exceptionally high in this area. Compared to other well investigated karst areas in the world the ratio blind:nonblind cavernicolous spiders is unique: very roughly 1 blind to 2 nonblind in Yugoslavia, 1:9 in the Pyrenees, 1:18 in Japan (see also Deeleman-Reinhold, 1980).

What could be rhe reason of this extraordinarily high density of blind spiders in southwestern Yugoslavia?

Two basic causes can be proposed: a) the geological and climatological history of the area, and b) the present conformation of the area and its implications on its quality as a habitat. Explanation a) does not account for the poorness of troglobites in adjacent karst areas (eastern Serbia, northern Greece, Bulgaria, Italy) as these areas have good karst terrain and similar climatical histories as western Yugoslavia. As regards b), Yugoslavia is distinguished from the surrounding areas today by the much greater extent of the karst surface, the larger scale, more dynamically, of the karstification processes. It is my suggestion that b) is of much more importance than a) in the development of the terrestrial troglobites. In Yugoslavia, in my opinion the major agent in their evolution is the physical properties of the subterranean environment, and the climate. Factors playing a part in this specific conformation are the high rainfall, the great, uninterrupted mass of uncovered carbonate rock, the enormous depth of them (up to 5000 m) and the specific structure of the rock, offering optimal conditions to support a diversified community of microflora and fauna which is relatively independent from that of the surface and in which loss of eyes and other adaptational transformations are selectively advantageous.

Elsewhere in the world, i.e. one of the Hawaiian Islands, a rich troglobitic spider fauna has been found in the lava caves which apparently are not older than 10,000 years (Gertsch, 1973). This fauna includes the first two blind Lycosidae and a blind erigonid Linyphiidae. It suggests, that, if only the proper environmental conditions are realized, troglobitic forms may develop almost in any family, in any place and rather rapidly. It certainly opposes the idea that troglobites are among the oldest elements of the fauna.

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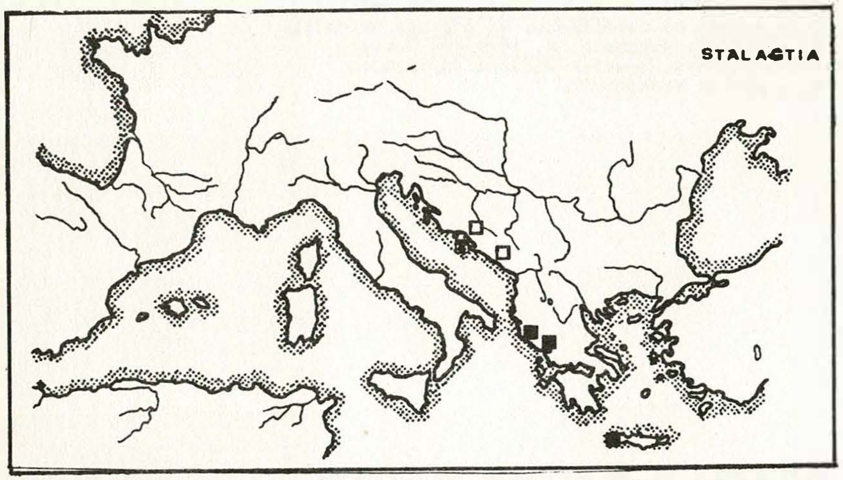

Figure 1. Distribution of species of Stalagtia (Dysderidae). White squares, blind species: S. hercegovinensis (Nosek), S. inermis (Absolon & Kratochvil), S. monospina (Absolon & Kratochvil) and others. Black squares, species with normal eyes: S. kratochvili Brignoli, S. argus Brignoli, S. spec.

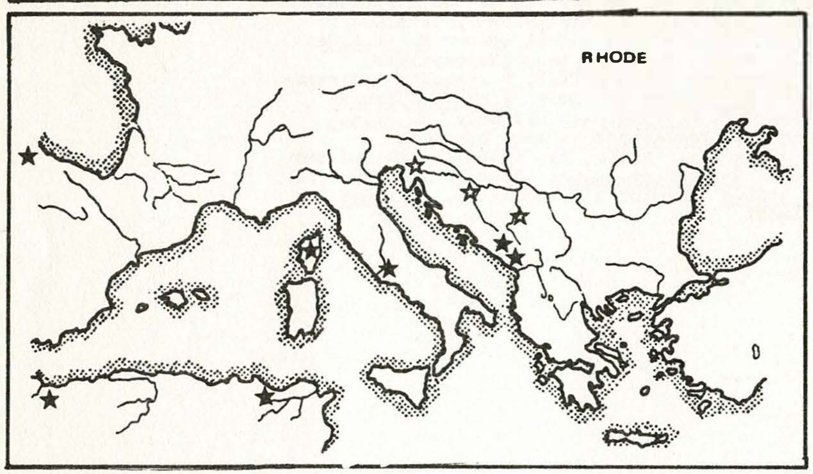

Figure 2. Distribution of species of Rhode (Dysderidae). White asterisks, blind species: R. aspinifera Nikolić, R. stalitoides Deeleman-Reinhold, R. subterranea (Absolon & Kratochvil). Black asterisks, species with normal eyes: R. biscutata Simon, R. scutiventris Simon, R. tenuipes (Simon), R. maginifica Deeleman-Reinhold, R. spec.

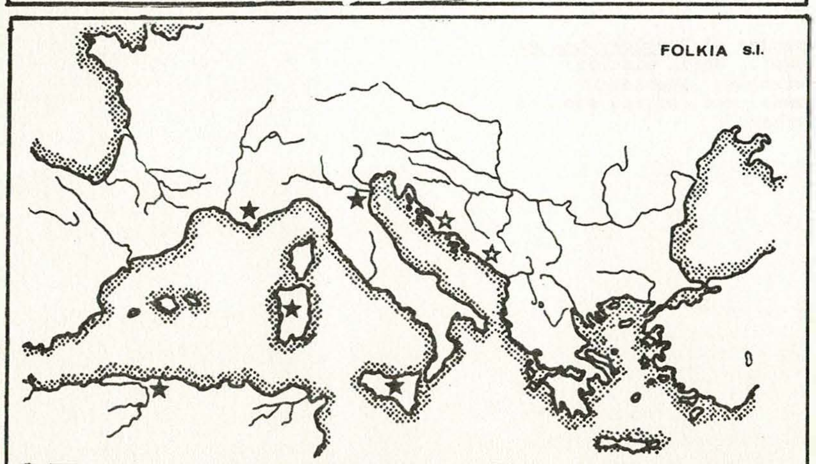

Figure 3. Distribution of species of Folkia s.l. (Dysderidae). White asterisks, blind species: Folkia haasi (Reimoser), F. mrazeki (Nosek) and others. Black asterisks, species with normal eyes: Harpactea arguta Simon, H. muscicola Simon, H. sardoa Alicata.

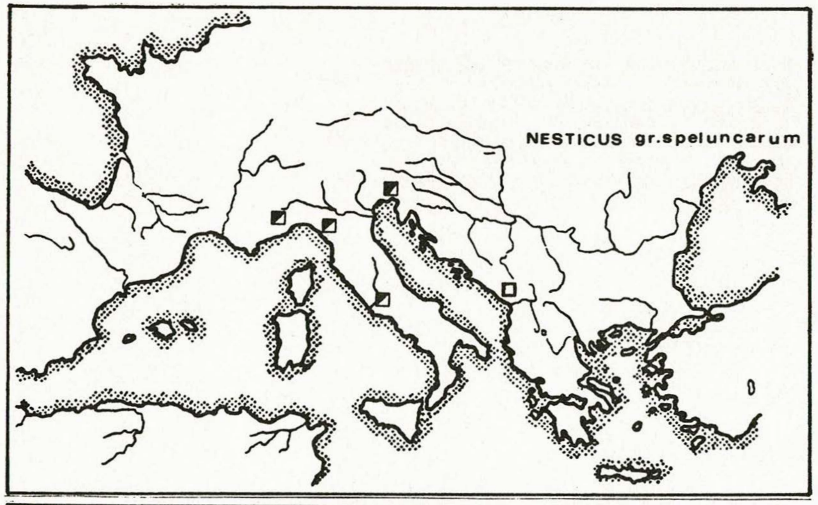

Figure 4. Distribution of *Nesticus* species group *speluncarum*. Black/white squares, species with *depigmented* eyes: *N. speluncarum* Pavesi, *N. menozzii* Di Caporiacco, *N. morisii* Brignoli, *N. sbordonii* Brignoli, *N. idriacus* Roewer. White squares, species without any eyes: *N. absoloni* Kratochvil.

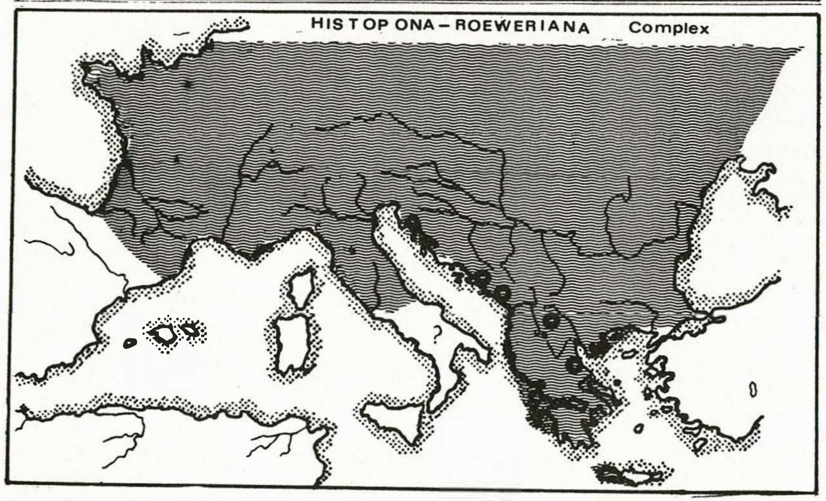

Figure 5. Distribution of the species of the *Histopona-Roeweriana* complex (Agelenidae). Hatched area: species with normal eyes: *H. torpida* (C.L. Koch), *H. conveniens* (Kulczynski), *H. luxurians* (Kulczynski), *H. sinuata* (Kulczynski), *H. italica* Brignoli, *H. palaeolithica* (Brignoli), *H. tranteevi* Deltshev, *H. vignai* Brignoli, *Roeweriana hauseri* Brignoli, *R. strinatii*. Asterisks, species with reduced eyes: *Roeweriana dubius* (Absolon & Kratochvil), *R. bidens* (Absolon & Kratochvil), *R. myops* (Simon).

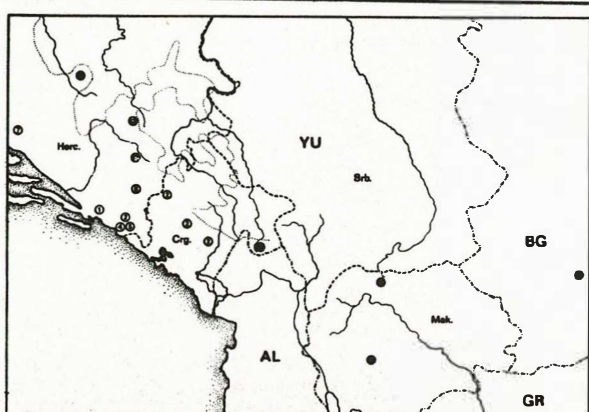

Figure 6. Distribution of the species of *Troglohyphantes* group *salax* (Linyphiidae). White circles: blind species, black circles: species with reduced eyes. Not shown: one epigean species with normal eyes in Turkey.

Thermoluminescence: A Method for Sedimentological Studies in Caves

Yves Quinif
Faculté Polytechnique de Mons, Belgique

Abstract

This paper is a preliminary study which shows the interest of the thermoluminescence in problems of karstic sedimentology. The light emission by heating of different minerals is an intrinsic property of these minerals, and, thus, serve to identify them. Thanks to this property, we can resolve questions which concern the karstic sedimentology: definition of lithological units in deposits of caves, origin of the different detritic sediments, paleogeomorphological reconstitutions.

Résumé

Ceci est une étude préliminaire qui montre l'intérêt de la thermoluminescence dans les problèmes de sédimentologie karstique. La thermoluminescence (TL) est une émission de limière stimulée thermiquement qui affecte des minéraux tels que le quartz, les feldspaths, la calcite. Les caractéristiques de cette émission constituent une propriété intrinsèque de ces minéraux et peuvent servir à les identifier. Par ce biais, nous pouvons donc résoudre des problèmes de sédimentologie karstique: définition d'unités lithologiques dans des accumulations détritiques en grotte, origine des différents sédiments, reconstitutions paléogéomorphologiques.

The Phenomenon of Thermoluminescence

Thermoluminescence (TL) is a property shown by some minerals, property by which these minerals (quartz, felspar, calcite) emit light when they are heated. This light emission happens under the incandescence temperature, and is characterized by a "glow curve" (Fig. 1) which describes the intensity of the emitted light in function of the temperature.

This phenomenon is the result of an accumulation of energy in defects in the crystal. These defects are physical (for example, dislocations) or chemical (impurities). Traps are created, in which electrons will be trapped. The energy which is supplied by heating permits to electrons to come back to fundamental levels. This transition is accompanied by a light emission: this is the thermoluminescence (McDougall, 1968).

Two treatments of the samples are possible. On the one hand, geological samples are heated and TL glow-curves are obtained: it is the "natural thermoluminescence" or NTL. It is an image of the density of trapped electrons in the crystal. On the other hand, one can heat the sample in an oven to suppress NTL. After this, one irradiates the sample by a radioactive source which "fills" the traps in crystal. In this way, we obtain an "artificial thermoluminescence" or ATL, which reveals the distribution of these traps in crystal ("the aptitude to the TL").

The apparatus (Fig. 2) is composed of a photomultiplier tube which capts an amplifies the emitted light, located above the sample which is heated by an electric resistance. The TL glow-curve is recorded on a plotting-scale or a magnetic-tape which is treated by a micro-computer. The sample can be a powder (with a defined granulometry: what we call macrothermoluminescence), or only one grain. In this last case, one speaks of "microthermoluminescence" (Baleine, Charlet, Dupuis, 1973; Charlet, 1969). In this paper, we study only natural macrothermoluminescence.

Utilisation of Thermoluminescence in Geology

A TL glow curve depends on the characteristics of defects in crystal (chemical impurities, physical defects created, for example, by mechanical constraints) and on irradiation undergone by the mineral. Thus, we see that TL is the result of the geological history of this mineral. For example, let's take a quartz grain in a sandstone. The shape of its glow-curve will be different according to the origin of this quartz grain: granite, quartzite, metamorphic rocks, and so on. Moreover, the TL intensity is dependent of the irradiation dose received by the quartz grain. Two great applications appear:

1°) Sedimentological applications (Charlet, 1971)

The TL of the mineral is an intrinsic characteristic and is used to find out the origin of the sediment. This concerns detritic rocks: sands, sandstones, ... and thus also deposits in caves. This is what we are going to talk about.

2°) Applications based on irradiation effects

The more the mineral is radiated, the more intense is its TL glow-curve. One can use this property as dosimeter and as geochronometer. If the sediment lies above an uranium orebody, its minerals will show an abnormal TL and can serve to detect this uranium (Charlet, J.M., Dupuis, C., Quinif, Y., 1978). On the other hand, the irradiation dose is a function of the time. The TL-intensity will be greater according to the intensity of radioactivity and the time of irradiation. If we know the irradiation-dose and the TL-properties of the mineral, we get a geochronometer, for example, to date potteries in archeology or speleothems in karstology. In this last case, the problem becomes very complicated because of the radioactive desequilibrium phenomena in speleothems and because of the TL properties of calcite, perturbated, for example, by crushing (see: PACT 2 and 3, 1978).

The Example of Deposits in the Cave "Grotte de la Vilaine Source" at Arbre in Belgium

This cavity is a very good example of resurgence-cave in a "Chantoir-resrugence" (swallow hole-resurgence) network (Quinif, 1977; 1978), which is characterized by little streams running from sandstones-hills to a subsequent dry valley, shaped in a stripe of middle-devonian limestones in which those streams flow down. They flow together underground to form a collector. The cave "Grotte de la Vilaine Source" constitutes the down-stream part of this collector (Figure 3a, b).

The general shape of the cavity is a large gallery which is partially filled by detritic deposits. We studied several section into these deposits using different techniques: litho-stratigraphy, palynology, mineralogy, paleomagnetism (Quinif, Y., Dupuis, C., Bastin, B., Juvigné, E., 1979).

We applied the TL-method to samples out of the section n°1 (Fig. 4). These samples are washed; we take the granulometric fraction between 74 and 105 µm. Three grams are attacked by HCl 5M for two hours and HF 40% for two minutes. After washing and drying, only quartz grains are left. (1)

Figure 5 shows a TL glow-curve of a typical sample of deposit in the studied cave. We see that this glow-curve has two peaks: the principal H_2 and a little H_1 which is only a simple inflexion on the side of H_2. We take as parameter the intensity of these two peaks and their temperatures. We draw these parameters into table 1, with values which characterize the TL glow-curves of quartz from rocks of the alimentation basin (emsian and famennian sandstone) and of tertiary sands. These sands constituted ouliers of a discordant cover which almost disappeared. Actually, we don't find these sands in the alimentation basin of the cave, but in dissolution-nests of the carboniferous limestones.

What is the contribution of the TL in this preliminary study?

The diagram of the Figure 7 shows that:

1) we have two groups of sediments. The TL is thus a sedimentological tracer like, for example, heavy minerals. The great advantage of TL concerns the nature of the tracer: TL refers to the most common minerals and, thus, to the sediment itself.

2) We see that the TL glow-curves of cave sediments are nearer to the tertiary sands than to the paleozoical rocks. These sediments (into the analyzed granulometric class) principally come from tertiary sands and may be some alterites of paleozoical sandstones.

Thus, in the cave, we find sediments which are the witness of a disappeared cover on the plateau.

Conclusions

This first study is an example which has the merit to show the power of TL as sedimentological tracer in karstic problems. Indeed, as we can't distinguish different sandy or clayey sediments by morphoscopy, TL

(1) Let's notice that we can, by physical and chemical preparations, separate TL from quartz, K-feldspars, Plagioclases and carbonates. In this preliminary study, we only studied quartz.

enables us to recognize different quartz or feldspar grains, and to study the origin of detritic alimentation. This permits to approach the paleogeomorphological problems, the evolution of the landscape around the karstic network, the definition, into sedimentary complexes in caves, of sedimentological units which we can find in other sections, elsewhere in the cave.

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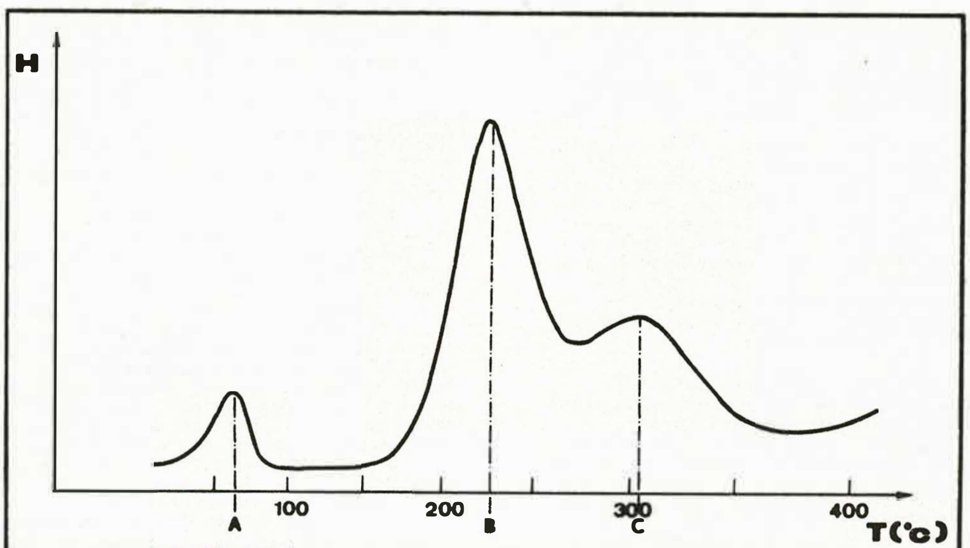

Figure 1. N.T.L.: Glow-curve example.
H. : Light intensity (arbitrary unity).
T. : Temperature (centigrade degree).
A. : Check peak supplied by an additional quartz which has got no other peak.
B. and C.: Characteristic peaks of the sample (here, a non-treated sediment of the cave).

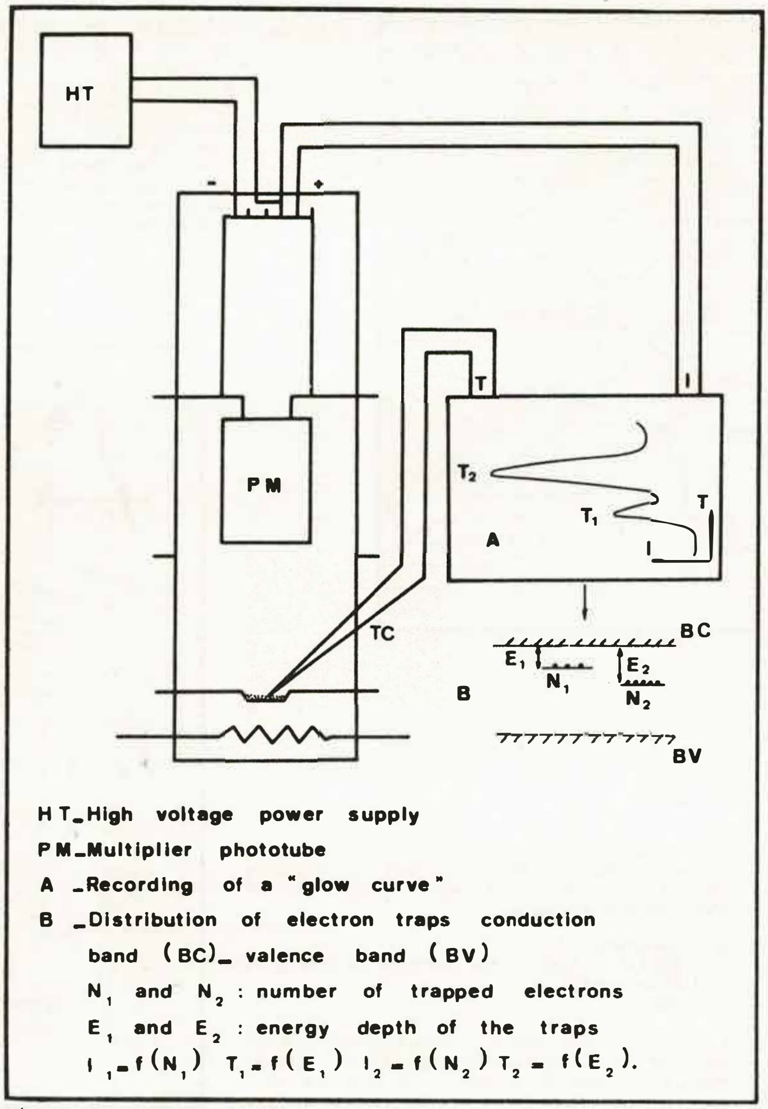

Figure 2. T.L.: Apparatus.

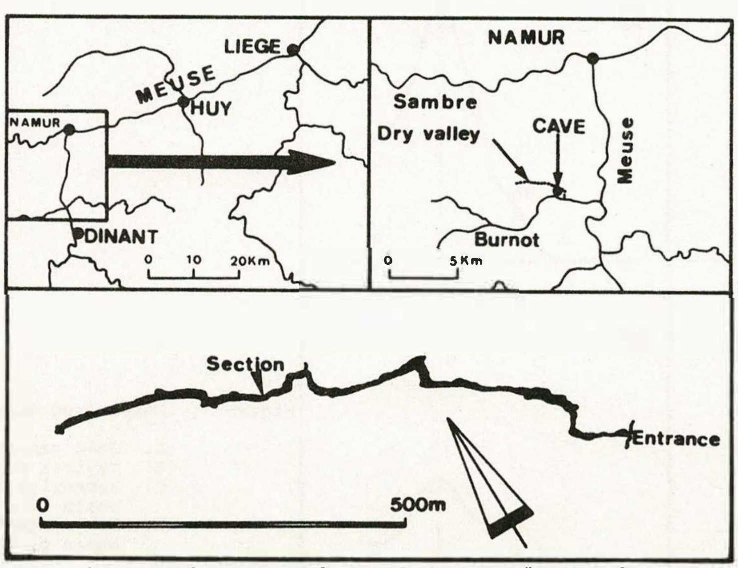

Figure 3a. Localisation and map of the cave "Grotte de la Vilaine Source" according to Quinif, Dupuis, Bastin, Juvigné, 1979.

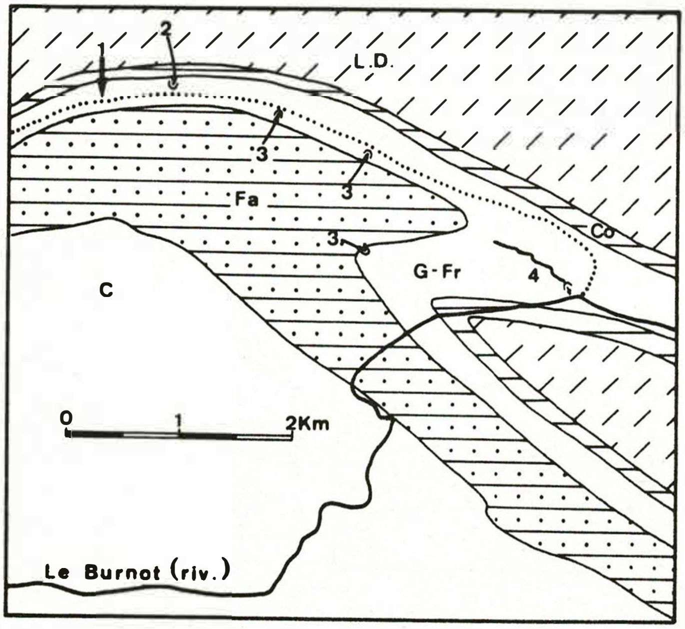

Figure 3b. Geological environment of the cave. The netowrk extends under the limestone complex of Givetian and Frasnian (G-Fr). This complex is a subsequent dry valley (1), dominated by sandstones hills of the Lower-Devonian (L.D.) in the north and of Famennian (Fa) in the south. The little streams flow down from these hills to the dry valley where they flow into swallow-holes (2 and 3). In 4, we have the scheme of the cave and the resurgence.

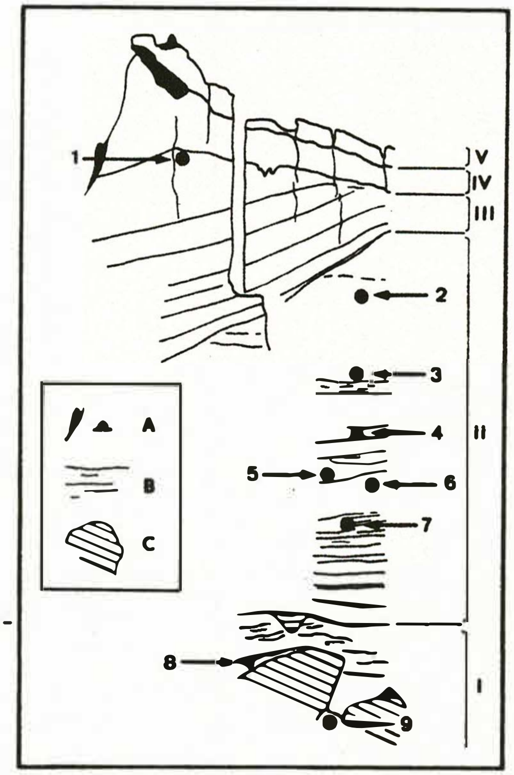

Figure 4. First profile in the cave (very schematic), according to C. Dupuis, in Quinif, Dupuis, Bastin, Juvigné, 1979, and localisation of the studied samples.

A. speleothems.
B. detritic sediments (aspect of the stratification).
C. Scree.

I, II, III, IV, and V: sedimentary units defined by lithostratigraphical and hydrodynamical considerations. TL permits to distinguish unit II among the other units.

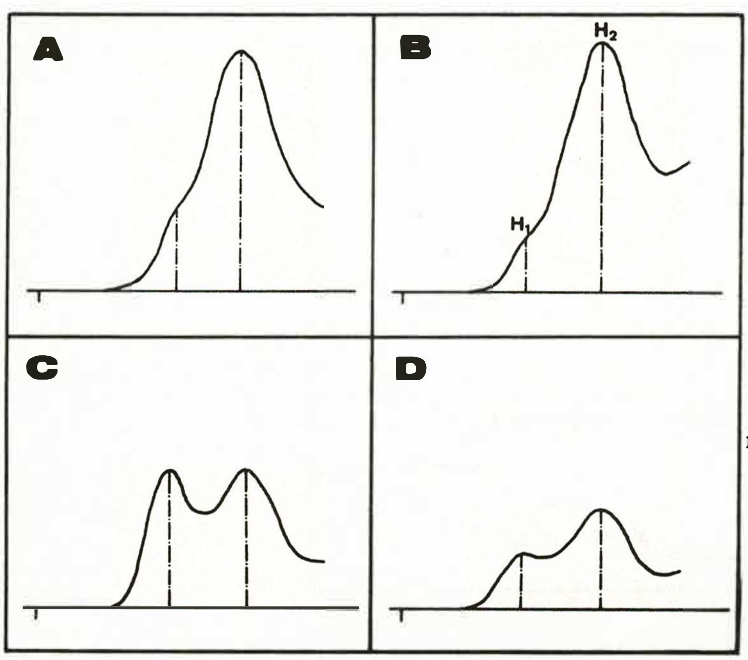

Figure 5. Comparison between TL glow-curves of

A. Sand sample of tertiary outliers.
B. Typical sample of deposit from the cave.
C. Famennian sandstone (south-alimentation basin of the net-work).
D. Emsian sandstone (north-alimentation basin of the net-work).

We see that the sand of the cave mainly belongs to the family of tertiary sands and is not similar to the paleozoic sandstones.

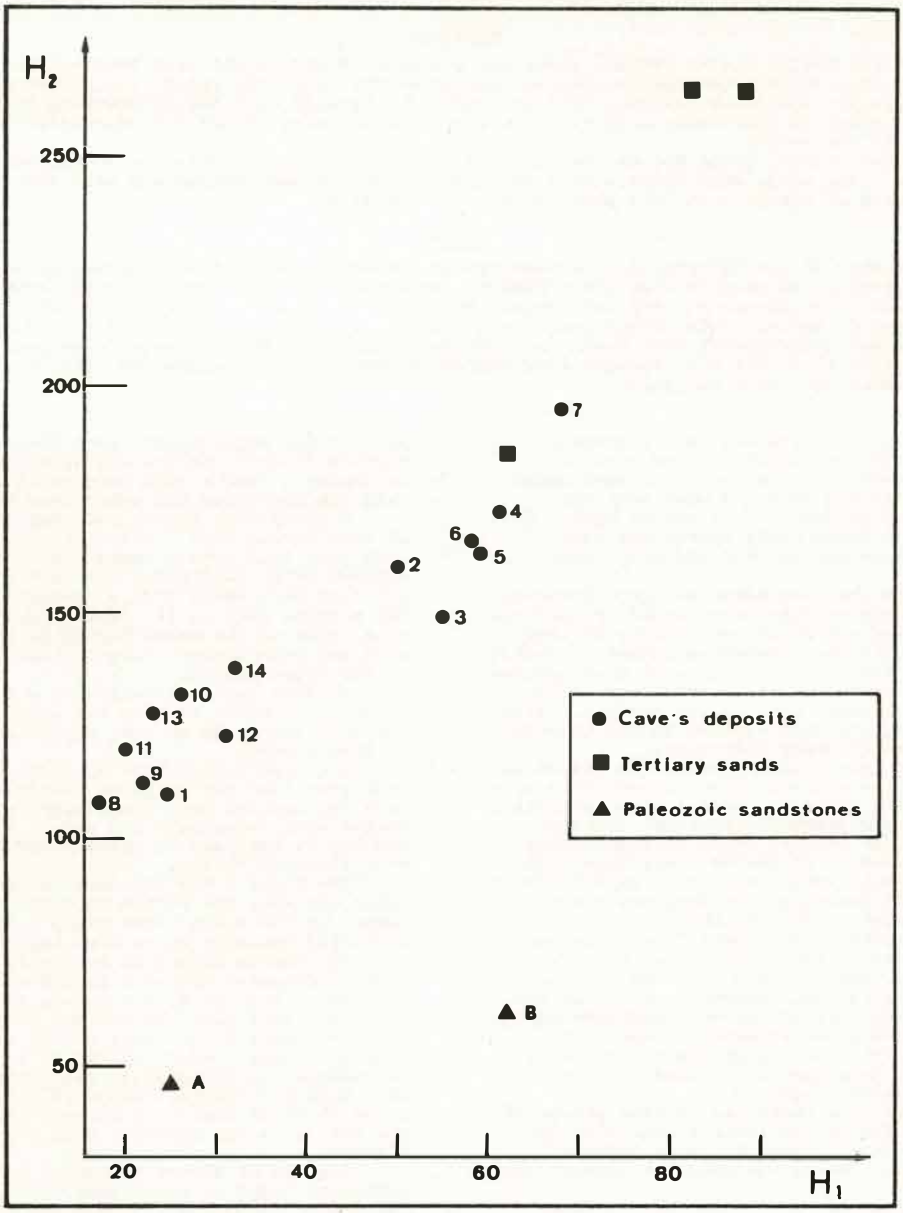

Figure 6. Diagram of H_2 in function of H_1.

A. Emsian sandstone.
B. Famennian sandstone.
1 to 9. Samples of the first section in the cave.
10 to 14. Samples of another section in the same cave.

We see that the samples of the cave distribute into two classes. They clearly belong to the family of the tertiary sands and not to that of the paleozoic sandstones.

Rescue Cave Divers and Their Equipment

Thomas Cook
N.C.R.C. Diving Officer, 378 Webster Street, Manchester, New Hampshire 03104 U.S.A.

Abstract

Within the NSS Caving Diving Section there are a number of people who have been active for several years in the field of underwater rescue, search, and recovery. Over the years, (mostly within the last five), techniques and equipment has been greatly improved. Coupled with the innovations in equipment that have taken place in the diving industry, the rescue diver today stands a much greater chance of accomplishing his job safely.

The equipment display gives you an idea of some of the diving and underwater rescue gear that is used in the U.S. The slide show deals with a practice flooded passage rescue and will give you an idea about the sequence of events that take place in such an operation.

Résumé

Dans la section de spéléologie, il y a beaucoup de personnes qui sont actives depuis plusieurs années dans le travail de secours sous l'eau Pendant les années (surtout dans las cinq dernières années), les techniques et l'équipement ont été très augmentés. Avec des innovations en équipement qui avait eu lieu, le plongeur de secours aujourd'hui peut pieux réussir et accomplis sa mission sans danger.

Le déplorement d'équipement vous donne une idée de l'équipement de secoursqu'on emplore aux Etats-Unis. Dans le film il s'agit d'un secours d'un passage inondé et nous donnera une idée de la succession des événements dans une telle opération.

In the past 10 years there has been a dramatic increase in the use of cave divers in the areas of rescue and body recovery. Up to this time such operations were usually off the cuff and done with the standard sport diving equipment that was on hand. To say the least some of these early operations were hazardous to those involved in them and many times unsuccessful.

The first action that was taken to place competent people in body recovery operations occurred in Northern Florida. Here a large number of cave divers resided and a concern grew over the increasing number of spring diving fatalities. Through the efforts of these people, later to become the cucleolus of the founding of the National Spelogical Society Cave Diving Section. Soon local law enforcement agencies started to use competent cave divers for these recovery operations.

In 1974 the NSS Cave Diving Section was formed and cave diving information started to be disseminated on a large scale throughout the U.S. Cave diving activities started to pick up throughout the country. Most of these diving activities started using Florida diving techniques and equipment. It became clear that such techniques and equipment would need to be modified to work in the cold dark waters of the West and North. NSS sump divers started to do just that.

In 1976 the National Cave Rescue Commission was organized and a Diving Officer appointed. The Cave Diving Section fully supported the NCRC and started to develop underwater rescue and recovery techniques and equipment. Within the past two years underwater equipment designed especially for underwater rescue and recovery has been built. Diving rescue and recovery techniques were also developed and tested in caves, quarries and white water rivers.

At this point in time there are several groups of Cave Diving Section divers available to the NCRC for underground rescue work. There is also a cache of specialized underwater rescue equipment to support their operations.

The NCRC rescue divers are standardizing their equipment and techniques. Not all such divers have such equipment. Through the general consensus among the divers the following equipment and techniques are those that are recommended for underwater cave rescue operations.

A rescue diver will usually have a dry suit, (wet suit for warmer waters), the reason for this is that a diver may have to make repetitive dives which will make him colder and less efficient. For an air source a diver will use a single tank or two singles hooked together with a temporary yoke(s). These tanks have "Y" valves and are mounted upside, (valve end down), down on the back pack. This achieves a complete mechanical redundent system. Doubles are rarely used in cave rescue unless the rescue scene is near the entrance of the cave.

Attached to the tank pack are various waterproof bags containing rewarming and communications eqiupment for establishing a warm camp on the other side of a flooded passage or a sump. The warm camp equipment includes: an underground warming tent, a stove and a pot to heat water in, first aid eqiupment, food and an intercom unit.

Rescue divers usually carry two primary lights and two secondarys. One of the primary lights is a helment light which the diver wears, this protects his head in zero visability and swift currents. These lights are not the super bright type that are commonly used in Florida diving. In the silt out conditions that usually accompany a rescue less intense lights actually illuminate the same area and cause less back scatter.

A heavy duty diving reel may replace the usal type of cave diving reel. This reel carries 150 feet of ¼ inch work line with a commo wire init. In silt out and unknown water conditions a ¼ inch line can be felt better and take more abuse than a thinner line. The reel case has a phone jack in it. When a diver emerges on the other side of the water hazard he plugs in his intercom unit and establishes communication with the other side of the water hazard.

In some cases personal S O N A R units can be used to enable a diver to find his way back to the entrance if for some reason he becomes separated from the reel line or disoriented.

The divers also have specialized hypothermia treatment gear that can be taken underwater. The exposure bag is a two layered bag, lined with reflective nylon and filled with Thinsulate and a foam ¼ inch pad on the back. The bag is designed to prevent any further loss of body heat from the victim.

The C and S hot air unit is used to introduce warm moist air into the victim in order to raise their body temp. It can either work off a 1 liter air bottle or activated manually by an Ambu bag.

The rescue sarong is basically a shorty wet suit that is fastened around a person by the use of velcro closures. This enables a person to be brought through a water hazard with the minimum of discomfort.

The warming tent that can be set up on the other side of a water hazard is mad of 4 mil. PVC sheeting, and is anchored to the passage walls with nylon line. It will hold 3-4 people. The heat is produced by a small stove which is also used to heat liquids. A person in the tent with wet overalls will dry out in 15 to 30 minutes.

The use of divers in rescue in caves involves two different types of operations, different at least from the divers stand point. Sump rescue involves bringing someone through a sump. This is usually a straight forward operation and usually involves few problems, unless extensive injuries and long distances are involved. A more complicated operation is rescue through a temporary water hazard. In this situation people are trapped in a cave by a sudden flooding of an exit passage. Cave divers may be used to either, bring people out or to make their entrappment more comfortable and safer.

When the divers arrive on the rescue scene the Dive Master will collect all relevant information about the situation and formulate a tentative dive plan.

Once at the water hazard a staging area is picked, and a warming tent and equipment area set up.

Depending on the projected length of the dive a "timed recon" team of 1 or 2 divers is sent into the water. The purpose of this dive is to determine such diving variables as current, visability, underwater obstacles, (logs, rocks, etc.), and passage configuration. If the recon diver(s) fails to appear on time a retrieval diver is sent in.

If the Dive Master thinks that his crew can operate with an acceptable margin of safety he then sends in a search team. This team may consist of 1 or 2 divers. They use the work/commo reel as a safety line. If the search team comes up on the other side of the water hazard, they set up their transceiver and give a status report to the Dive Master.

The search team will usually be carrying food, stove warm up tent and other equipment to establish a "warm camp" on the other side of the water hazard.

If the victims are not found right off a diver searches for them and the other erects a warm camp in a suitable location. Once the victims are located then a decision has to be made. Are the victims to remain at the warm camp until the water goes down or are they to be brought out underwater. In most cases the victims will remain at the warm camp. The divers will stay with them, if more supplies are needed the divers will get them. If the victims cannot remain on the other side of the water hazard they would be brought through the passage as in a sump rescue operation.

I hope it can be seen from this paper that divers are a unique resource that can be drawn upon for a cave rescue and their use in water problems should not be underestimated.

I must stress that divers not properly trained or experienced in sump diving and/or rescue practices could be a greater liability than an asset.

The NSS Cave Diving Section

Thomas Cook
N.C.R.C. Diving Officer, 378 Webster Street, Manchester, New Hampshire 03104 U.S.A.

Abstract

The NSS Cave Diving Section is the largest cave diving organizaiton in the United States. Members can be found in almost all of the fifty states. This wide distribution of personnel has broadened the perspective of the section.

Diving activities do not just focus on Florida spring diving. Section members have been involved in numerous other speleological activities such as: mine and sump diving in the northern states, high altitude sump diving in the West, motorized and stag diving in the South, sea cave diving in the Northeast, Bahama Blue Hole surveying and Mexican spring studies.

Offical section projects have included participation in various archaeological projects (in underwater caves), development of underwater rescue equipment, use management studies for springs in state and national parks, holding national technology transfer seminars twice a year and development and implementation of the nations most comprehensive cave diver and instructor training program. The accompanying slide show will serve as a pictoral presentation of the activities of The National Speleological Society Cave Diving Section.

Résumé

La division de spéléologie de NSS est l'organisation la plus grande des Etats-Unis. On peut trouver ses membres dans presque tous les cinquante états. Cette distribution agrandit la perspective de la division.

Les activités de plongeon ne concentrent pas seulement sur le plongeon au printemps a Florida. Les membres sont engagés dans beaucoup d'autres activités de spéléologie. Par exemple, le plongeon des mines dans les états du nord, et "stage diving" au sud, "sea-cave diving" au nord-est, "Bahama Blue Hole surveying", et les études des sources mexicaines.

Les projets officiels compfennent la participation dans des différents projets archéologiques (dans les cavernes sous l'eau), la développement d'équipement pour les secours sous l'eau, les études d'emplore et d'administration pour les sources de l'eau dans les parco nationals et dans les états. Aussi, il y a des séminaires deux fors par année et un programme compréhensif d'instruction pour les instructeurs et les plongeurs. Le film qui suit est une présentation illustré des activités de la Societé Nationale Spéléologie, division de plongeon.

On the Hydrogeological Characteristics of Karst Water in China and it's Exploitation

Yuan Daoxian
The Institute of Karst Research, Ministry of Geology, Guilin, Guangxi, China

Résumé

La repartition inégale est la caracteristique essentielle de l'eau karstique de la Chine, est là non seulement un probleme important et pratique, mais aussi un problème théorique sur la formation du karst.

Un grand nombre de matériaux releves sur le terrain au cours de reconnaissances d'hydrogéologie ont montré les differents niveaux de cette inégalité. Notre article étudie les relations entre ces niveaux et la geomorphologie, la combinaison stratigraphique, la forme de la géologie structurale et les conditions de couverture.

Selon les différents caractères de l'hydrogéologie karstigue, on peut diviser les région de karst en trois categories: region de karst nue, région de karst couverte (par des sédiments désunis) et region de karst caché (par les roches solides indissolubles). Notre article étudie leur état d'existence dans l'eau karstique, les niveaux de l'inégalité, les proprietés caractéristiques de l'eau, les régime de l'eau, et les prospections, les estimations des ressources en eau et les différentes methodes d'exploitation.

The essential characteristics of karst water is the heterogeneity (unevenness) of its distribution. This is not only a practical problem, but also related to some theoretical problems about karst evolution. Numerous hydrogeological exploration data collected from karst terrains in China show there are differences in the degree of such heterogeneity, which in term depends on the shape, magnitude, stretch pattern, and degree of combination and connection of subterranean karst forms. The distribution of different classes of heterogeneity is related to definite geomorphological, stratigraphical, strucral pattern and burying conditions.

The hydrogeological characteristics of various types of karst are quite different. The current method of classification being used in China is to divide karst into bare karst; covered karst (i.e., karst covered by loose sediments); and buried karst (i.e., karst buried by non-soluble bed rock). They are distinguished from each other by the differences in their occurrences, heterogeneity, water quality, and regimes of fluctuation in discharge and water table. These differences also bring about the differences of the methods of prospecting, estimating of water resources and its exploitation.

For the karst aquifer of covered karst and buried karst, the distribution of karst water is relatively homogeneous, and the regime of fluctuation stabler in general, so that the hydrodynamic methods based on Darcy's Law of filtration is still available for estimating water resources. In the karst aquifer buried beneath Mesozoic Red Bed in Sichuan Basin, there is haline water with total mineralization from 100-300g/l, which becomes an important resources of salt.

In the bare karst of South China, the distribution of karst water is very uneven, the main pattern of its storage and flow is subterranean streams. According to preliminary statistics, there are 1140 subterranean streams, with a total minimum discharge of 750M^3/s. Water quality is in general good, with total mineralization below 500 ppm, but is sensitive to pollution. The amplitudes of seasonal fluctuation are in general large, i.e., 10 - 100 times in discharge, and 20 - 100 M in water table. From all the characteristics cited above, it comes that the method suitable for estimating water resources in bare karst regions is chiefly the hydrographic analysis method, and in addition, various types of exploitation are adopted for different local conditions, e.g. construction of reservoirs by damming swallet; subterranean reservoir; pump stations on windows of subterranean stream; drainage tunnels; as well as various forms of Hydro-electric power stations on subterranean streams.

我国岩溶水文地质特征及岩溶水的开发利用

（摘要）

袁道先

（地质部岩溶地质研究所）

岩溶水的最基本特征是分布的不均匀性。它既是个重要的生产实际问题，也涉及岩溶发育的一些理论问题。我国岩溶地区大量的水文地质勘探资料说明此种不均匀性存在程度的差别，它们取决于地下岩溶形态的形状、规模、展布形式及组合联通程度，并受到地貌、地层组合、构造型式、及覆盖条件的控制。

不同类型的岩溶地区，具有不同的水文地质特征。目前我国水文地质工作中流行的分类是分为裸露、覆盖（松散沉积覆盖）、埋藏（非可溶基岩覆盖）三类。它们以不同的赋存状态、不均匀程度、水质及动态特征而带来了不同的勘探、水资源评价和开采方法。

覆盖型及埋藏型地区的岩溶含水层，一般情况下分布较均匀，动态比较稳定，水资源评价方法仍可采用以达尔西渗透定律为基础的地下水动力学方法，开采方式以钻井为主。四川盆地中生界红层下的岩溶含水层，产矿化度达100—300克／升的卤水，成为盐矿资源。

南方裸露型地区，岩溶水分布极不均匀，主要赋存运动型式是地下河，初步统计有地下河1140条，其枯季总流量达750米^3／秒，水质一般良好，总矿化度在500PPm以下，但易受污染。动态变化一般较大，流量年变幅可达10－100倍，水位年变幅达20－100米。根据以上特点，水资源评价主要用水文分析法，其开发利用也因地制宜采用了多种型式，如堵洞蓄水、地下水库、地下河天窗中的泵房、排洪隧洞、以及各种型式的地下河水电站。

（有附图）

On the Underground Stream and Cave Systems of Soliao Karst Area, Bama County, Guangxi, China

Yuan Daoxian
The Institute of Karst Research, Ministry of Geology, Guilin, Guangxi, China

Résumé

La rivière souterraine Suolue prend sa source dans un dôme de structure, a 20KM environ du district Bama du Kouangsi. La distance entre son entrée et sa sortie de la Rivière souterraine est de 14KM à vol d'oiseau. Le noyau du dôme de structure est formé de carbonate du Carbonifère et du permien. Sa surface est une forme morphologique type cône karst, couvert de grés et d'argilite du Trias.

Aux environs de l'entrée, sur une surface de 30KM^2, se trouvent plus de 100 grottes dont les galeries mesurent 15,000M de long. Voici les caracteristiques des trois plus importants systèmes de grottes.

On a décrit la corrosion de tous les systèmes de grottes principaux, l'état d'érosion et les caracteristiques de sédiment des cavernes et on a recherché les causes de la formation des grottes.

The Soliao underground system is situated at about 20km to the west of Bama County. It has a trunk length about 14 km measured in straight line between entrance and resurgence points. The entrance point is located near 107°04'E,24°09'N.

This underground stream is developed in a dome structure which has a diameter 12 km long. Carbonate rock of permo-Carboniferous systems outcrops in the nuclear part of the Dome where typical "cockpit" landscape ("peak cluster" in China) shows. But it is surrounded by normal-shape mountain ridges composed by sandstone and shale of Triassic system. The altitude of mountains is 700-900 m above sea level in general, whereas the highest peak towering up to 1038m. The general flow direction of the underground stream is from Nw to Se. The altitude of mean water level is 491 m above sealevel at Entrance, and 340 m at Resurgence. There is but one skylight along the whole underground course (at Yinhe, with mean water level 372 m above sea level).

Near the Entrance, many caves are found along the northern border of the Dome structure. In an area of 30 km^2, there are more than 100 caves with different size, and on different altitude. The total length of mapped horizontal passages is summed up to 15,000 m. Moreover, there are more than ten jamas deeper than 50 m, among them three are deeper than 100m, and the deepest one is 120 m. In a cave on an altitude of 600 m, (The Lonmo cave, near Naho), there are fossils of 17 species of Mammalia. Among them are Gigantopithecus. This is the fifth cave in China where ~~the fossils of~~ this important species of Mammalia had ~~been unearthed~~. The fauna of Lonmo cave is correlated to Middle Pleistocene.

The features of three main cave systems of the area (from west to east: The Wannai Cave; The Double-Entrance cave; and the Soliao underground stream cave system) are listed in Table 1.

In all these three main cave systems, gravel deposits of fluvial origin are found. The lithological composition of the gravel is chiefly allogenic material such as sandstone, vein quartz, which indicates a gradual emigration of the Swallow point of Soliao surface stream from west to east.

Characteristics of deposits in these cave systems are different. In wannai cave and Double Entrance cave, there are clay layers with a total thickness of 10-20 m, and various kinds of beautiful speleothem, such as dripstone, flowstone, rimstone pool as well as cave pearls. Deposits in the cave system along the modern course of Soliao underground stream is chiefly alluvial gravel.

The accessible part of the trunk passage of Soliao underground stream is 4000 m, and then drowned into a reverse-siphon tube. Diving exploration has not yet got through the reverse-siphon after a slope distance of 80 m and a vertical depth of 30 m underwater. The Height/width ratio of the cross section of the trunk passage reaches 3 (canyon shape) near the Entrance, but reduces gradually to 0.5 (Tubular tube) near the reverse-siphon. However, exploration drillings along the underground passage reveal that the alluvial deposit on the cave floor is thickened gradually inside (15.4 m near Entrance, but over 52 m near siphon tube). So if one reconstructs the original cross section of the passage on bed rock, a canyon passage with a Height/width ratio more than 2 can be got even near the siphon tube, that means the whole 4000 m accessible underground course is originally a canyon passage developed in vadose zone.

Table 1

Name	Total length of cave systems (m)	Trunk passage		Number of Branches	plane pattern	Height of highest point in cross section (m)
		Length (m)	Altitude of floor (m. A. S. L)			
Wannai cave	1,300	1,000	530	1	Y-shape	20
Double Entrance cave	1,600	1,000	520	2	Y-shape	20
Soliao underground stream cave system	7,600	4,000	490-480	16	S-shape	145

广西巴马所略地下河及洞穴系

（摘要）

袁道先

（地质部岩溶地质研究所）

所略地下河位于广西巴马县城西约20公里。主流进出口直线距离14公里。进口大致位于东经107°04'，北纬24°09'。

该地下河发育在一个直径约12公里的穹隆构造中，穹隆核部为石炭二迭系碳酸岩，地面为典型的峰丛地貌，周围被三迭系砂岩、页岩的常态山所包。山高一般海拔700—900米，最高峰达1038米。地下河的一般走向为西北向东南，水面标高进口处为491米，出口处为340米，中间只有一个天窗（阴河，水面标高372米）。

在穹隆北边，地下河进口附近有许多洞穴。在30平方公里范围内，有不同规模的，分布在不同标高的洞穴100多个，共测得水平通道15,000米，还有深度超过50米的竖井10多个，其中有三个深度超过100米，最深的达120米。在那合村附近，标高600米处的弄莫洞，曾发现17种哺乳动物化石，其中包括巨猿，为我国五个发现巨猿化石的点之一。弄莫洞化石动物群属中更新世。

该地区三个主要的洞穴系（自西向东为：晚内洞；眼睛洞；及所略地下河洞穴系）的特征列于表1。

表1

洞穴系名称	洞穴系总长（米）	主洞		支洞数	平面展布型式	横断面最大高度（米）
		长（米）	标高（米）			
晚内洞	1300	1000	530	1	Y型	20
眼睛洞	1600	1000	520	2	Y型	20
所略地下河洞穴系	7600	4000	490—480	16	S型	145

三个洞穴系内都有砾石层，砾石成份以外源的砂岩、脉石英等为主，反映所略地表小河消水点位置自西向东的迁移。

洞穴沉积物也有不同特色。晚内洞和眼睛洞内有厚10—20米的粘土层，并有很好的化学沉积，如滴石、流石、边石塘、穴珠等。在所略地下河进口段洞穴系，以现代河流冲积砾石层为主。

所略地下河进口段洞穴系的主干通道，可通行段长4000米，以下为反虹管所阻。潜水探测到水下斜距80米，垂距30米处仍未通过该反虹管。主干通道横断面的高宽比，在进口段为3：1（峡谷式），而在近反虹管处为1：2（扁平式）。但是洞内钻探说明，洞底冲积物厚度越向洞内越厚，进口处为15·4米，而在反虹管附近超过52米。如恢复洞壁基岩原来的横断面，则反虹管附近也是高宽比超过2：1的峡谷式通道。说明整个地下河通道中可通行的4000米段，原来都是在渗流带发育的峡谷式通道。

附：附图、参考文献。

Analysis of the Structural Control of Speleogenesis of Lilburn Cave, California, United States

Gail McCoy
1263 Yosemite Ave, San Jose, California 94126 USA

Abstract

Lilburn Cave is a complex marble cave 12,000 m long formed by a subterranean stream system. Located in the southern Sierra Nevada in the western United States, the cave lies at 1585 m elevation. The marble, along with schist and metachert forms a roof pendant surrounded by granitic rocks of the Sierra Nevadan batholith.

The frequency, orientation and effect of jointing on cave development vary throughout the cave. Larger passages, developed along sets of parallel, gently dipping joints display rectangular cross-sections. Passages dissolved along steeply dipping joints have acute angular bends clearly associated with the intersecting joints. Pits develop along steeply dipping joints. In contrast, some passages show minor fracture-control of orientation but enlarge along joints where they intersect the passage.

All measured joints have been plotted on Rose diagrams. Surface joints show strong, perpendicular trends of 345° and 70°. In contrast, subsurface joints have a strong trend of 325°. While the 345° trend of the surface joints subparallels the dominant subsurface trend, the other strong surface trend has no comparable subterranean equivalent but rather, aligns with a minor direction for subsurface joints.

Two major components in cavern development, regional waterflow and bedrock fractures, have reinforced each other in this cave. Orientation of the marble lens approximately coincides with the major stream, favoring subterranean waterflow. Extensive joint-sets trending 325° enhance subsurface flow. The strong linearity of Lilburn Cave, trending 345°, apparently results from interaction of joints and regional waterflow.

Zusammenfassung

Lilburn Höhle ist eine Komplexmarmorh-hle 12,000 m lang, die aus einem unterirdischen Stromsystem eststanden ist. Die Höhle befindet sich im südlichen Sierra Nevada Bebirge in den westlichen Vereinigten Staaten in der Höhe von 1585 m. Der Marmor, zusammen mit Gneis und Metachert, formt eine von Granitsteine aus dem Sierra Nevada Batolith umgebene Dachgehänge.

Die Häufigkeit, Orientierung und Wirkung der Klüftung auf die Höhleentwicklung sind in der ganzen Höhle verschieden. Grosse Gänge, die auf Gruppen paralleler, leicht inklinierter Ablösungsflächen entwickelt sind, zeigen rechteckige Querschnitte. Die auf steil inklinierten Ablösungsflächen aufgelösten Gänge zeigen spitzwinklige Bieden, die deutlich mit den Kreuzenden Klüfungen verbunden sind. Grube entfalten sich steilinklinierten Klüftungen entlang. Im Gegensatz dazu, einige Gänge zeigen weniger Bruchkontrolle der Orientierung aber eine Erweiterung die Ablösungsflächen entlang, die den Gang durchscheiden.

Alle gemessene Klüftungen sind in Rose diagramme eingetragen. Oberflächen brüche zeigen starke, senkrechte Streichrichtungen von 345 and 7+ Grade. Im Gegensatz, unterschichtliche Klüftungen zeigen eine starke Streichrichtung von 325 Grade. Obwohl die 345 Grad Streichrichtung der oberflächlichen Klüftungen die dominierende Unterschichtliche paralleliert, die andere starke oberflächliche Streichrichtung hat Kein vergleichbares unterirdishes Äquivalent aber richtet sich mit einer Nebenrichtung für unterschichtliche Ablösungsflächen aus. Zwei wichtige Bestandteile der Höhlenentwicklung, das heisst das lokale Wasserstrom und der Grundgesteinbruch, haben sich in dieser Höhle verstärkt. Die Orientierung der ungefähr zusammenfallenen linsenförmigen Marmorzone fördert den unterirdischen Wasserstrom. Die starke Linearität Lilburn Höhle, mit einer Streichrichtung von 345 Grade, ist anscheinend das Ergebnis der Zusammensetzung der Klüftungen und lokales Wasserstroms.

Introduction

Joints played an important role in the initiation and continuation of speleogenesis of Lilburn Cave. Examination of patterns of jointing present in this strongly deformed terrain, and of influence of joints on the development of this cave clarified the role of bedrock structure in its speleogenisis.

Throughout the cave the dominant joint-set trends 325° while joints measured on the surface, in all lithologies, form two perpendicular sets trending 345° and 70°.

The long axis of the cave trends 345° while the elongate, steeply inclined marble lens trends 350°. Redwood Creek, the major stream, is superimposed on the marble at several points in the canyon and is the principal source of subterranena waters. Two complimentary factors, regional ground water gradient and rock fractures markedly influence speleogenesis in Lilburn Cave.

Geology and Geomorphology of Redwood Canyon

Batholiths form much of the southern Sierra Nevada. Ross (1958) located and classified those plutons and isolated pendants in the area surrounding Lilburn Cave. Metamorphic rocks of the region, including the pendants, have been extensively deformed through regional and thermal metamorphism. The massive marble enclosing Lilburn Cave along with schist and metachert forms the north-trending Redwood Mountain pendant. This pendant consists of steeply inclined, elongate lenses of fine-grained black biotite schist, aphanitic metachert and spectacularly foliated marble.

The marble forms a massive, steeply inclined, linear lens that strikes 350° (Fig. 1). Platey lenses of metachert aligned with foliation in the marble occur rarely but neither these lenses nor the scarce schist nor the irregularly-shaped metachert inclusions extend for more than a few meters.

Fresh exposures of marble, especially in the cave, invariably reveal alternating white to light gray and medium to dark gray bands. This foliation consistently trends north and dips steeply but its expression varies from uniformly thick bands meters long to irregular, isolated patches. Darker, graphite-bearing foliations tend to be more dolomitic and fine-grained (Tinsley and others, these proceedings). Thermal metamorphism resulting from adjacent intrusions recrystallized the marble, obliterating original bedding and other depositional features. The grain size ranges from .75 cm to aphanitic.

Redwood Creek, the axial stream, crosses the marble lens and its dominant joint-set (325°). The latter subparallels both the trend of the marble lens and the overlapping reach of Redwood Creek for approximately .3 km north of the Lilburn Entrance. In this reach, many swallets occur. When stream flow exceeds the capacity of the swallets, some water bypasses the cave; during lower discharges surface water entirely disappears underground.

Big Spring, a vauclusian spring, is the only known resurgence from Lilburn Cave. The spring formed at the downstream edge of the marble/schist contact. Karstic features including swallets, the resurgent spring and more than 50 sinkholes frequently are the only clues to the existence of the marble lens under the valley floor. Thick surficial deposits of granitic debris ranging from cobbles to huge boulders and much loose soil plus thick coniferous vegetation cover most exposures of bedrock.

Lilburn Cave

Some 12 km of surveyed passages form an intricate maze (Fig. 1). All known passages would fit into a north-trending block 120 m deep, 900 m long and 75 m wide. This elongate network has a long and complicated evolution that continues today. Passages can be categorized by their initial development as perennial stream channels or as sinkhole drains.

Common in upper parts of the cave are canyons 10 m deep with half-bute ceilings of the same diameter as the canyon. These passsages typically are maze-like with frequent intersections. Not all of these passages actively collect water but may contribute sediments to the cave through mass-wasting processes. Floors usually consist of mud or sand of unknown depth while walls and ceilings have thick coatings of clastic sediments. This type of passage appears to have developed as a sinkhole drain. Evidenc leading to this conclusion includes the presence of sinkholes at the upper end of these drains, their location in the higher areas of the cave and the abundant sediments coating walls and ceilings.

Certain passages, generally found near the lowest elevations in an area of the cave appear to have developed differently than the sinkhole drains. Streams frequently occur in these passages, which have the form of braided, subparallel channels. Deep, narrow canyons frequently found in areas considered to be sinkhole drains appear uncommon. Cross-sections of these stream channels cannot be easily characterized by shape, some are cone-like, others are subround while still others are irregular. Floors usually consist of granitic sand, bedrock or, least commonly, cobbles; while walls and ceilings lack sedimentary coatings.

These latter passages were formed by a perennial stream. Evidence for this conclusion is the presence of perennial streams, channels similar to typical braided streams, and abundant sediments much like those sediments found in Redwood Creek.

Structural Patterns

Fractures altered the morphology of passages in many ways, depending on the interactions of the density and attitude of fractures, phreatic or vadoes conditions and the direction of the regional ground water gradient. Fractures generally refer to both joints, where no movement of opposing walls have occurred; and to faults, where opposing walls have moved in one or more directions. Faults are an insignificant control on speleogenesis in this cave, as they typically exhibit spectacular offsets of foliation but have no solution associated with the plane of the fault. The following discussion refers only to the effects of joints.

Study of seven areas of the cave helped clarify the influence of bedrock structure on speleogenesis. These sites occur near both ends of the cave as well as high in the cave to near the lowest area in order to determine the structural changes over a three-dimensional area. Sites chosen included ones that cross the narrow direction of this elongated cave. Passages examined include predominantly phreatic, combination and vadose areas.

Attitudes for joints were plotted on Rose diagrams. The Rose diagram for all subsurface data (Fig. 2) clearly exhibits a strong mode of 325°. Lilburn Cave trends 345°. Subparallel trends of joints and this cave indicate the influence of joints on speleogenesis.

Attitudes of joints in all lithologies were collected from surficial outcrops of bedrock. When plotted on a Rose diagram (Fig. 2), a distinct bimodal distribution of 345° and 70° becomes evident. The dominant subsurface trend of 325° subparallels the surface trend of 345°; however, the other surface trend of 70° lacks a clearly matching trend in the subsurface data.

Conclusions

Joints played an important role in the speleogenesis of Lilburn Cave. Joints provided the initial permeability that allowed the first small passages to develop in this massive marble. As time passed, joints continued to influence the trend, appearance and depth of the developing cave.

The dominant trend for subsurface joints, 325° has chiefly controlled the development of this elongate cave. While distinct joint-sets having this orientation do not occur in all areas studied, accumulation of data in the form of a Rose diagram clearly shows this trend. Both gently and steeply dipping joints follow this pattern.

Lilburn Cave trends 345° while the subsurface joint-set trends 325° and the marble is oriented at 350°, coinciding with the major stream. The trend and development of Lilburn Cave was controlled by complimentary factors in speleogenesis - joints, the regional ground water gradient and the orientation of the marble lens.

Acknowledgements

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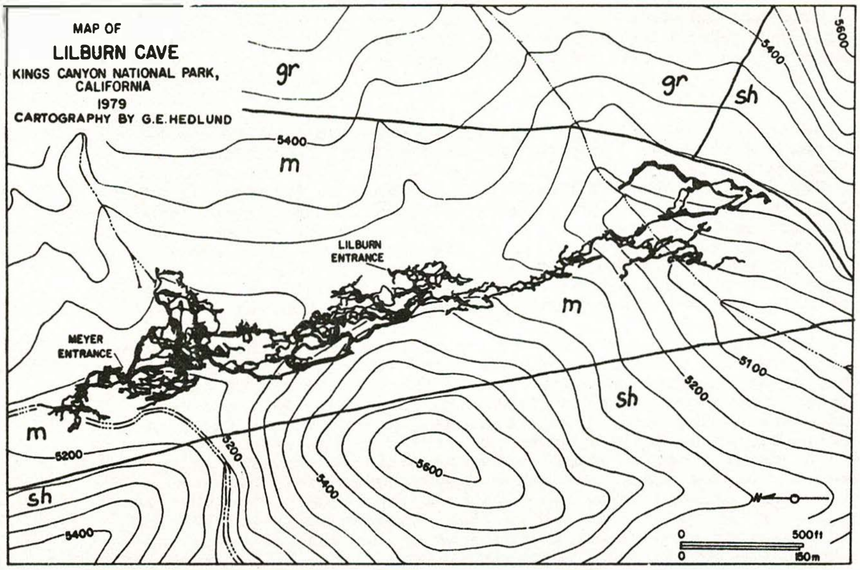

Figure 1. Map showing the relationship between Lilburn Cave, surficial geology and topography. Geologic units are: m-marble; sh-schist and metachert; and gr-granite.

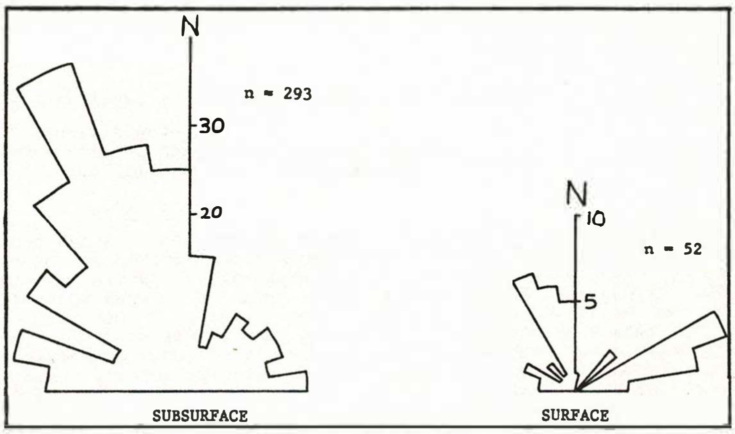

Figure 2. Rose diagrams for all subsurface and surface joints. Plotted orientations are grouped into 10° classes while lengths of rays are proportional to the number of joints per class.

The Climate of Castleguard Cave, Canada

Timothy Atkinson
Climatic Research Unit and School of Environmental Sciences,
University of East Anglia, Norwich NR4 7TJ, England

Abstract

Because of its simple passage layout and considerable length, Castleguard Cave has a microclimate which exemplifies features common to many mountain caves. The cave has two entrances, of which only the lower one is known. The mean annual temperature at the lower entrance at 2000m above sea level is around -3°C, while the surface of the Columbia Icefield above the end of the known cave passages is several degrees cooler. Between these extremes, the cave has a warm core, up to +4°C in the central section. The difference between core temperature and surface temperatures gives rise to a vigorous convective draft which blows inwards and upwards at c.50m³ per minute in winter and reverses direction in summer. A reversal occurred for two short periods at 12-36 hours in April 1980, when external temperatures ranged between +10°C and o°C averaging approximately 5°C, slightly warmer than the core temperature. The Castleguard draught is thus a very well-developed case of the "chimney effect" draughts described by Wigley and Brown.

The cave interior is well above mean annual surface temperature and appears to be maintained by the geothermal heat flux. Measurements were made over a 4 day period of air, rock, water and sediment temperatures between the entrance and the ice plug at the far end of the cave. The results showed differences of up to c.1°C between wall and air temperatures, which are attributed to transient heat storage effects associated with the warm weather conditions during April 1980. Seasonal heat storage effects might also be expected to occur and will be investigated on a computer model of airflow in the cave.

The moisture regime of the cave in winter conditions was investigated by making a traverse of relative humidity measurements from the entrance to the ice blockage. Water vapour transport increases in a downdraft direction indicating evaporation from the walls with relative humidity reaching 97-100% within 1000m of the cave entrance. Once the warm core of the cave is passed air temperatures begin to fall and vapour transport decreases. This change is indicated by a marked increase in the wetness of walls and sediments from the dry conditions found between the entrance and the warmest core. Both temperature and relative humidity show local variations related to the influx of seepage water into the cave.

The distribution of evaporite minerals on the cave walls and in sediments is clearly related to the pattern of evaporation and water supply. Evaporites are entirely absent where rate of water supply exceeds evaporation rates, but are abundant in areas where relative humidity remains constant or decreases in a downdraught direction.

Mechanisms of Calcite Speleothem Deposition in Castleguard Cave, Canada

Timothy Atkinson
Climatic Research Unit and School of Environmental Sciences,
University of East Anglia, Norwich NR4 7TJ, England

Abstract

The pattern of radiometric dates on speleothems which have grown in northern Europe and North America during the last 100,000 years suggests that widespread deposition appears mainly to occur by de-gassing of CO_2 from vadose drip waters, a process which requires a vegetated soil cover and CO_2 pressures greater than atmospheric values. These facts have led several workers to conclude that calcite speleothems can be used as an indicator of past climate in areas formerly affected by periglacial or glacial conditions, with widespread deposition indicating temperature conditions and curtailed deposition indicating cold climates. But Castleguard Cave is the world's only extensively known cave extending beneath glaciers, and it contains actively depositing calcite speleothems, even in the parts of the cave beneath the Columbia Icefield. What are the mechanisms by which this calcite deposition is occurring? Are they the result of factors unique to Castleguard or could they occur anywhere? Do the Castleguard speleothems disprove the general conclusion that speleothems growth is most typical of non-glacial climates?

Calcite deposition from water films and drops in caves may occur as a result of four possible mechanisms -

(i) A calcite-saturated solution may lose CO_2 gas to the cave atmosphere, causing calcite supersaturation and precipitation.
(ii) The solution may be partially evaporated, causing supersaturation and deposition.
(iii) Calcite, a relatively insoluble mineral, may be precipitated as a result of the solution dissolving dolomite or gypsum.
(iv) The temperature of the solution may change, causing supersaturation.

The chemical composition and physical environment of the drip waters of Castleguard Cave were studied in 1979 and 1980. The results show that the waters have evolved in contact with calcite, dolomite and a source of sulphate (gypsum or pyrite oxidation) in the rocks above the cave. Calcite supersaturation and precipitation appears mainly to be due to solution of first dolomite and sulphate and later continued sulphate solution (mechanism (iii) above).
Evaporation (ii) has been shown to occur, but at rates which account for only 1-10% of the deposition rate of larger calcite speleothems. De-gassing of CO_2 (i) is not important, confirming for the first time that this process plays no part in speleothem growth in cold caves. Mechanism (iv), temperature effect, has not been proven but if occurring it probably plays a minor role.

The Castleguard calcite speleothems owe their existence primarily to evolution of drip waters in the system $CaCO_3 - CaMg(CO_3)_2 - CaSO_4 - H_2O - CO_2$. Depositions of calcite by a similar mechanism will occur elsewhere under temperature conditions given the availability of the right minerals. Thus, before interpreting ancient speleothems as an indicator of non-glacial climates, attention should be paid to establishing that present-day speleothem growth in the same area is due to CO_2 de-gassing, which is climatically controlled, and not to complex mineral dissolution, which is not.

The Air Movements in the "Grotte De Nieaux" (Ariege) Consequences

Claude Andrieux
Laboratoire souterrain du C. N. R. S., Moulis 09200 Saint-Girons, France.

Abstract

The present paper deals to air movements in the "grotte de Niaux" (Ariége-France) during ten years (1971-1980).

The data (observations measurements) have been obtained, upon an average, each week; they relate to the direction of underground air movements, to the speed and to average air flow which have been measured at some places, as cave entrances.

The results show two types of air movements. In the first one, the gas exchanges between the cave and the outside happen through the galleries and the known entrances and also through all the fractures of the carbonate rocks. When it occurs, the cave can be divided in three main parts, each one having their own characteristics. The second one is observed only during very rainy times; the all cave is then subjected to air movement according to the "wind tube model". The air exchanges through the fractures are fixed by the percolation. The percolation zone is consequently submitted to diphasic waterflow.

Therefore, differents models of air movements in caves must be considered. These data show also it is needful that the air flow should be measured to understand the climatic phenomenons of the caves.

Résumé

Cette étude traite de la ventilation générale dans la grotte de Niaux (Ariége-France) au cours de la déconnie 1971-1980.

Les mesures et observations, effectuées régulièrement à raison d'une série hebdomadaire en moyenne, concernent: le sens des écoulements de l'aire souterrain, les vitesses de ventilation et les débits moyens correspondants évalués au niveau de certaines ouvertures.

Les résultats mettent en évidence deux régimes différents de l'écoulement de l'air. L'un fait apparaître que les échanges gazeux se produisent avec l'extérieur non seulement par l'intermédiaire des galeries et ouvertures accessibles à l'homme mais aussi à travers l'ensemble de la masse rocheuse par l'intermédiaire des fractures de tout genre qui l'affectent. L'autre est observé pendant les périodes trés pluvieuses, ce qui présente donc un caractère assez exceptionnel, pour lequel l'ensemble de la grotte est le siège d'un régime de circulation de l'air selon le modèle du "tube à vent" ; les échanges gazeux à travers la masse rocheuse semblent liés à l'importance de l'infiltration. Ainsi, la zone d'infiltration est essentiellement soumise à un écoulement diphasique.

Ces résultats conduisent à reprendre les différents modéles utilisés pour rendre compte des circulations d'air dans les grottes et indiquent la nécessité de réaliser des mesures de débit d'air si l'on veut effectivement comprendre les phénomènes climatologiques de ces cavités.

An Underground Thermal Stream Discovered For the First Time in Kweichow Province, China

Mao Chian-Chun
Kweichow Engineering Institute, Kweiyang, Kweichow Province, China

Abstract

In the course of field-work in November 1980, the Terrestrial Heat Scientific Research Group of Kweichow Engineering Institute discovered for the first time an underground thermal stream within the boundaries of Nan-Qiao Production Brigade, Shi-Gu People's Commune, Hua-Qiao District, 27 kilometres from the county town of Shih-Chian.

On the left side of Kai-Xia River valley lies this underground stream, the water temperature and discharge measured on Dec. 25, 1980 at the outlet are 32° - 34°C and 16.59 litres/sec. respectively. On Nov. 21, 1980, we spent a lot of time in search of an opening for going into the underground passage. The one we found lies 5 metres high above the outlet and it is so narrow that we had to crawl into it.

In the underground thermal stream passage we measured the mean depth of the water to be about 1m. with a maximum of 1.4m. The passage at a place about 200 metres up-stream from the outlet was found blocked by heaps of rocks, which might have been the result of collapse of the funel wall, so that we couldn't go any futher. The temperature of the water in the cave was found remaining between 32°C - 34°C but that temperature of the water gushing out from the crevice in the tunnel was as high as 43°C. No cold water had been found to mix with the warm stream water in so far as the underground stream reach we have observed. Near the opening we found the air temperature measured was 12°C but it rose rapidly to 34°C as we came into the cave. Obviously the underground thermal stream was developed in a tectonic fracture which occured in the moderately thick strata of dolomitic limestone belonging to the TongziZu of the ordorician's lower series. The cave trends from NNE to SSW. The tunnel averages 3 metres high with a maximum of 7m. and 3m. wide (maximum 8m.) and the water occupies only 1.2m of its width. The flow velocity is about 10 centimetres per second. The stream has a discharge of 30 litres per second (Findings mentioned above obtained on Dec. 25, 1980). Only some tiny "stone flowers" were found in the cave. The stalagmite growing there are also very small not more than 5 centetres high. No stalactites had been found. In the thermal water yellowish black silt constitutes the only sediment, which amounts to 20 - 40 centimetres thick. There are no deposit of pebbles and sand whatever at the bottom of the stream. A great number of bats were found to live in the cave and lots of shellfish and small fish in the thermal water.

The underground thermal stream was developed in a big fault zone which runs from ENE to WSW. It is believed that the unprecedented discovery of the underground thermal stream together with the further research of its origin and characteristics is of great significance in the study of terrestrial heat, karst, speleology and new tectonic movement in Kweichow.

Some Problems of Cave Names

Paola De Simonis
Via Campo Di Marte 2, Firenze, Italy

Abstract

This paper deals with some aspects of caves nomenclature in Italy and particularly in Tuscany by taking into account international examples also.

The names of caves as a whole are distinguished from those which refer only to some parts of them, because they are very different in origin, sense and function. The first ones, when are due to the inhabitants of the region, are to the popular culture and traditions. The second ones, on the contrary, represent the consequences of the choice made arbitrarily by the speleologist inside an place without names.

These speleological nomenclature can in this way be considered altogether a sort of anthropological micromodel, which is useful to understand some general rules which, even outside caves, have determined and continue to determine the attribution of names.

Résumé

L'ouvrage prend en examen quelques aspects de la toponomastique spéléologique toscane et italienne en se servant même de comparaisons sur échelle internationale. On distingue, étant donné leurs profondes différences d'origine, de sens et de fonction, les termes qui désignent la cavité toute entiére dans son complexe de ceux correspondants à une plus ou moins détaillée articulation.

Les premiers, dans la mesure où ils ont été crées par les habitants du lieu, renvoient en effet, plus précisément, à des considerations et à des problémes liés à la culture et aux traditions populaires. Tandis que les seconds représentent la consquence des choix connotatifs opérés arbitraiément par les spéléologues à l'interieur d'un milieu incontaminé même du point de vue des dénominations.

Ces spéléonymes peuvent donc être considérés, dans leur ensemble une sorte de micromodele antropologique utile, aussi que trés partiel, pour l'individuation d'au moins quelques uns des critéres généraux quim même au dehors du monde hypogée, ont réglé et/ou continuent de régler l'action toponomastique.

Sommario

Il lavoro prende in esame alcuni aspetti della toponomastica speleologica toscana ed italiana avvalendosi anche di raffronti su scala internazionale. Vengono distinti, in quanto profondamente differenziati per origine, senso e funzione, i termini che designano l'intera cavità nel suo complesso da quelli corrispondenti ad una sua più o meno dettagliata articolazione.

I primi, quando siano dovuti agli abitanti del luogo, rimandano infatti più specificamente a considerazioni e problemi legati alla cultura e alle tradizioni popolari. I secondi rappresentano invec la conseguenza di scelte connotative operate arbitrariamente dagli speleologi all'interno di un ambiente incontaminate anche dal punto di vista delle denominazioni.

Questi speleonimi si possono quindi considerare, nel loro insieme, una sorta di modello antropologico utile, anche se molto parziale, per l'individuazione di almeno alcuni dei criteri generali che, anche al di fuori del mondo ipogeo, hanno regolato e/o continuano a regolare l'azione toponomastica.

Speleo-. like many of its learned colleagues called back from the classical world this prefix also fullfills the cosmopolitan role asked of it, meaning in various different languages, object of science that unites us. However it is a question of slight thickness, that hardly cracks, we actually involve ourselves in what for me is a buca but for my colleagues from other regions of my country will be a grave and for those of another nation a cave. The datum can seem to be even too much discounted and devoid of consequences only for he who considers the languages as repertoire of etiquette marking the same objects: an attitude which, being taken to an extreme, is portrayed in the beating by the professor in Ionesco's Leçon, and according to which Rome is called Madrid in Spanish. As can be seen, the problem is, in reality, far more complex: not all terms from one language to another cover the same semantic field, in as much as they care "definites not positively so for their content but negatively so for their relationship to other terms in the system" (1). Yet even the limited sphere of the speleological toponymy confirms that "a particular organization of experimental data corresponds to every language" (2). For some an underground cavity will be a refuge or hiding place, for some an object to study, an opportunity for adventurous explorations, or a ritual site; some will look upon it with fear, others with indifference. The hypogean environment therefore takes on different names because men establish relationship with it, which are different during time, space and social stratification; because like every other actual datum, the hypogean environment is not composed of elements which, for themselves, correspond to the elements of pronounced sentences. Language does not exist within reality but has been created by man to serve him: "language is as old as coscience, language is the true conscience...language, like, conscience only arrives from necessity from the need for relationship with other men" (3). As a result of this it cannot be said that balma is a translation of höle, or that büs is a translation of abime: similarly it was useless to attempt establishing whether busa mean buca, dolina, or cave, whilst however marvelling at the semantic polivalence of the term or ethnocentrically motivating that polivalency likes a popular "error." At times there have been attempts to find a univocal term as well as a definitive precisiness typical of modern science, amongst a mass of names produced from an agricultural-pastoral world, which is certainly not imperfect but surely guided by its own logic, mentality and interests. It has been said for example, that "speleological societies should place the corresponding dialectic term [the underlining is my own] beside every generic italian term" (4). But it is precisely this which is not possible because it is a question of bringing together very different extentions and forms in semantic areas. The relationship cave/shepherd probably differs from that cave/peasant; as cave/french shepherd differs from cave/sardinian shepherd: and they all differ from cave/speleologist. It is not therefore that büs might mean fissure but also cavern, or pit, the fact is that for some it is a question of varying references and for others it is not. For the person who limits himself to looking into every opening in the earth whilst remaining outside, that opening will be a büs whilst he who explores it and discovers it to be a hundred metres deep will talk of it as an abyss, so as to distinguish it clearly from caves of a horizontal course. Speleology must rightly tend towards individualizing and fixing precise, rigorous terms: this however will be more easily realized if the dialectical terms eventually chosen will have a meaning based on new foundations, independent of their origins which do not belong to the scientific world.

With this series of considerations I will now coherently examine some aspects relative to speleological toponymy. Firstly, I will take the names formed before the arrival of speleologists. From an examination of these, even if summary, some fundamental criteria about definition come to light. For the man who is not speleological but rather of the peasant/shepherd type, the cave has had the function of a refuge: balma = protruding rock, of mediterranean origin stretching over a vast area in the field of toponymy, which goes from Catalognia, to France, to Belgium, to southern Germany, to the German and Swiss parts of Switzerland and as far as the Italian Alps. Tecchia, feminie of tecchio = roof, from the Latin tegere = to cover, which in the Apuane Mountains is equivalent to natural refuge. Grotta, from the Latin crypta which is from the Greek xpunty' = covered way, cavity. (As a note: in Tuscany the semantic evolution of tecchia and grotta which probably for synedoche, also mean stone, protrusion and precipice). In some instances the cave has also taken on an economic role: a container of snow for sale to wealthy households in the town: nivèra (Sicily), niviera (Puglia), giazera (Brescia). Otherwise the cave is "described" f[illegible]ts form: arnale (the southern part of Lazio) comes from the mediterranean origin arno and holds the value of river bed. Cala (Sardinia) = creek, comes from the Spanish cala which is however mediterranean in origin.

Gouffre (France) comes from the late Latin colpus which is from the Greek κόλπος = creek or vagina. Foiba (carnia) comes from the Latin fovea = ditch. The hypogean lay out appears in tana (Italy, the Swiss Alps and Savoy in the form tane, tannaz) which comes from cave sub(tana), which is underground. Often one finds the idea of "hollow": borna(Val d'Aosta), bornale (French Alps), borno (Languedoc) from a Ligurian origin borna = opening in a tree. Cave (France) from the Latin cavus, and cueva (Spain) from the Latin covus, parallel from of cavus. Tavono, taffone (Corsica) which stands for hole, opening. Metaphors exist with references to objects: coppo (Abruzzo) from coppa = cup; giara (Liguria) from the Arabic giarra = water recipient. There are frequently references to the human body based on that process of projective identification for which "a person tends to recognize his own body in the world" (5): la fronte del ghiacciaio (forehead of the glacier), il ciglio del fosso (the eyelid of a gutter), la lingua di terra (a tongue of land), il cuore della foresta (the heart of the forest) etc. In speleology there is: gorgozzo (Umbria) from the Latin gurgutia = gola (throat); urégia, oregion (como), dialectic terms = ear. Buca, from the late Latin buca, variant of bucca = bocca (mouth) to which (like fosso from fossa) links buco = (hole), often however with the allusive sense of orefice, anal or genital. In the past the cave has been considered an oral entrance in to the underground world: the Sibil's cavern at Cuma was the mouth of Avernus; the value of the wide open jaw is confirmed by the presence of the snarling Cereberus. In a like manner the northern underworlds are watched over by the dogs Gifr and Gess. Further to this, in the medieval "diableries","the cavity of hell was made from a wide curtain, on which was depicted the gigantic terrifying head of the devil" (6). With his mouth wide open. Furthermore "the medieval legends speak of numerous trous in different areas of Europe, which were considered the entrance to purgatory or hell and which, in the same period, in the vulgar tongue, were given an obscene meaning." (7). In the popular mentality os, uterus and anus were much less distant from one another, than they are for us today: the fact is part of a series of conceptions where start and finish are tied together, where continuous permutations are realised between high and low, heaven and earth. "In the grotesque world the mouth corresponds to the intestine and to the uterus" (8). Amongst many populations "the bosom of the earth is represented by a ditch or hole" (9). According to a fundamental myth from Guyana "in times long since passed men and animals did not have an anus and defecated through the mouth" (10). Correlations among corporeal orefices also transpire from the current tradition amongst Yurok Indians and is attested by ancient European beliefs recorded by Pliny:" the woman giving birth must keep her mouth closed in order that the child may pass freely from the vagina" (11). There is no lack of cases of antonomasia (La Buca = The Cave) obviously motivated by a narrowness of cognitive horizon, but normally all these generic terms are flanked by the specific ones which serve to distinguish the different cavities. Similarly, in this case, other general criteria can be cited, which however given the difficulty of finding the material in question refer almost esclusively to the Tuscan abmit: animal names, names of trees situated in the neighbourhood, names of persons, names of neighbouring localities, descriptive elements. Lastly, the traces and remains of popular beliefs can be in names of some caves: 1) Grotta del Drago (Cave of the Dragon), del Serpente (of the Snake). "From the discovery of fossil vertebrate thought to be remains of unicorns, dragons and basillisks or from the observation of the bone breccia left from the remains of the victims, arose the legends of their slaughter at the hands of saints, heroes and knights" (12). 2) Natural phenomena of collapse of a dolina were interpreted as divine punishment: Pozzo del Diavolo (Pit of the Devil) at Gaeta, Casa affonnata (Agro Pontino). 3) The cave can be a hiding place, secret refuge, usually negative (Buca dei ladri, dei briganti = Cave of robbers, thieves) but in Tuscany remains the memory of the struggle against the nazis in the Apuanine Buca of the partisans. 4) Archaic cults of the waters are so called owing to the Grotta Delle Pocce lattaie (Pienza) and the Tomba lattaia (Cetona) where there are "formations of stalagmitic figures, which with the continuous trickling of water rich in calcium, take the form of dripping udders" (13). In the rural civilization they feared the attack of evil forces that could deprive the new-born of the milky liquid, indispensable for growth. To reactivate the secretion of milk they took the waters, which on account of their calcium salt content, gave them a lactescent appearance and as such were considered suitable for homeopathic action (simila similibus); to this the iconic-allusive function of the udder concretions is added. 5) There are in Tuscany numerous Buche delle Fate (Caves of the fairies) which coheres to the belief that caves were the privileged seats of nymphs, elfs and other divinities; this fact also corresponds to one of the most widely difused medieval traditions, according to which one of the three kingdoms of the fairies was situated in the depths of the arth. However only a capillary investigation will be able to furnish us with more precise indications as to whether fata (fairy) is a generic term, "a sort of common denominator in that ambit which from the multiple attributes and from the various different activities could be considered as benevolent or evil figures." (14) A complex stratification of myths stand behinds the Tana dell'Uomo Selvatico (Cave of the Wild Man) in the Apuanine Mountains. The Wild Man is a character legendary for his repulsive looking, hairy face but gifted with an indisputable wiseness: it was he who taught the shepherds the technique of milking. This contradiction of wise/wild dissolves only to sink deeply back in time: at the roots of the Wild Man there does in fact stand an old agricultural demon of fertility, the satyr with a hairy body, with goats hooves, "king of the underworld, the prince of darkness and of fertility" (15). We know that the Wild Man lived "in antro" (16) (in a den) in the classical tradition and one reads and knows of him in the middle ages where although christianized, he reappears in the clothes of Marcolfo (17) and later those of Bertoldo (18), the popular stupid and ragamuffin heroes, who do however succeed in embarrassing kings and scholars with their logic impregnated by the old "culture diaboli". In France it is La Fontaine who proposes him anew (19) whilst in the celtic world Wild Man, Wilder Mann (20) had in the meantime also became an imp, gnome and elf. Others have seen in the Wild Man (but such an hypothesis is not ncessarily different from previuos ones) "the progressive degeneration of Hercules not withstanding the theological attempts to make him a christian symbol" (21). As witness there is the club alwais associated with the two figures. As already stated the toponomastic field of vision can only profoundly change with the arrival and intervention of the speleologists. Something analogous has already happened in the alpine world: the names of mountains had been for centuries, those created by the inhabitants of the place. The mountains had been for centuries, those created by the inhabitants of the place. The mountain was a work environment, the limits of which were the pastures; the peaks and the areas with which it was not possible to have a productive relationship did not interest anybody and nobody went there. As such "only the highest peaks had a name and these names were more or less the same in all the Alps...almost all the oldest names in the Alps are to be found in the zone of Chamonix"(22). But with the appearance of industrial mechanization so arose the development of sport: the physical activity not tied to work. It shows itself so "a dicotemy ever more resolute of work-free time a worship of movement and evasion not otherwise recuperable" (23). It is obvious that owing to such a new attitude that which was insignificant before and therefore indistinct became individualized: now every summit constitutes a goal. From now on the names will not depend on the community that lives and works in a place but from a single alpine climber that comes from the outside world: his conquists will carry its name or it will be he who dedicates them to someone or by them desires to remember an experience he has had. We owe "L'Aiguille de la Republique to the patriotic sentiments of E. Baujard and the Canalone degli Dei, Via Eterna, Via della Solitudine, Via della Tribolazione to conceptions which show traces of romanticism and of the myth of the "superman". Similarly, in speleology we place the learned abissi and antri, side by side, with bus of the vernacular, with the arnali of dialect, and with the ingenuous oregion. Among the criteria of further specifications remain that of the proximity to certain localities, but that of the dedication to someone stretches over all else. Another new fact is that even some components of the inside of the caves are subject to denomination. Purely descriptive terms emerge (scivola = slipway, fessura = crack, strettoia = narrow passage) but also metaphos which this time are not related to the human body but to strongly cultural references, corresponding to a period in history when man now forms the metaphors inspiring himself to a reality which is ever less natural and ever more marked by his intervention: galleria (gallery), sala (hall), salone (large hall), camera (room), portale (portal), vasca (basin). It would also be interesting to examine closely the system followed in the attribution of names: for example when and why do they get given and who gives them, whether indifferently given by any member of an exploratory group or by he who has the role of leader in particular; whether anything has changed with the growth in speleology of feminine participation, with respect to when the woman was only the maid of honour in whose name heroes entitled lakes and abysses. An instance worthy of note is that offered by fiume (river) and lago (lake), terms which in a grotta corresponds to water references, which on the surface would never have been defined in such a way because of their restricted dimensions. The justification is perhaps to be found in the fact that in the subterranean environment the water courses do not show strong differentiations in size: consequently it results in the lack of a hierarchy, ceases to function as a comparison with the surface world and therefore the more generic name comes to prevale, that which is less marked, whick according to Zipf's principle (the laws of minimum force (24) is used more frequently. Amongst the trends today which could be taken and made use of, above all for wells, is the one that simply employs the use of letters and/or numbers: it would be necessary to check if the reason dwells in the adoption of explorative techniques, which yielding to individual progression, have done away with the sociality, structurally connected with the use of ladders and safety ropes. However this archivistic logic and that opposite to it coexist, and the latter creatively avails itself with metaphors. "A metaphor can be understood only, if on the one hand, the linguistic code is common, to he who produces it, and to he who hears it, and on the other hand only if the perception of the similarity of elements in question is also common to both" (25). However in speleology, given the singolarity of the situational context, the metaphors are valid almost exclusively within a very narrow social nucleus, identifying itself with the jargon: it is a question of individual metaphors, not destined to be made lexical and be introduced into common language. Only one example: in the Grotta di Monte Cucco (Umbria) there is the Pozzo del Gytsmo because, with this name, in a science fiction novel, read by the first explorers, there were extra terrestral beings which "cut off breath", exactly what befell the speleologists coming up from the deep well. Therefore in some ways it seems that, since speleological activity also represents a means of evading daily reality, the creativity of speleological metaphors tries to react to the social inhibitions, that restrains the symbolism and allusive style and instead promote a language ever more technical and denotative. These are sympthoms both as real as they are minimal of an uneasiness in the confrontation with socio-existential macro-situations which will certainly not change in virture of the hypogean activity and metaphors.

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Limestone Hardness and Tropical Karst Terrain Types

Michael J. Day
Department of Geography, University of Wisconsin, Milwaukee, Wisconsin 53201, U.S.A.

Abstract

The hardness and compressive strength of limestones which give rise to tropical karst terrain in the Caribbean and Central America were measured using a Schmidt Test Hammer. Different terrain types, recognized on a mathematical basis, are developed consistently on limestones having markedly different hardnesses. "Doline Karst" is developed on the softest limestones and "tower karst" on the hardest.

Zusammenfassung

Die Härte und Kompressionsresistenz von Kalkformationen, welche tropischen Karstlandschaften in der Karibik und in Zentralamerika zu Grunde liegen, wurden mit Hilfe eines Schmidt Test Hammers bestimmt. Unterschiedliche Landformtypen, die mathematisch erfasst wurden, entstehen konsistent auf Kalkgestein mit jeweils unterschiedlicher Härte. "Dolinenkarst" entsteht auf den weichsten Kalkgesteinen, "Turmkarst" auf den härtesten.

Introduction

The mechanical properties of limestones are as important in controlling landform development as are the chemical contents, despite the fact that the denudation of limestone terrains is accomplished essentially by the chemical and petrologic nature of the rock they are no less influenced by mechanical factors and ultimately these are probably more important in determining whether, for example, steep slopes are developed and maintained in a limestone terrain. Despite the increasing awareness of material properties as important control in landform development (Strahler, 1952; Yatsu, 1966, 1971; Walley, 1976), little attention has been given to these in the context of limestone topography, this despite the comment of Yatsu (1971) that "Karst provides a good example of rock-controlled landforms, ..."

One particular aspect of rock mechanics which is important is the strength of the material in terms of resistance to stresses imposed by erosive agents. Surface strengths, both compressive and shear, are obviously of critical importance in this context. One problem which has been paramount here is that of sampling, either in situ or in a controlled laboratory situation. Geomorphologists, particularly those working on tropical karst, have been, and indeed still are, unable to effectively measure mechanical properties because of the paucity of equipment in such areas and the difficulties of transportation of bulk samples.

This problem has been partially overcome by the development of in situ mechanical testing using portable instrumentation which, although necessarily less accurate than sophisticated, but cumbersome laboratory equipment, provides a means of field investigation of rock properties. Such an instrument is the Schmidt Concrete Test Hammer (Type N) which has been used extensively in this study to determine the in situ surface compressive strength of limestone.

The Schmidt Hammer and its application in geomorphology have been discussed in some detail (Day and Goudie, 1977; Day, 1980). The hammer operates on the principle of rebound distance from a controlled impact, the elastic recovery depending upon the surface hardness which is itself related directly to mechanical strength. The accurate, quick and non-destructive test of surface hardness may be a better measure of resistance to erosion than the internal compressive strength of the rock.

The Schmidt Hammer is light, portable, robust, reasonably accurate compared with conventional triaxial compression apparatus and not subject to significant operator variance. Furthermore it is not affected by temperature variations, although surface wetting does produce a reduction in surface rebound values (Day and Goudie, 1977).

By use of caliberation curves it is possible to convert the measured rebound values into compressive strength (Day and Goudie, 1977; Yaalon and Singer, 1974). This conversion has not been carried out in this study as the primary interest is in the comparative hardness of limestones, which is adequately reflected by the rebound values, rather than in their specific compressive strength.

Procedure

In field use the practical constraints indicated (Day and Goudie, 1977) were all exercised. All values presented here are the mean of at least 10 separate impacts, and all values are corrected for horizontal impact (i.e. impact on a vertical surface). Repeated tests on one spot, location near to "edges" and testing of dirty and non-planar surfaces were avoided.

Results

Table 1 presents a summary of the results obtained from Schmidt Hammer testing of unweathered limestones in Central America and the Caribbean; Table 2 indicates comparative data from other limestone areas. Limestones are highly variable in terms of their compressive strength and, within the range of strengths exhibited by other limestones, the Caribbean and Central American examples are not unusual (Table 2). In terms of compressive strength, they present a representative limestone sample ranging from very soft to very strong materials. The softest (non-weathered) limestones recorded are the poorly lithified Pleistocene limestones in Barbadoe (<10) and Yucatan (<10) and the poorly lithified beds in the other Yucatan limestones (15.0 and 19.1). Among the lithified older limestones the softest is the Aymamón limestone of Pureto Rico (12.5). The hardest limestone recorded in the study is the dolomitic Peten limestone of Yucatan and Guatemala (Mean R Value 39.9). Surface hardness often exceedsinternal hardness as a result of case-hardening (Monroe, 1966; Day, 1978; Ireland, 1979).

Correlations Between Hardness and Other Material Properties

Mechanical strength might be expected to vary with differences in chemical composition and petrographic nature of the limestones as these relate to density, coherence and porosity. Petrographic analysis and determination of insoluble residue contents support this suggestion (Day, 1978). To summarize, there is a negative correlation between limestone purity, as expressed by the insoluble residue content, and the compressive strength; the hardest limestones are those with the highest percentage of non-carbonate material. Although the inclusion of non-carbonate material indicates a heterogeneous rock in which differential compaction might be expected, the primary non-carbonate mineral, silica, adds to the hardness of the rock and does not reduce compaction and coherence. Thus compressive strength is more dependent on internal structure and texture than upon the mineralogical center.

Petrographic analysis indicates that the three lithologies which exhibit the highest Schmidt Hammer hardness values, the Peten dolomitic facies, the Belize dolomitic facies and the Troy limestone of Jamaica, are all dolomitic (Day, 1978).

Compressive strengths for the other textural groups are similar although the predominance of biomicrites over other groups makes it difficult to assess the constancy of any distinction. Biomicrites and biosparites have similar compressive strengths yet micrites, whose low porosity might be expected to result in higher strength, have R values rather lower than average for the other groups. The two biosparities have R values very similar to those of the biomicrites, 34.7 as opposed to 34.2. Sparites are slightly higher, 35.2, and micrites slightly lower, 33.7 than these (Day, 1978).

Hardness and Terrain Type

Although limestone hardness has been shown to be a factor influencing the development and maintenance of individual landforms,such as the Pinnacles of the Gunong Mulu National Park, Sarawak (Day, 1980), no previous attempt has been made to investigate the association between hardness and overall terrain type.

Tropical karst terrains may be classified as one of three types (Day, 1978, 1979, 1981):

Type I: Terrain characterised by enclosed depressions of all types and subdued hills.

Type II: Terrain in which enclosed depressions and residual hills attain approximately equal prominence.

Type III: Terrain characterised by isolated residual hills separated by extensive near planar surfaces.

Analysis of the hardness values of limestone giving rise to the three terrain types in the Caribbean and Central America indicates an association between terrain type and mechanical strength. Type I terrain is developed on limestones having a mean R value of 32.5, Type II on limestones with a mean R value of 35.2, and Type III on limestones with a R value (ignoring the Aymamôn of Puerto Rico) of 37.6. Application of the Kruskal-Wallis H test demonstrates that there is, at the 0.05 level, a significant difference between the R values obtained in the three terrain types; limestones on which Type III terrain is developed demonstrates the greatest mechanical strength and those on which Type I terrain is developed exhibit the lowest R values. This result ignores the Puerto Rican Aymamôn limestone where Type III terrain is developed on a limestone which demonstrates extremely well developed surface hardening and hence higher effective surface R values (Day, 1978; Ireland, 1979).

Thus the most upstanding and spectacular forms of Type III terrain are developed on limestones with the greatest mechanical strength and, by inference, the ability to support large, steep-sided features such as towers. Relatively subdued Type I terrain, by contrast, is associated with limestones having low mechanical strengths.

This finding must be treated judiciously as the sample size is small and the predominance of biomicrites makes it difficult to investigate the role of petrographic character. However, the results suggest that the influence of mechancial strength upon karst landform development is worthy of continued attention.

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Table 1

Summary of Schmidt Hammer Hardness Values for Unweathered Limestones, Central America and the Caribbean

Location	Lithology	R value $\bar{x}$	R value s	Number of Impacts
Mexico (Yucatan)	Carrillo Puerto	35.9	2.97	40
"	Poorly lithified beds in above	19.1	0.77	20
"	Piste	35.7	3.05	20
"	Poorly lithified beds in above	15.0	1.00	10
"	Pleistocene limestone	26.5	0.81	10
"	Poorly lithified beds in above	<10.0	0.00	10
"	Dolomitic Peten limestone	40.1	2.11	50
Guatemala (Peten)	Peten limestone	37.9	1.90	30
	Dolomitic Peten limestone	39.7	1.25	35
Belize	Dolomitic limestone	39.8	2.87	30
	Biomicrites	38.2	2.51	40
	Micrites	38.2	2.51	25
Jamaica	Montpelier	32.6	2.21	40
"	Browns Town	32.1	2.32	80
"	Walderston	29.7	2.50	30
"	Swanswick	36.3	1.25	200
"	Bonnygate	30.4	2.01	30
"	Somerset	33.1	3.22	20
Puerto Rico	Lares	35.2	1.02	40
"	Aguada	34.5	0.91	140
"	Aymamôn	12.5	3.78	110
"	Lower Ponce	35.2	2.11	20
Antigua	Antigua Formation	33.3	4.27	55
Guadeloupe (Grande Terre)	Miocene limestone	33.4	2.13	40
Barbados	Pliocene limestone	29.8	2.12	35
"	Poorly lithified Pleistocene limestone	<10.0	0.00	15

Table 2
Schmidt Hammer Hardness Value for Other Limestone Areas

Location	Lithology		R value $\bar{x}$	s	Number of Impacts
Florida (U.S.A)	Pleistocene oolitic limestone	(s)	33.0	1.12	50
		(f)	31.4	0.50	10
	Eocene limestone	(s)	39.2	2.25	70
		(f)	38.4	1.09	30
Indonesia					
(1) Sulawesi (Maros)	Dolomitic limestone	(s)	48.2	0.08	260
		(f)	37.5	1.92	160
	Tufa	(s)	51.3	3.17	20
	Flowstone	(s)	34.3	1.02	40
		(f)	23.8	1.11	40
(2) Jave (Gunung Sewu)	Eocene(?) limestone	(s)	40.5	0.92	80
		(f)	21.2	1.71	60
Indiana/ Kentucky (U.S.A.)	Saint Genevieve limestone	(s)	38.3	1.96	100
		(f)	37.5	2.27	30
	St. Louis limestone	(s)	34.6	2.21	70
		(f)	32.5	3.78	20
	Salem limestone	(s)	37.8	4.51	30
	Girkin limestone	(s)	31.6	2.72	20

(f) indicates fresh, unweathered sample values

(s) indicates weathered surface sample values

Contemporary Limestone Erosion Rates in Gunong Mulu National Park, Sarawak, East Malaysia

Michael J. Day
Department of Geography, University of Wisconsin, Milwaukee, Wisconsin 43201, U.S.A.

Abstract

Weight losses suffered by pre-weighed limestone samples implaced in the Gunong Mulu National Park indicate that potential erosion rates are high within the range previously documented. These high rates, nearly 200 mm/1000 years beneath an alluvial soil cover, are a function of environmental conditions, particularly high annula temperature, rainfall and biological activity. The use of limestone samples of different shapes is discussed and experimental data is presented to justify mathematical standardization. The effect of petrologic variation is examined with particular reference to the samples used and the solutional behavior of the Melinau Limestone. Results suggest that the actual rate of erosion of the Melinau Limestone is about 40% of that experienced by the implaced samples.

Zusammenfassung

Gewichtzeinbussen vorher gewogener Kalksteinproben verschiedener Herkunft und Form, die im Gunong Mulu Park verteilt wurden, deuten darauf hin, dass potentielle Erosionsraten innerhalb der an anderem Ort dokumentierten Variationsbreite hoch sind. Diese hohen Raten, fast 200 mm/ 1000 Jahre unter einer alluvialen Bodenecke, sind eine Funktion von Umweltbedingungen, wie besonders hohe jährliche Durschnittstemperaturen, hohe jährliche Niederschläge und eine reiche, aktive Biomasse. Die Verwendung von Kalksteinproben unterschiedlicher Form wird diskutiert und experimentelle Daten werden vorgeführt, welche eine mathematische Standardisierung rechtfertigen. Die Auswirkung petrologischer Unterschiede auf das Erosionverhalten wird im Hinblick auf die Testproben im Vergleich mit den anstehenden Melinau Kalken untersucht. Resultate deuten darauf hin, dass die tatsächliche Erosionsrate der Melinau Kalke etwa 40% derjenigen der verteilten Testproben beträgt.

Towards a Numerical Categorization of Tropical Karst Terrains

Michael J. Day
Department of Geography, University of Wisconsin, Milwaukee, Wisconsin 53201, U.S.A.

Abstract

Tropical karst terrain is composed essentially of positive and negative landform units, residual hills and enclosed depressions respectively. Both can be expressed mathematically in terms of the ratio of their vertical component (C_v) compared with their horizontal component (C_h). On the basis of this ratio twelve types of landform units are recognized, six positive and six negative. Any terrain may then be classified in terms of the classes of its positive and negative components. The classification has a total of 36 possible unit associations which fit into a general framework of three terrain types:

Type I: Terrain characterised by enclosed depressions of all types and subdued hills.

Type II: Terrain in which enclosed depressions and residual hills attain approximately equal prominence.

Type III: Terrain characterised by isolated residual hills separated by extensive near planar surfaces.

Zusammenfassung

Die tropische Karstlandschaft besteht im wesentlichen aus positiven und negativen geomorphologischen Einheiten, nämlich Vollformen (Resthügel) und Höhlformen (eingeschlossene Depressionen). Beide können mathematisch im Verhältnis ihrer vertikalen (C_v) zur horizontalen Komponente (C_h) ausgedrückt werden. Auf Grund dieses Verhältnisses lassen sich 12 Einheiten von Oberflächenformtypen erkennen, 6 positive und 6 negative. Jede Landschaft Kann daraufhin nach ihren positiven und negativen Komponenten Klassifiziert werden. Die daraus resultierende Klassifikation umfasst 36 mögliche Landform Assoziationen, die in einen allgemeinen Rahmen von 3 Landschaftstypen passen:

Type I: Landschaften, die durch eingeschlossene Depressionen aller Art und durch Restvollformen charakterisiert sind;

Type II: Landschaften, in denen eingeschlossene Holformen und Restvollformen ungerfähr gleiche Prominenz aufweisen.

Type III: Landschaften, die durch isolierte Restvollformen charakterisiert sind, welche durch weite fast ebene Oberflächen getreent sind.

Introduction

Morphometric techniques proposed previously (Balazz, 1973; Williams, 1971, 1972a,b) are not applicable throughout the range of tropical karst terrain, but in combination they provide a potentially useful tool for the characterization of such terrain on the basis of the morphology of individual landform units. In the context of a simple classification, these methods are extremely valuable; they are less useful in terms of a methematical expression of the overall terrain character.

Tropical karst terrains have been expressed in terms of three general types (Day, 1978, 1979):

Type I: Terrain characterized by enclosed depressions of all types and subdued hills.

Type II: Terrain in which enclosed depressions and residual hills attain approximately equal prominence.

Type III: Terrain characterized by isolated residual hills separated by extensive near planar surfaces.

These three terrain types represent portions of a spectrum involving positive and negative landform units, residual hills and enclosed depressions respectively. These units can be used to give a finer index on the basis of their relative morphologies. Balazs (1973) classifies positive units, residual hills, on the basis of their height/diameter ratio; a similar approach has been adopted to enclosed depressions by reference to their depth/diameter ratios (see Day, 1978). Combination of these two techniques provides a useful indication of overall terrain character.

Procedure

Both positive and negative landforms can be expressed mathematically in terms of the ratio of their vertical component (C_v) compared with their horizontal component (C_h). On the basis of the C_v/C_h ratio, twelve types of landform units may be recognized, six positive and six negative (Fig. 1). Assuming that it is composed of a combination of these individual units, any terrain may be classified in terms of the classes of the positive and negative components. For example, a terrain composed of type 2 positive units and type 1 negative units would be ascribed to category 21 and a terrain containing type 3 positive and type 4 negative units would be classified as 34 (see Fig. 2 for example).

This classification system is most readily applicable where the terrain is composed almost entirely of distinct positive and negative landform units, i.e. in Type II terrain. It can, however, be applied to Type I and III terrain in which the majority of the terrain is not composed of distinct units. In Type I terrain, negative units are most conspicious and amenable to morphometric analysis. These units are, however, separated by extensive positive areas which can also be classified by recourse to the morphologic index. Similarly, in Type III terrain, distinct positive units are separated by extensive planar or negative areas. Where these extensive areas are not definable in terms of enclosing boundaries they can be classified by reference to a transect line joining the distinct positive unit individuals. Such extensive areas treated in this way never occupy unit classes higher than I, positive or negative, and are generally of type 0 (Fig. 1).

Discussion

This system of classification is flexible in that it can either apply to combinations of distinct units or to distinct units and the extensive areas which separate them. In this respect, it is not entirely consistent in terms of scale, being concerned only with the relative shape of landform units and the areas separating them. In Type II terrain this scale problem is not as marked as in Type I and III terrain where individual units and the areas which separate them are of different orders of magnitude.

One problem associated with this classification is the determination of boundaries of individual landforms. In Type II terrain the positive and negative units overlap conspicuously limits being drawn at the peak and trough crests (Fig. 3). In Type I terrain, negative units are defined in terms of their perimeter as evidenced by a change in slope angle (see Day, 1978); this method is also applied to the delimitation of positive units in Type III terrain. In both Type I and Type III terrain the delimitation of the extensive, inter-unit areas is not as crucial as it rarely affects their unit classification.

Despite its limitations, this simple method is capable of indicating consistently the overall nature of the terrain on the basis of individaul landform associations and it forms a basis for the classification of tropical karst terrain. Individual units, positive or negative, vary to some extent, although rarely deviating more than a single class in any given area, and the ascription of an area to a specific category depends on the mean morphometric nature of the units. Figure 2 illustrates both this particular point and the typical use of the method.

The classification derived using these criteria has a total of 36 possible unit associations. These may conveniently be fitted into the more general framework of the three terrain types proposed previously.

Where the category of the positive and negative components diverges by two or more units the one having the higher value can be argued to be dominant in terms of visual appearance and contribution to the overall nature of the terrain. Where values differ by less than two units both positive and negative components are of similar importance. Figure 4 demonstrates how, on this basis, the 36 combinations may be ascribed to terrain Types I, II and III.

This method, although extremely elementary, provides a rapid yet reliable index of terrain type and a basic means of classification. Its reliability depends largely upon the accuracy with which individual landform data is acquired. This is best gained by field survey, as employed dominantly hereto (Day, 1978), but can also be derived from maps and air-photography, or a combination of these sources. The major problem associated with the use of air-photographs is the difficulty of obtaining accurate altimetric measurements under dense vegetation cover. Maps are inaccurate both in this respect and in the representation of plaimetric data, for example consistenly understating the numbers of enclosed depressions and overestimating the height of residual hills (Day, 1978).

Acknowledgements

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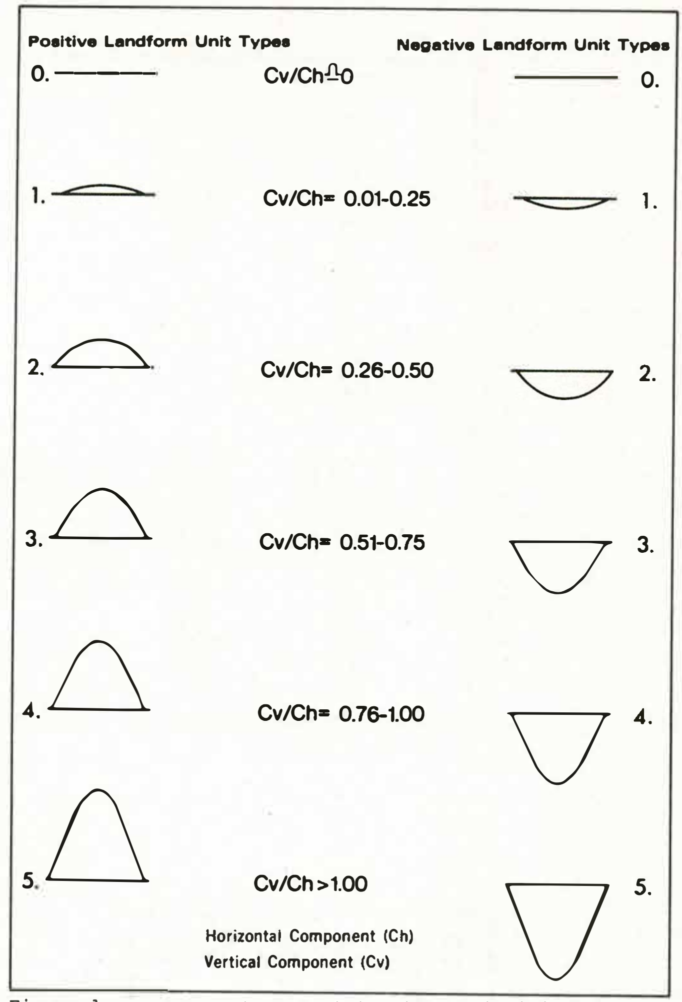

Figure 1. Morphological delimitation of individual positive and negative landform units

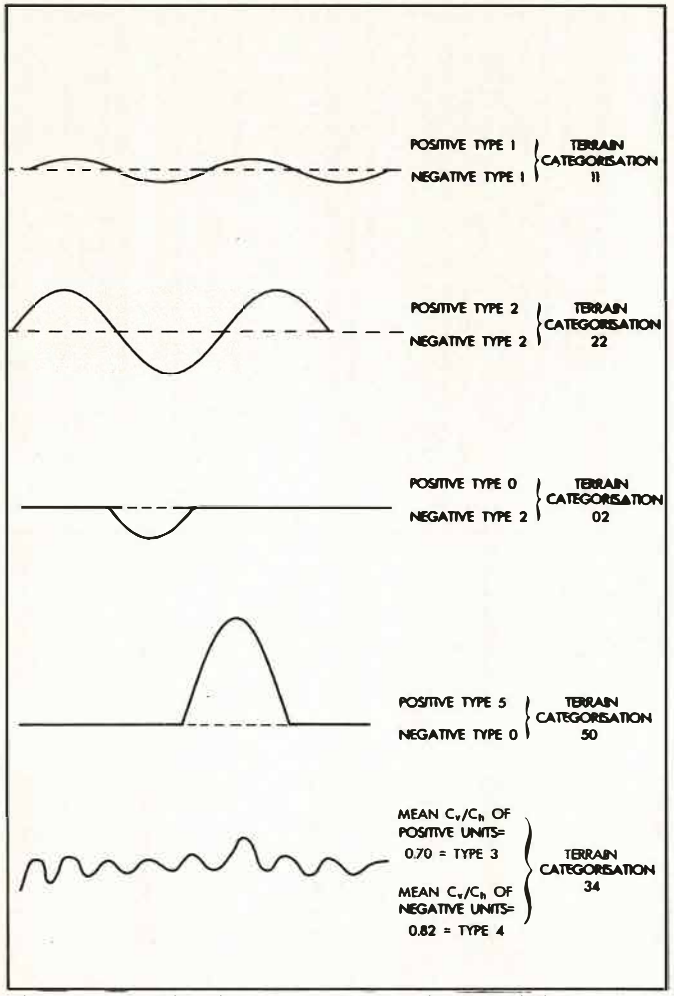

Figure 2. Application of landform unit classification in some theoretical tropical karst terrains

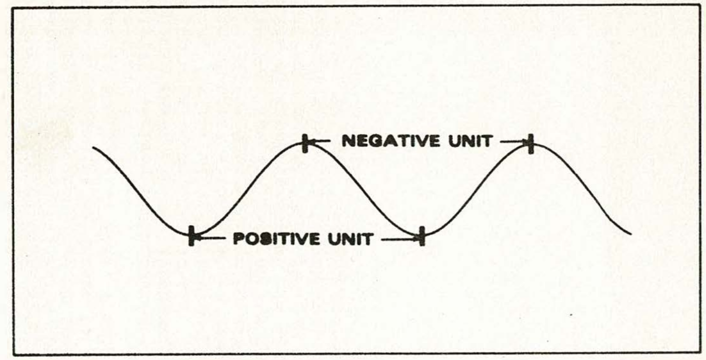

Figure 3. Delimitation of landform unit boundaries in Type II terrain

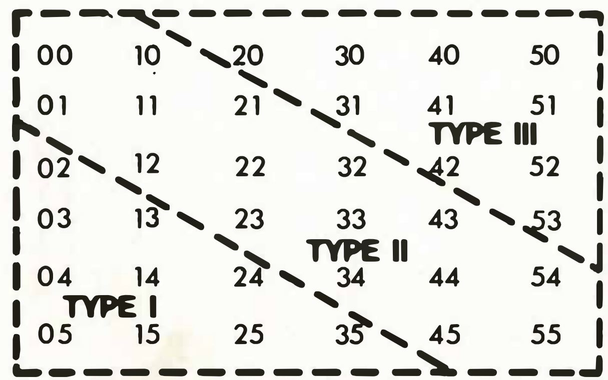

Figure 4. Terrain types on the basis of landform unit associations

Variation of Conduit Flow Velocities with Discharge in the Longwood to Cheddar Rising System, Mendip Hills

P. L. Smart
Department of Geography, University of Bristol, Bristol, BS8 1SS, England

Abstract

The results of 16 quantitative dye tracer tests under varying discharge conditions between the stream sinks at Longwood and the Cheddar resurgence (2.68 km) are presented. The travel time shows a non-linear relation with discharge, increasing more rapidly as discharge falls, but showing only minor increases at high flows. The time/concentration curve of dye at Cheddar indicates increasing dispersion with decreasing discharge, probably related to the increasing dead volume of the conduit. Multiple dye peaks suggest that a branched flow route is present, the relative significance of each branch changing with resurgence discharge. Even at low flow a pulse-test indicates that only a small proportion of the conduit is vadose. Some possible model configurations to explain these characteristics are proposed.

Résumé

Les résultats des 18 traçages du perte de Longwood à la résurgence de Cheddar (2.68 km) aux conditions hydrologiques divers sont réprésentés. La rélation entre le débit et la vitesse de circulation est non-linéaire, la vitesse augmentant rapide aux débits décroissantes mais montrant une décroissance minimale pendant des crues. La courbe de concentration en function du temps à Cheddar resurgence suggére une réparation augmentante aux débits décroissantes, peut-être le résultat de l'accroissement du volume passif du drains. Des Maxima multiples du concentration suggèrent un système de drainage bifurcant, la signification rélative des branches individuelles changeant aux débits de l'exutoire. Même pendant les étiages, la portion vadose du drain soutérrain est petite. Plusieurs des configurations du functionnement hydrodynamique des Karsts sont proposés.

Introduction

Longwood swallet on the southern flank of Black Down (Mendip Hills) is formed at the juntion of the impermeable Lower Limestone Shales and the purer upper Members of the Carboniferous Limestone Succession. Water derived from springs in the Limestone Shales and the underlying Old Red Sandstone sinks at three places in the valley floor, which continues dry beyond the most downstream flood sink. The water is again seen underground for 360m in August/Longwood Swallet cave, where it unites into a single stream in the Downstream Series. Its course is then unknown until it resurges at Cheddar 2.68km distant. The resurgence is complex with at least two discrete openings and a sequence of springs from talus into the bed of an artificial lake over a distance of 100m.

Methods

Rhodamine WT dye was used for all traces. It was injected upstream of the highest known stream sink and downstream of the gauging flume (ST 496557), in amounts varying between 20 and 8bg. Samples were collected at Cheddar resurgence below the falls leaving the lake (ST465539), thus integrating inputs from all known springs. Sampling frequency on the Rock & Taylor 48 Internal Sampler varied between 1 and 4 hours depending on flow. Both sink and resurgence discharge were continuously measured using Monroe water level recorders, and a fibreglass flume at Longwood and current-meter-rated section at Cheddar. Discharges are accurate to ±10%.

Results

Variation of Travel Time with Discharge

Travel times were calculated for the time of first arrival and the dye pulse centroid (the time at which 50% of the injected tracer has been discharged from the resurgence). The form of the travel-time/discharge graph (Fig.1) is not substantially different for these two measures, but the centroid travel time is a better measure of the average velocity of the traced water, time of first arrival being representative only of the fastest flow filaments. Travel-time shows a direct but non-linear relation with discharge, increasing rapidly at low discharges, but changing relatively slowly at the highest flows. The range of values is very large from 828 hours during the lowest gauged flows to 20 hours at the highest. Clearly it is therefore important to consider resurgence discharge when using conduit flow velocities in Karst areas.

The relation of travel-time, which is the inverse of velocity when considered beween any two points on a channel, and discharge can be modelled for two end members. Firstly in a wholly vadose (free air surface) conduit an increase in discharge is accommodated both by increase in channel cross-sectional area and increase in velocity. For surface streams increase in velocity contributes approximately one third of the increased discharge, while width and depth together produce two thirds (Leopold and Maddock, 1954). However in rectangular channels of constant width on the Mendips, measurements have shown that velocity changes accommodate two thirds of the discharge variations. In contrast for wholly phreatic (confined water-filled) conduits, increase in discharge can only occur by an increase in velocity, the channel crosssection being invariate. Therefore phreatic conduits will have a slope of -1.0 on a plot of log discharge and log travel time, while vadose and partially vadose conduits will have a slope less than -1.0 but probably greater than -0.3.

Replotting the Longwood-Cheddar data (Fig.2) and computing the best fit regression line, the gradient is -1.20 for all data or -1.0 if the two lowest flow tests with complete dye recovery are excluded (both significant at 99% level). The conduit is therefore clearly phreatic in nature. This was confirmed by a simultaneous flood and dye pulse test at low flow, which indicated only 9% of the conduit between the end of the August/Longwood cave stream and Cheddar was vadose (Smart and Hodge, 1981). Two other Mendip conduits have also been multiple traced (Stanton and Smart, 1981, in press), and again these are wholly phreatic (Fig.2). This is undoubtedly due both to the down-dip flow direction from swallet to resurgence, and the massive nature of the Carboniferous Limestone, which encourages conduit development below resurgence level.

The product of travel time and discharge in a pipe gives a meausre of pipe volume. If this relation is applied to the Longwood-Cheddar data, excessively large conduits volumes are obtained (3.78×10^5 m^3, equivalent to a 13.4 m diameter straight-line conduit, compared to known abandoned conduits of 3 to 4 m in diameter). Thus the resurgence discharge cannot arise wholly from the traced conduit, which must have a lower flow. However, because proportionality is maintained between the Longwood conduit discharge and that of the resurgence, the gradient of the log/log plot is not affected.

Variation of Tracer Dispersion with Discharge.

Fig. 3 presents selected time/concentration curves for Cheddar rising, converted to an injection equivalent to 195 ml of 20% Rhodamine WT (fluorescence is directly equivalent to concentration if temperature corrected). It is apparent that with increasing travel-time the curves become less peaky with increasingly long tails and lower dye concentrations. This is not caused by a decrease in dye recovery as the mean for all tests with complete sampling was 103% with a standard deviation of ±10.7%. The variation is adequately accounted for by gauging errors alone. There is therefore a significant increase in dispersion with decreasing conduit discharge. This is probably caused by the progressive increase of deadzone volume in roof pockets, blind chimneys, bends and boulder-chokes as velocities and turbulence are reduced at low flows. Dispersion of dye into these stagnant waters on the rising limb of a dye pulse, and slow release on the falling limb alernate the dye peak, and cause substantial tails to develop. Similar explanations have been advanced for tracer tailing in surface rivers (Nordin and Troutman, 1980) and work is now in progress to model this phenomena.

Multiple-Peak Dye Curves

The dye-curves (Fig.3) are also multi-peaked, even though significant flood pulses did not occur. This could not be due to the different sink points, because water movement was too rapid in the vadose zone to generate such delays, and the water from all sinks combines in the cave streamway. It must therefore be due to the presence of multiple conduits. Centroid travel times were therefore recalculated for individual peaks after separation by eye, and plotted against resurgence discharge (Fig.4). Three separate conduits can be separated from the resulting scatter of points because each peak for a single injection must lie on a different line. In all cases highly significant regression lines could be calculated with gradients of -1.08, -1.00 and -0.76 respectively for conduits 1 (the slowest), 2 and 3 (the fastest). Whilst conduits 1 and 2 appear to be wholly phreatic, conduit 3 could either be partially vadose, or composed of two separate segments, the high flow section of which is essentially vadose (slope -0.4 to -0.5). Unfortunately it is difficult to separate the multiple-peaks precisely, the data is thus too scattered to distinguish between these two possibilities.

As for the unseparated data the conduit volumes are excessively large, the data were therefore replotted using the swallet discharge, the minimum possible conduit flow (Fig.5). It was again possible to distinguish three main conduits, although in detail the interpretation differs from Fig. 4. Conduit 3 does in fact represent two separate units with markedly different slope. Furthermore there appears to be a minimum travel time for both conduit 1 and conduit 3A, suggesting that the head on both these conduits is controlled by an overflow system, probably represented by conduit 3B (high flow). Conduit 2 is not represented in the data for flows in excess of 30 l/sec, but all three conduits function simultaneously over a wide range of flows, with only conduit 1 active at the very lowest values studied. The onset of overflow conditions for conduits 1 and 3A appears to be controlled primarily by aquifer rest water level rather than conduit discharge because all points on the sloping segments of the plot are during low water level conditions in autumn and summer (excluding summer storms). This is also true for conduit 2. The distributary system must therefore lie depth in the aquifer. This interpretation relies wholly on the plot of measured swallet discharge against travel time, however when differential dye distribution is considered the pattern does not appear although the gradient of the plot steepens towards -1.0. Furthermore swallet flows are very variable, and if thresholds are present this could considerably complicate the anlaysis. These problems are at present receiving further study.

Conclusions

The Longwood-Cheddar coduit on preliminary analysis appears to be a relatively simple phreatic tube, the properties of which can be used to explain both the variation of tracer dispersion and travel-time with discharge. More detailed analysis suggests that the situation is more complex with multiple conduits, flow in which is controlled both by aquifer water levels and by overflow sytems dependent on the Conduit discharge.

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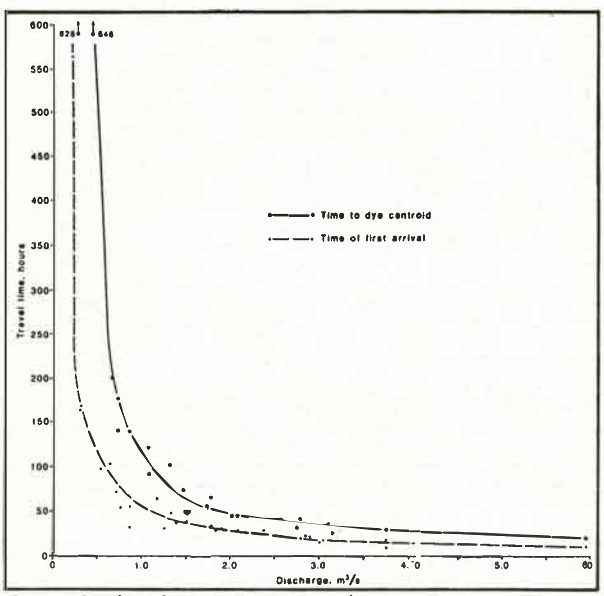

Fig. 1. Relation between Travel Time from Longwood Swallet to Cheddar Resurgence and Discharge at Cheddar.

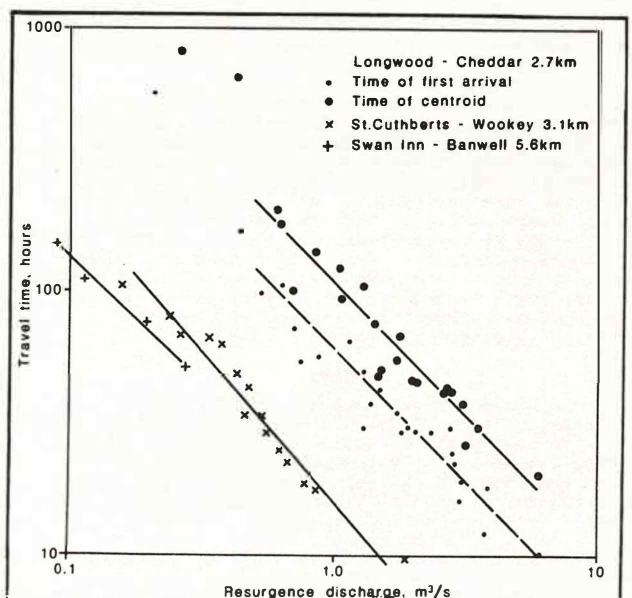

Fig. 2. Logarithmic Plot of Travel Time and Discharge for the Longwood-Cheddar, St. Cuthberts - Wookey and Swan Inn - Banwell conduits (based on time of first arrival) (Stanton and Smart, 1981, in press.

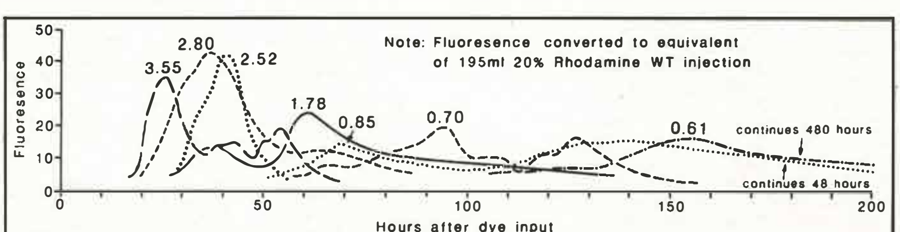

Fig. 3. Time/Concentration curves at Cheddar Resurgence for selected injections at Longwood Swallet. Figures above curves are discharges of Cheddar Resurgence at dye centroid in m^3/S.

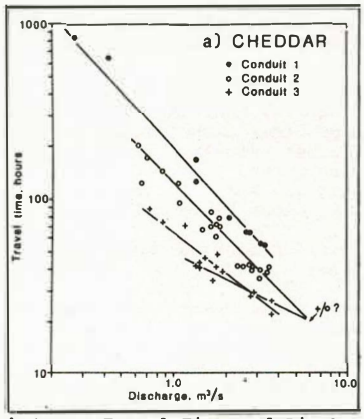

Fig.4. Relation between Travel-Time and Discharge at Cheddar Resurgence for separated data (based on time to centroid).

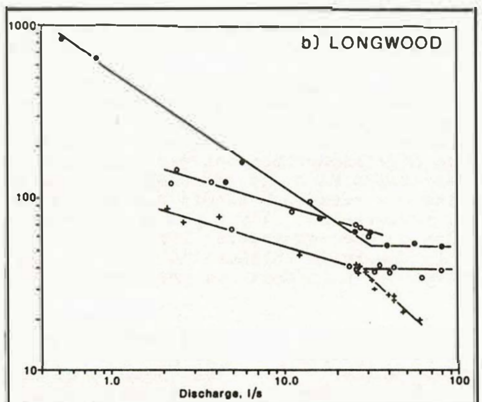

Fig. 5. Relation between Travel-Time and Discharge at Longwood Swallet for separated data (based on time to centroid, key as for Fig. 4.).

The Inner Bluegrass Karst Region, Kentucky: an Overview

John Thrailkill, Phillip E. Byrd, William H. Hopper, Jr., Michael R. McCann, Lawrence E. Spangler
Joseph W. Troester, Douglas R. Gonzie, and Kevin R. Pogue
Department of Geology, University of Kentucky, Lexington, KY. 40506, USA

Abstract

The Inner Bluegrass Karst Region of Central Kentucky, which has an area of about 5600 km^2, is in nearly horizontal limestone (with minor amounts of other lithologies) of Middle Ordovician age. It is geographically and stratigraphically distinct from another extensive karst (a portion of which has been termed the Central Kentucky Karst) in Lower Carboniferous rocks. The present population of the Region is in excess of 350,000 and increasing, and the Inner Bluegrass Karst Project was initiated in 1976 to assist in the solution of problems of water supply, pollution, and other karst-related hazards, as well as to investigate the fundamental nature of the Region.

Area studies of the Region include field reconnaissance, dye tracing, and approximate discharge determination of springs, with the goal of delineating individual groundwater basins. To date, about 475 km^2 has been studied, with the results supported by 85 dye traces up to 15 km long. The typical major groundwater basin has an area of about 20 km^2. In some areas where karst features are not shown on the map, much of the drainage is underground through stream bed swallets, while in other such areas (which are often on subsurface divides) there is little subsurface drainage and many of the groundwater basins are thus individual karst aquifers. Other work performed in the Project includes research in quantifying the use of optical brightener and yellow fabric dye used in the area studies by spectrofluorometric examination of fabric detectors.

Résumé

La région centrale du Bluegrass Karst se trouve au centre de l'Etat du Kentucky, et présente une superficie d'environ 5600 km^2 est composée de calcaire horizontale (et d'une certaine quantitée de lithologie) qui datent de la période Ordovician Moyenne. La géographie et la stratigraphie de cette région est distincte d'une autre grande région du Karst (une région qui a été delimité la région centrale Karst du Kentucky) située à une partie inférieure des roches carboniféres. La population actuelle de cette région est plus de 350,000 habitants et augmente toujours. Le projet du "Inner Bluegrass Karst" a été initié en 1976 pour essayer de trouver une solution aux problèmes de distribution des eaux, de la pollution, et des autres problèmes reliés à cette région. Aussi, pour rechercher et étudier les dispositions naturelles de la région.

Les études de la superficie de la région comprennent des services géographiques, des tracer de teintures, et des determinations approximatives de la décharge des sources dans le but de tracer les bassins individuels d'eaux souterrains. Jusqu'a maintenant, près de 475 km^2 ont été étudiés et les résultats proviennent de plus de 85 tracer de teintures de 15 km de longueur. Le bassin d'eau souterrain typique a une étendue d'environ 20 km^2, mais il y en a plusieurs qui ont été identifié et présente une superficie plus étendue. Dans quelques régions où les traits Karst ne se voient pas sur les cartes, la pluspart des décharges sont souterraines dans les lits des riviéres, tandis que dans d'autres régions semblables (qui sont souvent des lignes de partage d'eaux souterrains) il y a peu de décharge à la surface et la plupart des bassins d'eau souterrains sont donc des couches aquifieres individuelles. D'autres travaux comprennent des recherches pour mesurer l'usage des appareils optiques lumineux et les tracer de teintures jaunes employées dans les recherches régionales qui utilisent les méthodes spectrofluorometrique pour detection et examination.

The Inner Bluegrass Karst Region of central Kentucky covers an area of about 5600 km^2 and is developed in sedimentary rocks of Middle Ordovician age which are mainly limestone with minor amounts of other lithologies. The Region is both geographically and stratigraphically distinct from an extensive karst (a portion of which has been termed the Central Kentucky Karst) developed in rocks of Early Carboniferous age, as well from smaller karst areas in Kentucky in rocks of Late Ordovician and Silurian age. The Region occupies the crestal portion of the Cincinnati Arch, a major structural feature of the eastern United States, and the rocks over most of the area dip at about 10 m/km or less. The geographic extent of the region has been defined by inspection of topograhic maps (at a scale of 1:24000 and contour intervals of either 3 or 6.1 m) and including within the Region those 2.5 X 2.5 minute quadrangles on which at least one doline or other karst feature is shown (Figure 1).

The topograhy is gently rolling, with altitudes ranging from 430 to 1130 m but with local relief in most areas less than 50 m. The mean annual precipitation is about 1150 mm fairly evenly distributed over the year. Mean July and January temperatures are about 25 and 0°C, respectively. Except on steep slopes, soils are typically one meter or more in thickness and are largely residual (the entire Region is south of the area modified by Pleistocene continental glaciation). The present population is in excess of 350,000 of which more than half is concentrated at Lexington, the second largest city in Kentucky, which lies near the center of the Region.

Although the karstic nature of the area has been recognized (Matson, 1909; Jillson, 1945; Hamilton, 1950; Faust, 1977) relatively few investigations have been undertaken prior to the start of the present Inner Bluegrass Karst Project in 1976, probably due to the absence of many of the factors which have led to intensive study of other karst regions of smaller area. The principal karst landforms shown on topographic maps of the Region are dolines, and few of these have indicated depths of more than 10 m. Much of the area is mapped as possessing normal surface drainage with only scattered dolines. Flooding and subsidence have not caused severe problems due to their limited areal extent and the largely rural nature of the Region. Although most of the communities in the Region were located near larger karst springs and many smaller springs and wells are used for rural water supply, the availability of surface water precluded the need for the intensive study of the karst groundwater required for its increased utilization. Finally, although there are many caves in the Region, they are smaller than those (such as Mammoth Cave) found in the Lower Carboniferous karst regions of Kentucky, and the interest in karst studies shown by speleologists elsewhere has been nearly lacking in the Inner Bluegrass Karst Region.

Developments in recent years, however, have created a need for additional information and motivated the present Project. First, most population centers in the Region have experienced substantial population increases which has resulted in the urbanization of areas where flooding, subsidence, and similar problems have previously existed but were of little impact when the land was rural, as well as increasing the severity of the problems by drainage modifications and increased runoff from impervious surfaces. Second, the increase in legislation designed to protect the environment from adverse effects of industrial and similar developments has made it necessary to ascertain flow directions and other characteristics of the underlying groundwater. Finally, forecasts of future water needs in the area suggest that the groundwater of the Region will need to be increasingly utilized. Funding for the project has been obtained from several sources, with major support from the Office of Water Research and Technology, U.S. Department of the Interior.

Several areas in the Region have been examined since the initiation of the Project. Such area studies include field reconnaissance to locate major springs and other significant karst features (many of which are not shown on existing maps and are known only to local landowners), dye tracing, approximate discharge determinations of springs and, in some areas, determination of watertable slopes from field and water well information, all of which are combined to delineate groundwater divides. The availability of large-scale (1:24000) geologic maps in all parts of the Region has also permitted correlations of karst landforms, flow paths indicated by dye tracing, and the location of groundwater basins with stratigraphic and structural elements. In a few areas, access to caves which are serving as flow channels has also been possible. Portions of the Region with a total area of about 475 km^2 (less than 10% of the total area of the Region) have been studied using these techniques, with the largest being in Woodford County north of Versailles, in the area of Harrodsburg in Mercer County, and in southern Scott and northern Fayette counties between Georgetown and Lexington (Figure 1). A more detailed description of the hydrogeology of this last area will be found in Spangler and Thrailkill (this volume). A total of 83 water traces ranging in length up to 15 km have been successfully performed in the Region (only 7 were known prior to the start of the Project).

Several other studies have been undertaken as part of the Project, either to support the area studies or to investigate specific topics, such as karst hazards (Thrailkill, et. al., 1980), water supply (Thrailkill, 1980), and especially research on dyes and passive dye detectors. Most of the water traces in the area studies have been performed either with a fluorescent brightening agent (Crabtree, 1970) or a yellow fabric dye (Quinlan and Rowe, 1977). Techniques have been developed which produce semi-quantitative results from cotton fabrics detectors by spectrofluorometric examination. Fluorescein and Rhodamine WT have also been investigated, both to quantify their use with charcoal detectors and to evaluate their utility in quantitative travel-time and water budget experiments now being initiated.

Results of the area investigations suggest that the typical major groundwater basin has an area of about 20 km^2 and discharges at a spring whose base-flow is on the order of 50 l/sec. In some portions of the Region where no karstic features are shown on topograhic maps and the drainage appears to be in normal surface valleys, the drainage actually is largely diverted underground to the aquifer and mapped streams either do not exist or consist of short segments which terminate in swallets whose topograhic expression is not sufficient to appear on the maps. Elsewhere, however, little subsurface solution has apparently occurred and areas are present in which there is little or no karst development, generally located occur along groundwater divides. In portions of the region (Thrailkill, et. al., in press; Spangler and Thrailkill, this volume), groundwater basins are developed along linear trends which are interpreted as diaclases, but elsewhere underground flow is not related to such features, nor can it be easily be correlated with topograhic divides, surface drainage, bedrock lithology, or structural dip. In some areas, groundwater flow is beneath major surface streams. All of the caves and other karst landforms examined to date are active elements in the present hydrologic system; no evidence has been found of abandoned elements of earlier flow patterns. There is little indication that the zone of active groundwater circulation is deeper than about 25 meters below the present land surface.

The presence of areas of primarily surface drainage discussed above suggests that the Inner Bluegrass Karst Region is a merokarst (Sweeting, 1973). Their location along groundwater basin divides indicates that, since underground solution development may be virtually absent in such areas, each groundwater basin tends to be isolated, and a continuous karst aquifer does not exist. This has significant implications regarding both the quantity and quality of groundwater in the Inner Bluegrass Karst Region.

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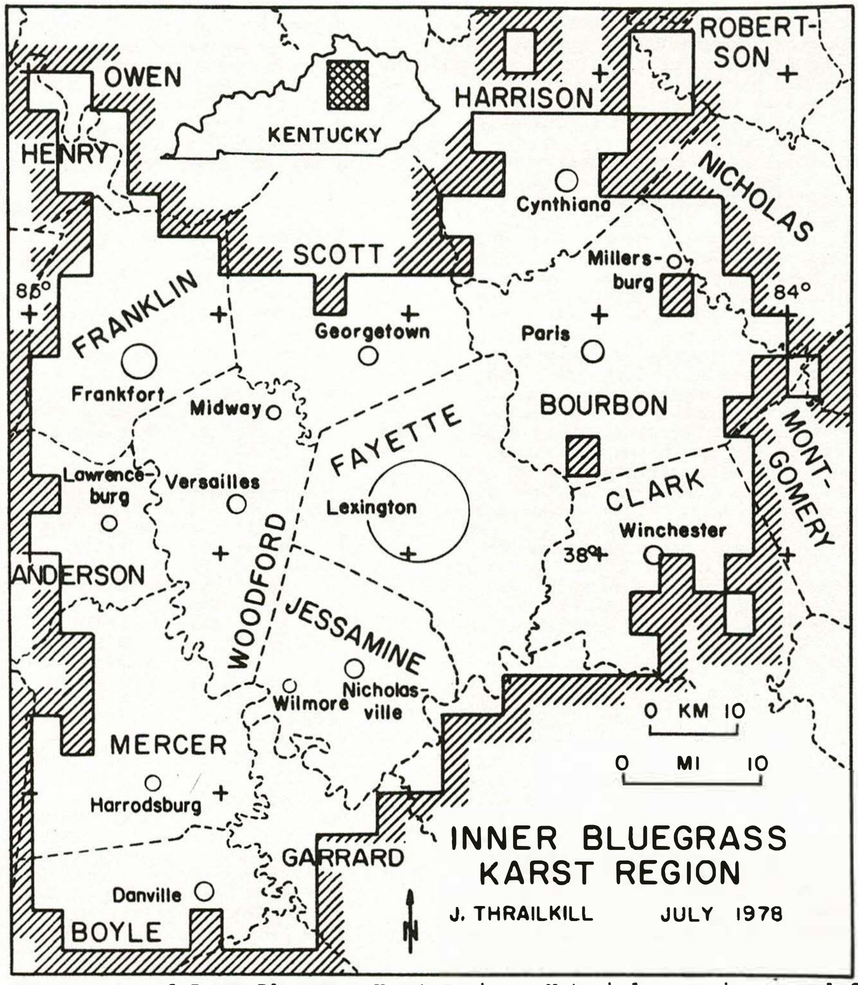

Figure 1. Map of Inner Bluegrass Karst Region. Note index map in upper left.

Extinct Vertebrates from Mammoth Cave, Kentucky

Ronald C. Wilson
Department of Biology, University of Louisville, Louisville, Kentucky 40292 U.S.A.

Abstract

The first extinct vertebrates (Arctodus simus, Platygonus compressus, Tapirus, and Mammut or Mammuthus) are reported from Mammoth Cave, Kentucky.

Résumé

On a reporté les premiers vertebres disparus (Arctodus simus, Platygonus compressus, Tapirus, et Mammut ou Mammuthus) de Mammoth Cave, Kentucky;

Despite nearly two hundred years of exploration (Brucker and Watson, 1976), the Mammoth Cave System of south-central Kentucky did not yield remains of extinct animals until the 1970's. Sutcliffe (1970) has described the importance of caves in the preservation of vertebrate fossils, and the long geologic history of the Mammoth Cave region has been described by Quinlan (1970), White, et.al. (1970) and other authors. That the longest cave in the world would eventually produce fossil bones are inevitable. This report is limited to bones of extinct animals. All bones were discovered by Cave Research Foundation parties in the Proctor Cave portion of the Mammoth Cave System, Edmonson County, Kentucky. Bones of extant vertebrates are known from other areas of the cave and will be described in a future report.

Three areas of Proctor Cave have produced remains of extinct vertebrates. All three areas are associated with vertical shaft complexes that are now blocked by collapse of the parent limestone and the overlying sandstone strata. A brief description of each find is provided below. All items are preserved in the Section of Vertebrate Fossils, Carnegie Museum of Natural History, Pittsburgh, PA, and were collected under authority of U.S. Department of the Interior Antiquities Act Permit No. 78-KY-115.

Tapirus cf. veroensis Sellards, 1918--Vero Tapir

Material. Accession No. 30991. R p/4.
Remarks. This isolated tooth is referred on the basis of size (length 21.4 mm, width 18.15 mm) and its close comparison with more complete material of the species from Crankshaft Cave, Missouri (Parmalee, Oesch, and Guilday, 1969). Remains of the Vero Tapir are known from the Rancholabrean of central, eastern, and southern United States, and are most common in Florida (Kurten and Anderson, 1980). This is the first Kentucky record of the species. Several specimens of the larger Tapirus copei are known from north central Kentucky (Cooper, 1931). The tooth described here was found by Tomlislav Gracinin at survey mark N 17 in the passageway known as the Proctor Crawl. It was collected 25 November 1978 by R. Wilson and party.

Platygonus compressus LeConte,1848--Flat-headed Peccary

Material. Catalogue No. CM 38362. L humerus, complete.
Catalogue No. CM 38363. R humerus, distal half.
Remarks. Platygonus compressus is one of the most frequently encountered Pleistocene mammals in eastern North America. Other Kentucky finds of this species are summarized in Guilday, Hamilton, and McGrady (1971) and in Wilson, Guilday,and Branstetter (1975). A good overview of the species is presented in Kurten and Anderson (1980). Both Proctor Cave specimens came from the same general area in the remote northwest corner of the cave. CM 38362 was collected from a stream at survey mark Y 76 by R. Wilson and party on 8 September 1979. CM 38363 was collected near a rat (Neotoma floridanus)nest in a dry passageway at survey mark Z 22. Both bones are similary preserved, stained dark brown and permineralized by long exposure to ground water. CM 38363 is partially coated with a thin layer of tan travertine. Measurements of the two specimens indicate that two individuals are represented. CM 38362: total length, 177 mm; width of distal end, 42.6. mm. CM 38363: width of distal end, 44.85 mm.

Order Proboscidea--Mastodon or mammoth

Material. Catalogue No. 38368. Metapodial? fragment
Accession No. 30991. Tusk fragment, four postcranial fragments.
Remarks. The material represented is too fragmentary for specific identification, but the remains are from either a mastodon (Mammut sp.) or a mammoth (Mammuthus sp.). The highly crushed bone fragments were found at survey mark X 117 among the terminal breakdown of Frost Avenue, a major passageway in Proctor Cave. The fragments are coated with a black veneer of manganese dioxide, but are soft and fragile due to loss of organic matter. The fragment of tusk ivory is pitted by solution due to exposure to water moving vertically through the terminal breakdown. The metapodial fragment was collected by R. Wilson on 8 September 1979. All other fragments were collected at the same spot on 2 August 1980 by Richard Hand and party.

Arctodus simus (Cope), 1879--Great Short-faced Bear

Material. Catalgoue No. CM 38359. Partial R mandible with /c, part m/1, m/2. Remarks. This is the second Kentucky record of this widespread species. A complete R femur was recovered from Glass Cave, Franklin County, Kentucky (Carnegie Museum collections, CM 12667). Although most teeth are missing from the Proctor Cave specimen, measurements of m/2 are diagnostic (length 29.2 mm, anterior width 19.5 mm and mid width 19.5 mm). These measurements compare favorably with those presented by Kurten (1967) for Arctodus simus. Preservation of the specimen is similar to that of the Platygonus material that was found nearby. The bear jaw was collected on 8 September 1979 from a ledge above the stream at survey mark Y 77-78. It was recovered by R. Wilson and party.

Conclusion

The four species recovered from the Proctor Cave area of the Mammoth Cave System are species of broad ecological tolerances. The remains were found as isolated bones that were not directly associated with any stratigraphic context. They therefore provide little information on the past climate of the region. The probable age of the remains is terminal Pleistocene, ca. 12,000 to 15,000 years before present. It is expected that an extensive bone deposit with good representation of area vertebrates will eventually be found in Mammoth Cave. Until such a deposit is located, however, the materials reported on here provide the first fleeting glimpses of late Pleistocene faunas in the vicinity of the world's longest cave.

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The Scanning Electron Microscope as an Adjunct to Environmental Reconstruction in Archeological Sites

Peter A. Bull
Christ Church, Oxford. OX1 1DP England

Abstract

The investigation of sand grain surface textures has enabled paleoenvironmental reconstruction of areas around archeological sites in Wales and England. Studies undertaken in Minchin Hole and Bacon Hole, Gower, South Wales, have shown distinct climatic variations indentifiable from sediment sequences devoid of conventional archeological remains. Used in conjunction with these more usual archeological indicators, the scanning electron miscroscope studies enable detail to be added to general framework of past occupancy and paleoclimatic sequences.

The considerable success of electron microscope investigations in Bacon Hole and Minchin Hole has enabled cold climate, high sea level and quiescent (interglacial) sequences to be identified. Whilst the results from Rhino Hole (Somerset, England) and Pontnewydd Cave (Clwyd, North Wales) did not match these obtained from the caves of Gower, they did enable more detail of paleoenvironment and sediment provenance to be gained.

Résumé

L'investigation des textures superficielles des grains de sable a permis la reconstruction de l'histoire géologique des sites archéologiques au Pays de Galles et en Angleterre. Des recherches faites à Minchin Hole et à Bacon Hole, dans le sud du Pays de Galles ont montre des variations climatiques bien distinctes, qui sont différentes des sédiments n'ayant pas des restes archéologiques conventionnels. Sil'on s'en sert de ces indicateurs archéologiques conjointment avec le microscope électronique à balayage, ces researches permittent qu'on ajoute du détail au cadre général de l'habitation dans le passé et à l'ordre sédimentaire paléoclimatique.

Le succès considérable des investigations faites par le microscope électronique de Bacon Hole et Minchin Hole a permis qu'on identific des strates glaciales, interglaciales et des niveaux de mer variés. Malgré le fait que les resultats de Rhino Hole (Somerset) et Pontnewydd Cave (Clwyd, Pays de Galles) n'ont pas égalé ceux obtenns des grottes de la péninsule de Gower, ils ont permis qu'on dérive beaucoup plus de détail sur le paléoenvironment et la provenance sédimentaire.

Introduction

Sediment horizons, normally deemed 'sterile' by conventional archeological investigations, all too frequently cause significant hiatii in the paleoenvironmental reconstruction of a cave and its environ. The investigation of cave deposits then normally reverts to conventional sedimentological site investigation and laboratory analysis in order to ascertain the gross conditions of deposition of the 'steile' sediment horizon. Such investigations consider whether the material represents autochthonous cave scree and breakdown or whether the deposit is an allochthonous input by wind, water or biotic elements. Necessarily, these interpretative techniques are only superficial indicators of paleoenvironment. However, the development and subsequent utilization of the scanning electron microscope in the late 1960's has enabled the development of an environmental discrimination technique designed by Krinsley and his co-workers (Krinsley and Doornkamp, 1973; Krinsley and McCoy, 1977; Krinsley and Wellendorf, 1980, for instance).

The basic rationale of the technique is simple; various environments comprise characteristic energy conditions that themselves impart specific modification textures upon the surfaces of grains within the different environments. By concentrating only upon quartz grains, obvious problems of inherent feature manufacture due to cleavage and mineral stability (often found in feldspars and heavy minerals) can be overcome. Careful analysis of the precise assemblages of surface textures present upon a statistically significant percentage of grains (after Tovey and Wong, 1978) allows a sequential environmental history to be illucidated from a deposit.

The advantage of this technique in archeological studies should require little explanation. To date surprisingly few archeological studies have published results utilising such electron microscope techniques. Those that do (for example, Tankard and Krinsley, 1975) have had only limited success in detailed environmental discrimination although such studies have led to a greater understanding of the more problematic sterile strata within a sediment sequence. It is the intention of this paper, therefore, to reinforce the proved ability of electron miscroscope surface textural analysis in archeological studies. Particular attention is paid to the analysis of deposits from Bacon Hole and Minchin Hole, Gower, South Wales; Pontnewydd Cave, Clwyd, North Wales and Rhinocerous Hole, Wookey, England (Fig. 1).

The Caves

a. Bacon Hole and Minchin Hole

Bacon Hole and Minchin Hole are both sea caves situated within Dinantian Limestones on the south facing coast of the Gower Peninsula (Fig. 1). Considerable archeological interest has focused upon the area particularly by the British Museum (Dr. A. Sutcliffe in Minchin Hole and Dr. C. B. Stringer in Bacon Hole) who have undertaken many seasons of site and laboratory investigations.

The sediment sequence at Bacon Hole is described in detail elsewhere (Stringer, 1977) on the basis of mammalian and bird remains, terrestrial and non-terrestrial molluscs, pollen, artefacts, geochronometric dates and foraminifera. Electron microscopy studies, carried out independently of these other investigations reinforce their general and specific findings. Indeed, the identification of a 'last' glaciation and previous interglacial phases (Table 1) is bettered by the suggestion of an earlier cold climate modification to the most basal units; the orange and grey sands. More detail can, however be extracted from such deposits. Provenance studies of the inherent characteristics of the quartz grains within the sediments have identified material exotic to the cave environ. A dual provenance for the material can be seen. The majority of the material is a glacially modified deposit presently found as marine sorted sands within the sub-littoral zone in the sea south of the caves. A significant percentage of the material, however, is land-derived, from the nearby basal Old Red Sandstone unit that comprises the higher ground immediately north of the cave site. These materials have been mixed and introduced into the cave primarily by marine storm action although a small amount has been introduced from overlying superficial deposits by rainwash or roof collapse.

The nearby Minchin Hole sediments, however, do not exhibit the ordered sequential progression from cold to warm climate deposits but rather shows a more complicated sequence due to much post-depositional erosion by water action (and by archeologists!). The electron microscope textural analysis has been useful in identifying the origins of a basal laminated deposit that is archeologically speaking, sterile, and appears from field observation to be macro- and microtexturally variant from the rest of the deposits within the cave.

Close analysis of this problematic deposit suggests that the material is not glacially derived debris as found both throughout Minchin and Bacon Hole but is a discrete sub-littoral sand exhibiting extensive grain surface fretting together with diagnostically high percentages of sub-littoral, mechanically derived surface textures (see for instance, Krinsley and Doornkamp, 1973). Such features indicate intertidal modification to the sediment, perhaps in a warm climate, before being deposited within the cave during a high energy phase of marine action, probably by the mechanism of overwash deposition. These details cannot be identified by means of other archeological or sedimentological criteria.

b. Pontnewydd Cave

Pontnewydd Cave, Clwyd, North Wales (Fig. 1) is a fossil cave, situated on upper valley slopes above the present-day river and is a site of much archeological importance following the recent discovery of many artefacts and two fragments of human remains dating from the Middle Pleistocene (Green, pers. comm., and in prep.). The cave comprises a chamber once filled with rubbly allochthonous material in places cemented by stalagmite deposition. Site investigation by the author revealed that the material was a mud slurry deposit injected in two or three phases not necessarily separated by any great time period. Such 'solifluction deposits' are well reported in the literature, are mostly inferential in design and normally lacking independent collaboratory data. Since much of the other cave deposits contained rich artefact finds, the presence of a volumetrically distinct and bulky sterile unit provided a considerable hiatus in the record of environmental history of the cave. Scanning electron microscope studies were therefore employed in order to throw light both upon the nature of the material (provenance) and upon the mechanism of emplacement in the cave (process).

The deposits proved to be a mixture of materials, the quartz grains were derived from basal conglomerate source rocks with limited post erosional water action; from well rounded fluvial sands; from mechanically modified sands; and from distinct two or three phase modifications of mechanical modified sands; and from distinct two or three phase modifications of mechanical fracturing, water rounding and chemical activity and final mechanical fracturing. The mixed nature of microtextural analysis supported the gross field observations that the deposit was derived from a partially differentiated till deposit that itself was of mixed origin. The lack of variation in textural assemblages upon the individual grains studied down-section suggested that the material, although two or three phase sediment emplacements, was either temporally restricted in deposition in the cave or that the outside environmental conditions acting upon the slurry-source (the till) was relatively inert chemically (that is lacking substantial groundwater movement and temperature fluctuation).

Uranium-thorium disequilibrium dates obtained from stalagmites incorporated within the mudflow yielded dates ranging from 125,000 + 6,000 years B. P. to 255,000+89/47,000 years. The deposit and its emplacement were then adjudged to be Middle Pleistocene in age.

c. Rhinocerous Hole

Rhinocerous Hole, Somerset, (Fig. 1) is a small ancillary cave, once associated with the larger, local, Wookey Hole. The cave attracted considerable attention from archeologists (particularly E. K. Tratman) and was thought to be an important effluent cave. Little was known of the cave deposits or their provenance until detailed electron microscopy of the material was undertaken. Surface textural analysis of the sands showed that the deposits were locally derived from Old Red Sandstone, had been weathered out of the rock, probably interglacially, had not been involved in any glacial modification, nor had any of the sediment derived from more varied further sources.

Although such results seem, in the first instance to be negative, they served to eliminate many options of environmental history that were being suggested at that time. Even such negative results prove useful when faced with the alternative of 'sterile' sediment classification.

Summary

The limited examples provided serve as an indicator both of the range of success that can be obtained from surface textural analysis and, despite such a range, of the detail that can be gained by from provenance and paleoenvironmental reconstruction studies. Detailed analysis are provided elsewhere (Bull, 1980, in press) but it remains the basic tenet of this report that it is only by the co-ordination of many skills learnt from many disciplines that successful archeological investigations can be undertaken. Past are the days of the myopic archeological approach adopted at the expense of accuracy, as these are making way for interdisciplinary collaboration using teams of researchers rather than individuals.

Acknowledgements

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Stratigraphic Layer	S.E.M. Summary of Textures	Suggested Climate	
Cemented breccias (Head)	-		
Upper cave earth	Mixed sample, some windblow	"Cooling"	
Upper sands	Angular, marine alteration	↑	increase
Coarse brown sands	V. Angular no water modification		cooling
Grey clays, silts & sands	V. Angular no water modification		
Sandy cave earth	No water modification,		Warmer,
	no fracturing	"Warmer"	chemically
Sandy breccio-conglomerate	No water modification,	↑	active
	no fracturing		conditions
Coarse orange sands	"Fresh" angular grains,		
	much fracturing		Glacial/
Coarse grey sands	"Fresh" angular grains,		Periglacial?
	much fracturing	"Cold"	
Limestone Rock Platform	-		

Table 1. Stratigraphy of Bacon Hole Deposits: Environmental Interpretation From Scanning Electron Microscope Analysis (from Bull, 1980).

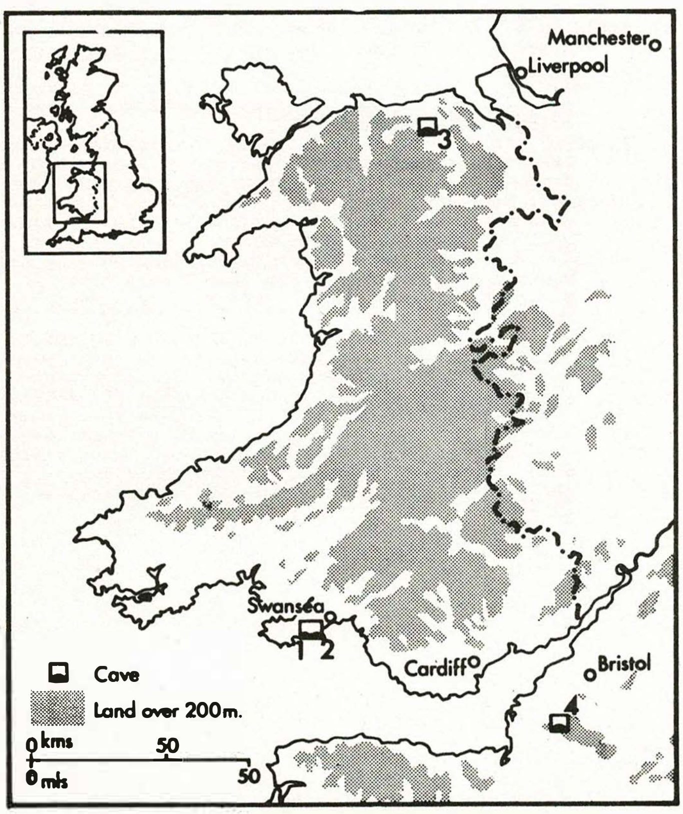

Figure 1. Cave Locations in England and Wales. 1. Minchin Hole, 2. Bacon Hole, 3. Pontnewydd Cave, 4. Rhinocerous Hole.

The Cavernicolous Carabid Beetles of North America

Thomas C. Barr, Jr.
School of Biological Sciences, University of Kentucky, Lexington, Kentucky 40506

Abstract

An estimated 250 species of troglobitic carabids have been discovered in the caves of North America, representing 4 tribes and 16 genera. Slightly more than half of the species had been described by late 1980. Three major centers of troglobite evolution may be distinguished: 1) eastern United States, with 6 trechine genera and one anilline genus, including the huge genus Pseudanophthalmus (approximately 200 species); 2) central Texas, with 11 species in a single species group of the anchomenine genus Rhadine; and 3) eastern Mexico and northern Guatemala, with all 4 tribes (Scaritini, Trechini, Anillini, Anchomenini), 10 genera, and about 30 species. Two species of Ardistomis (Scaritini) from caves of Jamaica are the only troglobitic carabids known at present from the West Indies.

Trechines are the dominant terrestrial troglobites of caves in eastern United States (Trechoblemus series: Pseudanophthalmus, Neaphaenops, Nelsonites; Aphaenops series: Xenotrechus; unknown affinities: Darlingtonea, Ameroduvalius). The Allegheny plateau, separating the two major cave regions of this area, is believed to have been a major interglacial refugium for ancestors of modern cave trechines. Although trechines also occur in caves of northeast Mexico (Mexaphaenops, Paratrechus), the anchomenines (Mexisphodrus, Rhadine) include about twice as many known species of troglobites and near-troglobites as are known for the much smaller trechines. The highly modified troglobitic Rhadine species of the subterranea group are known only from the Balcones fault scarp area and adjacent terranes to the west in central Texas (11 species) and from eastern Nuevo Leon (2 species).

Carabid beetles of North American caves include cavernicolous representatives of the tribes SCARITINI (Ardistomis, Antroforceps), TRECHINI (Pseudanophthalmus, Neaphaenops, Nelsonites, Darlingtonea, Ameroduvalius, Xenotrechus, Paratrechus, Chiapadytes, Mexaphaenops, Mexitrechus, and Mayaphaenops), ANILLINI (Troglanillus, Mexanillus), HOROLOGIINI (Horologion), and ANCHOMEINI (Rhadine, Mexisphodrus). Considering only troglobitic and habitually troglophilic species, there are approximately 250 known species in 18 genera and 5 tribes.

Three principal centers of adaptation to cave existences are 1) eastern United States, 2) central Texas, and 3) the uplands of eastern and southcentral Mexico. Two species of Ardistomis, related to mountain species from Cuba and Hispaniola, occur in caves of Jamaica. Speocolpodes franiai (Barr 1973) and Mayaphaenops sbordonii (Vigna-Taglianti 1977) have been described from isolated cave systems in Guatemala.

1. Eastern United States: Six genera of trechines predominate in caves of this region. Xenotrechus (Barr and Krekeler 1967), with two known species in extreme eastern Missouri, belongs to the Aphaenops series and is a possibly ancient isolate closely similar to Chaetoduvalius, a genus restricted to the Carpathians and Transylvanian Alps. Darlingtonea and Ameroduvalius (Kentucky, 1 and 3 spp., respectively) represent a new phyletic series exhibiting isotopic copulatory pieces and are of unknown affinities within the Trechini.

The third phyletic series of eastern trechines is the Trechoblemus series, represented by the huge, possibly polyphyletic genus Pseudanophthalmus, with more than 200 known species in Alabama, Georgia, Illinois, Indiana, Kentucky, Ohio, Pennsylvania, Tennessee, Virginia, and West Virginia, and by Neaphaenops (Barr 1979a), with one polytypic Kentucky species and Nelsonites (Valentine 1952) with 3 species in Kentucky and Tennessee. These genera indicate one or more introductions from Eurasia in Pliocene time or (probably) earlier.

Jeannel's (1949) hypothesis that cave species of these trechines colonized caves in faunal pulses during interglacial periods, spreading out from a Unaka mountain refugium during glacial maxima, requires modification in the light of a more comprehensive view of distribution and speciation patterns. The alternative hypothesis is offered that the Allegheny plateau was a far more important refugium and center of pre-cave diversification. Three lines of evidence favor this Allegheny refugium hypothesis.

a) No edaphobitic species of the Trechoblemus series--potential ancestors of the cave trechines--have been found in the Unaka region, despite extensive searches. The only edaphobitic trechine thus far known from eastern United States is Pseudanophthalmus sylvaticus (Barr 1967a), which inhabits spruce forest in West Virginia (el. 1050-1200 m) in the heart of the Allegheny plateau; it belongs to the grandis group, other species of which abound in caves of nearby Greenbrier valley.

b) In the Appalachian valley most Pseudanophthalmus spp. occupy caves near the Allegheny front; occurrence of Pseudanophthalmus becomes increasingly rare toward the Unaka front. Many groups of the genus include species in karst "islands" within but near the eastern Allegheny front as well as in cave systems of the Appalachian valley.

c) If ancestral stocks dispersed from a Unaka source, then an archipelago-like chain of related species should stretch from the Unaka region across the Appalachian valley, through some of the karst islands within the Allegheny plateau, and into the trans-Allegheny caves of the Interior Low Plateaus. Such a distribution pattern occurs in only one of 26 species groups (engelhardti group) of Pseudanophthalmus; the other species groups are very different on opposite sides of the Allegheny plateau, and there are no Appalachian valley counterparts to the Kentucky and Tennessee genera Neaphaenops, Nelsonites, Darlingtonea, and Ameroduvalius. This suggests a long period of evolutionary diversification of ancestral stocks in the richly diverse, mixed mesophytic forest of Allegheny uplands. Four successfive climatic shocks during the Pleistocene permitted dispersal into lowland areas east and west of the Allegheny plateau, with subsequent extinction of most of the edaphobitic fauna and preservation of relic trechine faunas in karst areas.

If increasing levels of adaptedness to the subterranean milieu reflect time elapsed since entry into caves, then trechines of the western margin of the Allegheny plateau in Tennessee may reflect at least four faunal pulses. The oldest wave of colonization is represented by species of Nelsonites, large (6.5-7.5 mm), semiaphaenopsian beetles which are very hygrophilous, rather rare, and nevertheless widely distributed. The second pulse left behind species of the intermedius group of Pseudanophthalmus, mostly allopatric, large (6-7 mm), slender, convex, species. The third pulse is reflected by species of the robustus group of Pseudanophthalmus (Barr 1962), which are medium-sized (ca. 5 mm), robust, and somewhat depressed. Their morphology suggests a shorter sojourn in caves, and their parapatric (conjunct) ranges suggest mutual exclusion, because their ecological niches have not sufficiently diverged to permit coexistence. A fourth wave of colonization (post-Wisconsin?) left behind the troglophilic species Trechus cumberlandus (Barr 1979b), which is related to T. schwarzi in the Unaka mountain ranges near Asheville, North Carolina.

In southeastern Kentucky caves where Darlingtonea, Ameroduvalius, and Nelsonites predominate there are few species of Pseudanophthalmus, and all of these are about 4 mm long or less. I venture the hypothesis that in these caves there is a limited number of available niches, and that a very important component of a cave trechine niche is body size, which is related to predation strategy and thus to size and kinds of prey eaten. If caves of this region were first colonized by Ameroduvalius, Darlingtonea, and Nelsonites, then the large- and medium-sized beetle niches would have been preempted, leaving only the small body-size niches available for later colonizing groups. North of the range of these three locally endemic genera there exists a medium-large (5-6 mm) species, Pseudanophthalmus rittmani (Krekeler 1973), which is an abundant, cursorial species recalling the habits of Darlingtonea. Like Darlingtonea it has adopted the practice of digging for eggs of the cave-cricket Hadenoecus cumberlandicus. South of the range of Ameroduvalius, which occupies the medium-sized niches, there has been explosive speciation of medium-sized species of Pseudanophthalmus.

other eastern troglobitic carabids include one anilline (Troglanillus valentinei Jeannel 1963) and the remarkable Horologion speokoites Valentine (1932). Troglanillus, from northeast Alabama, is very close to Anillinus, a widespread eastern genus; a closely similar edaphobitic species occurs in eastern Kentucky. Horologion, known from a single specimen taken in a West Virginia cave, is placed in tribe Horologiini within the Bembidiinae; its great rarity suggests that it is part of the interstitial fauna, occurring in open caves by accident.

2. Central Texas: The troglobitic carabid fauna of central Texas is limited to 11 known species of Rhadine (Barr 1974), an anchomenine genus widely distributed in western North America (only 2 eastern species are known) from southern Canada to northern Mexico. All of these species belong to the apparently monophyletic subterranea group, and some of them coexist with larger troglophilic Rhadine species of the perlevis and dissecta groups.

3. Mexico: The carabids of Mexican caves include a variety of trechines of the Paratrechus series; their affinities lie with the South American fauna rather than with that of Europe (as is the case with trechines of eastern United States). Two species of Paratrechus are troglobitic; Chiapadytes bolivari (Vigna-Taglianti 1977) is closely similar. Mexaphaenops includes 7 known species of aphaenopsian troglobites from uplands of northeastern Mexico; these fall into two rather different groups, suggesting a possible diphyletic origin of the genus, which is apparently derived from Paratrechus. Two non-troglobitic species of Mexitrechus are known from Mexican caves. Mayaphaenops sbordonii, from Huehuetenango province, Guatemala, may be more closely related to Mexitrechus than to Paratrechus.

Supposedly troglobitic genera of anillines (Mexanillus Vigna-Taglianti 1973) and scaritines (Antroforceps Barr 1961b) have been described from rare, isolated occurrences in Mexican caves. Vigna-Taglianti (op. cit.) places Mexanillus in the Geocharidius series. Antroforceps is probably allied with the Clivinina rather than the Forcipaterina as I previously supposed (Barr op. cit.).

Two anchomenine genera, Rhadine and Mexisphodrus, are conspicuous and widely prevalent in caves of Mexico. Rhadine is represented by two troglobitic species (subterranea group) from Nuevo Leon and by a number of troglophilic species, some of which, like R. araizai Bolivar, may be entirely restricted to caves despite possession of apparently functional eyes.

Mexisphodrus (Barr 1965) is either a very primitive, ancient group of sphodrines, or it has attained a sphodrine-like habitus through convergence; in any case the parameres are relatively simple and wholly unlike those of the European cavernicolous sphodrines. Because the neotropical anchomenines are a poorly known, notoriously difficult and diverse group, it is impossible profitably to speculate on the origins and affinities of Mexisphodrus, which may ultimately be merged with related species possessing eyes and wings. There are 12 described species, all of which are restricted to caves in very local areas, but only 5 of these are undoubted troglobites. The four species of the veraecrucis group (western Veracruz, northern Oaxaca, northern and southern Puebla) are the largest of the North American troglobitic trechines (12-19 mm); they have small, rudimentary eyes and are most frequent in the twilight zone of deep pits. Mexisphodrus profundus is a slightly smaller species from the Encino and Gomez Farías region of Tamaulipas. The monobasic Guatemalan genus Speocolpodes may ultimately be snynoymized with Mexisphodrus, but evolutionary intermediates have not yet been discovered, and such synonymy appears premature at present.

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A Karst Hydrology Study in Monroe County, West Virginia (USA)

William K. Jones
Environmental Data, Frankford, West Virginia

Abstract

Karst drainage boundries were delineated and flow conditions studied by dye-tracer techniques in three differing hydrogeologic settings within Monroe County, West Virginia (USA). The first area is a mature karst plain of about 170 sq. km. developed on the Carboniferous Greenbrier Limestone. All surface runoff from the surrounding clastic rocks is diverted through ponors and dolines into subsurface flow channels which often cross under former surface drainage divides. Subsurface flow direction is toward base-level springs, but the flow patterns and cave passage orientations do not correspond well with stratigraphic strike or the more obvious photo lineaments. Eight sub-basins were defined by dye tracing; dye-concentration patterns indicate some phreatic (closed channel) flow conditions at several of the larger springs.

The second karst area is developed on a north-east trending, 2 1/4 km. wide belt of Ordivician Limestones which are exposed in the eastern part of the county. Cavern development and subsurface flow directions are parallel to the stratigraphic strike, and vadose (open channel) flow conditions predominate.

The third area is a karst window developed on the Greenbrier Limestone in the central part of the county. An area of about 30 sq. km. drains through three hydrologically connected caves which contain over 10 km. of passages. The caves appear to have formed under primarily phreatic conditions, although the present flow is vadose in nature.

Résumé

Les bornes karstiques de l'écroulement des eaux étaient tracés et les conditions du cours étaient étudiées par la technique du tracé des teintures dans trois endroits hydrologique différents dans le compté de Monroe, West Virginia (USA). La premiére région est une plaine karstique mûre d'environ 170 km carrés développée sur Le Calcaire de Carboniferous Greenbrier. Tout ecoulement à la surface des rochers clastiques entourants est détourne à travers les ponors et les dolines dans les rivièrs souterrains qui traversent souvent les anciennes lignes des partages des eaux à la surface. La direction de l'écoulement souterrain est vers les sources karstique au riveau du base, mais les modèles de l'écoulement et les orientations des passages des grottos ne correspondent pas bien avec le litage stratigraphique ou les plus apparents linéaments photographiques. Huit sous-basins étaient déterminés par le tracé des teintures; les dessins de la concentration de teinture montrent quelqués conditions de l'ecoulement phréatique à plusieurs des plus grands sources karstiques.

La deuxième région karstique est developpée sur une ceinture large des Calcaires Ordivicians de 2 1/4 km d'une direction nordest qui sont exposés dans l'est du compté. Le développement des cavernes et les direction de l'écoulement souterrain sort parallèles au litage stratigraghiquex et les conditions de l'eau vadose dominent.

La troisième région est une fenêtre karstique developpée sur Le Calcaire Greenbrier dans lapartie central du compté. Un endroit d'environ 30 km carrés écoule à travers trois grottos liés hydrologiquement qui contienment plus de 10 km de passages. Les grottos parassent d'avoir être formés sours les conditions phréatiques principalement, bienque l'écoulement présent est d'une nature vadose.

Introduction

Karst flow conditions have developed in three distinctly different hydrogeologic settings in Monroe County, West Virginia (Figure 1). Area number one is a mature karst plain containing complex subsurface flow routes and at least eight sub-basins. Area number two is developed on a narrow band of carbonate rocks which are brought to the surface on the upthrown block of a major thrust fault. Subsurface flow routes and caves are very linear and parallel the stratigraphic strike. Area number three is a karst window which is drained primarily through three separate cave systems. A summary of the hydrogeologic setting and flow conditions for each area is presented in Table 1. Descriptions of Monroe County caves may be found in Davies (1965) and Hempel (1975).

All three areas have similar climatic conditions. A mean annual precipitation of 932 mm is fairly evenly distributed throughout the year. The mean annual temperature is 11°C.

Another characteristic shared by all three areas is that the principal source of concentrated recharge to the karst flow systems originates on clastic rocks which surround the carbonate areas. Infiltration of precipitation through the sinkhole plain provides a somewhat more diffuse source of recharge to the carbonate aquifers. All of the springs show rapid responce to individual storm events and the dye tracer tests indicate short ground-water residence times.

Area One

This area is the most intensely studied karst region in Monroe County. The writer did numerous dye tracing tests in 1972 for the U.S. Geological Survey, and Ogden (1974, 1976, 1977) studied this area as part of a Ph.D. dissertation. This area is drained to the north by Second Creek, to the west by Wolf Creek, and to the south and east by Indian Creek (Figure 2). Ground-water flow paths cross under former surface divides and base-level springs concentrate the flow from numerous input points. Many of the dye-traced routes do not appear to follow any particular stratigraphic or photo lineament orientation. Eight sub-basins were defined by dye tracing techniques. Discharge within each sub-basin is through a single spring which collects water from numerous input points. These springs are generally situated near local base level. Dickson Spring is the largest in Monroe County with an average discharge of 0.5 m^3/second and a recharge area of 67 km^2. Dickson Spring also shows less storm responce and has a somewhat flattened dye concentration curve compared to the other springs. Although some adjustment must be made in comparing the longer flow paths and larger catchment area of Dickson Spring to the other springs in the area, a large part of the discharge from Dickson Spring appears to be phreatic (closed channel) in nature.

A mature surface karst is developed in this area with numerous dolines and uvalas dominating the landscape. Cavern development, however, is rather limited compared to the surrounding karst areas. Caves in area one are typically uncomplicated and under 1000 m in length. Two interesting maze-type caves are situated along the eastern edge of the area near the limestone-shale contact. The rocks dip about 30 and a three-dimensional maze of passages has developed along the inclined bedding plains (see descriptions of Burnside Branch and Canterberry Caves in Hempel, 1975).

Area Two

The Beekmantown and Stones River Limestones (Ordovician) are brought to the surface along the eastern (upthrown) flank of the north-east trending St. Clair fault. The exposed carbonates form a 2 1/4 km wide band of mature karst. Most of the recharge to this area comes from streams originating on Peters Mountain which boarders the carbonates immediately to the east. The streams which sink into the limestone are diverted to the northeast or southwest in long linear flow paths parallel to the stratigraphic strike. Patton Spring in the northern part of the area is situated near local base level, but the resurgence near Zenith at the southern end is perched well above base level by the St. Clair Fault.

Area two contains several caves over 2000 m long. The passages are generally linear and parallel to the strike. The majority of cavern development in this area is vadose (open channel) in nature, but Pattons Cave appears to have undergone a complex sequence of development.

Area Three

Area three is a large (30 km^2) karst window developed on the Greenbrier Limestone. The entire area is drained by Laurel Creek. Laurel Creek flows southwest from clastic rocks onto the limestone and sinks in Laurel Creek Cave. The water then passes through Cross Roads Cave and Greenville Saltpeter Cave to its resurgence on Indian Creek. Much of the route can be traversed through large underground conduits. The caves show evidence of early phreatic flow conditions, but present flow is vadose in nature.

Acknowledgements

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Table 1. Comparison of Monroe County Karst Areas

Area #	Geology	Surface Karst	Area (Km^2)	Flow Characteristics
1	Mississippian Carboniferous Greenbrier Ls. Gentle parallel folds trending NE.	Mature sinkhole plain Numerous dolines, uvalas, ponors. Several prominate photo lineaments.	170	Complex subsurface flow routes. Inter-basin transfer common. Some high water overflow routes divert water to multiple sub-basins. Spring discharge shows a mixture of vadose and phreatic characteristics.
2	Ordivician Beekmantown and Stone River Ls. Bounded to the west by St Clair reverse fault.	Mature karst band about 2 km wide. Karren and dolines are common.	50	Flow paths linear and simple because of narrow exposure of carbonates. Most of the flow appears to be vadose.
3	Greenbrier Ls.	Area is a large karst window with blind valleys and dolines. Large caverns present.	50	Area is drained by Laurel Creek which flows through three caves to its resurgence on Indian Creek. Present flow is vadose, but the caves show a history of preatic development.

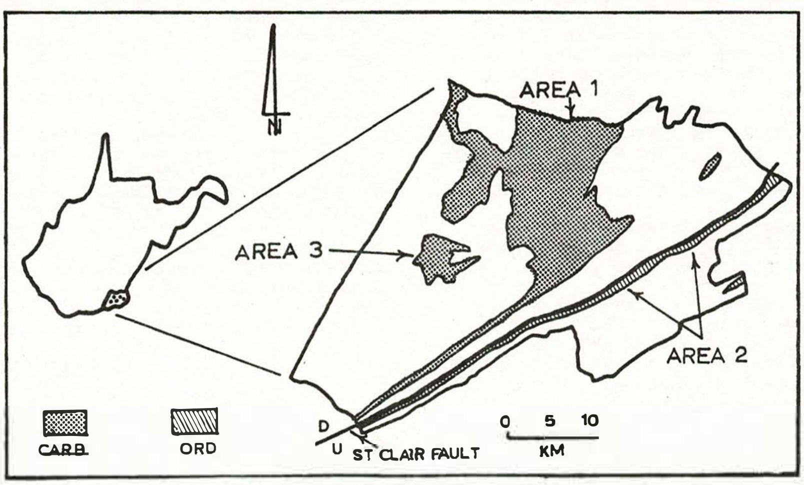

Figure 1. Map showing location and geology of study areas.

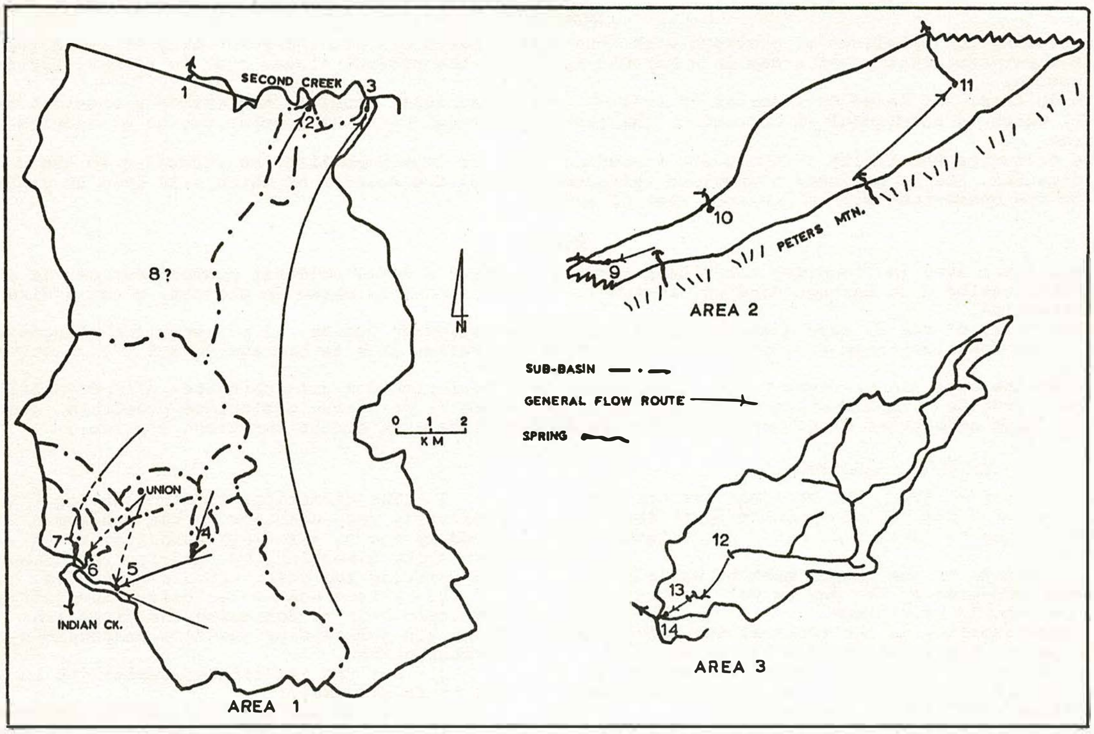

Figure 2: Map showing generalized dye-traced flow routes and sub-basins.

1 Ogdens Spring	8 Undetermined Resurgence Area
2 Rodgers Spring	9 Zenith Spring
3 Dicksons Spring	10 Crimson Spring
4 Cold Spring	11 Patton Spring
5 Indian Creek Spring	12 Laurel Creek Cave
6 Macpeat Spring	13 Greenville Saltpeter Cave
7 Walters Spring	14 Mill Pond Spring

New Contributions to the Problem of Dam Building in Karstic Regions

Dr. Adolfo Eraso
Cat. de Geodinamica Externa, Fac. Ciencias Geologicas 5ª Planta, Cindad Universitaria, Madrid, SPAIN

Abstract

Following the mainlines of previous work, the author makes his aim the possiblity of evaluating the cost of impermeabilisation of a dam in a karstic region at the project stage, that is to say, before its construction.

To do this, and based on a series of real examples, carefully studied, the author presents a method of work, which is successful at correcting the leaks of the dam site which occur due to a reactivation of the karst.

He evaluates the limits of the costs including those of impermeabilisation according to the degree of karstification, and he proposes a previous research program, the results of which will help to predict the price of the operations within a narrow area of error.

Résumé

Continuant avec la ligne des antérieurs travaux l'auteur a comme objectif pouvoir évaluer le coût d' impérméabilization d'un barrage dans une région karstique pendant la phase de project, c'est à dire, avant la construction.

Pour cela, et sur la base d'une série de travaux soignesement éudiés, il présente une méthodologie de travail, que fonctione avec succésdans la correction des fuites dans le barrage dûes à une réactivation du karst.

Il évalue dans une première étape, l'entourage de l'évolution des prix unitaires d'impérmeabilization, selon le degrée de karstification et il propose un programme de recherche géologique préalable, dont les résultats nous permetront d'estimer les coûts operationales dans un etroit entourage d'erreur.

Present Situation

When exploiting a river, the engineer selects the appropriate sites for dam building according to the hydraulic program to be developed, under three fundamental premises:

- The narrowness of the canyon must be maximum so that the volume occupied by the dam as well as the construction costs should be minimum.
- The impermeability of the rocks at the banks must be enough to permit the water to fill the reservoir.
- The rocks at the banks must be strong enough to support the charges transmitted by the body of the dam, under any filling condition of the lakes.

Karstic regions consisting of limestones and similar rocks, offer the best topographical places for dam building since they accomplish the first/and third conditions perfectly.

Due to karstification the second condition is so badly accomplished that this can make the purpose of the lake impossible, and many times investments are lost.

Actually, powerful water leaks sometimes appear immediately and in other cases they appear later and increase steadily, but in any case, since we are dealing with karst, they are important and worrying.

In order to correct those leaks, engineers have devised impermeabilization techniques which have been successful in many cases, although sometimes the cost of these methods nearly equalled those of the building of the dam.

Nearly all countries with important hydraulic programs and having wise karstic regions within their territory know very well all these problems.

The present situation shows, we think, not only the socioeconomic importance of the matter but the possibility of gathering experiences to solve it, as well. It is then evident that very little is known as yet of karst behaviour at a practical level.

Both in Spain, where more than 800 dams have been built, and Latin America, we have had the opportunity of taking part in some outstanding cases, what has allowed us:

a) To outline new ideas for the previous inspection campaigns, so that the information so provided should be adequate and effective to face the problem.

b) To select treatment and correction techniques, turned out most appropriate.

c) To firmly hold the view that the problems mentioned can not only be foreseen "a priori", but, closely enough, economically evaluated. This would permit the engineer in charge to choose the most adequate site helped by firmly based criteria.

Let us try to demonstrate it!

Investigating the Problem

Since 1972, the author has had the chance to take part, as a consultor, in the difficulty created by karst at the following dams in Spain: CANELLES, TOUS, ALCORLO and AIXOLA.

Based on the complete information from those dams, and thanks to data from other 15 dams in Spain and Latin America, the following points have been corroborated: (1), (2), (3), (4), (5) and (6).

1.- The directions of circulatuion follow planes preferably perpendicular to the minimum efforts, suffered by the massif. (σ_3) According to this, we can predict those directions by studying the microtectonics and defining the deformation ellipsoïdes.

2.- A previous speleological inspection may in some case help to determine the directions of drainage which are followed by the flow responsible for the karstification.

3.- For the grouting operation job to be successful it is necessary:

a) To use the SELF CONTROL GROUTING TECHNIQUE, that is intercalating the drillings in the screen according to modules so that the degree of closeness of previously grouted drillings can be observed.

b) Before grouting a given section it is necessary to carry out an essay of dynamic permeability (LUGEON essay), permiting us to select the viscosity of the initial slurry of the series. (Fig. 1)

4.- The chemical composition of the slurries, generally a mixture of cement and bentonite, is the most delicate part of the operations and has been patented in many occasions. In any case, the final resistances and their elasticity modules can be perfectly programmed "a priori." (Fig. 2)

5.- Clay fillings in karst are a peculiar problem since they can be extruded out of the conducts due to the new hydraulic gradients generated by the dam, what will cause deferred leaks making the problem even worse. i.e. (Fig. 3) shear stress of those clays under low humidity conditions reaches a value of:

0.6 to 1.2 Kg/cm^2

while under humidity next to saturation the value is:

0.01 to 0.02 Kg/cm^2

It is reduced from 60 to 100 times, making the mentioned risk evident.

6.- It is of great use to establish a system of piezometres down stream. This will not only pinpoint the ways followed by water in instant leaks, but moreover, deferred leaks will be detected before they actually happen, as the natural fill of clay comes out.

Results

Finally, reality shows, according to the studied cases, that each type of karst can be quantified in various ways, specially if we consider the kg of dry substance grouted per m^2 of screen and the price in \$/m^2 of the same substance.

Quantification is as follows: (see table 1, fig. 4)

1.- Total average values in kg/m^2 of dry substance grouted.

MOUNTAIN KARST	420
STRIKE SLIP FAULT KARST	343
ALTERNATING BEDS KARST	44
CORTICAL KARST	24

2.- The average of maximum values in kg/m^2 of dry substance grouted at the special sites (karstic conduits and karstified faults) of high admission:

MOUNTAIN KARST	3500
STRIKE SLIP FAULT KARST	3000
ALTERNATING BEDS KARST	172
CORTICAL KARST	66

3.- On the other hand, the number of special sites found in each dam as well as the percentage of grouting consum in them is as follows:

MOUNTAIN KARST	5	28%
STRIKE SLIP FAULT KARST	7	67%
ALTERNATING BEDS KARST	2	37%
CORTICAL KARST	9	32%

4.- Average of minimum values in kg/m^2 corresponding to the rest of the curtain where there are no special sites:

MOUNTAIN KARST	41
STRIKE SLIP FAULT KARST	30
ALTERNATING BEDS KARST	1.65
CORTICAL KARST	11

5.- Total price in $\$/m^2$ of finished curtain:

MOUNTAIN KARST	105
STRIKE SLIP FAULT KARST	81
ALTERNATING BEDS KARST	42
CORTICAL KARST	23

which enables us to estimate the cost of grouting once the surface of the screen is defined, according to geological considerations prior to the construction of the dam.

Critics and Comments

First we have to point out that the number of examples is still very little to be treated statistically, although the information handled has been collected for the last ten years. In order to overcome this situation we ask all specialists interested in the subject to get in contact and exchange information.

We lack well-studied examples in areas of tropical and hydrothermal karst, although we have good reasons to think that in both cases indexes of price and admission could be much higher than those mentioned here.

However, and in the case of hydrothermal karst, the more resistivity to karstification its mineralisations present, the more slowly deferred leaks will show when a paleokarst is present.

TABLE -1

UNITARY COSTS AND GROUTED QUANTITY IN ANY KARST TYPE TO CORRECT THE WATER LOSSES IN DAMS BUILT IN KARSTIC AREAS

	Kgr/ml.	Kgr/m^2	m/m^2	$\$/m^2$	KARST TYPE
MIN.	66	41	0'63	40	MOUNTAIN KARST
MAX.	1076	3485	3'1	490	
$\bar{X}$	366	320	1'15	105	
REM.	5 SPECIAL SITES			28%	
MIN.	90	30	0'30	25	STRIKE-SLIP FAULT KARST
MAX.	3250	2925	0'9	300	
$\bar{X}$	582	343	0'59	81	
REM.	7 SPECIAL SITES			67%	
MIN.	22	11	0'25	12	CORTICAL OR EPIGENETIC KARST
MAX.	32	66	2'1	50	
$\bar{X}$	85	24	0'28	23	
REM.	9 SPECIAL SITES			32%	
MIN.	3'3	1'65	0'5	5-6	ALTERNATING BEDS KARST
MAX	130	172	1'32	70-80	
$\bar{X}$	60	44	0'73	42	
REM.	2 SPECIAL SITES			37%	

In short, to correlate these values with some other possible cases, we feel the lack of a real theoretical basis for the genesis and evolution of karst, which will explain and quantify the idea of karstification potential as the primary cause for the described phenomena; which will explain and quantify the peculiar organisation of subterranean drainage; which will explain and quantify the liability of each rock to be karstified according to its tectonical structure and to the prevailing energy in each case.

Without this theoretical basis we still go on blindly.

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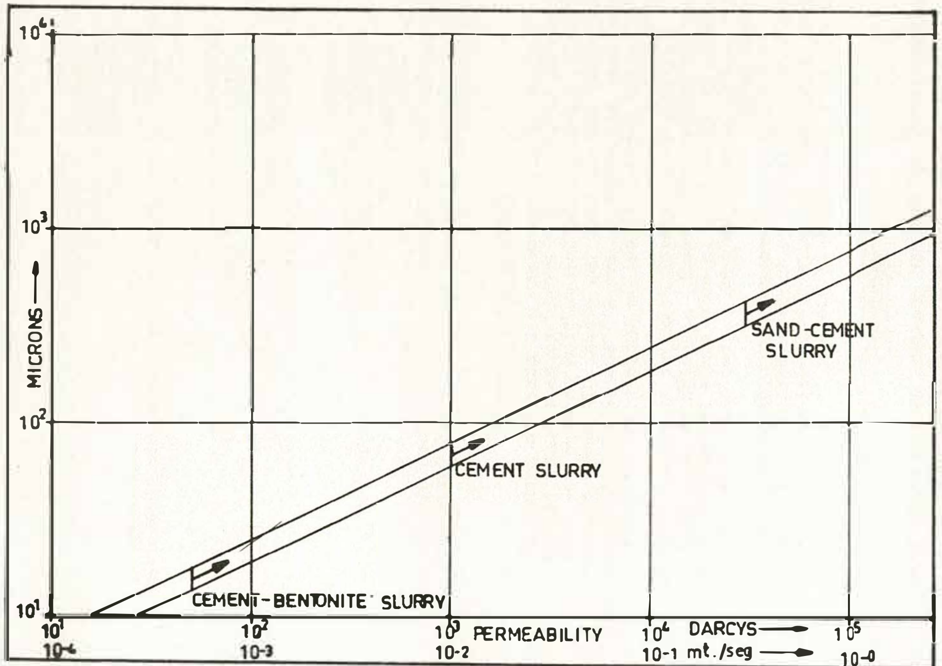

Figure 1. Penetrability limit of grouting slurry relation between rock permeability and grain size of slurry materials.

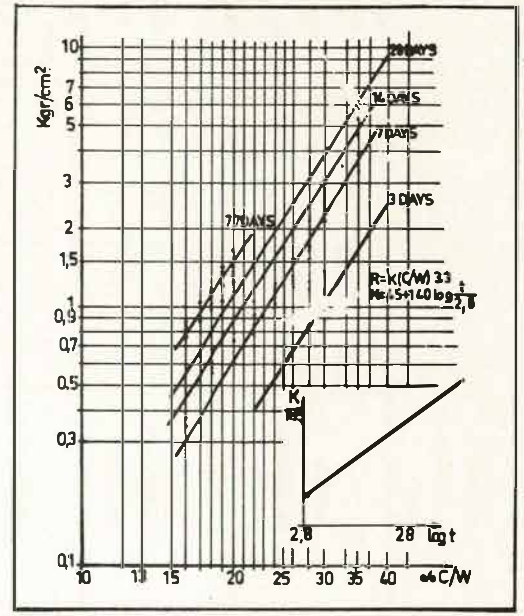

Figure 2. Relation between shear strength, sample age and dosification for bentonite-cement slurries.

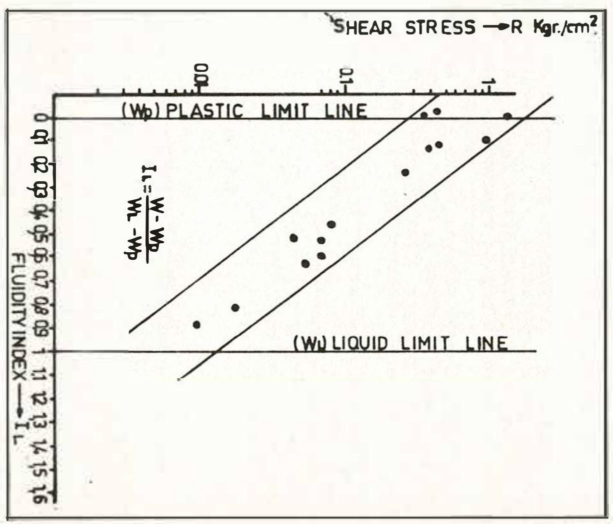

Figure 3. Relation between shear stress and fluidity index of several clays filling caves.

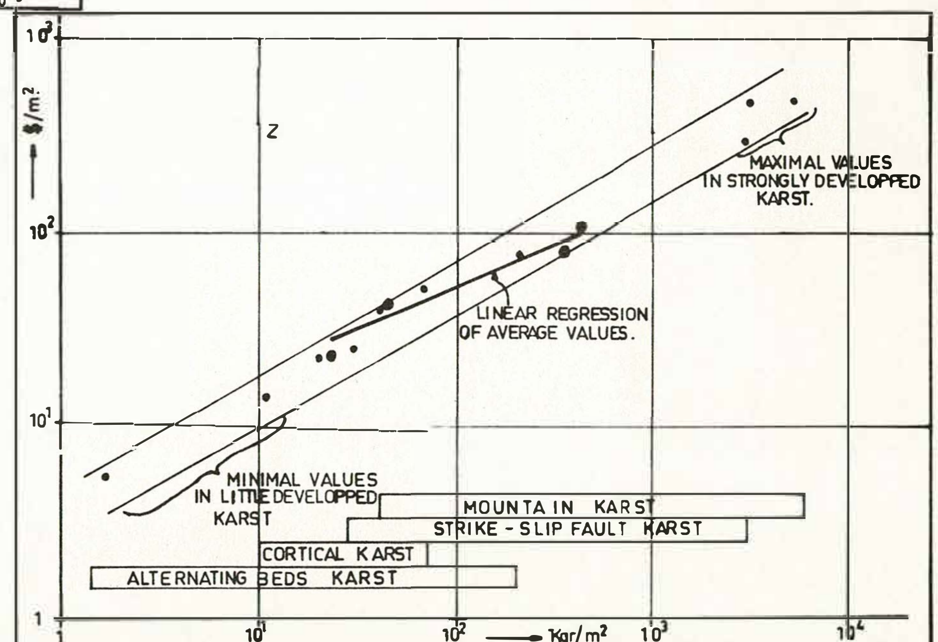

Figure 4. Relation between grouted quantity and costs for impermeabilitation work on several karst types.

Solute Uptake on a Magnesian Limestone Hillslope

S. T. Trudgill; A. M. Pickles; R. W. Crabtree
Department of Geography, University of Sheffield, Sheffield S10 2TN U.K.

Abstract

Dissolution experiments using dolomitic limestone (comprised of dolomite crystals with disperse calcite) indicate a dominance of calcium in solution in the early stages of dissolution and of magnesium in the latter. This pattern is compared with solute dynamics of soil water, soil drainage water, stream water and ground water. Soil water travel times are estimated using fluorescent dyes in the field and are controlled in the laboratory using leaching column displacement procedures. Weight loss of limestone tablets shows that solutional erosion decreases downslope with decreasing soil acidity.

Résumé

Au cours de la dissolution experimentale de calciare dolomitique, la concentration du Ca^{2+}est plus forte que cela du Mg^{2+} pendant le premiēr étage de dissolution, mais ces circumstances ont reversées plus tard. Ce modèle est contrasté avec les changes de la concentration des eaux de sol, des cours d'eaux et des eaux qui se trouvent au fond. Les temps de passage des eaux de sol sont mesurés par l'utilisation des teintes fluorescentes. Ces estimations sont comparés avec les résultats d'une analyse des léssivages de quelques échantillons des sol au laboratoire. L'analyse de la perte de gravité des pillules de calcaires montrent qu'il y a une augmentation de l'érosion et aussi de l'acidite des sols quand on ascend la pente.

Introduction

Many authors have shown that up to 80-90% of the solutional erosion in a karst system is concentrated in the soil and shallow bedrock zone (Atkinson and Smith, 1976, p. 167-174). In addition, there is interest in the study of hillslope hydrochemical processes in relation to the evaluation of karst features such as closed depressions. The aim of the work described in this paper is to contribute to the understanding of hillslope hydrochemical processes in these contexts. The processes involved have been studied by intensive hydrological chemical monitoring in order to investigate solute dynamics on Magnesian Limestone hillslope; this has been supported by laboratory dissolution experiments. In addition, the spatial patterns of solutional erosion have been investigated by the use of weight-loss limestone tablets placed at the soil-bedrock interface over the hillslope.

Geology and Dissolution Experiments

The limestone studied is the Lower Magnesian Limestone of Permian Age. It is an impure dolomite, with some diffuse cancite visible in microscope slides stained with Alizarin Red S. It is classified as a ferroan, high calcite dolomite and the mean composition from 50 samples is shown in Table 1.

Table 1. Mean composition of Magnesian Limestone

(50 samples, weight %)

Source: Steetley Quarries Ltd.

CaO	30.6
MgO	21.6
CO_2	46.4
SiO_2	0.65
Fe_2O_3	0.49
Al_2O_3	0.18
BaO	0.005
TiO_2	0.005
MnO	0.03
K_2O	0.002

Dissolution experiments have been undertaken in a reaction vessel into which 99% carbon dioxide has been bubbled with a fritted glass diffuser. 5 ml samples were withdrawn for calcium and magnesium analysis using Atomic Absorption Spectrophotometry and alkalinity analysis using a methyl orange indicator on an autoanalyses. pH was measured using a continuous recording pH meter. Agitation of the solution was achieved by a slow-speed impellor 1 cm above the base of the vessel. 2 g of rock material was used in 800 ml of deionised water. The results showed that on all the replicates tested, calcium dominated over magnesium in the initial stages of solution (Table 2). This is in accord with the results of earlier work suggesting that calcium dominated over magnesium in the early stages of dissolution, while magnesium dominance is thought to occur in the latter stages in relation to calcite saturation and precipitation (Trudgill, Laidlow and Smart, 1980).

Table 2. Calcium and Magnesium in solution during a dissolution experiment (on $mM.e^{-1}$)

Time (mins)	Calcium	Magnesium
0.45	0.079	0.022
1	0.120	0.0156
1.30	0.102	0.0308
2	0.130	0.0300
3	0.142	0.0350
6	0.155	0.0444
12	0.165	0.0452
24	0.205	0.0691
30	0.222	0.0802
45	0.264	0.1040
60	0.274	0.1090
90	0.319	0.1324
180	0.497	0.2010
1200	0.536	0.6256
1320	0.372	0.4113
1380	0.621	0.8800
1650	0.467	0.4915
2700	0.651	0.585
3360	0.611	0.325

Dye tracing of soil water

Rhodomine WT, Lissamine FF and Amono-G Acid dyes (Smart and Laidlaw, 1977) have been placed on the soil surface to label waters percolating into the soil. Detection has been by automated sampling and fluorometric analysis of water draining into throughflow troughs downslope. Water only moves laterally at the base of the slope (in reaction to a high water table) while dye tracing and throughflow trough monitoring upslope has shown that water invariably moves by vertical percolation, and only on three occasions in one year's sampling was horizontal movement recorded.

Dye arrival in stream-side through-flow troughs ranged from almost instantaneously to several hours after a rainfall event. Dye response time (time from rainfall commencement to detection in the downslope trough) could be interpreted in terms of antecedent rainfall conditions and rainfall intensity; very rapid response time (2-10 hours) occuring at very wet antecedent conditions (+40 - +50 cm soil water potential) or very dry conditions (-100 to - 200 cm tension) when soil cracking occured. Dye arrival was associated with calcium rich (and, inferentially, low residence time) water while base-flow was magnesium rich.

Laboratory leaching columns

Supporting data was gained from laboratory leaching columns. The results suggested that calcium rich water was associated with short solid-solvent contact times. Dye tracing also demonstrated the existence of rapid flow pathways.

Hillslope solutional erosion

Soil moisture potential increased down the slope studied, with groundwater emerging at the slope foot. Soil acidity increased upslope, with values of pH 6-8 at the slope foot and 5-6 towards the slope crest. The use of weight-loss tablets (Trudgill, 1975) of Magnesium Limestone showed that weight loss increased upslope in relation to increasing soil acidity (Table 3).

Table 3. Micro-Weight loss of Magnesium Limestone Tablets

Distance upslope from stream (m)	% Calcium Carbonate	Soil pH	Weight Loss (%)
0	20-30	7.5-8.0	0.05-0.15
10	5-25	7.5	0.10-0.20
20	5-10	7.0-7.5	0.20-0.25
30	5-10	7.0-7.5	0.20-0.35
40	2-5	5.0-6.0	0.25-0.45
50	2-5	5.0-5.5	0.35-0.55
60	0-2	4.5-5.5	0.55-0.65
70	0-2	4.5-5.0	0.45-0.70
80	0-2	4.5-5.0	0.65-0.80

Discussion

The results from the dissolution experiments, leaching columns and field dye-tracing converge in that it can be concluded that water residence time has an influence upon solute dynamics. Water residence times appear to be such that the hillslope output is comprised of
(a) long-residence time water (magnesium rich)
(b) shorter residence time water (calcium rich) and
(c) more or less instantaneous runoff of very low solute concentrations and serving to dilute (a) and (b). It would appear that water (a) is of extremely long residence time, possibly interstitial water of the order of magnitudes of residence time in years; water (b) would appear to be of the order of weeks to months residence time, though the evidence for this is circumstantial.

Erosion rates appear to be distributed in relation to soil acidity and are lowest in the wettest, but alkaline slope foot. The implication is that drainage conditions are important in relation to whether or not alkaline waters are removed from or supplied to any site in questions. The data also imply that soil pH is a good surrogate variable for the prediction of the distribution of solutional erosion in the landscape. This is in accord with earlier findings (Trudgill, 1977). In terms of landform evolution, it can be predicted that the slope is evolving by decline, that is the upper part of the slope is eroding faster than the lower. If this were also true for closed depressions, they could not be perpetuated in the landscape; this emphasises the importance of rapid drainage lines in the base of depression and also points to the importance of the proximity of ground water tables to the surface of a control on solutional erosion.

Acknowledgements

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The Tactics of Dispersal of Two Species of NIPHARGUS (Perennial, Troglobitic Amphipoda).

Marie-José Turquin
Laboratoire de Biologie animale et ecologie E.R.A. C.N.R.S. n° 849. Ecologie des eaux douces
Université Lyon I. 69622 VILLEURBANNE cedex

Abstract

N.virei and N. rhenorhodanensis were chosen to study the reproduction strategy of inhabitants of a reputedly stable environment. Despite the lack of thermal and photoperiodic fluctuations, the Crustacea show seasonal laying periodicity. The synchronization of layings, in the epigeneous world, is generally interpreted as being a means of resisting to predators. However, but for themselves, the Amphipods have no predators. The two Crustacea live in superposed environments in the space which are very similar from the point of view of physical factors: N. virei lays its eggs in the Summer; N. rhenorhodanensis, like fresh-water crustacea, in Winter. Why do they present this seasonal reproduction periodicity?

N. rhenorhodanensis, which lives in the non-saturated zone, must mate, lay its eggs, incubate for two months and the young on hatching have to disperse themselves while they still have time, i.e. for as long as percolations permit the biotopes to be well filled up. Then intra-specific predatory actions take place and only the strongest individuals survive the dry season in diapause at the bottom of their burrows.

The Summer laying of N. virei and therefore the recruitement of young at the moment when the network is refilled with water, would be due to phasing with the environment. When the water-table rises again, I noticed the presence of pulli with hydrophobic teguments even as far as the highest outlets in the network. The dispersal in altitude compensates for the devastations caused by floods along some galleries, the drains, and for the rheoxenous tendancy of the adults.

Thus the hydrological karstic factor provokes two very different tactical answers concerning two cave-living Crustacea, both aiming at preserving the species in the karstic system.

Résumé

Niphargus virei et N. rhenorhodanensis ont été choisi pour étudier la stratégie de habitants d'un environnement réputé stable. Malgré l'absence de fluctuations thermiques et photopériodiques les crustacés montrent une périodicité saisonnière des pontes. Le synchronisme des pontes, dans le monde épigé, est en général interprété comme un moyen de résistance à la prédation. Or, hormi eux-mêmes, les amphipodes n'ont pas de prédateurs.

Les deux crustacés vivent dans des milieux superposés dans l'espace et très semblables du point de vue des facteurs physiques: N. virei pond en été, N. rhenorhodanensis, comme les crustacés d'eau douce en hiver. Pourquoi présentent-ils cette périodicité saisonnière de reproduction?

N. rhenorhodanensis, qui vit dans la zone non saturée, doit s'accoupler, pondre, incuber deux mois et les jeunes, à l'éclosion doivent se disperser tant qu'il en est temps, c'est-à-dire tant que les percolations assurent un bon remplissage des biotopes. Ensuite la prédation intraspécifique s'installe et seuls les individus les plus forts passent la saison sèche en diapause, enfouis dans leurs terriers.

La ponte estivale de N. virei, et donc le recrutement des jeunes au moment de la remise en eau du massif, serait une mise en phase avec le milieu. Lors de la remontée de la surface piézométrique j'ai constaté la présence de pulli à téguments hydrophobes jusqu'aux points les plus élevés du massif. Cette dissémination "en altitude" compense et l'action dévastatrice des crues le long de certaines galeries, les drains, et la tendance rhéoxène des adultes.

Ainsi le facteur hydrologie karstique provoque deux réponses tactiques très différentes de la part des deux crustacés cavernicoles, toutes deux ayant pour but la conservation de l'espèce dans le système karstique.

HORNS (1978) writes: "In the game of life an animal stakes its offspring against a more or less capricious environment. The game is won if its offspring live to play another round. What is an appropriate tactical strategy for winning this game?"

As to cave animals the biologists answer: low fecundity, delayed and reduced breeding, long development, high parental survival for iterated breeding. These factors are the same as part of those associated with K-selection. In this paper we investigate the tactics of disperal of the young of two species of Niphargus, bionts of the so-called stable cave environment.

The Site

Our study was made in the French Jura Mountains; the region called Revermont is a succession of synclines (300 m high) and anticlines (400-700 m) where the openness of joints allows substantial infiltration. Most of this region is covered karst: however the soil is mainly rendzina so it does not hinder infiltration. In the bottom of the synclines brown clay tends to block joints in the underlying rock, but not enough for hydromorphic soil to develop. Impervious calcereous clay beds underlie the folded limestone beds so that some synclines constitute poljes. The penetrable caves of Revermont range from "dead caves" and numerous pot holes to long horizontal caves with several levels. Water tracing has permitted the relations between dry valleys and risings to be established. Because of the folded structure of limestone and "marl" the underground flow is deflected away, southeastwards, from the surface drainage pattern by the fold axes (N- SSE): the drainage is controlled by the number and openness of joints and faults along anticlines. The water of one polje rises in the next valley or joins the River Ain still farther East. This situation allows the biologists to study the drift of Invertebrates at the outlet of one polje.

The karstic system- in Jura- involves pressure flow: the sides of anticlines provide favourable structural conditions for the pressure required.

Material

Niphargus virei and Niphargus rhenorhodanensis are both found in the French Jura. The former lives in the lower saturated zone and in the intermediate zone where the cavities are intermittently flooded to capacity, the latter - in Revermont- in the superficial aquifers (glacial moraines) and in the upper unsaturated zone (vadose zone). On the left bank of the River Rhône, N. virei is absent: N. rhenorhodanensis inhabits the whole karst system.

The life-cycle of Niphargus virei is well known after GINET's work (1960). This animal breeds when 2.5 years old once a year then less. The average number of eggs is 60 and their development takes 90 days at 9°C. The adult molts twice a year then less. In laboratory conditions GINET reared Niphargus till 14 years. This author tested the response of the Amphipoda to the current: the animals are washed away with a water speed of 20 cm/s (which is less than the necessary speed to move an inert particle of the same size). In the karst population is inexorably driven out of the underground voids through the drains: the filtering of the outlets enables to capture of part of the concealed population (TURQUIN, 1976). Niphargus virei has one predator the troglobitic Hirudinea: Trocheta bykovskii, and is its own competitor: adults versus young.

The life-cycle of N. rhenorhodanensis was established on a population living in the pools of Grotte de Hautecourt (GINET, 1969) in the vadose zone. It is very similar to that of N. virei except that this species being smaller lives about 8 years and lays fewer eggs. The number of adults never exceeds 5.5 per square meter; their density is regulated mainly by intraspecific competition. The individuals are caught by means of baits: pieces of meat placed on the clayey bottom of gours. An artificial tunnel 6 to 15 meters deep, 500 meters long provides an opening in the upper part of the vadose zone. This site favours the observation of the movements of the Amphipoda all the year round. The cave-dwelling Amphipoda live in two separate biotopes of the same karstic systemes where the physical conditions are very similar. Yet, although both species have a definite breeding season, N. virei reproduces in summer and N. rhenorhodanensis in winter. What is the adaptive value of such converse behaviours?

The Annual Fluctuations of the Enviroment of N. rhenorhodanensis.

In the Jura the vadose zone receives water in autumn and winter: the infiltrations fill the pools, puddles, rimstone pools; here the animals are to be seen. They live also in the joints which are wide enough to permit infiltration from the soil percolating downwards for they can be caught by fitting nets under the drippings after heavy rainfall.

From April the evaporation returns water to the atmosphere: the runoff fails, temporary water collections recede;the dry season may last until November. While the environment shrinks, the competition between Niphargus increases. When there is no longer water on the bottom of the pools and probably in the joints, the crustaceans burrow into clay or hide under stones. They remain motionless for several months in the saturated atmosphere and they regain normal activity as soon as water fills the gours again. GINET (1969), after 5 years of observations in Grotte de Hautecourt, found that reproduction takes place 3 months after the beginning of the wet period. It is logical to think that reproduction cannot occur during the dry period as most of the animals are unable to move about and meet. Conversely after they have resumed normal activity, and feed, they breed. About two months later the young hatch and disperse away from their ravenous parents in search of vacant places. They swin laterally, they dig downwards through the karst conduits; on arriving in the intermediate zone they are eliminated by N. virei since the two species never occur together. They can even move upwards when water fills up small channels; as we proved in an experiment with glass pipes in which the animals crept up and down with the water level.

The Fluctuations of the Environment of Niphargus virei.

N. virei lives in the zone in which water moves dominently laterally. The rheoxenous animals tend to follow the stream flow. They go down the karst conduits and draw near the risings. The phenomenon is illustrated by the population pyramids we built with the individuals caught in nets for each annual hydrological cycle (TURQUIN, 1981, TURQUIN et BATHELEMY, 1981). The oldest Niphargus are about 10 years old which means they escaped many floods. We demonstrated that the floods' intensity may affect the populations drastically. During the low-water period some animals will be trapped in pools or even out of water as we observed in several caves. At the first flood of the season all the animals living in the large joints in which water moves quickly and in the conduits near the drain will be expelled from the karstic system. Then, as the galleries choke downstream the empty spaces tend to fill up, and the watertable so rises. The speed and pressure are such that water currrents can carry pebbles uphill (over heights of at least 100 m in La Luire pot-hole, Vercors, France). What happens to the fauna? Can we expect a vertical drift? Field studies allow to answer positively.

Discussion

The Crustacea's reproduction period is linked to seasonal conditions and in fact governed by changes, in one way or in another, in temperature and in photoperiod. In the absence of these stimuli in the subterranean environment, Niphargus must use other temporal pin-points in order to synchronize its reproduction. For N. rhenorhodanensis I envisaged (TURQUIN, 1975) the annual fluctuations in abundance of the figurate food.

Contrary to other fresh-water crustacea, N. virei shows a maximum number of layings in the Summer. This period would apparently appear unfavourable for adults as for the young. Indeed in intermediary zone caves, as the summer advances we observe that the living space decreases, intraspecific competition increases, and food becomes scarce. On birth, the pulli are moreover submitted to their parents predacity and even to the risks of dessication as they are unable to burrow into the clay as do adults to spend the dry period. In some occasional pools only the largest individuals remain.

This long-living crustacean's birth-rate seems high: indeed, for a stable and stationary population, whose individuals can live more than 10 years, in theory the generations could be renewed with only two eggs per couple. Whereas, reaching adulthood at 2.5 years, a female can lay at least 420 eggs in her life. GINET and DECOU (1977) have calculated that an adult couple, after having reproduced over 4 successive years, by the end of the fifth year, will have 60,000 descendants. N. virei appears to be very different from the K tacticians. What we have learned from hydrogeologues about the functioning of the Jurassian type of karst system permits envisaging a role being favourable, to the synchronization of layings with the moment of minimum availability and to this great reproduction effort.

1- at birth, the pulli possess non-wettable teguments for about two months. When laboratory bred, if they swim to the top they are hopelessly trapped by surface tension and die. In natural environment, on the contrary when water fills up the system again, it begins to circulate in all directions following the conduits and the young can be dispersed in the height of the karst volume and toward upstream following the levels of the water-table (phenomenon observed in nature). The adults too move up inside the conduits and cavities if the current flow is sufficient to passively transport them. The pulli are carried much higher and much further. Thus the simultaneous hatching of young at the end of the dry period allows a passive dispersal of the species in the whole network when water returns.

2- As for N. virei's disproprotionate laying effort as it would appear in the cave environment, it is necessary

- on the one hand, to compensate for mortality linked with floods whose influence is very great on the most abundant class: the young which hatch shortly before the beginning of the hydrological cycle.

-on the other hand, to assure the redispersal of the species every year after the dry period during which the rheoxenous population tend to go down towards the outlet following the currents.

HORN (1978) introduced the notion of dispersal and catastrophe in population models of r and K selection: "if adults can actively select habitats, then adults should disperse and leave well-provisioned offspring in appropriate places. If adults cannot move about or select habitats, they must broadcast young over both appropriate and inappropriate habitats. The first case is consistent with K-selection; the second entails very low survival of young and therefore accords more with r-selection".

Even though Niphargus lays half as many eggs as Gammarus of the same size, the r-K continuum it is less K than other cave-living invertebrates. The synchronization of layings- in the epigeneous world- was interpreted (HORN, loc. cit.) as being a means of resistance to predators; in the case of N. virei it would seem to be an adjustment to the environment so that the hatchings take place when the system is refilled with water: a means which is costly concerning young individuals but effective as far as dispersal is concerned.

Conclusion

N. rhenorhodanensis's behaviour is typical as far its dispersal method; adults remain in the same place and on their territory, the young are forced to emmigrate in search of a free space. Juvenile mortality is high; we estimate it to be 95% at the Hautecourt cave.

If the dispersal of the small species of the vadose zone is active, the dispersal of N. virei is passive; the synchronization of reproduction with the rising of the water-table represents an original means of conquering a three-dimensional aquatic biotope.

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Sea Tide Effect Study in Karst Caves on the Rim of Trst (Trieste) bay: Kras, Yugoslavia, Italy

Primoz Krivic
Geoloski zavod Ljubljana/Geological survey/, Parmova 33, 61000 LJUBLJANA, Yugoslavia

Abstract

During the hydrological study of coastal aquifer of Kras we have investigated a number of water caves and natural wells on the distance of 1000 to 5000 metres from the sea. These wells functionate as natural piezometers where the water table oscillates depending on sea tides.

The study of groundwater-table variations due to sea-tide effects enabled us to characterize the aquifer's general hydrodinamical behaviour and its characteristic parameters, as diffusivity for example.

We have also proposed several hydrogeological models of coastal aquifer in order to reconstruct the groundwater-table oscilations. This was done by using limnigraphs in karst caves and a maregraph in the Trst/Trieste/bay. The model that is most alike to the known geological conditions is the confined aquifer model with an effect of partial permeability of the drainage zone overlying horizontals. This model, together with the model of unconfined aquifer with delayed yield, gives the most satisfying reconstitution of sea tides observed in water caves.

Résumé

Dans le cadre de travaux hydrogéologiques de reconnaissance de l'aquifère côtier de Kras plusieurs grottes et puits naturels qui se situent à une distance de 1000 m à 5000 m de la côte adriatique ont été explorés. Ces avens fonctionnent comme des piézomètres naturels avec fluctuations du niveau piézométrique dues aux apports d'eau de pluie et aux marées marines.

L'étude de propagation d'ondes piézométriques dans l'aquifère côtier, sous l'effet des marées marines a permi de caractériser le comportement hydrodynamique de l'aquifère karstique et d'évaluer des paramètres caracteristiques du milieu tels que la diffusivité.

Pour reconstituer les marées observées, enregistrées par les limnigraphes instalés dans les grottes et par le marégraphe situé dans le golfe de Trst/Trieste/, nous avons examiné plusieurs modèles hydrogéologiques de l'aquifère côtier. Le modèle qui convient le mieux aux conditions géologiques connues est celui d'une nappe captive avec un effet d'étanchéité partielle du toit de la zone drainante. C'est ce modèle, et aussi le modèle d'une nappe libre avec un effet d'égouttement, qui permet la meilleure reconstitution des marées observées dans les grottes et gouffres.

On Karst Denudation Research Problematic

Anton Droppa
031 01 Liptovsky Mikulas Nobr. Petrovica 17, Czechoslovakia

Abstract

There are several methods for finding out the quantitative value on the chemical karst denudation. The hydrochemical method is the most used. It is based on the finding of dissolved stuffs quantity in a certain content of water. There are already several well known formulas for the quantitative number of the corrosion's intensity/J. Corbel 1959, P. Williams 1963, I. Gams 1969, M. Pulina 1968, A. G. Čikišov 1972, A. Droppa 1976/. Some formulas take into consideration only the content of $CaCO_3$, others also of $MgCO_3$.

The karst's corrosion intensity is equal to the increases of the dissolved stuffs in karst waters in a certain water's content and certain time during its karst-land flow. For account the corrosion's greatness in a karst flows of alochton origin there are not convenient those formulas, which do not subtract the beginning mineralization except of Pulina's formula.

According to our corrosion's intensity research in the karst region of West Karpathian Mountains, Czechoslovakia, is obvious, that in a reckoning of a corrosion greatness there is necessary to calculate with the total water's mineralization and not only with its total hardness. Yet the content of others dissolved stuffs is a componenet of the karst mineral. The difference between the karst's corrosion calculation - according the total mineralization is higher in 25-47% than according to total hardness.

The most exact method of finding out the corrosion's greatness is in this way: we subtract from the quantity of certain dissolved stuffs in g/s in waters at the end of a karst's ground or in a well the quantity of dissolved stuffs in g/s in waters near their mouths on the karst ground.

Here is the formula for this purpose:

$$A_M = \frac{11,68 . \Delta M}{P} . R$$

A_M - the total folated dissolved stuffs in m^3 /Km^2/ year, or in mm per 1000 years

ΔM - the increase of total mineralization in g/s during the water's flow through the karst's ground

P - the area of the draineg karst's ground in km^2

R - the reduction factor for surface flows / not necessary for wells.

Muck Spreading on Speleothems

A. G. Latham
Department of Geography, McMaster University, Hamilton, Ontario, Canada

Abstract

It is fairly common for stalagmites and flowstones to be covered with detrital material either from the feedwater or from floods. The foreign material includes quartz, feldspar, opaque and other grains, clays and ill-defined organic muck, according to the source. As observed in thin section the foreign grains and especially mats of muck often cause, 1) the nucleation of microcrystals. Detritus may line the sides of cavities or be included within the crystals. It may impart colour to some speleothems. Under certain conditions detritus may also cause minor morphological changes. The distribution of detritus is in turn affected by the feedwater and the crystal growth.

Résumé

Il est assez courant d'apercevoir des stalagmites et des concrétions, d'écoulement couverts de matière détritique provenant des eaux d'alimentation ou d'inondations. Cette mati re étrangère comprend du quartz, du feldspath, des grains opaques et autres, des argiles et de la matière organique décomposée mal définie, dépendant de la source. Tel qu'observé en section mince, les grains étrangers et les tapis de matière organique décomposée en particulier causent souvent 1) la terminaison de la croissance du cristal précédant et 2) la nucléation de microcristaux. Des détritus peuvent revêtir les parois des cavités ou être inclus dans les cristaux. Ils peuvent aussi communiquer une couleur à certains spéléothèmes. De plus, sous certaines conditions, ces détritus peuvent causer des changements morphologiques mineurs. La distribution de détritus est à son tour affectée par les eaux d'alimentation et par la croissance des cristaux.

Introduction

Speleothems may be thought of in terms of their gross morphology and crystal fabric. Included in the former are such factors as shape, size, uniformity, surface appearance, overall colour, hiatuses and whether they are 'dead' or actively growing. Included in the latter are factors such as crystalline type, size and shape, their relation to one another and to the growth surface, the presence of fluid inclusions, and the presence and influence of various types of foreign material.

The following discussion is confined to the common stalagmites and flowstones of calcite, having a simple growth layering. It is shown that foreign material and especially organic matter can considerably influence the crystal fabric and to a lesser extent, the morphology of speleothems.

The Crystal Fabric

Columnar or palisades calcite crystals are common in speleothems and are stacked approximately normal to the growth surface (Kendall and Broughton, 1978). This may readily be seen in stalagmites sliced down the middle and acid polished to bring out reflections from different face orientations. Stacked crystals near the centre have their long axes vertical, as they approach the side they appear to curve in 'jumps', ie, they give way to new, generally shorter, crystals having a more favourable orientation to the growth surface. The fast growth axis is usually the axis of symmetry of the crystal. Evidently a c-axis orientation that is at a more acute angle to the growth surface does not compete as well. This length-fast direction to the growth surface (calcite is uniaxially negative) is referred to by Folk and Assereto (1976), Kendall and Broughton and others as the 'normal' situation. Length slow calcite is abnormal. This point was contended recently by Dickson (1978) who argued that the shape of anhedral crystals is dependent only on the orientation of the greatest growth vector and is independent of the optic axis orientation. All but one of the speleothems examined herein were of the length-fast type.

Gascoyne (1977) argued for the presence of organic materials (humic and fulvic acids) to account for much of the colour of speleothems. Perhaps the best method of detecting and characterising organic materials in speleothems is to use IR spectra to compare functional groups of known organic acids with those from speleothems (D. Brook, pers. com: and Laverty and Crabtree, 1978).

Thin sections were prepared of non-white, impure spelethems from Bermuda, Canada, England, and elsewhere in conjunction with U-series dating and paleomagnetic studies. The observed calcite fabrics were largely as described by previous workers. In addition detrital material was present in the form of quartz and feldspar grains, opaque grains and organic material and was evidently deposited by flood waters. The detritus was laid along and marks out the growth layering of speleothems. Its effects were as follows:

a. Effects on Gross Morphology

In several stalagmites flood-lain detritus has coated the surface. The resumption of the drip process has splashed most of the muck from the central cap area and redeposited it down the sides. This 'splash' effect is common and many sectioned stalagmites show dark vertical sides enclosing a much purer central drip area.

A stalagmite from Mexico (DAS2) shows a hole up the middle with cusp-shaped growth layering. At various points along the hole are quartz grains, either loose or cemented into the calcite. What appears to have happened is that the drip splash has failed to dislodge sand grains while the stalagmite has continued to grow. Instead the splash has merely agitated the grains so as to leave behind a more-or-less vertical work-hole. Once the work-hole was established it was easily possible for successive floods to replenish the abrasive grains.

DAS2 also showed holes and microgours partly filled with detritus. The detritus may become cemented into the fabric, or cemented over as loose material. This effect is fairly common on the sides of stalagmites and on flowstones.

b. Effects on Crystal Fabric

Organic material was present in two ways;

1) As the presumed colouring of translucent calcite.

Coloured speleothems nearly always produce copious quantities of scummy froth upon acid dissolution, and is taken to indicate the presence of organics. By contrast 'pure' white speleothems seldom produce froth (Gascoyne, op cit, and this study). The speleothem colours are - black, brown, red-brown, red, (carrot speleothems), yellow or amber, and brown-pink.

An amber stalagmite from Bermuda showed calcite crystals of a mottled appearance. It is difficult to see how high molecular weight organics, which become incorporated into the calcite crystals, can fail to disrupt the lattice -- perhaps this is what the mottling represents. In that case one may infer that a uniform colouring indicates a narrow range of molecular weight, which in turn suggests that the organics were carried by, or were soluble in, the drip water.

2) As observed in thin section, - hazy, hard-to-focus fibrous material, often in the form of mats arranged along growth planes. Its effects were best observed in flowstones from Canada and Bermuda.

In Canadian samples ENF and BJTL small amounts of detritus were incorporated into palisade crystals without disrupting optical continuity. Often competing columnar crystals trapped and concentrated the fibrous material between them. The growth layers show a 'dip' in topography followed by the immediate nucleation of microcrystals. Gradually the more favourably oriented crystals dominate the continued growth of the speleothem, before the growth is once more interrupted by the next mat of detritus.

A piece of ENF was heated to about 700° C and a second thin section was obtained. The detritus had then become much more prominent presumably due to the (partial) carbonization of the organics. Some, apparently pure, white speleothems, can be shown to have 'hidden' organics by heating in this way (C. Yonge, pers. com.).

In Bermudan flowstone RCB large length-fast columnar crystals were terminated by organics and fine iron minerals (an red residue was obtained after dissolution). As above, those crystals having length-fast crystals oriented perpendicular to the growth plane eventually win over other orientations. These orientations include crystals whose optic axes are along the growth plane and which also appear to show strain effects. Many crystals growing in microgours are also zoned with fine sub-microsopic material thought to be of organic origin.

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Magnetostratigraphy From Speleothems: Establishment and Applications

A. G. Latham
Department of Geography, McMaster University, Hamilton, Ontario, Canada

Abstract

The measurement of the natural remnant magnetism (NRM) and U/Th dating of speleothems has enabled dated secular variation master curves to be produced. These master curves cover regions centred on West Canada, Mexico, and Britain for Holocene times. The origins of the speleothem NRM, its reliability as a recorder of the Earth's magnetic field and the accuracy of the SM master curves will be discussed. Besides the geophysical applications, speleothem NRMs have applications to magnetostratigraphy; examples are given.

Résumé

Le mesurage du magnétisme naturel résiduel (MNR) et le datage U/Th de spéléothèmes a permis la production de courbes maîtresses datées de la variation séculaire. Ces courbes maîtresses recouvrent des régions de l'ouest Canadien, du Mexique et de la Grande-Bretagne, pour l'Holocène. Les origines du MNR de spéléothème, sa crédibilité en tout qu'enregistreur du champ magnétique terrestre et l'exactitude des courbes maîtresses de variation séculaire seront discutées. En plus des applications géophysiques, les MNR de spéléothemes possèdent des applications en magnétostratigraphie; des examples sont donnés.

Introduction

It is known from observatory records that the Earth's magnetic field changes slowly with time. These changes in declination, D (the angle that a compass points away from north), and inclination, I (the angle a freely-suspended compass points down (or up) from the horizontal) are known as secular variation (SV) (see eg. McElhinny, 1973, or Aitken, 1974). The intervals of time involved in SV range from tens to tens of thousands of years. Different regions of the Earth have distinguishably different field signatures because of large geomagnetic anomalies which move, grow and decay. Thus a (constant speed) magnetic recorder would carry the impression of the SV of that site.

The most common natural recorder is a sediment. The record is produced from detrital magnetic grains (eg. magnetite) which settle on sea or lake beds aligned by the field. Cores from such sediments may be analysed using a magnetometer and they may be dated by ^{14}C or other means. The hope is to produce a magnetostratigraphic master curve for that region so that other sediments, including cave sediments (Creer and Kopper, 1974 and 1976; Ellwood, 1971), not amenable to radiometric analysis, may be magnetically matched to the master curve and so be dated. These dated sediments in turn yield information about the geological and biological records also contained within them.

Unfortunately quite a few sediment records have yielded poor or even spurious results due to a variety of factors to do with:

1) settling, flow or compaction
2) chemical remagnetization,
3) slumping, faulting or turbidity currents
4) bioturbation of burrowing organisms
5) various sampling problems (eg twisting of cores)
6) poor dating controls.

(see eg. Verosub, 1977; Verosub and Banerjee, 1977)

Stalagmites and flowstones having a measurable natural remanent magnetization (NRM) can be shown to be faithful recorders of the field. Many speleothems may also be reliably dated by the U/Th method within the dating limit of 350 Kyrs (see eg Gascoyne et al, 1978). The resulting SV records yield useful insight into the working of the Earth's magnetic field and provide good master curves for magnetostratigraphy. Reversely magnetized speleothems have provided age limits on cave development and which may in turn be related to surface geomorphological processes.

Field and Laboratory Methods

A simple aluminum device to hold a magnetic Sunnto compass and a three-arm U-tube were used to orient stalagmites with respect to north and the horizontal. A tripod carrying the compass and a clinometer were used to orient flowstones. The samples were cast in plaster of Paris and sawn up to produce sets of specimens from the growth layers. These specimen were then measured for their NRM (magnetically cleaned) using a sensitive cryogenic magnetometer at the University of Toronto. The orientation data and Fisher statistics were used to produce D and I variations as recorded up the speleothem. After all the magnetic measurements had been made selected specimens were dissolved up for dating by the U/Th method. (for some preliminary results see Latham, 1977, and Latham et al, 1979). A least squares fit for a constant growth rate was all that was warranted for the stalagmites reported here. Three Canadian flowstones from the Rockies were older than the dating limit and two of these were found to have reversed polarity. One of these latter is reported on here and the other is reported in the Castleguard Symposium of these proceedings.

Examples

VCCL, Vancouver Island, Canada

This sample was 50 cms long and sectioning revealed that floods had repeatedly deposited sand and magnetic grains on its surface. A soft part of the magnetization was found to be aligned along the direction of the modern field. There is no reason for believing that the stable part reflects anything other than the ancient ambient field. Figure 1 shows the D and I variations and dating of this stalagmite. Plotting the corresponding virtual geomagnetic poles (VGPs) (figure 2) show that they mostly precessed about the north geographic pole in a clockwise direction. According to Runcorn (1959) and Skiles (1970) this is related to large geomagnetic features which drift slowly westward. The U/Th data show that it took, on the average, about 1450 years for a complete cycle of drift to be completed (there are about 2¼ cycles in the record) if only one such feature was responsible. Most of the path is on the far side of the geographic pole as seen from the site (Vancouver Isl).

As a possible use of this record in magnetostratigraphy P. Hale at McMaster is presently studying beach and estuarine processes on east Vancouver Island but without radiometric dating control (pers. com.). His cores contain abundant quantities of magnetite it may be possible to match his (Holocene) core record with the record from VCCL, to provide estimation of sedimentation rates.

SJHS Chiapas, Mexico.

This stalagmite was about 29.5 cms high and possessed an outer coating of calcited dirt. In addition there were two or three short hiatuses near the top.

The magnetization of the coating was high by comparison with the inner clearer layers. It was found that the coating gave the same D and I values whether specimens were taken from the top or the sides. This is good evidence for saying that there are no depositional errors associated with the NRM.

The D and I and age data are given in figure 3. The stalagmite and its hiatuses cover a period of about 125 to 100 Kyrs. An anomalous geomatnetic field feature is claimed from sediments to have occurred about 114 to 108 Kyrs ago, called the Blake Event (Smith and Foster, 1969). There is no evidence for it from the SJHS record (or from many marine cores too for that matter).

The corresponding VGPs are given in figure 4. Any sediments from the Central American region and falling within this time span could be dated by magnetostratigraphic correlation with the SJHS record. It is noted in particular that the VGPs are near-sided to the observer, which is in contract to other speleothems in this study.

ENF, Alberta, Canada.

This flowstone was taken from Eagle Cave, the site of an ancient spring, in the Crow's Nest Pass. The uranium and thorium isotope data established that is was older than 350 KYr but probably less than 1 Myrs. The paleomagnetic data showed that it was reversely magnetized and therefore was older than 720 KYrs BP.

The modern perennial spring lies below the cave by about 100m. So it has been possible to suggest an erosion rate limit of not greater than about 0.4 m per thousand years. Ford et al (1981) have used these and other data to give some idea of erosion rates in the Southern Rockies of Canada.

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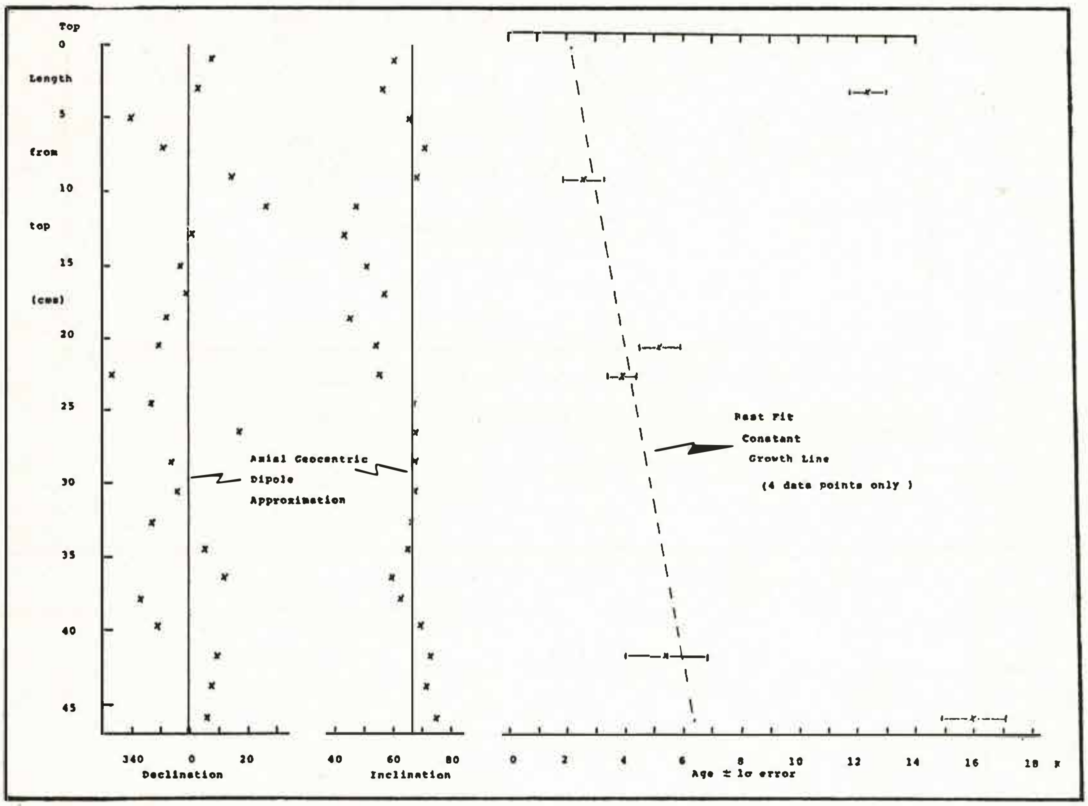

Figure 1 Declination, Inclination and Dates of VCCL.

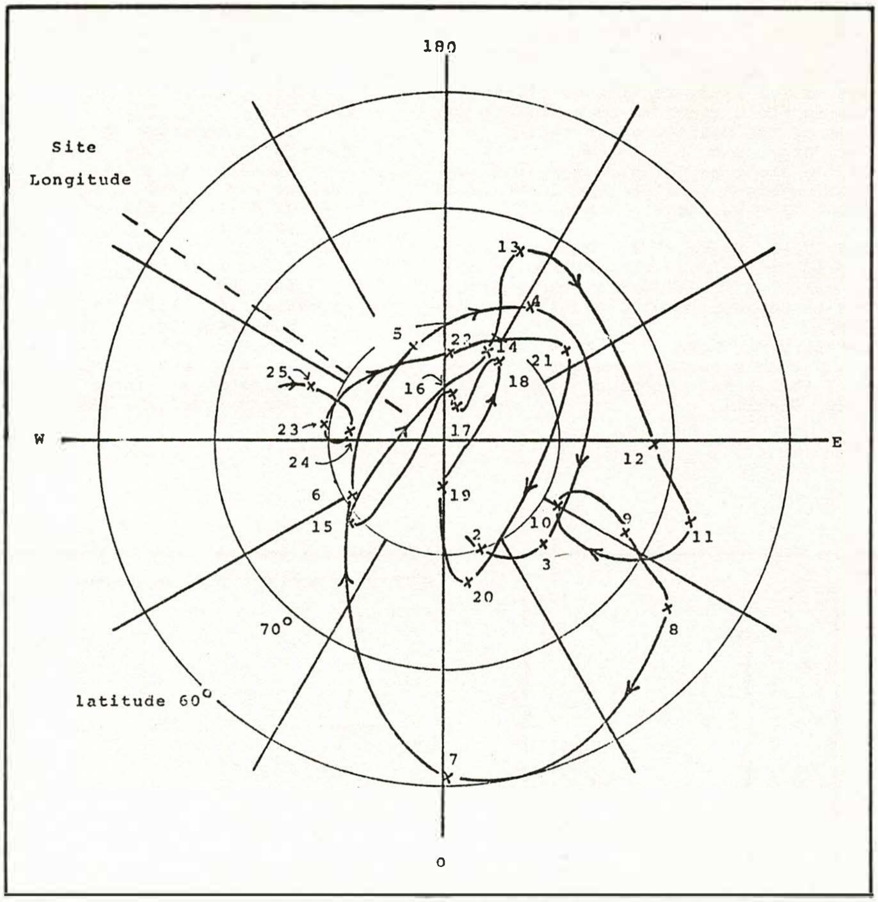

Figure 2 Virtual Geomagnetic Pole Positions for VCCL.

The numbers denote the cut and arrows denote direction of VG polar movement with time.

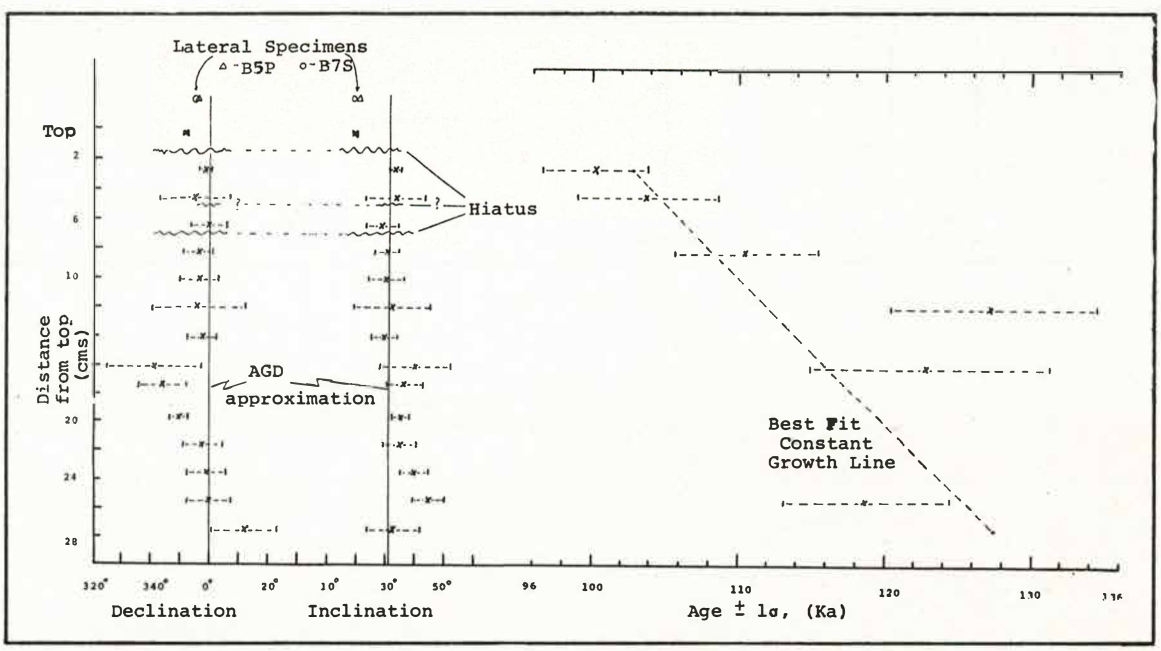

Figure 3 The Paleomagnetism and Dating of SJHS.
(Cuts 1, 3 (?) and 4 each straddle a hiatus)

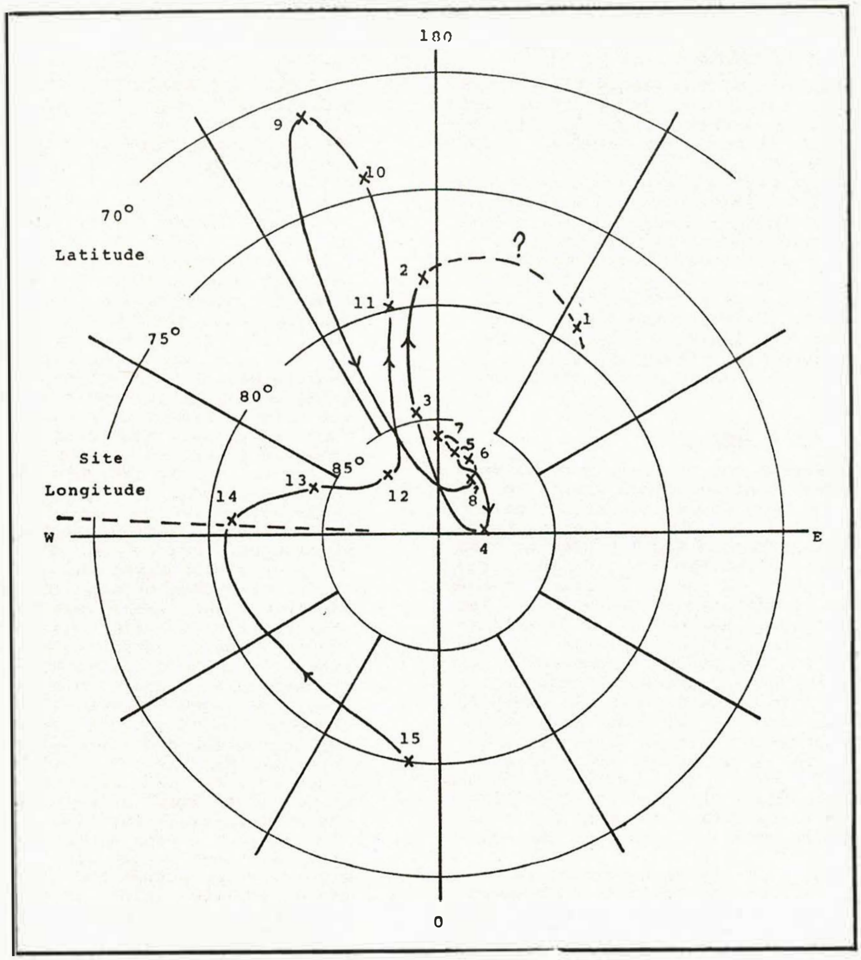

Figure 4 Virtual Geomagnetic Pole Positions for SJHS. The mumbers denote the cut and arrows denote direction of VG polar movement with time.

Hollow calcite crystals on surfaces of small pools in the Liethöhle/Sauerland, W-Germany

Gerd F. Tietz

Introduction

The Liethohle extends on two floors in Devonian Massenkalk. The shape of the pits varies from a vertical narrow to a horizontal shallow type. In pits above the karst water level small pools are developed showing characteristic differences:

in vertical narrow pits pools never contain calcite crystals, indicating undersaturation with respect to calcite. The water supply is seasonal, following more or less rainfall variations, and reaches a maximum after thaw. Major pool level fluctuations are common;

in horizontal shallow pits the linings of all pools consist of calcite crystals, indicating oversaturation with respect to calcite. Only small and slow, but continuously running water supply keeps the pool level nearly constant. Maximum of fluctuation doesn't exceed 2 cm.

Water chemistry

For further understanding it seems necessary to start with some chemical considerations about the cave water systems. In many caves it contains only dissolved ions Ca^{2+}, HCO_3^-, and CO_2. The equilibrium relationship among these ions is mainly ruled by the pH. Combined with the Ca^{2+} or the HCO_3^- content, the pH informs about saturation of the cave water, if there are no, or only minor, impurities by other ions. The conditions in the cave water system can be formulated in terms of an equilibrium relationship. If the product of concentrations in Ca^{2+} and CO_3^{2-} exceeds a distinct value - the solubility product - then $CaCO_3$ can precipitate until this value is reached. Temperature fluctuations that normally influence this value can be ignored if temperatures are as constant as in the Liethöhle, where the annual temperature curve moves from 9.2 to 9.6° C only. Finally, there are two ways for exceeding the solubility product of calcite:

1. by evaporation of the solution the concentrations of all components increase up to or beyond the solubility product;
2. by diffusion of CO_2 into the cave atmosphere. Normally there exists a constant equilibrium between CO_2 in the water and CO_2 in the contacting atmosphere. If now water enriched in CO_2 contacts a gas phase poorer in CO_2 then an emission of the CO_2 into this gas phase takes place. Following the simplified reaction scheme $2\ HCO_3^- \longrightarrow CO_2 + H_2O + CO_3^{2-}$ the solubility product for $CaCO_3$ can be reached or exceeded and calcite can precipitate in a stagnant pool.

This second way prevails in some parts of the Liethöhle because of the static ventilation, where the cave atmosphere is water saturated and no evaporation occurs (EBHARDT et al. 1979).

Description of calcite crystals

As mentioned above, linings of all pools in horizontal shallow pits consist of calcite crystals very different in size. Major interest is now set on the special feature of crystal rims surrounding the pools. Owing to a more or less constant water level on some pools an even platform up to 40 cm wide develops toward the pool centre. It consists of a network of ridges by crystal faces up to 10 cm in length. Crystal orientation is mainly perpendicular to the ground. Sometimes no coherent platform develops and only singular hollow calcite crystals are grown. They are terminated by three faces of a rhombohedron while the interior remains depressed. These hopperlike crystals show horizontal striations indicating growing stages combined with small water level fluctuations. In the interior part, there is no even horizontal crystal face, but rather a sequence of sub individual crystals grows parallel to the main rhombohedron faces. The hopper forms within the platform are more frequently covered by calcite crystals of different orientation up to 3 cm in size. In the area of water inlet there are small flood plains, where mini-pools separated by rectilinear and/or slightly curved limitations of calcite often occur. These rectilinear zones indicate the beginning of a large hollow hopper crystal generation. Beside these there grow small single crystals up to 1 cm in size. Their special shape is due to a parallel accumulation of single rhombohedron faces related to the fast growing rate because of a strong supersaturation in these minipools.

Factors influencing crystal growth

When entering the mini-pools water has an average pCO_2 of 0,006 atm, the cave atmosphere a pCO_2 of 0,0018 atm only. This difference leads to supersaturation of the water with respect to calcite and allows precipitation of $CaCO_3$. But precipitation does not start immediately because it is influenced by three factors:

1. degree of supersaturation;
2. concentration of disturbing ions (impurities);
3. presence of calcite nuclei.

In the environment of the Liethöhle supersaturation is never sufficiently high to start spontaneous nucleation, so precipitation starts only on already present calcite; that means where the water surface contacts the calcitic ground, either on Massenkalk or on elder generations of precipitated calcite. Therefore, fastest calcite growth takes places in the zone of mini-pools. Owing to crystallographic principles, crystals here are not able to extend on a large scale, but they are able to form permanently new faces (accumulation of parallel oriented rhombohedron faces in single crystals), or new individuals (poly individualism in curved bounderies around mini-pools). On reduction of pCO_2 difference between water and cave atmosphere, the diffusion retards (ROQUES, 1969) and supersaturation becomes smaller but continuous. Now optimum conditions exist for the growing of large hollow crystals. The fast growing crystal faces of the main rhombohedron ($h\ 0\ \bar{h}\ 1$) are clearly favoured and form a two dimensional lattice at the water surface, starting from the rim towards the pool centre. Parallel accumulation of carbonate material stabilizes the calcite ridges later to a platform. Very slow CO_2 diffusion out of deeper water zones towards the surface allows the ridges to grown downward also, and complete the calcite rhombohedron or contact the pool bottom. Water captured inside the now developed hopper crystal reaches, finally, an equilibrium in pCO_2 with respect to the contacting atmosphere and calcite growth (completing the crystal) stops unless fresh solution is added that may disturb the equilibrium. The final stage of calcite precipitation follows in the deeper parts of the pool. As already mentioned, very slow CO_2 diffusion towards the water surface pushes the concentration slightly beyond the solubility porduct of calcite. This slight, but permanent, supersaturation, in combination with almost constant temperature and nearly no disturbing ions, enables large calcite crystals to grow. The habit of these elongated crystals is ruled by the rhombohedron faces ($h\ 0\ \bar{h}\ 1$) and ($0\ k\ \bar{k}\ 1$) especially ($0\ 2\ \bar{2}\ 1$). According to KIROV et al. (1972), the form ($0\ k\ \bar{k}\ 1$) is a characteristic one for precipitations out of solutions, where the Ca^{2+} concentration exceeds the HCO_3^- concentration. In addition, the form ($0\ 2\ \bar{2}\ 1$) develops preferably at a temperature level around 10° C (RAMDOHR, STRUNZ, 1967). Both conditions are satisfied in the Liethöhle.

The influence of disturbing ions (Mg^{2+})

The influence of disturbing ions is remarkable when comparing calcite crystals of the Liethöhle with those of the Zoolithenhöhle (Franconian Alb), situated in a dolomitic hostrock. In the Zoolithenhöhle calcitic pool linings also occur, but no crystal extends beyond 3 to 4 mm.

Liethöhle			Zoolithenhöhle		
Calcite crystals:					
$CaCo_3$ %	$MgCO_3$ %	Mg/Ca	$CaCO_3$ %	$MgCO_3$ %	Mg/Ca
99,89	0,066	0,00078	96,09	3,46	0,043
99,09	0,087	0,00104	98,00	1,90	0,023
Contacting water:					
Ca mg/ml	Mg mg/ml	Mg/Ca	Ca mg/ml	Mg mg/ml	Mg/Ca
80,2	0,69	0,014	45,3	60,6	2,4
82,5	1,36	0,027	42,5	63,7	2,7
Hostrock: (RIETZEL, 1972)					
$CaCO_3$ %	$MgCO_3$ %	Mg/Ca	$CaCO_3$ %	$MgCO_3$ %	Mc/Ca
97,5	1,36	0,016	52,6	40,9	0,92

The evidence of Mg^{2+} inhibition on formation of calcite was reported by, among others, LIPPMANN (1960) and BERNER

(1975). To fit ions on a crystal surface it is necessary to remove the water coatings from the ions. The energy to do this is higher for Mg^{2+} (501 Kcal/mol) than for Ca^{2+} (428 Kcal/mol) (LIPPMANN, 1960). In addition Mg^{2+} now tends to become incorporated in calcite, therefore large calcite crystals grow in Mg^{2+} rich solutions much more slowly than smaller crystals where only few Mg^{2+} ions are poisoning the crystal surface. This is the main reason for the existence of only small crystals in dolomitic caves.

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Recent formation of carbonate mineral association in dolomite caves, Franconia, W-Germany

Gerd F. Tietz

Introduction and geological background

Nearly all caves in the Franconian Alb/Bavaria, extend in dolomitized limestones of the U-Jurassic (Kimmeridge) age. Karst and cave development took place in Lower Cretaceous times and lasted for about 30 million years. During a burying period, beginning in the Cenoman and lasting throughout the Turon up to the Coniac, the caves were plugged by sandy sediments. The erosion of these sediments and the excavation of the ancient caves started in the uppermost Cretaceous period and is still going on, especially in some eastern parts of the Franconian Alb. In the western region the erosion of Cretaceous sediments was already completed at the end of the Tertiary period, and Karst development started again (SCHRÖDER, 1971). Today most caves are cut off from major surface water supply by the lowering of the watertable by at least 30 m. The only remaining water source now is derived from rain and melting snow after a time-consuming passage through the covering dolomite. It is suggested that formation of speleothems began in the EemInterstadial, less than 100000 years ago, and is still going on. Various Ca-Mg carbonate minerals are created, which is very extraordinary for a terrigenous environment under temperature below 10° C.

Development of cave water

a. Chemical behaviour

After penetrating the soil the CO_2 partial pressure (pCO_2 as -log) of rain water will increase by contacting a CO_2 rich soil atmosphere. So this water becomes aggressive to limestone or dolomite underlying the soil, and dissolution of carbonate takes place, mainly at the very contact between soil and dolomite limestone, but also in the limestone complex itself when the water percolates downward. Aggressiveness regenerates as long as the water is still in contact with soil enriched in CO_2. Immediately after entering a cave the CO_2 diffusion starts out of the water into the contacting cave atmosphere which is normally poorer in CO_2. In most cases water dripping from the ceilings into the cave has the highest pCO_2, contrasting to water in pools which has evidently lower pCO_2. However, the CO_2 diffusion depends also on the dripping speed: a 10 sec drop interval allows a 10% decrement of the pCO_2 difference, a 3 min interval increases the decrement up to 50%.

There are at least 3 various water types:

1. quick dripping water (A),
2. slow dripping and/or trickling water (B),
3. pool water (C).

Average parameters for 3 out of 8 caves which I investigated may represent these types for different caves. These caves are Mammuthöhle (thin - less than 2 m - and well ventilated cover), Schönsteinhöhle (thick overlaying complex with rooms and collapsed areas), Zoolithenhöhle (thick, more or less unaffected, covered).

Accepting a pCO_2 average between 2,0 (= 1 Vol% CO_2) and 1,3 (= 5 Vol% CO_2) for European soils (SCHEFFER et al. 1976) water should have similar values when entering the cave (see Zoolithenhöhle). A deficiency in CO_2 and, in addition, a positive saturation index indicates precipitation of carbonate while percolating the covering dolomite complex. This precipitation took place most probably in rooms or collapsed areas above the measuring point where water had already contacted an atmosphere with a smaller pCO_2 (Mammuthöhle, Schonsteinhöhle). Compared with water type A the B and C types show evident differences: loss in Ca and ionic strength, but ± constant Mg content. This may be used as a proof for:

1. precipitation of $CaCO_3$, poor in Mg, as macaroni-like stalactities (out of water type B), and floor/pool linings (out of water type C);
2. precipitation of $CaCO_3$ is caused by CO_2 diffusion mainly because of a) decrement in ionic strength (evaporation: ionic strength remains constant), b) constant Mg content (evaporation: Mg will increase owing to a loss of water volume).

b. Annual fluctuation

During a 2 year period, seasonal fluctuations in water supply and chemistry from 8 caves were recorded. In general, there exists a seasonal cycle which sometimes interferes with annual pecularities like abnormal dryness (1976) and abnormal wetness (1977). The cycle starts between February and May with a more or less voluminous water supply depending on the snow quantity during the previous winter. Towards May water supply weakens and from June to October only few dripping points (water type A) are still working. In November water supply raises again, but the volume is much less than in February. Depending on frost intensity this second supply can last up to January in mild winters, but in cold winters it stops in December, followed by a dry phase that ends when the next year's cycle starts again, in February or March.

c. Development of carbonate precipitation

Formation of carbonate minerals takes place in stagnant phases that enables pCO_2 to reach an equilibrium. Most intensive precipitation is in June/July due to a relatively quick CO_2 diffusion into the cave air. With decreasing difference, diffusion slows down in August/October and precipitation is getting smaller. A minor precipitation phase exists from December to February when water supply stagnates again. Obvious examples in Ca and pCO_2 changes are shown in the following table:

Ca (mg/l):

water type	Feb/May	June/Oct	Nov/Jan	Feb/May
	1977	1977	1977/78	1978
A	95	99	100	103
B	68	36	66	56
C	56	36	46	52

CO_2 (Vol%) in cave air:

Schönsteinh.	0,05	0,05	0,05	0,05
Zoolithenh.	0,13	0,13	0,13	0,13

CO_2 (Vol%) in water type C:

Schönsteinh.	0,12	0,09	0,24	0,29
Zoolithenh.	0,27	0,18	0,19	0,33

The removal of Ca from water raises the Mg/Ca ratio if Mg remains constant. An extreme situation occured in January 1977 after a very dry winter when the Ca content in water dropped below 20 mg/l through an extensive second precipitation phase. Then the Mg/Ca ratio increased to 8, but after a thaw it dropped to 2 within only one week.

Formation and distribution of carbonate minerals

The following recently formed carbonate minerals were investigated by chemical and x-ray methods:

water-free carbonates: aragonite (rh) $CaCO_3$
calcite (trig) $(Ca,Mg)CO_3$ $Ca_{100-193}$ Mg_{8-50}
Mg-calcite $(Ca,Mg)CO_3$ Ca_{92-50} Mg_{8-50}

water-containing carbonates: monohydrocalcite $CaCO_3 \cdot H_2O$
barringtonite $MgCO_3 \cdot 2H_2O$
nesquehonite $MgCO_3 \cdot 3H_2O$
hydromagnesite $Mg_4(OH)_2(CO_3)_3 \cdot 3H_2O$

Dolomite is a common contamination from the hostrock. All the caves mentioned here belong to the "sackcave" type; that means there exists only one entrance and ventilation is restricted to those areas near the entrance (TRIMMEL, 1968). The investigated minerals are not developed everywhere inside or even outside the caves, but only in distinct areas depending on the influence of ventilation and/or CO_2 diffusion. So these areas can be classified as follows (TIETZ, 1978a):

Area 1: weathered and optimum ventilated zone in front (outside) of caves characterized by quick alternation of wet and dry conditions and large temperature fluctuations. Small scale precipitation of carbonate is derived from solutions concentrated mainly by evaporation. Diffusion of CO_2 is less important. Solutions develop on hostrock surfaces or by passing through fissures. Later on they become soaked in dolomitic sand that was sedimented in small, hollow depressions. Here the solutions evaporate and allow precipitation of crusts on top of the sediment. Already preconcentrated solutions may drop down a relief in hostrock. Scattering of the drops creates aerosols which are immediately oversaturated by loss of CO_2 (MARSCHNER, 1969). After being transported a very short distance by ventilation the small droplets settle, evaporate and precipitate carbonate, thus forming little studs on rugged rock surfaces. Minerals are in crusts: calcite + aragonite (+ hydromagnesite); in studs: Mg-calcite + monoghydrocalcite + calcite (+ aragonite). Diagnenetic effects transform monhydroclacite to calcite soon after deposition (TAYLOR, 1975). The difference between crusts and studs may arise from the fact that crystals in crusts grown from solution by slow evaporation of a large volume, contrasting to a very small volume and, therefore, quick evaporation on studs.

Area 2: well ventilated cave entrance zone (inside) with an alteration of wet and dry conditions. Constant temperature stratification: cold at the bottom (below 10° C), warm near the ceiling (up to 15° C). Formation of carbonates by combination of evaporation and CO_2 diffusion. Similar, but more frequent forms as in area 1 are growing. Studs and ~~mushroom~~-like forms prevail, owing to an increasing number of dripping points and only two (seasonal) ventilation directions. After scattering of drops, the oversaturated aerosols are transported near the bottom by ventilation to little obstacles where the droplets settle and subsequently slowly evaporate, creating a precipitation of calcite + Mg-calcite + monohydrocalcite + aragonite + nesquehonite (+ hydromagnesite). Not all minerals precipitate simultaneously, but in a definite order. Derived from the internal structure of studs and "mushrooms" there exist different coatings or even layers. Broad calcitic layers grow during times of maximum water supply when a high dripping rate produces a fog-like multidrop aerosol. Now studs and "mushrooms" are covered by a solution film that becomes oversaturated by CO_2 diffusion only, and is able to precipitate calcite. A decreasing dripping rate tends to produce single-drop aerosols with very small droplet diameters. The smaller the diameter, the higher is the partial pressure, not only in CO_2, but also in H_2O, so those aerosols become extremely supersaturated immediately after scattering. And this extreme supersaturation, enforced by very high pCO_2, enables the droplets, when settled, to start a subsequent precipitation of watercontaining carbonates like monohydrocalcite or even nesquehonite and hydromagnesite. So in area 2 a typical mineral cycle in "mushrooms" starts with a thick calcite layer followed by a smaller Mg-calcite layer and by watercontaining carbonates towards the end of the cycle.

Area 3: small ventilation in zones far from the entrance, only weak fluctuations in temperatures (about 3°C) and humidity. MAXIMUM in recent carbonate mineral formation. Oversaturation mainly by CO_2 diffusion with small additional evaporating during winter times. Similar forms as in area 2 are found, but crusts more often exist than "mushrooms". The main difference from area 2 is the decrease of water-containing carbonates contrasting to an increase in aragonite. In winter time some caves show an inverse (to summer time) difference of about 3° C between cold hall ceilings and warm hall floors because of very thin rock layers (less than 2 m) covering halls up to 20 m in height. Because of this difference a convection current is generated that moves warm air from the floor to the cold ceiling. Owing to this ventilation solutions are produced by condensation of CO_2-containing water on the ceiling where dissolution of carbonate starts. Later on, this water accumulates to form drops, these scatter as aerosols after dripping down. The aerosols are transported along the hall floor by convection current and evaporate after settling on the ground or on "mushrooms", allowing formation of aragonite. During ~~the summer, stagnant~~ temperature layers, cold at the bottom and warm at the ceiling, develop and only calcite is precipitated by CO_2 diffusion. Therefore "mushrooms" and crusts show an internal structure of broad calcite layers and smaller aragonite layers. Evaporation only sporadically reachs such a level that allows formation of Mg-calcite or even monohydrocalcite.

Area 4: very far from entrance, reduced ventilation, nearly constant temperature below 8° C and humidity (98%). Slow precipitation of calcite due to CO_2 diffusion, barringtonite becomes a common trace mineral (NASHAR, 1965). Forms are: stalactites, especially the macaroni type, and micritic floor linings and also cave beads (TIETZ, 1978b) and "Mondmilch" exist. Depending on the diffusion speed which rules the degree of supersaturation slow dripping stalactities grow faster than floor linings, which grow faster than "Mondmilch", which consists of calcitic whiskers. This is a good example of crystal growth following very close upon supersaturation.

Area 5: more or less separate areas with stagnant temperature and humidity. Lack of ventilation enables ~~generating~~ of CO_2-enriched layers close to the bottom. This retards diffusion and formation of calcite. Typical forms are skeletal crystals of calcite either as swimming crusts on pools or filigree crusts in pools. Their formation is due to supersaturation connected with a strongly reduced ion-transport in stagnant pools at low temperatures (below 8° C).

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Water type	ionic strength	Ca mg/l	Mg mg/l	Mg/Ca	pCO_2 -log	sat calc.	sat dol.	tot. hardness °DH
Mammuthöhle:								
A	0,0128	79	51	1,1	2,63	0,8	0,8	25
B	0,0108	60	55	1,6	2,77	0,8	0.9	21
C	0,0112	59	48	1,4	2.84	0,8	0,8	21
Schönsteinhöhle:								
A	0,0124	77	47	1,1	2,28	0,5	0,5	24
B	0,0117	69	46	1,1	2,54	0,6	0,6	22
C	0,0102	50	45	1,6	2,73	0,6	0,6	19
Zoolithenhöhle:								
A	0,0145	93	54	1,0	2,05	0,5	0,5	27
B	0,0119	63	51	1,5	2,56	0,6	0,7	23
C	0,0116	46	58	2,3	2,61	0,6	0,7	22

Sat(uration) index (log) means 0 for saturated solutions and positive values for oversaturated solutions, with respect to calcite (calc.) and dolomite (dol.).

Morphoclimatic Control - A Tale of Piss and Wind or a Case of the Baby Out with the Bathwater ?

J. N. Jennings
The Australian National University, Canberra, Australia

Abstract

The role of climate in karst style is assessed yet again, particularly with respect to the Nahanni (Canada) - Limestone Ranges (Australia) comparison. Its role has been simplistically exaggerated by many, including the author. Nevertheless it is conceived as more than minor despite obscurity cast by complex interaction of structure, process and time, and by uncertainty whether time and process intensity compensate for one another.

Résumé

On apprécie de nouveau l'influence climatique sur le modelé karstique, quant à la comparaison entre le Nahanni (Canada) et les Limestone Ranges (Australie) surtout. Il y a une surestimation simplistique à laquelle l'auteur a pris part. Néanmoins l'effet morphoclimatique est jugé plus qu'inférieur, malgré l'obscurité répandue par l'interférence complexe entre la structure, les processus et le temps, et par l'incertitude de savoir si la durée et l'intensité des processus se compenseront.

Conflicting views persist about the relative roles of rock and climate in karst geomorphology. Thus we may contrast Jakucs (1977), who confidently treats of 5 climatic karst styles, with Brook and Ford (1978), who reduce climate to a minor role because they find 'labyrinth' karst in the Nahanni Plateau of NW Canada, previously regarded as a tropical style. Paleoclimate is inevitably involved as well as modern. Tower karst at 5200 m in Tibet is regarded by the Chinese as tropical humid karst uplifted some 3000 m in the Pleistocene (for which there is independent evidence) so that the southwest monsoon could no longer sweep into Inner Asia. For Brook and Ford, this tower karst would have developed as a late stage of 'labyrnth' karst in a high mountain periglacial climate.

A return to the tower karsts of NE Queensland in 1980 prompts me to venture into this ramifying controversy. They are similar to the Limestone Ranges of NW Australia basically and comparison between these Ranges and the Nahanni is the lynchpin of the Brook-Ford argument. Calling the Nahanni after Verstappen's labyrinth karst of New Guinea is confusing because his description (1964) shows he is writing about polygonal karst of the doline and pyramid kind, distinctly different from the Nahanni.

Nobody disputes a minor role for climate in karst modelling, which may be illustrated by what may be novel examples to some. Phototropic algal corrosion features in the twilight zone are characteristic of NE Queensland caves, here to be measured in decimetres, not in metres as in the Mulu caves of Sarawak (Waltham & Brook, 1980). These are only to be found at the millimetre scale in southern New South Wales caves. Conversely, phototropic algal deposition works on the larger, metric scale in the latter warm temperate caves. On a visit to Australia not long ago, Steve Trudgill pointed out to us white zookarst - unfortunately not from a place called Heaven to balance Bob Folk's black phytokarst from Hell - in the form of parallel micro-rillen a millimetre across, running down the sides of rainpits and along solution flutes in the tropical seasonally humid NE Queensland karst (cf. Longman & Brownlee, 1980). Concentration of urine by evaporation under fierce isolation appears crucial. On Mt. Owen in the cool temperate Southern Alps of New Zealand, solution ripples, normally quasi-horizontal, are here blown at angles as much as 30° from the horizontal on particular rock faces; a tempestuous climate combines with the local rock geometry to give this variety to the detailed sculpture. But these are all minor features so is morphoclimatic control metaphorically just a tale of piss and wind as it is literally in these instances?

Optimistic assertions of mine in favour of climatic control on the large scale have been knocked down by better knowledge. From reconnaissance traverses in Papua New Guinea, Bik and I (1962) suggested an altitudinal zonation of karst as did Verstappen (1964), though we all declared the crosscutting effects of structure and history. Progressively this zonation has been whittled away by Williams (1972) and Löffler (1977). Only one distinction remains between the open alpine zone, with glacial interventions, and the forested remainder, though deforestation by men has its small-scale effects. In the Muller Range between 2000 and 3000 m (tierra templada), fluviokarst, crevice karst and four kinds of polygonal karst (cockpit karst, tower karst, doline and pyramid karst, arete and pinnacle karst) are all found together through rock control (Francis, James, Gillieson, & Montgomery, 1981).

In the rush to discount climate, however, let us not throw out the baby with the bathwater. No one has yet claimed active cockpit karst, and arete and pinnacle karst outside the humid tropics. Indeed the nearest landscapes to the last to be described outside Papua New Guinea are the 'assegai' karst of Palawan, Philippines (Longman & Brownlee, 1980) and the Pinnacles on Gunung Api in Sarawak (Osmaston, 1980). However, by morphometry, Williams (1978) has shown that the warm temperate rainforest karst of Waitomo in New Zealand falls into the broad category of polygonal karst, most like the doline and pyramid type. According to Williams, the most important factor in common with New Guinea is high intensity rainfall through nearly the whole year so climate is still in the arena in an important way. Waltham and Brook (1980) think the Mulu caves in Sarawak are the biggest caves in the world and attribute this to high rainfall and rank vegetation.

The Limestone Ranges are at the knub of the Brook-Ford case - 'labyrinth' karst on the Arctic taiga-tundra boundary and in tropical savana. But I must come at this by way of NE Queensland and eat humble pie there also. I wrote about the Chillagoe karst there before I set foot on it, though I had pored over the air photographs (1966). My motive was commendable, to see justice done to early writing by the Czech, Daneš, but that did not prevent me from leading others astray. From local evidence and by analogy with the Limestone Ranges, I argued that pediments must be an important component of the Chillagoe karst, making it another example of tropical savana karst, tower karst by pedimentation. This was accepted, indeed enlarged upon, by subsequent workers, Wilson (1975), Marker (1976), Lundberg (1977) and Ford (1978). For example, Lundberg demonstrated significant differences between pediments on fine-grained calcarenites and on coarse-grained marbles.

On my first visit to the area in 1975, the impressiveness of the bedrock plantation did not prevent me from recognising that many limestone tower flanks rose not from pediments but from slopes in non-karst rocks. Or else their flanks met opposing slopes in the latter; there were valleys along the contact. However the limited amount of ground I saw made me hesitate to draw too firm a conclusion. In 1980 I saw more of the Chillagoe karst and also some of the more northerly Mitchell-Palmer karst. Now I have no doubt that pediments constitute less than half of tower perimeters. For example, South Capricorn Tower, one of the largest Mitchell-Palmer towers, has thrust faults along its longer sides, which give an abrupt transition from limestone to clastics, though the cliffs are erosional, not tectonic. Only at the northern end is there a pediment; the rest of the flanks are descending slopes in cherts and slatey shales. Thus this tower is almost completely etched out by differential erosion and this is true of many others. If pediments were absent, the Chillagoe and Mitchell-Palmer karsts would still be tower karsts.

This is because the limestone is in discrete masses, formerly regarded as biohermal bodies surrounded by contemporaneous siliceous sediments but now considered by Ford (1978) to be fault slices, many faults making sharp angles with the strike. Previously (1969) I argued that this structure hastened karst along the way to tower karst. Now I think it was tower karst from the start.

This amendment in no way gainsays the power pedimentation has in the limestone here - to cut back tower flanks as with Mordor Tower (Mitchell-Palmer), to eat out the heart of a big tower as at Rookwood Racecourse with its ring of grandstand towers (Chillagoe), and to reduce equally large ones to a scatter of fragments and ruins as with Dram Tower (Mitchell-Palmer). The degree of planation is hard to equal in other rocks and perhaps also the variety, with convex profiles as well as concave, uniformly sloping to practically flat. The similarity with the Limestone Ranges is close.

Now to face the Nahanni-Limestone Ranges comparison. Certainly there are strong similarities. The Karst streets and the platea of Nahanni have their counterparts in the larger of the 'giant grikes' and in the 'miniature poljes' of the Limestone Ranges (Jennings & Sweeting, 1962). There are no true poljes in the latter whereas Brook and Ford properly claim them in the Nahanni; indeed their steep-walled examples are more like the poljes in Ordovician limestone along the Thailand-Malaysian border than the classical Yugoslavian poljes. Poljes are not, however, regarded as criteria for tropical karst.

One can compare the Nahanni to the 'giant grikeland' stage only of the Limestone Ranges and even there the differences are significant. Giant grikeland is cut up much more; the density of the network of linear solution features is of a higher order. Moreover residual ridges are diversified to a fantastic degree by diverse development of minor solution sculpture - some of it not so minor, with wall solution runnels into the tens of metres in length and into metres in other dimensions. In comparison the Nahanni relief is solidly tabular, with planar fracture surfaces in detail and frost pockets in the cliffs. The floors of giant grikes are flat and free of debris, though there are rockpiles at intervals; the Nahanni streets have a constant succession of scree slopes and doline ponds. Underground the Limestone Ranges have many, close-set, small-scale caves, whereas in the Nahanni they are few and far apart. Dolines declared characteristic of the Nahanni are rare in the Limestone Ranges. They are more frequent in the NE Queensland karst but angular in plan as well as vertically walled. Cenotes are absent in the Australian tropical karst, water standing below the level of the surrounding plains even inside towers. Despite more frequent high intensity rains, the Ranges drain out quickly whereas Nahanni poljes take years to do so.

More important in the comparison is that the Limestone Ranges are mainly in later developmental stages. There is not only the breaching of the walls between the equivalents of streets and platea to do this but encroachment from the outside by pediment extension, formation of marginal ampitheatres and by orderly, outwardly draining systems of box-valleys, with flat, well graded floors and accordant junctions. There is no equivalent in the Nahanni and it is reasonable to ask what indications there are that it will evolve along these lines. Pedimentation in the Limestone Ranges tends rapidly to eliminate most underground drainage and leave a field of towers rising from bedrock pediments. My impression from circling over the Nahanni is that one would be hard put to it to muster many more than half a dozen towers all told. There are no fields of towers, just the occasional 'butte témoine' of large sections of plateau. One can find the odd tower in karsts in many parts of the world without labelling them tower karsts.

There is a deceptive feature of the Australian tropical savana karsts to be noted. Unfamiliar with the talus slopes of cold climates, the Queensland cavers give the name of 'screes' to steep slopes, of 15-25° gradient littered with loose, angular blocks, below tower cliffs. But they are in fact bedrock slopes, with an incomplete detrital cover or at best a block thick. I call them 'ramps' descriptively but they are Richter denudation slopes. They are important elements in these tropical savana karsts but I saw none in the Nahanni where constructional slope abound.

Another significant difference is in calcite reprecipitation. In the Nahanni it is almost entirely underground, though cave coral and thin crusts can be found beneath talus blocks. In the Australian North, as well as substantial speleothems, surface manifestations are important - stalactites and curtains on cliff faces, tufa and travertine dams at springs and along streams, pseudo-anticlines on pediments, and tufaceous alluvium (Williams, 1978). The standard explanation of this in climatic terms has yet to be controverted.

The rock control of 'labyrinth' karst according to Brook and Ford resides in low primary permeability, widely spaced but extensive fracture planes, few bedding planes. Recent uplift is also needed to provide available relief. For coarse-grained solutional quartering of gently dipping platform as in the Nahanni this recipe may be true. The giant grikeland of the Limestone Ranges was uplifted in the Tertiary and developed in a variety of reef structures, with well bedded, flat-lying lagoonal facies as well as steeply dipping forereef which includes massive algal bioherms. Jointing is by no means sparse as the minor forms alongside the larger demonstrate. Likewise the wide range of New Guinea karst landscapes to which they liken the Nahanni is by no means all of coarsely fractured limestones of high crystallinity and low primary permeability. In fact Verstappen singles out his labyrinth karst for greater primary permeability than limestone forming other kinds of karst there.

If one can only compare the Nahanni with the early stage of development of the Limestone Ranges, the giant grikeland stage, is it just that more time is needed for Nahanni to follow suit, along the same lines but at a slower rate? Brook and Ford themselves argue that its solution rate of 50 Bubnoffs does not fall tremendously behind tropical rates. Even the Mulu karst rate is only 150 Bubnoffs (Laverty, 1980). It is true that the northern Australian karsts have had very much more time in which to evolve, perhaps going back into Miocene time. But the Nahanni is also likened to some of the karst in the central highland ranges of New Guinea. The orogeny that folded and overthrust these Eocene-Miocene limestones is Pliocene - Early Pleistocene in age but Verstappen placed the block uplift which elevated them later still. There hasn't been a vast amount of time for these elaborate karsts to form. Brook and Ford point to the intervention of glaciation in the Nahanni but for how long in the Pleistocene would it have been glaciated and need prior karst have been annihilated? There are parts of Greenland and the Canadian archipelago where the former presence of an icesheet has to be inferred but it had little or no effect on landforms (Sugden & John, 1976). The whole rate and time question needs more data and more consideration to see whether time can compensate for climate.

Following Sweeting, Panos and Stelcl especially, Brook and Ford confront with much justice the morphoclimatic fashion, which went too far and too fast, neglecting 'petrovariance' in Jakucs' terminology. In general climate sets its imprint within the large relief induced by structure, and this relief can engender its own climate in substantial measure. Climate's imprint is generally at the micro- and meso-scale but not entirely so. Climatic thresholds may be few as Ford (1980) argues and we don:t know to what extent time may balance rates of development climatically regulated. But we are still far from sorting out the roles of rocks, processes under climatic influence and history. To relegate climate to a minor role in our present stage of knowledge would be almost as rash as Corbel and some others of us were in the opposite sense.

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The History of Exploration of Canadian Hole

Peter R. Zabrok
70 Mayfair Cr., Hamilton, Ontario, CANADA L8S 4E7

Abstract

Canadian Hole, Pocahontas County, West Virginia, U.S.A. was discovered and entered in 1971 by cavers from McMaster University, Hamilton, Canada. Six short drops led explorers to dead ends in breakdown and low stream crawls. The cave was first extended in 1976 to yield the Crow's Nest Room, the Rocky River, the vast Monster Cavern and a connection with the Friars Hole System to make it over 30 km in length. A year of static exploration was ended in November 1978 with the discovery of the Ontario Extension. The Extension lies up valley of the rest of the system and can be reached only through a tortuous passage named Almost Hell. Beyond this two major streamways and some 5 km of passage were found. In June of 1980 a passage draining water away from the Ontario Extension was pushed into the West Virginia Extension where Rocky River II was discovered. This streamway carries the same water that appears as Rocky River I downstream in old Canadian Hole. Current exploration is about 5 km from the entrance. The Friars Hole System is 60 km in length and currently 8th longest in the world.

Résumé

En 1971, les speleologues de l'université McMaster à Hamilton, Canada ont découvert le'Canadian Hole; Pocahontas County, West Virginia aux Etats-Unis et y sont entrés. Les explorateurs, après six descentes courtes, ont trouvé les impasses dans l'éboulis et dans les passages étroits. En 1976 on a prolongé la grotte et ensuite on a fait la découverte de 'Crow's Nest Room', 'Rocky River', et la grande 'Monster Cavern'. Ici, on a trouvé une jonction avec le 'Friars Hole System'. Ce dernier système a maintenant une longueur de plus de 30 km. Au mois de novembre en 1978, après une année d'exploration statique, les spéléologues ont découvert l'Ontario Extension. L'Extension se trouve en amont du reste du système. On peut y entrer seulement par un passage torteuex qui s'appelle 'Almost Hell'. Au-delà de ceci on a découvert deux ruisseaux majeurs et quelque 5 km du passage. En 1980 au mois de juin, un passage mouillé quis'écoulait de l'Ontario Extension a été 'poussé' par les explorateurs jusqu'à 'West Virginia Extension' où on a découvert 'Rocky River II'. Ce ruisseau porte la même eau qui se montre en aval comme 'Rocky River I' dans le vieux 'Canadian Hole'. L'exploration qui se passe actuellement est à peu près 5 km de l'entrée. Le 'Friars Hole System' est 60 km de long et à ce moment il y en a seulement sept au mondequi sont plus longs que ce système.

Introduction

Canadian Hole, Pocahontas County, West Virginia, U.S.A., is the upstream or northerly section of the vast Friar's Hole System, now over 60 km in length and about the 8th longest cave system in the world. The System is located to the west of the Droop Mountain ridge and lies beneath a 7 km long valley descending gently to the south-west (Figure 1). Water that drains to the valley from Droop Mountain to the east and from the Jacox Knob highground to the west sinks to flow underground towards Spring Creek, the major resurgence in the area. The four principal rivers in the System, which include Rocky River in Canadian Hole, have all been successfully dye-traced to Spring Creek. Up-valley beyond the present explored limits of Canadian Hole the water drains in the opposite direction towards the Locust Creek Cave resurgence. Should Canadian Hole be extended across the drainage divide, it is likely that many more kilometers of cave system would be discovered, but the realization of this dream could be several years into the future.

The Discovery of Canadian Hole

In January 1969 the cave was entered by Julian Coward and Bill Skinner of the McMaster University Caving and Climbing Club, Hamilton, Canada. A small stream was followed down six short pitches leading to a termination in breakdown and low stream crawls. Wet conditions on the pitches prolonged the surveying until July 1971 when Bill Devereaux, an independent discoverer from the Baltimore Grotto of the NSS, helped to complete it. At a depth of only 50 m and length of 250 m, the cave had little traffice over the next few years.

The Alberta Extension

It was 5 years later in 1976 that Skinner returned with three Alberta cavers for a 'sporting' trip down Canadian Hole. Amongst the breakdown beyond the base of the sixth pitch Eric Nielsen chanced to poke his head through a black hole among the boulders and emerge into the Alberta Extension. After regaining the stream in First Canyon, the explorers followed the water to the Canyon Terminus where it was lost in mud-covered breakdown. On a subsequent trip, they followed the Crossover Passage to discover Crow's Nest Room, a large chamber (50 m x 90 m) complete with a 'valley' for a floor and a 'lookout' 10 m up on one wall. On the same trip they also found the Rocky River by two separate routes, followed McKeever's Passage to breakdown, and went for A Neasy Strole to the Downlets. In two weeks the cave had grown to about 2.5 km.

News of the discoveries reached Canada and MUCCC members Gascoyne, Latham, Mort and Recklies (the latter three having discovered the Friar's Hole-Rubber Chicken connection in May 1976) journeyed to West Virginia to begin the massive surveying project. Rocky River was pushed downstream by MUCCC members and later by Les Québecoises who also passed an upstream duck to discover the Watergate sump. Downstream, Rocky Horror Streamway is currently the lowest point in the System, 140 m below the Canadian Hole entrance.

It was not until the summer of 1977 that exploration resumed. While surveying in McKeever's Passage with Latham and Skinner, Oliver Slupecki crawled up a small inlet to emerge in the Flat Room, the beginning of the Highway. From here they were able to travel 600 m south, passing over First Canyon en route. Latham and Slupecki returned in August accompanied by Gascoyne to make the 'biggest' discovery as yet, the vast Monster Cavern, 130 m long, 70 m wide and 60 m high. A 30 m waterfall cascades into the cavern; this was subsequently climbed by the Americans to reveal a few hundred meters of passage.

Following the connection of Snedegar-Crookshank Cave to Friar's Hole-Rubber Chicken in the spring of 1976, the Friar's Hole System had grown to about 25 km in length. The Rubber Chicken Highway was headed straight towards the Canadian Hole Highway, but the frustrated Americans were unable to make the connection first because the major access route into Rubber Chicken had been sumped since January 1977. It was therefore in September that MUCCC cavers made the connection into the Friar's Hole System from the Canadian Hole side. The 'historic' through-trip exchange of cavers between Friar's Hole and Canadian Hole followed the next month, and over 3 years later this is still the longest through trip in the system, a distance of about 6 km.

The Ontario Extension

After the connection was made, an uneventful year of exploration ensued. The Americans bolted up First Canyon to find the Canyon Connection and Les Québecoises discovered the French Connection. However, during a single weekend in November 1978 the System suddenly grew by 3 km. Patty Mothes, Roy Jameson and other Americans succeeded in connecting Toothpick Cave into the System, while in Canadian Hole, Chas Yonge, Saul and Smart of MUCCC pushed 500 m through a nasty breakdown-filled passage to discover the Ontario Extension. The passage was named Almost Hell (indeed, Smart has never returned) and involves negotiating a chilly duck as well as many awkward crawls and squeezes. The final maneuver, known as The Extrusion, requires a complex body rotation in rather limited confines.

The same weekend, Yonge returned to Extrusion Chamber with Latham and Burns to explore Yonge Street (as in Toronto, not Chas!), Almost Heaven and Twinkle Chamber. While returning to Yonge Street, they stumbled upon Temptation Streamway which lured them away from their surveying duties and drew them towards Tin Can Alley where pop cans and other surface debris were found. Latham returned a few weeks later with Gascoyne and Pete Zabrok to explore and survey Double Decker Cavern.

During the winter of 1977-78 American and Canadian cavers alike pored over survey data and topographic maps in an attempt to locate a promising digging site above the Ontario Extension. Roadside Sink above Tin Can Alley was the most obvious choice, but proved to be very constricted and well choked. Hobbit Hole, a small cave excavated by Doug Medville and friends, failed to reveal a way on despite a strong draught and likewise Airspot Cave yielded little of anything. In April 1978, digging was begun at Trough Cave in an extremely tight and water-filled canal. The usual plan of attack was for several diggers to ream out the passage prior to the final push by the caver of the smallest caliber, inevitably the author. After several attempts, this physically and psychologically exhausting dig was abandoned.

Attention was again focused underground. In May and June of 1978 MUCCC made two trips into the Ontario Extension to explore and survey leads in the Twinkle Chamber area. Diminishing returns combined with the distance and difficulty of traversing Almost Hell necessitated establishing a camp in October. Latham, Yonge and Burns attempted to climb the avens in Tin Can Alley to connect with Medville's group which had been blasting and digging in Roadside Sink, but to no avail.

Discouraged and frustrated, we found ourselves in much the same situation as that facing us a year earlier. We had creamed off the best of the leads and although more surveying was yet to be done, we were really only mopping up the insignificant bits and pieces. The obvious remedy to the situation was to simply find another extension!

The West Virginia Extension

In May 2980, Latham and Zabrok were joined by Mothes in the latter's first taste of Almost Hell. Latham had for some time been interested in a small passage carrying water away from Tin Can Alley as the water did not seem to re-appear anywhere in the Ontario Extension. A low passage over cobbles was found to be taking a good draught but we figured that any breakthrough would require a lot of excavation.

Back in Hamilton, Latham got out the surveys and topographic maps to show Zabrok and Slupecki. From Williams' dye traces, we knew that the water from both Rush Run and Clyde Cochrane Cave (two nearby sinks) drained to Spring Creek by way of Rocky River (Figure 1). Latham noted that a line joining the sink of Rush Run to the Watergate sump in Canadian Hole passed directly through Clyde Cochrane Cave and came to within only 300 m of Tin Can Alley. This was the obvious place to dig. In fact, it was so obvious that Mothes returned two weeks later with Jameson and Paul Hadfield to dig it out for us, only to be halted by a sheer 5 m drop.

In June, Yonge, Burns and Zabrok returned to West Virginia with Fran Bagenal and learned of the Tin Can Alley news. After a day of photography in the Ontario Extension, the four set off from camp to descend the 5 m drop. A low crawl at the base led to a magnificent stream passage (Skid Row) averaging 3 m high and nearly 10 m wide carrying water directly away from Tin Can Alley. 700 m downstream we intersected an even larger stream passage, Rocky River II. We ran up and down this for a few hundred meters meeting breakdown at either end, then returned to explore the 300 m of Bourbon Street. The day's discoveries were among the author's most memorable experiences.

Zabrok later returned with Latham to survey upstream beyond the breakdown in Rocky River II, and a further trip in October saw a nine-person assault on the West Virginia Extension. Upstream Rocky River II was surveyed to impenetrable breakdown only 200 m from Clyde Cochrane Cave; downstream the passage ended similarly in a choke. The total length of Rocky River II is about 2 km, and there are no side passages at all, excepting Skid Row, over its entire length. Three avens in the new extension were climbed but none seemed to be likely candidates for the much-sought back entrance.

Conclusions

In early 1981, the exploration of the West Virginia Extension appears to be pretty well completed and there are only minor leads left to be checked out in the Ontario Extension. The new parts of Canadian Hole are a difficult 5 km traverse from the entrance, and a new entry point is very desirable. A large scale dig was organized in the autumn of 1980 by Medville and British caver Fincham which succeeded in opening a tight draughting crawlway in Herbert Hill II Cave, but this was later pushed to a miserable finish in breakdown. It is likely that the summer of 1981 will see renewed efforts at digging a top entrance to Canadian Hole, and perhaps a few trips beyond Almost Hell as well. Another possible way in could be through the sandy crawls leading away from the Crow's Nest Room towards Yonge Street, but this would require considerable digging as well. In the meantime, the Friar's Hole System will continue to grow slowly, patiently waiting for its explorers to make the next major discovery.

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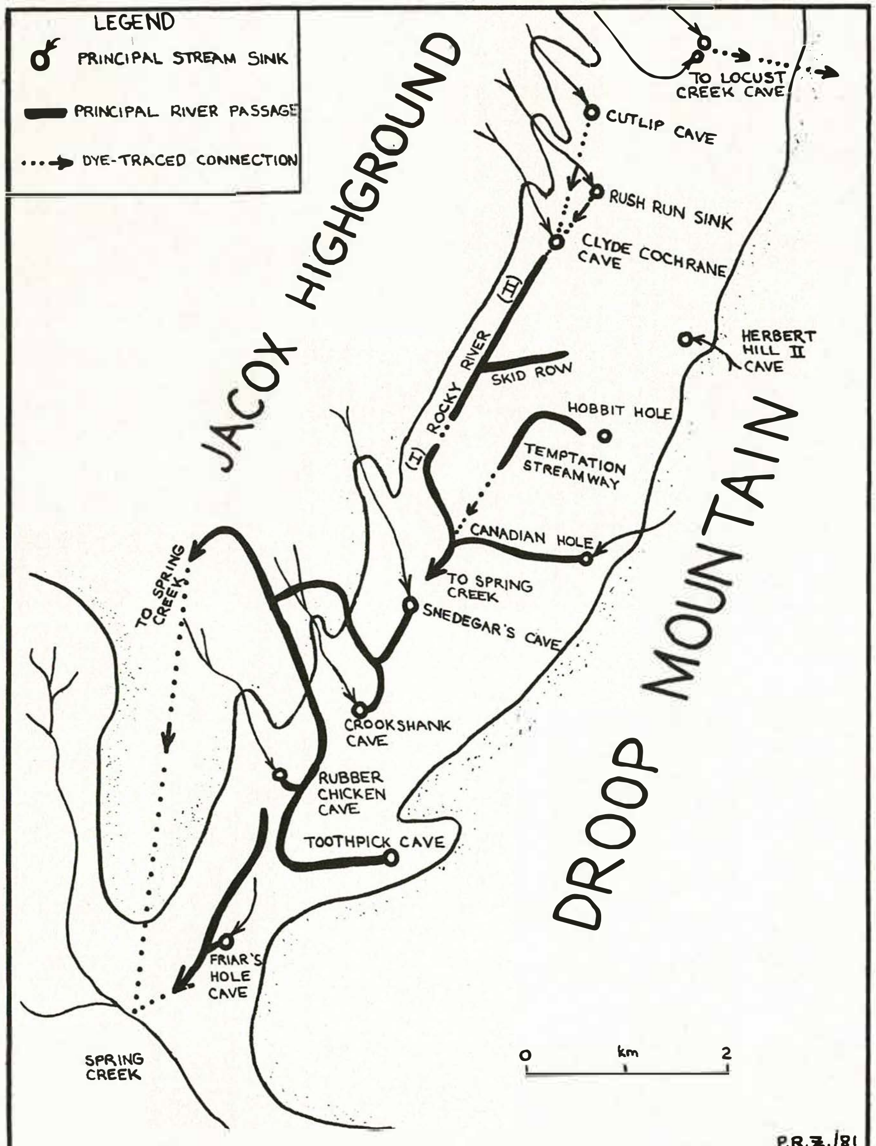

Figure 1. Drainage patterns in the Canadian Hole area.

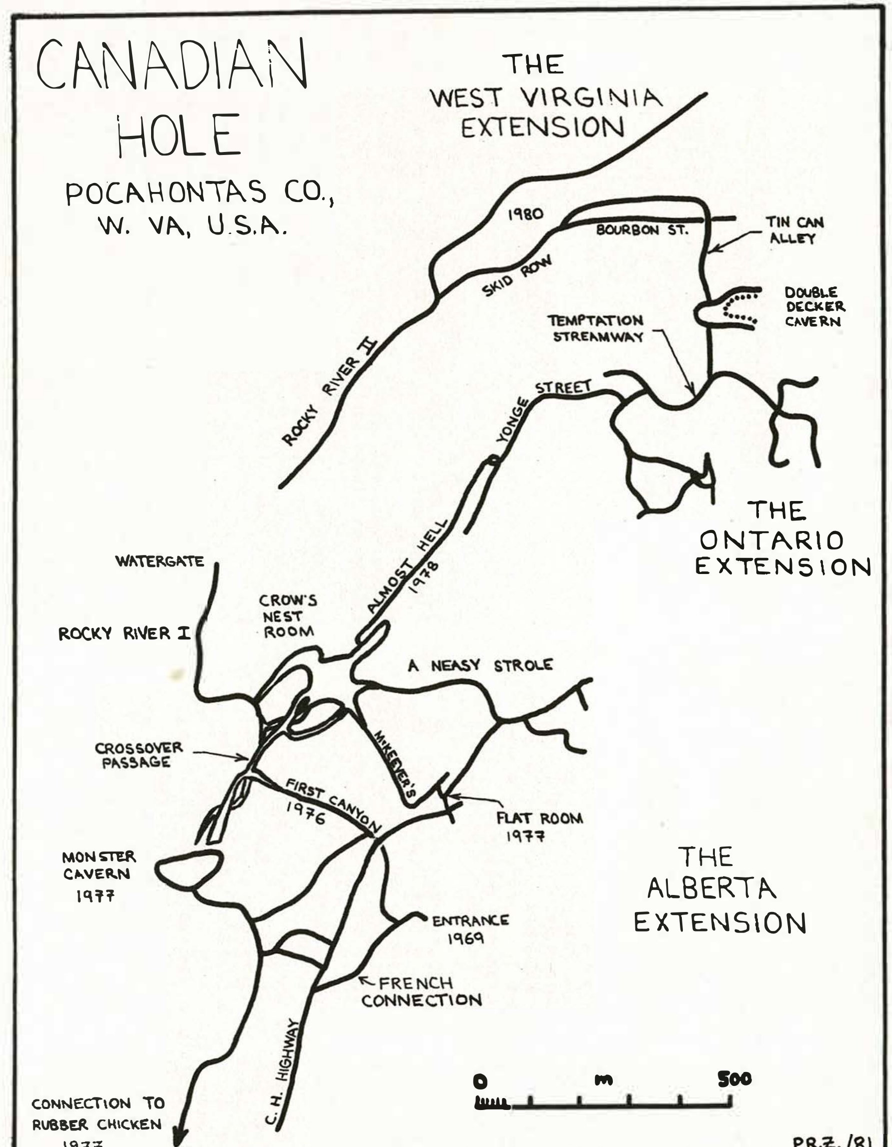

Figure 2. Generalized map of Canadian Hole.

The Cave Research Foundation

Richard A. Watson
Department of Philosophy, Washington University, St. Louis, Missouri 63130, U.S.A. (President of CRF: 1965-1967)
Philip M. Smith
464 M Street, S.W., Washington, D.C. 20024, U.S.A. (President of CRF: 1957-1965)

Abstract

The organizational principles and goals of a voluntary organization incorporated to promote research, convervation, and interpretation of caves and karst; current status; and future prospects.

Résumé

Les principles d'organisation et les buts d'un organisation bénévole constituée en vue de faciliter la recherche, la convervation, et l'interprétation des grottes et des karst; position actuelle; perspectives a'venir.

The Cave Research Foundation (CRF) was established in 1957 to support karst research, interpretation, and conservation. Since then nearly 2000 people have participated at Joint Venturers (JVs) in this work, with no more than about 300 active at any one time. In this paper we discuss some theories and problems in the organization and administration of this group.

CRF is a nonprofit, voluntary organization. It has flourished because its goals continue to motivate JVs to contribute substantial amount of time and money. The primary satisfaction obtained by these JVs consists of the activity itself and pride in CRF accomplishments. If CRF goals should either lose their attraction or be conclusively reached, then the organization would decline.

Most CRF JVs begin as active cavers, and few of them stay on after they cease caving. This reflects the fact that the major attraction and the bulk of CRF work has been in the exploration and mapping of unique cave systems in the Ozarks, the Southwest, California, and primarily in Kentucky. In Kentucky, one set of goals was to integrate the Flint Ridge Cave System, then to connect it with Mammoth Cave, and now to expand the Mammoth Cave System well beyond the boundaries of Mammoth Cave National Park. This essentially cartographic program continues to attract and hold enthusiastic, intelligent, and hard working JVs. Almost all CRF JVs work in the cartographic programs.

Because of the CRF axiom that responsible cave exploration requires detailed mapping and documentation of all caves explored as the foundation for further scientific work, a second level of JVs has emerged, consisting of professional geologists, biologists, archeologists, and their students. CRF provides a major ground for apprentice work in speleological sciences. About a fourth of CRF JVs work on these projects.

A third level of CRF activity covers interpretive, conservation, and administrative tasks. This group consists of fifteen to fifty JVs whose primary CRF interests are either in cartography or the other scientific programs. Members of this group act as consultants to government agencies such as the National Park Service, to conservationist organizations, and to local civic groups; they undertake contract research projects; and they support activities of the general caving and speleological community of which CRF is a part.

Finally, within the third level, a directorate of seven to eleven members sets policy and establishes goals and projects for CRF. The Board of Directors is self-perpetuating in that current directors elect their replacements. They have all made outstanding contributions to CRF and to speleology in general. They select themselves and all other CRF JVs on the basis of actual and expected contributions to the overall CRF programs. CRF is not an open membership organization. Anyone can apply to become a JV, but only those who can make specified contributions and relatively long-term commitments are invited to join.

A primary goal of CRF is to explore, map, and study scientifically both the longest cave in the world and some especially interesting caves elsewhere. The orgnanizational goal is to engage an elite group of top cave explorers and cave scientists in work that matches their talents, enthusiasm, and ideals. A major objective of CRF is to maintain the organization at a high qualitative level.

To maintain CRF's vitality, conscious attempts have been made from the beginning to avoid development along standard lines. Most voluntary organizations evolve toward collapse in well-known stages. First, an urgent and attractive goal becomes apparent to a few people. They recruit an enthusiastic group of workers. Under a charismatic leader, these workers either reach their goal in a short time, or they do not. If they do not, factions arise as the group enlarges, and splinter groups form under competing leaders. Most of these groups soon collapse. If the goal remains unreachable, enthusiam drops and the main group diminishes in size until only the leader and a few of his disciples remain. Well before the leader dies or loses interest the organization has effectively collapsed.

We believe that with careful planning of goals and organizational structure, CRF can avoid an early demise. First, the primary goal of cave exploration and study was set up in many stages, and is open to indefinite expansion. In the Mammoth Cave Region we started with five separate caves to be integrated into the Flint Ridge Cave System (one still is not), then we integrated the Flint Ridge System with Mammoth Cave, and now we are expanding into other ridges and the Sinkhole Plain. Once we thought the system would reach 300 miles in length; now we expect 500.

CRF projects in other karst regions, primarily in the Ozarks, the Southwest, California, and several foreign countries, have been established with the same guiding principle of expanding goals to maintain interest.

In terms of basic science, karst regions in the USA have barely been studied. Although about 1000 pieces of work have been published under CRF auspices since 1957, an enormous amount remains to be done.

And so the basic goal systems in exploration, cartography, and other sciences remain open. CRF still provides some of the best opportunities in the world both for apprenticeship and advanced work in speleolgy.

Our hope that CRF can avoid deflation, division, and collapse depends also on the success of CRF's radical organizational structure. We believe that vitality requires very careful cultivation and pruning of leadership, growth, and individual prestige. In effect, we attempt to maintain organizational leadership in a state or continuous revolution.

Most institutions, and almost all voluntary organizations, depend on a charismatic leader, and the most common cause of collapse of a voluntary organization is the loss of the leader. On the other hand, another common cause of collapse derives from the sheer success of the leader, who is nearly always inclined to eliminate the best of his disciples because he sees them as competition. Reducing his followers to sycophants, and proceeding without high-level critical advice, such a leader may destroy the organization.

We avoid these dangers by encouraging the rapid turnover of the president and the members of the Board of Directors of CRF. This is facilitated in part by the fact that caving is a strenuous and demanding activ ity which, like mountain climbing, provides a physical basis for separating real workers from hangers-on. The nature of cave work is such that only fully active leaders can command many followers. Caving is a young person's sport, and not many people are fully devoted to top-level, far-out caving for more than half a dozen years. By encouraging the best of the young explorers and field scientists to take over leadership as present leaders began to slack off, we try to avoid the dangers of entrenched programs ~~and leader~~ship.

Another problem for voluntary organizations is growth. First there is the problem of recruitment, and then the problem of incorporating ever-larger numbers.

Recruitment is difficult. The best era of CRF recruitment was when a few top workers were students and faculty members of Ohio State University, one of the largest universities in the USA. Some of their best recruits were not previously cavers. Thus we came to the view that it is often best to recruit someone primarily for talent and promise, and then make a caver out of the person. But we have not always had such a base, and at present recruitment comes primarily from individual JVs who invite promising people, and from students of the scientists working in the cave systems.

More difficult than recruitment is the problem of controlling and restricting growth. The nature of an organization is determined in part by its size. Large groups require bureaucratic administration, and inevitably raise the leadership problems described above. The greatest attractions of CRF voluntary work are in the high quality of the interactions with co-workers and caves. Thus we try to limit cave parties to four people, expeditions to twenty or thirty people, and total involvement to a few hundred JVs.

While CRF has survived nearly twenty-five years, and shows no signs of immediate collapse, we have not been entirely successful in our attempts to avoid the standard evolution of a voluntary organization.

For many years the big goal was the connection of caves in Mammoth Cave National Park. We reached this goal, and at the time the Flint Ridge Cave System was connected to Mammoth Cave in 1972, the enthusiasm of CRF JVs was very high. The immediate effect of reaching this goal was not a let-down, but led to a surge of growth and activity. There were other caves beyond. But it also led to conflict about how large CRF should be, and to an uneasy compromise that left advocates of both growth and steady-state conditions dissatisfied. Some people of both factions who had been very prominent in CRF activities dropped out. We have not yet solved the problems of size. Almost everyone agrees, however, that expeditions of more than twenty or thirty people are too large if the quality of the experience is to be maintained. Thus there is general agreement that there is an optimum steady-state size for groups working in any one area or on a given project.

Expansion to other karst regions represents another kind of CRF growth. The problems in each region are similar to those described above for the Mammoth Cave Region. In some areas goals are not continuously expandable and recruitment is difficult. As discussed below, integration of far-flung projects is difficult. At the present time CRF acts as an umbrella to shelter a number of geographically separated groups and projects, without exerting much central control over them. The basic unity of CRF continues to center on the Mammoth Cave Region. This is obviously because of the enormous potential of the Mammoth Cave System for exploration and scientific research.

As CRF has increased in size, it has also increased in prestige because of the large number of professional scientists who have contributed to CRF work and publications. There exists in CRF, then, a division between professionals and amateurs. However, this is a very difficult line to draw, for despite professional contributions and research grants, CRF remains an organization in which all participation is voluntary. And much of the professionals scientific work depends on the contributions of the amateurs. Another division--between scientists and sport cavers--is also very difficult to make, for almost all CRF cave explorers qualify as professional cave surveyors and cartographers, having the production of professional maps as their goal. There exists in CRF, then, the potential of a division between professionals who might wish to turn CRF into a contracting agency with salaried employees, and amateurs doing cartographic work as volunteers that no one would or could pay for. So far the general concensus has been to maintain CRF a voluntary organization, with the recommendation that any CRF members who do want to undertake karst research for profit should incorporate independently of CRF.

The greatest problems have always been and doubtless always will be with organization and administration. The caves are there, and as long as they provide opportunities for study and research, they will form a solid basis for CRF activities. The organization--its leadership, its maintenance, and its development--depends on people.

Leadership is of basic importance. Durings its twenty-four years, CRF has had seven presidents. Of these seven, three were good recruiters; another three were primarily organizers (we count ourselves here). Only one has excelled all-around. He and another past-president (one of the present authors, P.M.S.), after having made CRF a central part of their lives for nearly ten years, are now almost totally uninvolved in CRF activities. Such moving on represents the natural evolution of individual interests, and is unavoidable. In fact, it is to the good of the organization, provided that replacements have been groomed. Training replacements is an important part of CRF activities, and all top CRF personnel do it almost automatically. This does mean that sometimes the influence of past presidents and former directors must be moderated. Younger CRF members usually accomplish this by having their own ideas, and by taking the ideas of the old guard with a grain of salt.

Similar comments can be made about the fifty or so successive members of the Board of Directors. The Board started with seven members, and now has eleven. Only one member of the present eleven-person Board was a member of the founding group in 1957 (and he has not been on the Board continuously). The increase in size represents an expansion of interest and operations, somewhat to the detriment of unity and direction. A Board of seven to nine directors is generally thought best for person-to-person committee communication and control. In earlier years the directors were centered in Ohio, and had more personal contact with one another than today when they are scattered all over the United States. Communication and coordination by mail and telephone is not entirely satisfactory, but a unity of interest and approach has helped integrate the Board members. Turnover of members of the Board is always lively, and has in general been fruitful and efficient.

As in many organizations, both the presidency and the role of Director are always in danger of becoming honorifics, sought for and kept for their prestige. A self-electing directorate is necessary to avoid election from a large membership in popularity contests. But self-election also may lead to self-perpetuation among a group of self-satified prestige holders. CRF may be in some danger of reaching this stage. One way of avoiding it is through continual revision of the Table of Organization, so workers occupy roles that actually describe their activities. There have been numerous CRF Directors who would be better described as Project Managers. In effect, most major CRF workers manage special projects. Only a few have a general interest in the overall direction of CRF.

In conclusion, CRF Directors try to maintain an organizational structure that helps and encourages the best people to take over when they can contribute the most, and which does not alienate those who must give up leadership roles before their contributions to CRF cease. CRF can survive only with continual recruitment from the best of the young cavers and cave scientists, with the quick advancement of the best and most active of these to leadership roles, and then with their stepping aside after a few years to make places for others. This revolutionary program of recruitment, artful organization, and turnover of the best is the means by which CRF hopes to maintain quality and to avoid collapse.

NOTE: For the history of the Cave Research Foundation see "The Deveopment of the Cave Research Foundation" by Philip M. Smith and Richard A. Watson in STUDIES IN SPELEOLOGY, Vol. 2 (1970) pp. 81-92, and materials in THE CAVE RESEARCH FOUNDATION: ORIGINS AND THE FIRST TWELVE YEARS (1957-1968) (Nashville: Cave Books, 1981).

Archeological Investigations in Sand Cave, Kentucky

George Crothers
7254 Talave Ave., University City, MO 63130

Abstract

Sand Cave is a narrow, twisting passage formed by spaces between the large limestone breakdown blocks of a collapsed cavern. It was in January of 1925 that a local Kentuckian, Floyd Collins, while exploring Sand Cave in hopes of finding a large cavern below, became wedged in the narrow passage by falling rocks and was unable to pull himself free. For sixteen days rescue operations attempted to free the trapped man, but all efforts failed and Floyd Collins slowly died in Sand Cave.

In the Fall of 1980 archeological investigations were conducted inside and at the entrance of the cave to record, collect, and interpret the 1925 remains. The rescuers had left many of the tools, lanterns, bottles, cans, blankets, and other materials used in the struggle to free Floyd Collins. Wooden shoring is still in place where rescuers thought the passage needed stabilizing. Electric wires that supplied light for the rescuers and warmth to Floyd Collins still run through part of the passage. Some of the artifacts have deteriorated greatly in the wet conditions of the cave, but many of them, such as the glass objects, are still intact.

This paper is a report on the remains in Sand Cave: the original function of the artifacts, their possible function in the rescue operations, and how the types of artifacts and their location reflect the working conditions and activities in the cave.

Résumé

Sand Cave est un étroit passage tortillant formé entre de gros blocs d'effondrement en calcaire et causé par l'écroulement d'une caverne. En Janvier de l'année 1925 Floyd Collins, un natif du Kentucky, pendant l'exploration de la grotte en espoir de trouver une grande caverne souterraine, a été coincé par un effondrement et n'a pas su se lebérer. Durant seize jours on a essayé de libérer avec des opérations de secours, mais tous les efforts ont échoué et Floyd Collins a enfin décédé dans Sand Cave.

En automne 1980 on a conduit des recherches archéologiques à l'entrée et à l'intérieur de la grotte enfin d'enrigistrer, de ramasser, et d'interpréter les débris de 1925. l'équipe de secours avait laissé beaucoup de leurs outils, des lanternes, des bouteilles, des boîtes, des couvertures, et d'autres matériaux utilisés dans la lutte pour sauver Floyd Collins. Des supports en bois se trouvent encore là où l'équipe de secours les ont placés en mesure de stabilization. Des fils électriques destinés à conduire de la lumiére aux secoureurs et de la chaleur à Floyd Collins sont encore en place dans une partie du passage. Certaines restes ont sans doute été détruits à cause de l'humidité dans la grotte, mais beaucoup de vestiges, comme les objets de verre, sont restées intacts.

Cet exposé est un compte rendu des vestiges dans Sand Cave: la fonction originelle des vestiges, l' intesprétation des fonctions de secours, et la façon dans laquelle les vestiges et leurs enplacements reflétent les conditions de travail et les activités dans la grotte.

Field work for this paper was supported by the Cave Research Foundation and done in cooperation with the National Park Service.

Sand Cave is near the southeast boundary of Mammoth Cave Ridge and Flint Ridge. It is in Barren County approximately nine kilometers west of Cave City and 200 meters north of the Sand Cave historical marker on State Highway 255.

The Sand Cave site is a rock shelter approximately 20 meters wide, 15 meters long, with a maximum ceiling height of six meters. The shelter opens eastward into a valley formed by the collapse of a cavern ages ago. The mouth of Sand Cave is a short vertical opening at the back of the shelter, now sealed by an iron grate. The cave passage is approximately 45 meters long and formed entirely by spaces between the large limestone breakdown blocks of the collapsed cavern. The passage is narrow, twisting, and doubles under itself reaching a depth of 15 meters below surface.

Archeological investigations in Sand Cave pertain to the remains of unsuccessful attempts in the winter of 1925 to rescue Floyd Collins. Research for this project is partly based upon the reconstruction of the 1925 events published in 1979 by Robert K. Murray and Roger W. Brucker.

Floyd Collins was a semi-educated farmer and backwoods entrepreneur from Flint Ridge. He was an enthusiastic but foolhardy caver. Collins had discovered Crystal Cave and developed it for commerical business in 1917. It was a similar intention that led him into Sand Cave in 1925.

On Friday morning, January 30, Collins dislodged a rock in Sand Cave, trapping his left foot. Shifting dirt and gravel wedged him in the narrow passage. For five days rescuers brought him food and blankets, diverted water from dripping on him, and worked to free his foot. They enlarged the passage, installed shoring, and strung electric lights, but a cave-in early Wednesday morning, February 4, cut Collins off from the rescuers. A shaft dug to intercept Sand Cave reached Collins twelve days later, confirming what many already feared: he was dead. Collins' official death was put on Friday, February 13, 1925 (Murray and Brucker 1979).

In the summer of 1977 Brucker's group gained permission to reenter Sand Cave. They discovered that the cave was sealed by loose rocks and dirt at the First Squeeze, beyond this no one had entered the passage since 1925, remnants of the resuce still existed in the cave, and most astounding of all that a nine-inch crack bypassed the cave-in. The cavers were able to come within inches of where Collins had lain. The 1925 rescuers had never used this crack. Their original route lay up and over the nine-inch bypass; when that route collapsed they had given up (Murray and Brucker 1979).

Field work to record the remains of the Collins tragedy was conducted in the Fall of 1980. Work inside the cave was completed in two expeditions using three cavers and totalling thirty persons hours underground. An additional two working days were required to map the rockshelter and conduct an intensive surface collection.

Evidence of the 1925 activities at the rockshelter consists mainly of broken fragments of glass bottles and lantern globes, nails, and miscellaneous metal fragments. The most prominent feature is a two meter deep depression in the rockshelter floor left from the shaft excavation. The rockshelter site had also been occupied by prehistoric Indians as recorded by earlier archeological surveys (Schwartz 1958; Carstens 1980) and evidenced by the large number of chipped stone artifacts found there.

Sand Cave consists of four rooms large enough to sit up and turn around in. The rest of the passage is body-sized crawls and chutes connecting the rooms.

The cave mouth drops into the first and largest of the rooms. This room and a smaller adjoining room contain only a few modern items dropped through the grate by recent park visitors.

The bottom of the Second Room was sealed by rocks and dirt. Apparently no one had been beyond this point since 1925. The only remains in this crawl were several pieces of loose shoring and one shoring post held in place by a horizontal wooden wedge.

The end of this crawl forms the Second Squeeze, then opens into the Turnaround Room. It is large enough to fit three people and contained a concentration of 1925 remains. The artifacts include: a green "hobble skirt" Coca-Cola bottle manufactured in Bowling Green, KY and, similar to today's design but with a 1915 patent data, a small straight sided light bulb, a pocket size tobacco can, several fragments of a tin can, and several loose pieces of shoring.

The nine-inch bypass is a short, vertical corkscrew which only the smallest cavers were able to get through. It enters a steeply pitched chute just below the cave-in. Artifacts recorded in this chute include: a prescription bottle, the mouth of a broken mason jar, and two fragments of a rusted cylindrical lid with the stamped label, "Maxwell House, Good to the Last Drop." Features include two more shoring posts and a wooden wedge driven between two breakdown blocks. A pair of electric wires begin at the top of the chute, are wrapped several times around one of the shoring posts, and run to the end of the cave where they disappear into the sediment.

The "End Room" is the approximate location where Collins was trapped. The chute where Collins lay is now filled with water-deposited gravel and dirt. The largest concentration of artifacts was in this room: rusted fragments of three kerosene lantern bodies with cotton wicks, six other various metal lantern fragments, two prescription bottles, two plain bottles, a quart mason jar with screw cap, three fragments of a metal container or canteen with an outer textile cover, a painted rectangular metal "Maxwell House Tea" can, a fragment of a china cup, four wool textiles remains which may have been one or more blankets, several loose pieces of wood, a six-pound sledge hammer head with a broken haft, and a 1.2 meter long, L-shaped iron rod with a looped handle.

Murray and Brucker's account of the Sand Cave incident details the activities inside the cave as reported by the rescuers. The archeological remains relate closely to the details of their reconstruction. Hot coffee, milk and prescription whiskey or medicine were brought to Collins in bottles, jars contained hot soup or other liquids, and containers such as the Maxwell House Tea can were packed with sandwiches and other solid food. The lanterns were discarded by the rescuers. Blankets, quilts, and burlap were put around Collins to keep him warm. The sledge hammer was broken while attempting to enlarge the passage and also discarded. The L-shaped iron rod was possibly used to reach along Collins body and scrape out gravel or as a lever in attempting to pry the rock from Collins' ankle.

A total of 34 artifacts were collected and eight features were recorded in Sand Cave relating to the 1925 events. The artifacts represent mainly discarded remains of the rescuers: empty bottles, useless lanterns, or broken tools. Several key rescue tools, such as the several jacks and crowbars used in an attempt to lift the trap rock have not been accounted for either in the archeological remains or the historical records. Perhaps most of the items of value or potential value as souvenirs were collected by the rescuers as they departed at the end of the ordeal.

The 42 artifacts and features recorded inside the cave can be classified under five possible functions in the rescue: 1) seventeen are remains of containers for food or liquid, 2) eleven are remains of artifacts which provided light for the rescuers, 3) eight are remains of attempts to improve the passage, 4) five are remains of blankets, and 5) only one artifact, the L-shaped iron rod, can be classified as a tool used in the rescue.

Some questions remain unanswered about Sand Cave. The passage ends at the sediment-filled chute, but the electric wires continue into the sediment. The wires are known to terminate in a single light bulb placed on Collins' chest to keep him warm (Murray and Brucker 1979). Brucker's party attempted to excavate the chute following these wires, but never reached the end. To continue this work would require working upside down confined by the narrow chute, the exact situation which hampered the 1925 rescuers. To find the end of these wires would, however, mark the exact spot Collins lay in the passage.

No one has seen what lies below this filled chute since 1925. Collins rigged a rope and descended a pit some 60 feet deep before he was trapped when returning to the surface (Murray and Brucker 1979). Several passages of Bransford Avenue in Mammoth Cave lie underneath Sand Cave and the Cave Research Foundation has thoroughly surveyed each of these, but no leads were found to connect with Sand Cave.

Below the chute where Floyd Collins met his death in the winter of 1925 lies the last passage he explored, which no other caver has seen since. As Brucker wrote in 1955: ". . .one day, perhaps, the headlamp of an explorer will fall upon a rotten rope hanging from the top of a pit where Floyd rigged it. A few feet farther on he may come to the gallery that Floyd found (but) with prudence and care, the explorer need not be victim of a watermelonshaped rock and well-meaning but inept rescue attempts" (Murray and Brucker 1979: 272).

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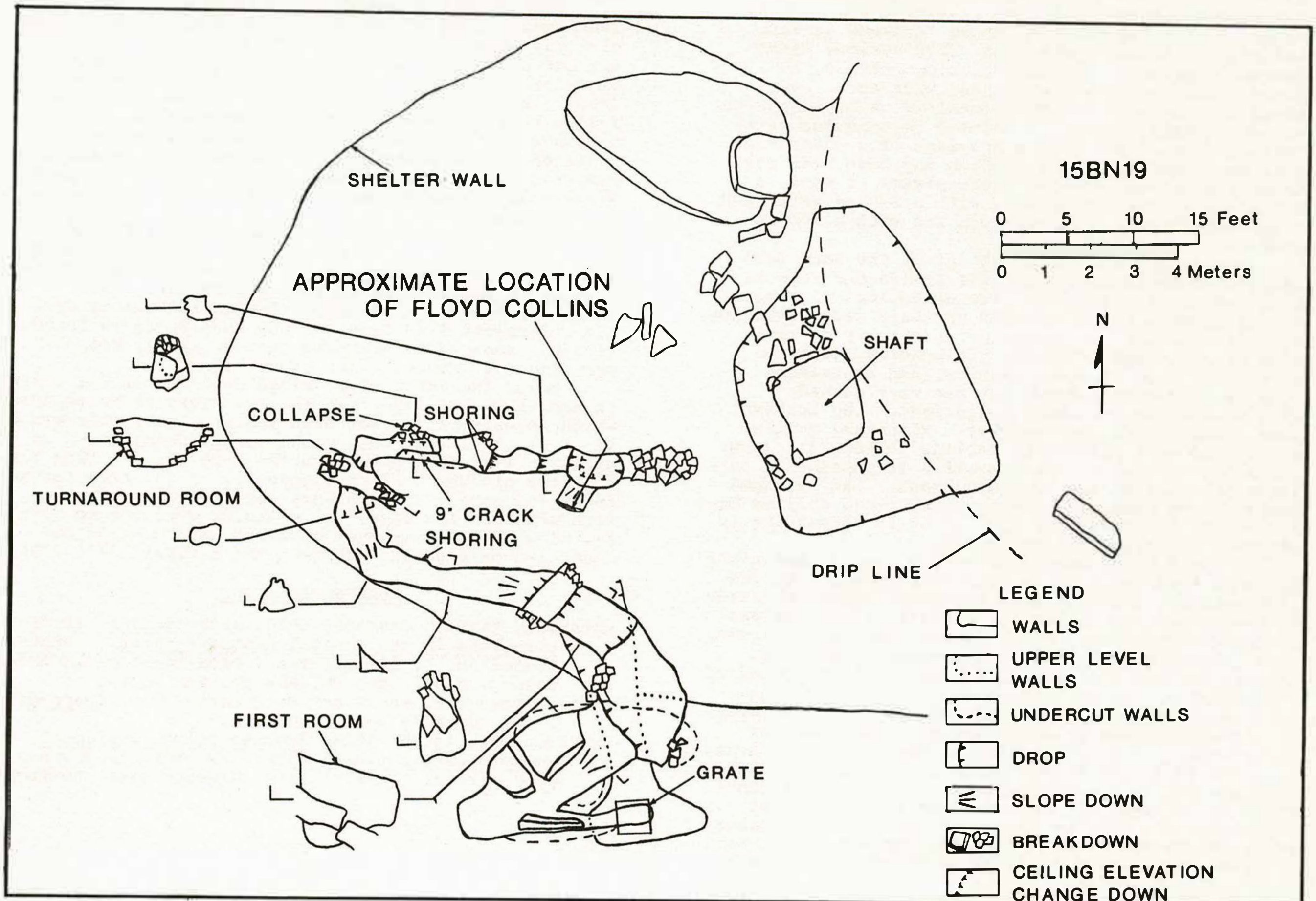

Fig. 1. Sand Cave, Kentucky

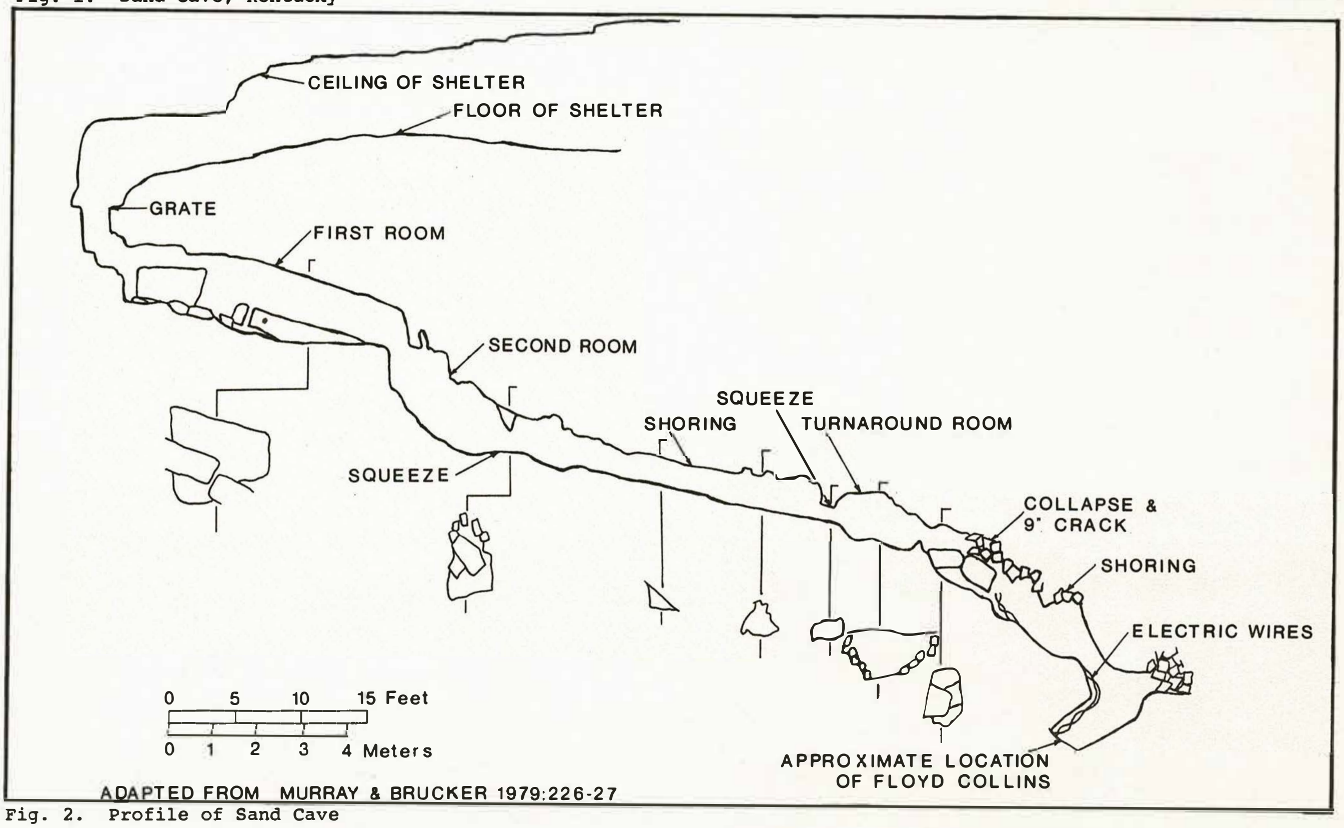

Fig. 2. Profile of Sand Cave

Paleontology and Archeology of Jaguar Cave, Tennessee

Louise M. Robbins[1], Ronald C. Wilson[2], and Patty Jo Watson[3]
[1]University of North Carolina, Greensboro, North Carolina, [2]University of Louisville, Louisville, Kentucky, and [3]Washington University, St. Louis, Missouri

Abstract

A large cave in north central Tennessee, recently mapped by the NSS, has been found to contain skeletal remains of several extinct, non-human mammalian species as well as the unique record of a cave trip made 4500 years ago by 9 human explorers. Detailed documentation of the paleontological material and of the much younger archeological evidence is described, with special emphasis on 2 skeletons of an extinct species of jaguar (late Pleistocene) and on the human use of the cave (ca. 2500 B.C.). Some information is derivable about the physical appearance of the aboriginal cavers from a close study of the numerous footprints they left in a mud-floored passage now known as Indian Trail or Aborigine Avenue.

Résumé

Une grande grotte située dans la partie nord-centre du Tennessee, récemment cartographiée par le NSS, vient de révéler la présence de restes osseux de plusieurs espèces mammifères non-humaines disparues, ainsi que le seul record d'exploration de grotte effectué il y a 4500 ans par huit ou neuf humains.

Une documentation detaillée du matériel paléontologique et de traces archéologiques beaucoup plus récentes est décrite, avec une insistance spéciale sur deux squelettes d'une race disparue de jaguar (dernière (ou fin) Pléistocène) ainsi que sur l'utilisation humaine de la grotte (aux environs de 2500 A.J.C). Une très forte somme d'information peut être rassemblée sur l'apparence physique des aborigènes de la grotte d'après une étude détaillée des nombreuses traces de pas qu'ils ont laissées dans un passage de terre battue que l'on connaît à présent sous l'appellation de "Indian Trail" ou "Aborogine Avenue."

Cave Research Foundation

The archeological and paleontological remains described in this paper were discovered in a cave in northern Tennessee in 1976 by NSS personnel mapping the passageways (Figure 1). Since that time research teams under our direction have documented both kinds of materials. We report here the major results to date.

Paleontology

Nonhuman vertebrate fossils presently known from Jaguar Cave include skeletons (largely complete, but extremely fragmentary), footprints, claw marks, and fecal specimens of two jaguars; footprings of bobcat (Lynx rufus), raccoon (Procyon lotor), and possibly an otter (Lutra canadensis); and a rich talus cone deposit containing several dozen species.

Preservation of both jaguar skeletons was poor. Although well articulated, the bones of both animals were chalk white, highly broken, soft, and brittle due to repeated desiccation and loss of organic matter. The larger skeleton (Carnegie Museum #30071) represents a large male that died in mid-lelve passage parallel to Tremendous Trunk. It was discovered in July, 1976, by NSS cavers Deane, Arnold, and Garza. The smaller jaguar skeleton (CM 30174), a female, was found in September, 1976, by NSS cavers Socky and Voelker in that portion of Horrendous Trunk known as Carnivore Corridor. Crushed by slabs of limestone that fell from the ceiling, the anterior half of the skeleton was exceptionally fragmentary. The posterior half was better preserved by an encrustation of calcium sulfate up to 6.2 mm thick. The skeletons compare favorably with remains of other fossil jaguars from Tennessee (Guilday and McGinnis, 1972) and are probably of similar age (ca. 35,000 to 10,000 YBP). Preservation of the bone and jaguar fecal specimen (the only one known from the eastern U.S.) was too poor to permit radiocarbon dating.

Jaguar footprints and clawmarks occur in approximately two kilometers of passageways. The tracks compare favorably with those described by Simpson (1941) from Craighead Caverns, TN and by Oesch (1969) from Berome Moore Cave, MO. Jaguar tracks are significantly absent from the Enchanted Forest, Aborigine Avenue, and The Only Crawl. The lack of tracks in other areas is due to the lack of suitable substrate. Travel routes suggested by the jaguar footprint distribution indicate that the most likely point of entry for the cats was at the talus cone at the north end of Tremendous Trunk.

That an entrance existed at this point at some past time is supported by the presence of a large bone deposit within the talus. Although analysis of the materials is incomplete, more than 50 vertebrate species have been identified. Extinct taxa include Ectopistes migratorius, Mammut americanum, Mylohyus nasutus, Canis dirus, Equus, Tapirus, and Camelops. The most significant of these is Camelops. Represented by a single tooth identified by S.D. Webb (University of Florida), this is the only confirmed record of the genus east of Oklahoma (Kurten and Anderson, 1980). The probable age of the deposit is latest Pleistocene. Further analysis of the materials is expected to add much to our understanding of Wisconsinan environments in the Interior Lowlands of eastern North America.

Archeology

Prehistoric human explorers with cane torches apparently entered Jaguar Cave the same way we do now and explored the length of Tremendous Trunk. In addition, on at least two occasions small groups left the main passageway of Tremendous Trunk, went into Aborigine Avenue (also called Indian Trail), walked to the end, looked around there, and then returned to the main passage.

Evidence of aboriginal exploration in the main cave consists of sparsely scattered bits of charcoal on the passage floors and among the breakdown rock, and charcoal smudges on walls and ceilings. The cave opening is quite conspicuous and a small stream issues from it. Once inside, one climbs over mud banks and slippery boulders to the foot of an immense jumble of breakdown called The Towering Inferno, at the top of which is the route to the cave interior via The Only Crawl. This is a low, wide passage with a mud floor in which are imbedded occasional small fragments of charcoal. A few charcoal bits have also been found in the breakdown of The Towering Inferno, and there are charcoal smudges on walls and ceilings in several places between the entrance complex and The Inferno.

On the far side of The Only Crawl lies the junction of two large passages, Tremendous Trunk and Horrendous Trunk. At the junction point, where one emerges high above the passage floor and then climbs down to go to Tremendous Trunk (to the right) or to Horrendous Trunk (to the left), there is a torch smudge on the ceiling in a position that would require the person making it to lean well out over the drop in the Trunk passages while bracing himself against the ceiling with his free hand.

Whether the Indians penetrated Horrendous Trunk is unknown but doubtful. There is a scattering of charcoal in Tremendous Trunk between the junction and the mouth of Indian Trail, however, and a thin scatter beyond Indian Trail. Enough charcoal was collected from one part of Tremendous Trunk to enable two radiocarbon determinations to be made (2745 B.C. ± 85 and 2580 B.C. ± 85; SI 3006 and 3005 respectively).

The footpring passage (Indian Trail or Aborigine Avenue) is floored with sand or clay, interrupted frequently by breakdown or flowstone; and it is in the damp, still soft clay that the NSS caver Deane and his exploration party first saw the prints of bare human feet. The first prints are 150 m into the passage, but there are a few unmistakeable torch smudges and a thin scatter of charcoal in the passage between Tremendous Trunk and this initial patch of prints. The passage itself is about 500 m long, and is characterized by occasional flowstone and dripstone, as well as a few deep drop-offs where the mud floor has been washed away into a lower level. The last 150 m is very low and it does not appear that the Indians went very far beyond this point. Throughout the part of the passage they explored, wherever the floor is muddy or soft, there are many whole and partial footprints with numerous orientations, but obviously the main flow of traffic was up and down the passage, roughly east-west. There are also occasional charcoal fragments and a few torch smudges along the aboriginal route. Sufficient charcoal was collected to permit a radiocarbon determination (2640 B.C. ± 75; SI 3003).

Most of the prints seem to be of bare feet, and they indicate a total of 9 individuals. A total of 269 individual prints have been mapped (Figure 2), and casts have been made of 9 of them (Table 1). A narrow age range for each individual represented in the table cannot be assigned beyond noting whether the foot size and morphology indicate an adultiform internal skeletal structure of the foot. Thus, footprint No. 33, with its short bulging toes (especially toe 5) and fullness of arch, has a young adolescent or even childlike form. The No. 67 print appears to be a skeletally mature foot with a small gracile form, a combination usually found in females. Statural estimates are tentative because formulae for estimating stature from foot size do not exist for prehistoric North American Indians. In a small sample of contemporary Indians, foot length is approximately 15% of stature for males and females. Footprints Nos. 3 and 32 demonstrate why dimensions alone should not be used for assigning footprints to particular individuals. Dimensionally, they are quite similar except for ball width; but differences exist in their morphologies exceeding the range of variation in prints of the same individual. The particular contour form of the medial ball and the light impression of the little toe, even with weight-bearing pressures on the lateral ball, are distinctive, and recurring, traits of No. 3. In some footprints of that person, the little toe touches the ground so lightly that the foot seems to have only four toes. Number 72 frequently pressed only four toes to the ground also, but that print, and others of that individual, differs from No. 3 in dimensions, morphology, and in placement of weight-bearing pressures along the length of the foot. Footprint No. 15 was equally distinctive in morphology as well as in the strong pressure exerted by all five toes and the broad ball of the foot. Some details of the foot morphology can be seen in the moccasin impression of No. 132, also. The shape contours of the foot are visible in the moccasin print because of the pressures of the foot on the ground as the individual walked along the cave passage.

On the basis of repeated observations of the footprints in the passage floor, we believe there to have been nine individuals who walked into and out of the passageway. The faint outlines of some footprints, superimposition of others, and erosional effects on still other footprints suggest that at least two trips were made through the passage at different times. The obscurity of specific footprint details makes it difficult to determine whether or not the nine identifiable individuals participated in more than one round trip through Indian Trail.

Conclusions

Thus it appears that during the third millennium B.C., there were aboriginal cave explorers in northern Tennessee as well as farther north in the Flint Mammoth Cave System of the central Kentucky Karst and in Wyandotte Cave in southern Indiana (Watson et al., 1969; Watson ed., 1974). As was the case with the Flint Mammoth Cave System, the Jaguar Cave Archaic people explored the cavern much more extensively than any succeeding population for 4000 years. But unlike the situation in Kentucky, the prehistoric Tennessee cavers do not seem to have spent much time deep inside Jaguar Cave, perhaps because it does not contain the kinds of minerals seemingly so valuable to the earliest explorers of Salts Cave and Mammoth Cave. At any rate, the evidence left us in Jaguar Cave suggests only a few exploration trips, not long-time visitation or exploitation as are amply witnessed by the remains in the Flint Mammoth Cave System.

Acknowledgements

Bill Deane first contacted us about Jaguar Cave. We are grateful to him and numerous other NSS cavers not only for informing us of the remains in the cave but also for guiding us to them and providing a variety of other support. The map created by several cavers working under the direction of Lou Simpson is invaluable to us; we are deeply appreciative of their exploring and cartographic skills.

The work reported here could not have been done without the interest and hospitality afforded us by the families who own land over the cave--Mr. and Mrs. Juan Copley, Mr. James Williams, and the Misses Lera and Loma Pile--and we are thankful to them. Nor could we have accumulated the data summarized in this paper without the continuing strong support of many CRF JVs and archeology students. The footprint mapping technique devised by John and Pat Wilcox was patiently and persistently applied by Michael Fuller and a series of field crews made up of longsuffering Washington University students. The photographic record was skillfully compiled by Roger Brucker, Diana Daunt, Mark Elliott, James Goodbar, Bill McCuddy, and Ken Russell. We are much indebted to all of them.

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Table 1. Preliminary Classification of Human Footprint Casts from Jaguar Cave.

Fp #	Foot Side	Age Range	Sex	Ht. (± 1")	Foot Length	Ball Width	Heel Width	Moccasin Length	Moc. Ball Width	Moc. Heel Width
1	R	Adult	M	66"	250 mm	95 mm	64 mm			
3	R	Adult	M?	63"	242 mm	85 mm	65 mm			
13	R	Adult	M	69"	262 mm	108 mm	60 mm			
15	L	Adult	M	66"	250 mm	110 mm	65 mm			
32	L	Adult	?	64"	242 mm	90 mm	63 mm			
33	R	Adoles?	?	59"	223 mm	78 mm	65 mm			
67	L	Adult?	F?	55"	210 mm	80 mm	47 mm			
72	L	Adult	F?	62"	235 mm	75 mm	50 mm			
132	F	Adult	M	62"	225 mm	90 mm	70 mm	235 mm	100 mm	75 mm

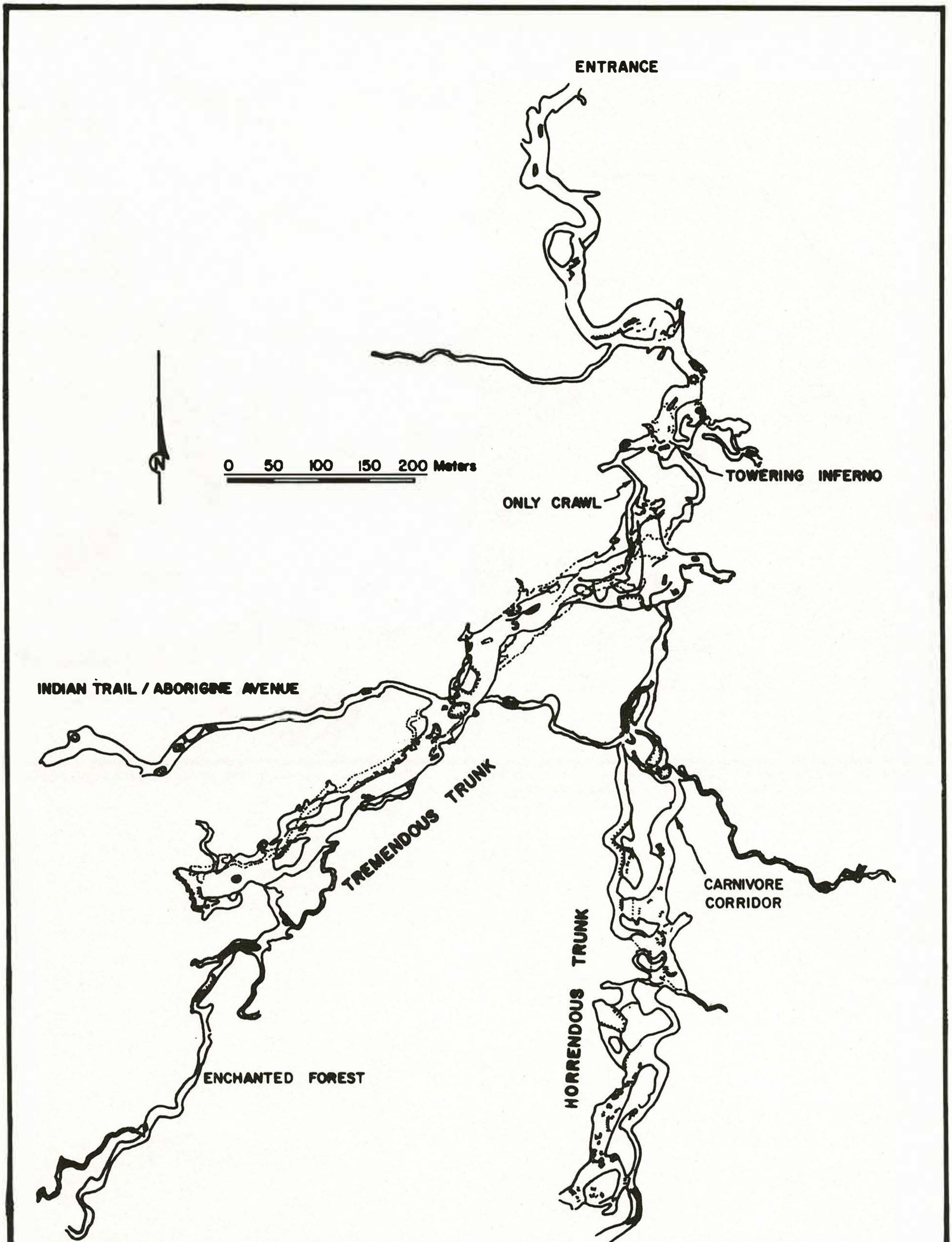

Figure 1. Jaguar Cave, Tennessee. Adapted by Michael Fuller from the NSS map produced under the direction of Louis E. Simpson.

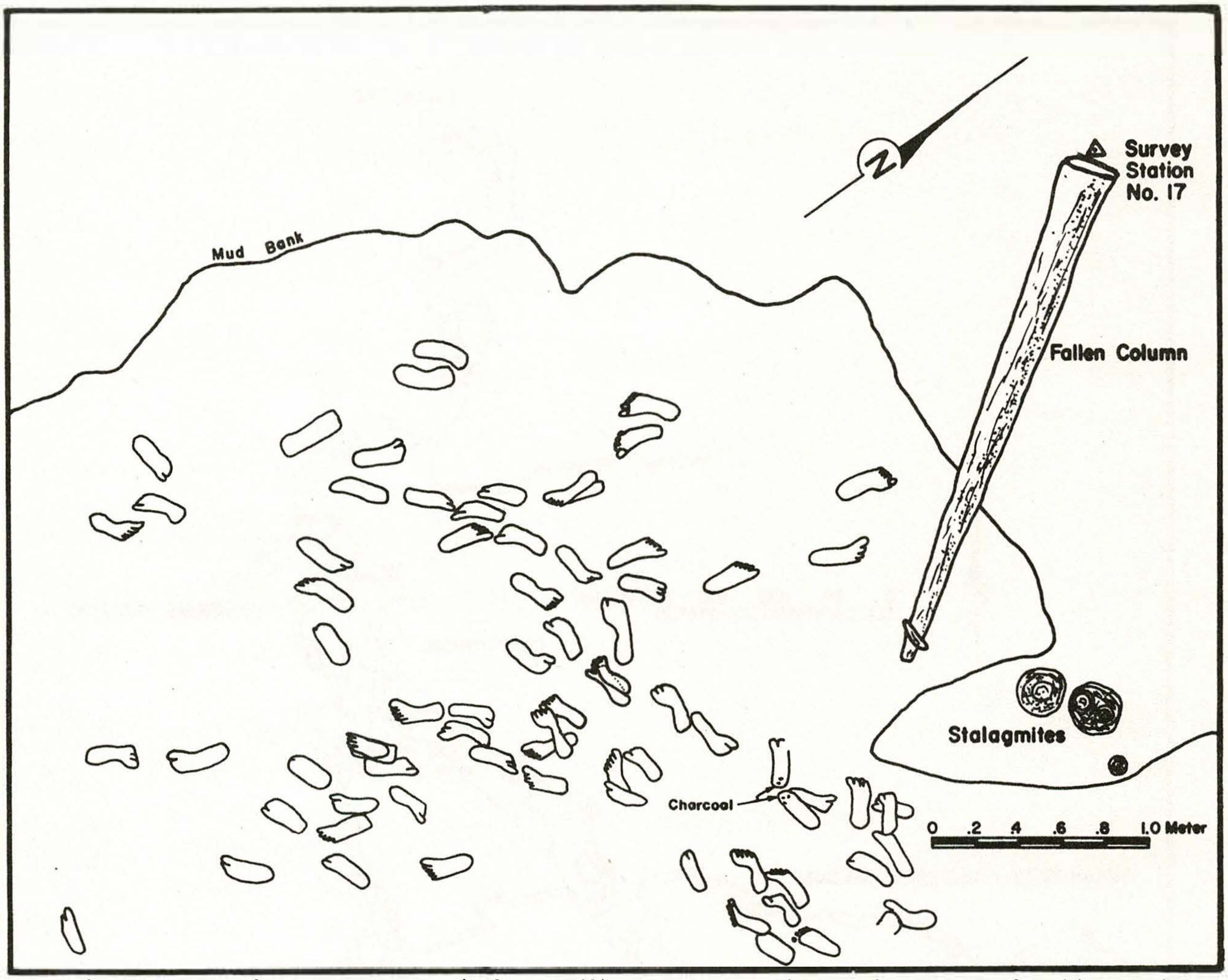

Figure 2. A portion of Aborigine Avenue (Indian Trail), Jaguar Cave, showing the pattern of prehistoric human footprints. Draftsman Michael Fuller.

Cavernicolous Pseudoscorpions In North And Middle America

William B. Muchmore
Department of Biology, University of Rochester, Rochester, New York, 14627

Abstract

In the eastern United States, some 60 species, representing 11 genera, of pseudoscorpions have been foudn incaves. A few of these are clearly accidental intrusions of litter dwelling, epigean forms, but most are strongly modified morphologically and are certainly obligate cavernicoles. The distributions of the caveadapted forms are quite varied. Most widespread are Keptochthonius (Chamberlinochthonius) and Hesperochernes, which are found generally throughout the southwestern cave regions; however, the former has not been recorded from Georgia or Alabama or the Ozarks, and the latter, which is usually associated with bats, is not known from West Virginia. Cave-adapted Apochthonius, Aphrastochthonius, Mundochthonius, and Tyrannochthonius are restricted to the periphery of the range of Keptochthonius with little or no overlap. Microcreagris is unusual in that troglobitic forms are known only from the Tennessee River drainage area in Alabama, Tennessee and Virginia, while epigean forms are widespread through the southern states.

In the southwestern United States and Middle America only a small part of the cavernicolous pseudoscorpion fauan ahs been studied carefully. Nevertheless, about 65 cave-dwelling species have been recognized, representing about 30 genera. Here few distinct patterns of distribution are evident. Tejachernes, which is apparently closely associated with bats, is widespread through the area. However, some other genera seem to be rather restricted in their ranges; This is especially noticeable in Albiorix, Aphrastochthonius, Leucohy, Paravachoniu, Troglohy, Typhloroncus, and Vachonium.

Zusammenfassung

Elf Gattungen von Pseudokorpionen, vertreten in etwa 60 Arten, wurden in Hohlen der süd-östlichen USA beobachtet. Während es sich in einigen Fällen offensichtlich um die Zuwanderung von bodenständigen Freiluftformen handelt, zeigen die meisten dieser Arten starke morphologische Modifikationen und sind offensichtlich echte Trglobionten. Die Verbreitung der angepassten Arten ist ziemlich unterschiedlich. Am weitesten sind die Gattungen Kleptochthonius and Hesperochernes verbreitet, die in allgemeinen in Höhlen den gesamten sädöstlichen USA gefunden werden. Kleptochthonius wurde jedoch nicht in Georgia, Alabama and dem Ozark-Gebiet beobachtet, und Hesperochernes, der meistens mit Fledermäusen assoxiiert vorkommt, wurde nicht in West-Virginia gesichtet. Die Verbreitung der Höhlenarten der Gatungen Apochthonius, Aphrastochthonius, Mundochthonius and Tyrannochthonius beschränkt sich auf die Randgebiete des Vorkommens von Kleptochthonius mit geringer bzw. keiner Überlappung. Die Gattung Microcreagris ist ungewohnlich insofern das Vorkommen ihrer höhlenbewohnenden Arten nur aus dem Einzugsgebiet des Tennessee in Alabama, Tennessee und Virginia berichtet wird, während ihre Freiluftformen in allen südlichen Staaten verbreitet sind.

Obwohl die höhlenbewohnende Pseudoskorpion-Fauna der südwestlichen USA und in Mittelamerika nur zum kleinen Teil sorgfältig untersucht worden ist, wird das Vorkommen von etwa 65 höhlenbewohnenden Arten aus ca. 30 Gattungen berichtet. In diesen Gebieten sind jedoch nur wenige Frundzüge der Verbreitung deutlich. Tejachernes - anscheinend eng assoziiert mit Fledermäusen - kommt dort überall verbreitet vor. Einige andere Gattungen, besonders Albiorix, Aphrastochthonius, Leucohya, Paravachonium, Troglohya, Thyphloroncus and Vachonium, scheinen jedoch in ihrer Verbreitung ziemlich beschränkt zu sein.

In 1960, Joseph C. Chamberlin and David R. Malcolm published an excellent survey of the cavernicolous pseudoscorpions in North America. At that time, they could report that 43 (14%) of the 314 known pseudoscorpions had been found in caves. They noted a wide variety of morphological adaptation to the cave environment, with the extremes being highly modified troglobites (see their Fig. 1). Also emphasized was the fact that most of the cave forms belong to the superfamilies Chthonioidea and Neobisioidea (their Table I). Since that tiem, extensive collecting by many cave explorers have provided material for further taxonomic work by Chamberlin, Beier, Benedict and Malcolm, and Muchmore. Five new genera and many new species have been described and the distribtions of many forms have been considerably extended. Now it can be said that about 150 (or nearly 30%) of the 500 or so described species of pseudoscorpions have been found in caves, and that they range over most of the cave area of the continent.

In the southeastern United States, including the Ozark region, about 75 species, representing 11 genera, are known to occur in caves (see Table I). Some of these, like Chthonius tetrachelatus and Microbisium confusum, are common, epigean, litter-dwelling forms nd their occurrence in caves is certainly accidental, or icidental to their normal habits. Most, however, are strongly modified morphologically, usually larger in size thatn their epigean relatives, with longer and more attenuate appendages, with eyes reduced or absent, and with the cuticle thinner and lighter in color; these are almost certainly obligate cavernicoles, as it is difficult to imagine how they could survive on the surface.

Distributions of the cave-adapted forms are rather varied. Most widespread of the genera are Kleptochthonius (Chamberlinochthonius) and Hesperochernes, which are found generally throughout the southeastern cave regions. The latter, formerly known under the name Pseudozaona, is usually found associated with bat guano. Two species have been described, but the variation, overall, is so great that the taxonomy is still uncertain. These forms are fairly common in bat caves through the entire region, except that noe has yet been collected from West Virginia. It is presumed that indiyiduals are carried from cave to cave by bats, or some other larger animal.

Kleptochthonius (C.), on the other hand, is represented by many distinct local species, each one apparently having adapted rather quickly to its own special habitat; 29 species have been decscribed to date. These are found commonly in caves of eastern West Virginia, central and western Virginia, eastern Tennessee and Kentuck, and southeastern Indiana; none has yet been foudn in other parts of these states or in the surrounding states of Georgia, Alabama and Ohio, or in the Ozarks.

Cave-adapted Apochthonius, Aphrastochthonius, Mundochthonius and Tyrannochthonius are found only at the periphery of the range of Kelptochthonius (C.) with little or no overlap. Thus, Apochthonius, are found in caves in northeastern West Virginia, central Kentucky, and the Ozarks. Aphrastochthonius has 2 species, both troblobitic, in north central Alabama: Mundochthonius has 2 cave-dwelling species, in northern Virginia and in souther Illinois: and Tyrannochthonius has several troglobitic forms in southeastern Tennessee and northern Alabama. In all of these genera, epigean species are more widespread, ranging freely into the area occupied by epigean Kleptochthonius (K.).

Microcreagris is unusual in the vary restricted range of troglobitic forsm. While epigean forms are widespread over the entiire southeastern United States south of Pennsylvania and the Ohio River, Cave-dwellers are known only from the Tennessee River drainage area in northern Alabama, northwestern Georgia, southeastern Tennesee and western Virginia.

In the broad region of southwestern United States, Mexico and Central America, collection and study of pweudoscorpions has been more random than in the east. Nevertheless, about 75 cave-dwelling species have been recognized, representing about 30 genera (see Table II). However, few distinct patterns of distribution are evident. The genus most consistently found in caves, and apparently over the widest area, is Tejachernes. As with cave-dwelling Hesperochernes in the east, representatives of Tejachernes are usually found on bat guano, and are presumably carried about by bats or some of their associates. And as with Hesperochernes, the taxonomy is difficult because of the wide range of variation within populations.

Unlike the situation in the east, western cave-adapted species of Microcreagris are found scattered about the range of the genus as a whole, in Oregon, Nevada, California and Texas. Widespread also are cavernicolous species of Aphrastochthonius, in California, New Mexico, Tamaulipas, San Luis Potosi, and Guatemala, while epigean forms are known only from Chiapas (and Cuba).

Most other western cave-dwelling forms are rather restricted in their ranges. Though epigean forms of Albiorix range widely through the drier parts of the area, cavernicolous species are known only from Guerrero and Oaxaca. In the closely related Typhloroncus there are three troglobitic species in Tamaulipas, Veracruz and Puegle, while the only known epigean species is from the Virgin Islands. Several genera are represented only by geographically restricted, highly adapted troglobites; these include Leucohya, Troglohya, Vachonium and Paravachonium. These genera, together with Mexobisium, ~~which does have wide epigean representation, have~~ been placed in two families, Hyidae and Vachoniidae. However, I believe that they are all basically similar, the differences being due simply to different adaptations to the cave environments.

hese occurrences of many cavernicolous forms with various degrees of modification for subterranean life and with varied distributions and relations to epigean forms pose many questions, for example: What are the functional correlates for the morphological modifications of troglobites, such as increase in size, attenuation of appendages, and reduction in numbers of setae? Why have certain common and widespread genera such as Kewochthonius, Novobisium and Tuberocreagris not produced any cave-adapted forms, while Kleptochthonius has produced ~~so many~~? Why has Kleptochthonius been so successful in the center of the southeastern cave region, but has given way to other genera at the periphery? How can we explain the very restricted occurrences of cave-adapted forms in such widespread genera as Albiorix and Microcreagris? How are Hesperochernes and Tejachernes actually distributed from cave to cave?

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Table I Cavernicolous pseudoscorpions in the United States east of the 95th meridian

Genus	No. Species	Distribution
CHITHONIOIDEA		
Aphrastochthonius	2	AL
Apochthonius	11(+)	WV, VA, GA, AL, IN, MO AR
Chthonius	1	AL, TN, KY
Kleptochthonius (*K.*)	2	AL, TN
Kleptochthonius (*C.*)	29(+)	WV, VA, TN, KY, IN
Mundochthonius	2	VA, IL
Tyrannochthonius	(+)	AL
NEOBISIOIDEA		
Microbisium	1	KY, TN
Novobisium	1	AL
Microcreagris	10(+)	AL, GA, TN, VA
Chitrella	4	VA, WV, TN
CHELIFEROIDEA		
Hesperochernes	2	VA, GA, AL, TN, KY, OH, IN, MO, AR

(+) = one or more undescribed species

Table II. Cavernicolous pseudocsorpions in the United States west of the 95th meridian and in Middle America

Genus	No. Species	Distribution
CHITHONIOIDEA		
Tridenchthonius	1	Gro
Aphrastochthonius	6(+)	CA, NM, Tamps, SLP, GUAT
Apochthonius	3	OR, CA
Mundochthonius	1	Tamps, NL
Neochthonius	1	CA
Paraliochthonius	1	GUAT
Tyrannochthonius	2(+)	Tamps
Lechytia	1(+)	Gro, PANAMA
NEOBISIOIDEA		
Microbisium	1	TX, Oax
Paroblisium	1	OR
Microcreagris	8	CA, TX
Mexobisium	4	Ver, Tab, GUAT, BELIZE
Leucohya	2	NL
Troglohya	2	Oax, Chiap
Paravachonium	4	Tamps, SLP
Vachonium	8	Yuc, BELIZE
Chitrella	(+)	NM, TX
Pachychitra	3	Tamps, Chiap, Yuc
Albiorix	3	Gro, Oax
Typhloroncus	3	Tamps, Ver, Pueb
GARYPOIDEA		
Archeolarca	4	AZ, CA, TX
Larca	1	CA
Pseudogarypus	3	CA, AZ
CHEIRIDIOIDEA		
Cheridium	(+)	Yuc
CHELIFEROIDEA		
Dinocheirus	(+)	NM, MEXICO
Epichernes	(+)	MEXICO
Hesperochernes	(+)	MEXICO
Incachernes	1	EL SAL
Lustrochernes	1	Yuc

Endangered Species Legislation In The United States

Thomas M. Lera
NSS International Secretary, 1266 Royal Oak Drive, DeSoto, Texas, 75115, U.S.A.

Abstract

In 1966, Congress passed legislation which afforded native animals legal protection. Since that time, this legislation has been twice revised. The current Endangered Species Act of 1973 provides not only animals but also plants with what appears to be a reasonable degree of protection. Recent court decisions support the concept and validity of the 1973 Act.

The 1973 Act has been amended by Congress four times. The last amendment in 1978 was the result of an extended and complex series of compromises between the Fish and Wildlife Service, the Carter Administration, Congres and the environmental community. Several important features of the 1973 Act have been strengthened including the consultant process, listing of species and critical habitat designation.

This paper discusses endangered species legislation and how it can be used as a management tool to protect threstened and endangered plants, animals and habitats.

Zusammenfassung

Im Jahr 1966 kam der amerikanische Kongress mit der Gesetzgebung heraus, welche eingeborene Tiere unter offiziellen Tierschutz stellte. Diese Gesetzgebung wurde seitdem zweimal ueberarbeitet. Das gegenwaertige Gesetz, erstellt im Jahr 1973, fuer "Gefaehrdete Spezien", umfasst nicht nur Tiere, sondern auch Pflanzen und verschafft einen angebrachten Grad von Beschuetzung. Neuerliche diesbezuegliche Gerichtsentscheidungen erhalten das Schutzgesetz von 1973 aufrecht.

Der Beschluss von 1973 wurde bereits viermal vom amerikanischen Kongress berichtigt. Die letzte Berichtigung im Jahr 1978 war das Resultat einer Reihe erheblicher und verwickelter Kompromisse zwischen dem Amt fuer Fischerei und Forstwesen, der Regierungsverwaltung unter Praesident Carter, amerikanischen Kongress, und der Umweltschutz-Interessengemeinschaft. Mehrere wichtige Punkte des Beschlusses von 1973 wurden verstaerkt, einschliesslich des diesbezueglichen Beratungsvorganges, Veroeffentlichung von Spezien und Bezeichnung/Ernennung von Vorkommen/Fundorten.

Dieses Dokument diskutiert die Gesetzgebung fuer gefaehrdete Spezien und wie es gebraucht werden kann als ein Verwaltungsinstrument, um bedrohte und gefaehrdete Pflanzen, Tiere und die Gegend der Vorkommen/Fundorte zu beschuetzen.

Early Congressional

The first formal involvement by Congress in endangered species legislation began with the Tendangered Species Preservation Act of October 15, 1966 (Public Law 89-669, 80 Stat. 926). This law acknowledged a national responsibility to act on behalf of native species of wildlife which were threatened with extinction whatever the cause. Its amended version, the Endangered Species Conservation Act, was enacted on December 5, 1969 (Public Law 91-135, 83 Stst. 275). This revision to the 1966 Act greatly expanded the scope of effort to conserve endangered species. It also sought to ensure that the United States would not contribute to the extinction of other nations' wildlife. Although the 1969 Act laid the framework for an effective endangered species conservation program, with controls on traffic in threatened species as well as habitat preservation and restoration, it did not automatically afford native endangered species adequate protection.

A Congressional study has found "...that various species of fish, wildlife and plants in the United States have been rendered extinct as a consequence of economic growth and development untempered by adequate concern and conservation" and that others are "...threatened with extinction" (16 U.S.C. 1531 (1975)). After this study and Presidential urging, the Endangered Species Act was passed on December 28, 1973 (Public Law 93-205, 87 Stat. 884, amended by Public Law 94-325, 90 Stat. 724 (1976), Public 94-359, 90 Stat. 911 (9176). Public Law 95-212, 91 Stat. 1493 (1977), Public Law 95-632, 92 Stat. 3751 (1978).

A major purpose of the 1973 Act is the "conservation of endangered and threatened species" (16 U.S.C. 1531 (5)(b)(1975)) and "conservation" is strictly defined as "...the use of all methods and procedures which are necessary to bring any endangered or threatened species to the point at which the measures provided pursuant to this Act are no longer necessary" (16 U.S.C. 1532 (2) (1975)).

The 1973 Act also commits all Federal agencies to "utilize their authorities in the furtherance of the purposes of the Act by ...taking such action necessary to ensure that actions authorized, funded, or carried out by them do not jeopardize the continued existence of such endangered and threatened species or result in the destruction or modification of habitat of such species which is determined by the Secretary of Interior...to be critical"(16-U.S.C. 1536 (1976)). Also keynoted in the Act was "the President shall provide assistance to foreign countries and urge international cooperation in establishing programs to protect endangered species" (16 U.S.C. 1537 (a) and (b)(1975). Finally, the 1973 Act authorized legal action by provate citizens seeking "to enjoin any person, including the United States and any agency on other governmental instrumentality...whoe is alleged to be in violation of any provision of this Act or regulationd issued..." (16 U.S.C. 1540 (g)(1)(A)(1975).

Court Decisions

Inrecent years court decisions concerning endangered species have increased in frequency and have proven to be of major significance in that the decisions have embodied individual and governmental attemps to make difficult and yet practical decisions concerning the preservation of species in an increasingly technological and urbanized environment which often casts aside the fate of endangered species themselves.

The primary issue in Froehlke (534 F. 2nd 1289 (E.D.Mo., 1976)) became whether the Army Corps of Engineers had adequately considered the fate of the Indiana bat (Myotis Sodalis) in its environmental impact statement regarding the construction of the Meremac Dam near St. Louis, Missouri. Other major court decisions include National Wildlife Federation, (529 F. 2nd 359)5th Cir., 1976)), Hill(98 S. Ct. 2279 (1978)), Defenders of Wildlife(428 F. Supp. 167 (D.D.C.,1977)) and Capparet(375 F Supp. 456 (D.Nev.,1974)).

These decisions begin to show the basic judicial interpretation of the 1973 Act. The burden of proof lies with the plaintiff and not with the Federal agency responsible for the action. Secondary impacts must be evaluated in order to ensure the continued existence of an endangered species and to ensure that the critical habitat will not be modified or destroyed. Social and scientific costs are more relvant than the financial resources which ahve been expended. The Federal government must use all methods to encourage and promote recovery of an endangered species. The protection of an endangered species is more important than private property rights in some cases.

It would appear that, at least for the moment, through application fo the 1973 Act, the cours are engaged in ecological tinkering, getting species through the bottlenecks until management of entire ecosystems, including habitats, can be realized and accomplished.

1978 Amendments

On November 10, 1978, President Jimmy Carter signed the Endangered Species Act Amendments of 1978 (Public Law 95-632, 92 Stat. 3751 (1978)). This action reauthorized the administration of the Endangered Species Act of 1978 and, among other things, established an exacting two-tiered review process to consider exemptions under Section 7. The amendments also affected the consultation process, listing of species, Critical Habitat determinations, cooperative agreements with States, enforcement and penalties, recovery planning, captive-held raptors, and public hearing/notice procedures.

A new section requires the Secretary of the Interior's biological opinion, which is rendered at the conclusion of the consultation process, to detail how the proposed action would affect the listed species or its Critical Habitat. The opinion must also suggest reasonable and prudent alternatives that would avoid jeopardy to the species or adverse modifications of its Critical Habitat.

Once the consultation process has been initiated, the amendments stipulate that no irreversible or irretrievable commitment of resources may be amde which forecloses the implementation of alternative measures to avoid jeopardy or adverse effects on the species or its Critical Habitat.

Critical Habitat has been defined for the first tiem, revising the Service's definition (by regulation) to include "the specific areas within the geographical area occupied by the species at the time it is listed ... on which are found thouse physical or biological features which are essential to the conservation of the species and which may require special management consideration or protection; and ...specific areas outside the geographical area..., upon a determination by the Secretary of the Interior that such areas are essential for the conservation of the species." (16 U.S.C. 1532 (5)(A)(1980)).

The amendments now require the Secretary of the Interior ot consider the economic impact of specifying any particular area as Critical Habitat. In reviewing the economic impact the Secretary of the Interior may exclude any area from the Critical Habitat if he determines that the benefits of such exclusion outwiegh the benefits of specifying the area as part of the critical habitat, unless he determines, based on the best scientific and commercial data available, that the failure ot designate such area as critical habitat will result in the extinction of the species (16 U.S.C. 1533 (b)(4)(1980)).

In designating a Critical Habitat a public hearing must be held with notices placed in local units of government affected and scientific journals. Finally, to the extent possible, the Secretary of the Interior must include a description of activities which may adversely modify the habitat or which may be affected by the designation. This description is to be included in the recovery plan for the endangered or threatened species.

Conclusions

The amendments retains the initial intergrity of the Endangered Species Act of 1973 while allowing some flexibility which permits exemptions from the Act's stringent requirements. It cannot be said that the Endangered Species Act of 1973 has been gutted rather a practical conflict resolution procedure has been probulgated. The important point to remember is that the destruction of the life on an endangered or threatened species should never be taken lightly, no matter how insignifican the species may appear today.

This legislation is a valuable tool for speleologists. There are five endangered species of bats with critical habitats indentified for several fo them. The endangered bats are Gray Bat (*Myotis grisescens*). Hawaiian Hoary Bat (*Lasiurus cinereus semotus*), Indiana Bat (*Myotis sodalis*), Virginia Big-eared Bat (*Plecotus townsendii virginianus*) and Ozark Big-eared Bat (*Plecotus townsendii ingens*).

Management of caves must confront two interdependent issues: protection of habitat and education of the public. Both issues must be undertaken if cave bats wre to survive as a viable segment of our fauana. As pointed out by Humphrey (1978), Tuttle (1979), LaVal (1980) and in many recovery plans, protecting caves will be to no avail if summer foraging habitat is so degraded that it will not produce a food supply sufficient to allow bats to increase or sustain their populations. I is unreasonable to expect the course of progress to be altered substantially in deference to endangered bats. Nevertheless governmental agencies thru the endangerd species legislation have become sensitive to the impact of their projects on these species in the last three years.

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Hydrology of Harlansburg Cave, Lawrence County, Pennsylvania, USA

Kenneth M. Long and J. Philip Fawley
Westminster College

Abstract

This maze extends over an area of approximately 200 m by 200 m and has a total passage length of about 4500 m. The floors are mostly mud and water-covered mud.

Water levels in two pools were measured and samples removed for analysis at two-week intervals for eight months, with occasional measurements for another year. Calcium (II) concentrations were determined by EDTA titrations. Correlations are made between the water levels and the calcium concentrations, the concentrations of saturated solutions, and the percent saturation. Cave water levels are compared with water levels in a USGS well in the county.

Biological activity in the cave includes visits by raccoons and hibernation of bats.

Résumé

Ce labyrinthe couvre une superficie d'environ 200 m sur 200 m et s'étend à une longuer d'environ 4500 m. Le plancher consiste pour la plupart en boue at en boue couverte d'eau.

A des intervalles de deux semaines pendant une période de huit mois le niveau d'eau dans deux flaques a été mesuré et des échantillons ont été analysés, en considérant aussi certaines données d'une autre année. Des concentrations de Calcium (II) ont été determinées par titrages EDTA. Il existe des correlations entre les niveaux d'eau et les concentrations de Calcium, les concentrations de solutions saturées, et le pourcentage de saturation. Les niveaux d'eau de la caverne ont été comparés aux niveaux d'eaux dans un puits USGS dans la même "county".

L'activité biologique de la caverne comprend des visites par des ratons laveurs, et l'hibernation de chauve-souris.

Harlansburg Cave was discovered in 1950 when highway construction cut through the Vanport Limestone just west of the village of Harlansburg, Pennsylvania. Following the rescue of three teenagers in 1966, the entrances of the cave were closed with concrete (Smith, 1970). Unknown people opened one of the entrances to provide access to the southern part of the cave.

The Westminster College Caving Club began working in the cave in 1978. Most of the southern portion has been mapped. The maze extends approximately 200 m south from the face of the cut and perhaps 100 m east and west from the entrance. In this small area are more than 4500 m of passages. Long passages are oriented in a north-south direction with shorter east-west connecting passages. Clay covers the floor nearly everywhere. In places the clay is soft mud as much as 0.5 m deep. In much of the cave, water covers the mud to depths of up to 1.0 m.

Rooms appear to have formed primarily through breakdown and the intersection of passages. Speleothems occur mostly in the southern and western parts of the cave. The Ruby Room with its red-orange stalactites, bacon and stalagmites is notable. Tidrick's Place with soda straws up to 20 cm long is attractive.

A very small colony of bats hibernates in Harlansburg Cave. They apparently live elsewhere in summer. Raccoons frequent the eastern parts of the cave and occasionally the wetter western parts of the cave, as evidenced by their tracks. Near the entrance a few cave orb spiders have been seen. Two rooms near the highway cut have actinomycetes growing on the rock surfaces. The rooms are known as the "glow-rooms" because of the reflective nature of the moist surfaces of the colonies.

The Vanport Limestone in which the cave has formed is a dense gray formation in the Allegheny Group of the Pennsylvanian System (Poth, 1963). This limestone has a low magnesium content (about one to two per cent) and is quite uniform in composition. Eighteen analyses of samples from quarries in Lawrence County and adjoining Butler County show an average of 93.62 ± 2.36% $CaCO_3$. Silica analyses averaging 2.77% are reported for 16 samples (O'Neill, 1976). In the area where the cave is located the thickness of the Vanport varies between 3.0 and 4.5 m (Poth, 1963). Just east of the cave, where the village of Harlansburg is located, a channel has been cut through the Vanport. In some locations 10 to 20 cm of the Buhrstone (limonitic) iron ore lie atop the Vanport. Overlying the iron ore is the lower Kittanning Formation, a channel sandstone. The total thickness of the Kittanning Formation and unconsolidated deposits ranges from 7.5 to 15 m in this locality. At some points in the cave where breakdown has occurred, some think Kittanning beds are "draped" over the underlying limestone blocks. Where passages in the cave are wide, there is danger of breakdown of the Kittanning sandstone. One member of a mapping team was narrowly missed by a block of rock weighing perhaps 40 or 50 kg.

Maze development is typical of the Vanport. Other examples are Brady's Bend Cave, Hineman Cave, Porter's Cave, Portersville Cave and Rose Point Cave (White, 1976). The latter two have been destroyed by quarrying operations.

Although Harlansburg Cave is very wet, no large water inlets have been found. At times of heavy rainfall or rapid snowmelt there is rapid dripping at many points in the cave. At such times the water level rises quite rapidly and then falls more slowly. Tables 1 and 2, Figure 1.

At times of high water levels, water may be seen flowing in the cave. The observed flow has been to the west and north in the western half of the cave. One drainage point has been found about 63 m west of the entrance. Water flows north and west to reach the drain where water runs underneath the side wall of a passage. Evidence of flow to the east is observable in the eastern part of the cave.

Two pools were selected for study: Carl's Table Pool and the Crystal Lake. Carl's Table is a large flat-topped block of limestone breakdown. The pool, average temperature 9.8 ± 0.1°C, is protected from casual intrusion by cavers by an overhanging ledge. When near its low level it has an area of about 7 to 8 m^2 and has a reversed "j" shape. Carl's Table is located 115 m due south of the entrance.

Crystal Lake, about 130 m south-southwest of the entrance, is much larger. Its surface area is about 175 m^2 and it extends through approximately 128 m of passages. It is occasionally stirred up by cavers who are willing to walk through its cold (average temperature 9.4 ± 0.1°C) waters that are up to 1.0 m deep. The walls of the passages are nearly vertical so the area occupied by the lake does not change very much when the water level changes.

In each pool an arbitrary reference point was established so that water levels could be measured without entering the water. All levels in Tables 1 and 2 are based on these reference points.

On some trips pH readings were determined with a Cole-Palmer Digi-Sense Digital pH meter, Model 5986-00. The pH of the water in the pool was read and then the pH of a sample of water removed from the pool and saturated with an excess of recrystallized calcium carbonate (Fisher Certified or J. T. Baker Reagent grade $CaCO_3$) (Picknett, 1964).

Identical water samples were collected in polyethylene bottles. Each pair of samples was analyzed for total calcium (as $CaCO_3$) by EDTA titration.

Water and air temperatures were measured with a Markson Portable Digital Thermometer, Model TC-100. On occasion relative humidity was determined with Airguide No. 113-B Micro Hygrometers.

Ground water level data from USGS well number 1040 in Lawrence County show large fluctuations during the period from February 1979 to September 1979 (the most recent data available). The range is 4.93 feet (150 cm) with a trend toward lower levels, Figure 1 (Taylor, 1980). Carl's Table Pool and Crystal Lake show a similar trend with correlation coefficients of -0.8740 and -0.7997, respectively. However each cave pool varied over a much smaller range during this time period, a range of 28.4 cm for Carl's Table Pool and a range of 14.8 cm for Crystal Lake.

Water levels in the cave increase rapidly during the spring thaw or if there is continued heavy rainfall. When water levels fall, they do so more slowly. Clearly in the case of Carl's Table Pool the only way the water can leave is by slowly moving through the clay that forms the sides and bottom of the pool. Probably the same is true of the much larger Crystal Lake except when flow to the north has been observed at very high water levels.

As shown in Figure 1, the percent saturation shows a generally inverse relationship to the water level. As the water level falls, the concentration of $CaCO_3$ increases, but the concentration of a saturated solution increases more rapidly. This clearly indicates that the change is not due to loss of $CO_2(g)$. Loss of CO_2 would reduce the capacity of the water to dissolve $CaCO_3$, the opposite of the effect observed. When the water level rises sharply, the percent saturation drops. This may be due to an increased concentration of CO_2 in the water entering the cave. Since very little limestone lies over the cave in these poor areas, little additional calcium carbonate can be dissolved by this water as it enters the cave pools.

Acknowledgements

We thank members of the Westminster College Caving Club for their assistance in collecting samples and Jeffrey K. Long for performing some of the water analyses. We thank the Westminster College Faculty Research Fund for support of this project.

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TABLE 1

Data from Carl's Table Pool

Date	water level	t_{H_2O}	t_{air}	R.H.*	pH_1	pH_2	saturation	$CaCO_3$	$CaCO_3$	saturation
020579	31.3cm	9.8°C		95%				133.5	132.8	100%
021979	27.6	9.8	10.2°C	96	7.69	7.67	100%	135.8	138.5	98
030579	35.3									
030979	34.2	9.8	9.9					129.9	151.2	86
031979	30.6	9.8	12.1	94	7.76	7.85	98	132.9	147.3	90
040279	30.5	9.8	11.4		7.65	7.56	102	139.2	136.4	102
041779	33.8	9.8	10.1	84	7.48	7.59	96	131.4	143.3	92
043079	29.3	9.8			7.74	7.73	100	107.7	143.5	75
051679	29.8	10.0	9.9					134.5	137.8	98
052879	29.4	9.8	10.5					137.0	140.6	97
062079	28.0	9.8	10.7		7.82	7.92	98	140.2	139.0	101
062879	26.7	9.8						139.7	141.2	99
071179	24.6	9.8			7.80	7.99	96	141.4	141.2	100
102679	22.0	9.7						144.5	150.4	96
081179	17.8	9.7						145.0	150.5	96
090479	12.0	9.7	10.1	95				148.9	170.2	87
121679	2.0	9.6								
122979	10.4	9.6	9.8	93				136.6	133.8	102
011580	13.6	9.6						139.1	156.2	89
021680	10.5	9.6						137.8	149.8	92
030180	8.4	9.8						137.8	139.1	99
070280	9.1							143.2	144.2	99

* Relative Humidity

1 = value for water sample

2 = value for water sample sturated with $CaCO_3$

TABLE 2

Date from Crystal Lake

Date	water level	t_{H_2O}	t_{air}	R.H.*	pH_1	pH_2	satu-ration	$CaCO_3$	$CaCO_3$	satu-ration
020579	31.2cm	9.4°C	9.8°C	81%				96.2	104.1	92%
021979	30.5	9.4	9.9	82	7.36	7.70	91%	105.8	108.6	97
030579	34.5	9.7	9.8							
030979	31.7	9.6						111.0	140.8	76
031979	30.5	9.5		79	7.54	7.90	92	106.6	136.3	78
040279	30.2	9.5	10.4		7.49	7.53	98	125.9	125.9	100
041779	31.7	9.6	9.9	75				101.8	160.1	64
043079	30.3	9.5			7.26	7.73	84	107.7	143.5	75
051679	30.2	9.6						87.1	113.4	77
052879	31.0	9.5	9.8					111.1	111.1	100
062079	30.2	9.4	10.5					104.9	110.9	95
062879	29.7	9.4						113.0	116.2	97
071179	27.0	9.4	10.2		7.42	8.02	84	117.3	120.9	97
072679	24.5	9.4						122.4	130.9	94
081179	22.5	9.3						124.6	136.5	91
090479	20.0	9.3	10.4	81				127.8	147.6	87
092079	19.7	9.2						134.1	161.4	83
121679	21.5	9.2						110.9	121.0	92
122979	27.5	9.2	9.7	80				70.2	81.6	86
011580	30.2	9.2						82.0	88.5	93
021680	28.0	9.3						97.6	105.2	93
030180	28.0	9.3						78.9	97.7	81
070280	25.9							113.8	121.4	94

* Relative Humidity

1 = value for water sample

2 = value for water sample saturated with $CaCO_3$

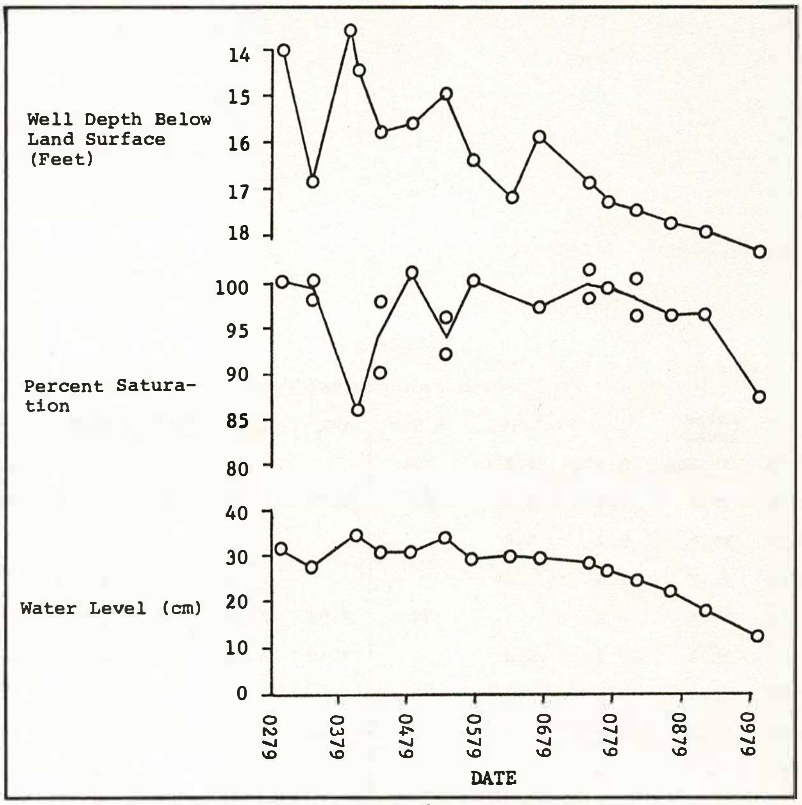

Figure 1. Well depth below land surface in relation to water level and percent saturation ($CaCO_3$) of Carl's Table pool. Harlansburg Cave, Lawrence County, Pennsylvania, USA.

La Genese Des Formes Du Karst De La Haute-Saumons, Facteurs Determinants

Jean Roberge
Centreau, Université Laval, Ste-Foy, Québec, G1K 7P4, Canada

Résumé

Le karst de la Haute-Saumons est situé dans la partie supérieure de bassin de la rivière aux Saumons, sur l'île d'Anticosti, au Québec. Sa partie occidentale, qu'un drainage karstique colonise progressivement, nous procure un site favorable à l'observation de la morphogenèse karstique.

Dans ce secteur, une couche de till de 0 à 3 m d'épaisseur recouvre les strates subhorizontales de calcaire. Il se compose de fragments calcaires disposés au sein d'une matrice argilo-limoneuse. Nous distinguons les formes karstiques liées à la capture de cours d'eau de celles liées à de l'infiltration diffuse. Toutes se sont établies au dépend de diaclases.

Les pertes de cours d'eau ont creusé des dépressions de dissolution dans le calcaire. Leur dimension est proportionnelle à la taille du cours d'eau alors que leur forme dépend plutôt de l'angle de recontre avec la diaclase. La présence de niveaux argileux dans le calcaire peut y induire une part d'effondrement. Quelques véritables dolines d'effondrement, formées au-dessus de conduits souterrains, sont aussi une conséquence (indirecte) des captures karstiques.

Les résultats morphologiques de l'infiltration dépendent surtout de l'épaisseur de la couche de till. Si elle a 30 cm ou moins, l'infiltration élargit toutes les diaclases et un pavement karstique apparaît. Sinon, l'eau ne s'infiltre dans les diaclases pour les dissoudre, qu'en un nombre limité de points. Entre 30 cm et 2 m d'épaisseur, on observe de nombreus puits, souvent alignés le long de diaclases principales. Avec plus de 2 m d'épaisseur, le till envahit entièrement les diaclases où l'infiltration les élargit, formant en surface, des dolines de soutirage.

Abstract

Haute-Saumons karst is located in the upper aux Saumons river basin, on Anticosti island, Québec. Its western end, where karstic drainage is progressively settling, provide favorable conditions for observation of karst landform development.

In that area, the nearly flat lying limestone is covered with 0-3 m of till composed of limestone fragments embedded in a silty clay matrix. We distinguish karst landforms related to stream capture from those related to diffuse infiltration. All are established on joints.

Stream sinks form solutional depressions in limestone. Their size depend on the importance of the stream and their shape, on their angle of intercept of the joint. Presence of shaley levels in the limestone may induce a collapse component. The few pure collapse dolines, created above subsurface conduits, also result (indirectly) of stream capture.

The surface morphogenetic effect of diffuse infiltration is controlled by till thickness. Where till cover is 30 cm or less, infiltrationopen all joints and karst pavements result. With thicker till cover, water infiltrate joints and dissolve it on discrete points. Between 30 cm and 2 m, numerous solutional pits are observed, often aligned on major joints. Beyond 2 m, the till infill the pits as they enlarge, generating suffosion dolines.

Introduction

Le karst de la Haute-Saumons est situé dans la partie supérieure du bassin de la rivière aux Saumons, sur l'île d'Anticosti au Québec. Sa partie occidentale qu'un drainage karstique colonise progressivement (Roberge, 1977, 1979), procure un site favorable à l'observation de la morphogenèse karstique.

Le karst est développé entièrement à l'intérieur de la formation de la Rivière au Fusil. Le calcaire est en strates de minces à moyennes subhorizontales et relativement pures. On trouve aussi des strates de schiste d'argile intercalées dans la partie supérieure de la formation. Le tout est recouvert d'une couche de till à 0 à 3 m d'épaisseur composée de fragments calcaires disposés au sein d'une matrice argilo-limoneuse. Le terrain est plutôt plat et occupé par des tourbières particulièrement abondantes hors des limites du karst.

Les formes se sont toutes développées au dépend d'un ensemble de diaclases hautement perméables et orientées à 110°-290°. L'apparition des formes karstiques en surface est une conséquence directe des modifications du drainage associées à l'implantation du karst dans un secteur. Il en résulte un passage graduel d'un drainage subhorizontal dans des cours d'eau de surface à un drainage subvertical vers des drains situés à plus de 15 m de profondeur. Toutes les formes observées sont issues soit de la capture souterraine des cours d'eau soit de l'infiltration diffuse provenant des terrains forestiers ou des tourbières.

Les formes dues aux cours d'eau

A leur point de capture principal les cours d'eau creusent une dépression dans le substratum dont la taille est plus ou moins fonction de l'importance du cours d'eau. Si l'écoulement intercepte perpendiculairement la diaclase on remarque un élargissement souvent bilatéral de la dépression qui peut mesurer jusqu'à 120 m de longueur. Si l'intercept est plutôt parallèle, on a une dépression asymétrique allongée aussi dans le sens de la diaclase. La présence de niveaux argileux peut induire une composant d'effondrement dans leur creusement. D'autres dépressions causées uniquement par l'effondrement sur des conduits sous-jacents sont aussi un résultat secondaire des captures de cours d'eau.

Le till a ici un effet morphologique secondaire en modifiant l'aspect de certaines dépressions qu'il envahit partiellement en y glissant à partir des terrains adjacents.

Les formes dues à l'infiltration diffuse

Les résultats morphologiques de l'infiltration dépendent surtout de l'épaisseur de la couverture de till (cf. figure ci-jointe). Là où il y a moins 0.3 m d'épaisseur l'eau s'infiltre à travers toutes les diaclases de la surface calcaire qui se transforme en pavement karstique.

Une couche de till de 0.3 à 2 m d'éapisseur exerce un effet sélectif sur l'infiltration. L'eau ne s'infiltre dans les diaclases pour les dissoudre qu'en un nombre limité de points alignés le long de diaclases les plus perméables. Les ouvertures prennent souvent la forme de puits qui peuvent avoir jusqu'à 2 ou 3 m de largeur et une quinzaine de mètres de profondeur. Le long de 5 alignements cartographiés (Roberge, 1979) leur espacement moyen varie entre 10 et 35 m et leur distribution est toujours aléatoire. Peut-être les ouvertures se forment-elles au point de recontre des diaclases les plus perméables et des zones de till possédant une infiltrabilité supérieure ? On peut le supposer puisque pour pouvoir dissoudre ces ouvertures, l'eau doit traverser jusqu'à 2 m de till carbonaté assex rapidement pour ne pas se saturer.

Là où l'épaisseur de till excède 2 m, en plus de concentrer la dissolution en des points privilégiés le long des diaclases, il exexce un effet de comblement. A mesure qu'une ouverture se forme, le till tend à l'envahir entièrement, faisant apparaître à la surface, des dolines de soutirage. Celles-ci, plus rares et dispersée que les ouvertures précédentes, ne forment pas d'alignement important.

Conclusion

L'importance du till dans la dynamique morphogénétique actuelle constitue sans doute le point saillant de nos observations. Au plan des formes creusées par les cours d'eau son effet se limite à modifier la morphologie de certaines pertes par remplissage partiel. Par contre il joue un rôle déterminant sur toute la superficie du karst quant à l'effet morphogénétique des eaux d'infiltration. Ce rôle s'exerce surtout à travers ses tendances à concentrer l'infiltration rapide et à combler les ouvertures qui en résultent. De plus, on peut imaginer que la distribution de la couverture de till peut avoir un impact hydrologique significatif au niveau de la dynamique de l'infiltration dans le karst et éventuellement sur la morphologie souterraine.

Références

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Roberge, J., 1979. Géomorphologie du karst de la Haute-Saumons, île d'Anticosti, Québec. Thèse de maîtrise, Université McMaster, Hamilton, Ontario, 335 p.

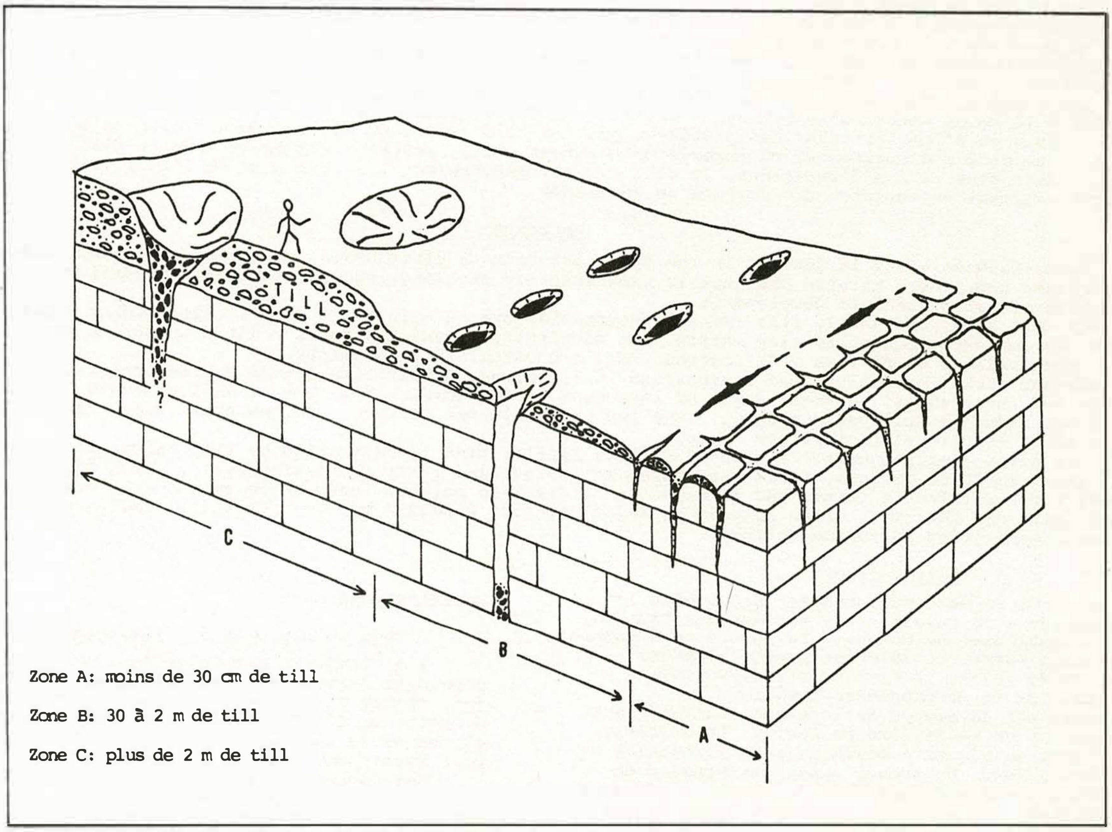

Figure 1. Influence de l'epaisseur de till sur les formes produites par l'infiltration.

La Dissolution Du Calcaire Dans La Partie Superieure Du Bassin De La Riviere Aux Saumons, Anticosti, Quebec

Jean Roberge
Centreau, Université Laval, Ste-Foy, Québec, G1K 7P4, Canada

Résumé

Dans le bassin supérieur de la rivière aux Saumons, le calcaire est recouvert par endroit d'un till carbonaté sur lequel reposent de nombreuses tourbières. Un karst draine les eaux de cours d'eau et de tourbières d'une partie du bassin vers une seule résurgence. L'analyse chimique d'eaux de surface a été réalisée en été en mesurant les températures, pH, duretés en calcium et magnésium et alcalinités et en calculant PCO_2 et SIc.

La plupart des eaux échantillonnées provenaient de cours d'eau, les autres de vasques diverses. Les caractères chimiques des eaux de vasque reflètent leur environnement. Sur le calcaire ou le till, elles sont saturées avec une PCO_2 en fonction de leur degré de contact avec la végétation. Dans des vasques de tourbière, la matière organique isole du contact avec le matériel carbonaté et les eaux pauvres en $CaCO_3$ demeurent agressives.

Parmi les eaux courantes on distingue: les ruisseaux, les rivières et la résurgence. Ces groupes s'individualisent facilement par leur PCO_2, leur dureté calcique et aussi leur SIc. Les rivières sont presque toujours saturées ou sursaturées. Les ruisseaux, plus riches en CO_2 à SIc égal, sont tantôt saturés, tantôt sursaturés. Les eaux de la résurgence sont toujours agressives et très riches en CO_2.

Donc durant la saison estivale, la dissolution n'est active qu'au niveau de l'écoulement des eaux du sol, des tourbières et des ruisseaux ainsi que dans les drains souterrains. Les rivières ne dissolvent pas mais acheminent seulement les matériaux dissous ailleurs.

Abstract

In the upper aux Saumons river basin, limestone is covered partially by carbonated till supporting numerous bogs. In a portion of that basin, karst drains streams and bogs to a single resurgence. Chemical analysis of summer surfact waters was carried with measurements of temperature, pH, calcium and magnesium hardness and alkalinity and calculations for PCO_2 and SIc (calcite saturation index).

Most of the sampled waters were from streams, the others from various pools. Pool water chemical characteristics reflect its immediate environment. On limestone or till, they are saturated with a PCO_2 according to their degree of contact with vegetation. Agressive waters with low harness are observed in bog pools where organic deposits act as insulator from a direct contact with carbonate material.

Among stream waters, we distinguish creeks, rivers and resurgence. Those groups could be easily differenciated on the base of their PCO_2, calcium hardness and also SIc. River waters are saturated or supersaturated. Creeks could be either agressive or saturated (with higher PCO_2 than rivers at the same SIc). Resurgence waters stay agressive with high PCO_2 content.

Results indicate that summertime solution is associated mainly with soil, bog and creek water circulation and may also occur in subsurface drains. Rivers carry dissolved load but do not dissolve by themselves.

Introduction

Dans le bassin supérieur de la rivière aux Saumons, le calcaire est recouvert par endroit d'un till carbonaté sur lequel reposent de nombreuses tourbières. Un karst draine les cours d'eau et les tourbières d'une partie du bassin vers une seule résurgence (Roberge, 1977, 1979). Durant l'été 1976, 152 échantillons d'eau ont été prélevés et analysés. 127 provenaient de cours d'eau, les 25 autres de vasques dans des environnements variés.

La température et le pH des échantillons sont mesurés "in situ" alors que la dureté en Ca^{++}, en Mg^{++} et l'alcalinité sont obtenus ultérieurement par titration. A cause de pannes du pHmètre, le pH n'est disponible que pour la moitié des échantillons. La PCO_2 et le SIc ont été calculés pour les échantillons dont tous les paramètres étaient disponibles si l'erreur sur la balance ionique ne dépassait par 15%.

Les eaux de vasques

Ces eaux quasi stagnantes reflètent leur environnement. En contact avec le calcaire ou le till, elles sont saturées ou proche de la saturation. Leur PCO_2 ainsi que leur dureté en calcium est alors fonction de leur degré de contact avec la végétation. Elles varient respectivement de $10^{-3.5}$ à $10^{-1.3}$ atm et de 80 à 150 ppm de $CaCO_3$.

Dans les tourbières, le fond des vasques est souvent couvert d'une épaisse couche de matière organique qui semble inhiber les échanges chimiques entre les eaux de la vasque et le matériel carbonaté sous-jacent. Ces eaux demeurent pauvres en carbonates dissous (0 à 25 ppm de $CaCO_3$). Il en est probablement ainsi des eaux inhibant la tourbe environnante. Leur PCO_2, située généralement entre 10^{-2} et $10^{-1.3}$ atm, est influencée par le périmètre de contact avec la végétation, le volume de la vasque, la superficie du plan d'eau et son degré d'exposition au vent.

Les cours d'eau

A priori, on en distingue trois types: les ruisseaux, les rivières et la résurgence. Les ruisseaux regroupent les plus petits cours d'eau qui prennent leur source dans des tourbières et dont les berges sont en étroit contact avec le sol et la végétation. Larges de 1 à 3 m, leur interface de contact air-eau par unité de volume est limitée par rapport à celui des rivières. Dans ces dernières, beaucoup plus larges et peu profondes, l'eau est plus étalée mais a moins de contact avec la végétation des rives. Le contact air-eau supérieur et les échanges gazeux plus faciles. La résurgence draine les eaux de rivières, de ruisseaux et d'infiltration (des sols forestiers et des tourbières) qui ont transité dans le karst souterrain.

Les eaux de ces trois groupes s'individualisent bien par leur PCO_2, leur SIc et leur dureté en calcium. La meilleure séparation graphique est obtenue avec PCO_2 et Ca^{++} (Figure 1). Sur le graphe PCO_2 vs SIc (Figure 2) on constate que:

- les points ruisseaux et rivières forment deux alignements distincts et parallèles.
- Pour un même niveau de saturation, les ruisseaux sont plus riches en CO_2 que les rivières.
- Les rivières sont à peu près toujours saturées ou sursaturées.
- Les ruisseaux sont tantôt agressifs tantôt sursaturés.
- Le déplacement le long des alignements de points correspond aux fluctuations du débit.
- Les eaux de résurgence sont toujours agressives et très riches en CO_2.
- Elles suivent une évolution saisonnière avec augmentation de la PCO_2 et baisse du SIc.

Interprétation: évolution des eaux dans le bassin

Les eaux des tourbières, où les ruisseaux prennent leur source, sont riches en CO_2 et pauvres en $CaCO_3$. En chemin vers et dans les ruisseaux, elles dissolvent du calcaire mais perdent du CO_2 jusqu'à saturation ou sursaturation. Les rivières sont alimentées par la confluence des ruisseaux et des apports latéraux vraisemblablement plus pauvres en $CaCO_3$. La perte de CO_2 dans l'air y est facilitée et le SIc plus élevé. Chaque alignement représenterait un niveau de compromis entre les apports et les pertes en CO_2 déterminé par les caractères du milieu.

Pour expliquer la forte PCO_2 et le faible SIc des eaux de la résurgence, on doit supposer que les eaux d'infiltration (un groupe qui n'a pas été échantillonné) ont une forte teneur en CO_2 (10^{-2} à 10^{-1} atm) et qu'elles transitent trop rapidement à travers le karst souterrain pour avoir le temps de se saturer. De plus, pour maintenir à la résurgence une teneur en CO_2 aussi élevée, l'essentiel de l'écoulement souterrain doit se faire en système fermé, c'est-à-dire dans des conduits noyés.

Conclusion

La dissolution estivale n'est pas active dans les rivières qui sont à peu près toujours saturées. Elles se contentent de transporter plus loin des matériaux dissous ailleurs. C'est davantage au niveau des eaux circulant dans le sol, les tourbières et les ruisseaux que la dissolution est efficace. Les drains souterrains reçoivent une eau avec un fort potentiel agressif mais leur efficacité à la transiter rapidement réduit sensiblement la dissolution qui s'y déroule.

Références

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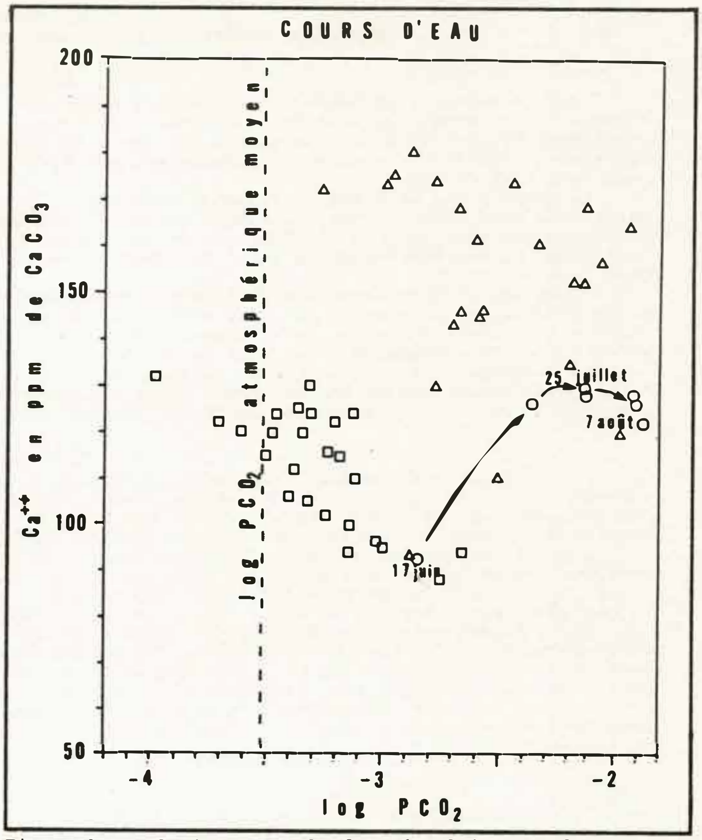

Figure 1. Relation entre la dureté calcique et log PCO_2 pour les ruisseaux (△), les rivières (□) et la résurgence (○).

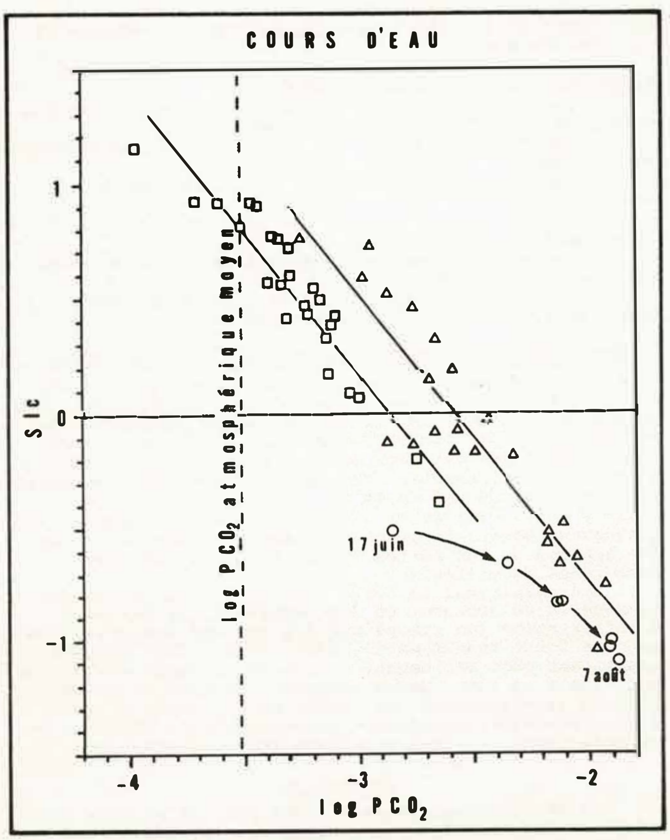

Figure 2. Relation entre SIc et log PCO_2 pour les ruisseaux (△), les rivières (□) et la résurgence (○).

Probable Cave Deposits in the Ellsworth Mountains of West Antarctica

John P. Craddock and Gerald F. Webers
Macalester College, St. Paul, Minnesota

Abstract

A series of probable cave deposits exists in the southwestern Heritage Range of the Ellsworth Mountains of West Antarctica. The deposits, or "breccia bodies" (Craddock et al., 1964), are distributed over a length of about 80 km and are found only within the Minaret Formation of Cambrian age.

The breccia bodies occur as cylindrical, podlike lenslike, or irregular masses. It is probable that more than one hundred breccia bodies exist in the Marble Hills and Independence Hills (centered at about 80S, 82W) of the Heritage Range. One vertical cylindrical body, perhaps the largest, measures about 245 m high and 90 m in diameter. No overall network of the breccia bodies is apparent.

The breccia clasts are composed of marble fragments ranging in length from a few centimeters to two meters. They show randomly oriented bedding and in some bodies a weak stratification is evident. The clasts are typically surrounded by laminated calcite with voids often present. No open caves were observed.

The breccia bodies crosscut folding in the Minaret Formation and are thus younger than the Triassic folding of the Ellsworth Mountains. As such, they are younger than the Paleozoic cave deposit from the Transantarctic Mountains (Lindsay, 1970).

Collapse of cave walls and ceilings associated with the development of a Karst topography appears to be the most probable origin of the breccia bodies.

Zusammenfassung

Eine Abteilung wahrscheinlicher Höhlenablagerungen kommen in dem sudwestlichen Heritage Gebirge der Ellsworth Berge in West-Antarktis vor. Die Ablagerungen, oder Brekziekörper (Craddock, et al. 1964), sind uber eine Ferne von achtzig Kilometern verteilt, und sind nur in der Minaret Formation Zu finden.

Die Brekziekörper erscheinen als zylindrischer, linsenartige, zigarrenförmige, oder unregelmässige Massen. Es ist wahrscheinlich, dass es mehr als hundert Brekziekorper in den Marble Hills und den Independence Hills (ca. 80S, 82W) des Heritage Gebirges gibt. Ein senkrechter, zylindrischer Korper, vielleicht der grösste, ist ungefähr zweinhundertfünfundvierzig Meter hoch, und hat einen Durchmesser von neunzig Metern. Keine weitentwickelte Anlage der Brekziekörper ist sichtbar.

Die Brekzieklasten bestehen aus Marmortrümmern, die in einer Lange von ein paar Zentimetern bis zwei Meter zu finden sind. Sie weisen unregelmässig orientierte Schichten und Bruchschieferung, und sehen identisch mit der umfassenden Minaret Formation aus. In einigen Körpern ist eine schwache Schichtung offenbar. Normalerweise sind die Klasten von feingeschichtetem Kalzit umringt, mit Poren manchmal dabei. Keine offenen Höhlen wurden gefunden.

Die Brekziekörper durchbrechen die Faltung in der Minaret Formation, und sind deswegen jünger als die triassiche Faltung der Ellsworth Berge. An und für sich sind sie jünger als die paläozoischen Höhlenablagerungen von den Transantarktischen Bergen (Lindsay, 1970).

Beim Einstürzen der Höhlenwände und Höhlendächer, verbunden mit der Entwicklung eines Karstreliefs, entwickelten sich hochstwahrscheinlich die Brekziekörper.

The Ellsworth Mountains of West Antarctica (Fig. 1) are about 360 km long, 80 km wide, and are divided into a northern range, the Sentinels, and a southern range, the Heritage. They are the highest mountains in Antarctica, reaching elevations in excess of 5100 m above sea level. The sequence of strata in the Ellsworth Mountains is more than 13,000 m thick and ranges in age from Cambrian to Permian (Craddock, 969).

A series of probable cave deposits exists in the south-central and southwestern Heritage Range and are found entirely within the Minaret Formation of Late Cambrian age.

The Minaret Formation is almost entirely exposed in the Heritage Range. It is thin to absent in the northern Heritage and the thickness increases to as much as 600 m in the southwestern Heritage. It is composed of white-to-gray marble. Oolites and pisolites are common, and the formation has yielded a number of fossil faunas of Late Cambrian age. Metamorphism reaches the lower greenschist facies and folding varies from gentle to isoclinal. Axial plane cleavage is usually present and some beds are intensely sheared. The cleavage parallels the orientation of the Ellsworth Mountains with a steep (average 65 degree) westerly dip, and is well developed in all exposures of the Minaret Formation which contain probable cave deposits.

The probable cave deposits, here referred to as "breccia bodies" are present in the Rhodes Bluff-Mt. Chappell area of the south-central Heritage, and are common in the Marble and Independence Hills of the southwestern Heritage. These deposits are distributed over a distance of at least 80 km. It is probable that 100-200 breccia bodies exist in the Heritage Range with the vast majority of them occurring in the Marble and Independence Hills.

The breccia bodies exhibit a variety of shapes including cylindrical, podlike, lenslike, and irregular. There appears to be no preferred orientation or overall pattern to the deposits. They range in size from less than a meter to more than 200 m in height. Contacts with the wall rock range from sharp to rather diffuse. In some of the breccia bodies with diffuse contacts, breccia clasts appear to be "floating out" from the wall rock and would fit back into the wall.

One vertical cylindrical mass, perhaps the largest (Fig. 2), was estimated to be 245 m in height and 90 m in diameter. This deposit has a sharp contact with the wall rock and shows a weak stratification of clasts. To the right of the cylindrical mass on Figure 2 is a second breccia body with a rather irregular outline. This second body is roughly circular in cross-section and elongate in horizontal orientation (into the picture). These two breccia bodies in Figure 2 typify many of the variations found in breccia bodies.

Clasts typically make up 50 percent or more of the breccia bodies, but one deposit showed no clasts at all. This latter body cross-cut another breccia body and was composed of coarsely crystalline calcite. Breccia clasts range in size from a few centimeters to blocks up to 2 m in length. All of the clasts were of identical lithology to the wall rock. Axial palne cleavage was present in all of the marble clasts but the cleavage in each clast was randomly oriented to the other clasts and to the wall rock.

Matrix surrounding the clasts varies from fine-grained iron-stained, pink calcite, to white, sparry, lamellar calcite with a grain size up to 5 mm. Open void spaces up to 20 cm were often associated with the sparry, lamellar calcite matrix. A red ocherous powder was often present within the void spaces. No open caves were found.

The most plausible origin for the breccia bodies is the formation of paleokarst by the percolation of phreatic waters. A major question associated with this possibility is whether or not the Ellsworth Mountains were in a latitude conducive to cave formation after their folding and uplift. Reconstructions of continental positions by Elliot (1972) would place the general area of the Ellsworth Mountains in cool-temperate to subpolar latitudes in the Late Jurassic to Middle Cretaceous time, with a movement to polar latitudes by Late Cretaceous.

It appears possible that even subpolar climates could produce caves. Assuming a subpolar environment, and a minimum uplift of 6100 meters (Craddock, 1964), it appears that phreatic circulation of ground water would be spontaneous if a water table existed. The Minaret Formation is exposed on top of a northwest plunging anticlinorium and abundant austral summer meltwater could provide a suitable (seasonable?) water table to percolate down the plunge. The Minaret marble is relatively pure sparitic/micritic carbonate and corrosion of this type in a polar setting would be enhanced by low CO_2 pressure and cold water temperatures. The overall rock structure has been influenced by metamorphism resulting in a decreased primary porosity (increased grain size), but increased secondary permeability in the form of cleavage, joints, faults, and stylolitic surfaces. Rutford (1972) offers evidence of extensive stream erosion in the Ellsworth Mountains and considers the major valleys present today to be the result of stream erosion with later glacial modification. It would thus appear that after the uplift of the Ellsworth Mountains there was sufficient water available for ground water systems.

Other problems with a paleokarst model include the lack of an overall pattern to the deposits, and the lack of rock clasts of other rock types. Weighing the evidence, however, it appears that the only plausible method of breccia body formation is a solution process of percolating ground water producing caves, collapse of cave walls and ceilings producing the clasts, and ground water calcite deposition depositing the laminated calcite matrix.

The age of the breccia bodies is difficult to pinpoint. They crosscut the folds of the Ellsworth Mountains, and are thus younger than the age of the folding established to be about 180 million years ago (Late Triassic-Early Jurassic). Assuming the breccia bodies to reflect a paleokarst origin, the only other bracketing age is that of the development of the Antarctic Ice Sheet. This was estimated to have started about 25 million years ago (Hayes and Frakes, 1970). Considering the evidence offered by Elliot (1972) cited above, it would seem most likely that the breccia bodies formed sometime between earliest Jurassic and Middle Cretaceous-a period from about 180 to 90 million years ago.

The only cave deposit presently reported from Antarctica is from the Queen Elizabeth Range in the Central Transantarctic Mountains (Lindsay, 1970). Here a single tubular, breccia-filled cave is exposed in the Shackleton Limestone of Cambrian age. The age of cave formation was considered to be pre-Permian (older than about 280 million years). The deposit established the possibility of cave formation in the geologic past of Antarctica, although it is considered to have no direct relationship to the Ellsworth Mountain deposits.

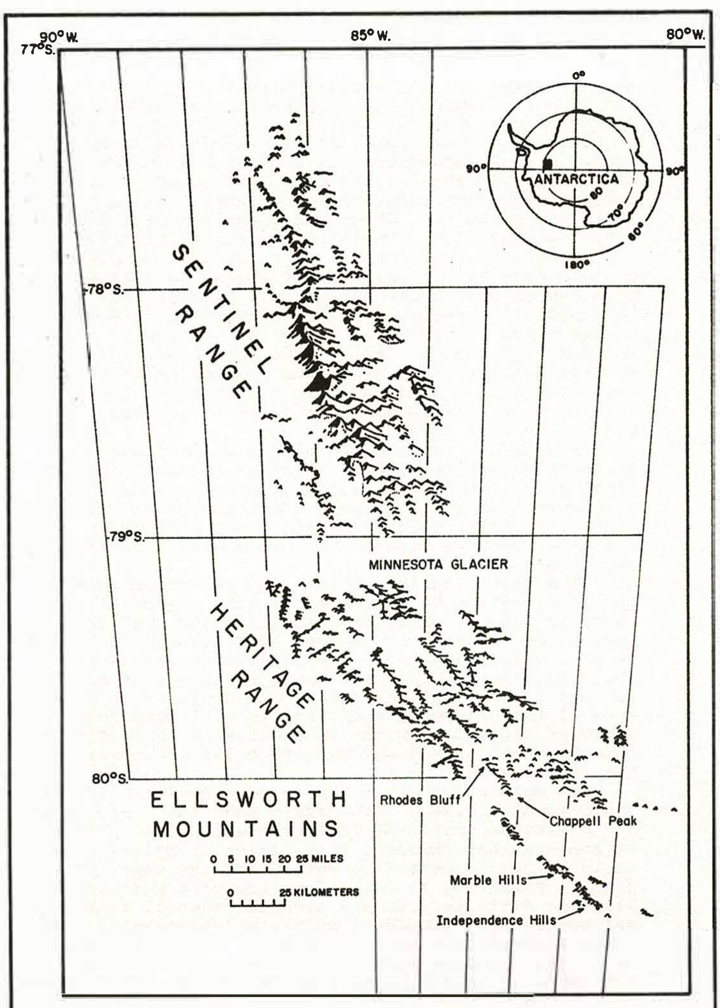

Figure 1: Generalized landform map of the Ellsworth Mountains with Antarctic location inset.

Acknowledgements

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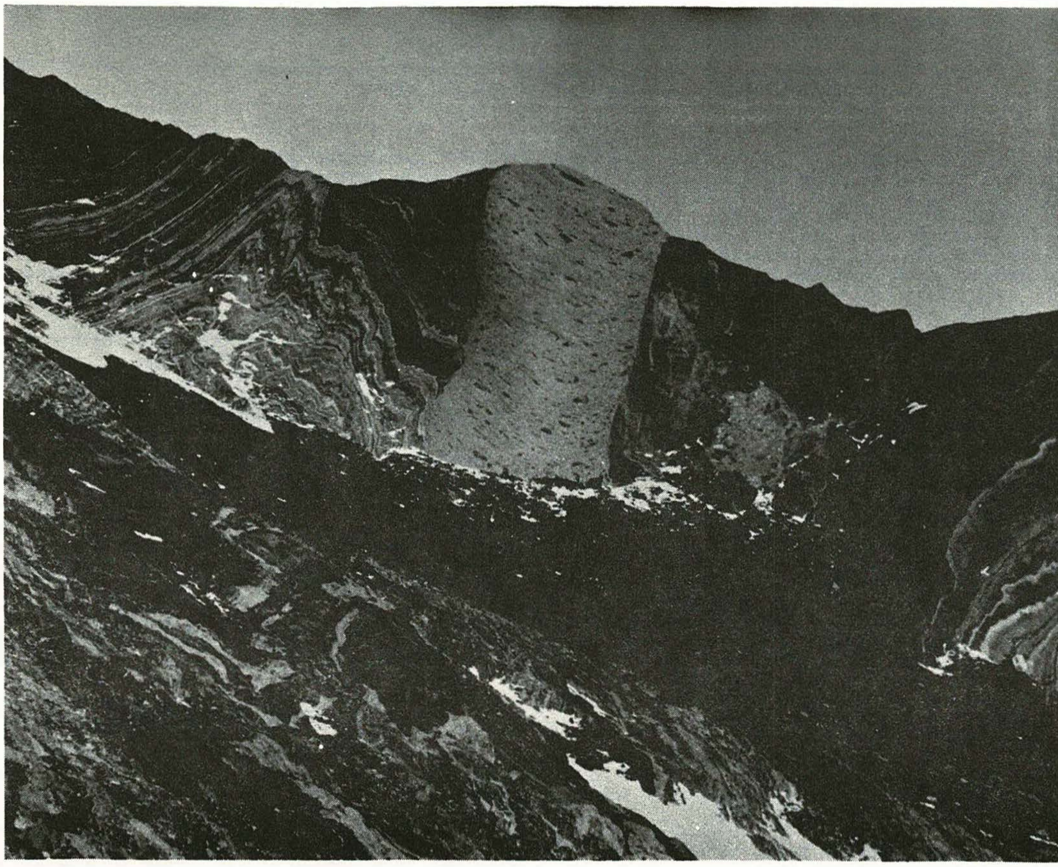

Figure 2: Breccia bodies in the folded Minaret Formation of the Marble Hills.

Major Groundwater Flow Directions in the Sinking Creek and Meadow Creek Drainage Basins of Giles and Craig Counties, Virginia, USA

Joseph W. Saunders, R. Keith Ortiz, and William F. Koerschner, III
3207 Melody Lane, Lansing, Michigan 48912

Abstract

Groundwater tracing with fluorescein dye has determined the resurgence points for underground drainage from ten sinking streams in a compound anticlinal carbonate valley in the Virginia mountains (eastern US). Springs of five of six underground drainage basins are involved in distributary flow patterns, with co-resurgences located from 100 to 2000 m apart and all but one co-resurgence pair operating only in higher flow stages. The fluorescein tracing indicated that the surface and subsurface drainage divides roughly coincided where the eastern continental divide crossed the valley, despite the headward growth of the Atlantic Ocean drainage at the expense of the Mexican Gulf drainage.

Zusammenfassung

Die mit Fluoresceinfarbstoff Grundwasserausspürung hat in einem zusammengesetzten kalksteinenen Anticlintal den Gebirgen Virginias (östliche US) den Brunnen der von zehn sinkenden Bächen unterirdischen Entwässerung versetzt. Aus die Brunnen sechs unterirdischen Einzugsgebieten schliessen sich fünf in Austeilungsfliessanlagen. Die Ko-austeilungsbrunnen stellen sich 100 bis zu 2000 m entfernt. Bis auf eins Ko-austeilungsbrunnenpaare verbinden such nur bei den höheren Fliess-ständen. Die Farbstoffausspürung deutet an, dass die oberflächlichen und unterirdischen Wasserscheide ungefähr zusammentreffen, wo die östliche Kontinental-wasserscheide das Tal durchschneidet. Wegen der von Atlantikentwässerung talaufwärts Erweiterung bewegen die Wasserscheide westlich auf Kosten vom Golf von Mexiko schon fort.

Introduction

In the central Appalachian mountains of the eastern United States, two of the major structural settings in which karst has developed are the long mountains and the anticlinal valleys. Both settings are characterized by topographic orientations along the trends of regional folding and faulting. Anticlinal valleys where narrow are typically floored with limestone or dolomite, whereas underlying clastic units commonly have been exposed in the wider anticlinal valleys, leaving the carbonates in strips on either side of the valley. Most of the anticlinal valleys maintain a relatively uniform width, and several terminate in distinct valley heads where the carbonates or underlying clastics on the floor plunge beneath the sandstones with typically form the rims of the valleys. Where faults are found on the valley floor, they are usually associated with crosssectional asymmetry of the valley.

The two anticlinal valleys studied here contain two major surface streams. Meadow Creek leaves the eastern valley head through a gap after rising at two large springs nearby. Westward flowing Sinking Creek heads at a spring complex 10 km from the end of the eastern valley, which has been made somewhat asymmetric by the Saltville Fault that enters the western end of the valley near Newport and runs the entire length of the valley. North of Newport, Sinking Creek crosses the fault complex and flows northward into a second valley. Clover Hollow at the eastern end of this second valley has a simple anticlinal structure. Westward to the New River the valley is wider with more complex structure.

Stratigraphically, both valleys are rimmed with Silurian sandstones. Cambro-Ordovician dolomites form the central floor of Clover Hollow and the eastern valley, with Ordovician limestones on the floor and lower slopes on either side of the dolomitic core. The dolomite is more resistant to weathering and tends to form a central ridge down the middle of Clover Hollow and the eastern valley, bordered on both sides by parallel talwegs on limestone. Westward from Clover Hollow both the valley and the limestone exposures on either side of the dolomitic core widen.

Surface drainage in the two valleys consists of small mountainside streams and the two master streams Sinking Creek and Meadow Creek. Most if not all mountainside streams heading near the rims of the valleys sink upon encountering the limestone. Flow from some of these sinking streams resurfaces at springs along Sinking Creek or Meadow Creek, with flow from the remainder resurging at either of the two rises of Meadow Creek or along the New River. Both Sinking Creek and Meadow Creek sink completely for much of the year.

Methodology

Sodium fluorescein in quantities of ½ to 8 kg was applied to sinking streams in the period 1974-1978. Fresh activated charcoal granules contained in 5 cm square staple-bound envelopes of nylon screening was used to absorb the fluorescein. Elution was accomplished with 10% KOH in 95% ethanol, with an ultraviolet lamp used to aid in visualization if necessary. With few exceptions, the charcoal traps were collected only once from each location for each test. Duplicate traps were usually placed in different spots at each spring to minimize risk of theft or chance contamination.

Results of Water Tracing and Descriptions of Major Groundwater Basins

Thirteen fluorescein dye tests were made from eleven locations in the two valleys to a total of ten springs from the New River in the west to the Meadow Creek Gap in the east. The sink-to-spring straight lines shown on the map (Figure 1) indicate that multiple outlets for groundwater are not unusual in the structural settings encountered there. Four of the six major groundwater systems studied discharge from more than one outlet.

Meadow Creek Drainage

Meadow Creek waters reach the Roanoke River and the Atlantic Ocean after leaving the anticlinal valley at Meadow Creek Gap. The eastern anticlinal valley is actually a hanging valley, surrounded on both sides by Atlantic-bound streams at 400-450 m elevation, which is at least 150 m below the lowest elevation in the anticlinal valley. Meadow Creek rises at two large springs near the gap through the sandstone rim. Local base level in the eastern end of the anticlinal valley, as well as the elevation of the springs, is determined by the elevation at which Meadow Creek spills over the lowest point of the rim. Meadow Creek has no doubt, grown immensely from a small mountainside stream on the outer rim wall of the anticlinal valley to a major karst-headed stream by the continuing process of headward drainage caputre to the west. Fractures in the valley head associated with the anticlinal plunge provided the weaknesses needed by the early mountainside predecessor of Meadow Creek to breach the sandstone rim and initiate piracy of the headwaters of the Gulf of Mexico bound Sinking Creek. Because of the steeper drainage gradient through the Meadow Creek Gap than westward along Sinking Creek to the New River, the Eastern Continental Divide (between the Atlantic Ocean and the Gulf of Mexico) has been moving westward.

Fluorescein dye tracing has established that there are two branches of Meadow Creek, with drainage being roughly divided by the central dolomitic core in the anticlinal valley. The northern branch is predominantly a surface stream fed by several small springs. After a surface route of four kilometers, it sinks in all flow stages into a large closed depression known as the Sinks of Meadow Creek. The north branch of Meadow Creek resurges at Dudding Spring 2 km from the Sinks. A portion of subterranean Meadow Creek can be seen at Cove Cave 500 m west of Dudding Spring. Cove Cave ends downstream in collapse, whereas upstream sumps. Most of the 60 m length of Cove Cave appears to be developed along or near the Saltville Fault. At high flow stages water discharges from the cave entrance. Thus the north branch of Meadow Creek has both a perennial and an intermittent rise.

The south branch of Meadow Creek rises from an impounded spring at the fish hatchery. In contrast to the north side of the anticlinal valley, drainage to the fish hatchery spring on the south side is entirely underground, excepting the sinking streams along 9 km of mountainside. Like the resurgences on the north side of the valley, the Fish Hatchery spring is developed in the limestone. It is the only major limestone spring in the study area that does not have a major associate distributary outlet, although there are two small flood outlets located within 30 m. It is likely that the difference in mass wasting which has kept drainage on the south side of the Meadow Creek valley well underground, whereas the surface of the north side of the valley is lower with predominantly surface drainage is due to the much higher dip and the Saltville Fault on the north side.

Head of Sinking Creek

Sinking Creek upstream from Newport is fed by numerous small to moderate sized springs in dolomite and limestone. The creek there is draining land with a low doline density. 1500 m west of the topographic divide with Meadow Creek, Sinking Creek rises at Early Spring on the south side of the valley. In higher flow stages an intermittent spring 100 m away becomes the surface head of Sinking Creek. A fluorescein trace in high flow from a mountainside sinking stream just west of the surface drainage divide tested positive in Early Spring and the intermittent spring, as well as at Slovensky Spring 300 m to the northwest. Considering that a sinking stream just east of the topographic divide had been traced to the fish hatchery spring, it would appear that the Eastern Continental Divide, known locally as "the Allegheny", coincides approximately with the groundwater divide.

Travertine Spring on Sinking Creek at Saltville Fault Complex near Newport

There is a conspicous travertine deposit 2 m high, 10 m wide and 6 m long associated with a small spring along Sinking Creek where the Saltville Fault complex crosses the creek.

Subterranean Meander Cutoffs at Link's Bend

Dye dropped in Sinking Creek upstream of Link's Bend was detected in charcoal traps in Link Spring on the west (downstream) side of the bend the following day, and was thought to be visible in the spring at dusk forty minutes after the drop. No intake point is visible along the creek bank at the bend, so the waters that reappear at Link Spring after cutting under the neck of the meander must sink into the floor of the creek. There is a 30 m crawlway cave just above creek level on the upstream side of Link's Bend almost directly upstrike from Link Spring. This small cave probably originated as a meander cutoff, and may still function as such during very high creek levels. To the south and out on the bend is Link's Cave, with about 300 m of passage and major trend along the strike. Link's Cave most likely is an abandoned subterranean meander cutoff route.

Clover Hollow Drainage

Most mountainside drainage in Clover Hollow sinks soon after encountering the limestone; only during very heavy runoff does surface drainage flow directly into Sinking Creek. Dye placed in Clover Hollow Cave and two sinking streams on the north side of Clover Hollow in separate traces was recovered in both Smokehole Spring and Tawney Spring on Sinking Creek, indicating a flow split. A careful examination of the main stream in Smokehole Cave behind the spring revealed a location where the cave stream split, with a major porportion entering a humanly impassable crevice while the remainder continued on out to Smokehole Spring. Subsequent in-cave dye drops from both just upstream and just downstream of the stream fork in Smokehole Cave, with traps at Smokehole Spring and the upstream reaches in Tawney's Cave behind Tawney Spring, indicated that all flow entering the crevice at the stream fork in Smokehole Cave resurged only at Tawney's Cave and Tawney Spring, whereas flow not entering the crevice resurged at Smokehole Spring. Together, these traces indicated that a single flow split existed.

Surveys of Tawney's Cave and Smokehole Cave indicate that the two caves are closely situated and represent major conduits for past and present drainage from Clover Hollow. It is clear that during the evolution of Smokehole Cave flow shifted direction from a westerly strike parallel trend to a southerly trend across the strike to the present Smokehole entrances, leaving large passage abondoned on the west side of the cave.

A dye trace from a sinking stream 1500 m north of the Smokehole-Tawney spring complex indicates that drainage from the far side of the dolomitic core is being transmitted across the strike and through the core rather than along the strike to a more distant spring. The next logical step in a study of the Clover Hollow karst hydrology would be the indentification of cave stream branches corresponding to the traced sinking streams in Clover Hollow, and subsequent analysis of waters from these tributaries of likely contrasting transmission routes.

The Rise of Sinking Creek

For about half the year the entire surface course of Sinking Creek down to the junction with the New River contains flowing water. At the lower flow stages the total flow of the creek is swallowed by several sink oints, the first visible one at a distance of 5 km from the New River. No passable openings are visible along the creek in the vinicity of the sinkpoints.

Despite being one of the largest springs in Virginia, the rise of Sinking Creek on the New River has a noticeably unimpressive appearance. Water discharges from a 30 m stretch of rubble forming part of a railroad embankment at the foot of a cliff.

Besides the trace of Sinking Creek to the rise on the New River, only one other sink point was traced to that rise. The stream sinking into Williams Cave 1500 m northwest of Tawney's Cave was traced in low flow stage to the rise of Sinking Creek only. Two traces in high flow stage, however, were detected both at the Sinking Creek to the New River is one of high doline density with very little flowing water, precluding an easy trace to define the low flow divide between Bell Spring and the rise of Sinking Creek.

Bell Spring Drainage

Doe Run was traced to Bell Spring from an upstream sink point, one of several along the stream course. A considerable portion of the doline field east and south of Doe Run probably drains to Bell Spring as well, as do areas within a mile of Sinking Creek during high flow stages, as the traces from Williams Cave demonstrated.

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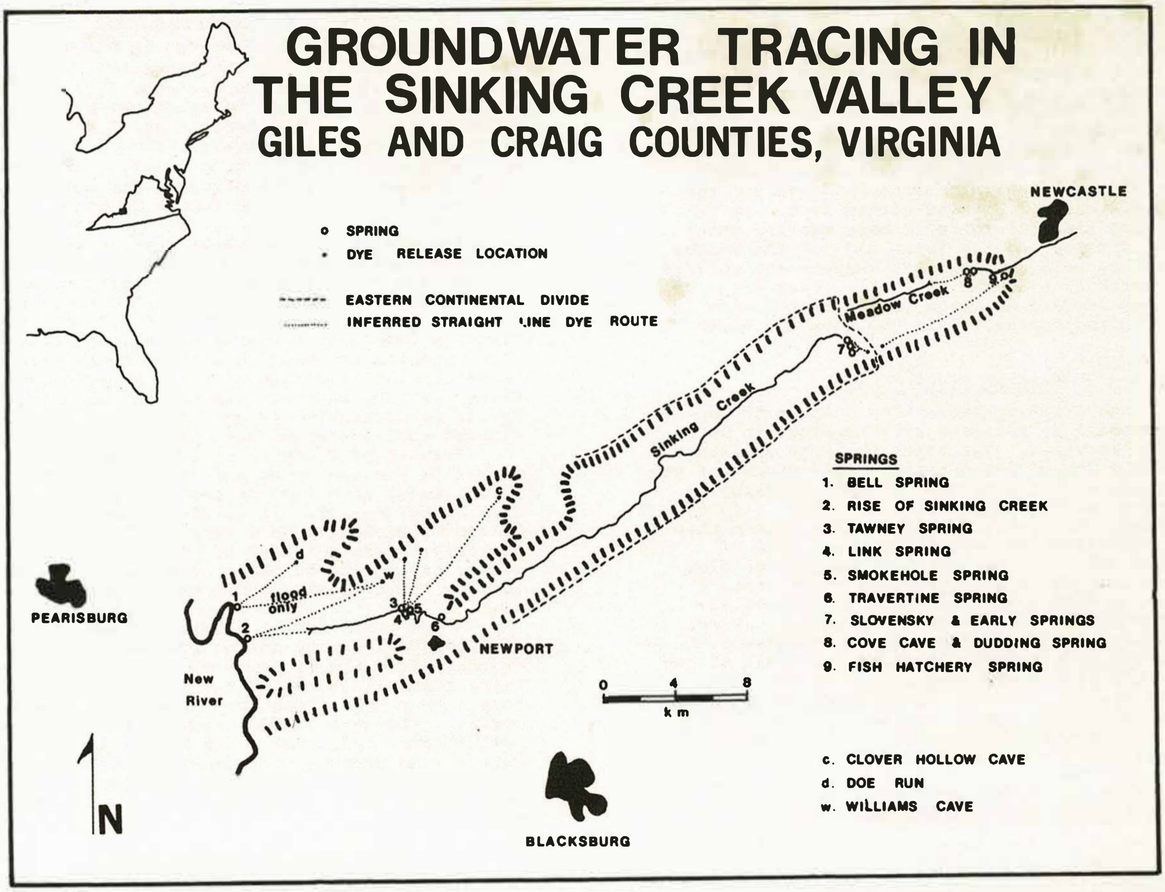
GROUNDWATER TRACING IN
THE SINKING CREEK VALLEY
GILES AND CRAIG COUNTIES, VIRGINIA
o SPRING
• DYE RELEASE LOCATION
EASTERN CONTINENTAL DIVIDE
INFERRED STRAIGHT LINE DYE ROUTE
NEWCASTLE
Meadow Creek
Sinking Creek
SPRINGS
1. BELL SPRING
2. RISE OF SINKING CREEK
3. TAWNEY SPRING
4. LINK SPRING
5. SMOKEHOLE SPRING
6. TRAVERTINE SPRING
7. SLOVENSKY & EARLY SPRINGS
8. COVE CAVE & DUDDING SPRING
9. FISH HATCHERY SPRING
PEARISBURG
flood only
NEWPORT
New River
0 4 8
km
c. CLOVER HOLLOW CAVE
d. DOE RUN
w. WILLIAMS CAVE
N
BLACKSBURG

"Figure 1"