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Lists of participants and of organizers
Papers of the Section Geology of Karst

Edited by Dr. VLADIMÍR PANOŠ, CSc.

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Après la transcription le texte n'était pas corrigé

TABLE DE MATIÈRS

TOME II

COMMUNICATIONS
DE LA SECTION
GEOMORPHOLOGIE KARSTIQUE

SECTION B

GEOMORPHOLOGIE KARSTIQUE

Convocateur: Doc.Dr. Jaromír D e m e k, CSc.,
Institut de Géographie Akad. Sci., Brno

SOUS-SECTION Ba

GEOMORPHOLOGIE DES SURFACES KARSTIQUES

Convocateur: Doc.Dr. Emil M a z ú r, DrSc.,
Institut de Géographie Akad. Sci., Bratislava

Ba 001 Ashton K. (Nouvelle-Zélande):
Classification and typological theory of karstic structures

Ba 002 Balász D. (Hongrie):
Karst types in the Philippines

Ba 003 Bögli A. (Suisse):
Der Alpine Karst in der Zentralschweiz

Ba 004 Brook G.A., Ford D.C. (Canada):
The Nahanni North Karst: A questionmark on the validity of the morphoclimatic concept of karst development

Ba 005 Brown M.C. (Canada):
On the uses of spectral analysis in karst studies

Ba 006 Чикишев А.Г. (СССР - URSS):
О применении количественных методов для оценки интенсивности карстовой денудации

Ba 007 Чикишев А.Г. (СССР - URSS):
Спелеологическое районирование СССР

Ba 008 Динич Й. (Югославия - Yougoslavie):
Спелеологические исследования Свирлишской котловины

Ba 009 Джишкариани В.М. (СССР - URSS):
О спелеологических особенностях известнякового массива Асхи (Западная Грузия)

Ba 010 Eraso Romero A. (Espagne):

Nuevo metodo en la investigación del karst, los modelos naturales y la convergencia de formas

Ba 011 Fantasny D. (RDA):

Einige Bemerkungen zur Bestandskarte der Karsterscheinungen im Gebiet zwischen Leine- und Thyratal im Zechsteingürtel des Harzsüdrandes mit besonderer Berücksichtigung der Hohlformen

Ba 012 Fenelon P. (France):

Niveaux de base géographiques et niveaux de base karstiques

Ba 013 Fermor J.H. (Grande-Bretagne):

Karst development in Barbados

Ba 014 Fink M.H. (Autriche):

Polygenetische Formen im Karst der Ostalpen

Ba 015 Fish J., Ford D.C. (Canada):

Karst geomorphology and hydrology of the Sierra de El Abra, S.L.P. and Tamps., Mexico

Ba 016 Ford D.C., Brook G. (Canada):

The Nahanni North Karst, Northwest Territories of Canada

Ba 017 Gams I. (Yougoslavie):

Forms of subsoil karst

Ba 018 Гвоздецкий Н.А., Мариннин А.М. (СССР - URSS):

Карст и пещеры Алтая

Ba 019 Harasimiuk M., Henkiel A. (Pologne):

Karst features in East Poland

Ba 020 Иванов Б.Н. (СССР - URSS):

Принципы карстологического районирования

Ba 021 Jennings J.N. (Australie):

History of a dry valley on Cooleman Plain, N.S.W., Australia

Ba 022 Кавришвили К.В. (СССР - URSS):

Карстовые феномены межгорной озерной котловины Рицы (Большой Кавказ)

Ba 023 Коржуев С.С. (СССР - URSS):

Древний карстовый рельеф Сибири и крупные циклы его образования

Ba 024 Коржуев С.С. (СССР - URSS):

Карст зоны многолетней мерзлоты и его типи

Ba 025 Kunaver J. (Yougoslavie):

Kotlič - a specific depression form of subnival Alpine karst

Ba 026 Lysenko V. (CSSR):

The geomorphological development of the northern part of the Slovak Karst dependent on the tectonic structure

Ba 027 Mazúr E., Jakál J. (CSSR):

Basic principles of the typological division of karst in the Western Carpathians

Ba 028 Miotke F.D. (RFA):

Baselevel and structural control on the karst hydrology and the genesis of karst geomorphology

Ba 029 Mitchell R.W. (USA):

Physiography and geology of the Huastecan Province of Mexico

Ba 030 Monroe W.H. (USA):

Dendritic dry valleys in the cone karst of Puerto Rico

Ba 031 Núñez Jiménez A. (Cuba):

Los cayos de San Felipe: un valle cársico intramontano anular

Ba 032 Núñez Jiménez A. (Cuba):

Hoyada de la Catalina

Ba 033 Olivon P., Salvayre H. (France):

Sur quelques anciens témoins de la karstification de la région méridionale des Grandes Causses

Ba 034 Pfeiffer S., Wadewitz S., Sternisko H. (RDA):

Darstellung einiger Gipskarstformen im Zechsteinausstrich des Südharzrandes der DDR (Teilgebiet Mooskammer)

Ba 035 Попов В. (Болгария - Bulgarie):

Типы карста Предбалкана в Болгарии

Ba 036 Priesnitz K. (RFA):

The problem of surface modelling by solution, a case study

Ba 037 Раквиашвили К.Ш. (СССР - URSS):

О карстовых явлениях Рачинского хребта (Западная Грузия)

Ba 038 Reuter F. (RDA):

Bemerkungen zu Senkungs- und Erdfallerscheinungen in Salzkarstgebieten der DDR

Ba 039 Sauro U. (Italie):

Observations on some great solution runnels with nested solution pans of the Venetian Prealps

Ba 040 Sencu V. (Roumanie):

Die Eigenschaften des Karstes in dem Anina-Gebirge (Rumänien)

Ba 041 Ступишин А.Б., Лаптева Н.Н. (СССР - URSS):

Региональные особенности поверхностного и подземного карста в Среднем Поволжье

Ba 042 Štelcl O. (CSSR):

Geomorphological characteristics of the karst regions in the Czech Socialist Republic

Ba 043 Tell L. (Suède):

About karst in general and Swedish karsts in particular

Ba 044 Trudgill S.T. (Grande-Bretagne):

Limestone erosion under soil

Ba 045 Wadewitz S., Pfeiffer S., Sternisko H. (RDA):

Erdfall-Form- und Volumenberechnung als Grundlage zur Erfassung der Zusammenhänge zwischen Erdfall und Gelände

Ba 046 Warwick G.T. (Grande-Bretagne):

The metamorphosis of karren in the North of England

Ba 047 Watson R.A. (USA):

Pseudo-karst of the Klutlan Glacier, Yukon Territories, Canada

Ba 048 Werner E., Medville D. (USA):

Karst and cavern development in the Gros Ventre Mountains

Ba 049 Wójcik Z. (Pologne):

Relicts of Tertiary karst forms in later relief on the landscape

Ba 001

CLASSIFICATION AND TYPOLOGICAL THEORY OF KARSTIC STRUCTURES

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A b s t r a c t. A successful classification of structured objects cannot be achieved without due regard being taken of the form of structuring involved. The present paper considers a form of structure adequate for karstic phenomena and defines the minimal criteria needed for a classification, giving examples from the field of cave structure. Such classifications yield models, called here quotient structures, families of which constructed along the lines shown here, form a typology of the original structure.

The first step into any scientific or systematic study involves the definition of the domain and objects of interest, the establishment of a vocabulary, and the determination of criteria by which observables may be fitted into the classification implied by this process. Such classification tend to be highly subjective in the first instance and become logically effective only after much revision as the nature of the study becomes clear. When successful the result is strikingly effective, as in the specialized language of any developed scientific discipline. When we classify a tree according to its leaf type we actually imply a classification of a whole structure; in two trees of the same species the entire structure, from biochemical relations and cell structure to gross morphology, is similar.

In the present paper we present a particular aspect of a general theory of the classification of structures in a form which, it is hoped, may be of use to the geomorphologist. This utility will however be somewhat Aristotelian, delineating conditions that an analysis must satisfy rather than presenting an algorithm for such analysis. At each stage in our development we shall firstly describe a construction, refine the description mathematically and give illustrations from the field of cave structure. It is hoped that parallel illustration in more general karst morphology will occur to the reader simultaneously.

The type of structure we shall consider will be a simple, heirarchical one. That is to say, we shall imagine a basic set or collection of objects, called the level zero set. From certain assemblages of these objects, new objects will be constructed into certain configurations, these new objects forming the level one set. This process will then be repeated forming higher levels of objects, each level consisting of objects built as configurations of objects from the previous level. For the purpose of our present applications, and to simplify the mathematics, we shall suppose that each level is formed from the previous one by means of only one type of configuration.

Let A_k represent the set at level k and F_k the configuration (a function) which constructs level A_{k+1}, and suppose that F_k is a configuration of m objects from A_k, then any member of A_{k+1} has the form $u = F_k(x_1, \ldots, x_m)$ where $x_1, \ldots, x_m$ are objects from A_k. In general, not all objects of the form $F_k(x_1, \ldots, x_m)$ need be in A_{k+1}. A simple, heirarchical structure G (for Gestalt) is therefore an (n+1)-tuple $\langle A_o, A_1, \ldots, A_n \rangle$ of sets of objects where each A_k, $k = 1, \ldots, n$ is formed from A_{k-1} by means of a function F_{k-1}.

If we consider A_5 to represent a cave (or A_6 a group of caves), then lower levels, in sequence, might comprise such sets as:

A_o - the basic components of the rocks present,

A_1 - specific facies presented as segments of passage walls (including fills),

A_2 - sections of passages (of some constant characteristic),

A_3 - passages,

A_4 - assemblages of passages.

Mathematically the idea of classification is based on the equivalence relation, that is a relation between pairs of objects which partitions the whole set of objects into disjoint classes, called equivalence classes. Such a relation may usually be paraphrased as a relation of "similarity" and each equivalence class comprises all those objects which are mutually similar.

Thus in defining a piezometric surface across a cave region we may, in fact, be declaring that certain discrete water surfaces observable within the caves are "equivalent" in some sense, the surface being a geometrical abstraction containing all members of this equivalence class and no others.

If R is an equivalence relation we shall symbolize the equivalence of objects a and b by "$a_R b$" and the class of all objects equivalent to a will be denoted by [a]. Note that if $a_R b$, then [a] = [b].

In practice such a relation is defined by giving a diagnostic feature, thus all sparry rocks may be considered mutually equivalent as opposed to all micritic rocks; sections of passages may be classified as horizontal, sloping or vertical; as containing or not containing fill - or water; or according to presumed processes of formation that may have occurred within them.

The use of classes of objects, rather than the objects themselves, entails a loss of information content; it is a deliberate "blurring" of the field of view for the purpose of achieving a comprehensive and comprehensible model. It is therefore of interest to note that the general theory predicts that, for a very wide range of structures, there exist families of classifications, each of which involves its own blurred viewpoint, but which together entail no information loss. In this sense the definition of an adequate structure G is equivalent, in all respects, to the definition of an adequate family of classifications.

Equivalence relations classify sets of objects and therefore, in order to classify a heirarchical structure $G = \langle A_o, \ldots, A_n \rangle$ we require an (n+1)-tuple $R = \langle R_o, \ldots, R_n \rangle$ of equivalence relations where, for each $k = o, \ldots, n$, R_k is a relation on the set A_k. Not surprosingly, such a set of relations will not, in general, suffice but certain conditions must be satisfied, for the purpose of defining which we must make the following preliminary definitions.

Suppose that u and v are objects in A_{k+1} and we have a relation R on the lower level A_k. Suppose further that u and v are constructed in the same manner but from different members of A_k (e.g. two passages of the same approximate form but running through differing strata)

i.e. $u = F(x_1, \ldots, x_m)$ and $v = F(y_1, \ldots, y_m)$.

Then we say that u and v are related by the i n d u c e d relation of R, symbolically $u(R)_i v$, exactly when $x_1 R Y_1$ & $x_2 R Y_2$ & ... & $x_m R Y_m$.

To paraphrase, $u(R)_i v$ if and only if u and v are constructed in the same way and their corresponding components are related. Note that $(R)_i$ is a relation on the set A_{k+1}.

In the example above, suppose that the strata had been classified into classes having the same erosional effects, then two passage sections would be related by the induction of this relation exactly when they showed the same erosional morphology.

Less important is the notion of the subduced relation. Suppose that u and v are objects in A_k, R is a relation on A_k and u and v are similar in configuration:

i.e. $u = F(x_1, \ldots, x_m)$ & $v = F(y_1, \ldots, y_m)$.
Then we say that for $j = 1, \ldots, m$; $x_j(R)_s y_j$.
In other words, each pair of corresponding components is related by the subduced relation, a relation on A_{k-1}. For two objects x,y in A_{k-1}, $x(R)_s y$ exactly when they play the same role in the construction of two objects in A_k related by R.

Thus, in the above example, if we had classified the passage sections initially according to their erosional features and we noted that the passages had similar structure, then we would have subduced a relation between strata on the basis of their erosional capacities. Note that petrological analysis might then refine this derivative classification.

The aim of a classification is to provide a simplified model, an image of the original structure, indeed in algebraic terms, a homomorphic image. Suppose our initial structure is $G = \langle A_o, \ldots, A_n \rangle$ and we wish to consider $R = \langle R_o, \ldots, R_n \rangle$ as a possibly suitable classifier. Two conditions must be satisfied. The first condition simply requires that, for $k = o, \ldots, n-1$, $(R_k)_i$ is a relation on A_{k+1}, a condition that will always be satisfied in the present domain of application since the fact that objects appear in A_k implies that they are employed in some object of A_{k+1}.

The more significant condition is that, for $k = o, \ldots, n-1$,

$$(R_k)_i \subset R_{k+1} ,$$

that is to say that if $u(R_k)_i v$, then $uR_{k+1}v$: at each level, the relation must be no finer than the relation induced from the previous level.

Thus any two objects of the same configuration, and constructed from similar components *must* be related on their own level. Other objects not so constructed may also be related.

Consider a passage containing the passage sections of the above example and also a section which, while maintaining its general form, continues into a region of differing geology. The two earlier sections are related *a priori* as described above but we may also wish to include the later sections of the passage within the same class on some other basis. Thus each relation, on each level, is an extension of the induction from the previous level.

Any sequence $R = \langle R_o, \ldots, R_n \rangle$ satisfying the above requirements will yield a simplified structure, having the same form as G, but with fewer elements, the new elements being equivalence classes of the elements (objects) of G. This simplified structure is called, by analogy with algebra, the quotient structure with respect to R and is symbolized as $^G/_R$.

As a simple example, suppose G is a cave system in which two types of passages occur, say phreatic and vadose, this statement itself constituting a grossly oversimplified classification. Then $^G/_R$ is a system having just two passages, one representing "phreaticness" and the other "vadoseness".

In constructing suitable relations it is often of help to use a family of relations and to take their intersections as the defining relation: that is, to use relations $R_1, R_2, \ldots, R_t$ all defined on the same level and then to say $u_R v$ if and only if uR_1v & uR_2v & ... & & uR_tv, taking this as the relevant relation. Thus the criterion for equivalence of two passage sections may be that they have the same erosional features and the same fill, or absence thereof and the same slope etc. The use of such families has justification in the earlier remarks concerning classification without information loss.

It may also be shown that, under the conditions considered here, the subduced relation, on any level, is the coarsest possible relation on that level. Thus, as exemplified in the above paragraph on subduction, this process is a useful starting point for the constuction of a classification where the treatment for some particular level seems fairly clear.

Having achieved a consistent quotient structure the interesting problem then remains, to explain why the particular scheme of classification fits the structure.

Given two classifiers $R^1 = \langle R^1_o, \ldots, R^1_n \rangle$ and $R^2_o = \langle R^2_o, \ldots, R^2_n \rangle$ for G, we say that R^2 is coarser than R^1 if for k = o, ..., n, $R^1_k \subset R^2_k$. In such a situation it can be shown that $^G/_{R^2}$ is a model, or image of $^G/_{R^1}$, just as $^G/_{R^1}$ is an image of G.

The problem of a typology is simply to establish a sequence of classifiers of increasing coarseness to include as wide a range of structures as possible within the same moder or *type*, to enumerate these types and explain their significance. Thus within a cave we may group increasing sets of passages together, despite certain minor differences, until this is no longer consistently possible: the resulting classes represent the *types* of passage present. Similarly we may compare caves throughout a region with regard to similarities of their entire structure, and construct a typology of caves within that region. Further, we might consider the whole karstic environment as a heirarchical structure and repeat the analysis to derive a karstic typology. Our general theory can give only the broad outlines of proceedure but it does guarrantee that if any karstic assemblage can be represented as an example of a common heirarchic structure, then there exists a family of classifiers which can describe karstic phenomena completely, without loss of information. The converse statement is also true.

We have here considered our phenomena as static but, if such a structure as the above can be definec, there we can construct a diachronic model of karstic development in terms of mappings of quotient structures.

ZUSAMMENFASSUNG

Eine erfolgreiche Klassifizierung strukturierter Objekte kann nur unter Beziehung der Struktur selbst gewährleistet werden. Das vorliegende Referat betrachtet eine für karstische Probleme angemessene Art der Struktur und definiert die möglichst kleinste Menge von Kennzeichen, dass für eine solche Klassifizierung benötigt ist. Beispiele aus dem Gebiet der Höhlengefüge sind vorhanden. Solche Klassifizierungen liefern Modelle, dessen Familien, wie im Referat konstruiert, eine Typologie der Urstrukturen gewähren.

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Ba 002

KARST TYPES IN THE PHILIPPINES

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The calcareous formations are very common features in the Philippines, the extension of the karst areas amounts nearly ten per cent of the total surface.

The Philippine Islands have a young geological history, even the rocks of the karst areas are mostly of Tertiary and Quaternary age. The young crustal movements have been active, the karst regions are considerably tilted and faulted. There are thousands of limestone outcrops, but the extensive karst plateaus can be found only on the mayor islands (fig. 1).

The archipelago has a great quantity of annual rainfall, therefore the development of the karst topography is very intensive. The karstic features are greatly diversified, there can be found all variation of the forms characteristic for the wet tropical karstlands.

The geomorphological research of the Philippine karst areas are still neglected. There are only some studies about the Bohol karst hills, but the other rather inaccessible karst areas are almost unknown.

GEOLOGY

The oldest calcareous rocks are small marble deposits in the Pre-Jurassic basement complex. Also a few limestone lenses are found of Jurassic and Cretaceous age.

The bulk of the calcareous sediments is of Post-Cretaceous periods. According to the geological surveys, the main karst areas of the Philippines consist of limestones as follows:

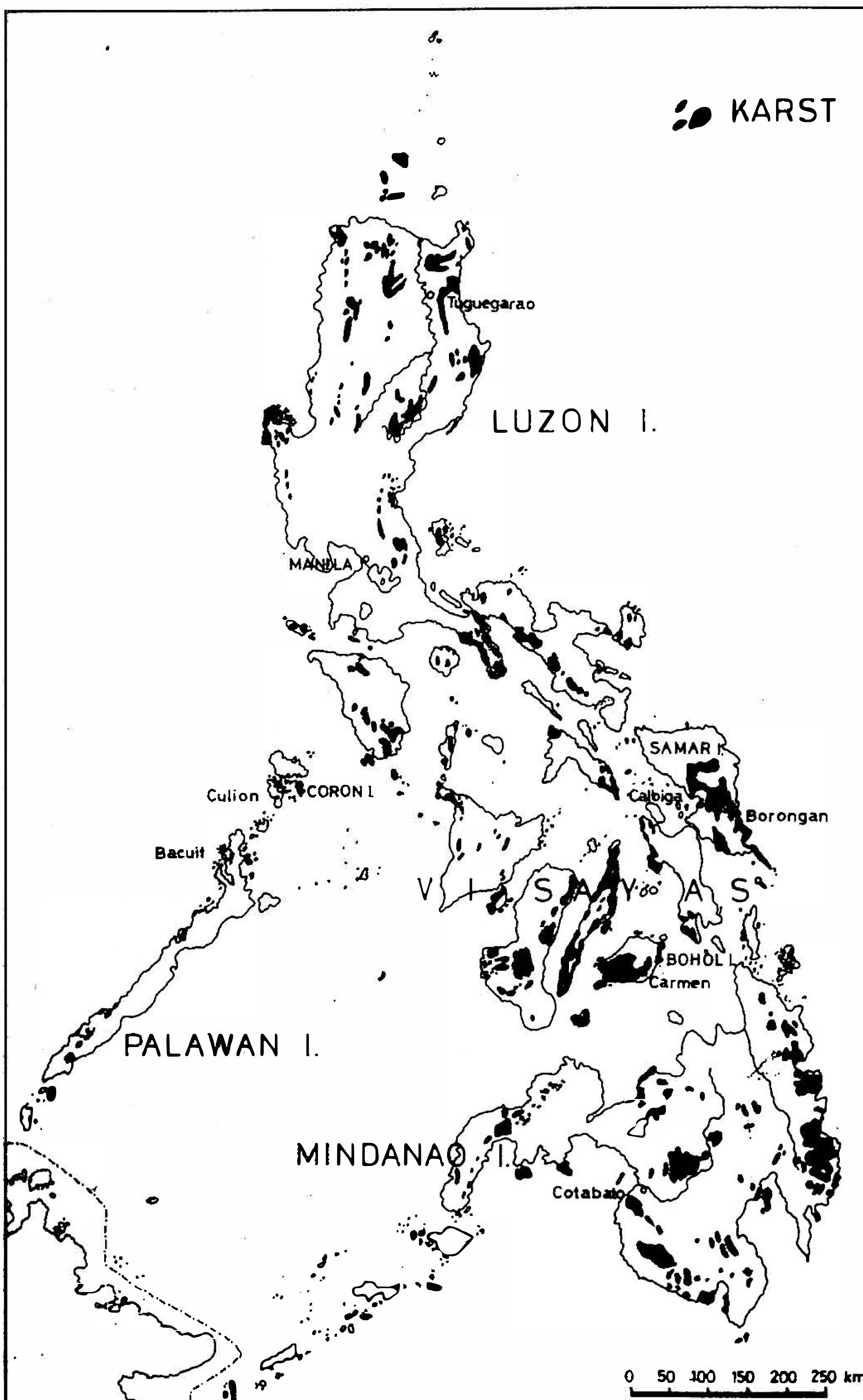

Fig. 1. Karst areas of the Philippine Islands. The geographical situation of the different karst types discussed in this paper.

Period	Type of calcareous rock	Approx. per cent of total karst	Distribution
Holocene	Raised coral reef	10	Many parts of the archipelago, esp. in Visayas
Pliocene-Pleistocene	Marine sediments and extensive reef limestone	30	Bicol, Visayas, Mindanao
Upper Miocene-Pliocene	Marine clastics (calcarenite) silty and reef limestone	15	Luzon, Central Visayas, Mindanao
Oligocene-Miocene	Mixed shelf marine deposit, reef limestone	40	Visayas
Oligocene	Marine sediments	1	Small quantity in Cebu
Paleocene-Eocene	Mixed shelf and deeper water deposits	3	Visayas
Mesosoic	Metamorphic rocks	1	Romblon etc.

The chemical analyses of Philippine limestone have given the following results:

	CaO	MgO	SiO_2	Al_2O_3	Fe_2O_3	CO_2 (loss on ignition)
Limestone of Pliocene-Pleistocene age (7 samples from Bohol, Voss, 1970)	47,89	1,25	4,78	3,10	1,70	40,08
Limestone mainly Miocene age (110 samples, Bureau of Mines, Manila)	53,50	0,90	0,80	0,40	0,30	42,00

According to these samples, the dominant Miocene limestones are relatively pure having a $CaCO_3$ content of 90-98 per cent. There is also found dolomitic limestone in the islands Cebu, Negros and in Batangas Province (Luzon).

The Philippine Islands are the most faulted and tilted part of the Malayan Archipelago. Young Tertiary sediments are uplifted into more hundred meters elevation in many places. These tectonical movements are continueing even today.

CLIMATICAL FACTORS

The Philippine Islands are situated between 6-20 degrees north of the equator. Their climate is wet tropical. The yearly mean temperature are C° 25-27, the relative humidity 70-80 per cent.

The karst areas of the Philippines have the average annual rainfall between 2000-5000 millimeters. The intensity of rainfall is high, especially in Luzon, where the tropical cyclones (taifun) are responsible for at least one-third of the total precipitation. The rainfall in the Philippines is seasonal particularly in the western islands of Visayas under the influence of south-east-Asian monsoon.

The Philippines consist of three geographical regions: Luzon, Visayas (the central islands) and Mindanao. The characteristic annual precipitation in these regions is as follows (Manalo, 1956):

	Average annual rainfall, mm	Average rainy days (annual)	Greatest daily rainfall ever recorded, mm
Luzon	2739	170	880 (in Baguio)
Visayas	2402	179	571 (in Borongan, Samar)
Mindanao	2365	182	424 (in Surigao)
Philippines	2550	175	

The average monthly rainfall (mm) in selected places nearby the extensive karst regions (see their position on fig. 1).

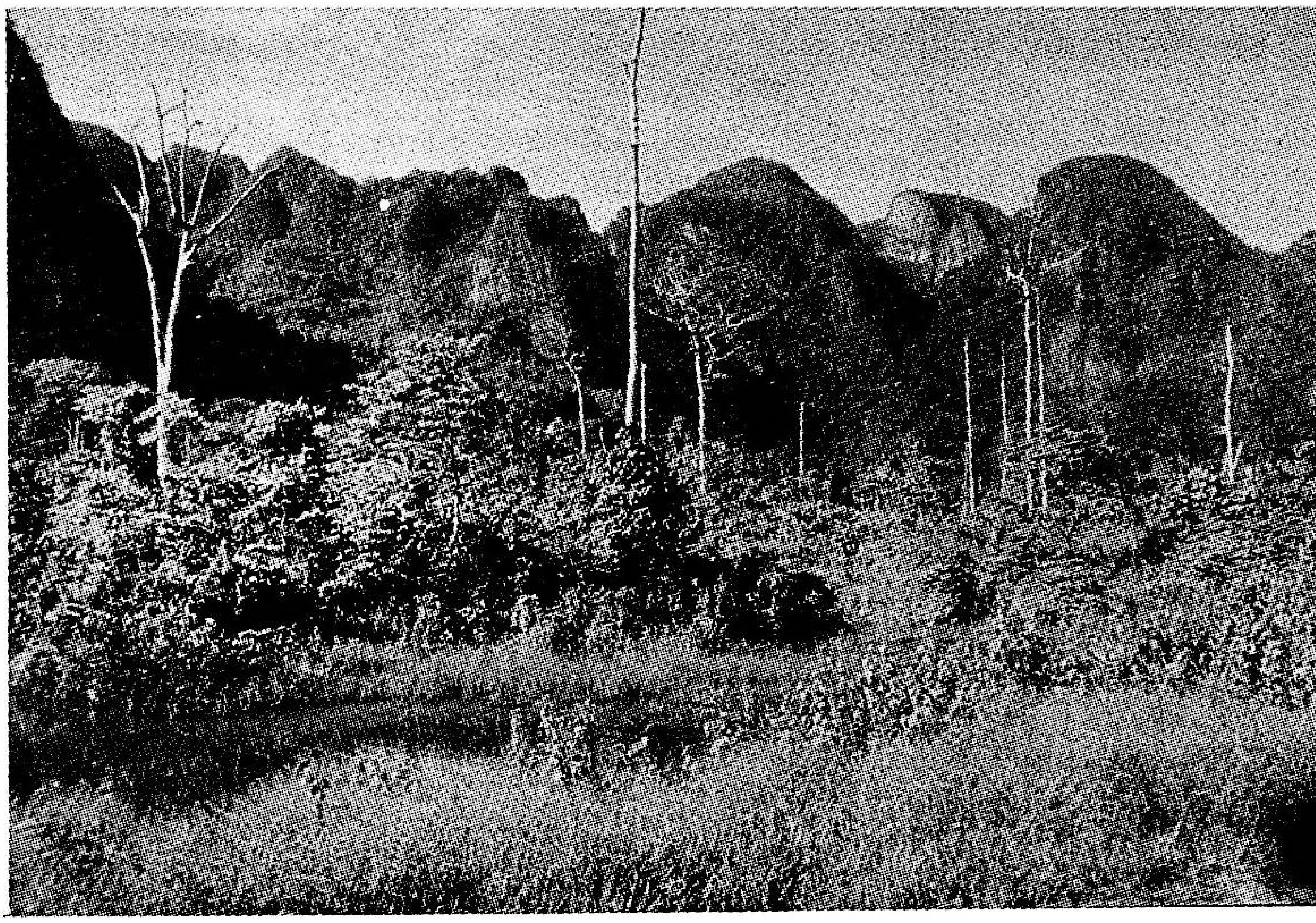

Fig. 2. Limestone towers of Moung Saint Paul Range from the Culiatan polje, Ulugan Bay, Palawan Island.

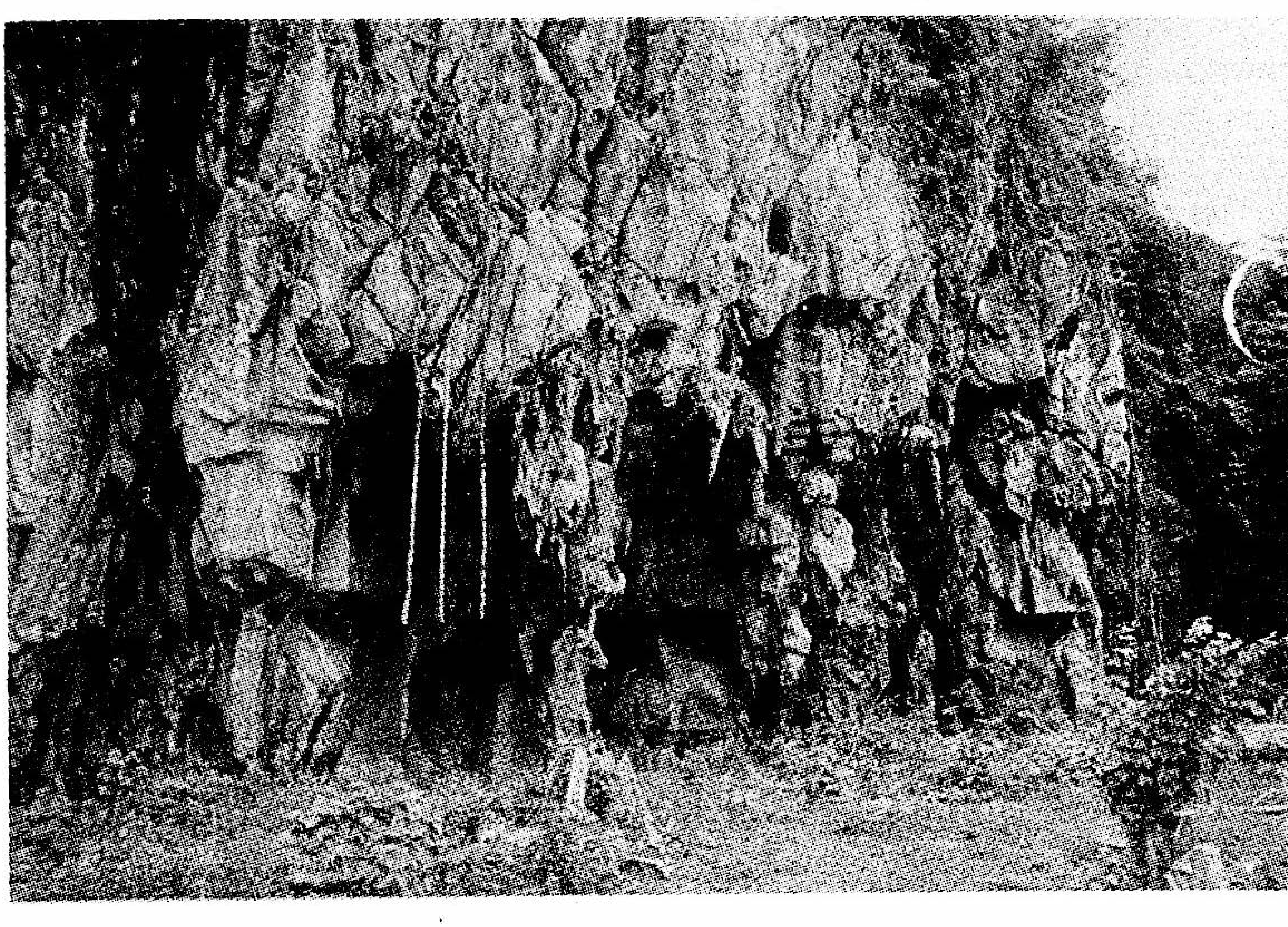

Fig. 3. Rock shelters along the foot of limestone hills in the Mount Saint Paul Range.

	Tuguegarao (N-Luzon)	Culion (Palawan Province)	Carmen (Bohol)	Borongan (Samar)	Cotabato (Mindanao)
January	31,5	28,7	216,4	640,1	84,1
February	23,4	19,1	110,0	440,2	89,7
March	32,0	11,2	110,2	359,6	89,6
April	67,8	52,6	48,3	257,8	150,6
May	137,9	207,0	147,6	265,9	218,7
June	158,0	350,8	197,7	231,7	238,5
July	245,9	669,8	207,3	189,7	271,3
August	206,5	603,8	201,4	149,4	239,0
September	236,2	517,6	199,6	179,8	223,0
October	232,9	291,3	220,7	336,3	278,9
November	274,3	254,0	286,0	549,4	186,7
December	145,3	100,8	262,6	656,1	107,4
Year	1791,7	3106,7	2207,8	4256,0	2177,5

The hydrogeological situations of the Philippine karst regions are very variant according to the relative altitude above the base--level of erosion. There are very big underground rivers with collapsed dolines and natural bridges. The longest known cave-system is situated in Luzon, Cagayan Province, near by Penablanca town. It is called Callao Cave, its lenght is 9 kms with an active waterflow. There are also low limestone regions partially with surface drainage (e.g. Kegelkarst in Bohol). The carbonate hardness of the karst waters is relatively low, but it is counterbalanced by the abundant quantity of precipitation.

The primary v e g e t a t i o n of the Philippine karst areas is generally very dense tropical rainy forest. In consequence of the human activity, some lower parts of the karstlands were burned up and they are now covered by grass.

CONTRIBUTION TO THE KARTS TYPES OF THE PHILIPPINES

The topographical features of the Philippine karst areas are very multifareous. There are found all the types and variations of the tropical humide karst called with a general term as "Kegelkarst". By way of introduction, we have to mention of it, that not all limestone topography will form this special surface relief. For instance the uplifted young coastal coral fields and the different outcrops of limestone in the folded mountains usually have no characteristic form of cone karst, although the steep slopes or vertical walls are dominant.

As the climatical conditions of the Philippine Islands have close similarity, the main reason of the variety in the karst topography is the difference in the lithology, geomorphological position and the lenght of denudation.

Here following are presented a few types of limestone topography characteristic of the Philippines. As the technical terms are not unambigouos in the different languages ("Kegelkarst", "Turmkarst", "Kugelkarst", "Sinoidkarst", "Cone Karst", "Tower Karst", "Cockpit Karst" etc.), the karst areas studied by the author are compared with similar - better known - karst regions, as control types.

1. YANGSHUO TYPE KARST

Yangshuo or Jangso is a small town in Kwangsi Province of China. In its vicinity are found the best examples of isolated, tower-shaped, high karst island-mounts (Wissmann, 1954; Balázs, 1960). Similar features can be found along the west coast of the Palawan Island in the Philippines. Some of these are situated on the main island among nonkarstic rocks (a), or formed isolated sea islands or peninsulas (b).

a/ Mount Saint Paul

The base rock of this karstblock is the thick hard limestone of Middle-Miocene age, which is quarried as marble. The karst has an area of 35 sq. kms (fig. 4).

The characteristic features are the vertical towers up to 600-1000 mts a.s.l. The top of towers is covered by rough pinnacles and the steep walls have large deep grooves extending down ("Spitzkarren"). Among the towers there are deep star-like depressions ("Cockpits"). The karstmass is crossed by a big unnamed underground

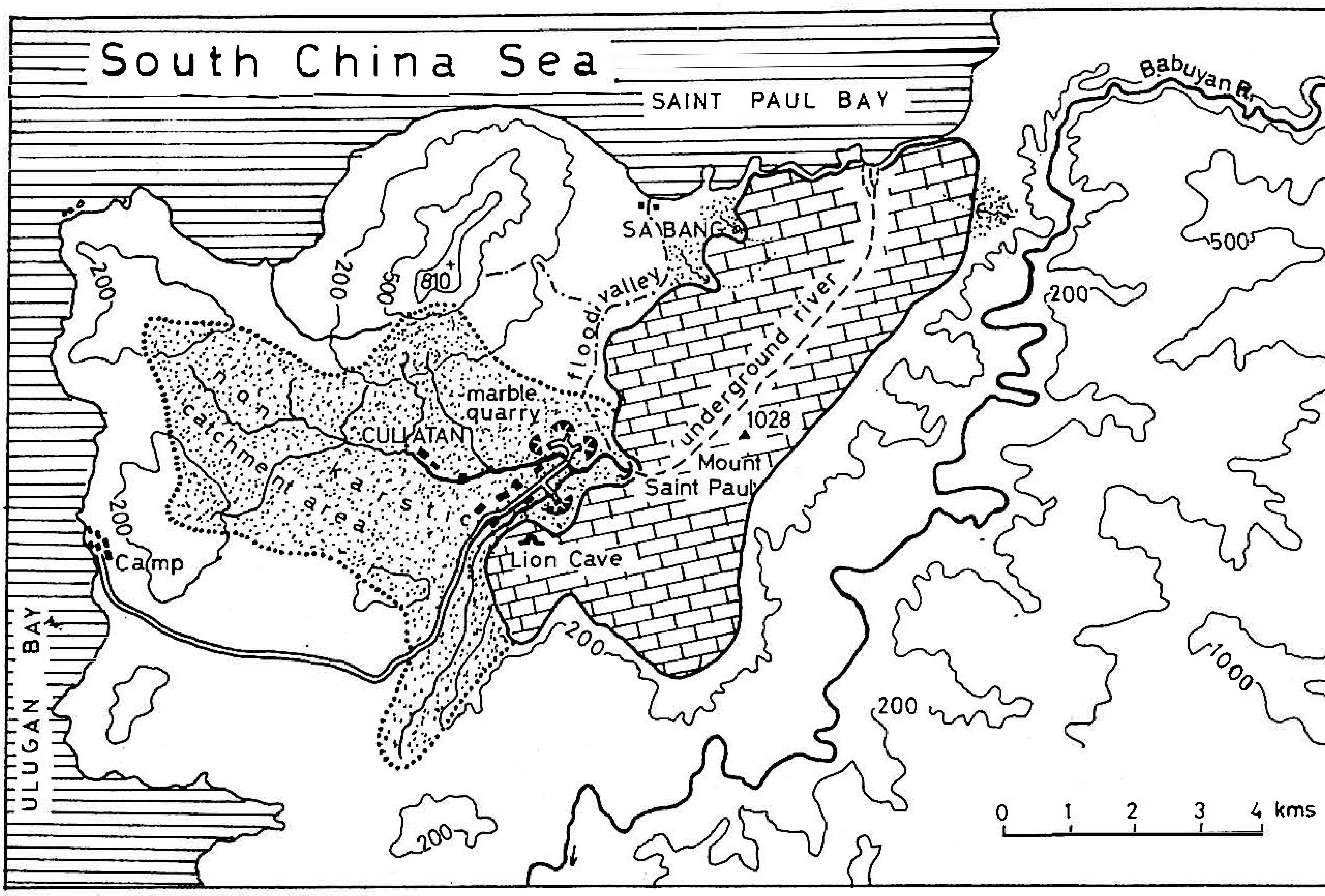

Fig. 4. **Karst region of Mount Saint Paul with the surrounding nonkarstic catchment area.**

river carrying the water of the Culiatan interior basin (polje), which is a nonkarstic catchment area of 30 sq. kms. A survey of the 6 kms long underground channel was carried out by the author and his filipino companions by boat from the sea entrance.

b/ Bacuit Archipelago

Along the west coast of the Palawan, the erosion of sea has formed a line of island groups and isolated peninsulas. The faulted and uplifted rocks are mostly hard grey limestone of Middle Miocene age using as precious marble.

The best known karst-peninsula (a few hundred years ago it was an island) is the Lipuun Point in the southern part of the Palawan near Quezon. (Synonim on map: Albion Head Point, 203 meters.) Many valuable archeological findings were excavated here in the Tabon Caves during the last years (Fox, 1970).

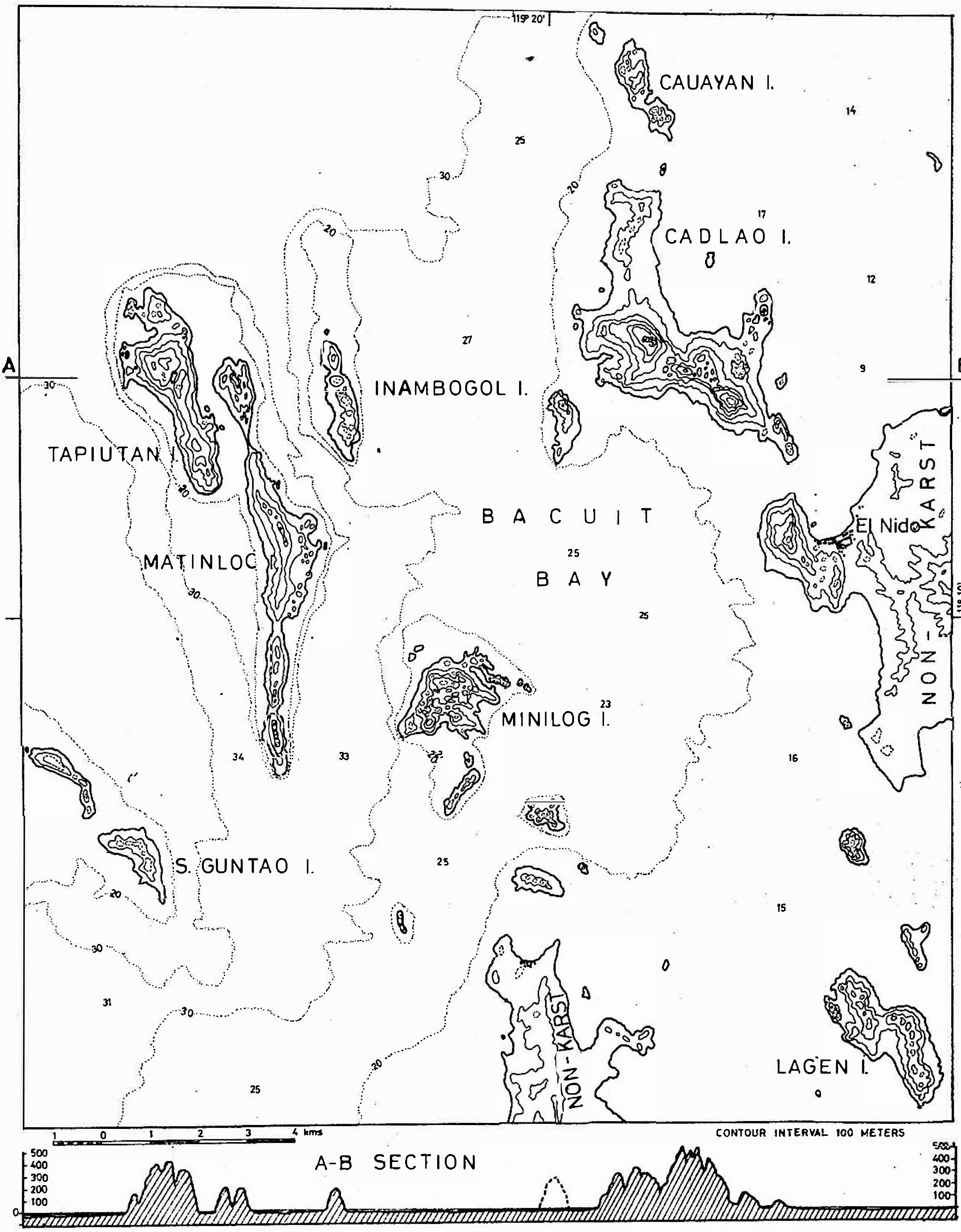

Fig. 5. Karst islands and peninsulas of the Bacuit Archipelago, Palawan Island.

The karst islands and peninsulas of Bacuit Bay in the Northern part of the Palawan are less known. (Enclosure 1.) The karst islands occupy an area extending from N to S 25 kms, from W to E 15 kms. The islands belong to the administration of El Nido municipality. The main karst islands and peninsulas are as follows:

	Approx. area	Highest point
Cadlao Island	9,8 sq. kms	609 meters
Matinloc Island	5,1 " "	393 "
Tapiutan Island	3,7 " "	436 "
Lagen Island	3,1 " "	378 "
Minilog Island	2,0 " "	367 "
Cauayan Island	1,1 " "	258 "
Inambogol Island	1,1 " "	202 "
South Guntao	1,0 " "	182 "
Other smaller islands (about 30)	6,1 " "	330 "
El Nido Peninsula	2,8 " "	457 "
Cudugman Peninsula	1,2 " "	160 "
Total area	37,0 sq. kms	

As the islands are well isolated and have relative small areas, the hill-forms are the dominant karst features. Their number is about 110. In the bigger island can be found also some small starshaped depressions ("cockpits", about 18). More thousands of caves are situated in the steep naked walls. In these caves are living the balinsasayao birds (C o l l o c a l i a f r a n c i s a g e r m a n i), which make the famous edible nests. These are collected by the local fishermen (called boceadors) and transferred to Manila.

Other similar karst archipelago are found S of El Nido in the Pagdanan Bay and on the E coast in Taytay Bay.

2. ORGANOS TYPE KARST

The name-giving control types are the steep-sided limestone hills of the Sierra de los Órganos in Cuba ("mogotes"). The bulk of the karsts in the Philippines has some resemblance to these forms, but there are regions with transitional features.

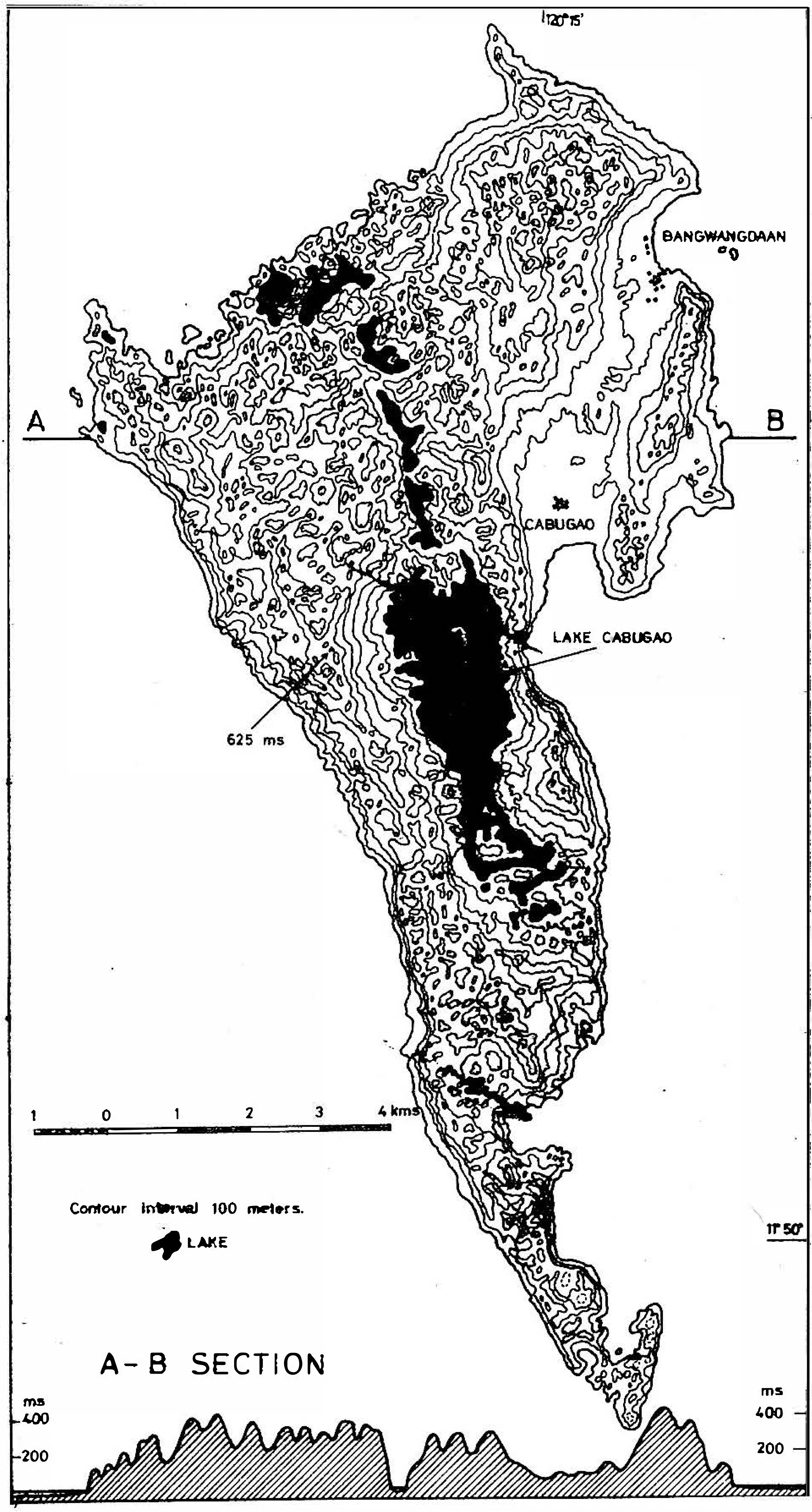

Fig. 6. Coron Island (Palawan Province).

a/ Coron Island

This island belongs to the Palawan Province (fig. 5). The rocks of the nearly impassable mountains are hard Miocene limestone. The N - S extension of the island is 20 kms, from W to E 9 kms. The highest towers have an elevation over 600 meters a.s.l. The island is crossed by a fault in the direction NNW - SSE, along it there are some depressions sunken under the sea level and filled with water. The island has a total area of 75 sq. kms with the intercollin lakes. The biggest lake is the Lake Cabugao (4,2 sq. kms, depth 5-13 meters), all the 9 lakes have a surface of 6,5 sq. kms.

Morphology: The very rough relief is made of about 490 karst hills and 150 closed depressions. The steep, sharp hills covered by dense rainy forest have an average height of 200-300 meters above the base level. The rate of the closed depressions is about 20 per cent. There are plenty of caves, but the most of the springs appear under the sea level.

The karst of Coron Island is a transitional form between the tower shaped Yangshuo and the Órganos type.

b/ Calbiga Karst

One of the greatest karst plateau of the Philippines is found in the Samar Island, Eastern Visayas. About one fourth of the total territory of Samar has an open karst topography. The most compact karst is the region E of Calbiga town, in the Middle Samar, with an area of 900 sq. kms. His extension from N to S is 55 kms from Tinane River to Basey River and in the W - E direction 20-30 kms (enclosure 2).

Morphology: The vast area of Calbiga karst plateau has an average top level 300-400 meters a.s.l. and only the highest hills have a height of 600 meters. The plateau is separated from their surroundings by thrust faults. The young developed steep hills have a relative height of 100-200 meters in general. Characteristic forms are the steepsided zigzagged long depressions (fig. 7/I). These are special "tropical uvalas". As the classic uvalas in Yugoslavia are formed by the coalescence of several dolines, the tropical uvalas of Calbiga karst are coalesced star-shaped cockpits. The proportion of the depressions is comparatively high in some places of the plateau (20 - 30 per cent). There are plenty of dry caves and big underground rivers.

Fig. 7. Northern part of the Calbiga karst region, Samar Island.

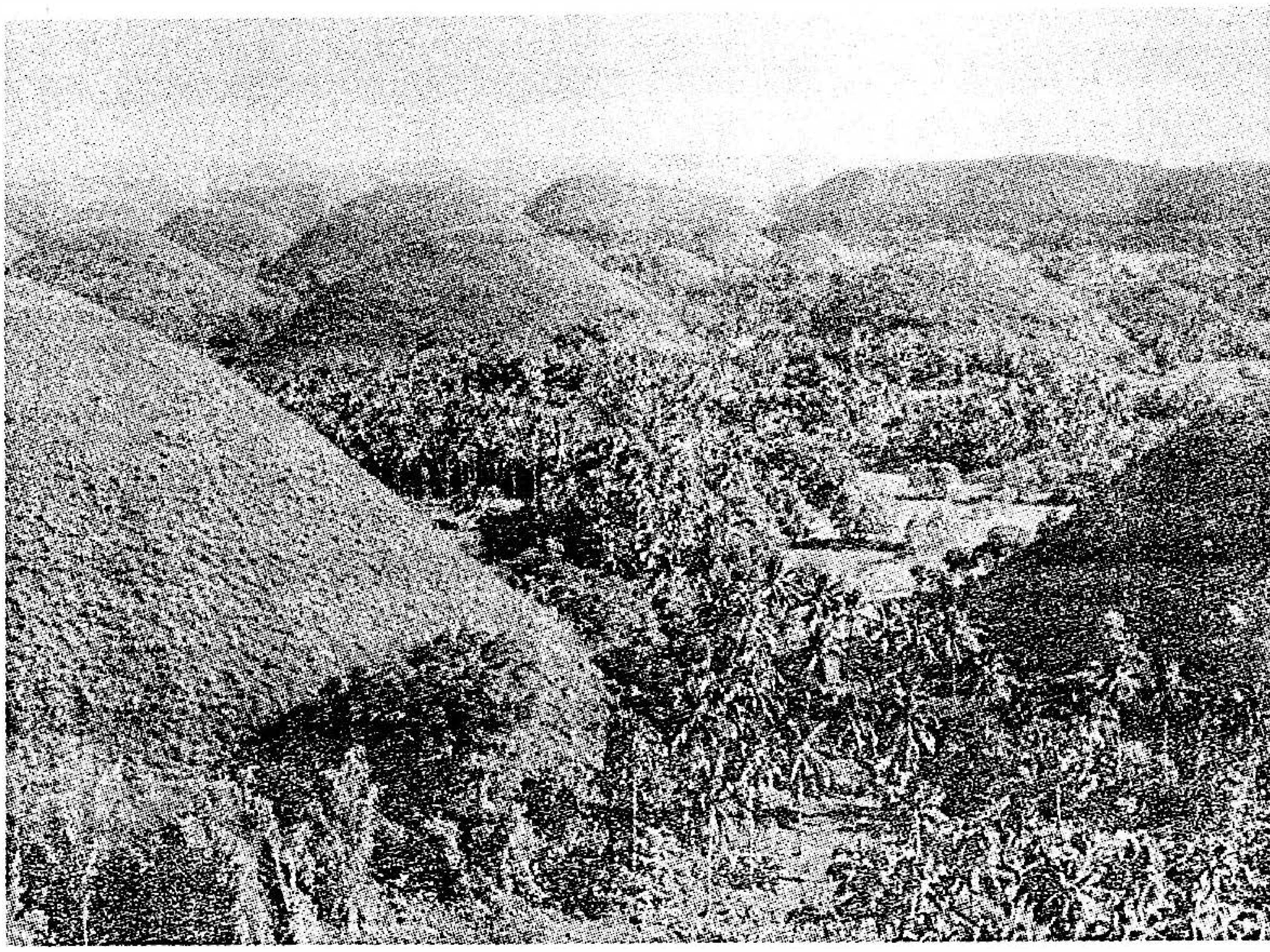

Fig. 8. The Carmen Thousand Hills in Bohol Island, Visayas.

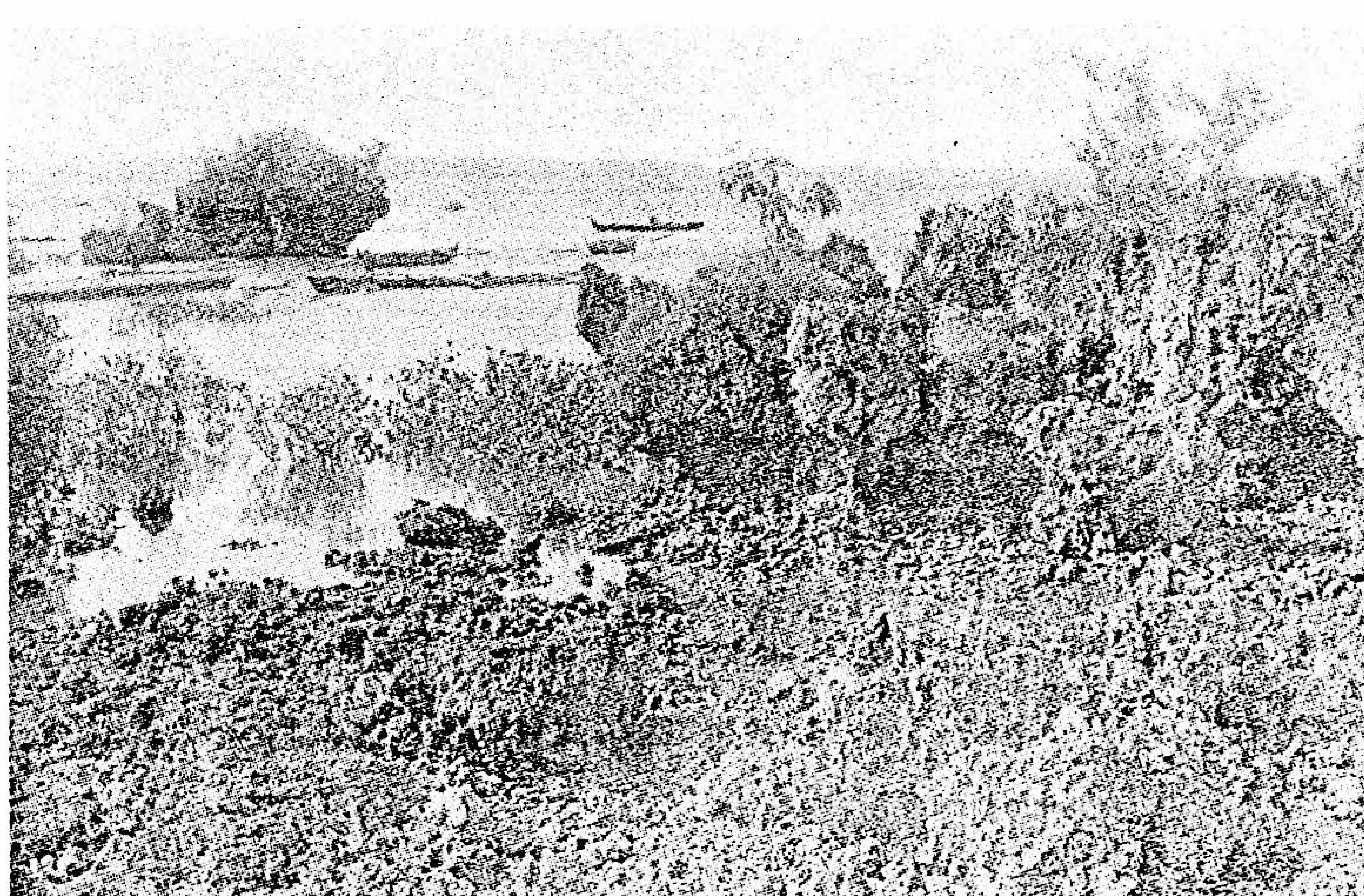

Fig. 9. Uplifted Quarternary coral reefs on Mactan Island, Visayas.

The Calbiga karst is a transitional form between the Órganos type and the Gunung Sewu type "Kegelkarst" in Java (Lehmann, 1936).

3. SEWU TYPE KARST: CARMEN THOUSAND HILLS

The best known and published karst regions in the Philippines are the karst hills of Bohol Island. The popular local name of these rounded conical hills is the "chocolate hills", one of their researchers (Teves, 1947) called them as "haycock hills", but may be the best name is the "Carmen Thousand Hills", used by the first scientific explorer, L.A. Faustino, chief geologist in Manila (1932). The most recent valuable explanations are given by F. Voss (1970).

The Southwestern part of the island has a karstic surface of about 600 sq. kms. The base rock is the loose coral limestone of Pliocene and Quarternary age.

Morphology: The Carmen Thousand Hills have similar forms to the Gunung Sewu Mountains in Central Java, but it should be remembered, however, that each karst region is the result of an individual development and many different factors contribute to the trend of development. For instance the Gunung Sewu - as control type - consists of more harder and older (Middle Miocene) limestone, therefore the hills are in some places more resistant against the erosion. The Gunung Sewu are crossed by many underground rivers of exogen origin in contrast of Bohol, where the caves are comparatively seldom.

There are more different hill forms in the Bohol karst regions. The most remarkable formations are around Carmen town in the centre, especially near Buenos Aires village (fig. 8). These hills have a height about 300-380 meters a.s.l. and from the flat base level about 50 to 90 meters. They are more or less dome-shaped, cone-formed and now covered by grass. There are twin-hills or compound hills and their distribution is in general linearly directed ("gerichteter Karst"). Teves (1947) found three sets of summit elevations. Voss (1970) stressed the importance of the complicated pattern of anticlines, synclines and related structures in the present karst morphology.

The analyses of the spring waters collected among the hills show a relatively high rate of denudation. The karst springs have $CaCO_3$ about 200-300 milligramm/liter in solution and the Loboy River has a hardness of about 200 mg/l $CaCO_3$ near the Loboc powerstation. These data correspond to the annual chemical denudation of 55 - 60 millime-

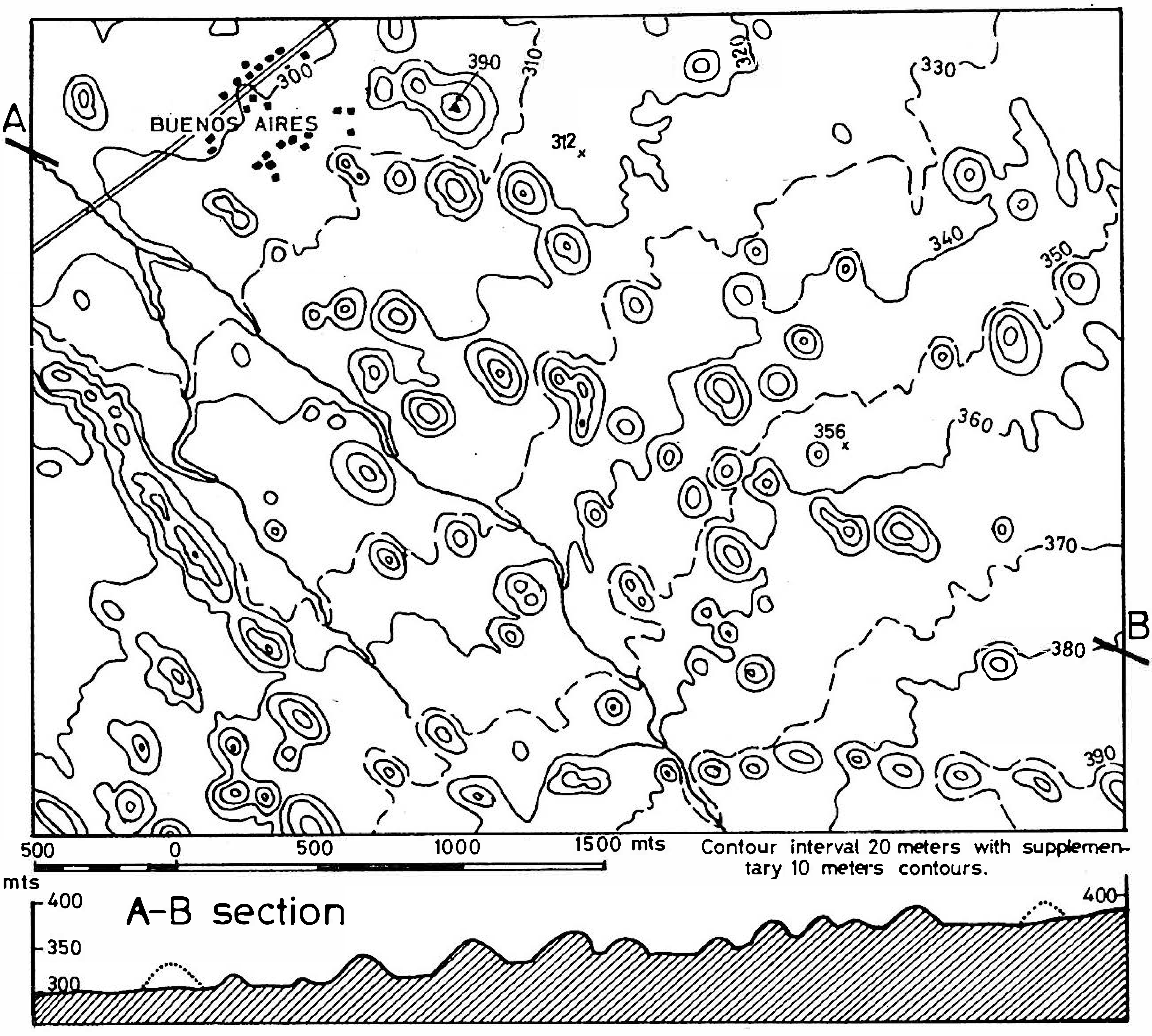

Fig. 10. Karst hills ("haycocks") South of Carmen town, Bohol Island.

ter/1000 years. As the physical denudation of this loose rocks is probable two or three times higher than the chemical effect, the age of these hills may be only 200.000 - 300.000 years.

4. TUAL TYPE KARST

The less fascinating karstic landscapes are the very young uplifted rocal reefs, like on the Kai-Ketjil Island (Indonesia) near Tual (Balázs, 1968, 1971).

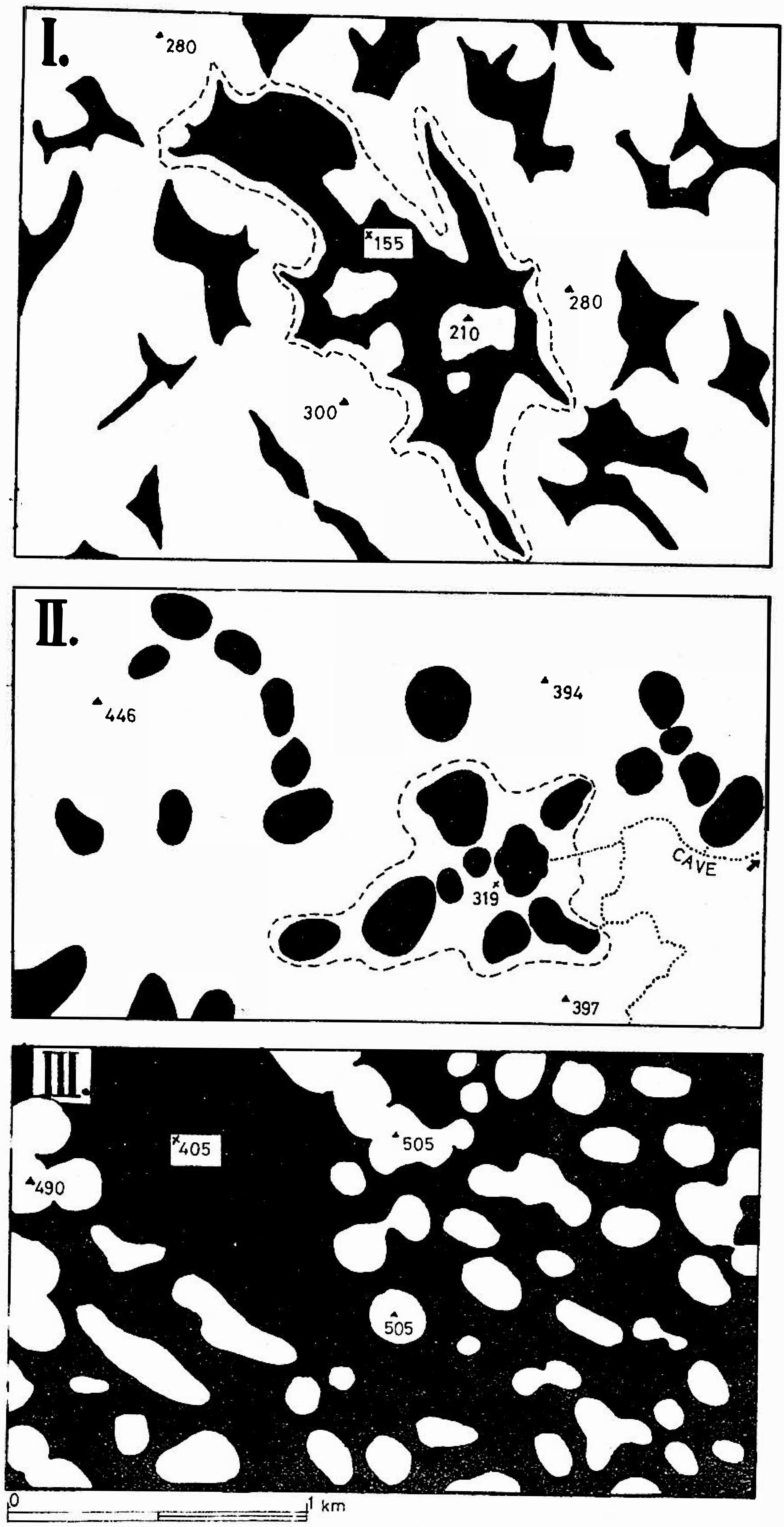

Fig. 11. The forms of closed depression (black spots) and their distribution in three different karst areas. I - Northern part of the Calbiga Karst, Samar Island. A special "tropical uvala" is found in the middle. II - Dolines and one uvala in the Middle European karst type of Aggtelek NE of Mount Pitics. III - Intercolline plains among the karst hills of Bohol Island, South of Carmen.

There are two typical appearences of this karst topography: the strip karst and the lowland karst. The first one is narrow edges of an uplifting island with a breadth of some hundreds meters up to several kms. Such coral rims are situated in Cebu, Negros, Panay, Leyte etc. islands. The lowland karst sometimes occupies a whole coral island, like in Visayas the Mactan, Panglao, Bantayan and other islands.

The main features are the numerous little shallow depressions and the sea caves. These areas are usually transformed by human activity (agriculture etc.).

GENERAL COMPARING

Summarizing what has been said, the following table contains some morphological parameters for comparing of the studied Philippine karst areas:

Name of karst are	Age of rocks	Number of hill forms on 1 sq. km	Number of closed depressions on 1 sq. km	Percentage of closed depr. of total area	Relative height of the hills m	Average relief-energy m/km^2
Mount Saint Paul	Middle-Miocene	3,0	1,3	15	300-600	400
Bacuit Archipelago	"	3,0	0,5	5	200-400	250
Coron Island	"	6,5	2,0	15-20	150-250	250
Calbiga Karst	"	6-8	3-4	20-30	100-200	150
Carmen Thousand Hills	Pliocene-Pleist.	8-12	1-2*	30-80*	40-90	80
To compare: a Middle-European karst (Aggtelek, Hungary)	Triassic	2-4	6-8	70-80	50-150	100

According to these selected examples, the karst areas of the tropical Philippines are very variable in forms and ages. This paper has given only a short introduction with the requirement, that more

* Intercolline lowland

detailed investigations are necessary in the future. The Philippines are short of experts on karst morphology, therefore it is most desiderable to give them more powerful help by the scientists of the developed countries. These studies would be useful both for the economical development of the Philippines and for the enrichment of the international karst science.

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Ba 003

DER ALPINE KARST IN DER ZENTRALSCHWEIZ

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Hitzkirch, Schweiz

Der alpine Karst ist gekennzeichnet durch das Zusammenwirken glazialer und karstischer Formungsvorgänge, die sich gegenseitig beeinflussen. Der alpine Karst ist somit ein karstglazialer Formkomplex auf und in gefalteten Gesteinen. Die gegenseitige Beeinflussung besteht einerseits in einer Lockerung des Gesteinsverbandes durch korrosive Erweiterung der Klüfte in den Kluftkarren und der Schichtfugen, wodurch der Zusammenhalt der Kalkbänke verringert wird. Andererseits wird der Gletscher die gelockerten Bänke abtransportieren und dadurch eine gestufte Landschaft bilden, die der Autor 1964 als "Schichttreppenkarst" bezeichnete, wenn die Schichtung nahezu horizontal verläuft, und als "Schichtrippenkarst" bei stärker geneigter Lagerung. Das ist gleichzeitig die Grundlage für typische Karrenbildungen.

Der alpine Karst ist aber auch durch das Klima mitbestimmt, durch die langen schneereichen Winter und die kurzen niederschlagsreichen Sommer. Mit zunehmender Höhe sinkt die Temperatur und das in tiefern Lagen noch vegetationsfreundliche Klima wird zunehmend vegetationsfeindlich. Konsequenterweise treten zwei klimamorphologische Typen auf, der alpine Hochkarst, ein nackter Hochgebirgskarst, im wesentlichen oberhalb der Waldgrenze, und der silvane Karst, der Waldkarst, ein grüner Karst, unterhalb. Dazwischen befindet sich eine Uebergangszone, wo sich beide verzahnen. Die obere Grenze des Hochgebirgskarstes ist gegeben durch die Frostschuttgrenze. Die Frostschuttzone mag als Nichtkarst gelten, doch beweist die teilweise unterirdische Entwässerung, dass sich auch hier noch Verkarstungsvorgänge abspielen. Es handelt sich im wesentlichen um ein dynamisches Gleichgewicht zwischen der Bildung der Korrosionsformen und deren Zerstörung durch Frost.

Die drei Bereiche des silvanen Karstes, des nackten Hochgebirgskarstes und der Frostschuttzone lassen sich in den hohen Kalkalpen überall unterscheiden, so auch im Muotatal. Hier beginnt der silvane Karst schon am Rande der Talsohle auf 630 müM und reicht hinauf bis gegen 1700 m, die Uebergangszone bis 1800 m, und darüber folgt der nackte Hochgebirgskarst, der zwischen 2300 m 2400 m von der Frostschuttzone abgelöst wird. Im Gebiete Bödmeren-Silbern-Karrenalp nimmt der silvane Karst 20% der Fläche ein, die Uebergangszone 5% und der nackte Hochkarst 75%. Das weist darauf hin, dass über der Kote 1800 müM ausgedehnte plateauartige Flächen auftreten.

Es sei noch kurz eine weitere Beziehung aufgezeigt. Das ganze Gebiet war während Hochwürm tief unter Eis begraben, der silvane Karst zwischen 1000 und 400 m, darüber mit weniger als 300 m. Der inneralpine Eiszerfall erfolgte nach dem Bühlstadium sehr schnell. Während des Geschnitzvorstosses wurden die heutigen Hochkarstgebiete bis tief in die Zone des silvanen Karstes hinunter noch einmal von Eis bedeckt. Kurz darauf wurde das Gebiet endgültig eisfrei, und auch der Daunvorstoss konnte nur noch die höchsten Lagen der Karrenalp erfassen in einem Bereiche, der heute noch zur Frostschuttzone gehört. Auf Grund dieser Entwicklung wird offenbar, dass der heutige silvane Karst einst so nackt war wie der gegenwärtige Hochkarst. Wir finden hier die gleichen Grosselemente, den Schichttreppenkarst, den Schichtrippenkarst, und die glazialen Rundhöcker.

Der nackte H o c h g e b i r g s k a r s t ist gekennzeichnet durch das karstphysiognomisch dominante Auftreten verschiedenster Karrenformen. Im deutschen Sprachraum ist wie in keinem anderen Sprachraum über Karren und alpinen Karst gearbeitet und geschrieben worden, und zahlreiche namhafte Geomorphologen haben hier gearbeitet (Bögli 1951). Deshalb sind auch mit ganz wenigen Ausnahmen die Fachausdrücke hier entstanden, ausgenommen etwa Termini wie Kamenica.

Der s i l v a n e K a r s t war mehr noch als der Hochkarst Ziel zahlreicher Diskussionen. Otto Lehmann beispielsweise schloss der "karrigen Plattenlandschaft", die identisch mit dem nackten Hochkarst ist, nach unten eine Region der "Karrendolinen" an, unregelmässig geformten Dolinen, und noch tiefer eine "Dolinenlandschaft". Rathjens begründet diese Einteilung tiefer, indem er betont, dass Karren und Dolinen zwei verschiedenen, klimatisch bedingten Höhenzonen angehören. Diese Einteilung wurde, mehr oder weniger variert, allgemein übernommen. Haserodt seinerseits negiert aber diese zonale Gliederung, wenigstens was die Dolinenlandschaft angeht. Die Entscheidung, ob das eine oder das andere Zutreffe, ist eher eine Frage des Blickwinkels und lokaler Besonderheiten als ein effektiver Gegensatz. Im Walde verdecken Bodenbildungen und Vegetation die Karren weitgehend, wodurch die Dolinen, es sind meist kleinere Formen, karstphysiognomisch dominant werden. Aus einer gewissen Distanz betrachtet sind fast nur die

Dolinen zu sehen, aus der Nähe aber erweist sich der Fels als restlos mit Karren bedeckt.

Noch einige Worte zu den Höhlen. Als alpiner Höhlentyp werden tiefreichende Schachtsysteme angesehen, welche nur die Zone der Vadosen vertikalen Wasserbewegung umfassen. Das ist ein Trugschluss, da die Erforschung häufig oben beginnt und in den meisten Fällen die Zone lateraler Wasserbewegung noch nicht erreicht hat oder wegen Versturzen oder Siphons nicht erreichen kann. Das grosse Ausmass der Zone vertikaler Wasserbewegung mit vadosen Bedingungen ist ein wesentliches Element alpiner Höhlen. Es sei an die Schachthöhlen Frankreichs und Österreichs erinnert. Ursache dafür ist die schnelle Eintiefung der Täler im Pliozän und Pleistozän. Damit wurde auch der Vorfluter für den Karstbereich schnell tiefer gelegt, und die unterirdische Verkarstung folgte mit einiger Verzögerung. Braucht diese viel Zeit bis zur vollen Entwicklung der unterirdischen Entwässerung, dann liegt der Vorfluter tief und die Zone vertikaler Entwässerung wird bis zu 1000 m und mehr mächtig. Setzt aber die unterirdische Verkarstung schnell ein, dann liegt die piezometrische Fläche schon in Tiefen zwischen 200 m und 300 m unter der Oberfläche, so dass sich hier bei lateralen Wasserbewegungen "horizontale" Gangsysteme entwickeln können. Mit der phasenweisen Tieferlegung des Vorfluters werden neue, laterale Systeme in tiefer Lage aufgebaut. Das Hölloch im Muotatal (120,5 km Länge, 808 m Höhendifferenz 1973) gehört diesem alpinen Höhlentyp an und weist drei Hauptniveaus auf. Es vertritt somit den vollständigen alpinen Höhlentyp mit einer Zone primärer vertikaler Wasserbewegung von 200 m bis 300 m Mächtigkeit.

Wenden wir uns noch zum Schlusse der Karstdenudation in den beiden Karsttypen zu (Bögli 1971). Auf Grund zahlreicher Messungen, wobei auch die Kalkgehalte des Höllochwassers beigezogen werden konnten, ergaben sich die folgenden Resultate:
Im nackten Karst ist der maximale Kalkgehalt durch den CO_2-Gehalt der atmosphärischen Luft allein gegeben. Der mittlere Kalkgehalt des in die Kluftkarren einfliessenden Wassers liegt bei 17 ppm. Da der jährliche Abfluss im Mittel 2100 mm beträgt, ergibt sich ein Oberflächenabtrag von 15 mm im Jahrtausend. Das ist der gleiche Wert, der durch die Sockelhöhe der Karrentische ebenfalls wahrscheinlich gemacht wird.

Daraus ergibt sich, dass ein grösserer Anteil des Gesamtabtrages unterirdisch weggelöst werden muss. Ein wesentlicher Anteil wird schon in den ersten 10 m bei der Bildung der Kluftkarren verbraucht. Ein

Stollen, der 40 m unter einem solchen Karrenfeld hindurchführte, wies nur wenige korrosiv erweiterte Klüfte auf, nicht signifikant mehr, als das in den tiefern Teilen der Fall war. Umgekehrt sickert im silvanen Karst das Wasser durch Bodenbildungen hindurch, reichert sich mit $CaCO_3$ an, und im Bergesinnern ist es kaum mehr korrosionsfähig oder scheidet sogar Tropfsteine aus. Eine Gegenüberstellung der Abtragswerte im silvanen Karst und im nackten Karst ergibt die folgenden Resultate:

Waldkarst	Gesamt abtrag	Abtrag oberird.	Abtrag unterird.	Verhältnis O : U
Waldkarst	91 mm	81 mm	10 mm	8 : 1
nackter Karst	71 mm	14 mm	57 mm	1 : 4
Waldkarst : nackter Karst	9 : 7	8 : 1,4	1 : 5,7	

Es zeigt sich eindeutig, dass im nackten Karst trotz der tieferen Temperaturen, etwa einem arktischen Klima entsprechend, trotz der merklich höheren Abflussmenge (18% mehr als im Waldkarst) der Abtrag um 22% geringer ist als im Waldkarst. Damit wird deutlich, dass das Ausmass der Karstdenudation in erster Linie eine Funktion der Vegetation, der biologischen Aktivität und der Bodendecke ist.

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Ba 004

THE NAHANNI NORTH KARST: A QUESTIONMARK ON THE VALIDITY OF THE MORPHOCLIMATIC CONCEPT OF KARST DEVELOPMENT

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INTRODUCTION

In 1936 H. Lehmann recognised that in the Sewu Mountains of Java the karst cockpit formed at the earliest stages of karst development and was not simply a later stage in the evolution of the doline as proposed by Grund. Lehmann was the first to propose in the morphoclimatic theory, that the morphology of karst landforms is largely a function of the climate under which they develop. Since then, climatic controls have been widely invoked to explain regional variations in the characteristics of karst landforms and it has been claimed that certain features can form only under particular climatic conditions. Climate has further been employed in the classification of karst landscapes, for instance, the terms tropical karst, or arid and semi-arid karst are in common use. In particular, tropical and extratropical karst forms have been differentiated. As an example, towers, mogotes, cones and cockpits are thought to form only under tropical or sub-tropical conditions. Where such features have been identified outsice of present-day tropical limits, they have been labelled as fossil or relict forms which date to a previous warmer geological period, usually designated as the Tertiary.

The intensity of development and the varied nature of karst landforms in hot, wet areas of the world, has further suggested that solution is more rapid in tropical areas and diminishes in intensity towards regions of polar climate. Attempts have been made to establish a global model of limestone solution rates. Corbel (1957, 1959), for instance, considered that because carbon dioxide is more soluble in water at lower temperatures, solution of limestone must be more rapid in colder areas. Adams & Swinnerton (1937), however, claimed that the controlling factor in the solution process was not temperature but the partial pressure of biogenic carbon dioxide in the soil atmosphere.

Optimum conditions for the production of biogenic carbon dioxide are considered to be found in areas of tropical rain forest. Both the production of carbon dioxide and solution rates are thought to decrease towards higher latitudes.

The diversity of karst landforms present in the Nahanni North Karst of northern Canada casts considerable doubt upon the validity of the morphoclimatic concept in its present form. Furthermore, present-day solution rates in the area suggest that a global model of limestone solution based solely upon climatic considerations is entirely unrealistic.

THE NAHANNI NORTH KARST

Intense karst development in the southeastern Mackenzie Mountains at 61° N occurs in a belt of country 6-12 Kms. wide extending for 50 Kms. north of First Canyon, South Nahanni River (fig. 1). The karst assemblage which constitutes the most northerly complex karst known, is more typical of a tropical or sub-tropical climate than the prevailing cold continental interior climate (Siberian type, Koppen Dfc-E). The mean annual temperature is -2° C and the mean annual precipitation of 520 mm falls mainly as rain during the short summer season. Karst features identified to date include many types of karren, extensive tracts of limestone pavement with grikes, labyrinth karst made up of networks of bogaz, corridors and karst canyons, solution dolines, collapse and subsidence dolines, cenotes, uvalas, poljes, karst towers, natural bridges, caves and dry fluvial canyon systems. Forms occur both in mantled and bare karst areas.

Four major physiographic components formed by folding and thrust faulting in thick sequences of Palaeozoic sedimentary rocks are of importance. The Nahanni Range (1,300-1,500 m), the most southerly range of the Franklin Mountains, and the Nahanni Plateau (1,000-1,700 m), the easternmost component of the southern Mackenzie Mountains, are bounded on their eastern flanks by west-dipping thrust faults (Douglas & Norris, 1960). Between these two upland masses, at 350-830 m is the Mackenzie Plain which narrows from 50 Kms in the south to half this value in the north where it accommodates the Ram Plateau reaching up to 1,700 m (figs. 1 & 2). Both the Nahanni and Ram Plateaus are broad dome-shaped structural highs between which, and locating the major

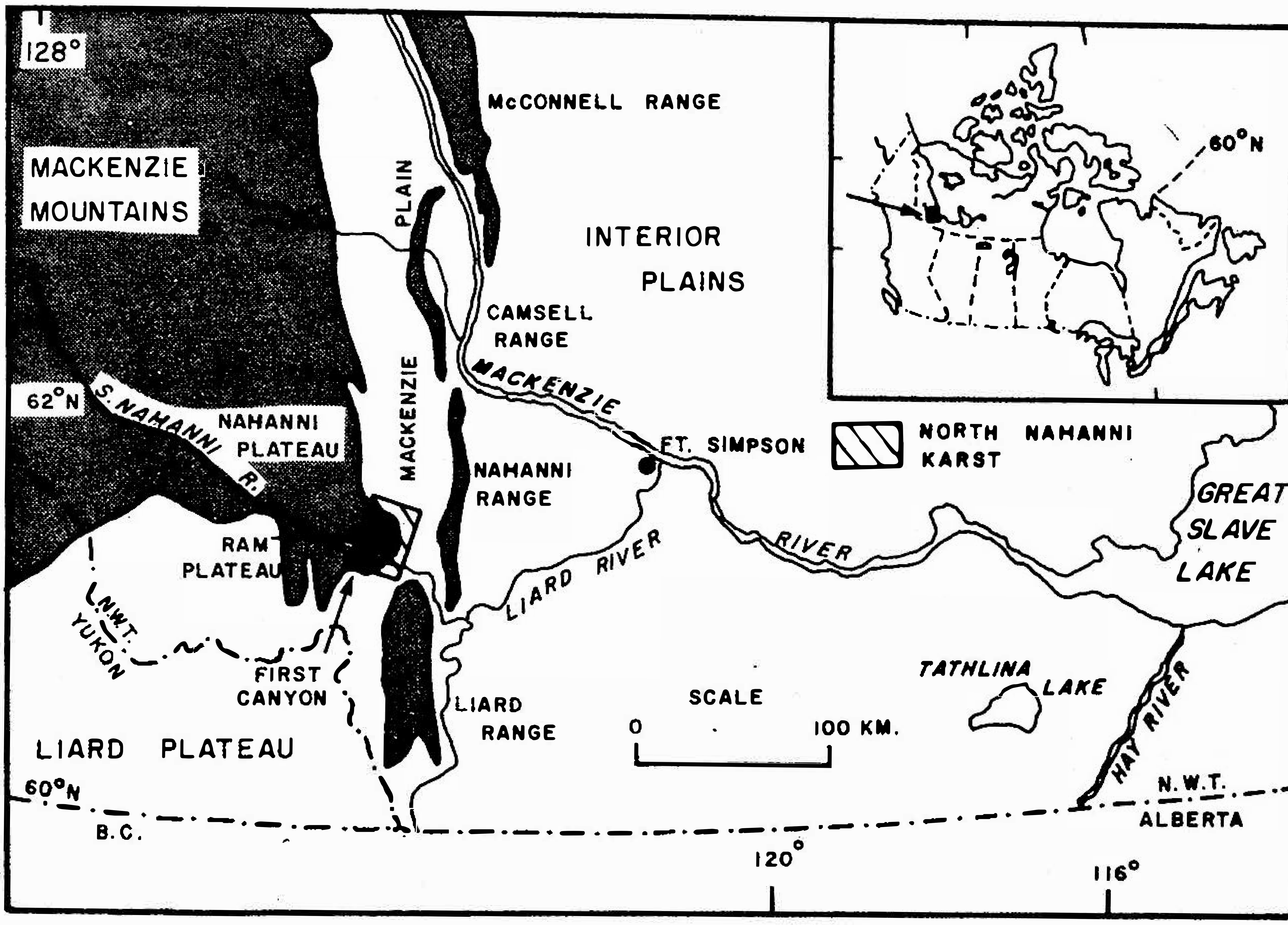

Fig. 1. Physiography of the Upper Mackenzie River area and the location of the Nahanni North Karst.

karst development is the shallow, heavily fractured Nahram Syncline. Rock dips are generally less than 10°.

Solutional processes have operated principally in the Middle Devonian Nahanni Limestone, a medium to massively bedded, fine-grained limestone 150-250 m thick. Underlying the Nahanni Limestone and important in limiting the downward progress of solution are three further stratigraphic units, an argillaceous limestone, a coarsely crystalline dolomite and a fine-grained dolomite. Above the limestone and an important source of acid water are shales of the Upper Devonian Simpson Formation, which may attain a maximum thickness of 600 m.

The southern Mackenzie Mountains is foremost a fluvial province. Where the South Nahanni River crosses the southern flank of the Nahanni plateau in an area of possible antecedent drainage development, First Canyon, 15 Kms long and 1,150 m deep has been incised. Both the Nahanni and Ram Plateaus are deeply dissected by steep-walled canyons to depths of 1,150 metres. The magnitude of the fluvial dissection has encouraged the vertical development of karst landforms.

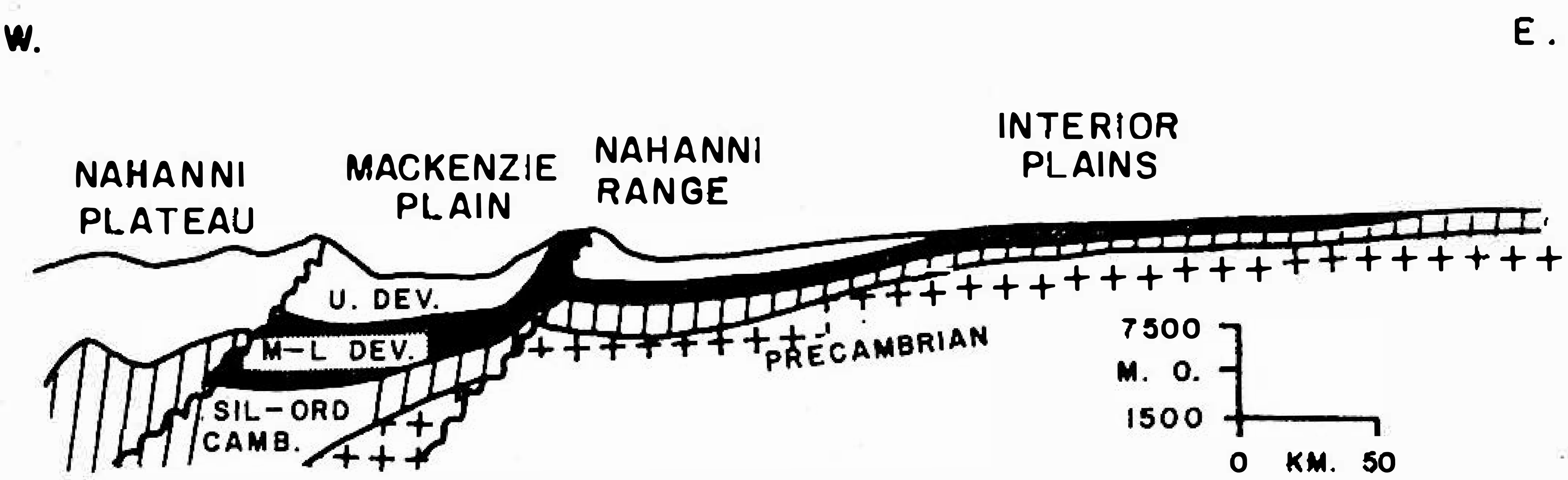

Fig. 2. Schematic geological cross section throubh the southeastern Mackenzie Mountains (modified after Law 1971).

Much of the southern Mackenzie Mountains may have escaped glaciation during the Wisconsin or Würm period (Wilson 1958; Prest, 1967), but the area was certainly covered by Laurentide ice from the east during at least one of the earlier glacial periods. Erratic material derived from the Canadian Shield and deposited at altitudes in excess of 2,000 m attests to the thickness and erosive power of this ice sheet. The present state of knowledge indicates that ice caps with radiating valley glaciers were present on both the Nahanni and Ram Plateaus during the final glacial episodes. It is also evident that throughout this period much of the karst belt remained free of ice. The Ice Cap Glaciation is believed to represent the maximum extent of Wisconsin ice in this area. Because much of the karst belt shows no evidence of glaciation at this time, it is apparent that some karst forms may have been developing without serious interruption since at least the end of the Illinoian (Riss) Glacial. This fact differentiates this area from most other limestone areas at similar or higher latitudes.

THE KARST ASSEMBLAGE

The landforms of the Nahanni North Karst are broadly divisible into those that occur within and those that occur outside the boundaries of the area glaciated by the Ice Cap Glaciation. Glaciokarstic forms, particularly extensive tracts of limestone pavement with grikes and bogaz, as well as a suite of smaller-scale solutional forms, dominate the landscapes of glaciated areas. Non-glaciated areas are characterised by extremely large-scale solutional forms. Particular attention will be given here to a description of the most spectacular features occurring in areas not glaciated during the Wisconsin; these include labyrinth karst, poljes and dolines. One glaciokarstic form of considerable magnitude, the dry fluvial canyon system, will also be described.

LABYRINTH KARST

Dominating the Nahanni karst belt is a suite of solutional forms which, following Verstappen (1964, 1969), constitute labyrinth karst. Labyrinth karst is made up of intricate networks of linear solution streets[1] which result from the solutional widening and deepening of fractures (fig. 3). Street dimensions range from grikes up to 3 metres deep, 2 metres wide and a few metres long, through bogaz and corridors to karst canyons which may be up to 200 metres deep, a few hundred metres wide and one or more kilometres long. Walls are vertical and exhibit fragments of phreatic and paraphreatic caves suggesting that streets were created by groundwater moving both vertically and laterally along fractures. Floor profiles are irregular due to uneven collapse of street wallw; solution dolines and ponds in this breakdown material are characteristic. The scale of street development depends upon both the vertical and horizontal extent of host fractures or narrow fracture zones, and period of development. Where only one discrete fracture is enlarged, streets tend to be narrow and of medium depth; where solution acts within narrow zones of fractured rock, streets will be considerably broader and generally deeper. The most massive labyrinths have formed around a west-dipping reverse fault approximately parallel to the axis of the Nahram Syncline.

1 The analogy is made between the complicated networks of negative linear forms constituting labyrinth karst and the streets in an urban area.

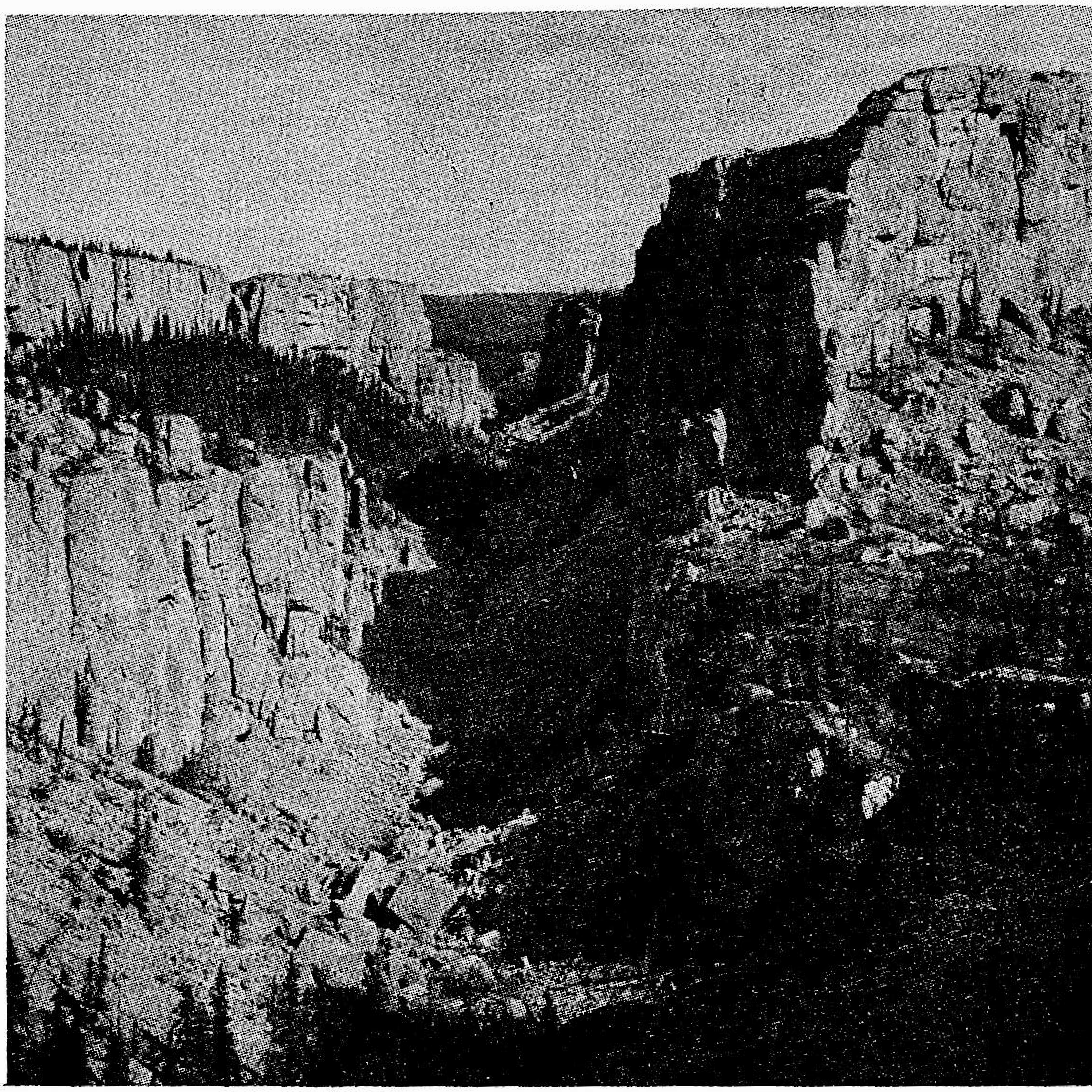

Fig. 3. A karst street in the North Karst which has developed along a fault with slight vertical displacement. The dimensions of streets are variable and their walls may contain fragments of phreatic caves. Floors are composed of irregular talus fills and contain shallow solution dolines and karst ponds.

One karst canyon displaying 150-200 metres vertical walls to east and west and only slightly lower cols to north and south, contained in 1972 what may well be a perennial lake of considerable depth. Raven Lake may have formed following the partial blockage of outlet sinks in the floor of the canyon (fig. 4). As with other streets, water enters both by surface and underground routes. Hydrological investigations in the area suggest that Raven Canyon receives water via underground donduits from extensive areas of smaller-scale labyrinth karst to both east and west. These in turn are charged not only by precipitation but also by surface runoff from adjacent impermeable shales. That inflow

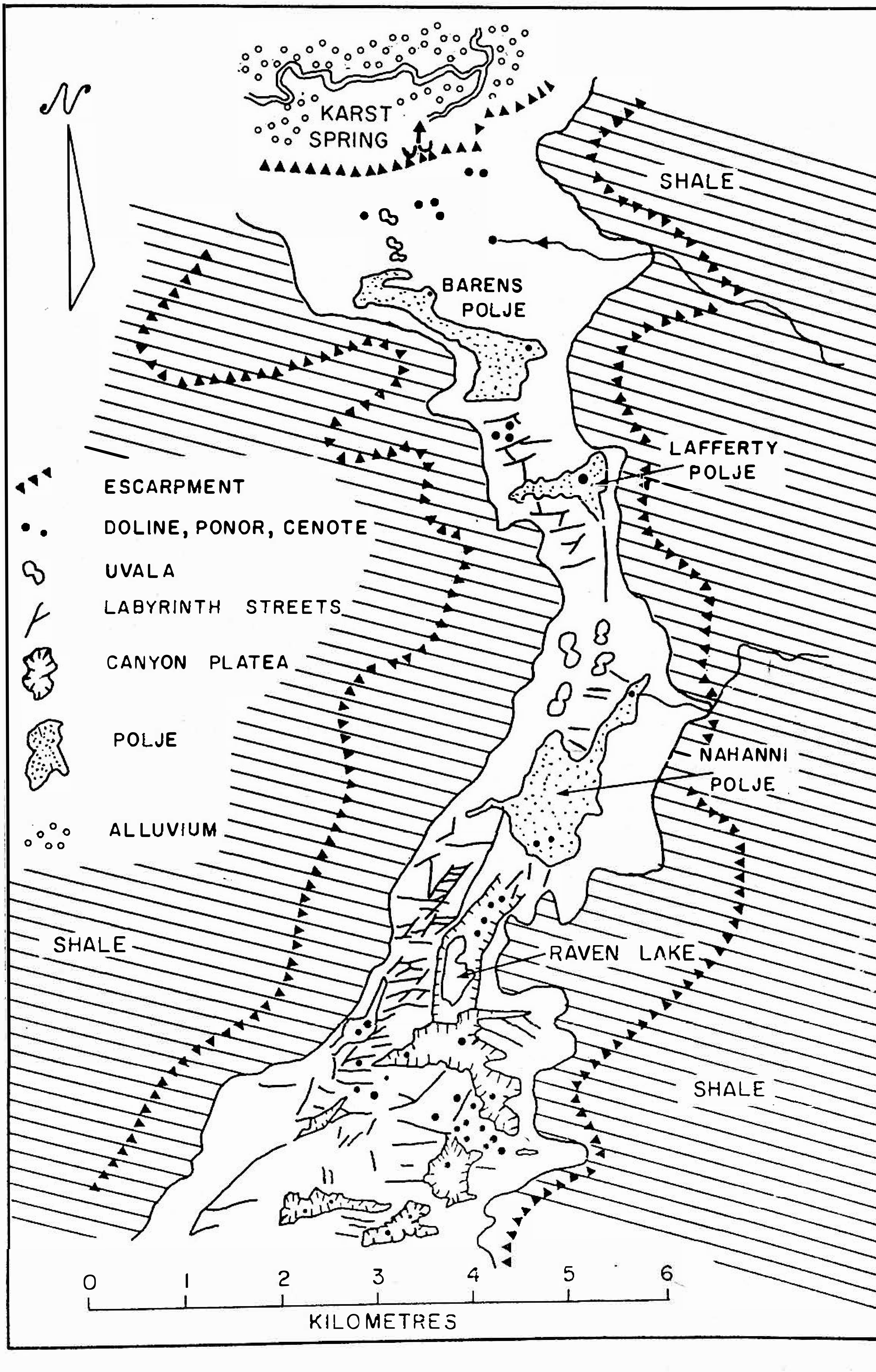

Fig. 4. Sketch map to illustrate the assemblage of karst landforms in the northern part of the Nahanni Syncline. The area was not glaciated during the Wisconsin period.

rates into Raven Canyon can at times far outweigh rates of discharge was conclusively established in late July 1972, when, following 203 mm of rainfall in eight days, the level of Raven Lake rose by almost 35 metres in a matter of days, indicating a rapid flow-through time between it and the small-scale labyrinth karst.

Once the vertical limit of solutional penetration along a given set of fractures has been reached, widening of streets both by solutional undercutting of the walls and by gravitational collapse aided by frost action predominates. This leads to the consumption of inter-corridor areas with the formation of residual karst towers and irregularly-shaped closed depressions, here referred to as karst platea[2]. These may be differentiated from dolines in that a number of streets radiate from them. Jennings & Sweeting (1963) and Jennings (1969) called features formed in a similar way, but differing in their morphology, "box-valleys". In the Nahanni, the coalescence of the largest streets, karst canyons, has produced canyon platea that may reach depths of over 200 metres. Canyon platea are entirely closed, vertical-walled features with irregular, debris-covered sides and floors, Debris is massive with blocks 10-20 metres in diameter not uncommon. Floors contain one or more partially alluviated dolines. In times of heavy rainfall dolines can not always cope with the volume of inflowing water and temporary ponds lasting only a few days are formed. Labyrinth karst has been reported from Austria (Bauer & Zötl 1972), Brazil (Tricart & Da Silva, 1960), West Irian (Verstappen, 1964, 1969) and Australia (Jennings & Sweeting, 1963; Jennings, 1969), where street depths vary up to a maximum of 50 m. The Nahanni labyrinths appear to be the largest features of this kind known.

POLJES

Generally for a closed depression to qualify as a polje it must be several square kilometres in area. Four closed depressions in the Nahram Syncline between the Nahanni and Ram Plateaus, the largest of which has dimensions of 2.5 x 1.5 kilometres, show virtually all the characteristics of tropical poljes except that they are of small di-

[2] The analogy is made between the market place or square of an urban area, which constitutes a large open space within a street network, and the closed depression characteristic of karst labyrinths. The term platea (pl. platea), is derived from the Latin noun platēa and the Greek plateia meaning a public square.

mensions. As a variant of the polje, these features constitute the most northerly examples of this karst form known, and the only examples in Canada. All three northern poljes (fig. 4), have steep to vertical sides 30-120 metres in height with an abrupt break in slope between floor and walls. Floors are flat and alluviated with one or more ponors. Two of the poljes contain small residual limestone hills or hums. Ten kilometres S.W. of these poljes is another of definite glaciokarstic origin. It is apparent that following the formation of an ice-scoured closed depression, solutional and periglacial processes operated to widen the depression and steepen its walls. A residual karst tower and small pitons are visible in the polje floor which is alluviated and contains ponors, possible springs and a seasonal river channel.

There is considerable controversy as to the origin of poljes. Many features in Yugoslavia are considered to be of tectonic origin, occupying fault-angle depressions, fault troughs and synclines. The four Nahanni poljes appear to occupy either shallow fault troughs or fault angle depressions. Vertical displacement of faults appears to be slight so that solution has been extremely important in their formation. Examination of Lafferty and Barens Poljes in July 1972 revealed the presence in both of distinct strandlines in talus aprons. In addition, a marked solution notch with a number of small youthful caves was evident around the perimeter of Barens Polje at between 3-10 metres above the floor. That the poljes suffer periodic inundation, as this evidence suggested, was left in no doubt in late July 1972, when after 203 mm of rainfall, all three northern poljes flooded. Two sources for the floodwater were identified, spring flow and surface runoff from surrounding shales. Flood water was turbid indicating that a considerable volume of suspended material is funnelled into these sediment traps during flood periods.

By the beginning of August 1972, large areas of the Lafferty and Nahanni Poljes had been inundated. Maximum water depths were probably of the order of 10 metres and 20 metres respectively. At the same time Barens Polje had become a large lake (fig. 5) with depths of up to 12 metres and had developed a surface overflow discharging about 5 m^3/sec. at its northwest extremity. At the end of August, there was no sign of a decrease in this surface discharge nor of a lowering of lake levels. In all likelihood the poljes contained water when the 1972/1973 winter freeze-up began. It has not been determined whether flooding takes place during the snowmelt season as well as at times of heavy summer rainfall, nor is it possible at this stage to say at what frequency

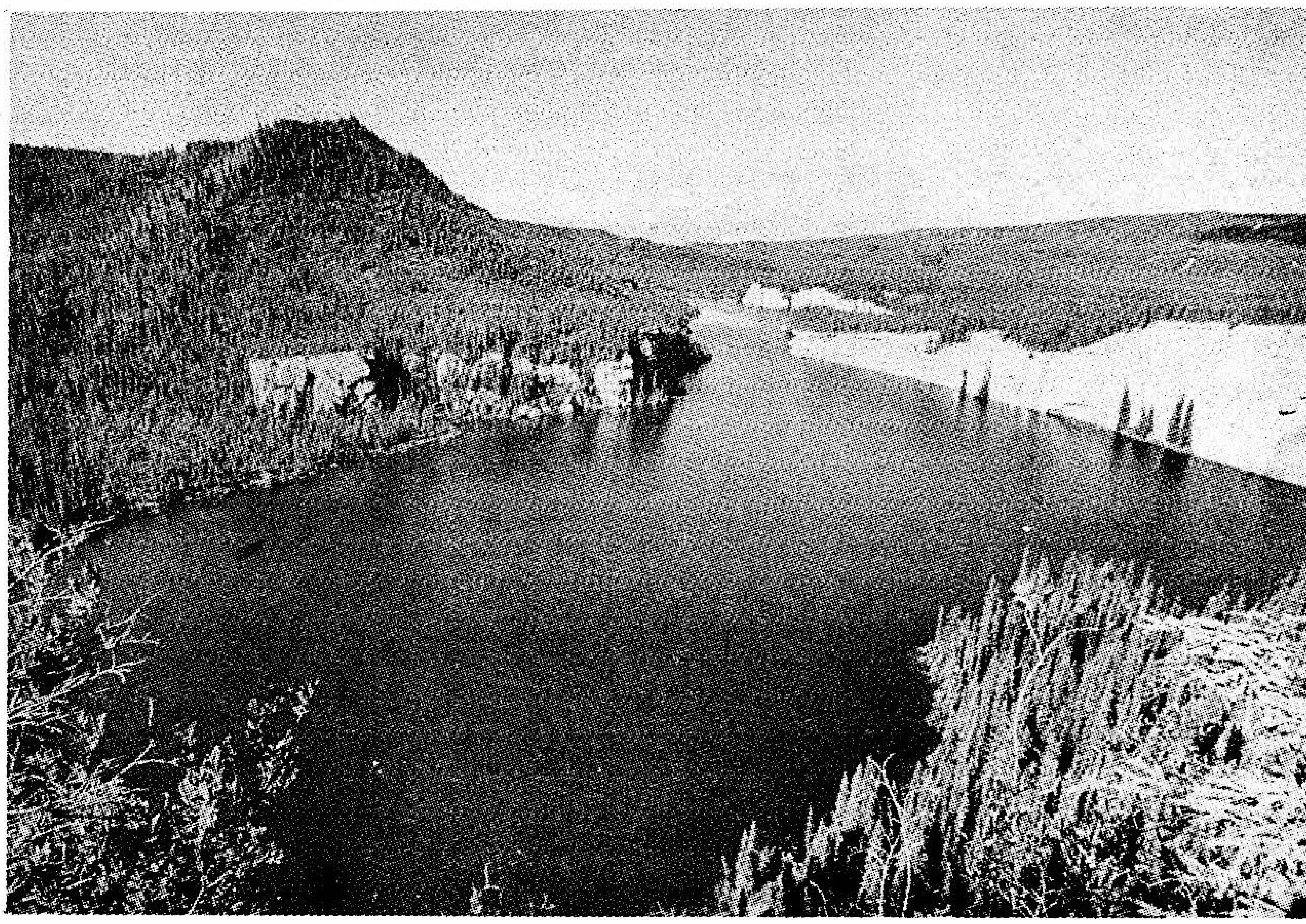

Fig. 5. Barens Polje in flood following intense rains in July 1972. A surface overflow developed discharging about 5m 3/sec. The lake is 5-20 metres in depth.

flooding occurs, although it occurs sufficiently often to inhibit tree growth on polje floors.

DOLINES

The most characteristic landform of most karst areas is the doline. Solution dolines are scattered throughout the Nahanni while collapse and subsidence dolines are common where there is a thin cover of shale or alluvium. Sinkholes have developed where perennial streams flow from shale areas and sink underground upon reaching limestone. Forms occur both in bare and till-mantled karst and are to be found on plateau surfaces, in valley floors and occasionally even in steep valley and canyon walls.

Also present and remarkable for such an area is the cenote. These features are vertical-walled solution cylinders containing permanent ponds. Numerous examples are to be found, some being 20 metres in diameter and extending 30 metres to the surface of the pond. In classical cenotes such as those of the Yucatan Peninsula, Mexico, the pond surface is at the level of the local groundwater table; in the Nahanni features, water levels vary so much between closely-spaced individuals that water bodies are undoubtedly perched. The presence of water in cenotes can only be explained in terms of low bedding plane transmissivities and the blockage of vertical percolation routes by permafrost ice bodies. In winter ponds freeze and in this area of sporadic permafrost only partial melting occurs during the short summer season. The surfaces of some cenote water bodies were still covered by ice at the end of August 1972. These landforms appear to derive their water from the melting of drifted snow. The cenotes of the Nahanni are a cold climate variant of the classical tropical form. A most remarkable concentration of features occurs at Cenote Col, a narrow residual rock platform between two deep canyon yards. Twenty five solution dolines, cenotes and sinkholes are concentrated into 0,7 square kilometres (fig. 6). Such dense karstification may be observed in humid tropical areas such as parts of Mexico, Guatamala and Honduras, but under cold climates it is unknown.

CLOSED FLUVIAL CANYON NETWORKS

In the karsts of temperate countries and in highland tropical areas such as Central Mexico, it is common to find river valley systems that are now drained completely via underground routes. Seven closed river canyon systems have been identified in the North karst area. The largest of these dendritic networks, Canal Canyon, is more than 14 kms long and 1,000 metres deep. All canyons contain permanent or semi-permanent lakes whose waters sink into alluvial dolines. These features are of glaciokarstic origin. The fluvial canyons existed prior to the Ice Cap Glaciation when they were occupied by valley glaciers which built up sizeable and moraine and fluvioglacial-outwash deposits. At this time sub-glacial meltwaters may have been partially routed underground. Following ice retreat, those canyons that had already developed or could subsequently develop effective underground discharge routes, remained closed and were deepened by solution. Where this did not happen, normal surface drainage was re-established.

Fig. 6. Cenote Col a narrow limestone platform between two canyon platea. 25 solution dolmes, cenotes and sinkholes are concentrated into 0.7 kms^2. The photograph clearly illustrates the effect of jointing upon the karst development. The steep slope in the background marks the break between limestones and the overlying Simpson shales.

WATER CHEMISTRY

During the summer of 1972, 150 water samples from shale, till-covered limestone, glacial deposits and bare limestone were analysed to determine their chemical characteristics. Calcium and magnesium hardnesses, temperature, pH and alkalinity were measured. Two major conclusions can be drawn from the results. First, total hardness values which generally range between 80-120 p.p.m., but for spring waters may be as high as 355 p.p.m., are higher than a consideration of latitude and climate would suggest. Secondly, pond, lake, stream and spring waters appear to be distinguishable on the basis of their chemical characteristics. It is also evident that within each of these broad water categories, water chemistry differs from one surficial and bedrock geological type to another.

In an attempt to explain such variation, the carbon dioxide content of the soil atmosphere was measured at 35 localities. The results indicate high CO_2 percentages of 0.03-2.25% in shale soils and low values of 0.002-0.08% on glacial end moraine and outwash materials. Shallow soils in limestone areas contained between 0.01-0.42% CO_2. Variations in soil atmosphere characteristics from one soil type to another are largely a function of differences in soil depth, drainage properties and the density of the covering vegetation. Soils on shale are of considerable thickness and support a dense coniferous forest, whereas thin limestone soils with lower production of biogenic CO_2 are much less densely covered. High water hardness values can thus be explained in terms of equilibration with soil CO_2 partial pressures. Extremely high values are characteristic of waters that have passed from shale to limestone by either surface or underground routes.

Water chemistry and soil CO_2 data has revealed that the Nahanni Karst is actively developing today at a surprisingly rapid rate for an area at 61° N with a sub-arctic climate.

DISCUSSION

From work carried out in the Nahanni North Karst, it has become increasingly obvious that the almost tropical or sub-tropical nature of the karst assemblage questions the validity of the hypothesis that a hot humid climate is necessary for the development of some karst landforms. The presence of vast tracts of labyrinth karst on a scale not known elsewhere, poljes with tropical rather than temperate characteristics, karst towers and an uncommonly high density of negative forms, suggests that under ideal conditions these landforms can develop over a much wider range of climates than is suggested in the literature. Nor is it possible to argue that the karst assemblage is relict, having been moulded during earlier warmer and wetter conditions, for these landforms are certainly of Quaternary age. It is further apparent that such an argument is unnecessary, for water chemistry data indicate that the present rate of denudation in the area can adequately account for features which have been evolving since at least the end of the Illinoian Glacial. Because it escaped the brunt of Wisconsin ice, the

Nahanni karst is the only known sub-arctic karst that has had time to fully develop.

If the existence of the Nahanni karst suggests revision of the morphoclimatic concept, it also points to possible alternatives. The Nahanni assemblage indicates the influence of structure in determining the course of solutional development and the ultimate morphology of karst landforms. An abundance of sub-vertical open fractures in a massively bedded limestone with few open bedding planes has left the solutionally widened fracture, the karst street, the most common landform of this region.

In conclusion, support must be given to the contention that with an adequate period of development, suitable lithological, structural, topographical and geological controls, the formation of any single karst landform should be possible under a wide range of climatic conditions.

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Ba 005

ON THE USES OF SPECTRAL ANALYSIS IN KARST STUDIES

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1. INTRODUCTION

This paper is concerned with both the realized and the potential utility of a relatively new statistical tool, spectral analysis, for karst studies. Following a brief discussion of the technique, its limitations, assumptions, power, and mechanics, attention is paid to applications in such diverse fields as karst hydrology, meteorology, and automatic surface pattern recognition. Some of the karst applications have utility to fields outside karst studies.

2. EXPOSÉ OF SPECTRAL ANALYSIS

Assume a time record $x(t)$ of some geophysical event which is Gaussian and stationary. Then a regular sample at interval t will yield a time series n, t_1, t_2, t_n. Then the function's values at a given set of points are completely determined by the ensemble averages:

$$\bar{x}\ (t_i) = \text{average}\ [x(t_i)]$$

and the covariance:

$$C_{ij} = \text{covariance}\ [x(t_i),\ x(t_j)]$$
$$= \text{average}\ [x(t_i)-\bar{x}(t_i)].[x(t_j)-\bar{x}(t_j)]$$

If we can assume the average is o $(\bar{x}(t_i) = o)$

$$\text{then}\ C_{ij} = \text{average}\ [x(t_i).x(t_j)]$$

Then, because stationarity implies independance of statistical properties from the time origin,

$$C_{ij} = c(t_i - t_j)$$

If we compare the series with itself at one Δt later in time (ie, t_1 with t_2; t_2 with t_3, etc.), then two Δt later, up to l a g τ, we then define the covariance at lag τ as:

$$c(\tau) = \text{average } [x(t).x(t+\tau)]$$

which is the autocovariance function (similar operations produce the autocorrelation function), a time domain function. Sometimes we prefer to Fourier transform this into the frequency domain, and produce a graph called the spectrum. The spectrum is:

$$\text{Spectrum} = 2 \int_0^{\infty} c(\tau).\cos 2\pi f\tau.d\tau$$

when "m" is the number of lags and also the number of bandwidths, the plot of frequency vs. contribution to total variance is the v a r i a n c e spectrum, as in Jenkins and Watts (1968, p. 21). The spectrum gives a direct estimate of the contribution of various frequences, or frequency bands, to the variance of the original record. Thus a periodic or a p e r i o d i c sine curve of wavelength (λ) of 12 minutes will yield a spectrum with a peak at 1/12 = .083 cycles per minute. It is important to note that as m increases (relative to n), although we produce more line estimates, narrower bands, or better resolution, our confidence in the statistical significance of the estimates drops correspondingly. This is because of truncation, so that if m/n x 100 = 50%, for example as in Hanna and High (1970, p. 222), 50% of the original data is lost and the spectrum becomes "jittery". Tukey (1958) recommends < 10%, although slightly larger values are also advocated. A one-dimensional spatial series (eg. a land traverse) can also be so analyzed. If a series is compared not with itself, but a second series, the c r o s s - c o v a r i a n c e can be calculated. This is a complex quantity, made up of the product of the in phase (co-specturm) spectrum and the out of phase (quadrature) spectrum. The c o h e r e n c e specturm measures the frequency "correlation" between the series, and the phase spectrum shows lag or lead of the series at specific frequencies. Finally, poly-dimensional spectra can be computed, and this has led to startling results. (Consider, for example, Rayner and Golledge's 1971 (p. 66) empirical verification of Christaller's K = 3 net for the state of Iowa.) The power of the statistic, for those who remain dubious, can be illustrated by an example from Blackman and Tukey (1958, p. lv); they report significant resolution of an ocean wave off La Jolla, California, caused by the Indian Ocean, with = 1 km and amplitude = 1 mm!

3. APPLICATIONS

A - KARST HYDROLOGY

Any water quality data sampled regularily will be amenable to spectral analysis. This includes temperature, chemical quality, etc., and should reveal fundamental information about the aquifer. I have also extended Ashton's (1966) methods by treating a cave as a Black Box (Brown, 1973) and examining the cross-covariance and spectra of stage input and output of a large karst system in Western Alberta (Brown, 1972). Fig. 1 shows the cross-covariance which resulted, the output spectrum with a discernable 80 hr. peak as waves move through the system, and simultaneous dye test results (see also Brown 1971). The co-spectrum substantiated the hypothesis inferred from these: large unknown inputs to the system leave it 20 hours before the known input waves enter the system.

We are presently considering three-dimensional cave passage meanders, as information from these would extend considerably the work of Scheidegger (1970) and Yalin (1972) concerning river behaviour. By substituting solution for erosion, and eliminating g in phreatic tube formation, we hope to reach fundamental answers about river morphology.

B - CAVERN MICRO-METEOROLOGY

Plummer (1969) has provided a most useful example of spectral analysis in cave meteorology. It has been observed that some caves, and some passages within caves, have more or less regular wind reversals, with periods of the order tens of seconds. In the U.S., this is termed

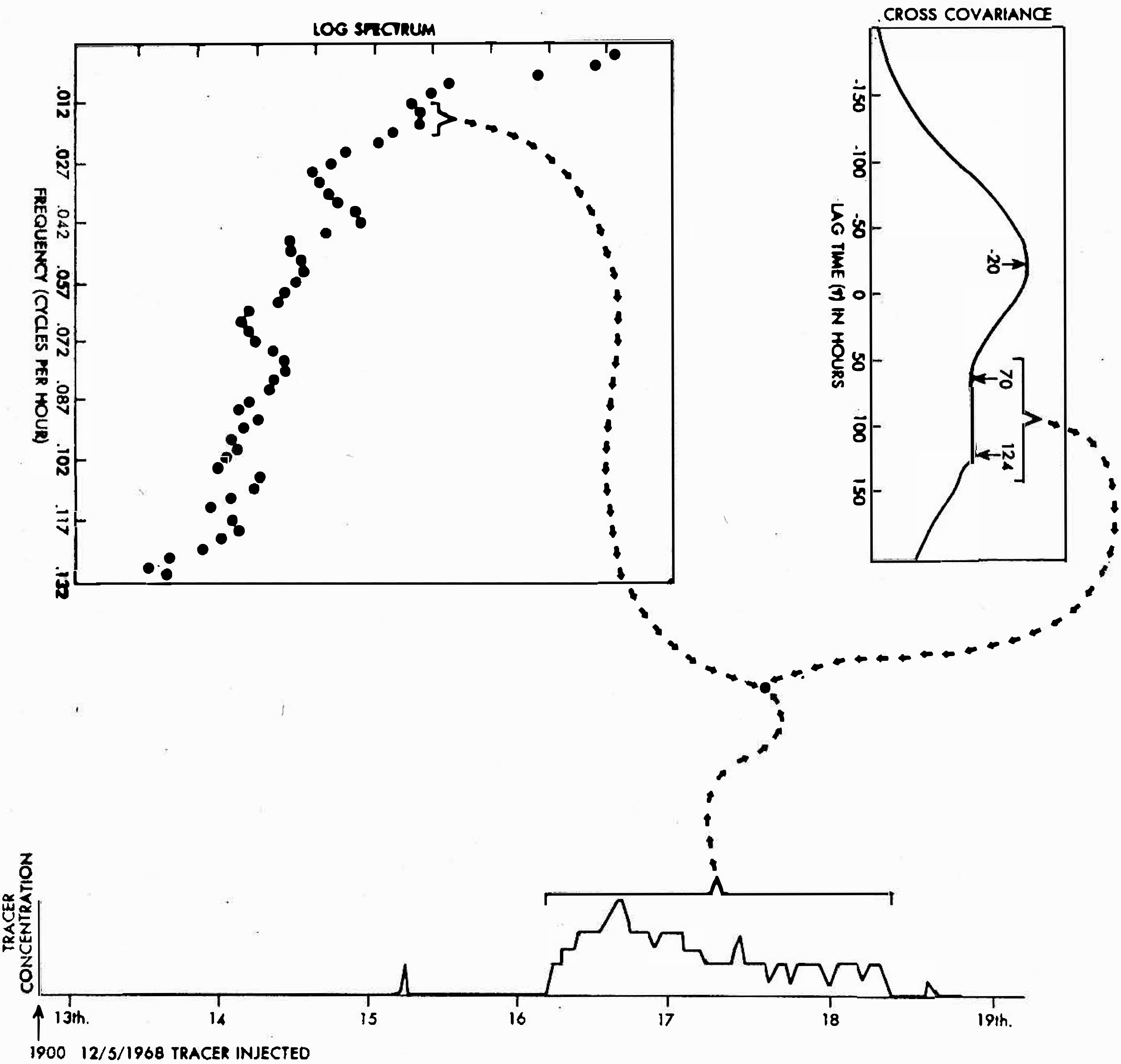

Fig. 1. Maligne Basin, Western Alberta. Input/Output Cross-Covariance (n = 400 2 hr. sample stages; m = 100); Output Log Spectrum; and Simultanecus Tracer Test (1.8 Kg Rhodamine WT).

precision, expensive laser optics), and indeed Fourier and other optical filtering and analysing systems are now widely used in remotely "cave breathing". Simple measurements have proven this to be Helmholtz-type resonation. Plummer has analysed the spectra of winds in caves, and proposes that these could be used to indicate the existence of chambers of various sizes and distances away from the measurement site.

C - PATTERN RECOGNITION

It is a feature of spectral analysis that it can be performed optically (advantages: speed, real-time filter changes; disadvantages: loss of sensed automatic pattern recognition. Given appropriate boundary filter conditions, I propose that karst landforms could be automatically identified by such features as round holes or enclosed basins, lineations on exposed limestones, etc.

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Ba 006

О ПРИМЕНЕНИИ КОЛИЧЕСТВЕННЫХ МЕТОДОВ ДЛЯ ОЦЕНКИ ИНТЕНСИВНОСТИ КАРСТОВОЙ ДЕНУДАЦИИ

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Количественная оценка интенсивности современных карстовых процессов позволяет прогнозировать особенности развития карста, что имеет важное научное и прикладное значение (Максимович, 1963; Гвоздецкий, 1970; Чикишев, 1971). Для определения скорости карстовой денудации применяются следующие методы: Корбеля, карстово-гидрометрический, Уильямса и карстово-гидрохимический.

Метод Корбеля. Скорость карстовой денудации карбонатных пород французский исследователь Ж. Корбель (Corbel, 1959) предложил определять по формуле:

$$X = \frac{4\ ET_n}{100}, \qquad (1)$$

где X - величина поверхностной карстовой денудации, $м^3/км^2$. год, или мм/тысячелетие; E - высота слоя стекающей воды, дм; T - содержание в воде карбоната кальция, мг/л; $\frac{4}{100}$ - коэффициент перевода весовых единиц в объемные через величину удельного веса $CaCO_3$ (2,5); n - коэффициент, показывающий, какая часть территории сложена карбонатными породами.

Величина подземной карстовой денудации вычисляется по формуле:

$$X' = \frac{4\ E'T'}{100} \qquad (2)$$

где X' - величина подземной карстовой денудации, $м^3/км^2$. год, или мм/тысячелетие; E' - высота слоя воды, стекающей под землей, дм; T' - содержание в подземных водах $CaCO_3$, мг/л.

По данным Ж. Корбеля, общая карстовая денудация представляет собой сумму поверхностной и подземной химической денудации, а также механической эрозии (на долю последней в горных странах приходится 50% от поверхностного растворения, а на равнинах - 10%).

По методу Корбеля была подсчитана скорость карстовой денудации для многих районов Земного шара, а также для различных карстовых участков Советского Союза (Костин, 1967; Беляк, 1968, Джишкариани, 1970). Она изменяется в широких пределах, причем с повышением местности на каждые 1000 м увеличивается примерно вдвое.

Карстово-гидрометрический метод предложен польским исследователем М. Пулиной (Pulina, 1968 а, 1968 б). Формула его имеет вид:

$$Д = \frac{12,6 \cdot QT}{P}, \qquad (3)$$

так как $$V = \frac{Q}{P} \cdot 1000, \qquad (4)$$

то $$Д = 0,0126 \cdot VT, \qquad (5)$$

где Д - скорость карстовой денудации, $м^3/км^2$ год, или мм/тысячелетие; Q - средний годовой сток, $м^3/сек$; T - содержание в воде растворимой карстующейся породы, мг/л; V - модуль стока, л/сек . $км^2$; P - площадь карстующихся пород, $км^2$.

Этот метод М. Пулина (Pulina, 1971) применил для подсчета скорости карстовой денудации многих карстовых районов, расположенных в зонах умеренного и субтропического климатов. Однако им не дается описание гидрометрического метода, а приводятся лишь конечные формулы. Возможно, он выведен эмпирически.

Название "гидрометрической метод" употребляемое М. Пулиной применительно к методу оценки интенсивности карстовой денудации, не совсем удачно, поскольку так называется один из гидрологических методов, широко применяемый при гидрогеологических, географических, а также и карстоведческих исследованиях. В Этой связи указанный метод правильнее и точнее называть карстово-гидрометрическим.

Независимо от М. Пулины нами было показано, что карстово-гидрометрический метод является модификацией метода Корбеля. Как известно, слой стока за определенный промежуток времени и с определенной площади равен (Давыдов и Конкина, 1958, стр. 281):

$$У = \frac{86400 \cdot TQ}{P \cdot 10^6} \cdot 1000 \qquad (6)$$

где У - величина слоя стока, мм; T - время, сутки; Q - расход потока, $м^3/сек$; P - площадь бассейна, $км^2$.

Подставляя это выражение в формулу Ж. Корбеля (1), получаем:

$$Д = \frac{4 \cdot 86400 \cdot 365 \cdot QT}{P \cdot 1000 \cdot 100 \cdot 100} \qquad (7)$$

$$\text{или} \quad Д = \frac{12{,}6 \cdot QT}{P} \qquad (8)$$

$$\text{и} \quad Д = 0{,}0126 \cdot MT , \qquad (9)$$

где Д – скорость карстовой денудации, $м^3/км^2$. год, или мм/тысячелетие; Q – среднегодовой расход, $м^3$/сек; Т – содержание в воде карбоната кальция, мг/л; Р – площадь бассейна, $км^2$; М – модуль стока, л/сек . $км^2$.

Карстово-гидрометрический метод впервые применен нами в 1967 г. для подсчета скорости карстовой денудации Валдайской возвышенности. Результаты этих исследований в мае 1969 г. были доложены на У1 пленуме карстовой секции АН СССР. Позже карстово-гидрометрическим методом нами была подсчитана скорость карстовой денудации для многих карстовых регионов СССР.

Подсчет карстовой денудации карстово-гидрометрическим методом осложняется несовпадением границ поверхностных и подземных водосборов. Это требует предварительного детального карстологического анализа изучаемой территории.

Интенсивность карстового процесса в значительной мере связана с объемом стока и поэтому сильно меняется по сезонам года и в разные годы, что хорошо выявляется при анализе данных, полученных, карстово-гидрометрическим методом.

Имея данные по сезонам года и за отдельные годы, можно проследить динамику карстовых процессов во времени. Что касается общего показателя скорости карстовой денудации, то он подсчитывается по среднемноголетним данным, причем чем больше ряд наблюдений, тем значение показателя ближе к действительной величине.

Таким образом, величина общего показателя интенсивности карстового процесса, полученная карстово-гидрометрическим методом, является осредненной как по территории, так и во времени.

Метод Уильямса. Кроме рассмотренных нами модификаций формулы Корбеля (8 и 9) существуют и другие. Наибольший интерес среди них представляет выражение, предложенное П.И. Уильямсом (Williams, 1963):

$$X = \frac{E\ (T_c + T_m)}{10\ D}, \qquad (10)$$

где X - скорость карстовой денудации, мм/тысячелетие; E - сток, дм; T_c - содержание в воде кальция, мг/л; T_m - содержание в воде магния, мг/л; D - плотность известняка.

Карстово-гидрохимический метод. Если объем выносимой из карстового массива породы отнести к площади, то равенство примет вид:

$$C = \frac{V}{P}, \qquad (11)$$

поскольку $$V = \frac{86400 \cdot 365 \cdot WT}{2,5 \cdot 1000\ 000\ 000}, \qquad (12)$$

то $$C = \frac{0,0126 \cdot WT}{P}, \qquad (13)$$

где C - скорость карстовой денудации, $м^3/км^2$. год, или мм/тысячелетие; V - объем выносимой из карстующегося массива породы, $м^3$; W - суммарный сток, л/сек; T - содержание в воде карбоната кальция, мг/л; P - площадь карстующихся пород, $км^2$.

Предлагаемый метод, названный нами карстово-гидрохимическим, удобен для подсчета карстовой денудации по данным сравнительно небольших поверхностных и подземных потоков.

Как показали исследования, метеорные воды имеют довольно значительную минерализацию (0,5-0,8 мг=экв.), составляющую до 10% и более конечной минерализации вод карстовых источников (Дублянский, 1967, Колодяжная, 1970). В этой связи интересно предложение М. Пулины (1968 а), который заменил T в формуле Корбеля на ΔT, обозначающее увеличение содержания в воде карбоната кальция при взаимоотношении атмосферных осадков с карбонатными породами или при пересечении реками карстовых массивов. Оно равно:

$$\Delta T = T_I - T_a, \qquad (14)$$

где T_I - минерализация карстовых вод; T_a - минерализация атмосферных осадков и транзитного стока.

Постоянная ошибка, равная 6-8% в сторону увеличения показателя скорости карстовой денудации, связана также с условным принятием удельного веса известняка за 2,5, тогда как в действительности он несколько выше. Для получения более точных значений интенсивности карстового процесса это обстоятельство следует учитывать.

Рассмотренные методы основаны на учете стока и содержании в воде растворимой карстующейся породы, поэтому они могут рассматриваться как модификационные варианты, учитывающие параметры основных составляющих скорости карстовой денудации.

QUANTITATIVE EVALUATION OF THE INTENSITY OF KARST DENUDATION

A. G. Chikishev

SUMMARY

The rate of karst denudation may be determined by one of the following techniques, that of: 1) Corbel, 2) Karst-hydrometric, 3) Williams, 4) Karst-hydrochemical. According to J. Corbel, a French scientist, the rate of karst denudation in carbonate rocks can be determined by means of the following formula: X = 4 ET/100. M. Pulina from Poland suggested his karst-hydrometric method expressed as D = 12,6 QT/P. But Pulina fails to describe his technique citing the final formulas alone. The author shows that the karst-hydrometric method is a modification of the offered by J. Corbel. Among other modifications of Corbel's formula rather interesting is that suggested by P. Williams (1963), which now looks as follows: $X = E(T_c+T_m)./10\ D$.

If the volume of the rock removed from the karst is correlated to some definite areas this equation will become as follows: C = V/P; since V = 86400 · 365 · T/2,5 · · 1000.000.000 we shall have C = 0.0126 WT/P. We have called the suggested technique as karst-hydrochemical. It is convenient to evaluate karst denudation on the data from comparatively small surface and subsurface karst flows.

By the Corbel technique and its modifications hased upon the flow volume and $CaCO_3$ content in water one can quantitatively determine the intensity of karst processes in carbonate rocks. The discussed techniques can be also applied when evaluating the rate of karst denudation in halogenic formations.

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СПЕЛЕОЛОГИЧЕСКОЕ РАЙОНИРОВАНИЕ СССР

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Спелеологическое районирование Советского Союза представляет собой трудную и в значительной мере новую задачу. Развернувшиеся в последние годы широкие спелеологические исследования позволили накопить значительный фактический материал об особенностях распространения карстовых пещер, их морфологическом строении и фазах развития. Это явилось основой для выделения спелеологических регионов, а также установления закономерных связей между морфоструктурными и биоклиматическими факторами карстообразования и особенностями распространения пещер. Однако слабая разработка вопросов о критериях районирования и признаках тексономических единиц разного ранга затрудняет составление карт спелеологического районирования.

Вопросы районирования пещер рассматривались в работах Н.А. Гвоздецкого, Б.Н. Иванова, Г.А. Максимовича, Л.И. Маруашвили, А.Г. Чикишева и других исследователей. Однако схема районирования пещер Советского Союза до сих пор не разработана.

Спелеологическое районирование является одним из видов специального комплексного карстоведческого районирования. Специфику его составляет локальное распространение подземных карстовых полостей, что связано с прерывистым развитием карстующихся образований. В задачу районирования пещер входит выявление объективно существующих спелеологических регионов разной величины и сложности, а также установление их естественных границ. В основу районирования должны быть положены морфоструктурные факторы. Биоклиматические условия как бы накладываются на литоморфную основу, обуславливая своеобразие подземных карстовых форм, интенсивность и направленность карстовых процессов.

Основываясь на этом принципе мы выделяем в пределах Советского Союза 12 спелеологических стран, 27 спелеологических областей и 38 спелеологических провинций. При более дробном районировании могут быть выделены спелеологические округа и районы.

Восточно-Европейская спелеологическая страна, территориально совпадающая с Русской равниной, характеризуется значительным распространением карстовых пещер, приуроченных к карбонатным и галогенным породам палеозойского, мезозойского и кайнозойского возраста. Наиболее широко карстовые пещеры распространены в Валдайско-Кулойской, Камско-Средневолжской, Прикаспийской и Днестровско-Причерноморской спелеологических областях, которые подразделяются на несколько карстовых провинций: Двинско-Мезеньская, Средневолжская, Уфимско-Камская, Дема-Уфимская, Западно-Прикаспийская, Восточно-Прикаспийская и Приднестровская.

В пределах Восточно-Европейской страны исследовано и закартировано 385 карстовых пещер. Наиболее крупные из них Оптимистическая (длина 92000 м), Озерная (80100 м), Крывченская (18785 м), Млынки (14120 м), Вертеба (7820 м), Кунгурская (5600 м), Ленинградская (3100 м) и Северянка (2500 м).

Особый интерес представляет пещера Оптимистическая, занимающая по общей длине подземных галерей первое место в СССР и третье в мире (после пещеры Флинд Ридж - длина 121000 м и Хеллох - длина 109182 м). Она располагается на левобережье Днестра близ с. Короливки. Пещера образовалась в тортонских гипсах. В ней выделяется три этажа. Галереи характеризуются различным морфологическим строением. На пересечении их в результате обрушения кровли формируются гроты. Самый крупный грот, расположенный в дальней части пещеры, достигает 80 м длины и 25 м ширины. Общая длина пещеры 92000 м. Средняя температура воздуха $8^{\circ},6$. Встречаются постоянные озера.

В пределах Уральской спелеологической страны выделяются Североуральская, Среднеуральская, Южноуральская спелеологические области, а также Западно-Североуральская, Восточно-Североуральская, Западно-Среднеуральская, Среднезауральская, Западно-Южноуральская и Центрально-Южноуральская спелеологические провинции. Здесь описано и закартировано более 420 карстовых пещер, приуроченных к палеозойским известнякам и гипсам. Наиболее крупные из них Сумганская (длина 8000 м), Дивья (3240 м), Хлебодаровская (2854 м), Капова (1900 м) и Шемахинская (1620 м).

Крупнейшая на Урале Сумганская пещера расположена в бассейне р. Белой. Она начинается шахтой глубиной 70 м и представляет собой сложный лабиринт горизонтальных и наклонных галерей и гротов, приуроченных к двум уровням. По центральной галерее нижнего этажа течет подземная река шириной 5 м и глубиной 2 м. Пещера отличается крупными гротами и обилием натечных образований. Суммарная длина ее 8000 м, глубина 135 м, объем 200000 $м^3$.

Карпатская спелеологическая страна. Восточные Карпаты выделяются в качестве самостоятельной спелеологической области, которая подразделяется на три провинции. Наиболее широко карстовые пещеры распространены в Центрально-Карпатской спелеологической провинции близ горы Драговский Менчул, где в высоких скалах, сложенных мраморизованными известняками верхней юры, исследовано 23 пещеры. Выделяется пещера Дружба, достигающая длины 220 м.

Крымско-Кавказская спелеологическая страна охватывает области Горного Крыма и Большого Кавказа. В горном Крыму исследовано более 700 пещер, приуроченных к карбонатным породам верхней юры. В том числе Красная (длина 13100 м), Солдатская (длина 1700 м, глубина 410 м), Узунджинская (длина 1500 м), Эмине-Баир (длина 1158 м), Молодежная (глубина 261 м) и Каскадная (глубина 246 м).

Наибольшей известностью пользуется пещера Красная, расположенная на западном склоне Долгоруковского массива в 23 км от г. Симферополя. Она образовалась в верхнеюрских известняках. В пещере выделяется шесть разновозрастных этажей. Для нее характерны крупные гроты и длинные широкие галереи, имеющие вид подземного каньона. По дну пещеры почти на всем ее протяжении течет подземная река, среднегодовой расход которой составляет 0,1 $м^3$/сек. Температура воздуха 9,8-11^о,6. Галереи верхних этажей богато украшены причудливыми натечными образованиями. Общая длина пещеры 13100 м, объем полостей 196400 $м^3$.

В спелеологической области Большого Кавказа выделяется три провинции Северо-Кавказская, Восточно-Кавказская и Горно-Колхидская, в пределах которых исследовано 620 пещер. Наиболее крупные из них Воронцовская (длина 8000 м), Буткова 1 (7000 м), Анакопийская (3285 м), Абрскила (2500 м), Снежная (длина 2500 м, глубина 770 м) и Географическая (длина 2500 м, глубина 510 м).

Знаменитая Анакопийская пещера находится близ Нового Афона. Она образовалась в известняках нижнего мела. Пещера состоит из двух морфологически резко различных частей - вертикальной (глубиной до 139 м) и горизонтальной. Горизонтальная часть пещеры представлена огромными гротами, соединенными между собой широкими и высокими проходами. Самый крупный из них грот Грузинских спелеологов достигает 260 м длины, 75 м ширины и 50 м высоты. В пещере имеются постоянные озера с площадью зеркала до 1000 $м^2$ и глубиной до 8 м. В некоторых гротах широко распространены натечные образования. Температура воздуха в горизонтальной части изменяется от 11,8 до 12^о,8. Суммарная протяженность Анакопийской системы 3285 м, а объем 1006600 $м^3$.

Особое положение занимает самая глубокая в Советском Союзе карстовая пропасть Снежная, расположенная на южном склоне Большого Кавказа в Бзыбском хребте. Верхняя часть ее до глубины 230 м почти сплошь покрыта многолетним льдом и снегом, что и определило название пещеры. Снежная представляет собой систему вертикальных, горизонтальных и наклонных колодцев и ходов. В ней выделяется пять гротов. Самый крупный из них Большой достигает 120 м длины и 70 м ширины. В Вертикальном лабиринте появляется ручей. Ниже он превращается в значительный поток с дебитом 20-30 л/сек, который местами образует причудливые водопады до 8 м высоты. На глубине 700 м при выходе из Водопадной галереи ручей впадает в крупную подземную реку с расходом до 500 л/сек. Эта река по ступенчатому проходу шириной 2-6 м стремительно несется вниз и исчезает в каменном завале, которым пока заканчивается пещера. Общая глубина пещеры 770 м, длина 2500 м, объем 150000 $м^3$.

Переднеазиатская спелеологическая страна охватывает Армянское нагорье, Туркмено-Хорасанские горы и Паропамиз. На территории Советского Союза она представлена частями двух спелеологических областей Нагорно-Армянской и Туркмено-Хорасанской, которые подразделяются на Нахичеванскую, Зангезурскую и Балхано-Копетдагскую провинции. Карстовые пещеры изучены слабо. Наиболее крупные из них Дашкалинская (длина 2000 м), Килитская (1000 м) и Бахарденская (250 м).

Туранская спелеологическая страна территориально совпадает с равнинами и плоскими плато Средней Азии. Пещеры наиболее широко развиты в пределах Устюртско-Мангышлакской карстовой области, которая подразделяется на две спелеологические провинции Мангышлакскую и Устюртскую. Здесь исследовано 70 карстовых пещер. Наиболее крупная Омаратинская (длина 342 м).

Памиро-Тяньшанская спелеологическая страна включает горные системы юго-востока и востока Средней Азии. Она подразделяется на три спелеологические области: Тяньшанскую, Гиссаро-Алайскую, Памиро-Таджикскую и четыре провинции: Туркестано-Алайскую, Зеравшано-Гиссарскую, Западно-Таджикскую и Памирскую. В пределах страны описано 236 карстовых пещер. Наиболее крупные из них Капкотан (длина 6000 м), Канигут (3000 м), Карлюкская (1050 м) и Яккабагская (600 м).

Пещеры Тургайско-Казахстанской спелеологической страны, охватывающей Тургай и Центральный Казахстан, исследованы крайне слабо. Среди них наибольшей известностью пользуется пещера Конураулие, достигающая длины 120 м.

Алтае-Саянская спелеологическая страна подразделяется на четыре области: Алтайскую, Салаиро-Кузнецкую, Саянскую, Тувинскую и семь провинций: Западно-Алтайскую, Центрально-Алтайскую, Восточно-Алтайскую, Кузнецко-Алатаускую, Западно-Саянскую, Минусинскую, Восточно-Саянскую.

В пределах Алтае-Саянской страны исследовано 460 карстовых пещер. Наиболее крупные из них Большая Орешная (длина 11000 м, глубина 160 м), Баджейская (длина 5500 м, глубина 170 м), Кубинская (длина 2500 м, глубина 274 м), Торгашинская (длина 1500 м, глубина 174 м), Бородинская (длина 1020 м), Белая (длина 900 м, глубина 100 м) и Музейная (длина 700 м).

Пещера Большая Орешная расположена на левом берегу р. Таежный Баджей близ. пос. Орешное. Она развита в карбонатных конгломератах ордовика. В пещере выделяется три этажа. Гроты в основном небольшие, площадь наиболее крупного из них составляет 2400 $м^2$. В гроте Каменном имеется ручей с дебитом 2,5 л/сек. В самых низких частях пещеры встречаются небольшие озера. Натечные образования представлены красивыми сталактитами, сталагмитами и полупрозрачными драпировками. Общая длина пещеры 11000 м, глубина 160, объем 120000 $м^3$.

Средне-Сибирская спелеологическая страна включает Средне-Сибирское плоскогорье, Северо-Сибирскую низменность и горы Бырранга. Карстовые пещеры наиболее широко развиты в южной части территории, которая выделяется в качестве Ангаро-Ленской спелеологической провинции, входящей в Лено-Енисейскую область. Здесь выявлено более 80 пещер. Наиболее крупные среди них Худугунская (длина 3000 м), Балаганская (1200 м), Нижнеудинская (550 м).

Байкало-Становая спелеологическая страна охватывает Прибайкалье, Забайкалье, Становой хребет и хребет Джугджур. Карстовые пещеры наиболее широко распространены в Байкальской, Забайкальской и Джугджурской областях. Здесь исследовано 85 карстовых пещер, в том числе Института географии Сибири (длина 870 м), Лургиканская (200 м) и Соткуйская (130 м).

Дальневосточная спелеологическая страна распологается на крайнем юго-востоке Советского Союза. В ее пределах выделяется две области Приамурская и Приморская. Карстовые пещеры наиболее широко распространены в Хингано-Буреинской, Северо-Сихотеалиньской и Южно-Сихотеалиньской провинциях. Здесь исследовано 116 пещер. К наиболее крупным пещерам относятся Приморская (длина 800 м), Спасская (760 м) и Мокрушинская (150 м). Интересна шахта Белая глубиной 100 м, расположенная недалеко от бухты Ольга.

Предлагаемую схему районирования пещер Советского Союза, представляющую собой первый опыт такого рода исследований, необходимо рассматривать как предварительную, поскольку она не исчерпывает возможностей более дробного расчленения территории и нуждается в уточнении границ выделенных спелеологических регионов разного таксономического ранга.

SPELEOLOGICAL REGIONALIZATION OF THE USSR

A. G. Chikishev

SUMMARY

Speleological regionalization of the USSR is a difficult and considerably new task. The wide speleological research particularly intensive lately has made it possible to accumulate many facts on the specific distribution of karst caves, their morphological structure and evolution phases. Meanwhile, up to now no scheme of cave regionization in the Soviet Union has been elaborated yet.

A complex speleological regionization should reveal objectively existing speleological regions of different size and complexity and also fix their natural borders. 12 speleological countries, 27 areas and 38 provinces have been distinguished by the author in the territory of the Soviet Union on the account of geographical and geological conditions of karst caves, intensity and direction of karst processes.

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СПЕЛЕОЛОГИЧЕСКИЕ ИССЛЕДОВАНИЯ СВИРЛИШСКОЙ КОТЛОВИНЫ

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Сврлишская котловина является одной из поперечных котловин в Карпато-балканской горной дуге Восточной Сербии. Она тектонически спущена среди Сврлишских гор на юге и Девицы и Тресибабы на севере. Обод этой котловины главным образом из нижнемеловых, отривских и бамемских известняков а дно котловины покрыто толстыми слоями озерных миоценовых отложений. В гидрографическом отношении, Сврлишская котловина принадлежит бассейну Сврлишского Тимока.

Активность карстового процесса в известковой местности краев Сврлишской котловины способствовало, кроме возникновения поверхностных карстовых форм, еще и созданию многочисленных пещерных каналов. Спелеологическими обследованиями было охвачено восемь наиболее инересных пещер этой области, как то: Преконошка Печина, Велика Печ, Равна Печ, Кулска Печина, Пештерина, Валивода, Понор у Пандирала и Црнолевичка Печина. В этой работе мы дадим основные резултаты этих исследований (рис. 1).

Преконошка Печина находится на левой стороне долины Преконошке Реки в 2 километров южнее села Преконоге. Отверстие пещеры находится на 130 метре над уровнем речного русла, а длина пещерного канала равняется 370 метрам. Натечные минеральные образования в пещере весьма богаты и разнообразны, так что Преконошка Печина является одной из самых красивых пещер Сербии. В средней части пещеры, около "Джердапа" сохранились слои глины - осадок бывшего когда-то здесь пещерного русла. Эту пещеру подробно исследовал И. Цвийич, а в наше время план пещеры сделала группа института исследования карста из Постойны (Цвийич И. в 1891 году, Претнер Е. в 1959). В ней найдены остатки пещерного медведя и каменные орудия палеолитской эпохи (Бродар С. 1954).

Велика Печ. Отверстие этой пещеры находится лишь в 20 метрах от Пещеры Преконошка. Общая длина пещерного канала равняется 76 метрам. Принимая во внимание непосредственную близость канала этой пещеры можно предположить их генетическую связь.

Равна Печ. Приблизительно на пол-километра к северо-западу от

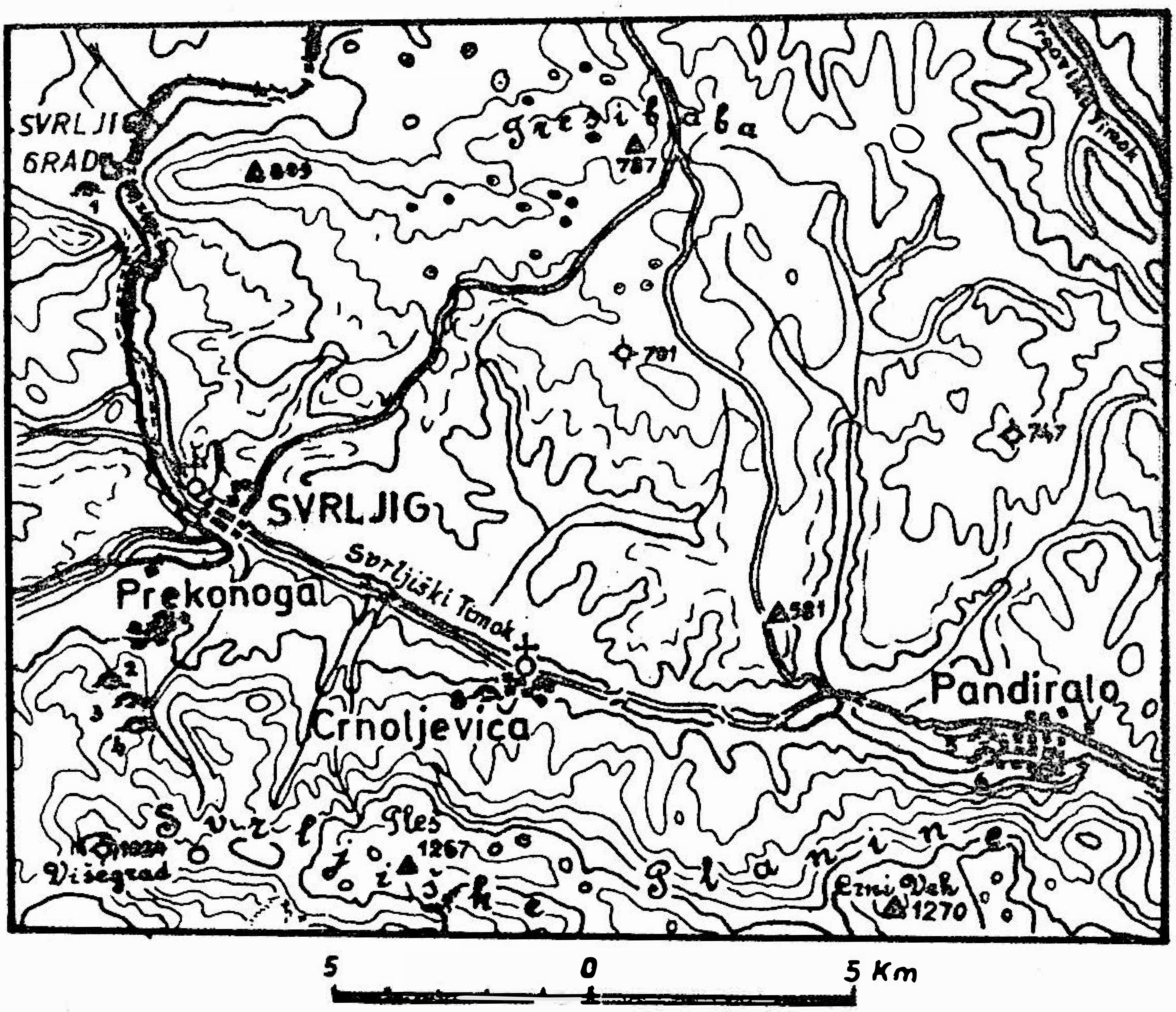

Рис. 1. Положение пещер в Сврлишской котловине. л. Кулска Печина, 2. Равна Печ, 3. Преконошка Печина, 4. Велика Печ, 5. Пештерина, 6. Валивода, 7. Понор у Пандирала и 8. Црнолевичка Печина.

входа в пещеру Преконошка, на дне асиметричной воронки находится вход в пещеру Равна Печ. Длина пещерного канала - 110 метров, а в задней ее части, по обеим сторонам, выделяются узкие эрозионные террасы на двух уровнях, несомненно эрозионного происхождения. Это, как и наличие глинисто-илистых осадков на дне пещерного канала указывает на участие речного течения при формировании этой пещеры.

Кулска Печина. Под развалинами средневековного города Сврлига, по левую сторону ущелья Сврлишского Тимока находится пещера Кулска Печина, длиною в 75 метров. Ее вход прямоугольной формы и находится в 180 метрах над уровнем Сврлишского Тимока. Следы эрозионной работы сохранившиеся в первой входной части канала пещеры потверждают что и эта пещера речного происхождения. Ее развитие было в непосредственной зависимости от эволюции продольного профиля Сврлишского Тимока, т.е. скорости его размыва.

Црнолевичка Печина. Под известковым разрезом с левой стороны долины временного водотока, близ села Црнолевице находится отверстие пещеры, из которого водоток вытекает. Оно расположено на 360 метров апсолютной высоты. Через канал пещеры частично проходит водоток, и то в его передней и задней части, которая заканчивается сифонной формой. В начале коридор пещеры раздваивается на верхний и нижний уровень, которые затем снова соединяются. В многих местах на дне верхнего канала находятся щели связывающие верхний и нижний каналы. Кроме двух упомянутых каналов, чья длина равняется 81 метру, существует и третий, самый низкий канал, по которому в настоящее время вода протекает от понора до истока (Динич Й. 1965).

Понор сврлишского Тимока у Пандирала. Канал этой пещеры отличается простой морфологией, характерной для понорных пещер. Его стенки отшлифованы с небольшим эрозивными террасами и углублениями. При входе в канал, дно его покрыто крупными булыгами. При дальнейшем проникновении в понор, на каменистом дне обнаруживаем наносы песка и ила. Проникновение в понор возможно лишь в период затяжных засух, когда Сврлишский Тимок теряет воду сквозь щели, на дне русла, вверх по течению от понора. Общая длина обследованной части канала равняется 165 метрам.

Пещеры у истока Сврлишского Тимока. В 500 метрах вниз по течению от понора Сврлишского Тимока, его потом вырывается из отверстия пещеры ввиде сильного карстового источника, на высоте в 520 метров. Он находится при дне каменистого амфитиатрального склона, которым кончается сухая висячая долина между понором и истоком. Фактически, это - часть долины Сврлишского Тимока, которая разложена и превращена в ряд воронок.

Со стороны этого склона, против существующего истока, находятся входы двух пещер Пештерины и Валиводы.

Вход в пещеру Валиводу находится в 25 метрах над существующим истоком. Пещерный канал имеет длину в 82 метра, спускается к внутренней части и заканчивается пространным залом, в котором находится озерко с водой и илистый нанос.

Несколько метров ниже, в непосредственной близи, находятся два входа в пещеру Пештерина. От них ведут каналы, которые в 15 метрах от входа соединяются, а общая длинна их равняется 48 метрам.

МОРФОЛОГИЧЕСКАЯ ЭВОЛЮЦИЯ И ВОЗРАСТ ПЕЩЕР

Все упомянутые пещеры в Сврлишской котловине несомненно речного происхождения. Их каналы образовались под механическими и химическими воздействиями подземных водотоков, которые создавались из первоначальных шелевых систем в известняке. Ввиду того, что развитие продольных профилей этих водотоков непосредственно или с его притоками связано с продольным профилем Сврлишского Тимока, устойчивые флювиальные уровни (определяющиеся по речным террасам) являлись нижним базисом эрозии пещерных водотоков. На основании генетической корреляции уровней отверстий пещер (относительной высоты) и речных террас в долине Сврлишского Тимока, определен возраст всех сухих пещер. Пещеры с временным или постоянным водотоком все еще находятся в зависимости от эволюции их продольных профилей, так что по возрасту значительно младше прежних.

Самой старой пещерой в Сврлишской котловине является пещера - Кулска Печина. Относительная высота ее входа (180 метров) указывает на то, что она сформировалась прежде самой высокой речной террасы в 130 - 150 метров, т.е. в течение верхнего плиоцена (Динич Й. 1973 г.).

С уровнем речной террасы в 130 - 150 метров, которая сформировалась в период верхнего плиоцена, связанно возникновение пещер Преконошка Печина и Велика Печ. Приблизительно такого же возраста и Равна Печ, так как ее вход находится на дне воронки, на дне висячей окарстованной долины. Ввиду того что ее висячее устье находится в 140 метрах над теперешним водотоком, окарстование этой долины произошло конечно на речном этапе в 130 до 150 метров.

О значительном возрасте приведенной группы пещер, свидетельствуют и крупные осадки травертина и разнообразные пещерные натеки, которыми покрыты пол, потолок и стены их пещерных каналов.

Понор Сврлишского Тимока у Пандирала и группа пещер у истока Сврлишского Тимока - значительно моложе. Их возраст определяется по уровню дна фосилной окарстованной долины между понором и истоком Сврлишского Тимока, которая сейчас превращена в ряд воронок. У понора дно фосилной долины имеет относительную высоту в 20 метров, а над истоком - 30 метров, что соответствует речной террасе в 25 - 35 метров. Имея ввиду тот факт, что эта терраса - довюрмского возраста (Петрович Д. 1970), можно сделать вывод что разложение этой сухой долины произошло до Вюрма. Пещеры Пештерина и Валивода, при истоке Сврлишского Тимока представляют высшие уровни его истоков, которые сейчас вне гидрологической функции. Она единственно сохранилась в верхнем зале ввиде маленького озера. На основании этого и ила, который покрывает дно этого вала, Цвийич с правом считает: "что вода из пещеры по которой протекает Сврлишский Тимок пробивается в зальце пещеры Валивода но вода тут никогда не поднимается настолько, чтоб могла быть наружу через отверстие" (Цвийич Й. 1891 г.).

Все высше изложеное указывает на типичный пример подземной бифуркации пещерного канала понора Сврлишского Тимока, которая определяется по опущению Сврлишского Тимока.

По времени своего возникновения, пещера Црнолевичка Печина - самая молодая. Через нее и сейчас еще частично протекает водоток, который при максимальной водности, заполняет все уровни каналов. Поэтому ее водоток все еще активный агенс, определяющий дальнейший ход ее развития. При этом характерно то, что несмотря на формирование пещерного канала на трех уровнях, и бифуркации подземного тока, все же не было вертикального опущения пещерного отверстия. Это-то и потверждает зависимость продольного профиля пещерного тока от развития продольного профиля временного протока, с которым он связан. Так же нужно иметь ввиду и присутствие неогеновых миоценских осадков, исполняющих роль относительных запрудов, как это определил Д. Петрович (Петрович Д. 1970 г.).

Связывая возникновение и формирование пещер с развитием карста в Сврлишской котловине вообще, нельзя терять из вида что сам литологический состав известняка, принимая во внимание его однородность, не влиял существенно на различие интенсивности и характера карстового процесса. Значительно больше влияние имели миоценские осадки, которые, после исчезновения Сврлишского неогеного озера достигали немалой высоты, свыше 650 метров, а и больше. Они исполняли роль запрудов, замедлявших развитие карстового процесса, особенно вдоль северной, более низкой части известнякового обола Сврлишской котловины. По мере постепенного снижения уровня запрудов, в зависимости от интенсивности флувио-денудационных процессов, сукцесивно возрастает карстовый процесс и подземная карстовая циркуляция, а тем самим и создание пещерных каналов.

Вторым важным фактором, определяющим интенсивность и характер карстового процесса, были климатические условия. После продолжительного периода умеренно-топлого и умеренно-влажного климата, который являлся переходным типом между медитеранским и саванским климатами (Пантич Н. 1956 г.), (Милич Ч. 1962 г.), в конце плиоцена произошло похолодание. В течение дилювия, от гинца до риса, чередовались медитеранский и средне европейский климаты, а в вюрме - средне-европейский и степной (Милич Ч. 1962 г.). В течение ледниковых глядиалов, температуры воздуха приблизительно на 6° ниже теперешних (Вольдштет П. 1954 г.). Тогда создались наиболее благоприятные условия для развития карстового процесса. Оподзоливанием красных почв и других типов почв, они становятся более водопроникаемыми, а агресивность вод вследствие холодов значительно увеличена (Милич Ч. 1965 г.).

Постепенным снижением уровня запрудов и приведенным климатическими переменами прогрессивно улучшаются условия для развития карстового процесса. Таким образом на известняковой местности Сврлишской котловины, этот процесс все больше вытесняет флювиальный процесс, разлогая речную сеть. По мере ее опускания в глубь известняковой массы и активной механической и химической работы создаются упомянутые пещеры. Среди факторов, вызывающих их морфологические различия и различный возраст. Кроме уже упомянутых, необходимо подчеркнуть и различную степень фисурации известняка и развитие первоначальных систем трещин, а так же и продолжительность карстового процесса.

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О СПЕЛЕОЛОГИЧЕСКИХ ОСОБЕННОСТЯХ ИЗВЕСТНЯКОВОГО МАССИВА АСХИ (Западная Грузия)

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Известняковый массив Асхи, расположенный в междуречье Техури-Цхенисцкали, занимает периферическую часть южного склона Большого Кавказа и является одним из наиболее высоких и обширных карстовых массивов Грузии. Площадь массива - 450 км^2, а его высшая точка Годиракили имеет высоту 2519 м.

Массив представляет собой платообразное нагорье с тектогенными формами рельефа. Северная ступень представляет собой синклинальную впадину Квибиа (длиной 12 км) и плато Майдани, а южная ступень осложена синклинальными польями Турчу-Дидгали и эрозионными каньонами р.р. Цачхури, Абаша, Окаце и др. Северная и восточная границы массива обозначены высоким (более 300 м) обрывом.

В строении геологического комплекса массива большую роль играют меловые карбонатные отложения. Здесь представлен полный разрез мела, от валанжина до датского яруса включительно, мощность которого более 1500 м (Джанелидзе, 1941).

Массив является сложной тектонической единицей. Геологический комплекс массива располагается в Сухуми-Душетской зоне южного склона Большого Кавказа. Массив обнаруживает все признаки глыбовой тектоники и состоит из двух глыб: на севере - глыба Квибиа-Майдани, а на юге - глыбы Турчу-Кинчха, занимающая более низкое гипсометрическое положение. Вся структура в целом имеет горст-антиклинальный характер (Гамкрелидзе, 1957).

Спелеологическую особенность массива обусловливают: геолого-геоморфологическое строение района, развитие складчатых и дизъюнктивных структур, расположение его на разных гипсометрических уровнях, обилие атмосферных осадков (более 2000 мм), химическая чистота карстующихся пород и повышенная трещиноватость. Наиболее развиты системы трещин с азимутами простирания ССВ-ЮЮЗ и В-З, расположенные между собой почти под прямым углом. На примере массива Асхи подтверждается общее теоретическое положение о том, что в районах, сложенных карбонатными породами, карстопроявление связано только с трещинной водопроницаемостью.

Интенсивность закарстованности на массиве весьма высока. Напр. плато Майдани, котловина Квибиа, плато Табакела, Урочище Дидкарави, Сачиквано и др. характеризуются обилием как поверхностных (карры, воронки), так и глубинных форм (колодцы, шахты, пещеры) т.к. на западной окраине массива, по мере увеличения уклонов поверхности, интенсивность закарстовывания уменьшается (Огедже, р-н Шакби и др.). Таким образом, подтверждается, что топографический фактор играет первостепенную роль в пещерообразовании в горных районах (Гвоздецкий, 1972); Тинтилозов, 1969).

На 1.1.1973 г. на массиве обнаружено и исследовано 79 полостей (38 колодцев и шахт и 41 субгоризонтальная пещера). Суммарная длина всех полостей массива составляет 3409 м при суммарной глубине 1383 м. Площадь дна пещер равняется 16.300 м^2, а объем пустоты 192.500 м^3. Густота пещер на массиве 1064 на 100 км^2, а плотность - 17,5 на 100 км^2.

Выявлены некоторые закономерности в пространственном распределении карстовых форм. Лабораторными исследованиями подтверждено, что химической чистотой здесь отличаются известняки баррема и турон-сенона. Вертикальные полости в основном приурочены к массивным известнякам баррема, а субгоризонтальные пещеры к горизонтально залегающим известнякам турон-сенона.

Как в горизонтальных, так и в вертикальных полостях массива плохо выражена ярусность. Это объясняется положением массива в зоне активных неотектонических поднятий.

Вследствие движений, карстовые полости не успевали прорабатываться (Тинтилозов, 1968).

В пещерах массива можно выделить разнообразные генетические типы отложений: 1. тип хемогенных отложений, слагающийся из двух подтипов: натечных образований и отложений из водных растворов (пещеры Тоба 1, им. А. Окроджанашвили, Тоба IV, Мотена, Джорцку, Инчхурис Кваби и др.). 2. аквальные механические осадки, слагающиеся из аллювия пещерных рек, отложений пещерных озер и кольматационных осадков (Тоба 1, Мотена, Джорцку Дзедзви, Ргвеули, Цкаро и др.). В пещере им. Окроджанашвили, в конце зала "Университет - 50", встречаются крепко сцементированные галечники (8-14 см диаметра), мощностью 3 м. Степень обработки галечников указывает на то, что они транспортированы мощными подземными потоками со значительного расстояния; 3. Обвальные накопления (Рехи, Мотена, Тоба 1, им. Окроджанашвили, Тоба IV, Рачха, Диди гарами, Дидгали и др.). 4. Органогенные отложения в виде гуано, скопления костей животных (Дзедзви, Бегела, Сацереко, Патара Гарами и др.); 5. Антропогенные отложения, содержащие многочисленные остатки стоянок первобытных людей (Джорцку, Цачхури, Тоба Ш, Бегела, Лесхулухе, Мотена и др.), 6. Криогенные отложения в виде снега, фирна, метаморфизованных и сублимационных натечных льдов (Котанцкали, Дидиква, Дакидули, пропасть Майдани, Сациви и др.; Джишкариани, 1971).

Микроклиматические особенности пещер массива определяются гипсометрическим фактором, а очень часто формой полостей. В пещерах, расположенных на низких уровнях, наблюдается сравнительно высокая температура (14,5-12,5^{O}), а в полостях, расположенных выше 1600-2000 м, температура достигает 6-5,0^{O}. В некоторых из них она даже отрицательная, что способствует сохранению криогенных отложений в них в течение всего года (Кипиани и др., 1966).

Сравнительно высокая температура воздуха (12,0-5,0^{O}) и другие благоприятные экологические условия способствовали заселению этих полостей пещерной фауной. Некоторые из них являются эндемичными для Кавказа.

Почти во всех пещерах, за исключением шахт Майдани, обитает Dolichopoda euxina Sem. В подземных потоках и водоемах обитают бокоплавы (Niphargus sp.). Во многих пещерах массива Асхи выявлены следующие представители подземной фауны: в пещере Лесхулухе - Oligochaeta; Isopoda; Aranei; Acarina-Ixodes vespentilionis; Eulaelaps stabulatoris; Collembola-Onychiurus, Plutomurus. В пещере Джорцку - Oligochaeta-Lumbricidae; Aranei; Diplopoda; Collembola-Willowsia buski; в пещере Мотена - Amphipoda-Zenkevitchia revasi; Aranei; Diplopoda; Diptera; в пещере Инчхури - Copepoda-Moraria vatica; Isopoda; Aranei; Collembola-Onychiurus (Джанашвили, 1971).

Массив Асхи представляет собой обособленный карстовый массив с проявлением центробежного стока. Источники приурочены к разным гидродинамическим зонам и гипсометрическим уровням, порой вытекают из горизонтальных пещерных галереи и образуют великолепные водопады высотой в 40 (Тоба 1) - 105 (им. Окроджанашвили).

В массиве хорошо выражены следующие гидродинамические зоны: аэраций, сезонного колебания уровня, полного насыщения и глубинной циркуляции. Всотный диапазон между областями питания и разгрузки карстовых вод варьирует в пределах 1200-1800 м.

Основные источники массива - Цачхури (0-2,53 м^{3}/сек, т - 8^{O}; у с.

Салхино - 9,04 $м^3$/сек); Рачха (Q-1,18 $м^3$/сек; т - 7,6^o); Тоба (Q-1,43 $м^3$/сек, т - 10,2^o); Джоноула (Q-0,88 $м^3$/сек, т - 5,8^o); Чери (0,125 $м^3$/сек, т - 10,9) и др. Эти воды в основном, кальциево-гидрокарбонатные. Содержание отдельных ионов изменяется в следующих пределах (мг - экв): гидрокарбонат - 81-95; Са - 81-91,5; Mg - 5-15; Na - 4-9; общая минерализация 257-334 мг/л (Джишкариани, 1971).

Дебит карстовых источников на массиве в среднем более 11 $м^3$/сек, а суммарный сток рек, дренирующий массив, более 33 $м^3$/сек (Владимиров, 1963, Гигинейшвили, 1965).

На современном этапе гидрогеологического развития массива единой уровенной поверхности подземных вод не наблюдается. Они циркулируют обособленными потоками.

SPELEOLOGICAL PROPERTIES OF LIMESTONE MASSIF ASKHI

V. M. Jishkariany

SUMMARY

The article deals with basic speleological properties of Askhi massif, its´ genetic types of cave deposits and hydrodinamic peculiarities of underground waters.

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NUEVO METODO EN LA INVESTIGACION DEL KARST, LOS MODELS NATURALES Y LA CONVERGENCIA DE FORMAS

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1. EL PROBLEMA ACTUAL EN EL KARST - DESENFOQUE DIALÉCTICO

La Karstología como cualquiera otra de las ciencias de la naturaleza se fundamenta en una filosofía particular, definible como lógica reductiva que lleva implícito el fenómeno aleatorio.

Se basa pues en la observatíon y experimentacíon, de la que la adquisicíon de informacíon e interpretacíon subsiguiente se acercará tanto más a la realidad cuanto mayor sea la populacíon de datos sobre los que dicha interpretacíon se apoya la cual, como ya hemos dicho, está sujeta a las leyes de la probabilidad.

Si la bases científicas en las que se apoya nuestra jóven Karstología fuesen sólidas y fundamentadas cabría esperarse, a tenor de la lógica reductiva en que se fundamenta, que al estudiarse una regíon determinada por diversos especialistas, estos pudiesen discrepar entre sí al principio, cuando la respectiva informacíon adquirida tuviera un bajo peso estadístico, pero a medida que éste aumentase al crecer la cantidad de informacíon, los resultados comenzarán a parecerse para llegar a ser muy semejantes al finalizarse sus respectivos estudios. Como por desgracia esto casi nunca ocurre, sospechamos que la deficiencia está en la base.

Además la Karstología tiene una particularmente delicada impostacíon entre otras disciplinas, que afecta a su desarrollo, al estar situada a caballo entre varias fronteras dentro de ese artificial encasillamiento que el hombre ha sometido a la naturaleza para enmarcar el campo de desarrollo de cada ciencia.

En primer lugar quienes están en condicíon más favorable para adquirir la necesaria informacíon son los espeleólogos, sin embargo en ciertos países su actividad está cuajada de móviles deportivos por lo que no debe exigírseles demasiado a pesar de su buena disposicíon, ya que muchas veces su condicíon de tales no implica la necesaria formacíon científica que el caso requiere.

Dentro del mundo científico, se ocupan del Karst dos grandes grupos de investigadores, los hidrogeólogos de un lado y los geomorfólogos de otro. Como los objectivos que se plantean no son comunes, ya que los primeros son de índole pragmática, casi técnica, al par que más pura y mediata los segundos, resulta que existe frecuentemente un olvido mutuo bastante notable entre ambas especialidades del que sale perjudicado el estudio del Karst, como consecuencia de un planteamiento incompleto. Aunque en algunos países se aprecian esfuerzos de coordinacíon entre organismos ingenieriles y universitarios, que en cierto modo representan ambas tendencias, queda todavía un largo camino por recorrer.

Por otro lado existe intrínsecamente en el Karst un obstáculo que dificulta extraordinariamente su estudio. Efectivamente, influyen en el proceso de la karstificacíon numerosos factores de diversa índole, entre los que merecen destacarse los físico-químicos, geológicos, climáticos, bioquímicos, hidráulicos, geotécnicos, etc. por sólo citar unos cuantos; este variopinto panorama precisa de especialistas que lo sean en todas y cada una de las materias, para abordar adecuadamento los problemas.

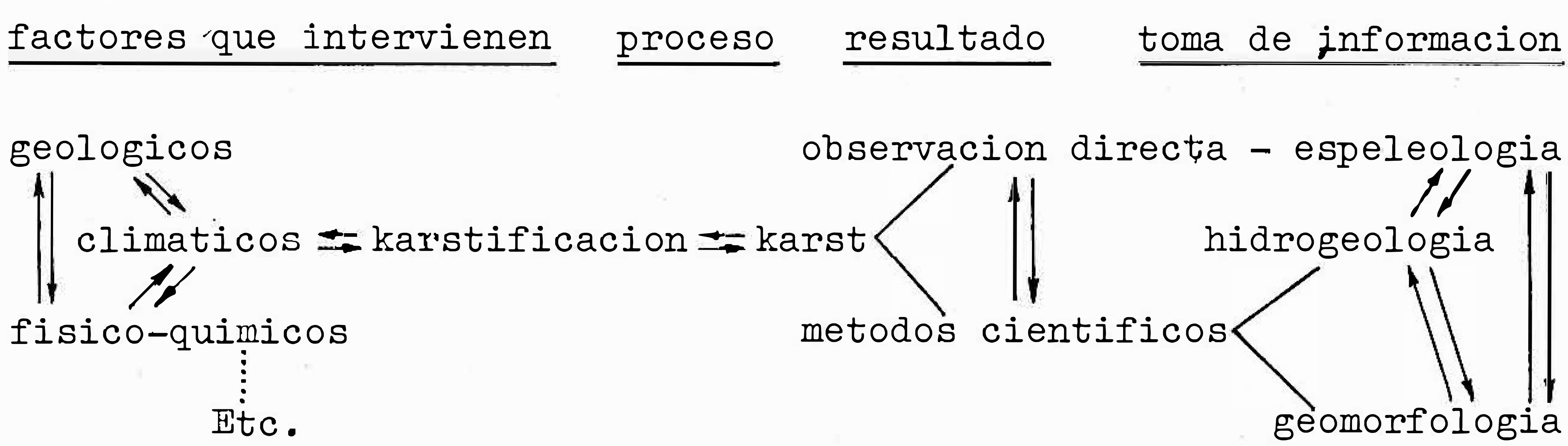
Como esto es muy dificil de reunir en una sola persona, resulta evidenta que el Karst debe ser estudiado en equipo para que realmente se obtengan fructos.

Otra cuestíon que tampoco favorece el panorama que estamos pintando, es la propia cinética de la disolutíon de las rocas calizas en la agua, la cual es tan sumamente lenta que dificilmente pueden apreciarse cambios notables en el corto espacio que en comparacíon supone la vida humana. Esto dificulta enormemente la experimentacíon directa al tener que usar tiempos de observacíon tan largos.

Pero todavía la dificultad no termina aqui, puesto que lo más notable en el Karst es que de la actuacíon de los diferentes factores del proceso de la karstificacíon, resultan formas específicas que a su vez afectan al proceso, modificando las condiciones anteriores, es decir, que estos factores no son independientes sino que actúan interrelacionados durante todo el proceso, y que a su vez el resultado de este proceso influye estos factores.

En otras palabras, que en el proceso de la karstificacíon existe implicito un f a c t o r d e i n t e r r e l a c í o n como consecuencia del cual la acción de los diferentes factores citados no debe estudiarse nunca aisladamente, sino simultáneamente para poder avanzar en su conocimiento, cosa que hasta ahora creemos no se ha hecho.

A esta falta de visión nos referimos cuando calificamos la situación actual de d e s e n f o q u e d i a l e c t i c o, que podría subsanarse siquiendo esquemas conceptuales adecuados, como por ejemplo:



en el que las flechas en doble sentido representan la interrelación citada.

2. UN NUEVO ENFOQUE EN SU INVESTIGACIÓN

La naturaleza, a la que nunca observamos lo suficiente, en perfecta concordancia con las leyes que la gobiernan, nos envía numerosos mensajes, alguno de los cuales adecuadamente captados nos muestran caminos que reducen en alto grado muchos de los problemas que el estudio de sus mecanismos nos plantea.

A - LA CONVERGENCIA DE FORMAS COMO MODELO NATURAL

Ocurre en la naturaleza de manera evidente y reiterada que determinada forma de resultados de una acción geodinámica cualquiera se presente en materiales de los más diversos tipos.

Así por ejemplo, pueden observarse secciones idénticas de conductos y galerías en cavernas excavadas en materiales como caliza, yeso, sal, basalto, hielo, etc. cuyas litologías son básicamente diferentes.

También se encuentran facilmente en diversas litologías, formas específicas, algunas muy estudiadas como huellas, de corriente, "pendents" freáticos, canales de disolución, corrosión por mezcla de aquas, algunas formas de lapiaz, etc.

Peor no solamente la semejanza de formas existe cuando se trata de formas de excavación como las descritas, sino que también las encontramos en formas de relleno, especialmente estalactitas, estalagmitas y coladas, en las que el tipo de material puede ser además de calcita, sal, yeso, hielo, carbonatos compleyos, basalto, etc.

Bien, pues a esta semejanza de morfología tanto de excavación como de relleno u otro tipo que se dan diferentes litologías, es a lo que denominamos convergencia de formas, independientemente de si las caucas que las motivaron son idénticas en todos los aspectos, comparables bajo algunos de ellos, o completamente diferentes en apariencia.

Adjuntamos un conjunto de fotografias como ejemplos demostrativos de la referida convergencia de formas en litologías tan diversa como caliza, yeso, sal, arcilla, hielo, pizarra y carbonates complejos de cinc; y en morfologías como lapiaz, secciones de conductos, estalactitas y estalagmitas, corrosión por mezcla de aquas, "pendents" freáticos, huellas de corriente y canales de disolución; cuya clave de identificación queda reflejada en el siguiente cuadro:

litologia \ forma convergente	canales de lapiaz	secciones de conductos	estalactitas y estalagmitas	corrosion por mezcla de aguas	"pendents" freaticos	huellas de corriente	canales de disolucion
caliza (ó calcita	1 A	2A / 2C	3B / 3D	4 B	5A / 5C	6 A	7 A
yeso	-	2 B	-	-	5 D	-	7 C
sal	-	2 D	-	-	-	6 B	7B / 7D
arcilla	1 B	-	-	-	-	-	7 E
hielo	-	-	3A / 3C	4 A	-	6 C	-
pizarra	-	-	-	-	5 B	-	-
carbonatos complejos de cinc	-	-	3 E	-	-	-	-

El fenómeno de la convergencia de formas es tan abundante en la naturaleza, que no puede ser considerado como algo meramente casual. A nuestro juicio obedece a una significación profunda sumamente importante, que nos hace pensar ante la semejanza de efectos, en una semejanza de caucas en virtud de una cierta dependencia funcional, es decir en un m o d e l o n a t u r a l del que sólo vemos los resultados.

B - LA SEMEJANZA DINÁMICA EN LOS MODELOS

Muchos do los ejemplos presentados, especialmente los relativos a formas de excavación, se dan en rocas con mayor o menor grado de solubilidad frente al aqua, vgr: sal, yeso y caliza, es decir, que fácilmente podría pensarse en la existencia de una cierta relación entre las caucas, como par ejemplo, de un lado las características hidráulicas del aqua y de otro, su grado de satiración en dicho componente (sal, yeso o caliza), siéndonos lícito buscar relaciones cuantitatives identificando vgr: el tipo de flujo o el número de Reynolds, y el referido gradiente de concentraciones.

Esto que parece tan intuitivo para dichos materiales solubles, no lo es tanto con materiales insolubles como la pizarra o la arcilla, de las que presentamos algunos ejemplos. Aqui para encontrar la semejanza, tendríamos que ampliar nuestro concepto de disolutión por otro más amplio que englobase el paso de determinada cantidad de material del estado sólido al seno de un líquido que lo transporte. Los parámetros difinitorios de las características de flujo se conservarían aqui, variando únicamente el concepto de disolución que habremos de reemplazarlo para estos materiales por el de suspensión coloidal.

El asunto, que todavía es menos intuitivo para el caso del hielo, del que también mostramos ejemplos, es también sumamente sencillo. Las morfologías descritas como huellas de corriente, o corrosión por mezcla de aquas, no tienen ningún significaco semántico en este caso, pues nunca han sido las aquas sino las corrientes de aire las responsables. Ahora bien, si reemplazamos aquellas por el aire, las características de flujo podemos conservarlas cuantitativamente con los mismos parámetros, y los gradientes de solubilidad vendrían reemplazados aqui por contenidos de vapor de aqua en su seno, directamente ligado a su temperatura. En definitiva, bastarían aqui para encontrar la semejanza de caucas, un gradiente de temperaturas entre hielo y aire, una distribución de humedades en este último, y un número de Reynolds para el flujo del aire.

Siguiendo analógicamente derroteros parecidos, se encontraría también semejanza de caucas en la génesis de los conductos o tubos lávicos en basalto, sin más que considerar las variaciones de viscosidad y características mecánicas a que está sujeto el magma en función de su temperatura.

En las morfologías de relleno el planteamiento es idéntico; la forma de las estalactitas y estalagmitas, parece relacionada por un lado con una cierta cantidad de material depositable, que hace su entrada disuelto y por otro, por la velocidad con que dicho material puede ser depositado. Lo primero podemos expresarlo cuantitativamente con el caudal y concentración del aporte, y lo segundo con cualquier circunstancia condicione su sobresaturacióna (grado de humedad ambiental, presión parcial del CO_2 en al aire, etc.) y por consiguiente su deposición.

Para el hielo, como siempre, los gradientes de concentración habremos de reemplazarlos por gradientes de temperatura, a la hora de explicar los cambios de estado.

En definitiva, todos estos fenómenos de convergencia de formas, aunque las apariencias lo enmascaren, están relacionadas por un grupo especial de circunstancias que los hace dinámicamente semejantes.

Esta s e m e j a n z a d i n a m i c a se da entre varios procesos cualesquiera, cuando las diversas cantidades en el equilibrio de fuerzas o gradientes, medidas para las partículas consideradas en ubicaciones semejantes, guardan razones iguales, independientemente de que sus magnitudes absolutas no sean respectivamente iguales. Esto quiere decir que, en lo que respecta a la dinámica newtoniana, los procesos en cuestión son en realidad idénticos.

Trasladando estas cuestiones al campo experimental, la conclusión es importantísima, pues podemos experimentar un proceso cualquiera (vgr: difícil de medir por ser muy lento) mediante la adopción de un modelo dinámicamente semejamte (vgr: el más cómodo según las disponibilidades) en la sequieridad de que las conclusiones a que lleguemos serán válidas si en el transcurso del experimento nos hemos mantenido en todo momento dentro de las condiciones requeridas de conservación de semejanza ~~dinámica~~.

La implicación práctica de la semejanza dinámica en modelos, es de una importancia extraordinaria, pues nos permite p r e d e c i r, y por consiguiente a c t u a r, mientras que de otra manera solamente nos era lícito o b s e r v a r, pudiendo llegar todo lo más a i n t e r p r e t a r.

Si la naturaleza nos brinda tal suerte de modelos, porqué no los utilizamos?

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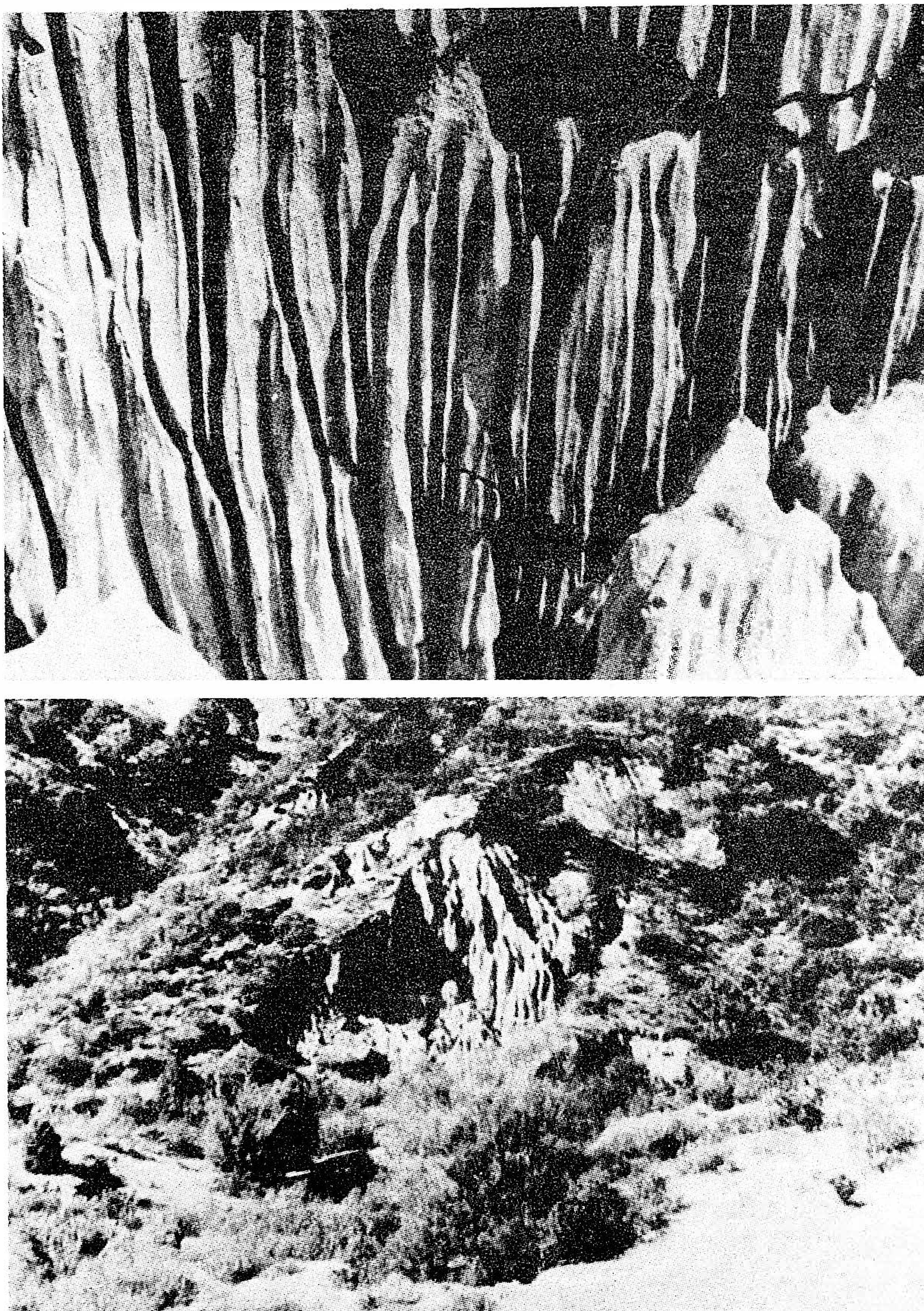
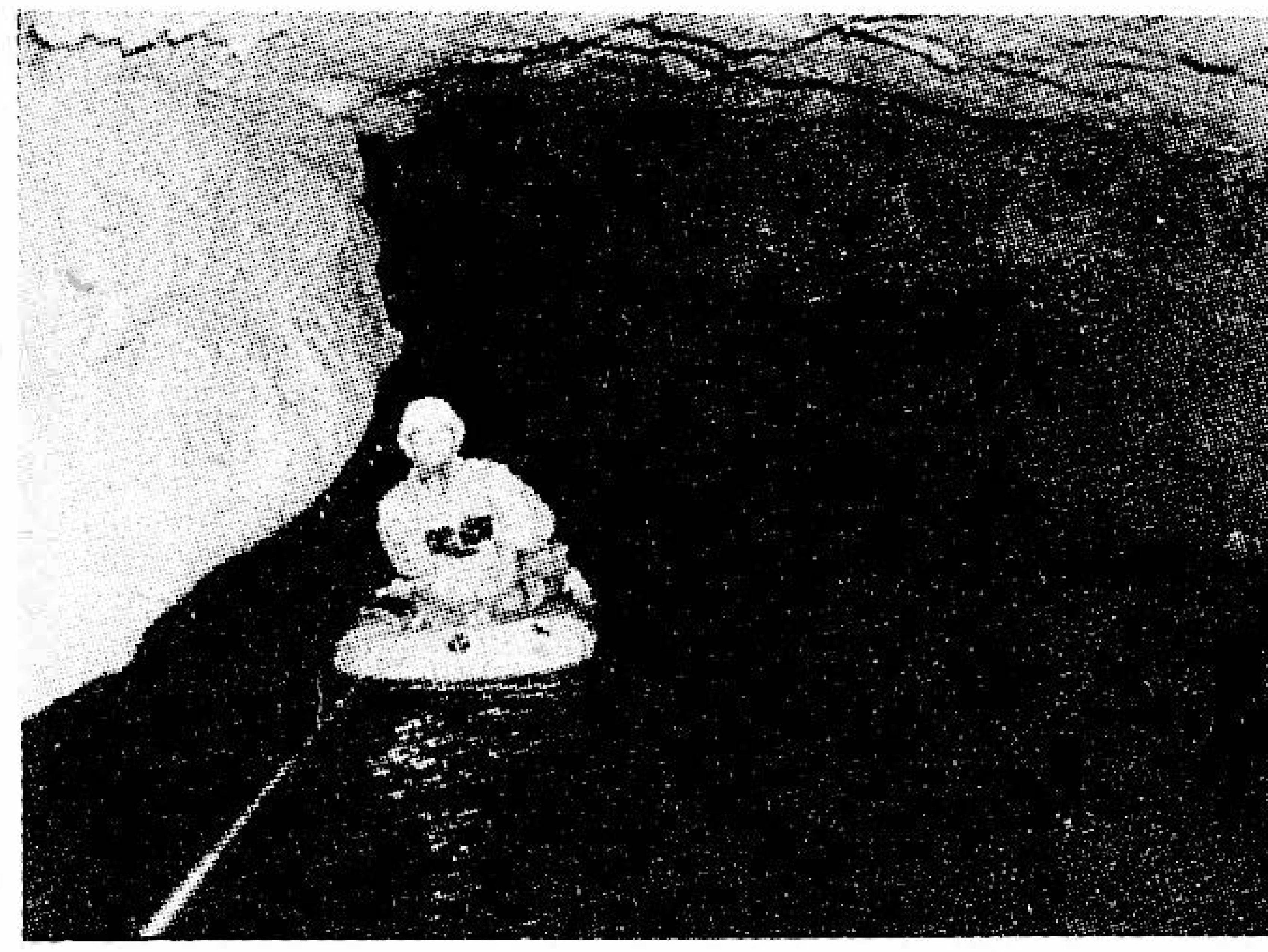


1A

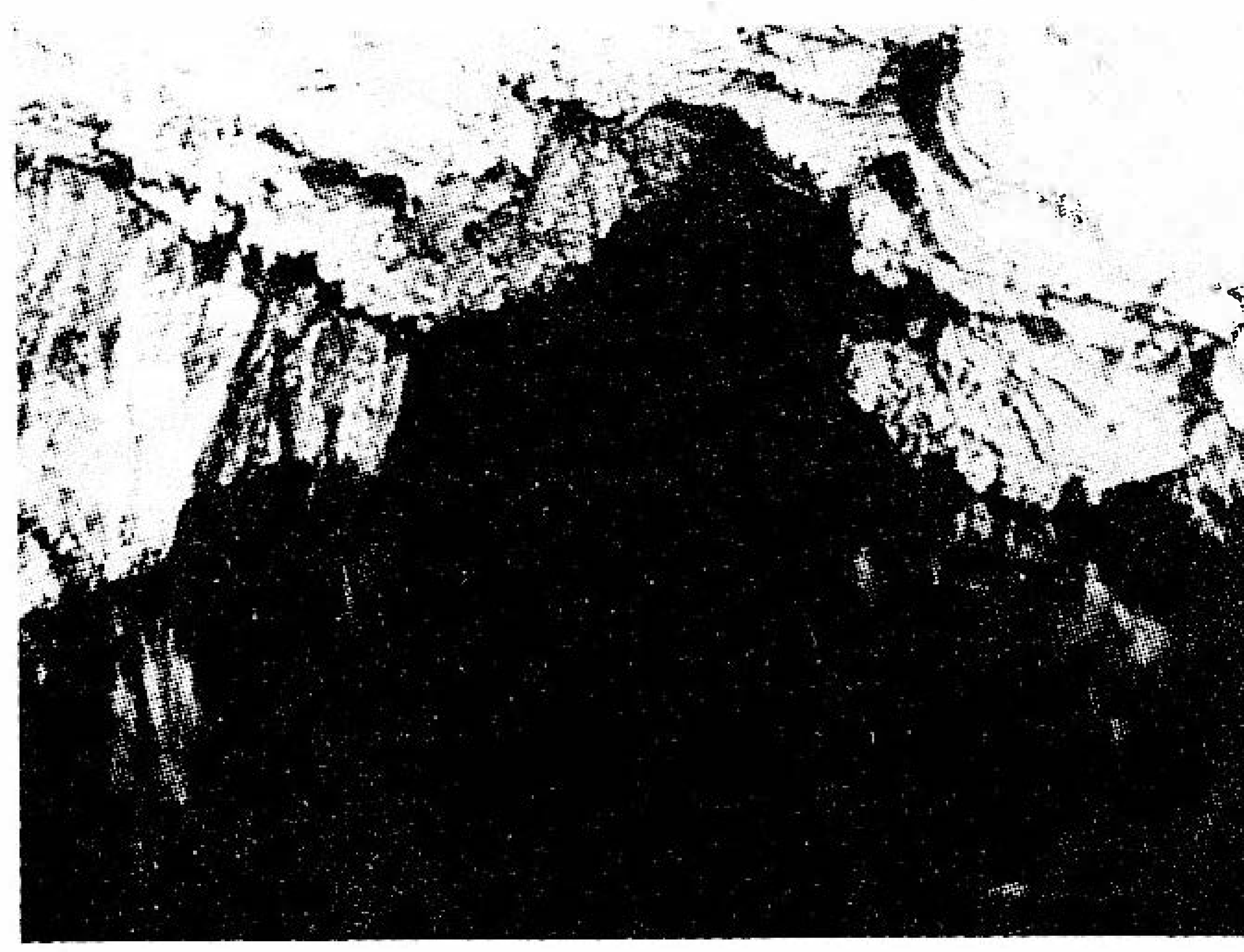
1B

Fig. 1.

2 D



2 A



2 B

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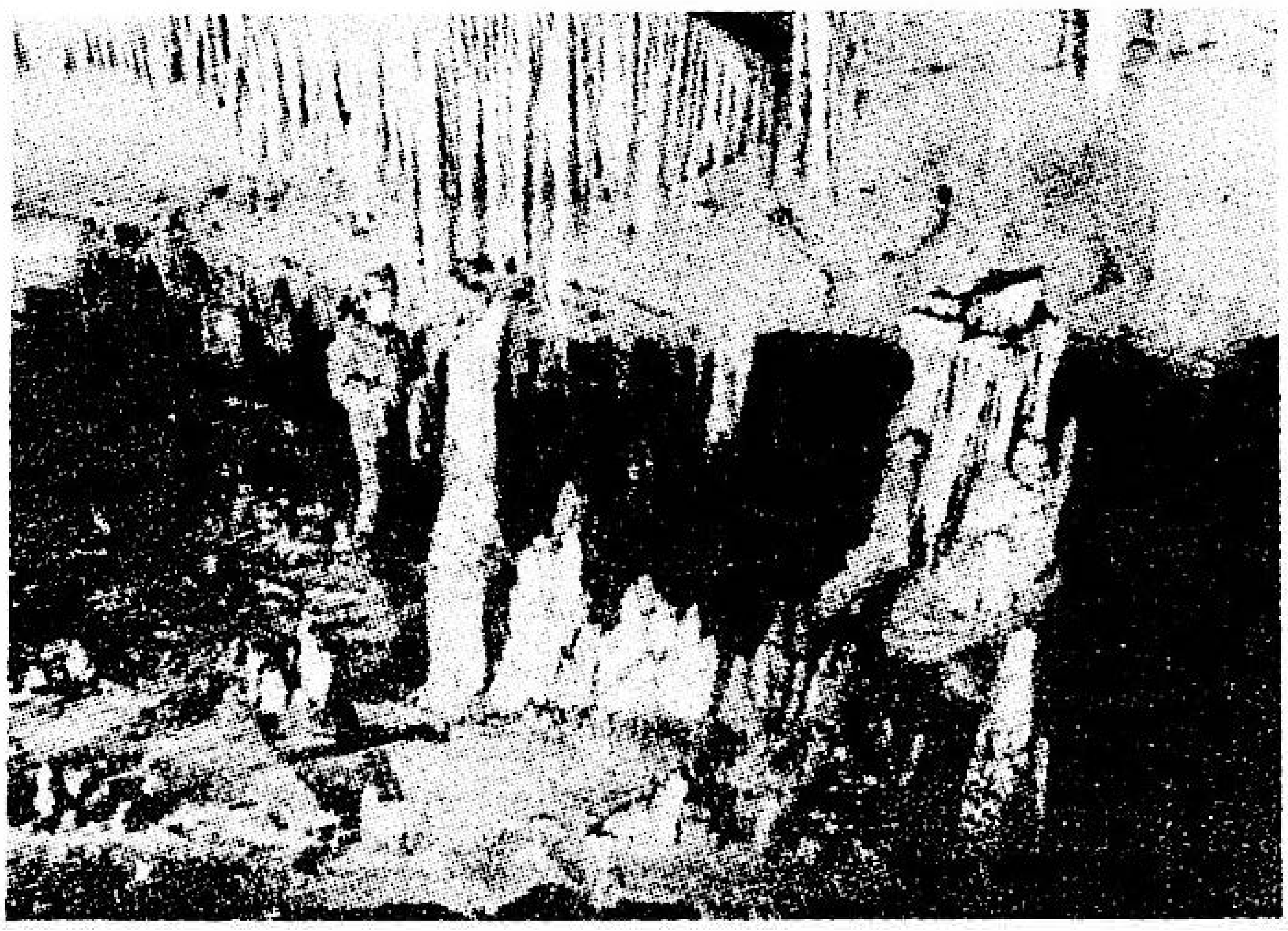
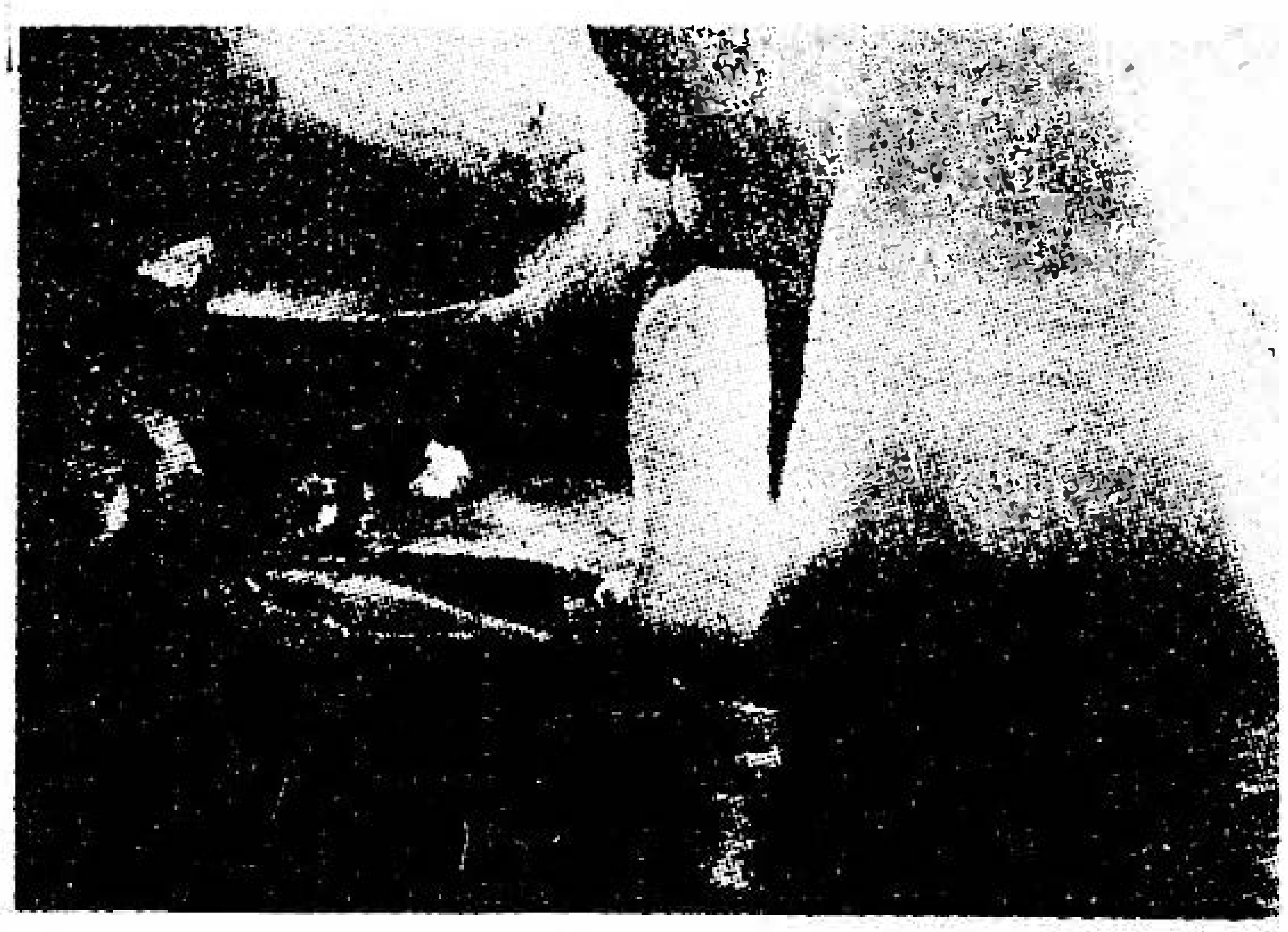
Fig. 2.

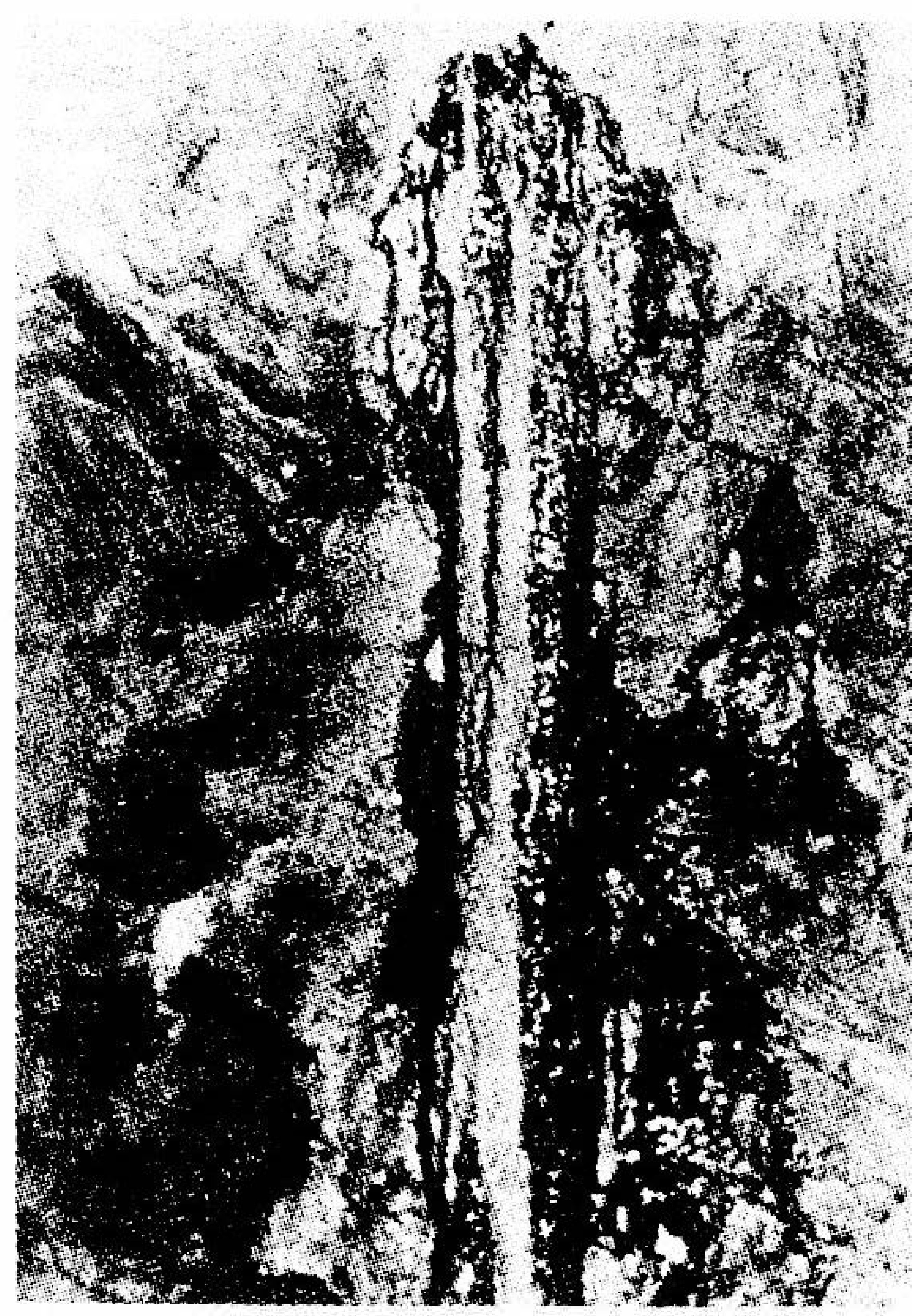


3B

3A



3C

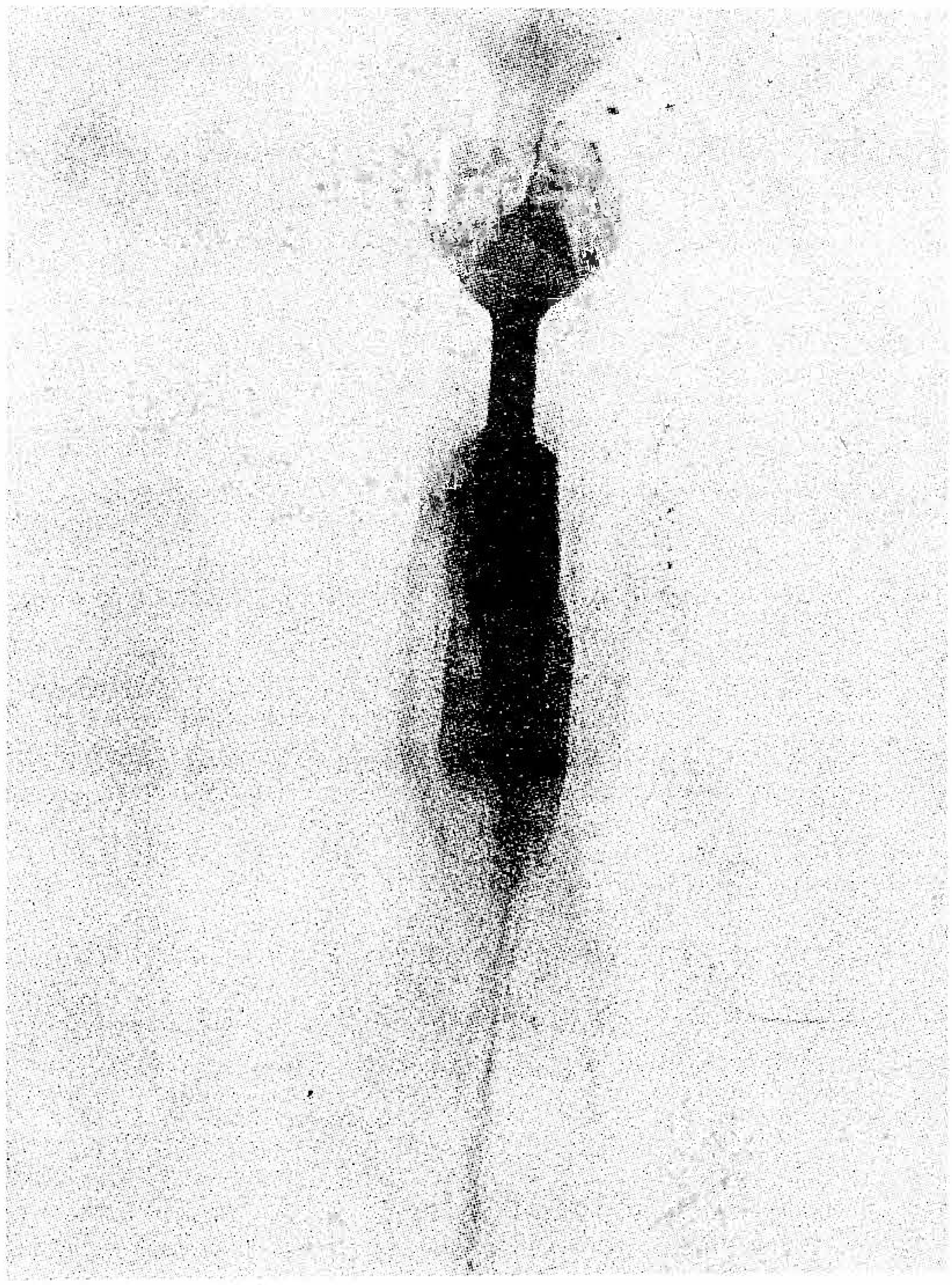


3E

3D

Fig. 3.

4A



4B

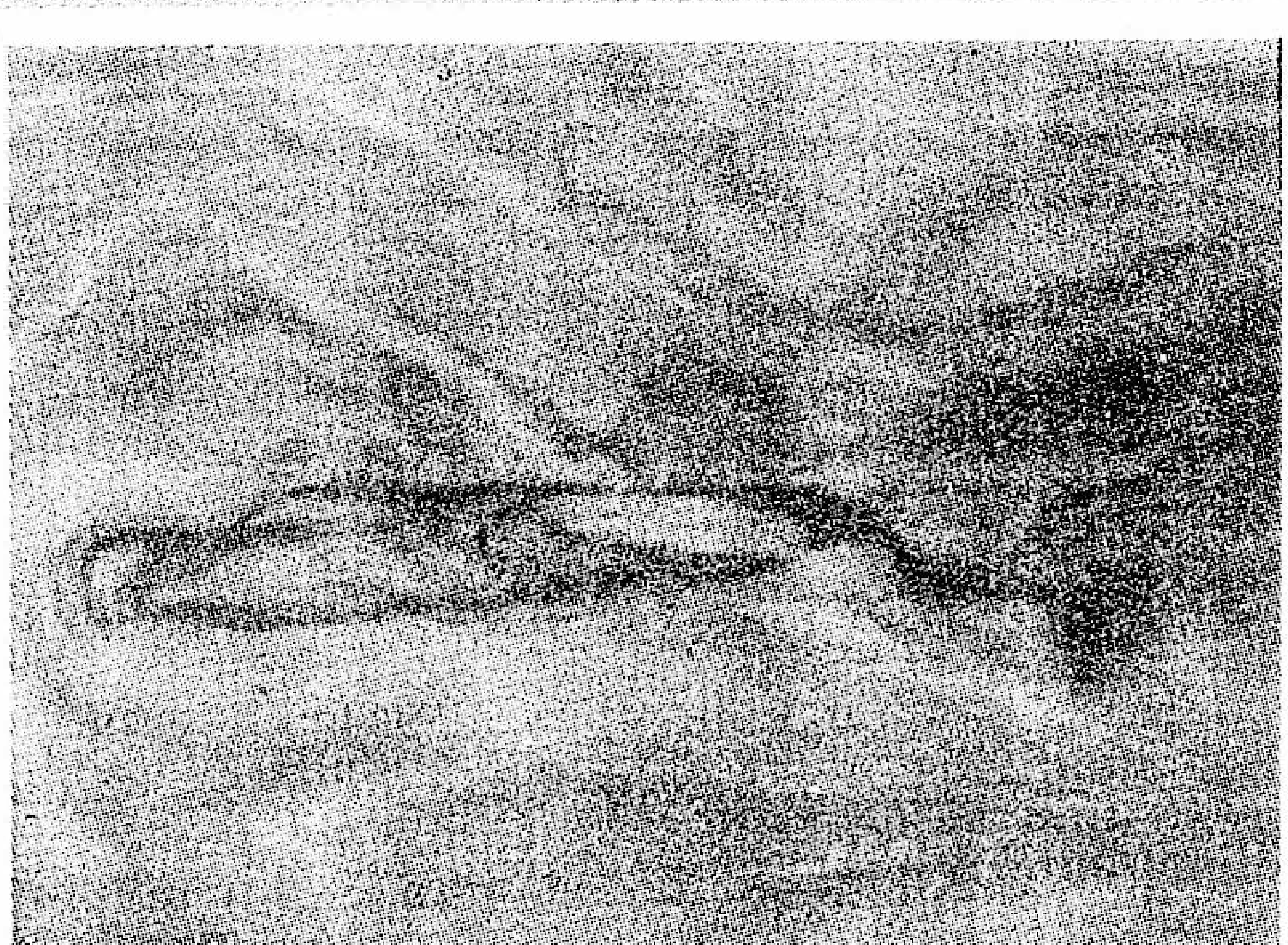
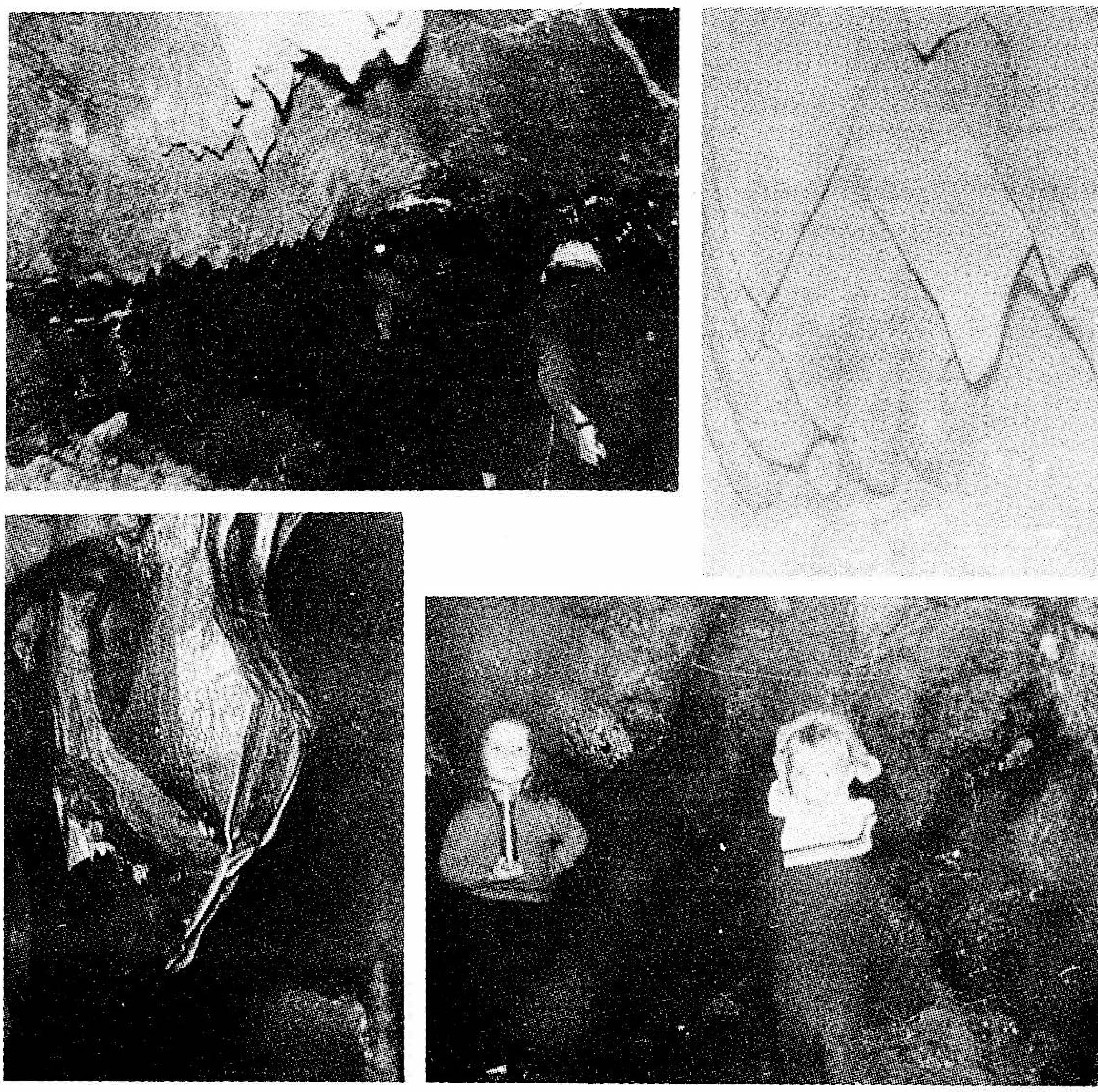
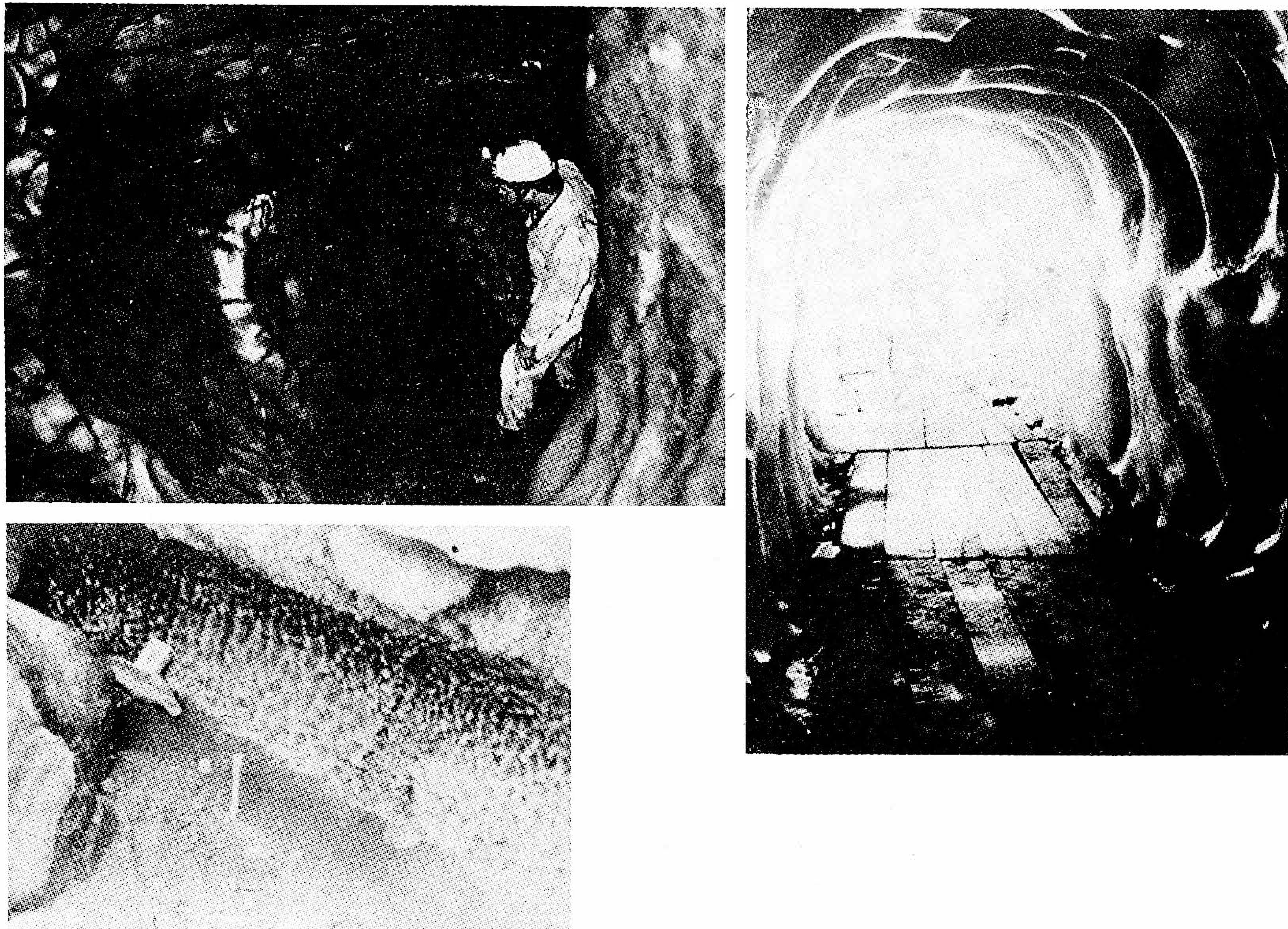


Fig. 4.



5B 5A 5C 5D

Fig. 5.



6A 6B 6C

Fig. 6.

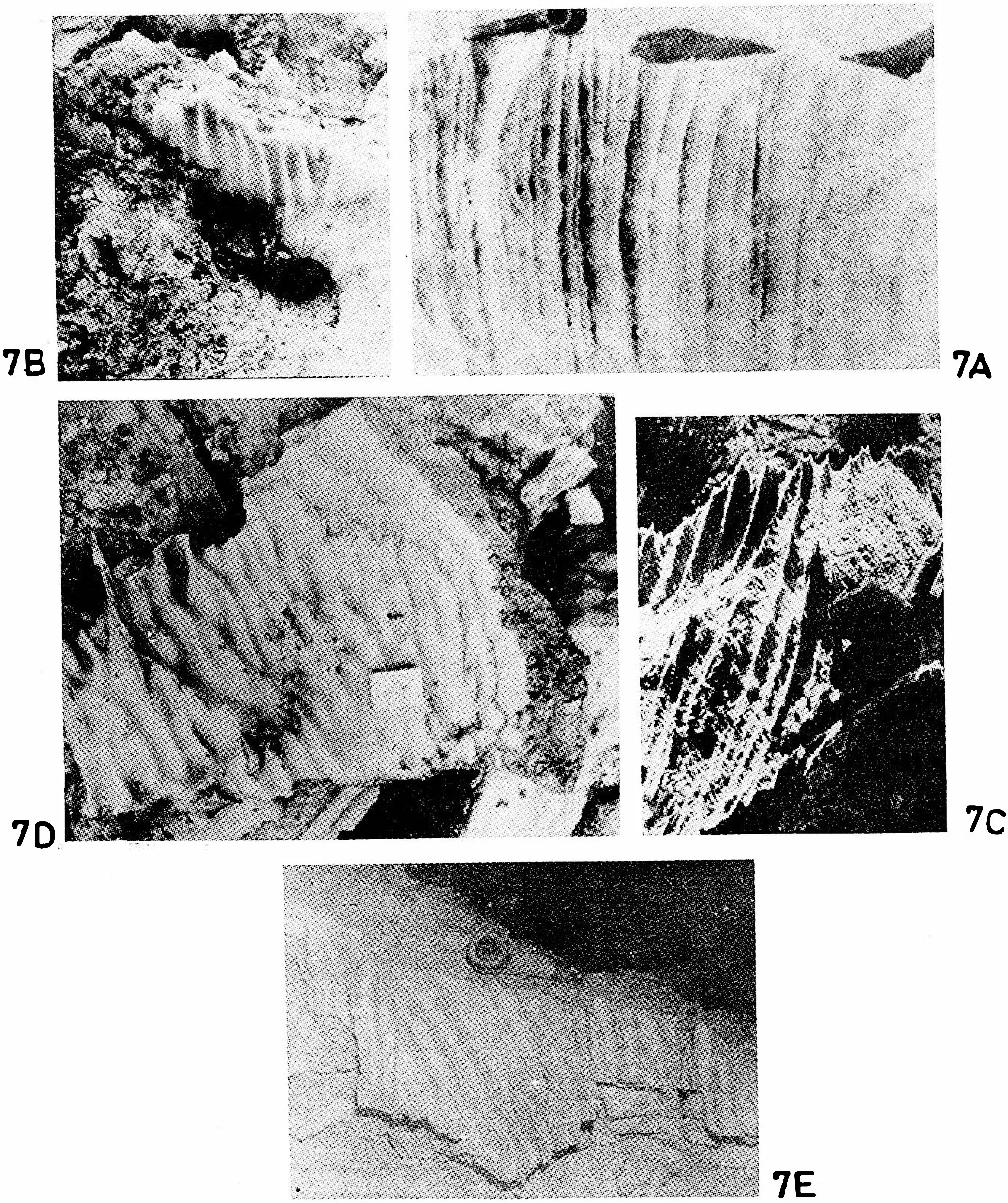


Fig. 7.

NEW METHOD IN KARST INVESTIGATION - NATURAL MODELS AND FORM CONVERGENCE

1. THE ACTUAL KARST PROBLEM - WRONG DIALECTIC ATTITUDE

Karstology as any other natural science is based on a particular philosophy which can be defined as reductive logic, including necessarily the aleatorious phenomena.

The basis is observation and experimentation, the following acquisition of information, whose subsequent interpretation is more and more getting nearer to reality when the number of data increases on which the mentioned interpretation is based and which is amenable to laws of probability.

If the scientific basis of our young Karstology would be solid and firm we could expect, according to the reductive logic on which she is based, that if various specialists would study a determined region they could have different opinions at the beginning, when the respective information has still a low statistical value. However, in the same measure as the number of information increases, the results would start to resemble and finally, at the end of their respective studies, would be very similar.

Since, unfortunately it hardly ever happens, we suppose that the deficiency is in the basis.

Karstology is situated further in a specially delicate way between other disciplines, what affects to her development, being situated between various limits of this artificial classification in which men have divided nature in order to mark the evolution sphere of every sciences.

Speleologists are, above all, in the most favourable conditions to obtain the necessary information. However, in some countries their activity is guided more by sporting motives and we therefore cannot ask too much in spite of their excellent disposition, since it happens often, that they do not have the necessary scientific formation.

Two bis groups of investigators of the scientific world are engaged in Karst, on the one hand hydrogeologists and on the other geomorphologists. Since their aims are not common, being the first group pragmatic quite technical, and the second more mediate and purer, often exists a quite considerable mutual neglect between both specialities, which as a consequence of an uncomplete investigation prejudices the Karst study. Although in some countries exist efforts to coordinate engineer and universitarian organisms, representing in a certain extent both tendencies, there is still a large way to be gone.

On the other hand exists intrinsically in Karst an obstacle which complicates its study extraordinarily. In fact, numerous different factors influence the karstification process, among which we like to mention only the most important as physical-chemical, geological, climatic, biochemical, hydraulic, geotechnical, etc. This plentiful panorama needs experts who are specialists in every and all matters, in order to resolve the problems in an appropriate way.

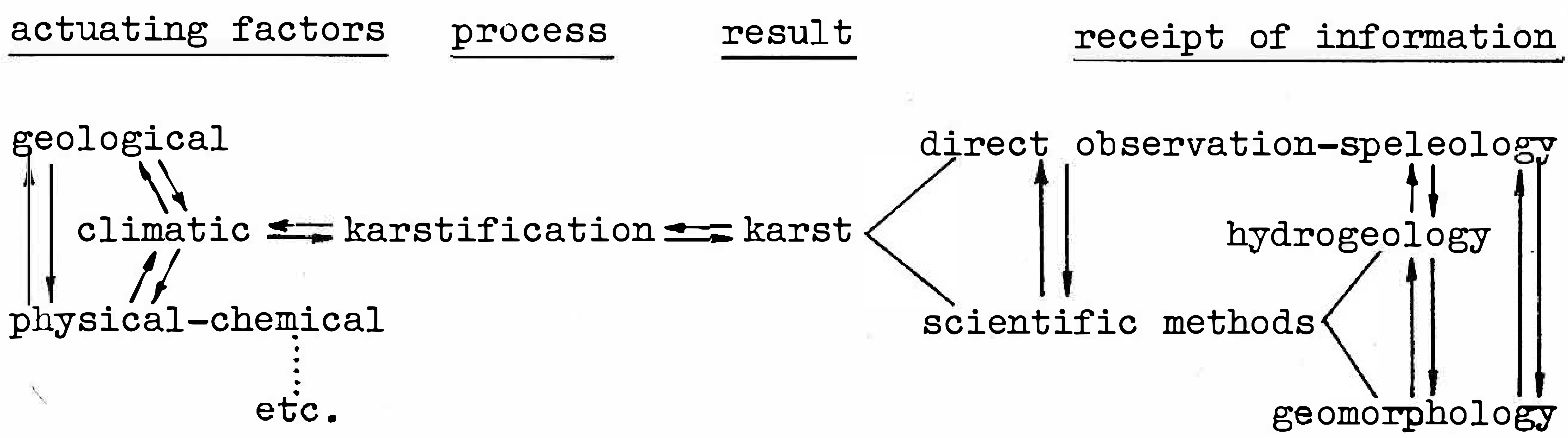
Since it is very difficult to find all these qualities in one person, it is evident that Karst should be studied by a team in order to be really successful.

Another factor which does not either favour this panorama is the own kinetics of limestone dissolution in water, which is as slow that considerable changes hardly can be observed in the short time representing in comparison human life. The direct experimentation therefore is very complicated, since we are obliged to use very long observation periods.

However, difficulties still continue, being the most considerable fact of Karst that the action of different karstification process factors produces specific forms which at their turn also affect the process, modifying former conditions; this means that these factors are not independant but "interrelated" during the whole process and that the result of this process influences these factors too.

This means in other words, that the karstification process contains implicitely a f a c t o r o f i n t e r r e l a t i o n. As its consequence the action of the different mentioned factors never should be studied isolatedly but simultaneously in order to progress in Karst knowledge, which up to now we think has nor been done.

To this lack of view we refer if we qualify the actual situation as a w r o n g d i a l e c t i c a t t i t u d e, which could be corrected following appropriate conceptual schedules, as for example:



in which the signs in both directions represent the cited interrelation.

2. A NEW ASPECT OF INVESTIGATION

Nature, which we never observe enough, in perfect agreement with its laws, sends us a great number of messages and some of them understood in an appropriate way show us how in a large extend can be reduced a lot of the problems which we find studying its mechanisms.

A - FORM CONVERGENCE AS NATURAL MODEL

In natura it happens evidently and repeatedly that determined, forms resulting from any geodynamic action are found in the most various materials.

We find for example identical gallery sections in caverns in material as limestone, gypsum, salt, basalt, ice, etc. whose lithologies are basically different.

It is easy to find specific forms in different lithologies, some of them already studied as s c a l l o p s, f r e a t i c "p e n d e n t s", d i s s o l u t i o n c h a n n e l s, c o r r o s i o n b y w a t e r m i x t u r e, some forms of karren, etc.

But form similarity does not exist only in hollow forms, we also can find it in filled forms in particular speleothems (stalactites and stalagmites) in which the material can be limestone, salt, gypsum, ice, complex carbonates, basalt, etc.

This similarity of morphologies, as well in hollow as in filled forms or other types which we find in different lithologies, is what we call f o r m c o n v e r g e n c e, independently if the reasons for its origin are identical in all aspects, comparable in some of them or completely different in their appearance.

We enclose some photographs as examples, demonstrating the mentioned form convergence in so different lithologies as limestone, gypsum, salt, clay, ice, schist, complex zinc carbonates and in morphologies as karren, gallery sections, dripstones, corrosion by water mixture, freatic "pendents", scallops and dissolution channels. Their identification is found in the following table.

lithology \ convergent form	karren	gallery sections	speleothems	corrosion by water mixture	freatic "pendents"	scallops	dissolution channels
limestone	1 A	2A / 2C	3B / 3D	4 B	5A 5C	6 A	7 A
gypsum	-	2 B	-	-	5 D	-	7 C
salt	-	2 D	-	-	-	6 B	7B / 7D
clay	1 B	-	-	-	-	-	7 E
ice	-	-	3A / 3C	4 A	-	6 C	-
schist	-	-	-	-	5 B	-	-
compex zinc carbonates	-	-	3 E	-	-	-	-

The phenomena of form convergence is so abundant in nature that it cannot be considered as merely casual. According to our opinion, it follows a very important profound signification, which induces to think in the presence of the similarity of effects in a similarity of causes, because of a certain functional dependance; that means in a n a t u r a l m o d e l of which we only can see the result.

B - DYNAMIC SIMILARITY IN MODELS

Most of the presented examples, specially those of hollow forms, can be found in rocks with more or less degree of solubility in water, e.g. salt, gypsum and limestone, that means we could easily think that there is a certain relation between the causes, as for example on the one hand the hydraulic water characteristics and on the other its saturation degree in this component (salt, gypsum or limestone). We only should find the quantitive relations, identifying, e.g. the flow type, or R e y n o l d s number and the mentioned concentration gradient.

This seams so clear for the mentioned soluble materials, but is not so for insoluble material as achist or clay, of which we give some examples. In order to find in these cases the similarity we must amplify our concept of dissolution by a larger one, including the passage of a determined quantity of material in solid state in a liquid transporting it. The defining parameters of flow characteristics can be conserved, modifying only the dissolution concept which for this material is replaced by colloidal suspension.

This case is still less obvious for ice, of which we also show examples, however very easy too. The morphologies described as scallops or corrosion by water mixtures do not have any semantic significance in some languages, since never water but air currents have been responsible for their formation. If we replace them by air, we can conserve quantitatively the flow characteristics with the same parameters and the solubility gradients are replaced by content of water vapour in air, directly connected to its temperature. Finally, in order to find the similarity if causes it would be sufficient to have a temperature gradient between ice and air, a distribution of humidity in the last one and a R e y n o l d s number for the air flow.

Following analogically similar practics we also can find a similarity of causes in the genesis of lava tubes in basalt, without taking into consideration the variations of viscosity and mechanical characteristics of the magma in function of its temperature.

In morphologies of speleothems the proceedings is identical. The dripstone forms seem to be related on the one hand to a certain quantity of material which is deposited and enters dissolved and on the other to the velocity in which the mentioned material can be deposited. The first can be expressed quantitatively by the rate and concentration and the second by any circumstance conditioning its oversaturation (rate of surrounding humidity, partial pressure of CO_2 in the air, etc.) and consequently its deposition.

For ice we must replace, as usual, the concentration gradients by temperature gradients in order to explicate the ~~change~~ of state.

Finally all these phenomens of form convergence, although they are covered by appearence, are related to a special group of circumstances, which make them dynamically similar. This d y n a m i c s i m i l a r i t y is found in various processes, when different quantities in the equilibrium of forces or gradients, measured for particles in similar locations, conserve the same relation, independantly of the fact, that their absolute magnitudes are not respectively the same. Referring to the dynamics of Newton this means, that the processes in question are in reality identical.

Transferring these questions to experimentation field, the conclusion is very important, since we can experiment any process (e.g. difficult to measure for being very slow) by adopting a dynamically similar model (e.g. the most convenient according to disponibilities), and we can be sure that the obtained conclusions are valid, if during the whole experiment we have respected at every moment the required conditions for conservation of dynamic similarity.

The practical implication of dynamic similarity of models is extraordinarily important, since it allows us to p r e d i c t and consequently to a c t, meanwhile in the other way we only could o b s e r v e and as a maximum i n t e r p r e t.

Since nature offers such a quantity and diversity of models, why we do not use them?

Madrid, January 1973

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Ba 011

EINIGE BEMERKUNGEN ZUR BESTANDSKARTE DER KARSTERSCHEINUNGEN IM GEBIET ZWISCHEN LEINE - UND THYRATAL IM ZECHSTEINGÜRTEL DES HARZSÜDRANDES MIT BESONDERER BERÜCKSICHTIGUNG DER HOHLFORMEN

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A b s t r a c t. Verfasser führte in den Jahren 1972/73 im Gebiet zwischen Leine- und Thyratal im Südharzer Gipskarst eine Bestandsaufnahme der oberflächigen Karsterscheinungen durch. Diese Kartierung ist Bestandteil der künftigen Gesamtkarstkarte Südharz (DDR - Anteil).

Ausgehend von dem Erscheinungsbild alter und rezenter Erdfälle deutet sich hinsichtlich der Subrosion eine 3-Zonen-Gliederung an. Die 907 dokumentierten Erdfälle und Geländedepressionen von kreisförmigem bis ovalem Umriss häufen sich scheinbar

- an der Buntsandstein-Anhydrit-Steilkante
- im Einflussbereich von Wasserschwinden
- an der Verbreitungsgrenze des Unteren Buntsandsteins
- entlang von Hauptkluftsystemen bzw. Störungen

Die statistische Auswertung ergab, dass zwischen Tiefe und Durchmesser der Erdfälle deutliche Wechselbeziehungen bestehen. Es wurde ein Korrelationskoeffizient von r = 0,932 errechnet. Die Zuordnung der Erdfalldurchmesser zu bestimmten Häufigkeitsklassen zeigt eine relativ gleichmässige Belegung der Klassen. Anders verhält es sich bei den Tiefen der Hohlformen. Hier ist der Teufenbereich 0-2 eindeutig am stärksten besetzt. Bis zur Tiefe über 10 m nimmt die Klassenbelegung ständig ab.

An der Erfassung und Dokumentation der Karsterscheinungen im Südharz wird auch künftig weiter gearbeitet.

1. VORBEMERKUNGEN

In den Jahren 1972/73 führte Verfasser im Gebiet zwischen Leine- und Thyratal im Zechsteingürtel des Harzsüdrandes eine Kartierung der oberflächigen Karsterscheinungen durch. Diese Kartierung ist Bestandteil der künftigen Gesamtkarstkarte Südharz (DDR - Anteil). An den Ergebnissen sind in zunehmendem Masse der vorbeugende Katastrophenschutz, Bergbau und Wasserwirtschaft, die sozialistische Landeskultur sowie die Planungsorgane der örtlichen Räte im Rahmen der Standortplanung von Bauvorhaben interessiert.

2. ARBEITSMETHODIK

Als Grundlage der Bestandsaufnahme diente die topographische Karte im Masstab 1 : 10 000, Ausgabe Volkswirtschaft. In der Bestandskarte wurden u.a. folgende Karstobjekte dargestellt:

Alterdfälle bzw. rezente Erdfälle, Geländedepressionen, Erdfalltäler, aktive Senkungskessel, Ponore, Quellen, Kluft- bzw. Kluft-Laughöhlen, Abrissklüfte, nackter Karst, Gipskuppen, geologische Orgeln usw.

Die lagemässige Bestimmung bzw. spezielle Vermessung von Karstobjekten wurde mit Hilfe von Teletop, Neigungsmesser, Kompass, Winkelprisma, Geometerstab, Fluchtstangen und Bandmass durchgeführt.

3. ARBEITSGEBIET

3.1. BEGRENZUNG

Das Kartierungsgebiet erstreckt sich über 15 km zwischen den Ortschaften Uftrungen im Westen (Thyratal) und Grossleinungen im Osten (Leinetal). Die gesamte kartierte Fläche beträgt 25 km^2. Die Nordbegrenzung der kartierung bildet das Ausgehende des Kupferschieferflözes (Zechstein 1), die Südbegrenzung fällt, von wenigen Ausnahmen abgesehen, mit der Verbreitungsgrenze des Unteren Buntsandsteins (Untere Trias) zusammen.

3.2. MORPHOLOGIE UND HYDROGRAPHIE

Das Arbeitsgebiet liegt zwischen + 240 - 340 m NN. Markantes morphologisches Element ist das harzrandparallele Auslaugungstal mit einem sanften, allmählich zum Paläozoikum überleitenden Nordhang und einem relativ steilen und plötzlichen Anstieg zu den Buntsandstein- bzw. Hauptanhydrit[1] - Hängen im Süden. Zahlreiche Bäche, die aus dem Paläozoikum des Harzes kommen, überqueren den Zechsteinausstrich mit mehr oder weniger grossen Versickerungsverlusten. Ein Teil der Bäche erreicht den Buntsandsteinausstrich am Südrand des Harzes nich, sondern verschwindet über Ponore an der Hauptanhydrit-Steilkante (Hainröder- und Dinsterbach, Hasselborn, Glasebach). Nur der Leine, Nasse und Thyra gelingt es, den Buntsandstein-Anhydrit Höhenrücken am Südrande o.g. harzrandparaller Auslaugungsdepression zu durchbrechen und nach Süden abzufliessen. Ihre Durchbruchstäler sind sehenswert.

Vom Glasebachponor (Periodischer See) und von der Dinsterbachschwinde liegen Färbversuche vor. Viete (1954) ermittelte zwischen Schwinde und Totensumpf (1 km) 7,80 m/min und zwischen Schwinde und Eckteich (1,3 km) 2,40 m/min Fliessgeschwindigkeit (s. Enclosure 1). Diese hohen Fliessgeschwindigkeiten dürften auf die relativ kurzen Entfernungen und auf das grosse Gefälle (30 bzw. 50 m Höhenunterschied) zurückzuführen sein. Der Dinsterbach weist Zuflussmengen zwischen 0,2 und 6,0 m^3/min auf, ohne dass Schwierigkeiten bezüglich der Aufnahmefähigkeit des Ponors festgestellt wurden (Spilker 1971). Im Tiefenkarst der Mansfelder Mulde wurden über eine Entfernung von ca. 20 km Fliessgeschwindigkeiten von 1 m/min (Jung & Spilker 1969) ermittelt.

3.3. GEOLOGISCHE VERHÄLTNISSE

Aus dem gültigen Normalprofil für den Harzsüdrand (Blei & Jung 1962) werden die Gesteinskomplexe aufgeführt, die im Kartierungsgebiet von Interesse sind (vom Liegenden zum Hangenden):

Zechsteinkonglomerat	(Z 1 C):	2,00 - 3,50 m
Weissliegendes	(Z 1 S):	0,00 - 12,00 m
Kupferschiefer	(T 1):	0,30 - 0,40 m
Zechsteinkalk	(Ca 1):	4,50 - 6,00 m

1) Unter der Bezeichnung Hauptanhydrit soll im Folgenden der Schichtenkomplex Hauptanhydrit, Sangerhäuser Anhydrit und Basalanhydrit verstanden werden, eine stratigraphische Trennung im einzelnen ist nicht möglich.

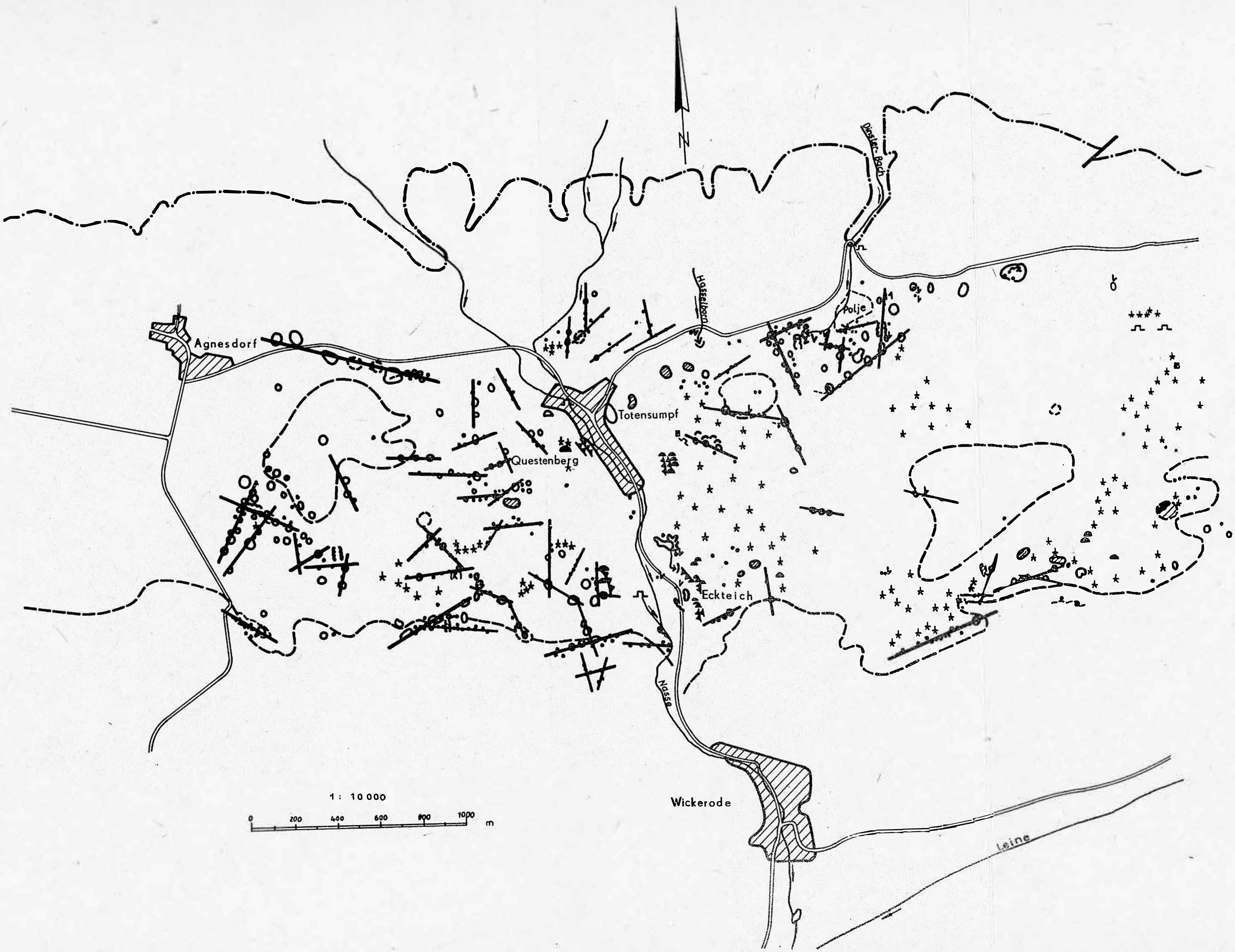
Unterer Werraanhydrit	(A 1 u):	30,00 -	35,00 m
Salzäquivalent des Werrasteinsalzes	(Na 1/A):	0,30 -	1,20 m
Oberer Werraanhydrit	(A 1o):	20,00 -	30,00 m
Stinkschiefer	(Ca 2 st):	6,00 -	7,50 m
Basalanhydrit	(A 2):	2,00 -	2,50 m
Sangerhäuser Anhydrit	(K 2/A):	0,00 -	100,00 m
Deckanhydrit	(A 2 r):	2,00 -	5,00 m
Grauer Salzton	(T 3):	3,00 -	6,00 m
Hauptanhydrit	(A 3):	40,00 -	50,00 m

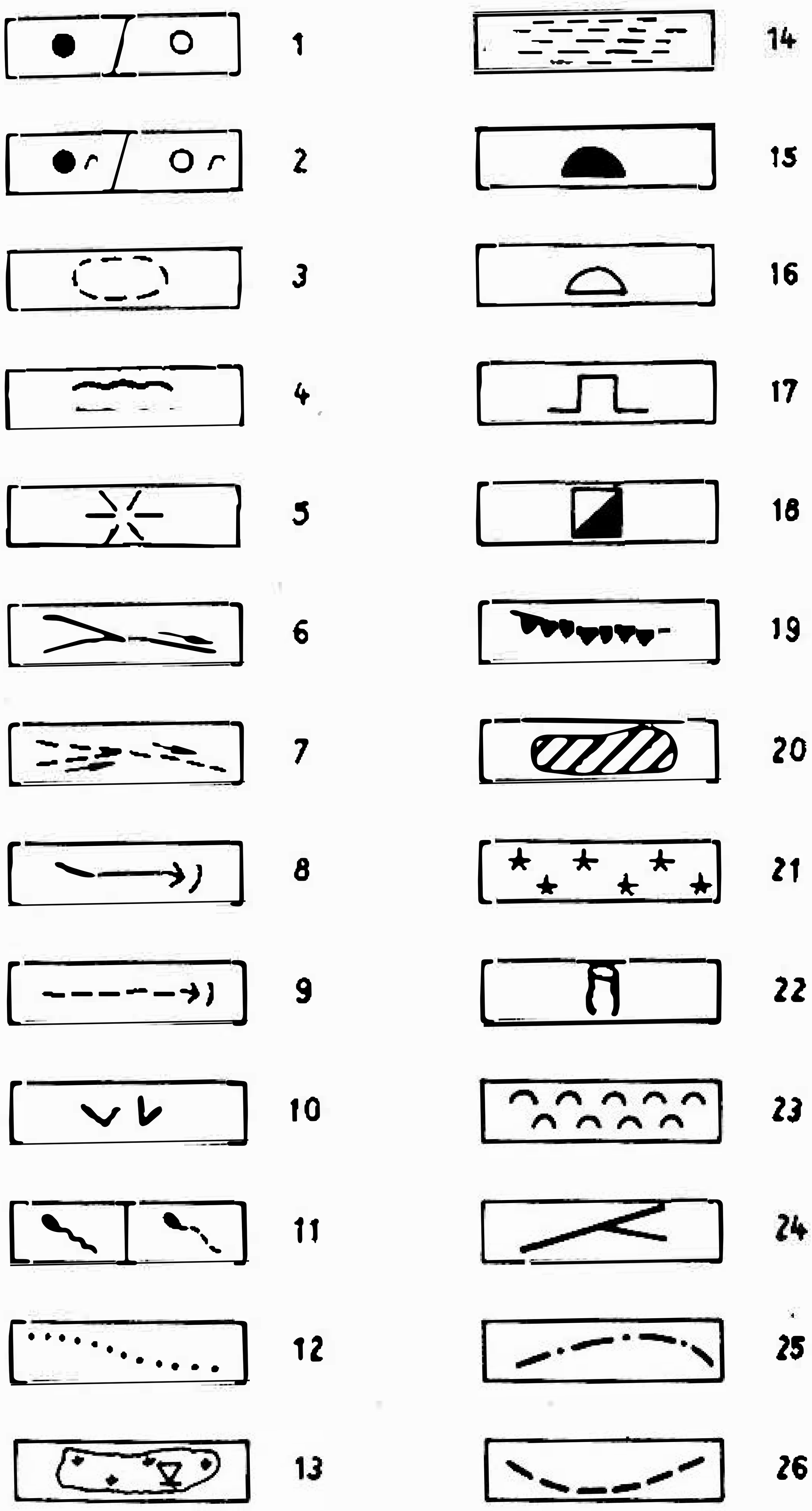
Das Fehlen von Steinsalz-Serien am Südrand des Harzes deuten v. Buelow & W. Schriel (1926), E. Fulda (1935) und E.v. Hoyningen - Huene (1963) als Folge postsaxonischen Auslaugung. Jung (1958a) kam bei der feinstratigraphischen Bearbeitung der Werraanhydrite zu der Erkenntnis, dass es zu einer faziellen Vertretung von Halit durch Anhydrit kommen kann und im Gebiet von Auslaugungshohlräumen (Höhlen) primär kein Steinsalz zur Ausscheidung gekommen war. Für die vorliegende Betrachtung spielt nur das Vorhandensein und der Verkarstungsgrad von Anhydrit eine Rolle.

In Folge mangelnder Aufschlussverhältnisse waren Rückschlüsse auf die Verkarstung nur mit Hilfe der Verbreitung von Erdfällen möglich. Wie Brendel (1973) für den Oberen Buntsandstein (Untere Trias) nachgewiesen hat, kann generell eine 3-Zonengliederung festgestellt werden:

Zone 1: gipsfreie Zone (keine rezenten Erdfälle)
Zone 2: Subrosionszone (fossile und rezente Erdfälle)
Zone 3: noch nicht subrodierte Zone (nur irreguläre Erdfälle)

Diese Gliederung kann man natürlich unter Beachtung regionaler Differenzierungen auch für den Südharzrand übertragen. Die reguläre Auslaugung (im Sinne Weber´s 1930) ist vom Ausgehenden der löslichen Schichtenfolgen bereits in Richtung Süden fortgeschritten. Daraufhin weisen die Bezeichnungen dolomitischer Kalk, Rauchwacke und Asche (Auslaugungsresiduen) der geologischen Landesaufnahme. Diese Gesteine (Zone 1) sind meist in einem schmalen Streifen südlich des Ausgehenden des Kupferschieferflözes vorhanden. Daran schliessen sich in Auslaugung begriffene vergipste Anhydrite der Werra-, Stassfurt- und Leine-Serie an (Zechstein 1-3). Die harzrandparallele Auslaugungssenke dürfte in ihrem Nordteil auf die Auslaugung der Werraanhydrite und im Südteil auf die


N
Agnesdorf
Hasselborn
Dinster-Bach
Polje
Totensumpf
Questenberg
Eckteich
Nasse
Wickerode
Leine
1 : 10 000
0 200 400 600 800 1000 m



Enclosure 1. Ausschnitt aus der Gesamtkarstkarte Südharz (DDR - Anteil): 1 - Alterdfall unter bzw. über 5 m Durchmesser, 2 - Rezenter Erdfall unter bzw. über 5 m Durchmesser, 3 - Geländedepression, oval bis kreisförmig, 4 - Erdfalltal, 5 - Aktiver Senkungskessel, 6 - Bachlauf bzw. Gerrinne, ständige Wasserführung, 7 - Bachlauf bzw. Gerinne, episodische Wasserführung, 8 - Ponor, ständiger Zufluss, 9 - Ponor, episodischer Zufluss, 10 - Inaktiver Ponor, 11 - Quelle, ständige Schüttung bzw. zeitweilige Schütung, 12 - Bachversinkung, 13 - Wasserfläche, ± ständig, 14 - Wasserfläche, zeitweilig, 15 - Klufthöhle, 16 - Kluft-Laughöhle, 17 - Stollenmundloch, 18 - Schacht, 19 - Abrisspalten mit Angabe der Bewegungsrichtung, 20 - Nackter Karst, 21 - Gipskuppen (vereinzelt Dolomitkuppen), 22 - Geologische Orgeln, 23 - Fossile und rezente Rutschungen, 24 - Geologische Störung (Verwerfung), 25 - Ausgehendes des Kupferschieferflözer, 26 - Grenze Zechstein/Unterer Buntsandstein.

des Sangerhäuser- bzw. Hauptanhydrits zurückzuführen sein. Die Zone 2 leitet zur Zone 3 über, in der gegenwärtig keine Auslaugung stattfindet.

Das betrifft das Gebiet wenige 100 m südlich der Verbreitungsgrenze des Unteren Buntsandsteins. Die Erdfälle überschreiten diese Schichtgrenze generell nur 200-300 m nach Süden, mit Ausnahme des Gebietes westlich und östlich Grossleinungen (Ankenberg, Mooskammer), wo Erdfälle und Depressionen noch bis 500, selten 600 m südlich der Buntsandsteinverbreitungsgrenze auftreten. Ab einer ~~bestimmten~~ Mächtigkeit der Buntsandstein-Überdeckung lässt offenbar die Vergipsung nach und erlahmt die Auslaugungsintensität.

4. ANORDNUNGSPRINCIP VON ERDFÄLLEN UND DEPRESSIONEN

Für die inzwischen kartierten 907 Hohlformen bietet sich als ein Erfahrungswert folgende Klassifizierung an, wobei sich Verfasser darüber im Klaren ist, dass diese naturgemäss relativ subjektiv ist:

- Erdfälle, typisch (Ø: Tiefe < 5 : 1)
- Erdfälle, gealtert (Ø: Tiefe ≥ 5 : 1 und < 10 : 1)
- Geländedepressionen (Ø: Tiefe ≥ 10 : 1)

In vielen Fällen ist man geneigt, dieser relativ willkürlichen Einstufung zu widerhandeln.

Nicht ohne weiteres zu entscheiden ist die Frage, ob die als Depressionen bezeichneten flachen geschlossenen Hohlformen von elliptischem bzw. kreisförmigem Grundriss eine 2. Generation gealterter Erdfälle darstellen oder ob es sich schlechthin um Ablaugungsformen von der Oberfläche her handelt. Beides scheint möglich zu sein. Interessant ist dabei, dass auch die Depressionen von meist 0,5-1,0 m Tiefe dem gleichen Anordnungsprinzip wie die Erdfälle (s. Enclosure 1) unterliegen. Die Erdfälle und Depressionen häufen sich scheinbar

a) an der Buntsandstein-Anhydrit-Steilkante[1)]
b) im Einflussbereich von Wasserschwinden
c) an der Verbreitungsgrenze des Unteren Buntsandsteins
d) entlang von Hauptkluftsystemen bzw. Störungen.

Zur Erläuterung hierzu dient Enclosure 1.

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1) oft nicht als Steilkante sondern Steilhang ausgebildet.

Auf die Dynamik in solchen akuten Verkarstungsbereichen wie unter b) angedeutet weisen

- fossile Hangrutschungen
- ausgeprägte Geländeabbrüche von 2-3 m Sprunghöhe in weiterer Umgebung von Schwinden (s. Ankenberg-Schwinde)
- Schwindenverlagerungen (s. Glasebach-, Dinsterbach- Ankenberg-Ponor)

hin.

Die Häufung von Erdfällen und Depressionen entlang tektonischer Elemente ist in der unmittelbaren Umgebung von Questenberg (Nassetal) besonders gut zu verfolgen. Von 69 mehr oder weniger deutlich erkennbaren Erdfallreihen bzw. Linien, die bestimmte für die Verkarstung bedeutsame Kluftrichtungen repräsentieren, dominiert die NW-SE und NE-SW Richtung vor der E-W Richtung. In der Rangfolge an 4. Stelle ist die rheinische Richtung vertreten. Das trifft auch für die Anlage von Tälern zu, die ~~bestimmten~~ tektonischen Richtungen folgen. Oftmals sind Erdfallreihen und Täler identisch. Der herzynischen, varistischen und rheinischen Streichrichtung folgen auch die Höhlen am Harzsüdrand (Ilausky 1953). Viete (1954) sieht in der seiner Meinung nach vorhandenen Bevorzugung von herzynischer und rheinischer Richtung das Ergebnis alter tektonischer Beanspruchungen zwischen Jura und Tertiär und bringt die jüngere E-W-Richtung mit der Hebung des Harzes oder mit der Einsenkung des harzrandparallelen Auslaugungstales in Verbindung.

In Tälern liegen die Längsachsen von Erdfällen und Depressionen meist in Talrichtung. In dieser Richtung wurden die Ränder der Hohlformen stark erodiert. Die Längsachsen einiger Erdfälle in Tälern liegen um 90° bzw. 45° gedreht zum Streichen der Talachse und zeigen die Beeinflussung durch andere Kluftsysteme. Das kann westlich des Nassetales zwischen Rotem Kopf und Talberg beobachtet werden. Im Kreuzungspunkt zweier Kluft- bzw. Störungssysteme (E-W und NE-SW Richtung) liegt hier ein Grosserdfall. Kreuzungs- und Schnittpunkte von tektonischen Elementen stellen Zentren der Karstwasserbewegung und somit Auslaugung dar. Das E-W Kluftsystem führt nachweisbar im Ostponor des Periodischen Sees versinkendes Wasser zu den Haupt-Quellaustritten im Nassetal (Viete 1954). Eine Häufung der Grosserdfälle mit Tiefen zwischen 5-10 m und über 10 m in der weiteren westlichen Umgebung der Quellaustritte weist ebenfalls in diesem Bereich auf Karstwasserabfluss bevorzugt auf E-W und NW-SE Kluftsystemen in Richtung auf die Haupt-Quelle (Wickeröder Quelle) im Nassetal hin. Diese Quelle schüttet ziemlich gleichmässig 4-7 m^3/min und ist damit eine der am stärksten schüttenden Karst-Quellen im Südharzgebiet. Dass sie auch aus anderen Einzugsgebieten als dem Periodischen See gespeist wird beweist die Tatsache, dass sie auch trotz nunmehr 2-jähriger Leerzeit des Periodischen Sees bei Rossla unvermindert fliesst.

5. STATISTISCHE AUSWERTUNG DER ERDFÄLLE UND DEPRESSIONEN I. O. G. GELÄNDEABSCHNITT

Im Gelände wurden Durchmesser, Tiefe und Böschungsneigung der Hohlformen gemessen bzw. geschätzt. Die Häufigkeit der Erdfälle, ihrer Durchmesser und Tiefen wurde in 3 Geländeabschnitten ermittelt:

Gebiet zwischen Leine- und Nassetal (11,34 km^2)

1. Häufigkeit der Durchmesser der Hohlformen

	0- 5 m	5-10 m	10-20 m	20-50 m	50 m	Gesamtzahl
Messwert:	54	41	48	37	1	181
Schätzwert:	7	17	16	14	4	58

2. Häufigkeit der Tiefen der Hohlformen

	0- 2 m	2- 5 m	5-10 m	10 m	Gesamtzahl
Mess- und Schätzwerte:	161	48	19	7	235

3. Erdfalldichte pro km^2: 21,0

Gebiet zwischen Nassetal und der Strasse Agnesdorf - Rossla (3,71 km^2)

1. Häufigkeit der Durchmesser der Hohlformen

	0- 5 m	5-10 m	10-20 m	20-50 m	50 m	Gesamtzahl
Messwert:	36	32	53	41	7	169
Schätzwert:		6	16	18	1	41

2. Häufigkeit der Tiefen der Hohlformen

	0- 2 m	2- 5 m	5-10 m	10 m	Gesamtzahl
Mess- und Schätzwerte:	162	54	16	3	235

Schätzwerte liegen in einigen unscharfen Erdfallrändern begründet. Eine Festlegung der Erdfallgrenzen ist hier subjektiv. Eine genaue Messung mit dem Teletop würde eine Genauigkeit vortäuschen, die in der Natur nicht vorhanden ist.

3. Erdfalldichte pro km^2: 63,3

Gebiet zwischen der Strasse Agnesdorf - Rossla und dem Thyratal (10,32 km^2)

1. Häufigkeit der Durchmesser der Hohlformen

	0- 5 m	5-10 m	10-20 m	20-50 m	50 m	Gesamtzahl
Messwert:	74	65	94	63	16	312
Schätzwert:	2	5	23	28	6	64

2. Häufigkeit der Tiefen der Hohlformen

	0- 2 m	2- 5 m	5-10 m	10 m	Gesamtzahl
Mess- und Schäztwerte:	287	104	38	8	437

3. Erdfalldichte pro km^2: 42,3

Bei der im Zentralen Geologischen Institut in Berlin erfolgten rechnerischen Auswertung wurden folgende statistischen Masszahlen ermittelt:

	Durchmesser [m]	Tiefe [m]	Böschungswinkel [g]
n	130	130	94
$\bar{x}$	12,3	3,6	45,2
S	9,9	3,0	11,8
v	80,3	81,5	26,1
μ_o	14,0	4,1	47,6
μ_u	10,6	3,1	42,9

Es bedeuten: n - Anzahl

$\bar{x}$ - arithmetischer Mittelwert

S - Standardabweichung

v - Variabilitätskoeffizient

μ_o - obere Vertrauensgrenze des Mittelwertes

μ_u - untere Vertrauensgrenze des Mittelwertes

Zwischen der Tiefe und dem Durchmesser der Erdfälle bestehen deutliche Wechselbeziehungen (s. Abb. 1). Es wurde ein Korrelationskoeffizient von r = 0,932 errechnet.

Zwischen dem Böschungswinkel und der Tiefe sowie dem Durchmesser wurde eine significante Korrelation nicht festgestellt.

Der soweit möglich bei der Aufnahme der Hohlformen ermittelte Böschungswinkel soll ein Hilfsmittel der relativen Altersdatierung sein, da auf geeignete Sedimente für Altersuntersuchungen meist nicht zurückgegriffen werden kann und diese Untersuchungen soweit sie die C^{14}-Analysen betreffen sehr kostenaufwendig sind. Verfasser ging davon aus, dass Erdfälle mit z.B. Böschungswinkeln über 50^g naturgemäss jünger sein müssen als bereits gealterte Erdfälle mit 20^g oder 30^g. Einer freundlichen Mitteilung von Herrn Dr. Wadewitz, Arbeitsgruppe Geologie des DWBO Leipzig zufolge gibt es in der Mooskammer zahlreiche Erdfälle, die offenbar alt sind aber durch ständig aktives Nachrutschen Böschungswinkel entstehen, die o.g. Darlegung einschränken.

6. AUSBLICK

Die Erfassung und Dokumentation der Karstobjekte im Zechsteingürtel des Harzsüdrandes wird unter Mitarbeit weiterer Fachgruppen für Höhlen- und Karstforschung des Kulturbundes der DDR zielstrebig fortgesetzt und o.g. geschlossenen Hohlformen weiterhin besonderes Augenmerk geschenkt. C^{14}-Untersuchungen sollen exakte Altersdatierungen ermöglichen. In der Querfurter Mulde konnte mittels dieser Methode für einige Erdfälle im Tötausstrich (Untere Trias) eine Alter von über 6 000 Jahren errechnet werden (Brendel 1972). Mit dem Aufmass von domartigen Hohlräumen in Höhlen des Gipskarstes - gewissermassen Erdfälle in statu naszendi - wurde begonnen, um Vergleichswerte zu den Dimensionen der Hohlformen an der Erdoberfläche zu erhalten. Alle Fachkollegen, welche die Möglichkeit haben, Messdaten beizusteuern, werden um diese gebeten.

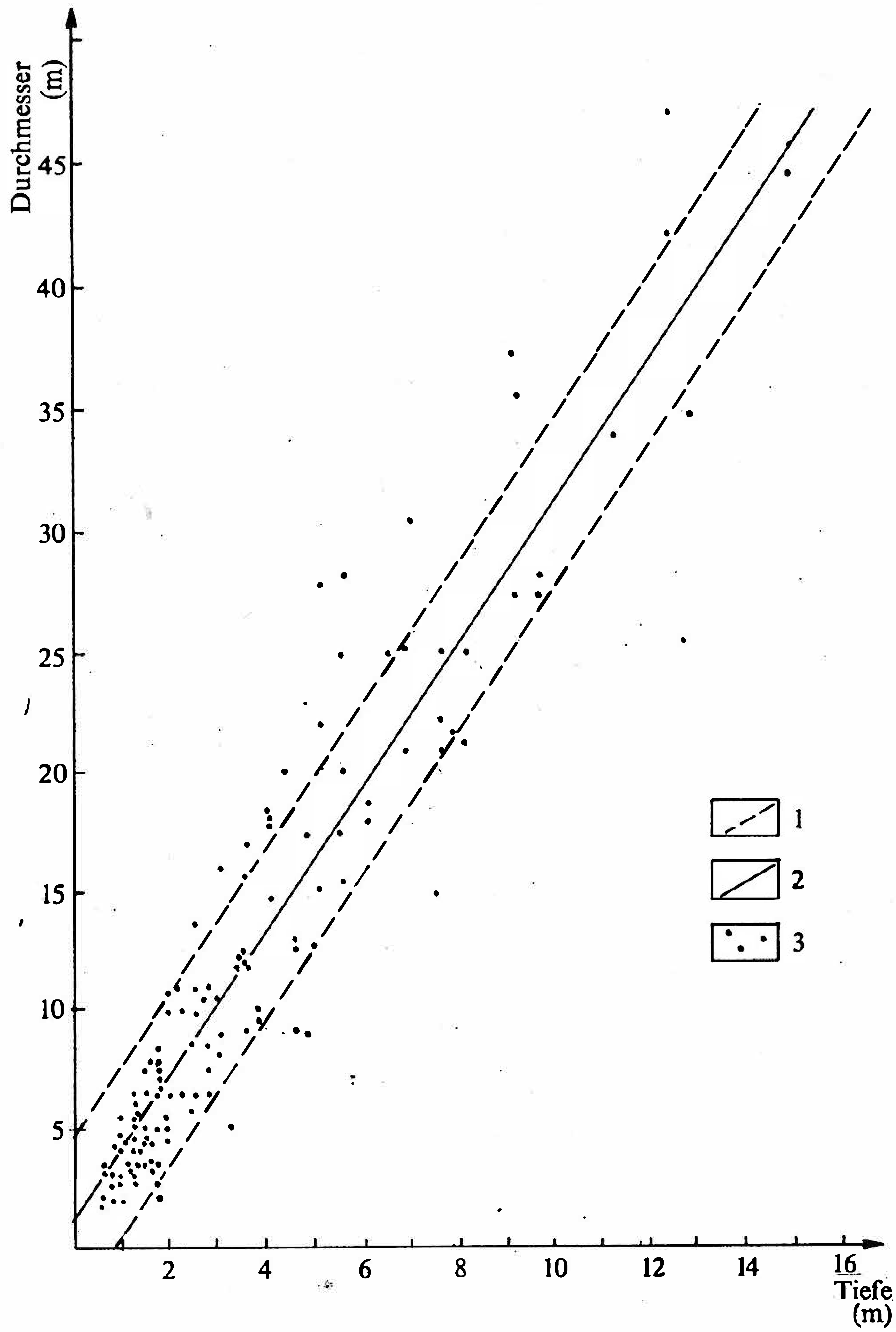

Abb. 1. Beziehungen zwischen Durchmessern und Tiefen bei Erdfällen (Untersuchungsgebiet: Gipskarst Harzsüdrand, Gebiet zwischen Leine- und Nassental): 1 - Streuung um die Regressionsgerade, 2 - Regressionsgerade, 3 - Erdfälle.

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Ba 012

NIVEAUX DE BASE GÉOGRAPHIQUES ET NIVEAUX DE BASE KARSTIQUES

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I. LE NIVEAU DE BASE GÉOGRAPHIQUE

Si l´on admet qu´un niveau de base détermine la zone a partir de laquelle s´établit l´équilibre entre les forces de destruction du relief et la résistance des roches à leur attaque, les niveaux de base karstiques, envisagés par les spéléologues, sont différents des niveaux de base géomorphologiques définis par les géographes. Les niveaux de base des géographes coincident d´ordinaire avec la surface des mers ou des lacs; c´est en principe le niveau au-dessous duquel un cours d´eau ne peut plus creuser, ou modeler sa vallée car il se heurte à la nappe océanique ou lacustre qui annule sa vitesse et par conséquent sa compétence; c´est également le niveau au-dessus duquel il ne peut remblayer sinon il retrouverait vers son embouchure une pente qui lui redonnerait la puissance d´éroder ses propres alluvions.

A cette notion de niveau de base s´ajoute normalement celle de profil d´équilibre; pressentie dès le XVII^{o} siècle par les ingénieurs italiens aménageant le cours du Pô, précisée plus tard par Surell (1872) à partir du lit des torrents alpestres, reprise par Dausse en 1872 et Powel en 1875. De la Noê et de Margerie la vulgarisèrent parmi les géographes à partir de 1888. En 1939 P.S. Iovanovici avait essayé d´en fixer les lois. Mais celles-ci ont été vivement discutées par H. Baulig (1925), P. Birot (1949) et M. Derruau (1965), car elles sont loin de correspondre à une réalité concrète.

Certes, pour les fleuves, le niveau de base c´est, au delà de l´estuaire ou du delta, le niveau des mers et des océans, ou bien celui des lacs; pour les cours d´eau secondaires c´est la confluence avec l´artère principale. A partir de ce point capital, par érosion régressive, ou par remblaiement, s´établissent les profils d´équilibre longitudinaux et transversaux des vallées tels que, par l´usure des seuils et le comblement des dépressions, se produise à la longue un équilibre entre l´áttaque du fluide qu´est l´eau et la résistance du matériel rocheux qui constitue le lit et versants de la vallée. Ainsi reculent et disparaitnont, si rien n'en trouble le rythme actuel, les chutes du Niagara et du Zambèze, ainsi se remblaieront de dépôts les profondeurs inférieures au niveau marin, du Danube aux Portes de Fer, de l'Amazone à Obidos, etc.

Un tel modelé des vallées est fonction de la pente et du débit des cours d'eau, de sorte que le profil d'équilibre tend vers l'horizontale à proximité du niveau de base et vers la verticale dans la région des sources; ainsi il devrait décrite une courbe concave vers le ciel. Mais cette courbe est purement théorique; c'est une vue idéalisée de la réalité, car il n'y a rien d'aussi instable qu'un niveau de base, fut-ce celui de l'Océan, ni d'aussi sinueux qu'un profil d'équilibre qui, en fait, n'est jamais atteint. Le niveau de base se modifie continuellement aux confluences des tributaires et de l'artère maîtresse par suite de l'évolution du profil longitudinal du cours d'eau principal; l'apport des affluents contribue même à faire évoluer la courbe du lit fluvial soit selon une brisure négative s'il est faible, soit selon une brisure positive s'il est abondant. Les niveaux de base lacustres sont eux-aussi soumis à des variations saisonnières qui obligent les affluents des lacs soit à creuser en période de basses eaux, soit à remblayer en période de hautes eaux. d'Ailleurs, à la longue, les lacs sont destinés à disparaître par comblement et vidagne s'il ne se produit pas de modifications climatiques ou tectoniques; c'est dans un bassin continental que s'établit alors le talweg d'un cours d'eau désormais privé de niveau de base local.

Le niveau même de la mer varie sans cesse avec la marée, de telle sorte que tantôt le fleuve creuse des chenaux et transporte des vases vers la mer, tantôt refoulé, il dépose sur ses berges et dans son lit une partie de ce que H. Enjalbert a appelé le "bouchon vaseux". Mais si l'on néglige cette variation quotidienne, on doit reconnaître que les phases eustatiques, dues aux glaciations, jouent toujours un grand rôle dans la section inférieure de la plupart des fleuves du monde. Ils sont en effet inadaptés au niveau actuel des mers par suite de la transgression post-glaciaire; les estuaires se comblent, car leur profil inférieur est au-dessous du niveau moyen des eaux marines. Rares sont les organismes fluviaux qui accentuent leur pente, comme le fait le Var au moment de se perdre dans les flots.

Le profil longitudinal est ainsi sans cesse remis en question; il l'est également tout au long de son parcours. Saisonnièrement, le cours d'eau creuse quand il est en crue, il dépose quand il est en décrue. Au cours des temps géologiques les variations de climat ont eu le même résultat selon leur degré d'humidité et de température. Les gains ou les pertes par capture ont influé eux-aussi sur la courbe du profil, qui a pu être modifiée également par des mouvements tectoniques.

Tout au long du lit d'un fleuve, érosion transport et alluvionnement alternent; les seuils rocheux sont érodés, les biefs retiennent les alluvions. De sorte que même lorsque le profil est proche de l'équilibre, il est loin d'être une courbe concave régulière; il se compose plutôt de courbes locales plus ou moins bien raccordées les unes aux autres, modifiées par l'inégale résistance des couches géologiques traversées, par les apports inégaux des affluents, en matière liquide aussi bien que solide. Le profil longitudinal peut même devenir convexe sur des bancs rocheux très durs, ou vers l'aval si, sous l'influence d'un climat plus chaud et plus sec que vers l'amont, le débit diminue en s'écoulant vers l'embouchure.

Il en est de même des profils transversaux en voie d'évolution vers l'équilibre entre les forces d'érosion et de transport d'une part et les forces d'inertie et de résistance des strates sédimentaires et des replats structuraux d'autre part; ainsi le relief parvient au point où les apports des versants vers le talweg sont très faibles. Mais ce stade n'est jamais atteint; l'équilibre le long des pentes, quoique tout proche, est sans cesse plus ou moins détruit par les mêmes causes que celles qui séparent le profil longitudinal de sa perfection. De sorte que les niveaux de base des géographes, aussi bien que les profils d'équilibre, qui en découlent, sont des vues de l'esprit et non des réalités exactes. Il n'en demeure pas moins que ces notions abstraites restent utiles pour comprendre l'évolution d'un relief tourmenté vers un aplanissement presque parfait. Si la séquence climatique et tectonique, qu cours de laquelle il a débuté, est d'assez longue durée, elle devrait déterminer à la longue une pénéplaine faiblement ondulée.

Toutefois, il convient de remarquer que dans ce cas d'équilibre morphologique, les forces d'agression et de résistance mises en jeu sont turtout d'ordre physique. Il n'en est pas de même en ce qui concerne le niveau de base karstique. Des éléments nouveaux interviennent dont il convient de tenir le plus grand compte, si l'on veut parvenir à une définition aussi satisfaisante et aussi complète que possible du phénomène.

II. LE NIVEAU DE BASE KARSTIQUE

C'est sans doute pour les avoir en partie passées sous silence que les conceptions sur ce niveau de base particulier divergent d'un auteur à l'autre. Ainsi, pour M. Margat (1971), c'est la surface de la nappe d'eau libre, souterraine ou subaérienne, servant de lieu de confluence aux nappes subordonnées et aux filets d'eau des galeries plus élevées, qui règle le jeu de l'érosion et de la corrosion dans les strates calcaires. Ce niveau est ainsi déterminé d'une part par la couche imperméable sous-jacente à la nappe principale, et d'autre part par l'alimentation extérieure, ce qui permet de rapprocher ce niveau de base karstique de celui des géographes, la nappe principale équivalant pour les nappes secondaires à l'Océan pour les fleuves. Mais une définition de ce genre néglige les sources sous-marines, sous-lacustres et sous-fluviales, sources dont les eaux, en dépit des niveaux de base océaniques, lacustres ou fluviaux, attaquent le matériel rocheux qu'elles traversent à des profondeurs parfois très grandes, à des dentaines de mètres et même à des milliers de mètres au-dessous de la surface des mers et des océans.

Par ailleurs, les auteurs d'un lexique français de Spéléologie (9) ont accepté comme définition du niveau de base karstique le niveau lé plus bas permettant la circulation de l'eau dans un réseau de galeries; ils le fixent donc à l'exutoire, à la résurgence la plus basse de ce réseau, à l'exception cependant des sources sous-marines, sous-lacustres et sous-fluviales; dans ce cas, le niveau de base redevient celui des géomorphologues, c'est-à-dire une mer, un lac, ou un fleuve.

Cette conception, soulève de nombreuses objections. Tout d'abord l'altitude de la résurgence est variable; selon l'alimentation, elle peut s'élever ou s'abaisser de plusieurs dizaines de mètres; en outre, sous l'influence de l'érosion, elle a tendance à se déplacer vers l'aval. On néglige également les variations souterraines de la nappe, dues soit au débit des galeries, soit aux différences de perméabilité des roches, soit aux formes extérieures du relief. Il faut tenir compte aussi des nappes captives entre deux zones imperméables. Certains spéléologues, comme Martel, ont même nie l'existence des nappes souterraines; dans ces conditions on ne voit pas ce que devient leur niveau de base.

Au contraire, Pierre Rat, de la Faculté des Sciences de Dijon, propose, comme niveau de base, la limite extrême en profondeur d'un réseau karstique, c'est-à-dire la zone imperméable créatrice d'aquifère. Et nous sommes à peu près d'accord avec lui. Effectivement si l'on définit les divers niveaux de base dans les memes termes comme étant les niveaux au-dessous desquels les phénomènes d'érosion ou d'accumulation par l'eau ne peuvent plus se produire par siute d'un équilibre approximatif entre les forces d'agressivité et les forces de résistance, on parvient à une conception plus précise du niveau de base karstique.

En effet, dans un massif calcaire imprégné d'eaux plus ou moins libres ou captives, douces ou dures, il faut envisager non, seulement leur pouvoir d'érosion et d'accumulation, mais également la pression hydrostatique et les phénomènes de dissolution et de précipitation du $CaCO_3$.

La pression hydrostatique, dite aussi pression artésienne ou charge ascentionnelle, existe toujours au sein d'une nappe souterraine, et peut se mesurer en gradients piézométriques. Au cours de forages sur les hauts plateaux algériens, à l'Ain Skrouna, on l'a trouvée égale à plusieurs atmosphères vers 300 m de profondeur; le bouillonnement de l'eau au fond des bassins de résurgence et le jaillissement des puits artésiens en sont des preuves indiscutables. Un effet de presse hydraulique joue nécessairement à l'intérieur des puits et des couloirs pleins d'eau, sinon comment expliquer les sources sous-marines dont la pression de leurs eaux douces d'origine continentale contrebalance celle de l'eau salée? Ainsi donc, sous l'influence de cette poussée souterraine, l'eau des nappes circule, non seulement en surface, mais également en profondeur, jusqu'à la couche imperméable qui limite vers le bas la nappe phréatique. En Australie n'a-t-on pas fait jaillir de près de 4000 m au dessous du niveau de l'Océan, des eaux chargées de calcaire?

Car, outre la pression hydrostatique, il faut encore tenir compte dans un karst d'un phénomène qui ne joue qu'un rôle réduit dans un réseau fluvial, c'est le phénomène chimique de la corrosion. Dans une masse calcaire, perforée de diaclases et de galeries, baignant dans une eau sons pression et chargée de gaz carbonique, ou d'acides divers, le carbonate de calcium est attaqué, transformé en bicarbonate de calcium très soluble dans les eaux en cours de migration. S'il y a une érosion de caractère physique dans les conduits à circulation libre, il se produit une érosion de caractère chimique dans les conduits entièrement gorgés d'eaux captives; c'est le phénomène de corrosion, agent spécifique de l'évolution des karsts.

Jusqu'où peut s'exercer cette action corrosive? en d'autres termes où se situe la limite inférieure de la dissolution karstique?

où se produit l'équilibre entre la corrosion et la résistance du matériel rochaux? où se trouve le niveau de base karstique? Ainsi posé le problème de ce niveau ne paraît plus poser d'ambiguité. Certes, la corrosion s'étend à toute la nappe et s'exerce sur les multiples interfaces liquide-solide, d'autant plus efficacement qu'ils sont très nombreux dans un calcaire fracturé et poreux. Mais cette activité destructrice des eaux souterraines trouve sa limite lorsqu'elle se heurte à un matériel insoluble, ou difficilement soluble, c'est-à-dire à des couches d'argile ou à des roches cristallines. Ainsi le niveau de base karstique s'établit au niveau de la zone qui arrête la progression vers le bas de la nappe souterraine, c'est-à-dire à la couche géologique imperméable, génératrice d'un aquifère.

Toutefois, la réalité est plus compliquée que ne le laisserait croire définition aussi schématique. La continuité, l'épaisseur et l'altitude des roches imperméables sont loin d'être régulières. Parfois les horizons argileux comportent des interruptions, des lacunes, des réductions de puissance qui favorisent les captures entre réseaux superposés et font descendre d'autant les niveaux de base. Parfois des masses calcaires compactes, mans diaclase ni porosité, n'étant pas imprégnées d'eau, provoquene des lacunes dans les nappes et, en conséquence, des ruptures, dans les niveaux de base. Ceux-ci ne sont pas nécessairement horizontaux, ni régulièrement inclinés, ni concaves ou convexes; ils épousent les dénivellations, parfois considérables, de la base des aquifères; ils peuvent être isolés en bassins sans communication les uns avec les autres. Enfin, fréquemment, à travers un massif calcaire s'intercalent des strates marneuses ou argileuses, chacune d'elles créant des nappes superposées, de sorte que l'on peut observer ainsi, sur les parois des grands escarpements calcaires, des suintements, des lignes de source qui correspondent, chacune d'entre elles, à un niveau de base particulier. Dans ce cas plusieurs zones se superposent où l'érosion chimique est arrêtée, équilibrée par la résistance à la dissolution d'une couche géologique insoluble, dépourvue de carbonate de calcium, mais composée de silicates d'alumine ou d'oxydes de silicium, avec des élements d'une morphométrie d'argile.

Certes on peut objecter que la dissolution en profondeur est rapidement stoppée, notamment dans un calcaire finement poreux; les eaux seraient saturées de CO_3Ca en quelques mètres et cesseraient d'être agressives. Sans doute; mais divers éléments entrent en jeu pour maintenir ou renouveler la corrosion, soit par élargissement des fissures ou des diaclases, soit par mélange des eaux inégalement agressives (la Mischungskorrosion d'A. Bogli), soit par variations latérales ou verticales de la nature des roches, de sorte que des exutoires favorisent la circulation des nappes souterraines à des vitesses infiniment variables et que mettent en évidence résurgences et exsurgences, puits et cours d'eau par leurs dépôts de tufr, de travertins ou de calcite pure. Le raisonnement exigerait une rapide saturation; l'observation montre le contraire et nous devons bien lui rendre des points.

Enfin peut-on envisager l'évolution complète d'un karst sous la seule influence de la corrosion jusqu'à la disparition totale de la masse calcaire au-dessus de son niveau de base? en d'autres termes est-il possible de concevoir un équilibre parfait entre les processus de dissolution et la résistance des couches insolubles? C'est encore, pour le niveau de base karstique, comme pour le niveau de base géographique, une limite qui n'est jamais atteinte. En effet, au fur et à mesure de la disparition du carbonate de calcium le relief karstique évolue de la doline et de la caverne aux tours et aux chicots, de sorte que la pression hydrostatique s'atténue de plus en plus tandis que l'érosion par les eaux libres s'acrroit; c'est le niveau de base géographique, c'est-à-dire le niveau des mers ou des lacs qui régit alors l'évolution du relief aux lieux et places du niveau de base karstique, avec tout ce qu'il comporte d'imperfection et d'inachevé, ainsi que nous l'avons déjà souligné.

En conclusion, il existe une différence très sensible entre les deux conceptions des niveaux de base speleologiques et des niveaux de base géographiques. Ceux-ci restent subaériens et soumis à des phénomènes mécaniques, déterminant, si la séquence géologique est assez longue, un équilibre entre l'usure et l'accumulation par les eaux fluviales d'une part, et la résistance du matériel rocheux d'autre part. Au contraire, les niveaux de base des karstologues sont souterrains et il s'y ajoute, aux actions mécaniques, sous l'influence de la pression hydrostatique et des acides carboniques et organiques, une dissolution lente, partiellement créatrice en profondeur de grottes et de cavernes, et en surface de dolines, de poljés et de hums. De tels phénomènes se produisent dans l'épaisseur des masses calcaires perméables jusqu'à la limite où il y a équilibre entre la corrosion et la résistance des roches à la dissolution.

Mais étant donnée la complexité des facteurs mis en cause, niveaux de base karstiques et niveaux de base géographiques, profils d'équilibre subaériens des cours d'eau et profils d'équilibre souterrains des karsts sont finalement plutôt des hypothèses idéales que des possibilités réalisables. Elles n'en sont pas moins utiles à la recherche géomorphologique et à la compréhension des modèlés karstiques et non karstiques, puisqu'elles représentent des cas limites qui devraient être atteints si n'intervenait aucun élément susceptible de modifier l'évolution actuelle de l'écorce terrestre, de sorte que, selon la Parole, "les montagnes seraient abaissées et les vallées seraient comblées".

SUMMARY

For geographers the ideal basis level is sea level, having as a corollary the lime of ideal equilibrium of subaerial water courses which flow into the oceans. This line may be defined as being the result of an equilibrium between the force of erosion or of accumulation in a water course and the resistance of the material over which it flows; in other words above or below which it can neither dig nor accumulate any further. It goes without saying in the case both of the basic level and in the case of the line of equilibrium we are dealing with a theoretical possibility; it is never perfectly attained, but they are both useful in explaining evolution in relief. Be as that may, whether the line of a water course is due to erosion or to deposite, it comes above all from mechanical phenomena.

Like geographers, karstologists have also created the basic karstic level. But opinions differ from one specialist to another. For some it is, it would seem, the surface of phreatic water existing in a karst. For others it is the level of the lowest outlet permitting of free circulation of water in a karstic network.

Now the level of an underground bed, like that of an outlet, is too variable to be considered stable. What is more, two important phenomena have been neglected, hydrostatic pressure and chemical erosion or corrosion. The first comes through submarine sources, and by siphonic channels; the second, linked to the first, sometimes occurs at great depths if the underground bed crops up again either as a result of gravity, or above all of pressure.

So that if, following the geographers, the basic karstic level is defined as being that below which karstification cannot occur, that level can only consist of the impermeable layer on which the limestone mass lies and which blocks the underground bed. Thus conceived, basic karstic levels can be complete or incomplete according to the degree of impermeability of the clastic rock, unique or multiple according to the

number of impermeable zones situated either at the base or at different levels of the limestone rock.

But is a line of equilibrium linked to this basic level? Undoubtedly it is the surface of the insoluble and impermeable stratum where corrosion ceases to act. Nevertheless, before that the corrosion ceases the mechanical erosion relaies it above the basic geographic level. Finally erosion and corrosion interfere to make away all relief if continents and oceans remain stable under a same climate.

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KARST DEVELOPMENT IN BARBADOS

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The island of Barbados is principally constructed of a series of raised reefs which form a limestone cap generally over 70 metres in thickness. Mean annual rainfall over this cap ranges from 1000-1800 m.m. and the water-table is everywhere well below the surface. Tricart (1968) has observed that the lithological and hydrological environment leads one to expect extreme Karstification, but that this expectation is not realized. Instead we find a low density network of valleys that are either dry or only ephemerally active, and on the wide interfluves a scatter of small shallow depressions.

Thorium-Uranium dates are available for reefs up to 250,000 years of age, and both younger and older reefs can be fitted to insolation maxima predicted in terms of absolute age from astronomical data (Mesolella et al. (1968)). Hence Barbados provides an ideal setting for the study of Karstification through time. The valley network is ill suited to such a study however, as it is widely suspected of being a fossil feature, and may even consist of linked sections of differing ages of inception or dessication, but similar durations of incision (Harrison & Jukes-Browne (1890)). Therefore attention is first concentrated on the sinkhole plains, seeking to trace their development and to account for the general attenuation of Karstification.

The basis data for the study is obtained from the 1:10,000 map series. This has a 6 metre contour interval, and depression counts are made by reference to closed contours with the addition of those sinkholes marked conventionally but without contour indication. Depression areas quoted refer to areas within the highest closed contour, and elongation ratios are similarly derived. As the vast majority of the depressions are shown only by a single contour no attempt is made to trace changes of depth with time.

Depressions in the raised reefs may be Karst solution features, Karst collapse features, or pseudokarst features inherited from the submarine environment, as previously reported by Verstappen (1960). In the subsequent analysis the majority of the depressions are assumed to be solutional features. From this working hypothesis, three factors are deduced as favouring high depression frequencies. These are rainfall, which should have a direct relationship with the rate of solution, the slope of the ground, which should determine the balance of run-off and percolation, and the duration of exposure of the reefs to sub-aerial conditions.

To gauge the influence of these factors, 82 Kilometre squares were selected on the coral limestone and for each a count of depressions was made. The selection of squares was based on the availability of comparable rainfall data, in this case the annual mean for the period 1890-1929, for one or more stations within each square. To assess the period of exposure, use was made of the assertion by Mesollella et al. (1968) that the tectonic uplift of Barbados has proceeded at a uniform rate of 0.3 metres per 1000 years. The height at the centre of each Kilometre square was converted using the formula and taken as the exposure time of the square as a whole. The selection of a slope index needs more circumspection. Lasserre (1961) has stated that the existence of very low slopes is of especial importance to doline development in the tropics. What is needed is a measure of the frequency of low slopes large enough to support such development, rather than the average slope. Accordingly each of the selected kilometre squares was overlaid with a grid of 256 squares, and the number of these grid squares uncrossed by a contour gave a flatness index. In its compilation the enclosed contours of the depressions themselves were ignored on the assumption that they represented subsequent development on a flatter initial surface.

An attempt was made to account for the variation in depression frequency for the 82 squares in terms of variations in rainfall, slope and age. Tab. 1 shows this to be a complete failure, as neither singly nor together do these factors produce a correlation of any magnitude or significance. A possible interpretation is that the influence of age, together with rainfall as a pace setter, on the creation of depressions, holds only for an initial period, other influences becoming dominant thereafter. An effective analysis requires a division of the data to coincide with the cessation of the stage of growth.

Matthews (1968) provides support for this interpretation and a rational choice for the division, through his mineralogical studies of the reef limestones. These show a gradual conversion from aragonite, the stable form under submarine conditions, to calcite, which runs to completion in 200,000-500,000 years, being swifter in wetter areas. The conversion involves solution and reprecipitation, and an 8% in-

T A B. 1. Relationships between variables on the coral cap.

	Flatness	Rainfall	Age
Frequency	.192	.007	.062
Flatness		-.704	-.635
Rainfall			.834

creas in the volume of the limestone, so that suppression of primary porosity seems probable, and a selective increase in secondary permeability at least a possibility. Matthews has mapped the boundary between the zone where aragonite is still present to some degree, and the zone of total conversion to calcite. The boundary was used to divide the foregoing sample of Kilometre squares into two groups, for each of which a further multiple correlation analysis was performed.

THE ZONE OF EQUILIBRIUM

Tab. 2 details the result for the calcite zone. The three variables of slope, age and rainfall explain 73.6% of the variation in depression frequency. However slope alone explains 71.1%, and a comparison of the restricted and full models using the F test, shows that the small additional explanation provided by the two growth inducing variables is not significant. The negative correlation between rain-

T A B. 2. Relationships between variables in the calcite zone.

	1. Flatness	2. Rainfall	3. Age
0. Frequency	.843	-.586	-.272
1. Flatness		-.540	-.245
2. Rainfall			.662

R^2 0.123 = .736 0 = .904 (1) = 1.86

R^2 0.1 = .711 S.E. = 2.15

fall and depression frequency may indicate that increasing rainfall favours the development of valleys rather than depressions.

The paramount importance of low slopes in the prediction of depression frequency is a confirmation of the view that these depressions are solutional rather than collapse features, since siting of the latter should be independent of surface form. There remains the possibility that primary depressions survive in this zone. The calculation of the flatness index ignored closed contours, so any such primary depressions would raise the index and so help to bring about the correlation between depression frequency and flatness. However the regression equation predicts a depression frequency roughly a tenth of the number of contour free squares, each square of 0.39 hectares being more than double the size of the majority of depressions. This suggests relatively extensive areas of low slope on which scattered depressions develop rather than small areas counted as flat simply because a depression exists.

THE ZONE OF GROWTH

Tab. 3 shows that within the aragonitic zone the most successful single predictor of depression frequency is the age of the surface. The growth inducing variables of age and rainfall explain 28.4% of the variation in frequency when added to the explanation achieved by slope. Despite its negligible simple correlation, slope adds 8.5% to the explanation achieved by age and rain alone.

T A B. 3. Relationships between variables in the aragonitic zone.

	1. Flatness	2. Rainfall	3. Age
0. Frequency	.017	.293	.415
1. Flatness		-.397	-.436
2. Rainfall			.302

R^2 0.123 = .287

Though this evidence supports the view that depression frequency is partly time dependent, and shows that slope also has some influence, the low level of explanation deserves comment. It may be that depressions on these lower reefs are a mixture of solutional and primary forms, with the latter in sufficient proportion to confuse the picture. While no certain typing of each individual depression is possible, general criteria can be used to test the credibility of this hypothesis.

The best guide to a primary depression appears to be its orientation. Fringing reefs commonly show lagoonal deepening behind reef crests, producing a tendency after emergence for linear depressions parallel to the shore. The orientation of all depression with elongation rations of 2 or more were compared with the alignment of raised reefs in their vicinity for two areas. The first area included all land below 100 metres on sheets 15-18 of the 1:10,000 series. This is entirely within Matthew's aragonitic zone, with mean rainfall below 1,250 m.m. The second area is all the land above 166 metres on sheets 7, 8, 11 and 12. It has a rainfall exceeding 1,500 m.m. and is within the calcite zone.

T A B. 4. The orientation of elongated depressions.

	Lower reefs	Higher reefs
Depressions in sampled area	270	248
Elongated depressions	40	48
Long axis oriented $< 30^\circ$ to generalized contours	32	17

Tab. 4 shows the proportion of elongate depressions with long axes within 30° of raised reef directions. On the younger reefs this proportion is significantly above chance levels. This is hard to explain if these depressions are solutional or collapse features. If depressions become elongate through gullying or through cave collapse high angles with raised reef edges are to be expected in concordance with the general trend of overland and groundwater flowlines. It is true that the lagoonal facies might present a more favourable environment for solution, or that hointing might be more developed parallel to reef fronts, but if so the proportion of elongate depressions oriented along the reefs should grow as time passes. Yet on the older reefs the preference for such orientations has all but disappeared which suggests that it is characteristic of relic features which are progressively eliminated by Karstification.

THE CESSATION OF GROWTH

Two distinct hypotheses can be advanced to explain the stabilization of doline densities for constant slopes. This may follow from the completion of the aragonite - calcite conversion, or it may mark the onset of competition between dolines.

The calcite zone has proved to be an area where depression frequency is independent of the age of the surface, but this does not prove the coincidence of the two distributions. As a further test predictions from the regression equation derived in the calcite zone can be applied to the sample squares in the aragonite zone. Fig. 1 suggests that the zone of time independent karstification is wider than the calcite zone. The additional squares added to the time independent zone fall within one standard error of the prediction, as many being under as overpredicted, and the group having a spatial unity which argues for the legitimate extension of the zone.

It is reasonable to look for a check on the colonization of a surface by additional depressions when all parts of that surface have come within the sphere of influence of existing depressions. The difficulty in the Barbadian setting is to decide when such a complete partition has been realized. Cellular depression fields are found only exceptionally, but it is possible that after storms sheet flow and throughflow may enter depressions from peripheral flatter surfaces. Whether such depression catchments, as distinct from the depressions themselves, become contiguous, and whether the onset of this contiguity coincides with the cessation of the growth in numbers, remain matters of conjecture.

Before leaving this question we may relate frequency to depression size, since the second of the foregoing hypotheses in its simpler form would require the two to stabilize together. Tab. 5 gives some evidence for a stabilization of size after an initial period of growth. The different means used to demonstrate this does not allow us

T A B. 5. The size of depressions in relation to the age of the surface.

Age (00,000 yrs.)	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9
Percentage of depressions > 0.18 ha	18	22	29	36	40	42	39	42	39

to say if this stabilization coincides with the stabilization of frequency, but the timing of stabilization is of the same order.

LOW KARST RELIEF

Tricart has drawn attention to the surprising attenuation of Karstification on Barbados. His explanation is that a high general porosity inhibits the localization of solutional activity so necessary for a Karst relief to develop. In the light of the foregoing discussion the explanation is supported when applied to the aragonitic zone, particularly for the younger reefs in that zone, but it loses force as time passes and as the aragonite-calcite conversion runs to completion. An explanation in terms of the youthfulness of the landscape loses force in like manner; for about half of the coral cap has a degree of doline development that is independent of age. In this zone on flatter surfaces dolines reach a density of up to 20 $Km.^{-2}$. It is not a lack of foci of solution that constitutes the problem, but the small relief of these dolines in comparison with other tropical karsts. A comparison will drive this home. The area of Barbados which now concerns us has a rainfall of 1500-1800 m.m. The median depth of the dolines in this area is about 6 metres, and only 6% of the dolines exceed 12.2 metres in depth. In Jamaica, by contrast, on the Troy-Claremont limestones of the parish of Cum-See, the rainfall is 1700 m.m. and by reference to the 1:12,500 map series, 100 depressions (cockpits) gave a median relief range of 76 metres, with the top 5% exceeding 137 metres.

Two further hypotheses are considered in the light of local information. The first of these is that local conditions favour soil accumulation on the older reefs sufficient to clog and hence stultify incipient karst development. Harrison and Jukes-Browne (1890) note that the choking of sinks with rainwashed soil is common on the higher reefs, and that the puddling of this soil holds up sinkhole ponds in some instances, so increasing evaporation at the expense of percolation. These authors give a purity of 96-98% for the reef limestones, which compares with values quoted by Hill (1955), for Cum-See, and Sinclair (1966), for the white limestone of Jamaica in general, of 99.9%. A further source of impurities is volcanic dust from St Vincent (Vernon and Carroll, 1965). However the near complete change, produced and maintained since around 1650, from tropical seasonal forest to sugar cane cultivation with its periodic clean tillage (Watts 1970) will have greatly increased soil wash. There is little to suggest that, under natural conditions, amounts of mobile insoluble material will differ radically from highly karstified regions elsewhere.

A more radical explanation for the lack of cockpit karst in Barbados can be reached by considering the views of Lehmann (1936) and Lasserre (1961) working in Java and Guadeloupe respectively. They see Karsts of high relief resulting from the dismembering of deeply incised valleys when the long profile gradients of these valleys have been sufficiently reduced. Lasserre claims that the sinkhole plains in Guadeloupe represent a dead end in karst development, which continues by their replacement with deep valleys. On this view Barbados shows attenuated Karst development because even the older reefs are in a youthful stage, taking valleys and sinkhole plains together.

There is much to be said for this hypothesis in Barbados. Valley incision is everywhere much deeper than the floors of depressions nearby. As the reefs age drainage densities increase, producing high side slopes that favour runoff rather than percolation. The sinkhole plains have dwindled in extent with time and the valleys that replaced them are now only ephemerally active at best, and in some areas show the first faint signs of Karstification of their floors. However the negative partial correlation of valley density with age when rainfall intensity is held constant (tab. 6), suggests that it is not age *per se* but continuing uplift that brings about the particular sequence of events in Barbadian Karst development. Moreover the latter day dessication of some valleys has been ascribed to a reduction in the frequency of intense storms rather than, or in addition to, lowered gradients of the valley floors (Tricart 1968, Fermor 1972). Neither objection is fundamental. They indicate that a rather specific tectonic-climatic history may be necessary for Karst evolution to progress as suggested. Nevertheless the model can serve as an explanation of low karst relief in Barbados, and may be applicable wherever Pleistocene uplift has occurred under moderately humid tropical conditions.

TAB. 6. Valley density, age, and rainfall intensity.

Station	(1) 20 yr. 1 day rain* (m.m.)	(2) Valley density (1/2 Km. radius)	Age (000 years)
Castle Grant	346	33	1000
Claybury	334	40	760
Lion Castle	312	39	940
Warleigh	297	38	220
Lancaster	270	31	400
Holetown 7̄	250	29	40
Alleyndale	237	25	200
Edgecumbe	202	9	210
Seawell	201	2	170

7̄ Valley density and age for circle centred on Lascelles

* From daily extreme rain 1953-70

$r_{23} = .54$ $r_{23.1} = -.61$ $r_{12} = .87$ $r_{13} = .82$

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Ba 014

POLYGENETISCHE FORMEN IM KARST DER OSTALPEN

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Zahlreiche Karstformen in den Ostalpen sind nicht allein auf korrosive Prozesse zurückzuführen, sondern verdanken ihre Genese einem unterschiedlichen geomorphologischen Kräftespiel. Vor allem im Hochgebirge ist der Anteil von Erosion und Akkumulation an der Landformung und somit auch am Zustandekommen von polygenetischen Karstformen bedeutend. In erster Linie waren es die pleistozänen Vergletscherungen, die den Alpen die typischen Hochgebirgsmerkmale aufgeprägt und die durch Glazialerosion und -akkumulation auch die Morphogenese der Karstlandschaft mitbestimmt haben. Die Vergletscherung folgte bevorzugt den präexistenten Talungen fluviatiler Genese, die bereits durch Verkarstung inaktiv waren und die das Auftreten grosser Karstmulden und Karstwannen begünstigten. In den Kalkvoralpen knüpfen sich die Poljen und anderen Grossformen fast durchwegs an solche inaktive Talungen. Darüber hinaus haben für die Entstehung polygenetischer Formen die Massenbewegungen aller Art, vornehmlich Bergstürze, Schutthalden und Rutschungen eine grosse Bedeutung.

1. POLYGENETISCHE FORMEN DURCH EROSIV-KORROSIVES KRÄFTESPIEL

Die Grossformen des Karstreliefs zeigen vielfach eine Bindung an alte Talungen, die durch die Verkarstung schon seit langem inaktiv geworden sind. Beispiele dafür bieten praktisch alle Karstplateaus, sowohl im Hochgebirge als auch im Mittelgebirge. Sie lassen eine mehrphasig entstandene Flurentreppe erkennen, deren Einzelelemente als bevorzugte Ausgangsflächen für das Karstphänomen in Erscheinung treten, die durch die Verkarstung zwar wesentlich umgestaltet, gerade dadurch jedoch weitflächig erhalten geblieben sind. Teils verlaufen die Talungen auf den flachwelligen Plateaus selbst und enden abrupt am Steilabfall zum jüngeren Ausraum, teils führen sie von der Altlandschaft in den Bereich der aktiven Täler hinab. Im alpinen Hochgebirgskarst sind die inaktiven Talungen zusätzlich vom Eis überarbeitet worden.

Als Beispiel für eine rein fluviatile Vorform für die Entwicklung von Karstformen möge das Polje "Auf den Böden" bei Puchenstuben in den niederösterreichischen Kalkvoralpen vorgestellt werden:

Die derzeit inaktive Hohlform ist in die kuppige Altlandschaft zwischen Hennesteck (1334 m) im Osten und Brandmauer (1276 m) im Westen eingesenkt. Der ebene, sanft gegen W geneigte Poljeboden liegt in einer mittleren Höhe von 1075 m. Das Polje ist 1,25 km lang und bis zu 500 m breit, die Längsachse verläuft Ost-West. An der tiefsten Stelle im W befinden sich die als episodische Ponore fungierenden Trichterdolinen. Die Eintiefung des Poljebodens bezüglich der tiefsten Stelle der Umrandung beträgt 25 m. Diese begrenzende Schwelle im W wird vom Hauptdolomit (Nor) gebildet, der ausserdem auch die tieferen Teile der nördlichen Umrandung aufbaut. Der Untergrund des Poljes besteht im W aus Hauptdolomit, im Mittelabschnitt aus Lunzer Sandstein (Karn) und im E aus Gutensteiner Kalk (Anis). An den Randzonen sind Dolinen eingetieft, die z.T. als episodische Ponore in Funktion sind. Das Polje wird rezent von keinem Gerinne durchströmt; die heftige Schneeschmelze kann jedoch einen Wasserstau verursachen. Das Polje hat sich aus einer Talung entwickelt, die in das anders orientierte Entwässerungssystem der tertiären Altlandschaft einbezogen war. Der schmale Ostteil des Poljebodens geht in ein sanft ansteigendes Muldental über, das abrupt am Steilabfall gegen das mächtige Karstsacktal des Pielach-Ursprunges in die Luft ausstreicht. Das Einzugsgebiet dieses Talstrunkes ist der rückschreitenden Erosion und Korrosion des Pielach-Karstsacktales zum Opfer gefallen. Vom Hennesteck im Osten zieht ausserdem eine muldenförmige, durch Verkarstung inaktiv gewordene Talung westwärts und mündet auf eine Ebenheit am Fuss des Hochstadelberges. Terrassenreste an den Randzonen dieser Ebenheit deuten darauf hin, dass ursprünglich die Entwässerung des Hochtales gegen die "Böden" hin erfolgt ist. Durch die Verkarstung wurden sämtliche hochgelegenen Talungen dieses Raumes funktionslos. Die Breite des Poljebodens ist sicherlich auch auf die verstärkte Lateralerosion im Bereich der weniger widerstandsfähigen Lunzer Schichten zurückzuführen.

Nicht nur die meisten alpinen Poljen, wie z.B. die Bodenwiese am Schneeberg, das Nassköhr auf der Schneealpe oder der Molterboden auf der Gemeindealpe bei Mariazell, sondern auch die meisten Karstmulden und Karstwannen (Uvalas) sind an fluviatile Vorformen gebunden, was vielfach in der reihenförmigen Anordnung dieser Hohlformen zum Ausdruck kommt. Ebenso sind viele Dolinenreihen an die Tiefenlinie fluviatil entstandener Talungen gebunden.

Zwischen den Formen der Glazialerosion und dem Karstphänomen gibt es naturgemäss sehr häufig Wechselbeziehungen. Die Alpen verdanken ihren Charakter als Hochgebirge in hohem Masse der pleistozänen und rezenten Vergletscherung.

In den Kalkalpen sind zahlreiche Kare in Karstmulden umgewaldelt worden, wobei es schwierig ist, festzustellen, ob etwa bereits präglaziale Karstformen Ansatzstellen für eine nachfolgende Karentwicklung darstellten. Beispiele für solche polygenetische Karstmulden bieten alle ehemals vergletscherten Kalkalpen. Aus dem Dürrensteingebiet in Niederösterreich sind mehrere solche Formen bekannt. Hier sind es vor allem die an der Südostflanke befindlichen Kare, die zur Gänze zu oberirdisch abflusslosen Karstmulden umgestaltet wurden.

Darüber hinaus sind es die glazial geformten Trogtäler, die der Verkarstung anheimgefallen sind und in ihrer Gesamtheit als polygenetische Formen anzusprechen sind. Ursprünglich rein fluviatil-denudativ unter anderen klimatischen Verhältnissen als Bestandteile einer Altlandschaft angelegt, sind sie in den pleistozänen Kaltzeiten vom Gletschereis zu Trogtälern und Eisgassen umgestaltet worden. Durch die Verkarstung erfuhren sie eine entscheidende Veränderung in ihrem morphologischen Erscheinungsbild, vor allem jedoch in ihren Abflussverhältnissen. Es ist nicht immer einfach, eine zeitliche Differenzierung der verschiedenen Formungsprozesse durchzuführen, da sich die morphogenetisch wirksamen Prozesse teils nacheinander, teils synchron abgespielt haben, so dass die Mehrzahl der alpinen Karsttäler nicht nur polygenetische, sondern auch Mehrzeitformen sind. Im Dürrensteingebiet stellt das Lueg ein typisches polygenetisches Karsttal dar:

Es beginnt als Karstsacktal, zu dem der Trogschluss umgestaltet wurde, und zieht vorerst als Trockental abwärts, bis nach einer Talstufe ein perennierendes Gerinne auftritt, das nach kurzem Lauf in einem Ponor versinkt. Nach einem episodisch aktiven Trockenbett erscheint abermals ein Gerinne, das eine Versinkung im Bachbett aufweist. Eine anschliessende, nur bei Hochwasser in Funktion befindliche Klammstrecke mündet in eine grosse Karstwanne, die in den Trogboden eingetieft ist.

Eine Reihe von Trogtälern, die vom Plateaurand mit sehr beträchtlicher Eintiefung in den umgebenden Talraum führen, sind auch als Karstsacktäler in den polygenetischen Formenkreis einbezogen. Das Grosse Höllental der Raxalpe, das Brunntal des Hochschwabs und die Dietlhölle des Toten Gebirges seien als Beispiele genannt.

Die Mesoformen des glazialen Erosionsreliefs, Rundhöckerfluren und zwischengeschaltete glazigene Wannen und Rinnen sind in den Kalkalpen häufig zu Karstformen umgestaltet worden. Der Dürrenstein bietet auch für diese Art von Polygenese ein Musterbeispiel. Das Gebiet Rotmoos-Obersee (1113 m) ist von der pleistozänen Vergletscherung zu langgestreckten Wannen und Rundhöckern umgeformt worden. Diese glazigenen Wannen werden zur Gänze unterirdisch entwässert. Die Entwässerung erfolgt in Form von Höhlengerinnen quer durch die begrenzenden Rundhöcker von einer Hohlform in die benachbarte, bis schliesslich das Gerinne in den Obersee einmündet. Der Obersee selbst nimmt den Boden eines Durchgangskares ein und wird ebenfalls durch periphere Ponore unterirdisch entwässert, wonach das Seebecken als polygenetische Karstwanne angesprochen werden kann.

2. POLYGENETISCHE FORMEN DURCH AKKUMULATIV-KORROSIVES KRÄFTESPIEL

Die vielfältigen und oftmals sehr differenzierten Akkumulationsformen haben auch für die Genese von Karsthohlformen grosse Bedeutung. In Frage kommen in erster Linie Formen der Massenabwanderungen, wie Bergstürze, Schutthalden und Rutschungen, daneben glaziale Akkumulationen, hauptsächlich Moränen, weiters auch fluviatile Akkumulationsformen, z.B. Schwemmkegel. Einige der polygenetischen Karstformen sind durch das Zusammenwirken verschiedener Akkumulationsprozesse mitbestimmt worden.

Eine Karsthohlform, die unter Beteiligung von Bergsturzmaterial entstanden ist, befindet sich an der Südseite des Hochschwabs bei Tragöss-Oberort "In der Klausen" (914 m). Das glazial überformte Tal wird zwischen Pribitz und Messnerin von mächtigen Bergsturzmassen erfüllt, die zur Abdämmung und somit zur Entstehung einer oberirdisch abflusslosen Wanne geführt haben. Der Bach aus dem Bereich der Klamm Alm bricht durch eine Klammstrecke und hat in die 500 m lange und rund 300 m breite Wanne einen Schwemmfächer eingeschüttet. Am scharfen Knick des Wannenbodens gegen die 60 m und höher aufgetürmten Bergsturzmassen bildet sich ein grösserer Wasserstau, der durch randliche Ponore entwässert wird. Da die Tomalandschaft einem Riegel aus anstehendem Wettersteinkalk (Ladin) auflagert, findet, nachdem der Abfluss des Klammbaches das lockere Bergsturzmaterial durchflossen hat, anschliessend eine echte karsthydrographische Entwässerung statt. Es kann angenommen werden, dass vor dem Niederbruch des Bergsturzes bereits eine Karsthohlform bestanden hat, die beträchtlich grössere Dimensionen als die derzeitige aufgewiesen hat.

Die Tomalandschaft grosser Bergstürze im Karstgebiet weist durch die wirre, unregelmässige Anhäufung des Sturzmaterials dolinenartige Hohlformen auf, die unterirdisch entwässert werden, da es sich um verkarstungsfähiges Gestein handelt. Eindrucksvolle Formen dieser Art sind im Bereich der gewaltigen Akkumulation des Dobratsch-Bergsturzes in Kärnten zu finden.

Häufig ist die Abdämmung von Talungen durch Schutthalden und Schuttkegel, wodurch oberirdisch abflusslose Hohlformen entstehen.

Im Dürntal der Reisalpe (1399 m) in den niederösterreichischen Voralpen hat eine gewaltige Rutschung zur Abdämmung des Tales geführt, wodurch an der Einmündung eines Seitengrabens eine grosse Hohlform zur Ausbildung gelangte, die zur Gänze unterirdisch entwässert wird. Das Gebiet der Reisalpe wird grösstenteils aus dünnplattigem Gutensteiner Kalk (Anis) aufgebaut, der flach gegen Süden einfällt. Er lagert auf den nichtverkarstungsfähigen Werfener Schichten (Skyth) auf, die westlich des Reisalpengipfels zwischen "Hahnfeichten" und dem Sattel "Gscheidboden" zu Tage treten und an der rechten Flanke des oberen Dürntales ebenfalls nach Süden herab streichen. Diese Schichten sind wasserstauend und weisen einzelne Gipsvorkommen auf. Darüber hinaus sind zwei Vorkommen von Lias-Fleckenmergel in diesem Bereich von Bedeutung.

In den pleistozänen Kaltzeiten mit verstärkter mechanischer Verwitterung kam es zur Entstehung einer mächtigen Schuttdecke, an der hier vor allem die wenig widerstandsfähigen Sandsteine und Mergel der Nichtkarstgesteine beteiligt waren. Daneben spielte die Verwitterung der harten Kalke an den Westwänden der Reisalpe und deren Akkumulation in Form von Schutthalden eine gewisse Rolle. In den Auftauperioden waren diese Schuttdecken sehr mobil und bildeten das für die Hangformung des periglazialen Bereiches sehr wesentliche Gekriech. Bei langandauernder Durchfeuchtung des aufgetauten Schuttmantels und bei Vorhandensein eines gleitfähigen Untergrundes konnte bei steiler Geländeneigung das Solifluktionsmaterial in Form einer Rutschung plötzlich abgehen. Dies war im Dürntal der Fall, wo aus der grossen Geländenische der Hahnfeichten unterhalb der Felswände das Schuttmaterial mehr als 2,5 Kilometer weit talauswärts abgerutscht ist. Der Höhenunterschied zwischen Abrissgebiet und dem Ende der Akkumulation beträgt über 500 Meter. Dabei wurde das gesamte obere Dürntal von der Massenbewegung be-

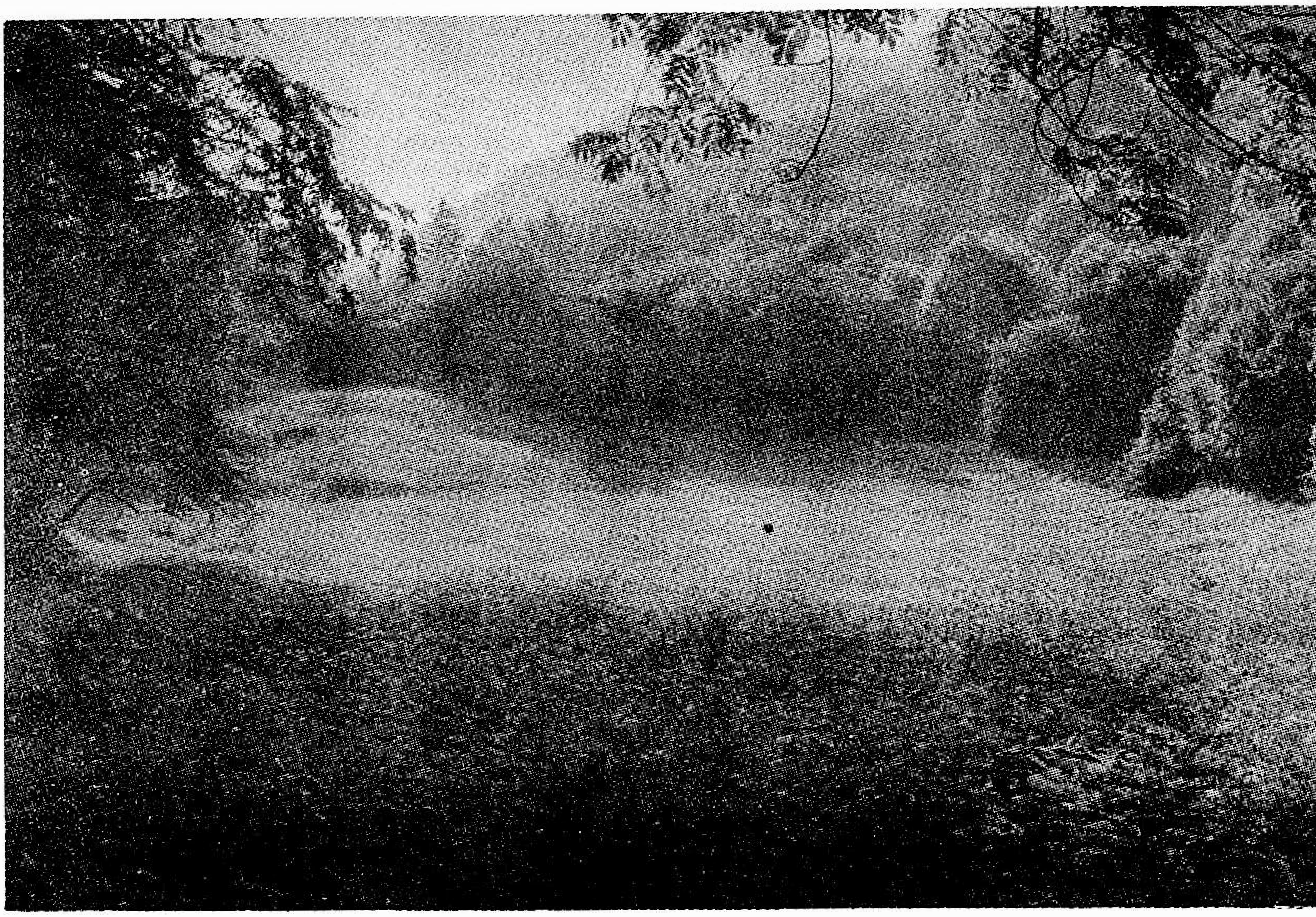

Abb. 1. Polygenetische Karstwanne im Dürntal; Situation im Sommer 1972. Im Hintergrund die sperrende Rutschung.

troffen und vom abgerutschten Solifluktionsschutt ausgefüllt, der heute als konvexer Schuttstrom deutlich zu erkennen ist. Im Zuge der Massenbewegung kam es zur Abdämmung eines Seitengrabens, der von Osten her von der "Almerin" in das Dürntal einmündet. Dieser Graben, der nur episodisch von einem Gerinne durchströmt wird, hat infolge der sperrenden Rutschung an seiner Ausmündung keinen oberirdischen Abfluss mehr. Das abgerutschte Material brandete an den Felswänden der linken Dürntalflanke und verschliesst somit den Seitengraben derart, dass eine weite, wannenartige Hohlform entstehen konnte. Die 150 m lange und bis zu 100 m breite Wanne weist einen annähernd ebenen Boden auf und besitzt eine rd. 8 m hohe Gegenböschung, die von der Rutschzunge gebildet wird. Die meiste Zeit des Jahres liegt die Hohlform trocken. Nach lang andauernden Starkregen und besonders zur Schneeschmelze führen die Wassermassen zweier episodischer Gerinne zu einem Aufstau in Form eines Sees (vgl. Abb. 1 und 2). Der Abfluss des Sees erfolgt im Normalfall durch wasserwegsame Fugen im Kalk der südlichen Umrahmung. Bei extremer Hochwassersituation können die verhüllten Ponore den gesamten

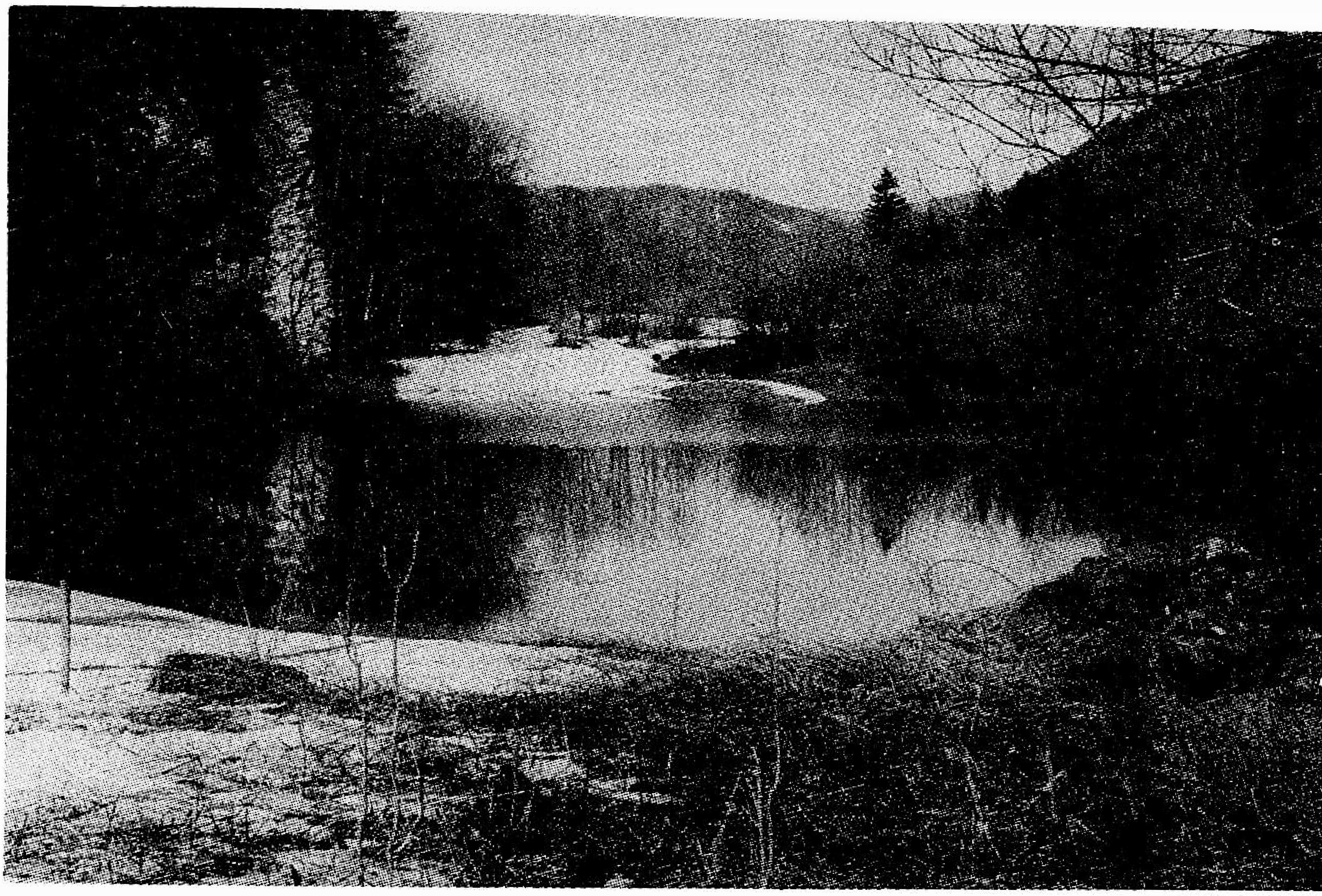

Abb. 2. Karstwanne im Dürntal; Situation im Frühjahr 1973. Der Abfluss der zu einem See aufgestauten Schmelzwässer erfolgt unterirdisch.

Zufluss nicht aufnehmen und es kommt zu einem Überlauf über die sperrende Schwelle. Der Überlauf hat zur Bildung eines Abflusstobels geführt, der das Aufschüttungsgelände quert und in das Hauptgerinne des Dürntales einmündet. Die polygenetische Karstwanne wird jedoch zumeist karsthydrographisch entwässert; die Wiederaustrittsstelle ist derzeit noch unbekannt.

An der Genese der flachen Hohlform am Seekopfsattel im Dürrensteingebiet bei Lunz sind glaziale, karstmorphologische und hangdenudative Prozesse beteiligt gewesen. Die poljenähnliche Wanne ist auf den undurchlässigen Lunzer Schichten angelegt, die beiderseits von Karstgesteinen begrenzt werden. Gegen Nordosten, nahe dem Steilabfall zum Lunzer See, wird die Wanne von einer risszeitlichen Moräne des Seetalgletschers begrenzt; im Südwesten hingegen von Solifluktionsschutt und Blockwerk des Kl. Hetzkogels abgedämmt. Über den wasserstauenden Lunzer Schichten hat sich ein Moor entwickelt, das durch ein Gerinne gegen NE entwässert wird. Der Bachlauf versinkt an der Gesteinsgrenze zwischen Lunzer Schichten und Gutensteiner Kalk in einer trichterförmigen Ponordoline.

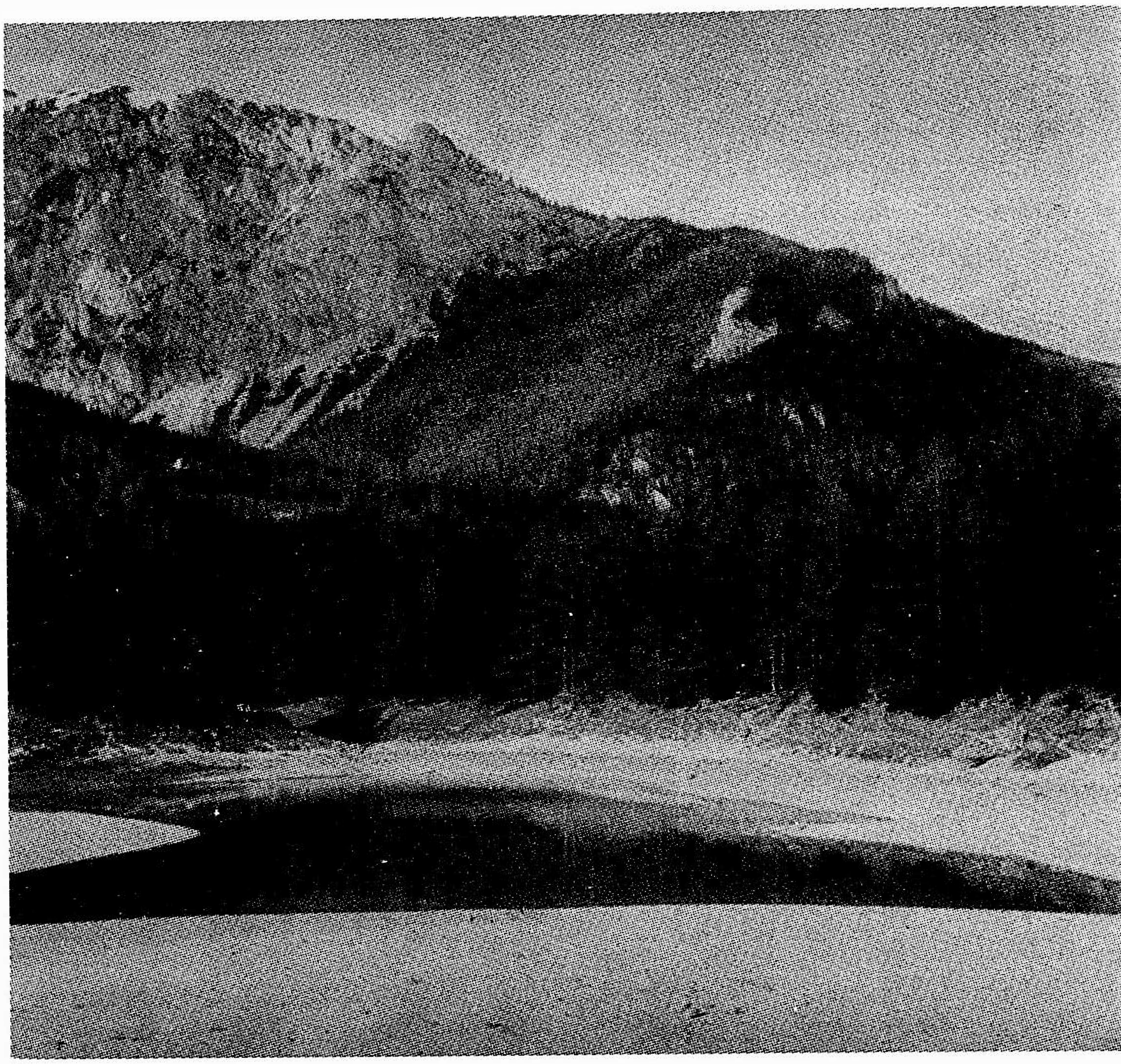

Abb. 3. Der Grüne See im Tragösstal (Hochschwab). Bergsturzmassen und Moräne (rechts) sind an der Genese der Hohlform mitbeteiligt.

Der Grüne See (770 m) an der Südflanke des Hochschwabes wird taleinwärts von mächtigen Bergsturzmassen, talauswärts hingegen von einer würmzeitlichen Moräne, z.T. aber auch von Bergsturzmaterial begrenzt und abgedämmt. Vom Trenchtling im Süden bauen sich ausserdem Schutthalden gegen das Seebecken vor. Der Grüne See besteht aus zwei ungleich grossen Becken, von denen das südliche das grössere ist. Beide Teilbecken werden von einer natürlichen Schwelle getrennt, die aber so niedrig ist, dass bei hohem Wasserstand eine zusammenhängende Seefläche vorhanden ist. Sowohl der Zufluss als auch der Abfluss erfolgt unterirdisch, so dass der See zu den Karstseen gezählt werden kann, da die begrenzenden Bergsturz- und Moränenmassen aus monomiktischem kalkalpinen Material bestehen. Der See weist einen sehr wechselnden Wasserstand auf. Da die basalen Werfener Schichten unweit davon im gleichen Niveau ausstreichen, wird das Aufquellen der Wassermassen im Seebecken verständlich.

Fluviatile Akkumulation in Form eines Schwemmkegels einerseits, ein Moränenwall andererseits ist am Zustandekommen der weiten, oberirdisch abflusslosen Wanne des Krastales in den Afritzer Bergen in Kärnten beteiligt gewesen. Von der Amberger Alpe hat ein Bachlauf einen Schwemmkegel in das Krastal eingeschüttet, der die Talung etwa in ihrer Mitte sperrt. Zwischen diesem Schwemmkegel und einem Moränenwall, der einer Oszillation des Draugletschers im Würm-Rückzug entstammt und der das Tal gegen NE sperrt, ist der flache Talboden zu einer Wanne eingeengt, die eine Längserstreckung von 500 m und eine Breite von 350 m aufweist.

Weitere polygenetische Formen sind an das Auftreten von Grundmoränen mit monomiktischer kalkalpiner Zusammensetzung gebunden. Im Erlaftal in Niederösterreich zeigt die risszeitliche Grundmoräne des Ötschergletschers Hohlformen beträchtlicher Grösse, die primär als Sölle (Toteislöcher) anzusprechen sind. Die grösste dieser Formen, die "Seebachlacke", wird von (Karst-)Grundwasser gespeist, das mit wechselndem Wasserstand die mehr als 100 m Durchmesser aufweisende Hohlform erfüllt.

In den polygenetischen Formenkreis gehören auch die Dolinen des von kristalliner Grundmoräne bedeckten Karstes im Bereich des Radstädter Tauernpasses. Die regelmässige Trichterform dieser Dolinen ist auf Nachsackungserscheinungen der Moräne zurückzuführen.

Im Hochgebirge spielt der periglaziale Formenschatz, vor allem die Vorgänge der Solifluktion und die der Nivation eine bedeutende Rolle bei der Überprägung der Karsthohlformen. Dabei ist die Exposition der Formen in Bezug auf Sonn- oder Schattseite, oder aber auf Luv- und Leeseite von Wichtigkeit. Viele Dolinen des rezenten perglazialen Bereiches erfahren durch die Wirkung der Schneeakkumulation eine weitgehende Umgestaltung. Die Querschnittsasymmetrie zahlreicher Dolinen lässt sich auf den verstärkten Einfluss der Nivation an der Leeseite zurückzuführen.

Die freiliegenden, aus Frostschutt bestehenden Flanken der Dolinen und Karstmulden werden von den Formen der Makrosolifluktion mitbestimmt. Steile Flanken weisen Steinstreifen, flachere Böschungen Girlandenböden und die Dolinenbasen Pflasterböden auf.

Diese ausgewählten Beispiele sollen veranschaulichen, dass polygenetische Formen in der alpinen Karstlandschaft relativ häufig sind und eine grössere Beachtung verdienen.

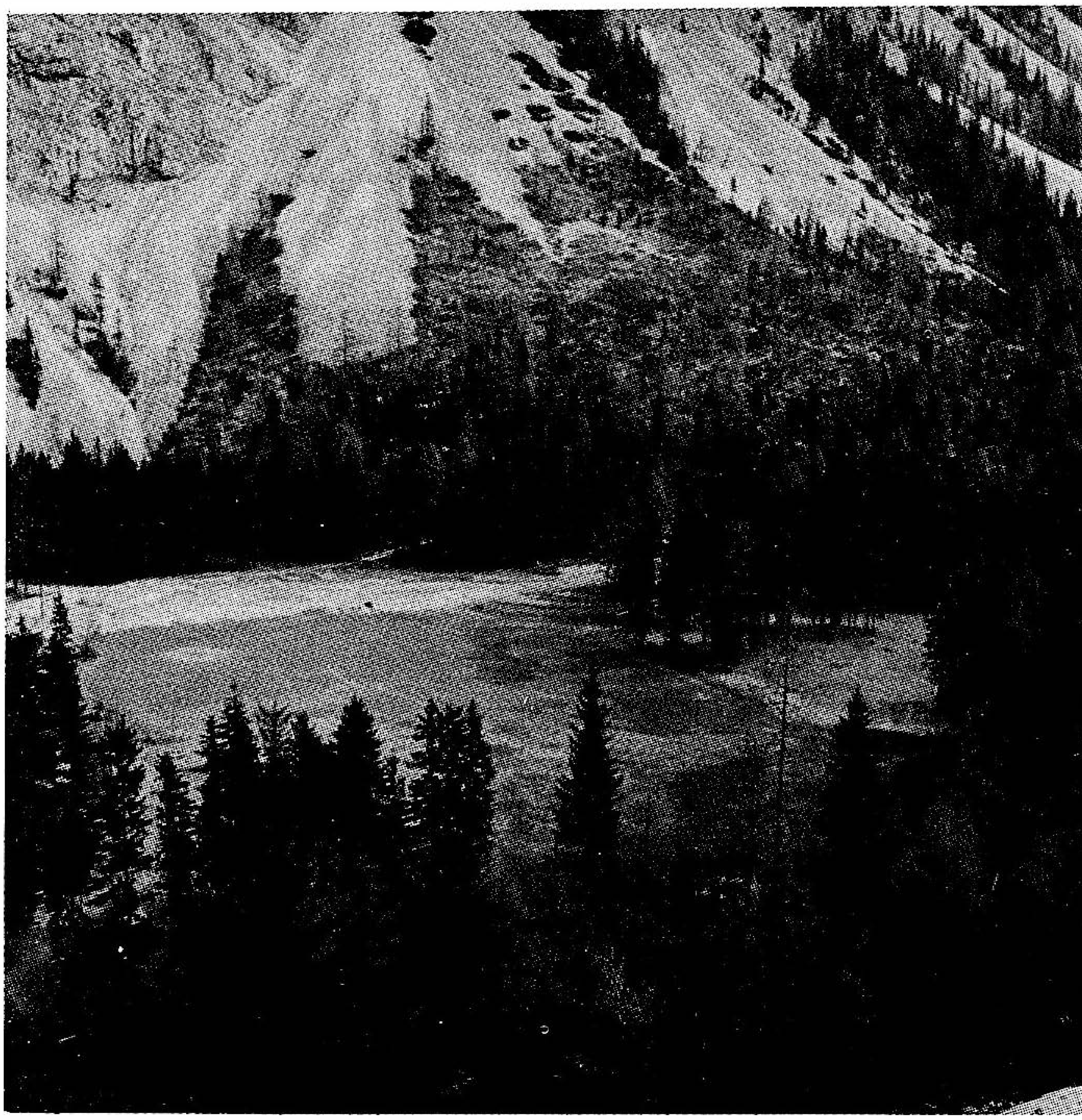

Abb. 4. Karstwanne "In der Klausen" (Hochschwab). Abdämmung der Hohlform durch Bergsturzmaterial und Schutthalden. Aufstau des Baches am Fuss der Tomalandschaft (Bildmitte rechts).

Ba 015

KARST GEOMORPHOLOGY AND HYDROLOGY OF THE SIERRA DE EL ABRA, S. L. P. AND TAMPS., MEXICO

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Abstract. The Sierra de El Abra is a north-south range of Cretaceous reef and back reef limestone, 130 kilometers long and 6 kilometers wide. On the eastern side a fault scarp rises sharply from a coastal plain of shale, elevation 50 meters, to a karst plateau, elevation 450 meters. A broad synclinal valley of shale bounds the western margin. Annual rainfall is 1,200 millimeters.

There are three distinct groups of caves: 1) floodwater systems formed by caputre of ephemeral streams on the western margin, 2) lapics wells and fossil phreatic caves on the plateau, and 3) active and fossil resurgence caves in the eastern scarp.

Two large and many small springs along the scarp average an aggregate discharge of about 17 cumecs. The small springs are normal limestone springs with total hardness about 225 ppm as $CaCO_3$. The large springs at base flow have total hardnesses up to 800 ppm derived mainly from dolomite and sulfates. Wet season hardness decreases to 215 ppm, almost entirely $CaCO_3$, with flood pulses up to 150 cumecs. The regional geology, water chemistry, cave morphology, and hydrographic data indicate an extensive phreatic aquifer, with some of the deeply circulating water coming from mountain ranges further to the west.

This paper is a brief report on a dissertation to describe and relate aspects of the surface and subsurface hydrology and geomorphology of a high relief tropical karst. Most previous works have dealt with surface forms. Few detailed cave descriptions and relationships can be found in the literature. Other papers following this one will amplify in more detail the subject matter of this summary.

The Sierra de El Abra is located about 120 kilometers west of Tampico in northeastern México. It is an elongate high relief cuesta - like range about 120 kilometers long and 6 kilometers wide. The range itself is covered by a dense forest of scrub trees, cactus and vines and is essentially uninhabited. The surrounding valleys of non-karstic rocks support many ranches and towns.

A pronounced seasonal climate affects the region. Nearly all the 1200 mm/yr average rainfall occurs during the hot humid months of June through September, often coming in the form of intense tropical storms from the Gulf of México. The remaining months range from warm to hot and are normally dry.

REGIONAL GEOLOGY AND GEOMORPHOLOGY

The Sierra de El Abra forms part of the eastern boundary of a Cretaceous paleo-carbonate province, the Valleys - San Luis Potosí platform, about 175 kilometers east-west by 250 kilometers north-south. A fringe reef - back reef sequence of limestone with basal dolomite accumulated to about 2000 meters thickness. Within the interior of the lagoon a thick section of gypsum (perhaps 1000 meters) was deposited followed by over 1000 meters of the thick bedded back reef facies of the El Abra limestone (see Bravo, José Carrillo, 1971). Above the El Abra formation was deposited a thick section of thin bedded limestone, marl and shale which is now found principally in the synclinal valleys. At the close of the Cretaceous and early Tertiary the area was uplifted and intensely folded along north-south axes.

Erosion has subsequently exposed the El Abra limestone on the anticlinal ranges and highlands and a well developed high relief karst has resulted. Non-karstic rocks are found in the synclinal valleys. Spectacular water and wind gaps attest to the long erosional history of the area.

The Sierra de El Abra is a north-south anticline with a belt of reef facies limestone less than a kilometer wide on the eastern margin, a plateau surface of gently dipping thick bedded limestone and a western margin with 10^{o}-20^{o} dips. A prominent erosional scarp of as much as 450 meters sharply separates the range from the coastal plain of shale at less than 100 meters elevation on the east. Intensive fracturing of immense vertical extent during the folding has been especially important for cave development.

SURFACE FEATURES

The surface of the El Abra is nearly structural with some fluvial dissection of the western margin. None of the "typical" tropical forms such as cones and cockpits are present. Pavements are predominant. The thin, often spotty soil cover has a large component of decaying vegetation. Numerous collapse depressions up to one-half kilometer across and 100 meters deep with walls grading from gentle slopes to vertical are found. Various types of cave and pit entrances are abundant.

HYDROLOGY AND WATER CHEMISTRY

Nearly all the recharge into the El Abra resurges from two large springs at the foot of the eastern escarpment. The southern spring, El Choy, rises from a 26 meter deep lake in a cave and has an average discharge of 4.9 cumecs (cubic meters per second). The northern spring, El Mante, resurges from an oval conduit 10 meters in diameter and averages 11.4 cumecs (discharge data obtained from Secretaría Recursos Hidráulicos, México, D.F.). Numerous small springs, some seasonal, do exist but they are not quantitatively important in the water budget. All the springs are flooded.

Four types of water have been distinguished by their physical and chemical properties. These are: 1) cave lakes, calcium bicarbonate water; 2) small springs, essentially calcium bicarbonate water; 3) thermal, sulfurous springs; and 4) big springs, distinguished by very high calcium, magnesium, and sulfate concentrations. Swallet streams and cave drips have not been adequately sampled to classify them but they appear to be mostly calcium bicarbonate.

From the water chemistry data and the regional geology it is apparent that the small springs derive their water locally from the Sierra de El Abra, whereas the big springs obtain a significant portion of their discharge from source areas further west. This is further supported by the fact that the Río Coy, another large spring in the region with a lowest recorded flow of 13 cumecs, originates from a small dome of a few square kilometers. Thus some water infiltrates ranges far to the west, circulates deeply, picking up its calcium sulfate and dolomite solute load, and passes through the tectonic structures to the eastern springs. Several other large springs in the region outside the El Abra range have similar chemical characteristics.

During the dry season the large springs maintain a large nearly constant base flow of clear water. Wet season flood pulses often rise well over 100 cumecs. In one pit, a deep water table lake has a dry season gradient of 1.0 meter per kilometer to the Choy spring. Infiltration water on the El Abra and swallet streams along the western margin produce a rapid response at the springs. The data indicate an extensive, welldeveloped phreas, with a low piezometric gradient, which has large open conduits and is rapidly drained after rains.

CAVES

Caves in the area are best summarized by the cross section model shown in the figure. The relationship of lithology, structure, type of input, topography, and location in the hydrologic system becomes apparent. The eastern face caves are active or paleo-phreatic resurgences, some of which are located over 300 meters above the present base level. These caves are either short phreatic fissures of immense vertical extent, with water probably having risen from depth (as at the Choy), or facies-guided phreatic conduits. The cave sediments are breakdown, colluvium from skylights, bat guano and phosphates.

Caves of the karst plateau are principally of two types: 1) diffuse vadose shaft inputs or l a p i e s wells, and 2) old slow-flow phreatic rooms, fissures and passage segments, extensively altered by breakdown, colluvium, guano and flowstone deposits. The phreatic caves are found up to the highest elevations of the El Abra, about 450 meters above sea level and are normally entered through a collapse opening. As indicated by the complex stalagmite growth and resolution phases, passage characteristics and geomorphic setting, a very long history is recorded here. Segments of phreatic flow loops 300 meters in vertical extent have been found. These were surely formed when the coastal plain (i.e., base level) stood at much higher levels than at present.

Along the western margin several ephemeral streams perched on impermeable rocks have been captured to form extensive complex floodwater caves. There was some phreatic priming but nearly all the enlargement has been by the floodwaters. The caves are relatively horizontal, flowing along strike or against low dips to reach the spring. The accessible portions of the caves show a strong structural and stratigraphic control, and terminate in perched siphons. These caves have many features similar to slow-flow phreatic caves due to their floodwater (eiphreatic) character.

CONCLUSIONS

In the Sierra de El Abra it appears that a large percentage of the solution occurs in the subsurface. Large joints permit deep circulation of water in a well developed phreas. Stratigraphic and facies control of groundwater movement is apparent particularly in the swallet caves. Intense tropical storms cause large vertical fluctuations of the water table and flush the aquifer.

The caves in the El Abra record the erosion of 400 meters of the coastal plain. They may be placed in a hydrological model which depicts present and past conditions.

The big springs of the El Abra are part of a regional groundwater system encompassing a large portion of the Valles - San Luis Potosí platform.

ACKNOWLEDGEMENTS

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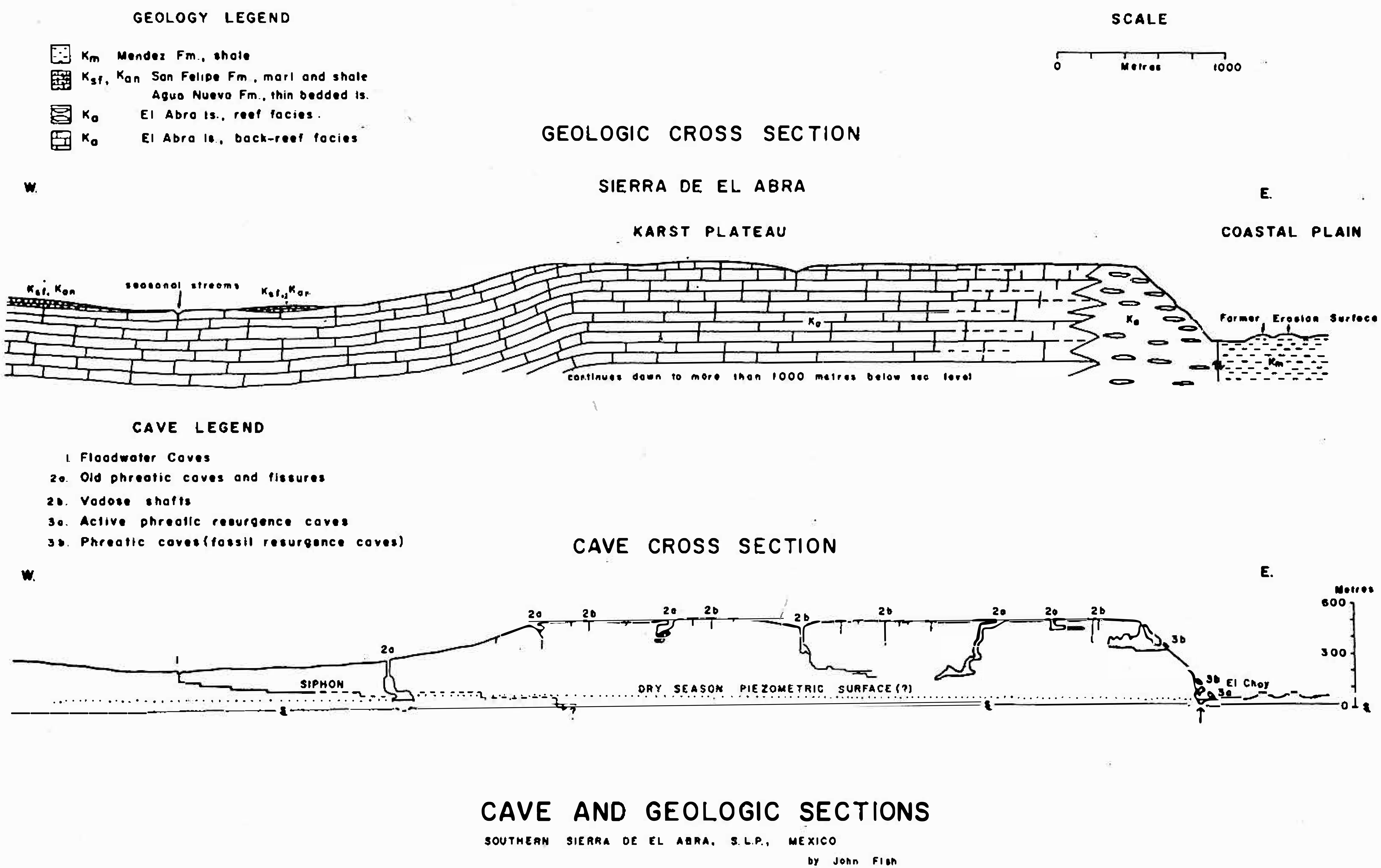

Fig. 1. Cave and geologic sections.

Ba 016

THE NAHANNI NORTH KARST: NORTHWEST TERRITORIES OF CANADA

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Karst landforms created by the solution of limestones and other soluble rocks are amongst the most complex and interesting landforms studied by geomorphologists. Karst areas are well known in Czechoslovakia and throughout the temperate climate regions of Europe. They are, however, more extensive and contain landforms of greater relief, density and steepness in the humid tropical and sub-tropical areas of the world, and also in a few warm temperate regions such as the classical Dinaric karst of Yugoslavia. The tower karst landscapes of southern China and North Vietnam, the mogote areas of Cuba and Indonesia, the cockpit country of Jamaica and the poljes of Yugoslavia are considered to be the world's foremost karst area. Geographers have studied the regional distribution of karst landforms and have proposed that the development of karst is more rapid in regions of hot, wet climate and diminshes in intensity towards regions of polar climate. In addition it is believed that certain karst landforms such as towers, mogotes and cockpits form only under hot, wet climatic conditions. This is the morphoclimatic theory of karst development. Thus, when a small number of karst towers are found as far north as Poland they are interpreted as relict features of a Tertiary subtropical climate. Similarly, supposed cone karst in a warm temperate area of South Africa has been interpreted as having formed under warmer and wetter conditions in the past. Although the morphoclimatic concept has been questioned by a number of workers, no positive proof has been presented to disprove it while it appears to apply to large areas of the world.

The Nahanni Karst of northern interior Canada contains many landforms of the "tropical type" as well as others that are unique to the area. These landforms appear to have developed during the Quaternary Period (the time of the Ice Ages), and it is evident that they are actively developing today. Karst features identified during our first season of exploration in July and August 1972 include many types of karren, extensive tracts of limestone pavement with kluftkarren, giant grikes, giant bogaz or corridors, labyrinth canyon karst, solution dolines, collapse and subsidence dolines, cenotes, uvalas, poljes, karst towers, natural bridges, caves and dry river valley systems. These forms occur both in mantled karst (limestone covered by soil) and naked karst (bare limestone) areas.

The Nahanni Karst is located in the southeastern Mackenzie Mountains, N.W.T., at latitude 61° N (fig. 1). Intense karst development occurs in a belt of country 6-12 Kms. wide extending for 50 Kms. north of First Canyon, South Nahanni River. The region is very remote and has been little explored. It lies outside the traditional hunting grounds of the Slave Indians living in the Mackenzie River Valley to the east, and was originally inhabited by a few Nahanni

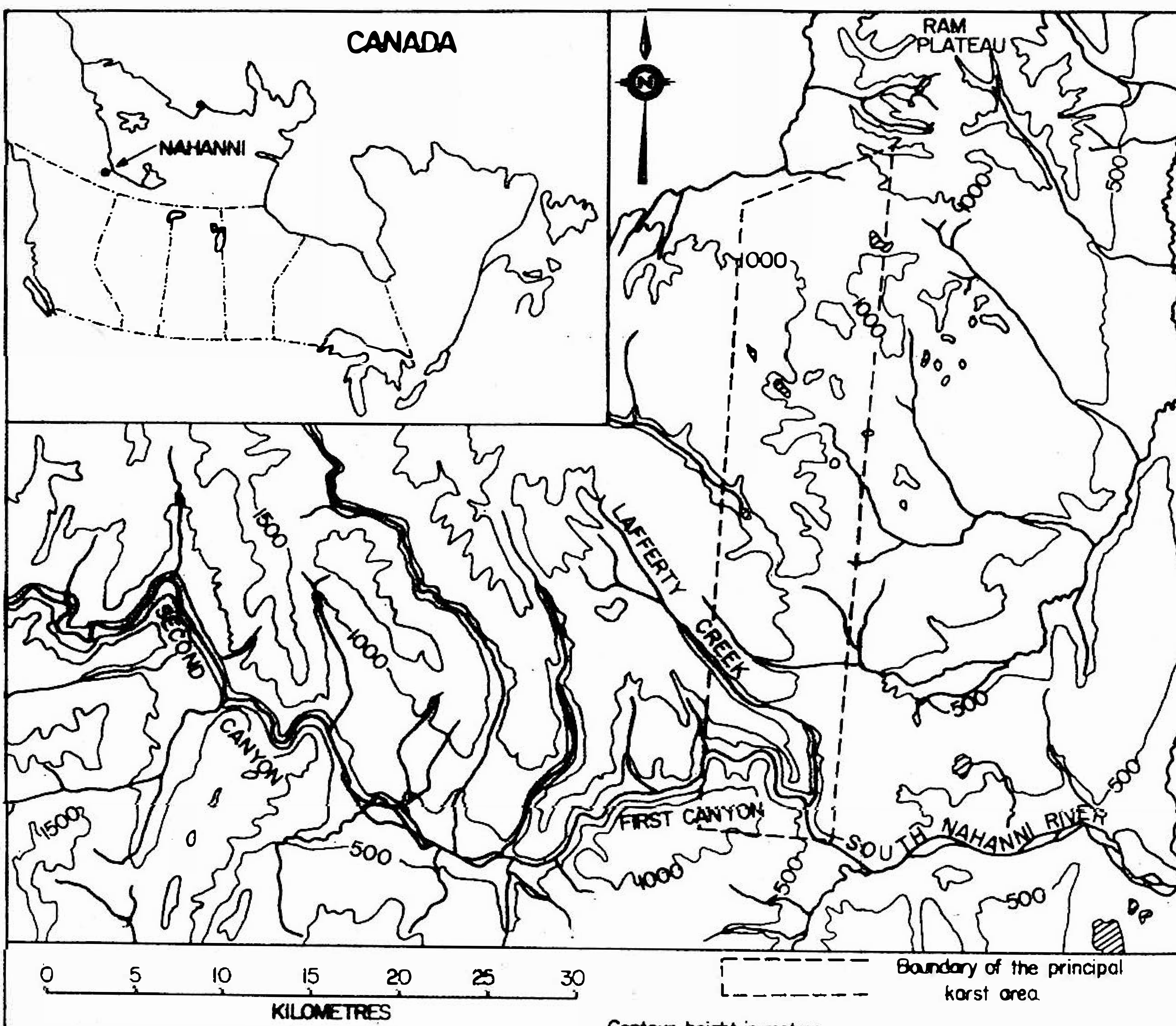

Fig. 1. The location of the Nahanni North Karst in the Northwest Territories of Canada.

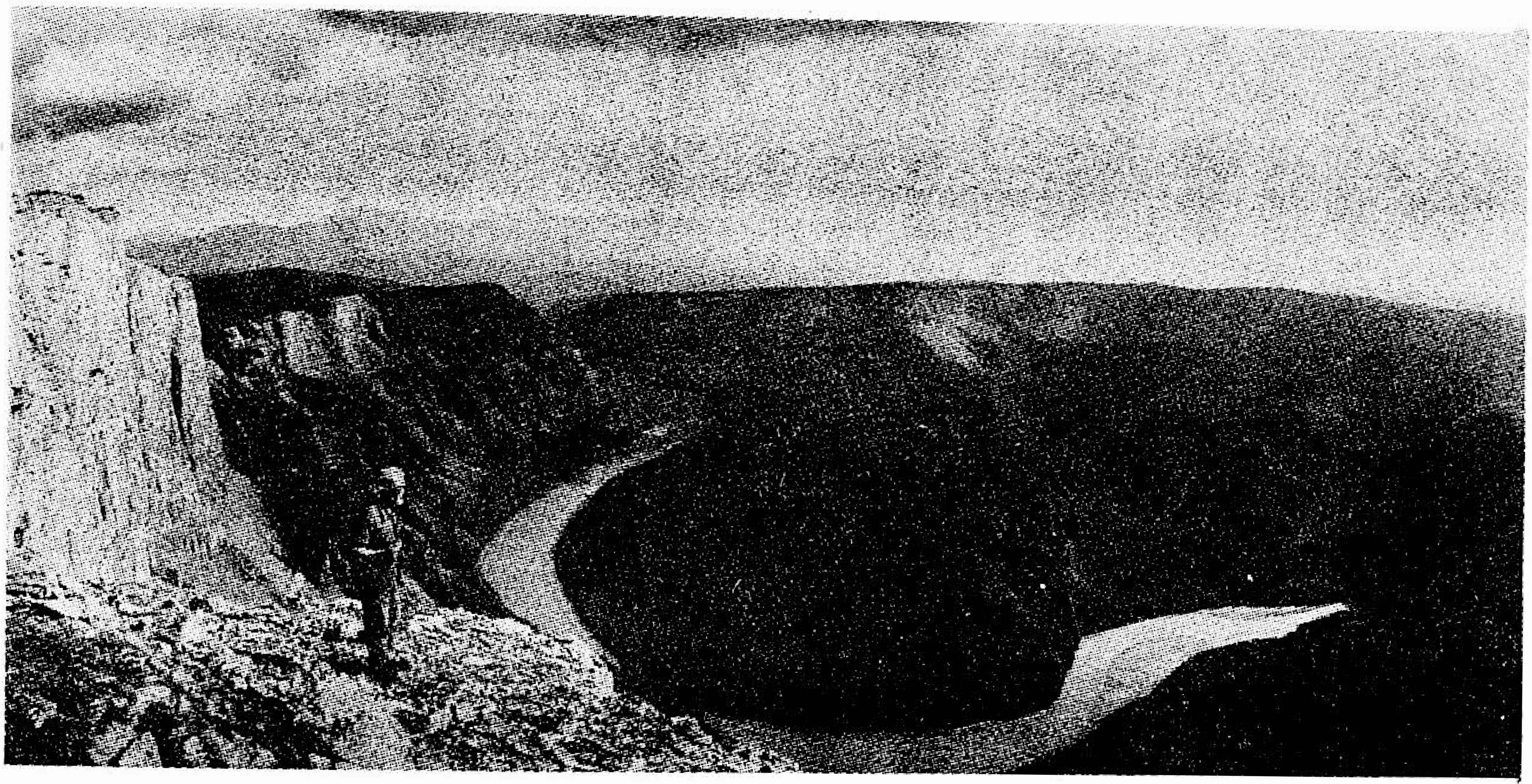

Fig. 2. The First Canyon, South Nahanni River, viewed from the North side. The canyon is of the antecedent, meandering type and is 1000 metres deep. The vertical cliffs behind the model are formed in the Nahanni Limestone and are 200 metres in height. A cut-off meander may be seen at right centre.

Indians - a mountain tribe. It was early visited by gold prospectors and in recent years by geological mapping parties.

The southern Mackenzie Mountains rise to an altitude of 1,000-1,500 meters above sea level. The mountain ranges were formed by folding and thrust faulting in thick sequences of Palaeozoic sedimentary rocks. The karst belt is located on the east side of a major dome and in an adjacent synclinal trough. Solutional landforms occur principally in the Nahanni Limestone, a medium to massively bedded, fine-grained limestone of Devonian age, 150-250 meters thick. Above the limestone is a thick shale deposit which is an important source of acid water for the limestone area.

The karst belt has a cold continental interior climate, at lower altitudes, becoming Polar above 1,000 meters, (Siberian-type; Koppen Dfc-E). The annual temperature is -6^{o} C with a mean annual precipitation of 520 mm. Precipitation falls mainly as rain during the brief summer period. The rugged terrain is covered by dense coniferous forest up to an altitude of 1,100-1,200 metres. Above this altitude, bare tundra vegetation is characteristic.

Two important facts should be mentioned before the karst development of the Nahanni area is discussed. F i r s t - during the Quaternary most of Canada was buried repeatedly by continental ice sheets, the most recent of which (of Weichsel age) receded only 6,000-8,000 years ago in northern areas. As a result much of Canada, especially arctic and subarctic areas, is dominated by glacial erosional and depositional landforms. But the Nahanni region escaped burial by the Weichsel ice sheet. Only a few very small glaciers formed in favourable localities. The stratigraphy of caves of the karst suggests that the region may not have been buried by ice during the past 300,000 years though it was certainly covered by an ice sheet from the east before that period.

One consequence of this is that there has been a long period of solutional development of the landscape without serious interruption by glacial erosion. Indeed, periglacial and competing solutional processes may have dominated landform development during the last few hundred thousand years.

S e c o n d - our radiometric dating of the Nahanni caves has indicated that the Mackenzie Mountains are evolving very rapidly. The dome to the west of the Nahanni belt has arched upwards approximately 550 metres during the last 400,000 years. The sedimentary rock strata were powerfully flexed, with the formation of exceptionally dense joint and fault systems. These fractures locate the karst development and partly explain it.

Labyrinth karst, consisting of interconnected, linear solution corridors following joints, is the most extensive karst landform. Corridor dimensions range from kluftkarren a few metres deep and a few tens of metres long, via giant bogaz 20-50 metres deep and 400-600 metres long, to karst canyons 200 metres deep and several kilometres in length. Walls are vertical and display fragments of phreatic caves, suggesting that corridors were created by solution acting both vertically and laterally. Corridor floor profiles are irregular because of uneven collapse of corridor walls aided by frost action. Solution dolines and karst ponds developed in this breakdown material are characteristic along corridor floors.

Dimensions of individual corridors are determined by the extent and depth of host joints and the duration of their development. The largest features, "box canyons", develop where solution processes have enlarged fractures, probably faults, which are extensive in both a horizontal and vertical direction. Once the bottom of the fracture has been reached, further solution acts laterally along bedding planes to undermine the walls and widen the canyons. Bedrock between adjacent corridors may be entirely consumed in this manner leaving wide, irregularly-shaped box canyons. At an earlier stage in the development of these canyons, residual karst towers with vertical sides and up to about 100 metres in height are characteristic.

Labyrinth karst is not unique to the Nahanni, having been reported from Austria, Brazil, West Irian and Australia. However in none of these countries do forms exceed 50 metres in depth. The Nahanni labyrinths appear to be the largest features of this kind known. The total length of karst corridors in the Nahanni is probably several hundred kilometres.

The most characteristic landform of all karst areas is the doline. Solution dolines are scattered throughout the Nahanni karst area while collapse - and subsidence - dolines are common where there is a thin cover of shale above the limestone. Ponors have developed where perennial streams flow from shale areas and sink underground upon reaching limestone. Also present and remarkable for such an area are the cenotes. These features are vertical-walled solution cylinders with permanent ponds at their bases. The most famous and classical cenotes are found in the Yucatan Peninsula of Mexico, where some served as sacrificial wells. Cenotes are uncommon in other tropical karsts and are rare in temperate regions. In the Nahanni numerous examples are to be found, some being 20 metres in diameter and extending down 30 meters to the surface of the pond. In the Yucatan, cenote pond levels correspond with the level of the regional water-table. In the Nahanni, pond levels may differ by as much as 20 metres between cenotes spaced only 60 metres apart. It is apparent that pond water is retained by permanent subsurface ice. This is not surprising in an area of sporadic permafrost, (tjaele). In fact the surfaces of some cenote ponds were still covered by ice during August 1972. Fig. 3 shows a group of 18 solution dolines, ponors and cenotes occupying a narrow residual rock platform between two deep box canyons in the North Karst.

A karst landform that has attracted a considerable amount of attention from geomorphologists is the polje. The polje is a large closed depression with a flat alluviated floor which may contain a permanent lake or be periodically flooded. At least four poljes have been identified in the North Karst and we suspect that more exist to the south.

Nahanni Polje is located in a tectonic depression. The west wall of the polje represents an eroded fault plane. A small hum or residual limestone hill protrudes through the alluviated floor at

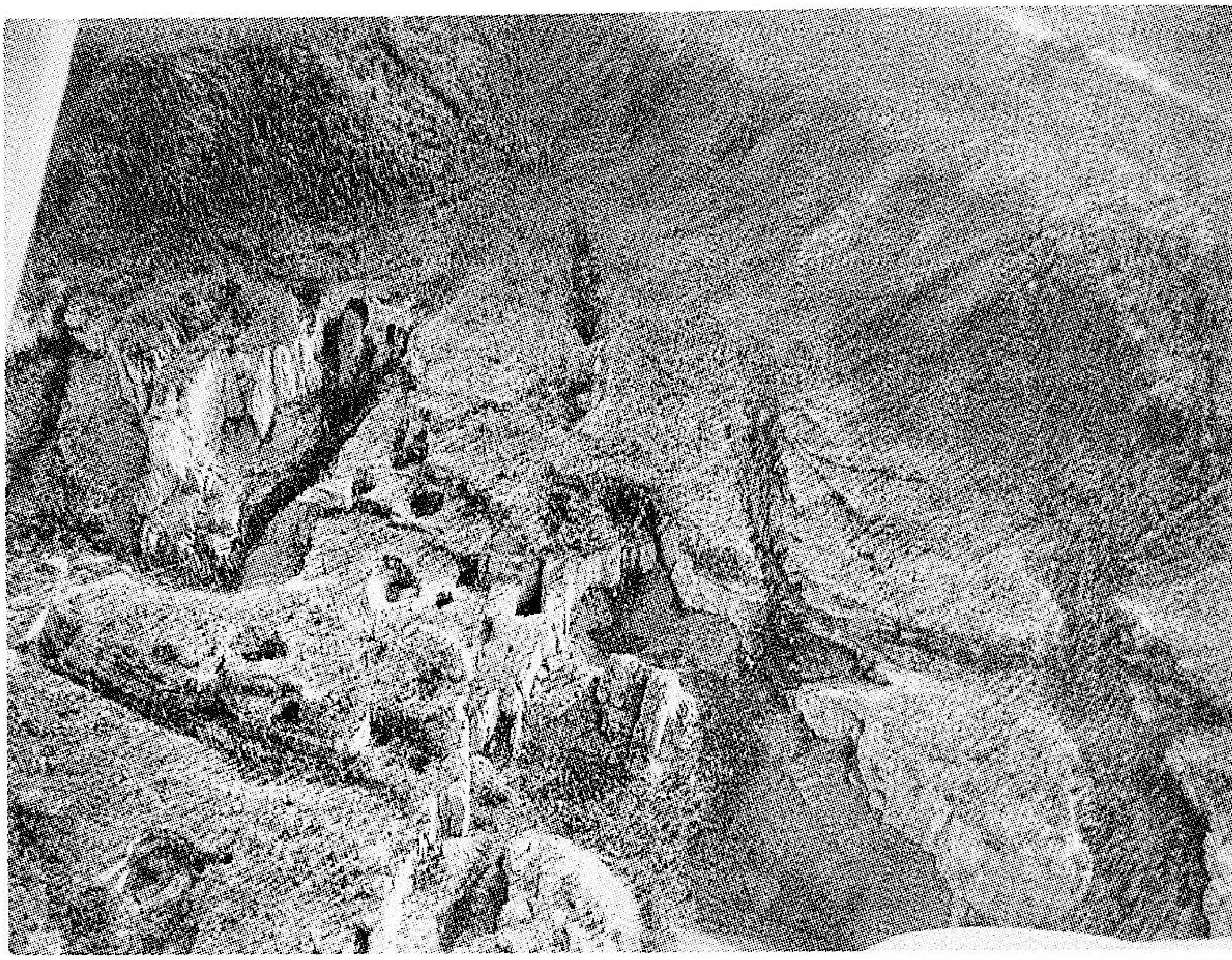

Fig. 3. A cluster of 16 large solution dolines, ponors and cenotes upon a narrow limestone platform between two huge box canyons in the North Karst. Such dense concentration of dolines, etc. would be exeptional in an intensely karsted tropical area and has never before been reported from an arctic region. The photograph clearly illustrates the effects of jointing upon the karst development. The steep slope in the background is of shale, which overlies the limestone.

its northern end. Similar tectonic poljes are common in Yugoslavia. Lafferty Polje and Barens Polje are true solution poljes. No tectonic deformation of the rock is apparent. These poljes are surrounded by vertical limestone walls 10-50 metres in height. The walls display corrosion notches resulting from periodic flooding (fig. 4). Ponors are common in the alluviated floors of all three poljes and a number of small, youthful caves penetrate the vertical walls at the level of high flood waters.

Ten kilometres southwest of these poljes is another of definite glacio-karstic origin. Following the formation of an ice-scoured closed depression, solutional and periglacial processes have operated to widen the depression and steepen its walls. A residual karst tower

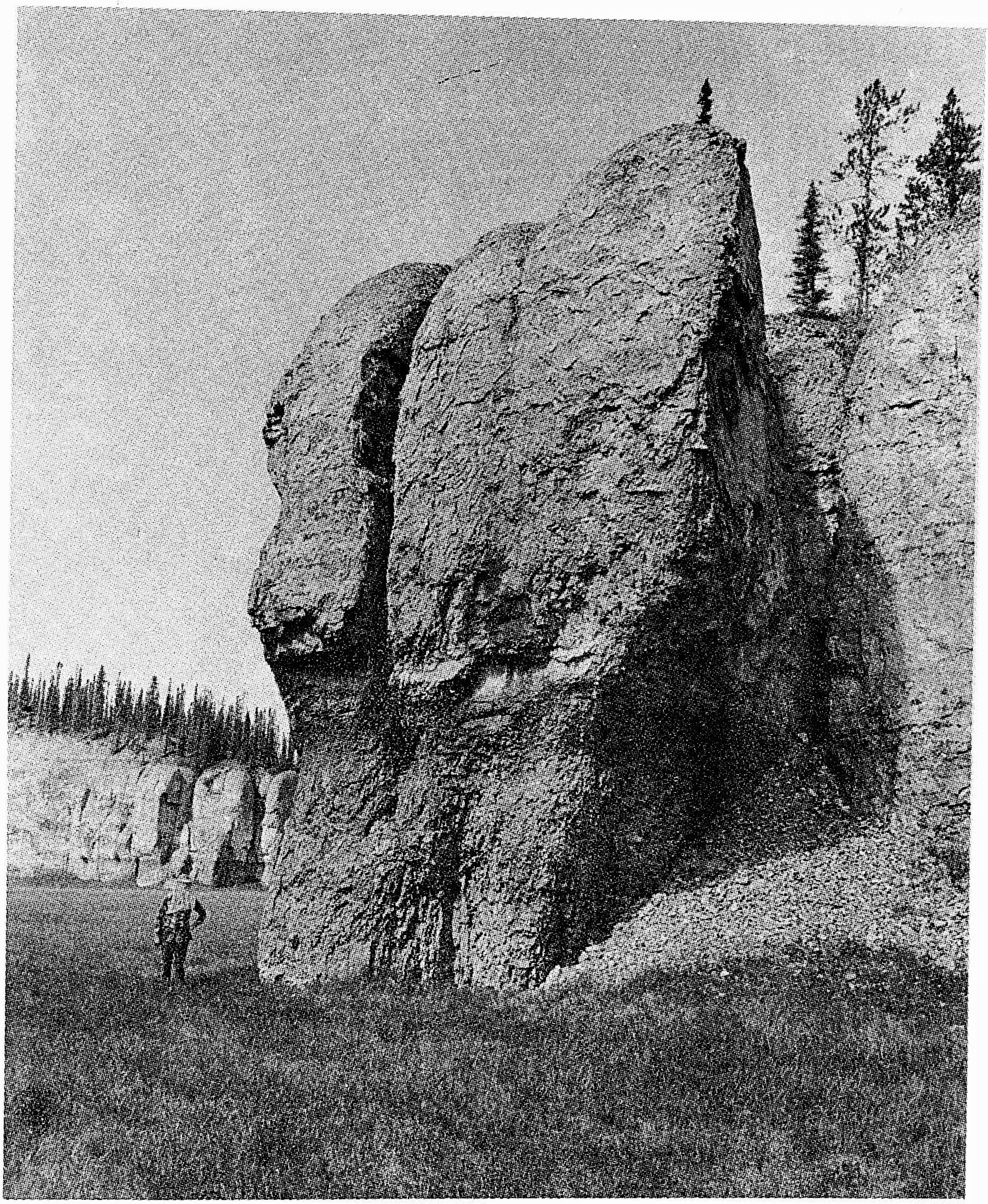

Fig. 4. Part of the alluviated floor of Barens Polje. The corrosion notch caused by periodic floodwater which fills the polje is clearly seen. The polje was observed to fill to the top of the notch after 203 mm of rain fell in eight days during July 1972.

and smaller "pitons" may be seen in this polje floor, which is alluviated and contains dolines, possible springs and a seasonal river channel. Also visible is one of the longest canyons of the labyrinth karst, extending North of the polje.

During an eight day period in July 1972, 203 mm of rain fell in the North Karst. Following this the poljes flooded producing lakes 5-40 metres in depth. Dolines in the floors of many box canyons flooded, while a sizeable permanent lake (Raven Lake) rose 40 metres. Surprisingly, levels in cenotes nearby did not change. The cenotes may derive their water from the melting of drifted snow.

In the karsts of temperate countries and in highland tropical areas such as central Mexico, it is common to find river valley systems that do not now contain surface streams. The water passes underground into caves in the limestone. Seven closed river canyon networks have been identified in the North Karst area, their surface waters passing underground to flow to unknown springs. The largest of these networks, Canal Canyon, is more than 10 Kms long and 1,000 m deep. One of the smaller canyons, Ram Canyon, has an alluviated floor and contains a number of shallow lakes (fig. 5). Streams meander across its floor, eventually encountering lakes where waters sink into the alluvium or tiny ponors in the canyon walls. The exits of several canyons, including Ram and Canal Canyons, are blocked by glacial moraine ridges built by valley glaciers. These obstructions may first have caused the rivers to seek underground channels the canyons becoming true karst features as their floors were deepened by solutional processes.

The density of surface solutional landforms in the Nahanni North Karst suggests the presence of cave systems through which the sinking waters flow. Active caves are rare but more than 100 fossil caves not now occupied by streams have been examined (fig. 6). The great majority of these caves can be explored for no more than a few metres. They are obstructed by frost-shattered rock, silt infilling and permanent ice, due to subsurface permafrost conditions. However in the north wall of First Canyon, South Nahanni River, and in an adjacent canyon, Lafferty Creek, three caves have been discovered that extend for 1,500-2,000 metres. These caves are all of the shallow phreatic type and developed when the present river was at or a little above their level. The river has now entrenched 300-550 metres below them, leaving them drained and fossil, high in the vertical limestone walls.

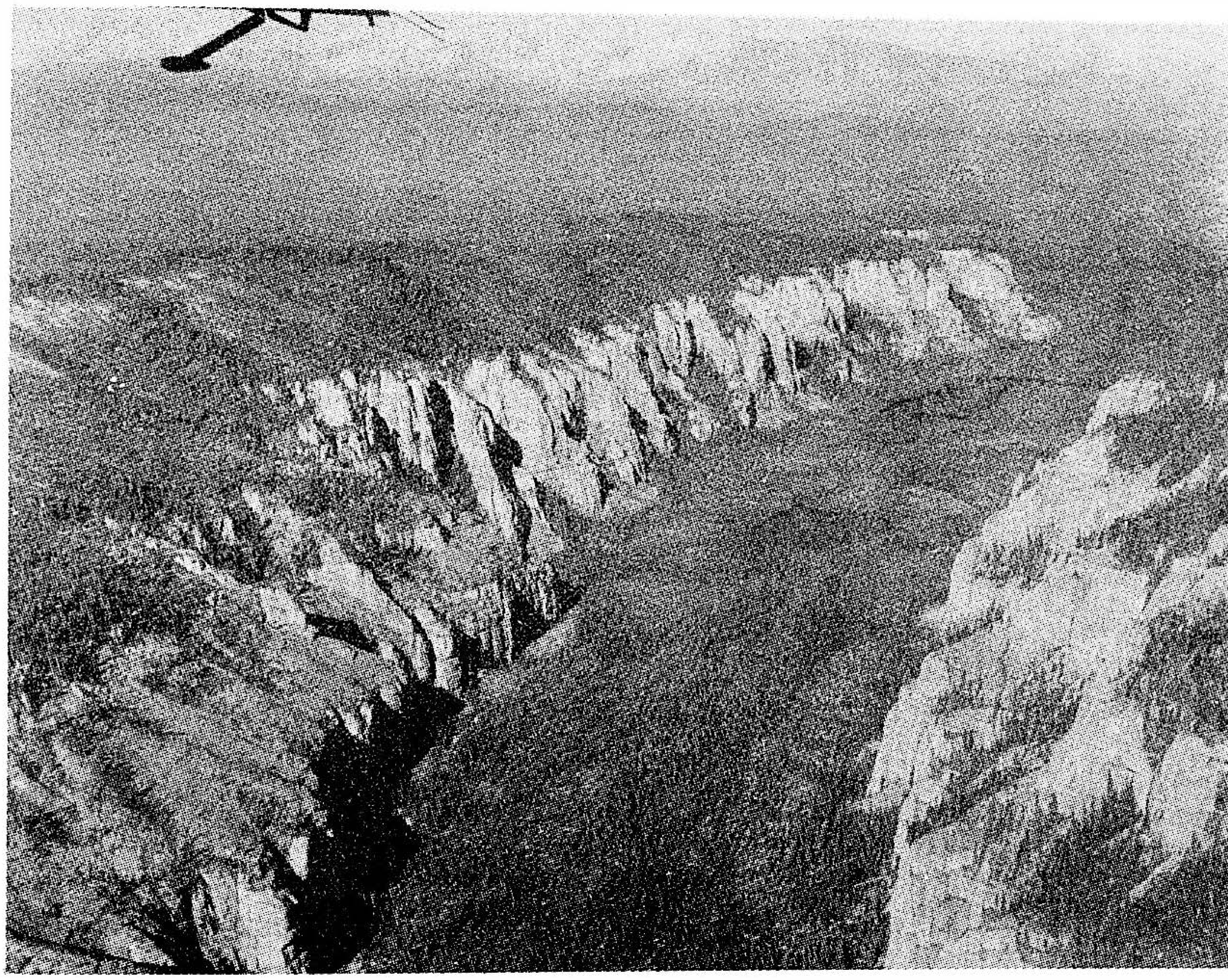

Fig. 5. Ram Canyon, ancient river canyon which is now drained underground. The alluviated floor contains local lakes and small streams which sink into the limestone.

These fossil caves contain three distinct climatic zones. The first is a zone close to the cliff face entrance which is warmed by the inflow of air during the summer. It is characterized by temperatures of +1 +0 +2° C. Water from the forest and tundra soils overhead is able to seep through the comparatively warm rock and deposit travertine. Modern stalactites have simple straight forms such as are found in cold climate caves elsewhere. Also preserved are large stalactites and columns elaborately ornamented like those of many temperate caves. Uranium/thorium radiometric dates for these features indicate that they were deposited between 300,000 and 200,000 years ago when the regional climate was warmer than that existing at present.

Further from the entrance is a second zone where rock temperature is close to 0° C. A small amount of seepage water penetrates the rock

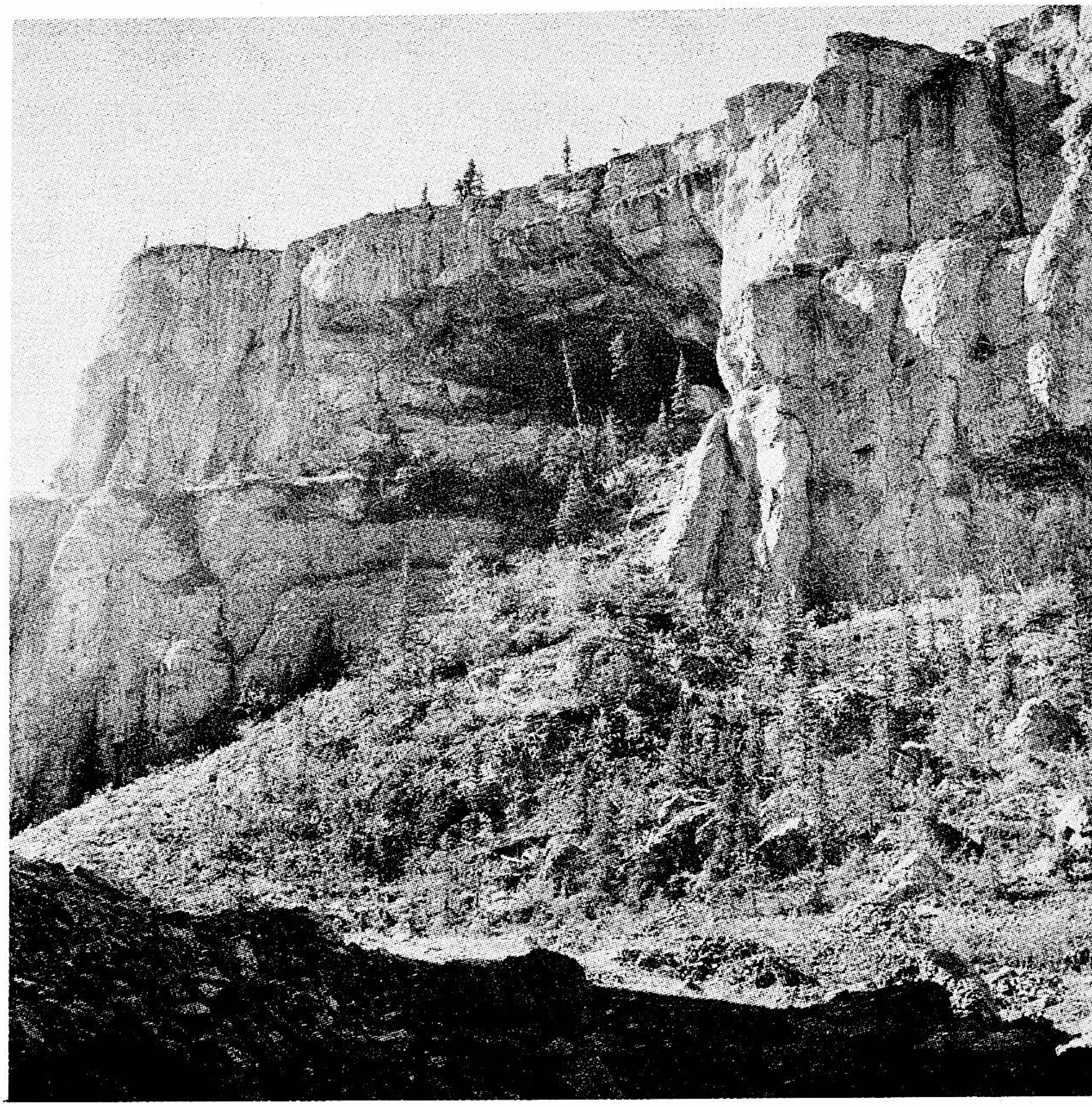

Fig. 6. The entrance to a fossil phreatic cave in a karst corridor wall in the North Karst.

and more trickles in from the entrance zone. Water vapour is also carried in by the flow of cave air. Liquid water freezes forming ice sheets and ice stalagmites upon the floor. Water vapour is precipitated as plate crystals of hexagonal form upon all parts of the cave walls and roofs. In exceptional cases, ice crystals may grow to diameters of 50 cms. Fig. 7 shows an ice crystal gallery 300 metres in length. Hexagonal crystals here have a diameter of 1-3 cms.

The third climatic zone is found in interior parts of the caves

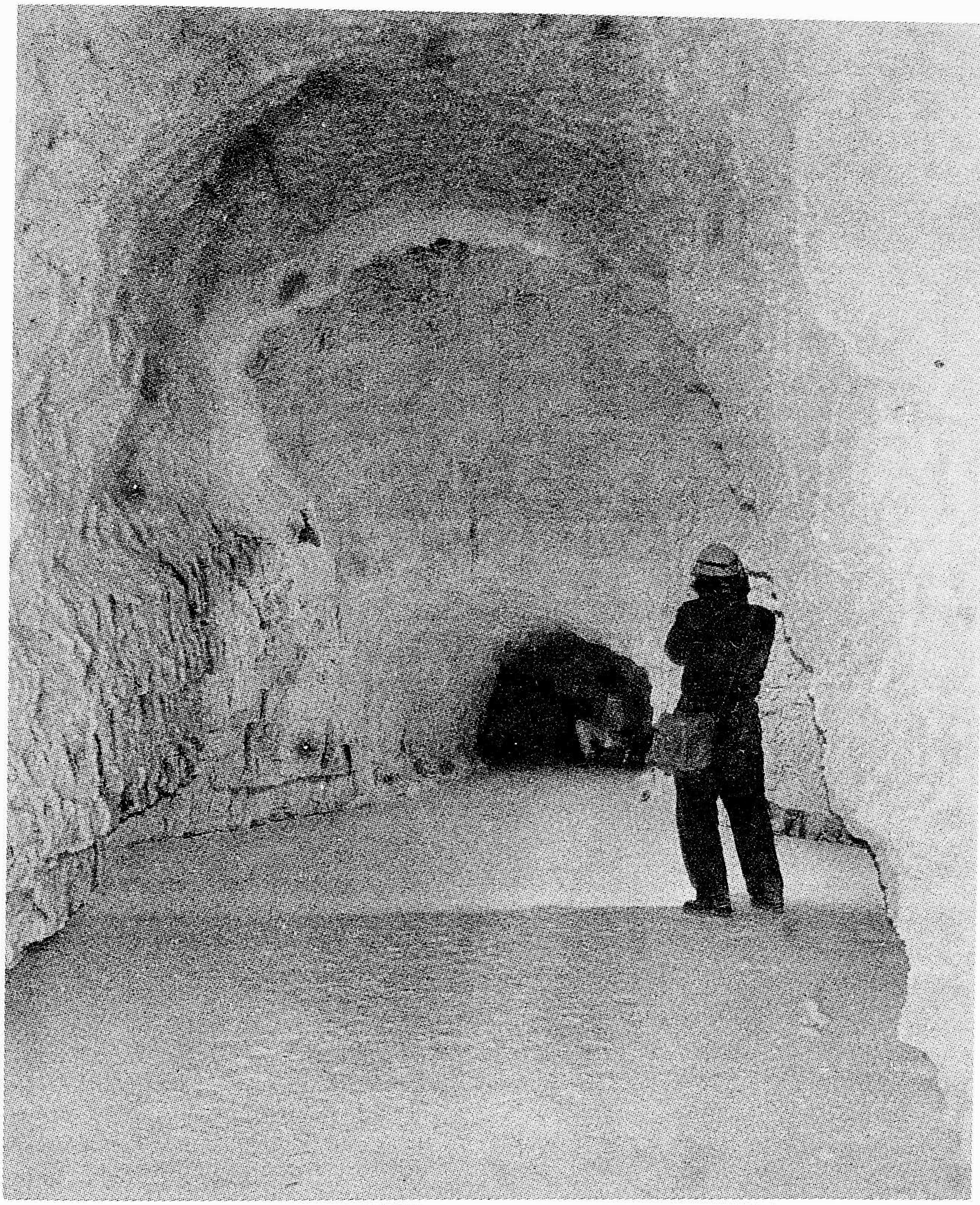

Fig. 7. The Ice Gallery of Grotte Valerie, First Canyon, South Nahanni River. The gallery maintains this form and dimensions for 300 metres and is coated throughout by hexagonal crystals of precipitated ice.

where galleries descend below the level of the cave entrance. Such galleries act as great siphons. Throughout the summer months they trap and retain the very cold, dense and inert air of the winter season. Air temperatures are -3° C. Water in these parts of the caves is permanently frozen. The fact that the galleries are dry and dusty and display no calcite or ice deposits suggests that little liquid water or water vapour has entered them for perhaps the last 8,000 years. These galleries are however decorated in another way for they contain delicate precipitates of gypsum and hydromagnesite and, remarkably, the preserved skeletons of 87 modern mountain sheep. Why the animals, male, female, old and young, died there will probably never be known.

The Nahanni Karst is a most exciting discovery. It contains a great variety of karst landforms, some unique to the area and others hitherto thought to develop only under tropical or warm temperate climates. The existence of the Nahanni North Karst suggests revision of the morphoclimatic theory of karst landform development, with greater concentration upon lithologic and structural factors as had already been emphasised by V. Panoš and O. Štelcl of Czechoslovakia from their distinguished research upon the karst landscapes of Cuba.

Ba 017

FORMS OF SUBSOIL KARST

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Subsoil or subcutaneous karst which is directly under the soil cover in the subjacent karst rock links the surface and underground karst zones of action. In science it links in the same manner surface morphology and speleology, and research into it yields evidence of the genesis of some surface and underground karst forms. It is not aim of this article to give a review of the literature on this topic which is still scarce (Haefke, 1924, Penck, 1924, Causin, 1957, Williams, 1966, Harasimiuk, 1969, Pluhar - Ford, 1970, Gams, 1971, Jennings, 1971). The main aim is to describe subsoil features as the initial forms for the development of some surface and underground karst phenomena as research of the Slovene part of the Dinaric Karst has demonstrated.

The literature describes subsoil forms mainly as they occure in two dimensions in road cuts or quarry walls. The occurence of deep pockets filled with loam is common there. This was the basis of the old term "geologic organs" (German: Geologische Orgeln). Better the subsoil forms can be studied in three dimensions where soil is stripped off as is usual in quarries. There the whole variety of the dissected subsoil karst is exposed. The German term "Karren" or the French term "lapiés" can be applied for this variety with the qualification "subsoil" - Subsoil karren (or subsoil lapiés). These forms can be classified into the following types:

1. Where the bedding of the limestone is running parallel to the surface s u b s o i l R u n d k a r r e n (solution runnels, acc. to Jennings, 1971) are often found under the humus. The literature contains controversial opinions as to whether the Rundkarren originated on the open air or primary as the subsoil form (s. Bauer, 1958, u.s.o.). At Prečna reber at Postojna and near the village Gozd (Hrušica) on the roadside Rundkarren constituing a Karrenfeld continue in the same form under the humus cover across its margins. Stripping off this cover reveals empty grikes as deep as 1 m. In contrast with the smooth surface of the subsoil Rundkarren, the walls

of the grikes are etched by solution, as the surfaces of stones perched in the open air usually are. On one spot in the quarry of Verd a meandering Rinnenkarren was found below the thin brown earth.

2. A subsoil niche is a typical recess in unbeded or thick bedded limestone. If the rock wall is vertical, the subsoil niche is more open and semicylindrical. On an inclined wall, the niche is more like a furrow. Subsoil niches are usually many times wider then deep. Only in some cases their depth is more then one dm. Niches are not regular in cross-section with the situation of the deepest point, varying in contrast with the case of riple marks. Similar forms are found in caves filled with loam or in caves where there is evidence of former loam (or clay) fillings (Gams, 1971).

3. A covered bogaz (subsoil bogaz) is a common subsoil form. It is more frequent in thick bedded or massive limestone. Dimensions of the bogaz found where the soil is stripped off are usually smaller then at the surface bogaz. It is mostly less then 3 m deep and less then 2 m wide. Genesis by widening of joints, fissures, faults zones and zones of fractured limestone is more evident in new enclosed bogaz than on the surface. After soil erosion, covered bogaz can be transformed in minor surface bogaz. Due to faster soil erosion there most surface bogazes occure on the inclined slopes.

4. Subsoil cavernose Karren or subsoil tubes (rock holes) are frequent subsoil forms in some kinds of limestone. In others they are absent. They run in all directions. With junger form, the origin in a joint or fissure is usually evident. Their round crosssection is an evident difference between the wide fissures on the open air and the subsoil rock holes. Tubes in rock fragments making up walls or heaps of accumulated stones at the edges of fields and meadows can be considered as a proof that the stones were cut below the soil cover (fig. 1).

5. A covered solution pan (Subsoil kamenitza, covered kamenitza) holds stagnant water after the soil has been stripped off. In comparison with surface kamenitzas some subsoil pans have more oval and elongated form and lack flat hottom.

In bare karst near the entrance to the Grotta Gigante (Karst of Triest), transition forms between surface kamenitza with vertical walls and flat bottom and subsoil kamenitza are very evident. This transformation form only occurs in case that after soil erosion there remains some soil or humus in the solution pan or later on stagnant water. The higher lying kamenitzas are in many places more trans-

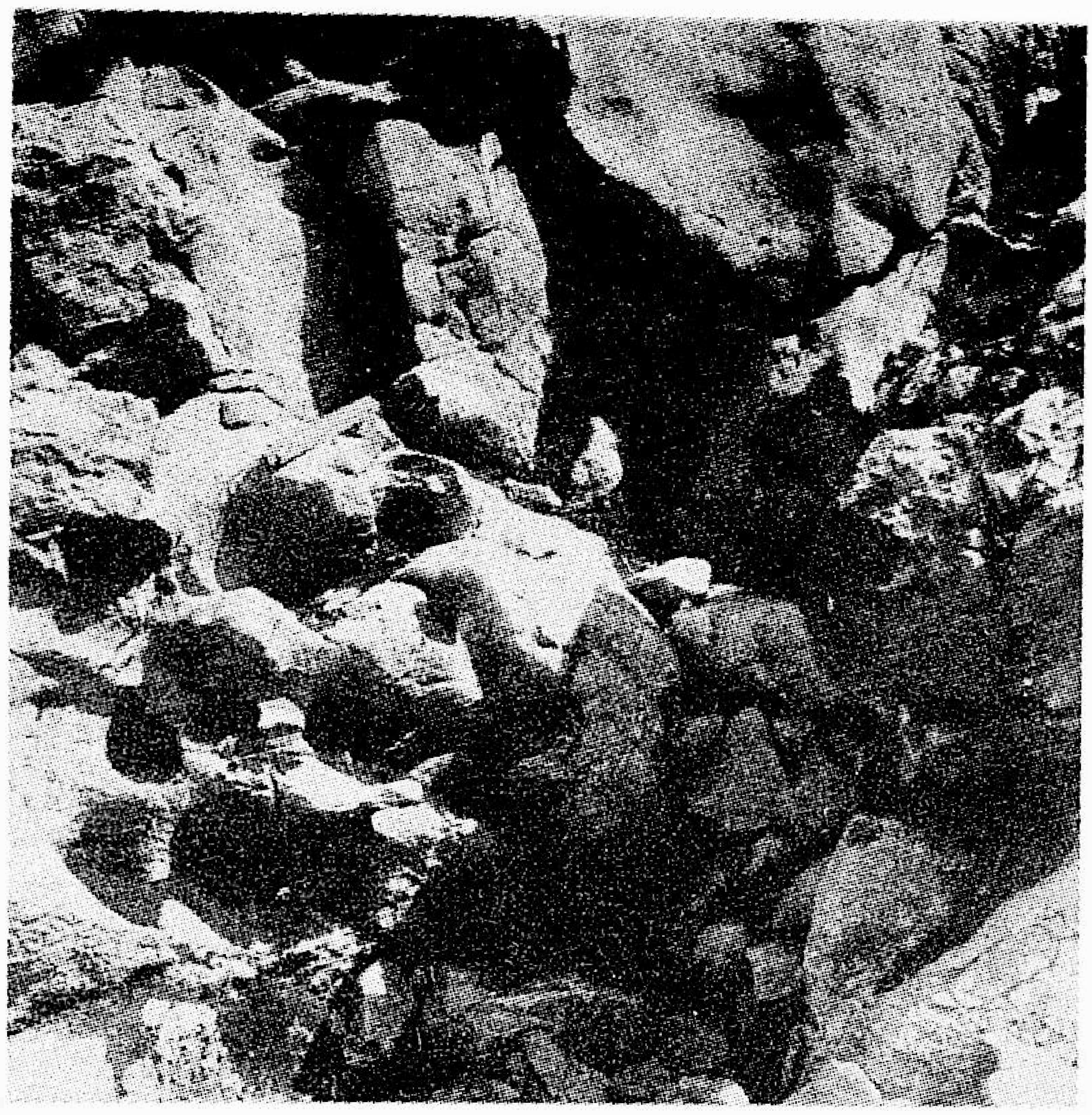

Fig. 1. Rock holes (stone tubes) or cavernose Karren in the left centre of the picture taken downward in the quarry of Verd (Dinaric Karst, Slovenia), where the soil was stripped off. The diametre of the holes is mostly less than 20 cm (compaire the folded mater-tape long 20 cm). In the block in the right upper corner an embryonic subsoil nish is to be seen.

formed than nearby kamenitzas in lower positions. The origin of some kamenitzas in a bare karst actuation, of course, cannot be denied.
6. A subsoil (covered) well is a funnel shape some metres deep and so wide form (fig. 5). When developed in fissure, it is more irregular. The subsoil well is rarer then other subsoil forms described here. They are relatively dense in gypsum karst observed in the quarry near Nüxei on the southern border of Mt Harz.
7. As with other subsoil forms described here also covered dolines are not descernible on the karst surface before the soil is stripped off. In contrast with the subsoil wells, they are wider then deeper, reaching in depth more then 1 m. Their form is irregular, slopes being much less graded than in the surface doline. Projecting out of soil fill on slopes, there are many rock ledges with loam pochets within them. After soil subsidence, surface doline can appear (fig. 2).
8. Retreating walls of quarries often reveal filled pits (fig. 3). In some quarries they occure more often than the empty

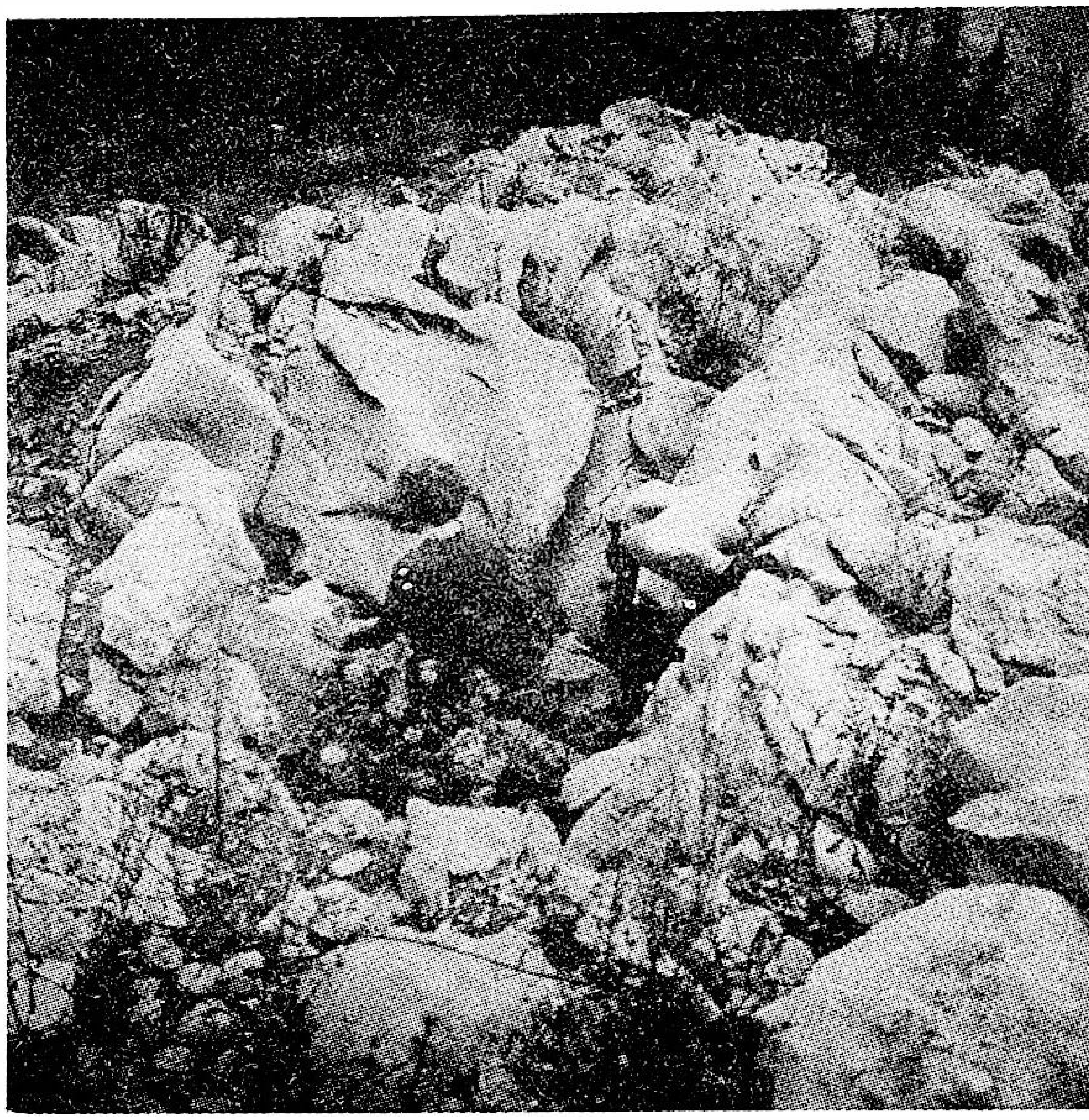

Fig. 2. A covered doline in the quarry at Podutik near Ljubljana, now free of soil is as deep as the height of a person.

pits. They are as much as 20 m deep (in the quarry at Verd, 1972). Their walls are less graded then in more accessible pits but empty in the karst underground. Inclined fissures often end in the walls. The fill of the pits is soil, loam, sand, gravel, rubble, etc. This fill can be autochtoneous or allochtoneous.

The genesis of the filled pits remains an open question. If the fill is allochtoneous, the pit as a rocky form seems to be fossil. On the bottom and walls of pits filled with autochtoneous material, proofs of recent corrosion can be often found in the areas where the yearly precipitation exceeds 1600 m. Precipitated water corroding the rock reaches pit walls at depths of many metres through side fissures. Some filled pits do not have parallel layers of the filling material, and so they prove the subsidence of the soil and both deepening and widening of the walls.

In many places in walls cut for new roads in vertical trenches in the depth of many metres the loam is mixed with limestone rubble

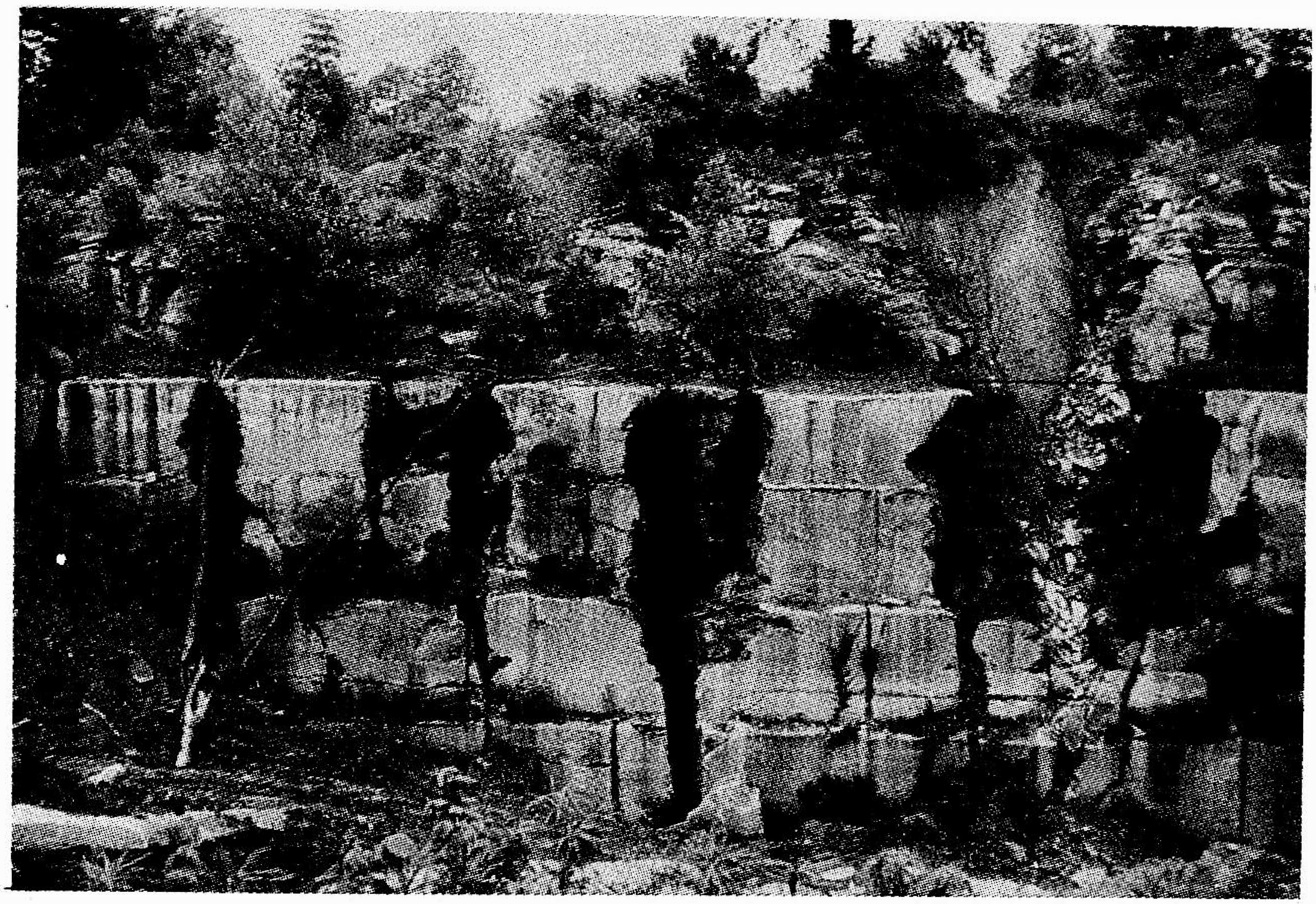

Fig. 3. Formerly filled pits now disclosed in the quarry in the Carboniferous Limestone near of Bedford, Indiana, U.S.A. Also here the pits are running rectangular to strata. Photo Arthur N. Palmer.

as well as with rest of the corroded rock. Such an occurence must be regarded as a primary stage in the development of such a form. In the better developed filled pits remmants of dissagregated rock are sometimes to be found. The coalescence of fissures in a fault zone or zone of more fractured rock is also a cause for the development of the filled pits (fig. 4).

Here some common features of subsoil karst are following. The steeper the slope, the less developed are the subsoil karst forms. The more massive and thickly bedded and homogeneous the rock, the more the limestone surface is sculptured. In lower karst areas subsoil karst is better developed than in high alpine region, in Southern Europe better than in Northern Europe. The deeper the soil the deeper the depression in rock surface. Near to the soil surface the stone surface is usually much more fractured than at deeper levels (fig. 5). Surface exposed to soil is smoother then surface exposed to air, evenif the stone fragments have quite pronounced

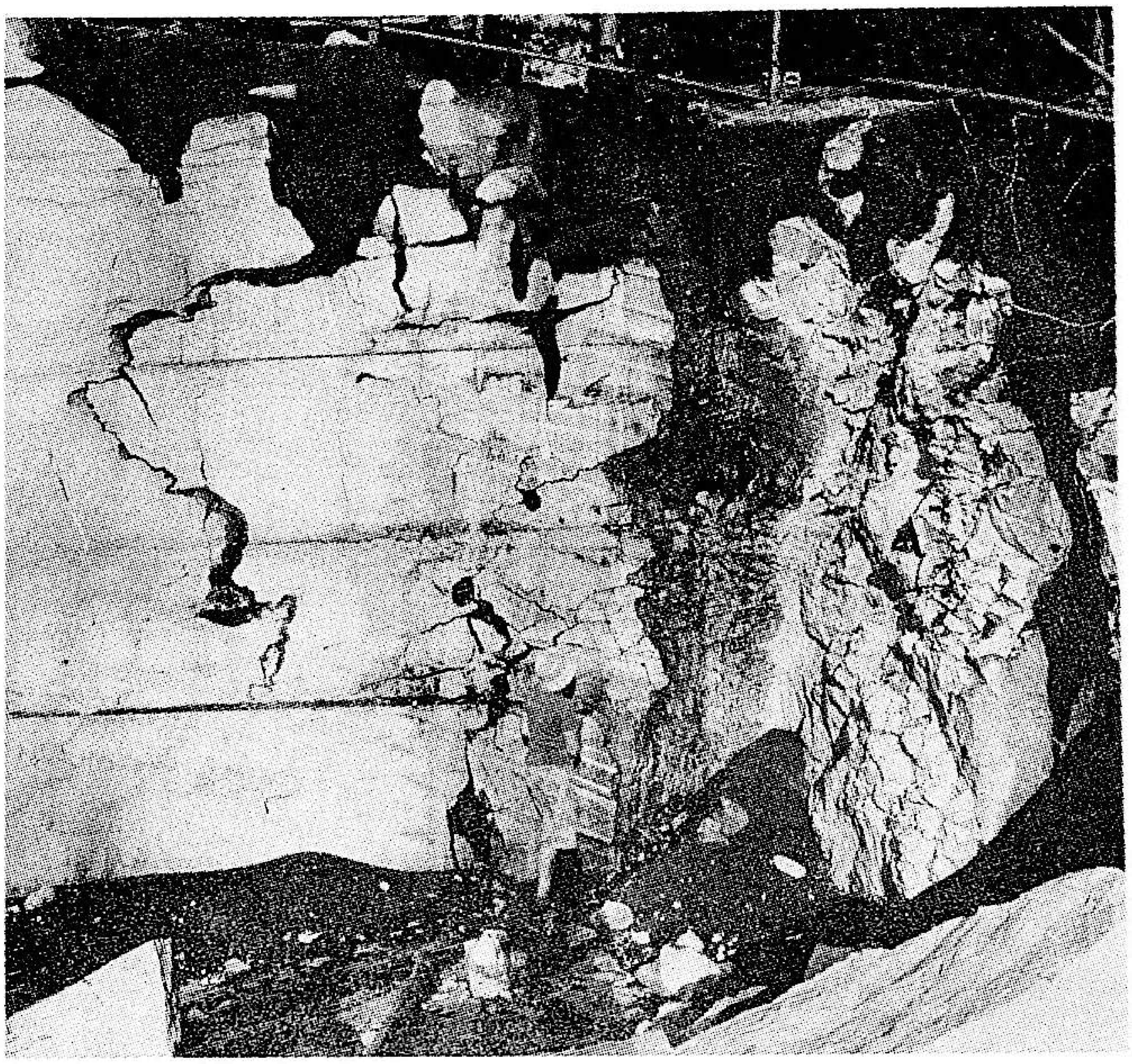

Fig. 4. 4 m deep pit disclosed in the quarry near of Marušići, Istria, in september 1973. Terra rossa which has filled the pits represents now a fan at the footslope. In geological future the rock holes and fissures on the left of the person will coalesce in a new secondary pit.

corners. Smoothness is also better developed in the more homogeneous rock. In thiny fractured rock and in sandy dolomite no smooth surface occur. Stone surface exposed to the atmosphere are riddled with closeset patterns of tiny depressions. They are less than 1 millimeter deep and wide varying with lighological structure.

The change from the sculptured surface above to the smooth one below occurs in the soil A-horizont. Along planes of weakness in the rock, fissures develop deeper and deeper upwards and the surface is more and more etched.

Also colour changes at this level of change in the A-horizont. Exposed stones have usually whiter surface than below but in some cases the exposed surfaces are darker - grey (fig. 6). The differences between the smooth surface of the subsoil rock and the fissured one, exposed on the open air, persist a long time after the soil cover has

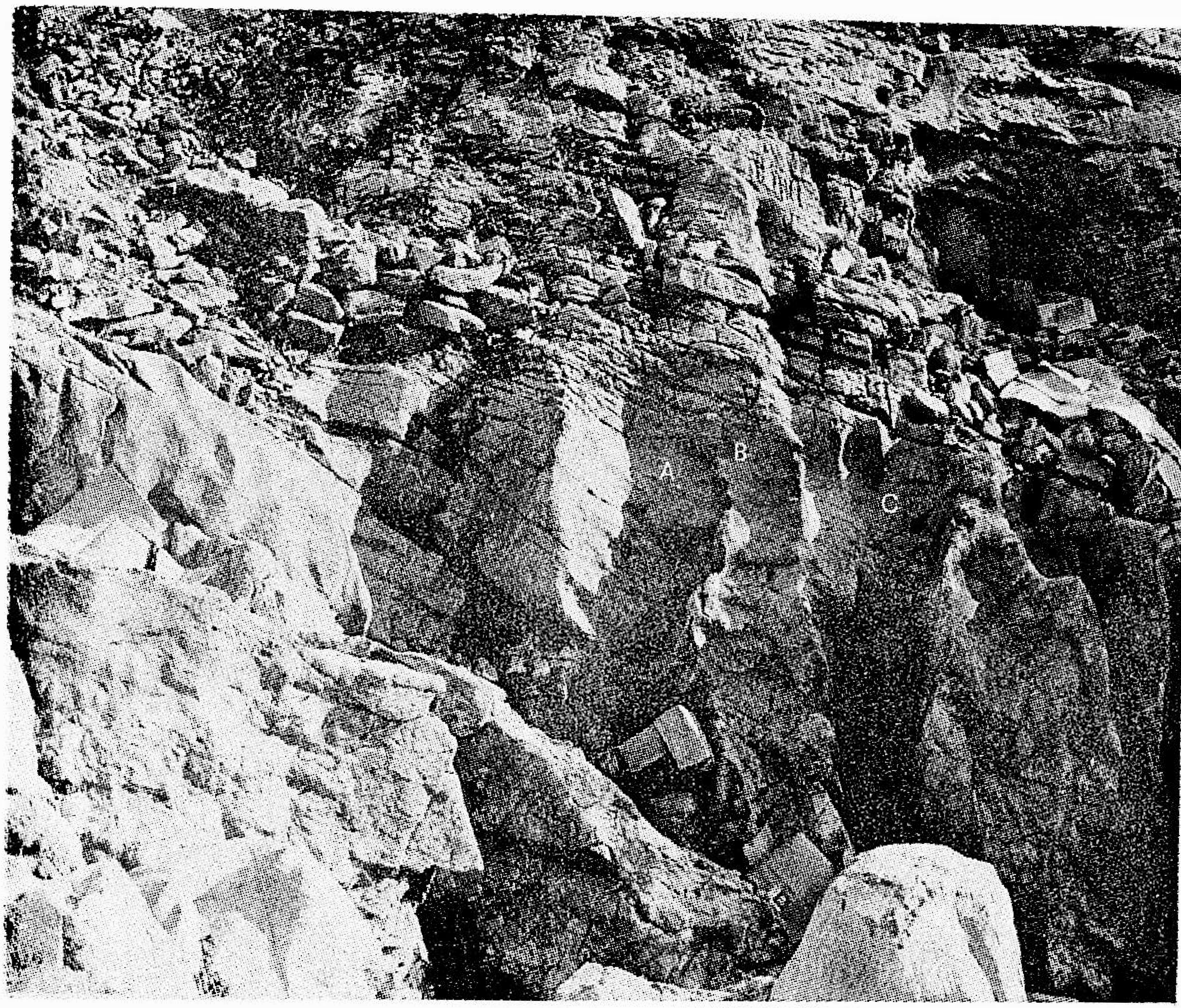

Fig. 5. In the covered well disclosed in the quarry of Verd, Slovenian Dinaric karst, in the difference between the smooth stone below and the fractured rock above the former soil level is still clear evident. The numbers 1, 2 and 3 mark furrow shaped niches. The well disclosed recently under soil cover is 4 m deep.

been remowed by meno or natural soil erosion. This line of change can be used as a criterion to determine how much the soil level was reduced in these ways (Gams, 1972).

Knowledge of such differences between surface and subsoil morphology can be generally applied. Near the town of Springen south of Hannover on the limestone plateau of Mt Deister many stone blocks of several tons weight are scattered. Solution pans are absent from the upper side of the blocks but do occur on the side wall (fig. 7). This provides evidence for overturning of the blocks for 90^{o}. The cause of the movement is problematic. Were the blocks turned once by glacier in the last glaciation or was subsidence of the underlying material responsible? The knowledge of the difference mentioned above is usefull in the archeology also (to discerne the carbonatic rock fragments

Fig. 6. The difference between the smooth whittish stone surface below and darker and more dissected stone surface above is still evident and indicates the former soil level (Island Cres, Quarner).

developed in the soil in situ or brought by men from the open air, etc.).

The smooth surfaces of subsoil karst must not be confused with the forms of fossil karst. Subsoil forms give rise to the question to what recent subsoil processes cause them, especially the nature of the locally accelerated corrosion which generated the depressions. This question was examined more closely in a quarry near Verd in the Slovenian Dinaric Karst. There are Jurassic oomicritic limestone with less than 10 % of microcrystaline calcite cement. Five thin sections showed no basic differences which could be the cause of the sculpture found there.

The percentage of insoluble material in the limestone of this quarry varies between 0,1 to 3,7 %. In the quarry two types of complex subsoil karst occur. First, karst with close but minor grikes of V-shape in cross-section. The forms are mostly holes, bogaz, covered but elongated and irregular dolines. The second type is karst with wider

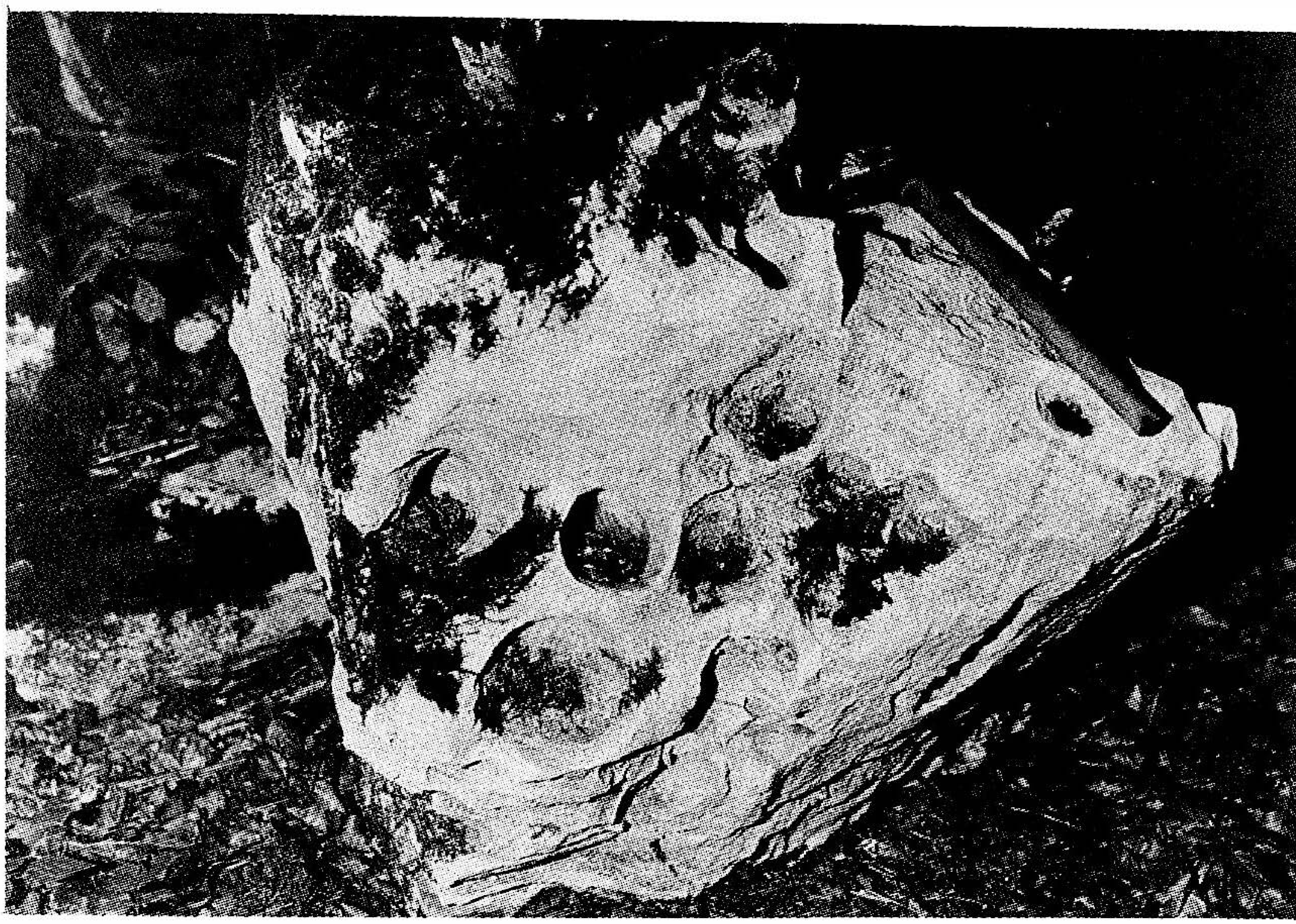

Fig. 7. One of the blocks on the karstic plateau of Mt. Deister near of Springen (W. Germany) shows subsoils pans (subsoil kamenitzas) on the almost vertical side wall - a proof of the overturning of the block for 90°. (Photo dr. F.D. Miotke.)

fissures which are U-shaped. The most typical forms here are subsoil niches, solution pans, covered pits and bogaz. In the first karst type the insoluble material in the limestone is more abundant (one analysis: 3,7 %) then in the second type of karst (4 analyses, 0,1 - 1,4 % of unsoluble material).

No clear relation has been found between subsoil karst forms and soil colour. The Monsen colours vary between 2,5 Yr 4/6 to 5 Yr 5/6, from grey to reddish brown. Deeper in the fissures the soil is redder, probably as a consequence of lower soil moisture, which is common in the Dinaric karst (Gams, 1972).

There are great differences in soil texture. The percentage of sand vary from 6 to 39,5 %, of silt from 14,6 to 38,4 %, and of clay from 34,8 to 83,9 % (5 analyses with a "Kalzimeter"). The causes of these differences are not yet fully understood. The depth is the dominant factor. In terra rossa, is the clay percentage in the horizont B 2-3 times higher then in the A-horizont (Sušin, 1968).

Special attention was given to the weathering crust. In the level of the soil A-horizont there is no clear weathered crust on the stones but then the crust thickens downward. At the depth of 1 m it is 1 mm thick, at the depth of 2-3 mm 1-2 mm thick. Oolithic limestones have thicker crust then other. The weathering crust has the same percentage of insolubles as the parent rock but reaction with sulphuric acid is more vigorous. The crust material shows the same figure on Röntgen as the parent rock (personal communication, Dr. V. Gregorič, Ljubljana). The parent rock in this quarry is grey but the crust at depth is usually whiter. If there are red calcite veins or red cracks in the rock the crust above them is also red. Transformation of ferrous oxide into ferrie oxide is playing a part in the crust formation. After the limestone rubble is fully dissolved in its place whittish dust remains in the reddish soil.

It is evident that corrosion under the soil is essentially different from that attacking the rock exposed to the air. In the B-horizont the calcite veins in the rock project as tiny ridges 1-2 mm high from the weathering crust. In the A-horizont this aspect disappears and higher up on exposed rock fissures develop on the surface along the calcite veins and the planes of stone weakness. Probably the mechanical weathering is the main cause of these differences. In any case the formation of the crust is connected with the development of the subsoil depression forms and is a proof that the penetrating gravitational soil water is only the means of transportation of disaggregated carbonate rock. A proof of corrosion by means of soil moisture and not of gravitational water are fissures which run not only vertically but also horizontally and under impermeable, solid overlying parts of stone. In the light of this specific surface (mass to surface area) is the most important factor in corrosion intensity. More fractured, more porous and thiny grained limestone are in this sence more liable for development of depressions in the subsoil karst.

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Ba 018

КАРСТ И ПЕЩЕРЫ АЛТАЯ

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На Алтае карстуются главным образом синийские и кембрийские мраморизованные известняки и доломиты, силурийские и в меньшей степени девонские и каменноугольные (в Рудном Алтае) известняки. Карстующиеся породы не отличаются как правило большой мощностью, чередуются со сланцами, эффузивами, слои их сильно дислоцированы, часто наклонены под большим углом. Поэтому карст распространен разобщенными районами и участками, пещеры не отличаются большими размерами, а естественные шахты и карстовые колодцы сравнительно неглубоки.

Развитию карста способствует интенсивная тектоническая трещиноватость карбонатных толщ. Распространение плоских вершинных поверхностей, расположенных в несколько ярусов (карстование идет преимущественно в диапазоне абс. высот 300-2500 м), также содействует развитию карста. Благоприятны в целом климатические и ландшафтные условия. Карстующиеся карбонатные породы распространены главным образом в более влажных районах северной половины Горного Алтая, получающих до 800 мм годовых осадков и местами более. Интенсивнее всего карст развивается летом при максимуме осадков (с июля по сентябрь около 45% годовой суммы) и в период весеннего таяния снежного покрова. Зимой же продолжается развитие лишь подземных форм. Около 70% территории занято горно-лесными ландшафтами, почвы и растительность которых обогащают выпадающие и фильтрующиеся сквозь почвы дождевые осадки и талые снеговые воды агрессивными компонентами.

Среди исследователей карста и пещер Алтая есть видные путешественники. В их числе П.С. Паллас, доктор Геблер, Гельмерсен, Н.М. Ядринцев, В.В. Сапожников. В советское время пещеры Алтая привлекают внимание археологов (П.П. Хороших), в них обнаруживаются палеолитические стоянки (М.В. Розен, И.И. Гохман, С.И. Руденко). Преимущественно в последнее десятилетие начинают выполняться более комплексные исследования карста Алтая, с вниманием не только к подземным, но и к поверхностным формам, а также к гидрографическим особенностям. Появляются обобщающие работы о карсте Северо-Западного Алтая (Черняева, 1967) и всего Горного Алтая, дающие общее представление о распространении карста и его районирование (Крюков, 1963; Тупотилова, 1965, 1968; Максимович и Костарев, 1971).

Из поверхностных карстовых форм на Алтае довольно широко распространены карры: желобковые и лунковые (Гвоздецкий, 1972а, б), бороздчатые, трещинные. Часто карры образуются за счет действия речных вод в прирусловой полосе и на островах (по рр. Катунь, Чарыш, Черга). Самыми распространенными поверхностными карстовыми формами являются воронки. Размеры их различны. Поперечник иногда достигает 80 м, а глубина - 20 м. По генетической классификации Н.А. Гвоздецкого (1972б), встречаются воронки всех типов. Наиболее обычны воронки поверхностного выщелачивания, или коррозионные. Максимальная плотность воронок - 16 штук на 0,01 кв. км - отмечена на водораздельном участке Теректинского хребта у истока р. Б. Яломан. Между расположенными рядом воронками здесь создаются перемычки в виде естественных мостов. В других местах карстовые мосты и арки образуются за счет роста карстовых ниш в узких известняковых грядах и в результате обрушения сводов пещер (Маринин, 1969а). В бассейне Ануя есть образовавшаяся путем обрушения свода пещеры котловина. Вообще же карстовые котловины встречаются на Алтае сравнительно редко. Зато обычны карстовые овраги, суходолы и лога.

В Северном, Западном и Центральном Алтае известны карстовые останцы. Они разбросаны в виде отдельных изолированных массивов, гряд и столбов с относительными высотами от 1,5-2 до 30-60 м. Мощное останцовое поднятие представляет собой гора Алтын-Ту ("Золотая гора"), возвышающаяся на 60 м над Канской степью. Подобные карстовые останцы являются свидетелями древних этапов разработки рельефа Алтая.

В карстовых районах Горного Алтая много мощных источников в известняках, например, Аржан в Теректинском хребте, дающий начало р. Б. Яломан. Некоторые источники представляют собой типичные воклюзы (в верхнем течении р. Тулаты, басс. Чарыша), есть восходящие источники типа Quelltopf, как-то источник в долине р. Шепеты (басс. Ануя), выбивающий из конусообразной воронки. В бассейнах Каменки, Чарыша и др. отмечены исчезающие под землю ручьи и реки. Лезый приток Чарыша р. Тулата в верхнем течении дважды уходит под землю и протекает под землей в общей сложности около 3 км. Полностью поглощается понорами в том же районе речка Сухая Каменушка. Исчезает под землю ключ горы Небо (Черняева, 1961). Несколько раз исчезает под землю ключ Известной с общей длиной подземного русла около 2 км. Приток Песчаной р. Куваш течет под землей приблизительно 700 м и появляется на поверхность вновь уже у самого устья (Тупотилова, 1968).

Докладчиками, с использованием классификации Н.А. Гвоздецкого (1972б), выделено на Алтае 9 типов карста: бронированный известняковый (пещера в линзе известняка под покровом магматической породы

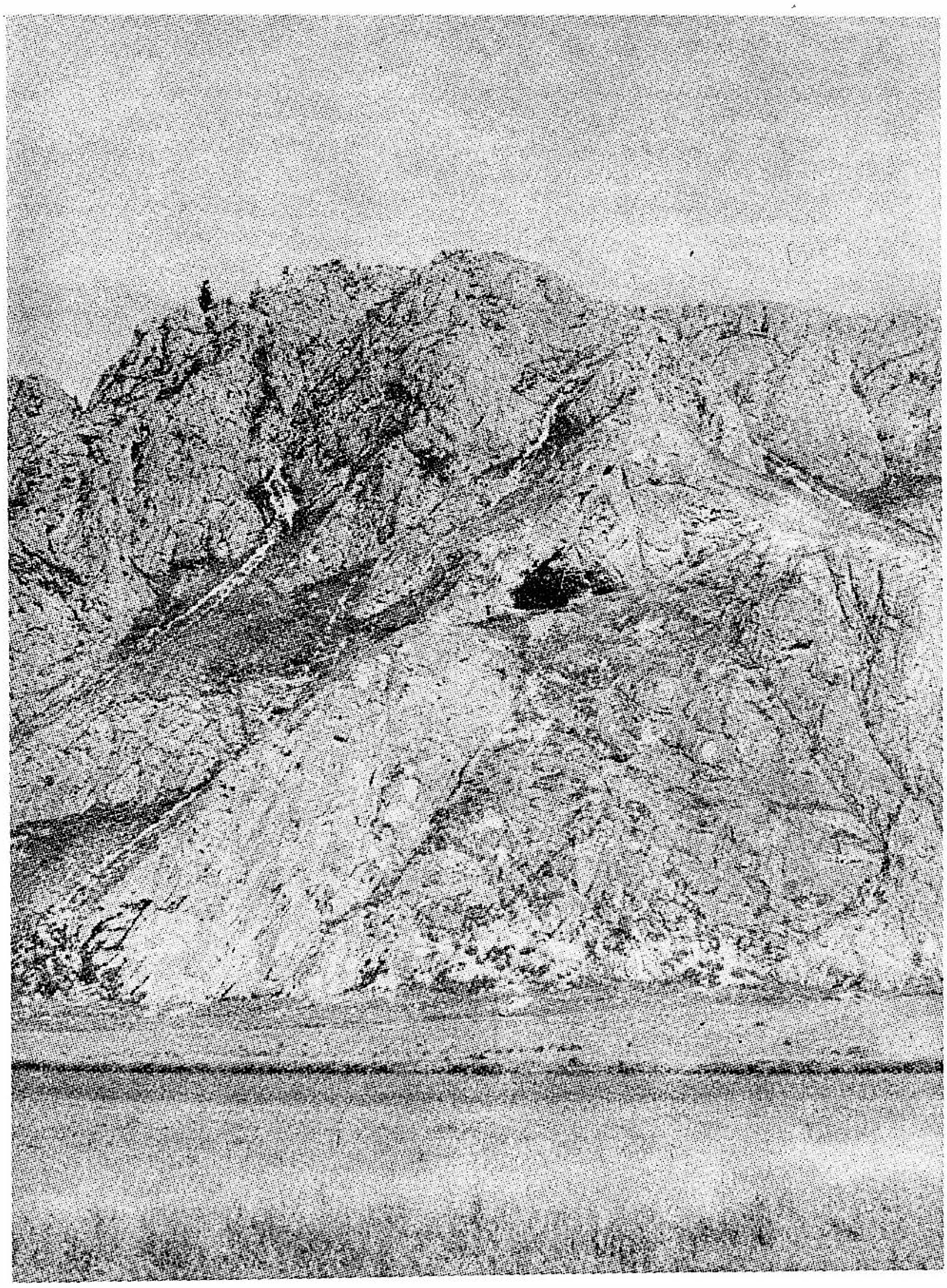

Рис. 1. Усть-Канская пещера в горе Белый Камень (из известняков силура) на правом борту долины верхнего Чарыша. Фото Н.А. Гвоздецкого.

в бассейне р. Песчаной), покрытый известняковый (известен во многих районах), задернованный известняковый (наиболее распространенный тип), задернованный доломитовый (в басс. р. Песчаной), задернованный карст в мраморах (по берегам Катуни у с. Усть-Муны), голый известняковый (распространен широко, чаще на фоне задернованного карста), голый известковисто-сланцевый (на берегу Телецкого озера), останцовый известняковый (распространен в виде отдельных реликтовых форм), карст, сочетающийся с вечной мерзлотой (встречен в высокогорье Алтая в кембрийских известняках Акташского ртутного месторождения). Выделено также 10 карстовых районов (Катунский, Кадринско-Баратальский, Чуйский, Теректинский, верхнего и среднего течения р. Песчаной, Ануйский, Канско-Чарышский, Среднечарышский, Прииртышский, Восточно-Алтайский), отличающихся своими индивидуальными особенностями.

Наиболее глубокой карстовой полостью Алтая является пещера Алтайских геофизиков, которая уходит на глубину 120-140 м. Типичные естественные шахты и карстовые колодцы неглубоки - до 63 м (шахта Ингурекская в северной части Алтая). Всего известно более 20 карстовых шахт и колодцев (Маринин, 1969б и др.).

Пещеры на Алтае приурочены к склонам карстующихся массивов по речным долинам Катуни, Бии, Чуи, Песчаной, Ануя, Чарыша, Ульбы, Бухтармы, Чулышмана и побережью Телецкого озера. Закартировано 203 пещеры, учтено более 300. Наиболее крупные из пещер Алтая: Музейная (в Ануйском районе) - длиной около 700 м, Большая Чуйская (в Чуйском районе) - 547 м, Алтайских геофизиков (в Катунском районе) - около 400 м, Старая Каракольская (в Ануйском районе) - 306 м. В крупных пещерах имеются разнообразные натечно-капельные образования.

Капельники представлены сосульковидными, трубчатными и реповидными сталактитами. Длина сталактитов достигает 40-50 см. Оригинальны натечно-капельные образования в Музейной и Старой Каракольской пещерах, они имеют вид морских кораллов, своеобразных каменных цветов и гроздей винограда. Сталагмиты поднимаются в виде свечей, конусов, бутылей, изредка - сложных ветвистых образований. Высота их обычно до 40 см, редко более, иногда до 3 м (в пещере Алтайских геофизиков). Во входном гроте Агайринской пещеры есть сталагмит метровой высоты с диаметром до 42 см. Для пещер характерны также драпировки, занавесы, натеки на стенах и колонны (сталагнаты). В малых пещерах натечно-капельные образования развиты слабо, чаще отсутствуют.

Морфология пещер часто определяется трещиноватостью. Развитие пещерных ходов связано преимущественно с тектоническими трещинами северо-восточного и северо-западного направлений. Связь планового изоб-

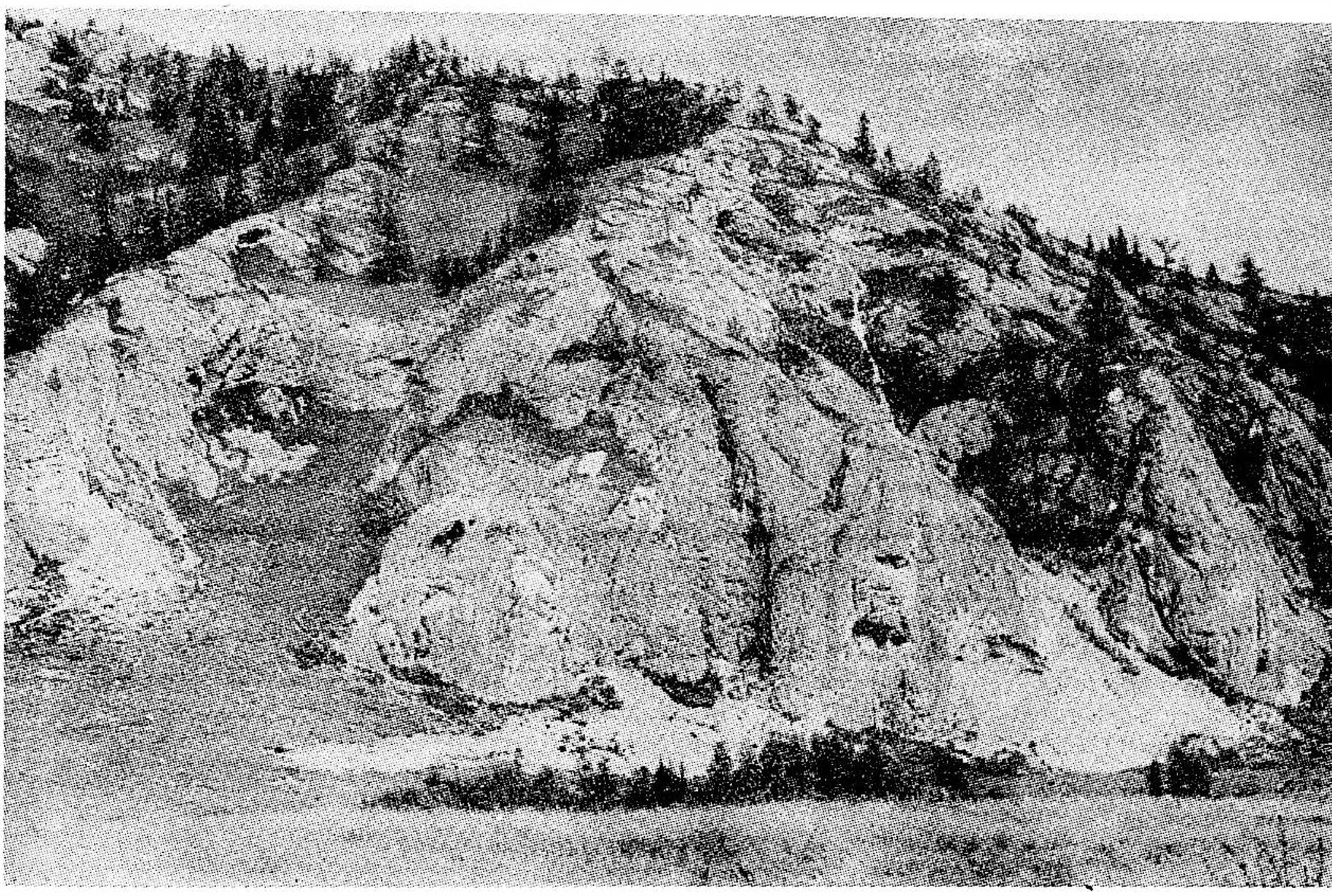

Рис. 2. Скалистые выходы силурийских известняков с нишами и гротами в урочище Шиверта (Канско-Чарышский район). Фото Н.А. Гвоздецкого.

ражения пещеры с системами трещиноватости наглядно видна на плане Большой Белобомской пещеры (Гвоздецкий, 1972а, б). Среди пещер Алтая распространены преимущественно одноэтажные полости, но есть двух= и трехэтажные.

Расположение пещер в кастующихся массивах по рр. Катуни, Чуи, Аную, Чарышу соответствует уровням речных террас.

По микроклиматическим условиям пещеры Алтая делятся на теплые, холодные и ветровые (сквозные). В холодных и отчасти ветровых пещерах происходит образование и накопление льда. Известно 11 пещер-ледников с постоянным льдом. В пещерах-ледниках встречаются разные формы льда: покровный лед (наиболее распространены сталактиты, сталагмиты, кора обледенения, ледяные кристаллы.

В пещерах Алтая найдены и описаны кости пещерной гиены, хорька, байбака, широколобого оленя, первобытного быка, лошади, носорога, тигра, барса, корсака и других животных.

В алтайских пещерах уцелели остатки человеческой культуры эпох палеолита, бронзы, железа. Пещеры Усть-Канская (в Канско-Чарышском районе, рис. 1) и Бухтарминская (Прииртышский район) известны палеолитическими стоянками (Руденко, 1960; Гохман, 1957).

В бортах ущелий и в обрывах отдельных известняковых массивов встречается множество ниш и навесов (рис. 2). Обычно они сухие, натечно-капельные образования в них отсутствуют.

THE ALTAI KARST AND CAVES

N. A. Gvozdietsky, A. M. Marinnin

SUMMARY

Mainly Sinian and Cambrian marbleized limestones and dolomites, Silurian, carbonoferous (in the Ore Altai) and in smaller degree Devonian limestones are karsted in the Altai. Karsting rocks are as a rule of great thickness alternating with shales and diffusions, their layers are greatly dislocated and very often inclined at a big angle. So that karst is distributed by disconnected regions and areas, caves are not large and pot holes and pits are comparatively shallow (from 63 m). Climatic and landscape conditions are rather favourable in the whole for the karst development.

Rillenkarren, Halbkugelförmighöhlenkarren, Rinnenkarren, Kluftkarren, sinks of various ganetic types, caves, karst gullies and blind creeks, karst outliers, natural bridges and arks are distributed there besides caves, pote holes and pits. Many karst resources are rivers and streams disappearing from the earth. The reporters have pointed out 9 types and 10 karst regions which differ by their individual features.

203 caves are mapped in the Altai and 300 caves are taken into account. The largest Altai caves are: the Museum cave (in the Anui region) is of 700 m in lenght, the Big Chuya cave (in the Chuya region) is of 547 m, the Old Karakol (in the Anui region) - 306 m. There are various sinter-drop formations in large caves. There are caves-glaciers (II with permanent ice) there. The Ust-Kan cave (in the Charysh region) and the Bukhtarma cave (in the Irtysh region) are known by the Paleolithic encampments.

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KARST FEATURES IN EAST POLAND

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Carbonate rocks which condition the development of karst features in East Poland only occur on a section of the meta - Carpathian ridge, which enters into the composition of this region. From the south it has a distinct geological as well as a morphological boundary. This is determined by a narrow area of tectonical divisions from which to the south, regions connected with Alpine folds occur (Carpathians with a tectonic foreland depression). Morphologically it is a ridge of a relative height usually exceeding 50 m. The northern boundary is not so distinct, but it also has a structural foundation. This is determined by a rather wide area, in which Mesozoic carbonate rocks penetrate to the north under a thick cover of Quaternary formations. The eastern boundary of the region was conventionaly drawn along the Bug river valley and the western - Vistula river valley. In such marked boundaries the whole Lublin Upland together with the Roztocze and the southern regions of Małe Mazowsze and Polesie are contained.

THE GEOLOGICAL STRUCTURE

The main element of the geological structure of this region are the rather differentiated carbonate deposits of the Upper Cretaceous (W. Pożaryski 1956). Here opokas, gaize, marls, marly limestones and chalk occur; they differ from each other in respect of the chemical composition as well as from their lithological properties. Among the mentioned types of rocks, opokas and gaize because of their siliceous framework do not submit to karst processes. The main element of the remaining types of rocks is $CaCO_3$ (usually above 75% and in the case of chalk above 90%) and the amount of silica varies between about 5%

to 20%. Marls, marly limestones as well as chalk are porous elements (to 40%) and are characterised by a small resistance to mechanical weathering.

In the south west part of the region older deposits - the Lower Cretaceous and Jura limestones (W. Pożaryski 1956) are exposed in a few points; they do not have a greater significance in the development of karst features because of their small expanse.

In the rather narrow area of the sourhern ridge of the Lublin Upland and the Roztocze, carbonate deposits of the Upper Miocene occur on Cretaceous rocks (B. Areń 1962, M. Bielecka 1967). This series is composed of detrital and lithotam limestone and of various types of reefy limestones. They are characterised by a $CaCO_3$ content of above 90%, a small porosity (to 10%) and a distinctly larger resistance than Cretaceous rocks.

On the carbonate rocks there lie isolated sandy and loamy layers of the Oligocene and Miocene deposits. In the Quaternary period the whole region found it's self in the reach of the Mindel glaciation, after which layers of glacial and fluvioglacial accumulation formations are preserved. On the other hand, the Riss glaciation only reached the southern part of the region, leaving behind formations, the thickness of which grows in the northern direction. Connected with the Wurm glaciation period, which did not reach the mentioned region, are thick covers of loess, dusty and sandy, eluvium and diluvium covers (A. Jahn 1956) which occur in layers and are widespread on the whole region.

KARST FEATURES

The subaerial development of the region's sculpture was begun in the Palaeogene. The main elements of the Lublin Upland formation originated in this period (A. Jahn 1956). Also the oldest traces of karst processes and the oldest karst fossil forms originated in this phase. On the Lublin Upland and Roztocze in a dozen or so points the occurrence of opokas and decalcificated gaize the thickness of which exceeds 10 m, was ascertained. They are the proff of intensive chemical weathering of limy-siliceous rocks. Taking into consideration, that they are covered with Upper Eocene and Oligocene deposits, their decalcification process should be dated on the Lower Eocene and Palaeocene (W. Pożaryski 1956, M. Harasimiuk 1965). The occurrence of typical karst forms connected with this period is ascertained to date only in the Chełm district. These are karst funnels and small karst valleys filled with Oligocene sea deposits (Ł. Górecka 1958, M. Harasimiuk 1965). The following phase of the development of karst forms took place before the transgression of the Upper Miocene sea. From this period, in the Chełm district, a few karst funnels of a depth to 30 m, filled with Upper Miocene sea deposits, are also preserved. A few karst funnels which can be dated on the Middle Pliocene have similar dimensions. They are filled with sandy and muddy deposits of the Upper Pliocene (M. Harasimiuk 1970).

On the Tertiary limestones of the Roztocze and the southern part of the Lublin Upland, traces of Pliocene and Lower Quaternary karst are met with quite often. On well preserved fragments of the Lower and Middle Pliocene planation surface, lapies fossils together with developed fossil soil of the terra calcis type occur (Nakonieczny, Pomian, Turski 1968). The character of the karstic surface and the chemism of the weathered covers indicate the warm and damp climatic conditions typical for the Middle Pliocene. The following karst generations are connected with the Upper Pliocene and Lower Quaternary phases of the raising and dissecting of the region. These are mainly sink-holes and karst funnel fossils connected with the lowering of the underground water-level and the animation of their circulation (M. Harasimiuk, A. Henkiel, K. Pękala 1969).

In the Quaternary period, in the areas of the occurrence of karstic rocks of the Cretaceous age, a series of development phases of karst forms of a reccuring typology took place. The most characteristic for karst on Cretaceous rock are mesoforms (H. Maruszczak 1966). These are first of all karst funnels of a diameter of several score meters and a depth of up tp about 10 m. Morphometrically they are differentiated between a flat-bottom and a cup-shaped. The variability of the shape results from the process and tempo of their filling up with mineral and mineral-organical deposits. It is also dependent on the character of processes which transform forms not directly connected with karst processes. In result of karst funnels joining, forms composed like ridges and karst valleys are created. Apart from surface forms the occurrence of karst funnel fossils connected with different Pleistocene phases is quite common (J. Rzechowski 1962). The development of surface forms is limited to the aeration area, and by that it is conditioned on a large scale by the fluctuations of the underground water-level. Karst funnels developed in various phases of the Pleistocene and Holocene. The Allerod and the subatlantic period, because of the low position of the underground water-level in these periods, are considered as the main periods during which most of the surface forms were created. Fossil forms are also connected with the erosion phases in the river valleys. On the basis of the character of deposits which fill fossil forms, the existence of not less than three generations of karst funnels from the Pleistocene period (the decline of the Gunz-Mindel interglacial, Mindel-Riss interglacial and Riss-Wurm interglacial periods) were ascertained. Widely occuring under slope planations and lakes of the Lublin Polesie also belong to forms connected with the karst processes in the mentioned region (H. Maruszczak 1966).

On Tertiary limestones of the Roztocze and the southern part of the Lublin Upland, Quaternary karst is first of all represented by a rich group of fossil forms. These are sink-holes, karst funnels and microforms filled with residual loam or clastic deposits connected with the periglacial surrounding. Connected with these forms are fossil soild of the boggy and redzina type, which indicate alternatively, moderate and cold climatic conditions (M. Harasimiuk, A. Henkiel, K. Pękala 1969). Nowdays in this area forms of karst funnel types are being created, reproduced in clastic Quaternary covers.

In the whole group of East Poland karst forms, in the region were Upper Cretaceous rock occur, underground karst forms do not occur. This results from the lithological properties of these rocks (H. Maruszczak 1966). Whereas in Tertiary limestones small and relatively few forms of this type were observed. There meagreness is connected with strongly creviced rocks and their small thickness.

The morphological role of the East Poland karst should be considered separately for Cretaceous and Tertiary rocks. Karst forms developing on Cretaceous rocks play an important role in the landscape of many Lublin Upland (the districts of Chełm, Rejowiece, Opole, Łęczna south of Hrubieszow) and also the Lublin Polesie regions (H. Maruszczak 1966). The number of karst funnels on a surface of 1 km^2 reaches 40-60 and in some places may even exceed 100 (J. Rzechowski 1964). The group of karst forms developed on Upper Cretaceous rocks, differs in a distinct manner from typical karst forms, that is why one can also speak of "the chalk karst type" (H. Maruszczak 1966).

Forms developed on Tertiary limestones are more similar to typical karst. But these rocks, in the mentioned region, are of a small expansion and with their specific lithological properties the impoverishment of the karst form groups is connected here. First of all fossil forms occur and the few surface forms do not play a significant role in the landscape.

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Ba 020

ПРИНЦИПЫ КАРСТОЛОГИЧЕСКОГО РАЙОНИРОВАНИА

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Анализ данных ряда опубликованных в СССР работ, трактующих вопросы районирования карста, показывает наличие четких исходных положений, принимаемых исследователями в качестве основы этого районирования. Так, Н.А. Гвоздецкий (1952, 1956, 1962, 1966) считает его литолого-тектонический (геологический) фон, определяющий наличие растворимых карстующихся пород. Физико-географические условия зонального или провинциального порядков, накладываясь на этот фон, формируют проявления карста, его характер и тип (1966). Г.А. Максимович (1956, 1958, 1962) принимает в качестве основы районирования карста геотектоническую и структурную зональность, определяющую распространение и залегание карстующихся пород в составе разновозрастных и разнотипных структур. При этом должны учитываться также количества и длительность континентальных перерывов, литология пород, влияния неотектонических движений и климатических факторов (1958).

Во многих случаях районирования карста и, как его разновидность, спелеологическое районирование основано на оконтуривании выходов разновозрастных карстующихся отложений (В.Н. Махаев для Крыма, 1937; I. Kunsky для Чехословакии, 1950 и др.). Широко распространено районирование закарстованных территорий по морфологическим разновидностям карстового рельефа, возникшим в разных климатических обстановках P. Birot, 1954; H. Lehmann, 1954, 1956; C. Rathjens, 1954; A. Bögli, 1956; G. Chabot, 1956, H. Louis, 1956, I. Roglic, 1956; H. Wissmann, 1957 и др.

Геолого-структурная основа районирования позволяет выделять такие подразделения (таксономические единицы) карстологической систематики как "карстовая страна-область-провинция-округ-район" (Н.А. Гвоздецкий, А.Г. Чикишев, 1966) или "карстовая страна-провинция-область-район" (Г.А. Максимович, 1958). В последнем случае они распространяются в пределах от основных геоструктурных единиц до территорий, отличающихся деталями геологического строения, литологии пород, наличием или отсутствием покровных отложений, особенностями морфологии карста.

Как правило, в карстологической литературе и на картосхемах, территории карстовых районов и, особенно, их отдельных частей описываются главным образом в аспекте поверхностного карста. В то же время небольшие участки либо хозяйственно осваиваемые, либо отличающиеся активизацией естественно-исторического карста техногенным карстом, вызванным деятельностью человека, подвергаются комплексным исследованиям высокой детальности. Многочисленные примеры этого приводятся в ряде работ преимущественно по инженерной геологии и гидрогеологии, прикладной геофизике, гидротехническому строительству, горному делу таких авторов как М.С. Газизов, Г.В. Короткевич, А.Г. Лыкошин, А.А. Огильви, И.В. Попов, Н.В. Родионов, И.А. Саваренский, Д.С. Соколов, А.Е. Ходьков и др. в СССР, Д. Яранов, Б. Каменов, П. Динев, М. Грънчаров и др. в Болгарии M. Matula и др. в ЧССР, Z. Wojcik, I. Glazek, I. Bazynski, I. Krason, S. Knothe и др. в Польше, M. Lukovic, F. Jenko, I. Gams, S. Mikulec, Z. Krulc и др. в Югославии и др.

Нетрудно видеть, что при отсутствии разработок по унификации требований к составлению комплексных характеристик карста для территории и геологического разреза различных подразделений карстологической систематики, качество таких характеристик будет оставаться крайне разнородным, а прогнозы влияний карста на среду - мало обоснованными.

Опыт упомянутых комплексных исследований в равной мере как и работы института минеральных ресурсов Министерства геологии УССР убеждают в том, что ограничение любых влияний карста требует инженерных решений. Отсюда следует необходимость существенного улучшения карстологических характеристик, их всесторонности и сравнимости сля территорий и геологического разреза любых подразделений карстологической систематики от карстовых блоков до карстовых провинций.

Осуществление изложенных требований по нашему мнению возможно при унификации карстологических исследований и картографирования карста. Ее целесообразно начинать с последовательного использования при полевых и аналитических работах принципов карстологического районирования в целях систематизации карстологических данных о взаимосвязах общих и местных условий и факторов развития карста, отображаемых в сочетаниях поверхностных и глубинных карстовых явлений. Одновременно возрастет эффект детализации районирования при едином построении карстологических характеристик и оценок для элементарных карстовых систем в геологическом разрезе блоков и их сочетаний в подразделениях более высоких порядков.

Опыт разработки принципов карстологического районирования я применением их к территориям Украины и Молдавии (Иванов, 1957, 1965, 1972) дает возможность изложить их сущность.

1. Общекарстологический принцип районирования предполагает обязательность всесторонней оценки условий необходимых для развития карста на поверхности и в глубине объема горных пород любого подразделения карстологической систематики. Среди них находятся: 1. карстующиеся породы, 2. разнотипная их водопроницаемость, 3. циркуляция вод, 4. их агрессивность по отношению к растворимым породам, 5. особенности тектонического режима структуры, 6. особенности техногенной деятельности человека в пределах изучаемого подразделения и его периферии.

2. Регионально-карстологический принцип обуславливает производство комплексного изучения местных особенностей указанных условий развития карста и факторов, придающих генетическую специфику карсту данного конкретного подразделения.

3. Территориальный принцип предусматривает необходимость рационального проведения границ между подразделениями предлагаемой нами карстологической систематики в пределах сложных морфоструктур первого порядка (для геосинклинальных и платформенных карстовых провинций), структур младших порядков (для карстовых областей и районов) и их элементов (для карстовых районов, подрайонов, участков, блоков) с учетом геоморфолог-гидрологических, гидрометеорологических и техногенных обстановок в их динамике.

PRINCIPLES OF KARST REGIONALIZATION

B. N. Ivanov

SUMMARY

1. The absence of elaborations of the unification of requirements for composition of karstic characteristics and maps of different scales lowers the quality of prognoses of the influence of karst on the nature surrounding and its industrial exploitation. However, there is an extensive experience of detailed study of the conditions and factors of karst development for small lots under various building constructions.

2. The comprehension and comparison of karstic characteristics and unity of their construction must be consistent in district for the whole of subdivision of karstic systematization from karstic blocks, plots, subregions, regions to the karstic provinces.

3. For this it is necessary to use the consistent principles of karstic division into districts: a) general karstic principle (study of dissoluble and perviousness of the rocks; circulation and aggressivness of water, tectonic relationship and economic

development of lands); b) regional karstic principle (calculation the local conditions and factors of development of karst); c) territorial principle (apportionment of the subdivisions with typological varieties of surface and subsurface karst).

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Ba 021

HISTORY OF A DRY VALLEY ON COOLEMAN PLAIN, N. S. W., AUSTRALIA

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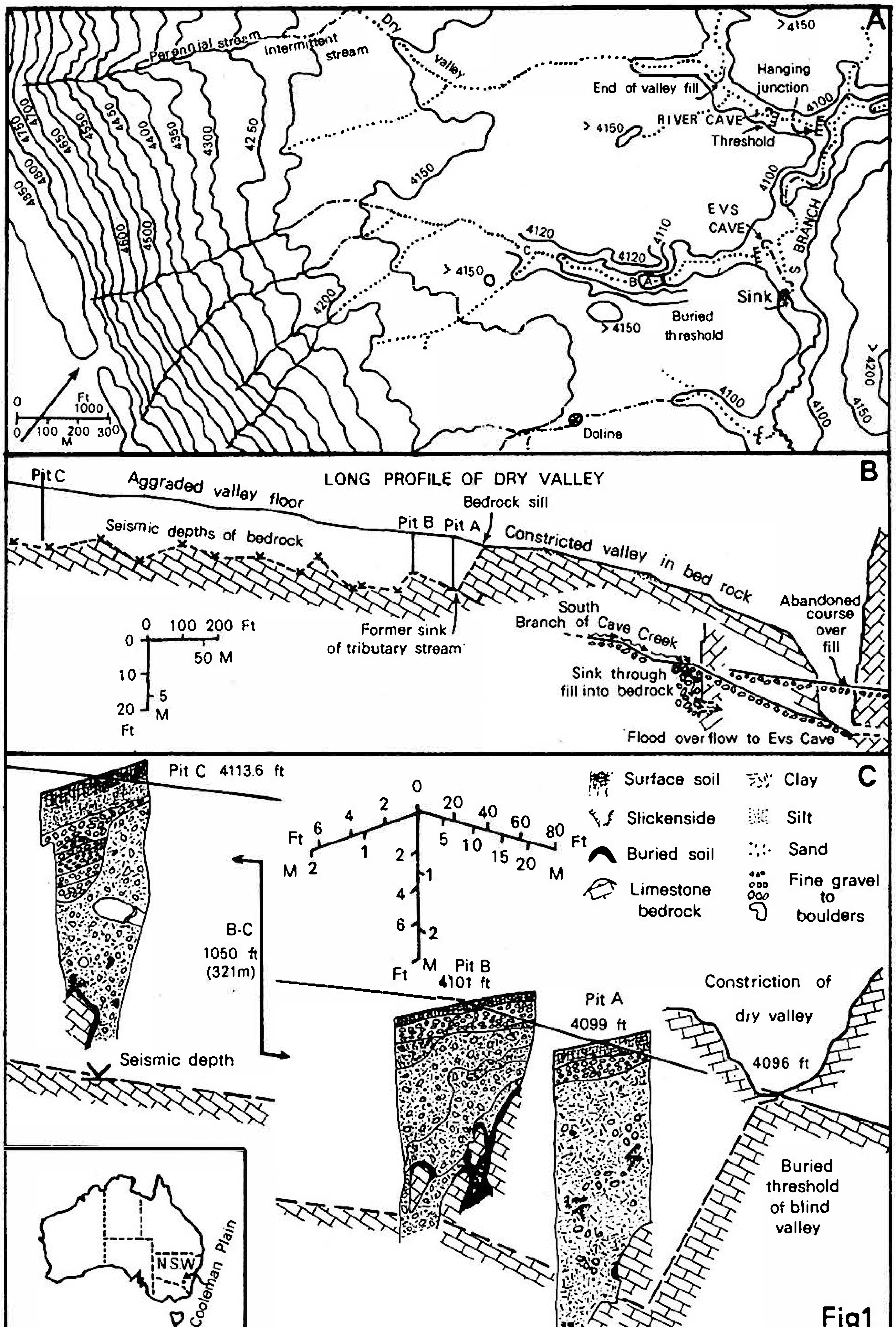
Abstract. On Cooleman Plain, a small impounded karst with a Köppen Cfb climate today, mudflow and fluvial fill blocked a karst blind valley and restored surface flow temporarily down a dry valley, most probably during a periglacial period about 30-15,000 B.P., which favoured increased slope instability and surface runoff.

The origins of karst dry valleys have been studied more than their later histories, though in certain cases these have proved of much interest (e.g. Sparks & Lewis 1957; Kerney and others 1964). Here attention is drawn to the evolution of a dry valley which is taken to be representative of those characterising the middle sections of the centripetal drainage of Cooleman Plain in the Southern Tablelands of New South Wales (Jennings 1967).

At 1250 m with a Köppen Cfb climate, this upland plain karst in subalpine grassland is surrounded by forested igneous ranges rising to 1650 m, except where Cave Creek escapes in a gorge through this rim. Small perennial streams flow down these igneous slopes of 5^{o}-30^{o} and a number of them sink into Silurian limestone at the margin of the plain, either directly or though inactive fans of surficial deposits. They are continued in dry valleys of gentle gradient inset up to 20 m below the very flat interfluves of the karst plain. These valleys generally have thin soil covers and frequent rock outcrops but for varying distances from the plain margin their floors are well buried by surficial deposits.

The dry valley investigated runs 1.5 km from the western margin of the plain NE by E to the South Branch valley a little below that stream's normal point of sinking but immediately above its flood overflow into Evs Cave (fig. 1A). Below this, South Branch does not flow at the surface though former channels are preserved on the valley fill.

For two-thirds of its length, the dry valley has a gradient of less than 1^{o} with a continuous valley fill. The remaining part to the



A
Perennial stream
Intermittent stream
Dry valley
End of valley fill
Hanging junction
RIVER CAVE
Threshold
EVS CAVE
S. BRANCH
Sink
Buried threshold
Doline
B
LONG PROFILE OF DRY VALLEY
Pit C
Aggraded valley floor
Bedrock sill
Pit B
Pit A
Seismic depths of bedrock
Constricted valley in bed rock
Former sink of tributary stream
South Branch of Cave Creek
Abandoned course over fill
Sink through fill into bedrock
Flood overflow to Evs Cave
C
Pit C 4113.6 ft
Surface soil
Clay
Slickenside
Silt
Buried soil
Sand
Limestone bedrock
Fine gravel to boulders
B-C
1050 ft
(321m)
Pit B
4101 ft
Pit A
4099 ft
Constriction of dry valley
4096 ft
Seismic depth
Buried threshold of blind valley
N.S.W.
Cooleman Plain
Fig1

Fig. 1.

confluence is narrower, deeper and virtually entirely in bedrock with only scattered thin patches of surficial deposits. Here it has a steepening profile and it finally hangs about 5 m above the flood overflow channel of South Branch.

In the downvalley part of the continuous fill, three pits were dug to bedrock and seismic refraction determinations of its depth were made between them with a Huntec FS-3 Seismograph (fig. 1B). This demonstrated a buried threshold of 4.5 m at the constriction beginning the bedrock floored part of the valley. There was thus a karst blind valley here prior to the aggradation.

The next dry valley to the north has an exposed threshold of the same size (fig. 1A). Fill ends some way above this threshold where the entrance to River Cave leads down to the underground course of South Branch through an inactive passage cut by a former stream along the valley.

The buried blind valley is to be related to the buried bedrock floor of South Branch, which feeds into the valley side bedrock at 4.3 m below the fill surface at its normal streamsink (fig. 1B). The aggradation of the dry valley restored to it a continuously falling profile to the S. Branch valley. At this time, the two valleys were nearly accordant since the main valley fill rises 3 m above the flood overflow channel which has been re-excavated in it.

All three pits exposed an irregular bedrock surface, with pinnacles up to 1.5 m high (fig. 1C). Draped round parts of these buried features and especially beneath overhangs, there are distinctive layers, 5-20 cm thick, of two materials grading into one another. One is a dark-brown porous, pedal silty clay, which is thixotropic. The dark hue is not due to organic carbon (0.02%) but to iron (Fe_2O_3 5.66%). The other is greenish-grey and less pedal but otherwise similar. Both are regarded as remnants from the original soil cover, though like all the fill they are weakly acid (pH 6.0-6.5). The clay minerals are illite and kaolinite. Montmorillonite is absent but this does not preclude residual origin from the limestone.

Most of the fill in all pits belongs to a common sedimentary body marked by very poor sorting and lack of bedding, though there are down valley changes. In pit B it is prevailingly stony (from fine gravel to boulders), with a matrix of silty loam and silty clay loam, varying from yellowish-red to strong brown in colour and often mottled. The large clasts are mainly igneous rocks, with much less frequent ironstone, occasional vein quartz and rare limestone, the latter most frequent close to bedrock. Some of the igneous clasts are highly weathered. As a whole the sediment is muddy gravel or gravelly mud (Folk 1964) with tendencies to two modes in the gravel and very fine silt-clay extremes. The proportions of stone and matrix vary so that the central tendency as measured by Folk's Graphic Mean $\frac{(\phi 84+\phi 50+\phi 16)}{3}$ ranges from 0.15 ϕ to 5.44 ϕ. The sorting varies from very poor to extremely poor (Folk's Inclusive Graphic Standard Deviation $\frac{(\phi 84-\phi 16)}{4}+\frac{(\phi 95-\phi 5)}{6.6}$ ranged from 3.42 to 5.48). Included were irregular bodies of stone-free silty clay, varying from white to yellowish red. Some of this clay was blocky with slickensided faces. The clay minerals present are illite and kaolinite; montmorillonite is absent so swelling properties are not involved. The structures are probably due to loading by the sediment above.

In pit C, 300 m up the valley, the sediment is very similar but it is marked by larger and more weathered boulders up to 1 m long. But pit A, only 25 m from both pit B and the bedrock still closing the buried blind valley, includes in the equivalent horizons much more stonefree material, though this remains closely similar to the matrix in pit B. One sample has a σ_I of 1.89, i.e. poorly sorted but within the range of fluvial sediments. Other parts remain identical with the pit B sediment. Possibly there was a doline pond intermittently here as the valley filled up rapidly.

This body of sediment as a whole, up to 4 m thick, is clearly a diamicton laid down by mass-movement, though the stone-free parts probably represent thin slurry deposit. Lack of preferred orientation in the large clasts indicates a rapid mudflow rather than slow solifluction as the mode of movement. The largest boulders in pit C in relation to the thickness seem to require that the whole mass moved together and a single event is indicated. The overall fining down valley registers the farther travel of the better lubrioated and more mobile parts of the flow.

Overlying the diamicton is a loose, bedded gravel, still with some silty clay matrix, but with coarser graphic means than the diamicton. It is generally only about 20-50 cm thick but in pit C it thickens to 1 m in a channel in which several beds varied in mode from coarse to fine gravel, the last being better sorted. The clasts have the same composition as in the diamicton but highly weathered rock is rare. This is a waterlaid deposit indicating a time of surface stream flow.

On top of this gravel in the down valley pits A and B there is only a thin (20-35 cm), dark brown loam, which is porous, friable and highly pedal but in pit C this modern soil grades downwards into another 50 cm of practically stone-free raddish-brown clay loam, less well structured and less porous. It is however penetrated throughout by channels of the darker surface soil. In size analysis all these materials capping the gravel correspond with the matrix of the diamicton. Surface wash incapable of moving its coarser fraction probably emplaced it though any bedding has been destroyed by pedogenesis.

The history of the dry valley may now be reconstructed in the context of Cooleman Plain's geomorphic history as a whole. The interfluves belong to a Tertiary karst corrosional plain developed closer to sea level prior to uplift of the Eastern Highlands (fig. 2A). Ferruginous sandstone covered the limestone surface, either by residual accumulation of bedrock insolubles or by through flow from a deep regolith developed on the overlooking igneous slopes. Apart from two small caves possibly indicative of true phreatic solution below the plain, there is little indication of karst development at this stage.

Uplift, probably all within the Tertiary, caused dissection by surface streams (fig. 2B). At this stage the now dry valley probably had an accordant junction with the South Branch valley. However exposure of limestone, initially along the valley sides, led to the development of underground circulation and the tributary continued to lower its valley above its sinking point to develop a threshold and a blind valley. The lower dry valley part came to hang a few metres above South Branch. From other evidence, South Branch then went underground itself near the junction. Thin soils formed on the limestone in the blind valley.

Then followed a period of aggradation (fig. 2D). Since there is no evidence for more than one such phase in the Cooleman valleys, it is assumed that the apparently fluvial fill in the South Branch and the mainly mudflow fill of the dry valley were laid down at the same time. Also there are on steeper slopes on Cooleman Plain gelifluction earths and small blockstreams formed from the earths by washing out of fines. These slope deposits have been correlated with blockstreams and gelifluction slope deposits in the Snowy Mts to the south (Caine & Jennings 1968), which belong to a major cold period dated about 30,000 to 15,000 B.P. (Costin and Polach 1971). It is therefore inferred that the dry valley fill also belongs to this phase with seasonally frozen ground and reduced vegetative cover, and so of reduced slope stability. The weathering mantles on the igneous rim be-

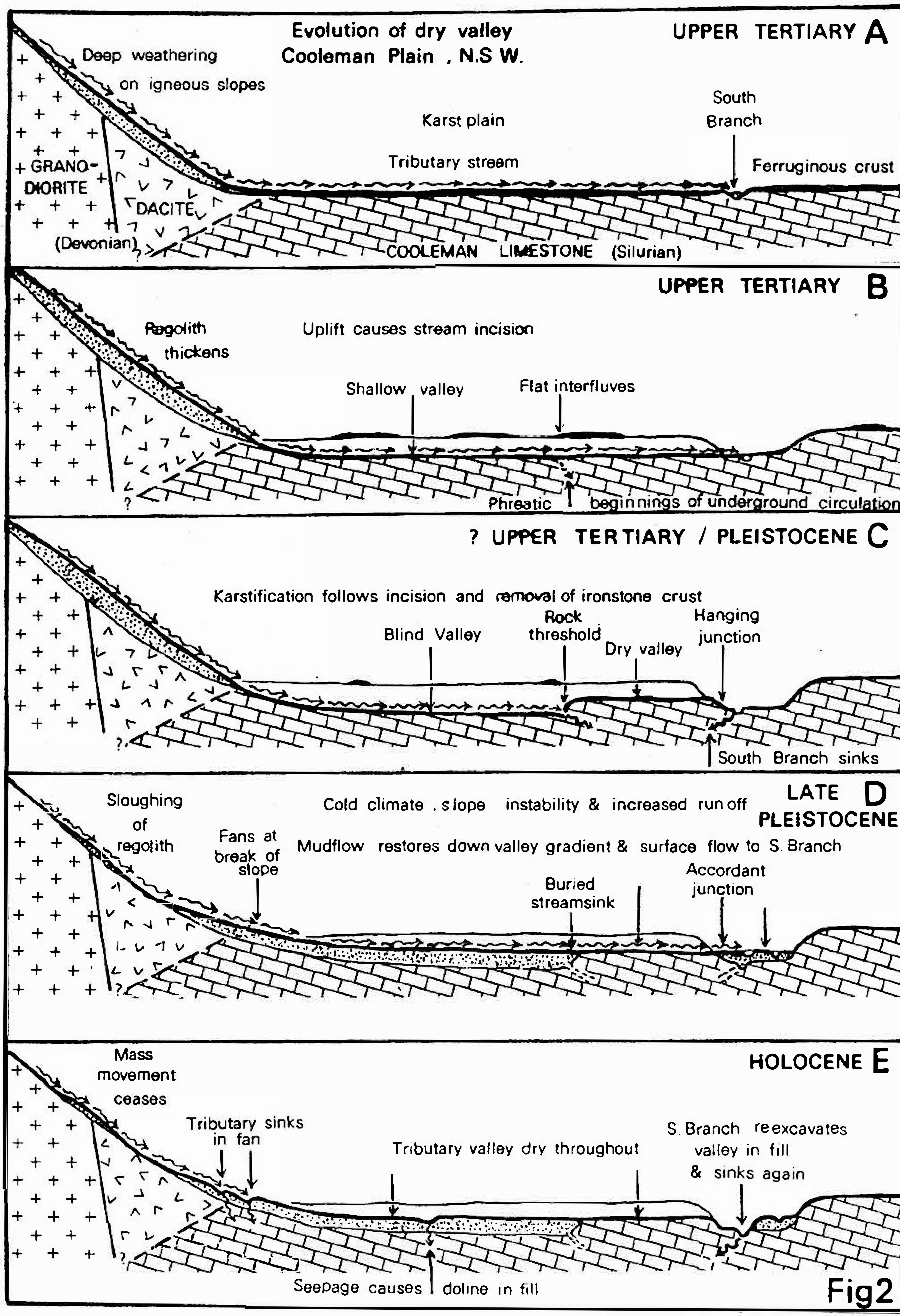


Fig. 2

came active and the mudflow of the dry valley constitutes a representative of the most mobile and far travelled of the consequent mass movements. This blocked the streamsink and restored a continuous downward gradient to the valley.

There succeeded a period of stream flow in the valley, which probably also belongs to the cold period with its reduced evapotranspiration, more effective precipitation and increased runoff. Frozen ground would also promote surface flow at certain times. By this time mass movements had stripped the slopes above of much of their regolith diminishing this kind of process. The runoff winnowed the mudflow deposits and redeposited the coarser fraction to form the overlying fluvial gravels.

With climatic amelioration after 15,000 B.P., runoff declined as precipitation became less effective; the valley fill would also become more pervious as the ground was subject to less freezing in winter. The clay and loams on top of the gravels were laid down in this time of declining surface flow.

The final change whereby the stream sank in the fan at the valley head, rendering all of it channel-free, is also attributed to the Holocene (fig. 2E). In the lower part of the aggraded section, the surface of the fill is slightly convex in cross-section. Two mechanisms could be responsible. During the reworking of the diamicton, if the limestone along the valley sides was able to receive water, some of the stream flow would be directed laterally into it and so give lateral slopes as well as a downvalley gradient (of Jennings and Sweeting 1959). Alternatively the form may be due to a secondary washing of material into the bedrock along the sides of the fill. The presence of small dolines in the fill, especially close to the valley sides, demonstrates that abstraction of material into the limestone is taking place tuday. However the convex form is rather too regular to attribute dominantly to such eluviation and subsidence processes; it may therefore be mainly inherited relief.

The role of cold climate in karst development is complex ~~and~~ paradoxical. Abundant supplies of snow and ice meltwater ~~can~~ promote cave development provided frozen ground and cave ice do not stup up all voids near the surface. Thaw-freeze action destroys much surface karst sculpture and cryoclastic waste may block caves and potholes. In the case of impounded karst, there is also the possibility that mass movements and streams may feed into it increased supplies of waste from surrounding impervious rocks suffering periglacial conditions to block streamsinks. Surface flow may be restored and karst morphogenesis interrupted as has been illustrated in this dry valley study.

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Ba 022

КАРСТОВЫЕ ФЕНОМЕНЫ МЕЖГОРНОЙ ОЗЕРНОЙ КОТЛОВИНЫ РИЦЫ (Большой Кавказ)

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Горное озеро Рица относится к числу глубоких (101 м) озер Грузии. Озеро расположено на южном склоне Кавкасиони (Большой Кавказ), на высоте 884 м над ур. моря.

Над Рицей со всех сторон высятся высокогорные хребты и плато, кольцом опоясывающие озеро. С севера над Рицей поднимается высокая стена Кавкасиони, носящая на этом участке название Ацетука. На западном и юго-западном берегах озера вздымаются высокие и оголенные эскарпы известнякового плато Пшегишха. С востока к озерной котловине вплотную подходят лесистые склоны хребта Анчхо, а с юго-востока, в некотором отдалении, возвышается известняковое плато Рыхва, поверхность которого изъедена каррами и изрыта карстовыми многочисленными воронками.

Карст занимает весь южный борт глубоководной озерной котловины Рицы, где им охвачены моноклинальное плато Пшегишха, каньон Юпшары и высокогорное синклинальное плато Рыхва. Господствует здесь ландшафт влажных горных пихтово-елево-буковых лесов, с вечнозеленым колхидским подлеском и лианами.

Пшегишха представляет собой структурное известняковое плато. Ввиду значительного наклона поверхности это известняковое, небольшое по площади, плато не изобилует карстовыми формами и слабо развитые карстовые воронки находятся в эмбриологической стадии своего развития. С другой стороны, благоприятные структурные условия тектоники и мощность барремских известняков слагающих синклинальные мульды на плато Рыхва обусловили изобилие карстовых воронок.

Высокогорное синклинальное плато Рыхва представляет мощный очаг водопоглащения, а высочайшая вершина его Ачибах (2378 м) изобилует эндемичной известняковой субальпийской растительностью, с Woronowia speciosa Albow, на фоне карровых полей. Все плато изрыто карстовыми воронками и польями, тем не менее здесь нельзя ожидать больших открытий глубинного карста (тем более горизонтальных пещер), так как плато в течение плиоцена-постплиоцена, как это утверждает Ш.Я. Кипиани, интенсивно и неуклонно воздымалось. С другой стороны, эти мощные подвижки суши обусловили исключительную контрастность рельефа - переуглубленность долины Юпшары, с Гегой, и основной артерии Бзиби, протекающей также в своем широтном участке по дну каньона.

По контрастности карстового рельефа окрестности озера Рицы могут соперничать не только со Словацким, Болгарским, Крымским, Провансским, но также и с Динарским карстом. Однако карстовые поля на Большом Кавказе не достигают масштабности Динарид.

Карст вызвал перераспределение стока, он же обусловил безводность всего южного окаймления озера Рицы, несмотря на большое количество атмосферных осадков.

Озеро окружено ландшафтом высокоствольных пихтово-елево-буковых лесов. Однако этот тип ландшафта представлен далеко неодинаково в северном и южном подрайонах. В южном подрайоне господствуют карстовые феномены, ими подчинены закономерности стока, ими обусловлен карстовый рельеф - все формы без исключения, а также характер растительности. В северном подрайоне карста нет.

Барремские мощные известняки, слагающие синклинальные мульды широтного простирания погружаются у тальвега реки Юпшары и тем самым дают выход высокодебитным карстовым источникам, расположенным фронтально вдоль дна меридианальной долины. Синклинальные поля по занимаемой площади превосходят саму Рицу и находятся на абсолютной высоте 1000 м, тогда как их крутые склоны, высотой в 600 м, образуют замкнутые безводные котловины.

Исключительный интерес представляет карстовое поле в урочище Ширван-Яшта (1.27^2 км). Дно этой замкнутой карстовой котловины находится на абсолютной высоте 1720 м и представляет вторичный луг (летнее пастбище), тогда как склоны поля украшены пихтово-еловым лесом. На дне поля протекает ручей (с дебитом в 50 л/сек), который внезапно поглащается в карстовую пещеру; вход пещеры завален снежником даже в разгаре жаркого лета. Весь поверхностный сток окрестностей поглащается пещерой Ширван-Яшта.

Еще более внушительной выглядит замкнутая котловины Кужба-Яшта. Гигантская эта воронка занимает площадь 6.2^2 км, а относительная высота склонов достигает 600 м. Дно воронки лежит на высоте 1093 м над ур. моря. Все ручьи воронки Кушба-Яшты относятся к числу карстовых. На востоке эта гигантская воронка сливается с широтно-ориентированными польями Джимаку. Эффектному развитию карстовых форм благоприятствует геологическая обстановка, а также большое количество атмосферных осадков (1500 мм/год), поступающих в межгорную рицинскую котловину из Черного моря через мередианальную долину-каньон Юпшары.

Все левобережные подземные притоки Юпшары разгружаются в виде карстовых источников у самого тальвега этой реки. Этому способствует тектоническая структура левобережья Юпшары - широтно ориентированные синклинальные мульды, постепенно погружающиеся на западе. Так, в синклинальной мульде скульптированная гигантская воронка (Кужба-Яшта, а также синклинальные полья Джимаку, поглащают поверхностные воды, а их подземный сток к западу осуществляется посредством погружающихся в этом же направлении осей синклиналей и плоскостями напластования барремских известняков.

Итак, карст вызвал перераспределение стока, он же обусловил безводность всего лесного ландшафта левобережья Юпшары, несмотря на большое количество атмосферных осадков и переувлажненный горный климат.

Обращает внимание тот факт, что с юга Рица не имеет постоянного поверхностного стока. Это результат сильного развития карста. Единственным источником озера служит река Юпшара, вытекающая из южного конца озера, а затем устремляющаяся на глубину 250 м - под хаос обвалившихся известняковых глыб плато Пшегишха. В 1.5 км к югу от озера имеется выход родниковых вод, образующих потом Юпшары длиной 8 км. Юпшара на протяжении 5 км протекает на дне глубокого каньона, ориентированного меридионально. Известняковые склоны высокими стенами (500-550 м высоты) обрываются у тальвега реки. Обращает внимание не только энергия рельефа, но и наличие карстовых феноменов.

Прежде всего интересны подземные "блуждания" Юпшары. Так вырвавшись из каньона, Юпшара внезапно уходит под землей, а затем пройдя около 500 м в подземелье вновь показывается на поверхности в виде мощных карстовых источников, имеющих фронтальное расположение. Дебит этих источников, по измерениям Г.Н. Гигинейшвили, более чем в три раза превышает расход реки Юпшары у ее выхода из озера Рицы. Поэтому надо предполагать, что именно здесь происходит разгрузка всех притоков Юпшары, поглащенных в многочисленных воронках и в объемистых карстовых польях.

Близ истоков реки Юпшары, на обвальном участке, можно обнаружить еще немало источников. Часть этих источников, расположенных у подошвы структурного известнякового плато Пшегишха, представляет разгрузочную фронтальную полосу для подземных речек правобережья Юпшары.

Итак, Юпшара вытекая из озера Рицы питается помимо озерных вод также и подземными притоками, в противном случае было бы трудно объяснить столь значительные различис между расходами воды в ее истоке и устьевой части.

Согласно данным Г.Н. Гигинейшвили теоретический и фактический расходы Юпшары, выше устья этой реки, совпадают. Это говорит в пользу того, что весь сток бассейна Юпшары, включая также бассейны реки Лашипце (северный физико-географический подрайон) и сток самого озера Рицы, после подземного течения полностью выходит на поверхность.

KARST PHENOMENA OF THE INTERMONTANE LAKE BASIN RITZA (THE GREATER CAUCASUS)

K.V. Kavrishvili

SUMMARY

Karst takes up the whole of southern flange of the deep lacustrine Ritza basin. It embraces sculpture plateau of Pshegishkha, the Yupshara canyon and a high-mountain synclinal plateau Rykhva. Here dominates the landscape of humid mountain fir-spruce-beach forests with evergreen colchis undergrowth.

Barrem thick limestones composing synclinal throughs of latitudinal trend plunge at the Yupshara thalweg and by that give way to high-flow karst springs located frontally. These synclinal polje surpass Ritza by the area they occupy (about 7 square kilometres) and are located at the height of 1000 metres whereas their slopes with the height of 600 metres form closed waterless basin. The high--mountain plateau of Rykhva is a major center of water absorption while the highest peak Achibskh (2378) is covered by corries against which endemic subalpian limestone vegetation consisting of Woronowia speciosa Albow is widely spread. The surface karst is well marked here, on other hand one cannot expect here major discoveries of deep karst or horizontal caves (as Sh.I. Kipiani holds it) because during the Pleistocene-Pliocene the plateau experienced an intense steady rise.

A remarkable overdeepening of valleys (the Yupshara and Bzyb canyons) is caused by ascensive movements and by this feature of landscape Crimean, Bulgarian and Slovakian karst cannot compete with that in Ritza's environs. Georgia, however yields to the Dinarides in the scale of karst polje.

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ДРЕВНИЙ КАРСТОВЫЙ РЕЛЬЕФ СИБИРИ И КРУПНЫЕ ЦИКЛЫ ЕГО ОБРАЗОВАНИЯ

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В настоящее время во многих местах как равнинно-платформенных (Сибирская платформа), так и горно-складчатых областей Сибири (Салаир, Алтай, Горная Шория, Кузнецкий Алатау, Восточный и Западный Саян, Тува, Прибайкалье и др.) имеются признаки интенсивного проявления древнего карста. Более того, есть основания предполагать, что карстообразование на Сибирской платформе имело место почти на всех этапах ее развития, начиная с протерозоя. Имеющиеся факты свидетельствуют также, что в отдельные наиболее благоприятные палеогеоморфологические периоды на территории Сибирской платформы существовал типичный сильно расчлененный карстовый рельеф, который, за исключением быть может некоторых южных ее районов, в настоящее время здесь отсутствует.

Для широкого развития карста на территории Сибири в прошлом имелись все необходимые геологические, гидрогеологические, геоморфологические, климатические и тектонические предпосылки. Важнейшими из них являются: 1) широкое распространение мощных толщ карбонатных, часто засоленных и загипсованных пород (известняков, доломитов и др.) разного возраста, начиная с протерозоя; 2) сильная трещиноватость этих пород, обеспечивающая свободную циркуляцию подземных вод; 3) существование обширных высоко поднятых подвижных пластовых плато, сложенных карбонатными породами; 4) преимущественно теплый климат с чередованием влажных и засушливых периодов и 5) высокая общая тектоническая подвижность территории.

Все эти условия обеспечивали в прошлом глубокий эрозионный врез и размыв, что поддерживало соответствующее колебание уровня грунтовых вод и свободный глубокий дренаж, а следовательно, интенсивное выщелачивание карстующихся пород на значительную глубину и их общее глубокое химическое выветривание. При таких условиях должны были интенсивно протекать процессы как поверхностного, так и подземного карста, что в целом приводило к формированию сильно расчлененного карстового рельефа.

Следы и признаки древнего карста широко известны сейчас в разновозрастных карстующихся породах многих районов Сибири. В большой или меньшей степени они свидетельствуют об общей значительной пораженности карстом ее территории. К признакам древнего карста относятся: 1) карстовые отложения или инфлювий; 2) следы воздействия на породы карстовых процессов и 3) коры выветривания.

Наиболее полно следы древнего карста прослеживаются на территории Сибирской платформы, которая в этом отношении является едва-ли не самым наглядным и ярким примером среди других платформ земного шара. В истории ее развития отчетливо выделяются несколько таких главных геоморфологических циклов, когда на ее территории формировались высокие плато, связанные с подвижками отдельных блоков воздымающихся сводов. Вдоль таких приподнятых плато интенсивно развивалась глубоко врезанная речная сеть, а на плоских пенепленизированных водоразделах размыв был незначительным, что благоприятствовало образованию и сохранению здесь мощных кор выветривания. На протяжении этих циклов происходили наиболее важные преобразования рельефа Сибирской платформы. С ними, в частности, связано формирование крупных региональных пенепленов и наиболее мощных кор выветривания. Можно поэтому достаточно уверенно считать, что в это время в пределах Сибирской платформы одновременно были и наиболее благоприятные условия для образования карста, крупные циклы развития которого должны были соответствовать ее основным геоморфологическим циклам. На этом основании важно подчеркнуть, что при прочих равных предпосылках для развития глубокого карста и мощных кор выветривания необходимы одни и те же общие условия. В целом это положение имеет огромное значение при изучении истории рельефа и уже теперь помогает наметить крупные разновозрастные циклы древнего карста Сибирской платформы.

Рассмотрим теперь кратко вопрос об инфлювии и следах воздействия карста на горные породы. Более подробно он анализируется нами, так же как и вопрос о корах выветривания, в других работах (Коржуев). Конечно, вопрос об инфлювии, который отличается большой сложностью строения (Лунгерсгаузен), по существу еще совсем не разработан. Особенно значительные трудности предстоит преодолеть в изучении древнего ископаемого инфлювия, прежде чем будут найдены простые и общедоступные диагностические критерии для его распознавания и выделения. Вместе с тем уже сейчас в ряде случаев древний инфлювий удается выделять вполне надежно в разных по возрасту отложениях. Инфлювий как прямое свидетельство существования карста имеет огромное значение в изучении истории карстового рельефа.

В пределах Сибири и, прежде всего, на территории Сибирской платформы, примеры инфлювия известны в настоящее время в ряде районов. Самыми древними образованиями, которые имеют, вероятно, инфлювиальное происхождение, являются карстовые брекчии и своеобразные пуддинги, связанные с карбонатными отложениями протерозоя, рифея и нижнего палеозоя.

На территории Сибири известны формы докембрийского, палеозойского, мезозойского и кайнозойского карста, которые в пределах Сибирской платформы хорошо увязываются с крупными геоморфологическими циклами развития рельефа и региональными корами выветривания дорифейского, додевонского, допермского, доюрского, домелового и доплиоценового времени, соответственно коротым выделяются шесть крупных одноименных региональных карстовых цикла (мегацикла).

Дорифейский карстовый цикл выделяется на основании редких пока находок древних карстовых брекчий и главным образом широкого развития мощных кор выветривания, формирование которых было связано с крупным и еще почти неизученным сложным геоморфологическим циклом выравнивания рельефа и образования первичного исходного протерозойского пенеплена, названного нами протопенепленом (Коржуев). Более определенно, хотя и невсегда уверенно, выявляются признаки рифейского карста, которые местами удается наблюдать (долина Лены и др.) в виде карстовых брекчий непосредственно в разрезах.

Додевонский карстовый мегацикл изучен крайне слабо. Он состоит из ряда отдельных крупных циклов, которые из-за отсутствия необходимых материалов пока не могут быть выделены. В нижнем палеозое развитие карста протекало в условиях господства низких морских равнин. Уровень грунтовых вод должен был располагаться тогда высоко и карстовый рельеф вряд ли достигал значительного развития, так как при таких условиях могло происходить лишь поверхностное карстование. В полном согласии с этим находятся малая мощность и преимущественно локальное развитие нижнепалеозойских кор выветривания. Все это говорит о том, что на данном отрезке истории развития рельефа Сибирской платформы в основном происходило местное развитие карста, преимущественно поверхностного типа. Надо полагать, что эти карстовые циклы были скорее всего прерывистыми и характеризовались незавершенностью развития.

Исключением, быть может, является средний кембрий, в течение которого карст и коры выветривания формировались достаточно широко и интенсивно (Иркутский амфитеатр, Анабарский массив и др.). Среднекембрийский карстовый цикл соответствовал региональному перерыву в морской седиментации, который предшествовал накоплению верхоленской свиты верхнего кембрия, залегающей несогласно осадкам разных горизонтов среднего и нижнего кембрия. Карст в предверхоленское время прошел полный цикл эволюции; он завершился образованием мощной элювиальной глинистой коры выветривания, которая залегает повсеместно в нижней части осинской пачки верхоленской свиты под водорослевыми доломитами. В пределах Иркутского амфитеатра породы осинской пачки выполняют карстовые формы, развитые в отложениях ангарской свиты нижнего кембрия (Замараев, Коржуев).

Если нижний палеозой был для Сибирской платформы временем преимущественного развития морских трансгрессий, то весь последующий период ее истории прошел большей частью при господстве континентального режима. В среднем и верхнем палеозое и мезокайнозое на ее территории широкое развитие получили мощные региональные коры выветривания и пенеплены. Карстовые процессы достигали своего максимального проявления, определяя широкое развитие сильно расчлененного карстового рельефа.

Самыми показательными в этом отношении являются допермский и доюрский карстовые циклы. С допермским циклом связаны, в частности, карстовые образования верхнепалеозойского инфлювия Хараулахских гор, обнажающегося в правобережном борту в приустьевой части Лены. Древний карст выражен здесь причудливыми сложными формами смятия пермских отложений и глубокого внедрения и проникновения их в резко размытую и неровную кровлю кембрийских известняков, сильно изъеденную карстовыми нишами, колодцами и пещерами, которые выполнены разнообразными допермскими обломочными образованиями инфлювиального комплекса. Подземные карстовые полости, располагающиеся на глубине 5-20 м ниже кровли кембрийских известняков, соединяются с поверхностью допермской суши разветвленными ходами и колодцами, которые завершаются пологими воронками, выполненными базальными порфировыми галечниками и озерно-болотными, углистыми сланцами (Коржуев, Лунгерсгаузен).

Доюрский карстовый цикл наиболее отчетливо прослежен в Иркутском амфитеатре (Вологодский, Коржуев). Доюрский этап характеризовался исключительно расчлененным рельефом, густой речной сетью и глубокими (до 200-250 м) преимущественно крутосклонными долинами. Широко развивался как поверхностный, так и глубинный карст, который по разнообразию и размерам форм намного превосходил современный. Его признаки представлены в толщах осадков погребенными карстовыми воронками и горизонтами брекчиевидных доломитов, которые состоят из беспорядочного нагромождения крупных и мелких неправильных угловатых обломков доломитов, известняков, местами глин, мергелей и доломитовой муки, цементирующих все эти осадки в единую массу. Мощность таких брекчий в южном Приангарье изменяется от 1-2 до 10-15 м. В других районах Сибирской платформы (долина Лены, Олекмы и др.) известны карстовые брекчии мощностью более 30-50 м. Образуются карбонатные брекчии путем выщелачивания и последующего обрушивания кровли пещер и карстовых полостей. В некоторых местах Приангарья обнаружены сотни погребенных воронок, заполненных кремневыми и доломитовыми брекчиями и каолином. Воронки перекрываются юрскими песчаниками; глубина их изменяется от 3-4 до 24 м, а длина от 60 до 200 м. Большая глубина распространения подземного карста доюрского времени, в том числе и горизонтов брекчий, свидетельствует, что базис карстования был тогда значительно ниже современного.

С домеловым карстовым циклом связано образование карста в юрском рельефе, представленного карстовыми воронками, которые имеют различные размеры и широко распространены в Енисейском кряже, где они выполнены каолиновой корой выветривания, а также установлены в последнее время в Вилюйской синеклизе. Древний карст доплиоценового карстового цикла развит в тех же районах, а также в бассейне верхней и средней Лены, на Алданском щите, в бассейне Ангары, Алтае-Саянском горном поясе и Прибайкалье. Отложения этого цикла, представленные каолиновой корой выветривания и красноцветным инфлювием, выполняют карстовые воронки и имеют меловой и палеоген-миоценовый возраст. В отдельных районах (верхняя Лена и др.) некоторые карстовые полости проникают на глубину до 150-200 м относительно поверхности верхненеогенового плато.

В заключение необходимо констатировать, что на территории Сибири и особенно Сибирской платформы древний карст имел широкое развитие и наряду с эрозией был основным агентом денудации. Он прошел сложную эволюцию, которая характеризовалась крупными и большим количеством малых циклами развития, а в некоторых районах в силу наложения молодого карста на древний имеет полигенный характер. В рамках крупных циклов (мегациклов) древний карст развивался в тесной связи с основными геоморфологическими циклами образования пенепленов и региональных кор выветривания, которые, также как и глубокий карст, формировались в специфических условиях высоких платообразных поверхностей, возникающих в процессе сводовых поднятий и дифференцированных блоковых подвижек, что при прочих равных условиях обеспечивало свободный глубокий дренаж и значительную глубину зоны выветривания и карстования.

ANCIENT KARST AND CYCLES OF KARST FORMATION IN THE SIBERIA

S. S. Korzhuev

SUMMARY

The conditions and prerequisites for development of karst on the Siberian platform are discussed; a wide development of typical karst relief during certain epochs is noted; major large megacycles of karst formation are recognised: pre-Riphean, pre-Permian, pre-Jurassic, pre-Cretaceous and pre-Pliocene. The conclusion is reached that cycles of karst formation coincide with the major geomorphological cycles of development of the platform relief, which was formed under conditions of arched uplifts and blocks shifts.

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КАРСТ ЗОНЫ МНОГОЛЕТНЕЙ МЕРЗЛОТЫ И ЕГО ТИПЫ

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Проблема - многолетняя мерзлота и развитие карста - еще недавно не вызывала интереса. Многим исследователям вообще казалось, что такой проблемы нет и быть не может, поскольку мерзлота сковывает развитие карста. Факты же проявления карстовых процессов в зоне многолетней мерзлоты, отмеченные в разные годы многими исследователями, приурочивались к участкам, лишенным многолетнемерзлых пород (талики и др.), т.е. не ставились в связь с самими мерзлыми толщами карстующихся пород. Естественно, что эти первые сведения были разрозненными и отрывочными и не давали сколько-нибудь полной картины развития здесь карста. Специально же эта проблема до сих пор никем не изучалась. Однако геоморфологическими и геологическими исследованиями последних лет, проведенными в зоне многолетней мерзлоты, наличие карста было установлено повсеместно во всех районах, где имеются карстующиеся породы, хотя развивается он в разных местах по-разному и с различной интенсивностью.

В настоящее время накоплено много фактов, свидетельствующих о широком проявлении карстовых процессов непосредственно во всей толще самих мерзлых карстующихся пород (Коржуев и Николаев, Басков, Корнутова, Коржуев, Долгушин, Пармузин, Соколов, Мирошников, Горбацкий, Луговой). Эти факты дают основание считать, что в растворимых карстующихся породах мерзлота лишь замедляет карстообразование, а не исключает его. Все это в корне меняет наши прежние представления о степени и характере закарстованности территории, скованной многолетней мерзлотой, и, следовательно, проблема - карст и многолетняя мерзлота - получает новое звучание как в научном, так и прикладном отношении.

Накапливающийся материал уже сейчас позволяет считать, что карст, приуроченный к зоне распространения многолетнемерзлых пород, по характеру своего развития значительно отличается от карста остальных областей. Чтобы подчеркнуть его специфику, мы назвали его мерзлотным карстом (Коржуев и Николаев, Коржуев). В настоящее время он выделяется в самостоятельный географический тип карста в СССР (Гвоздецкий). Своеобразие мерзлотного карста, резко отличающегося от карста других зон, заключается в том, что он развивается в многолетнемерзлых породах при отрицательном температурном режиме. Климат зоны многолетней мерзлоты резко континентальный, с отрицательной годовой температурой, с низкими зимними минимумами (-40-60°), продолжительным холодным и коротким теплым периодами. Незначительное количество зимних осадков при продолжительных низких температурах способствует глубокому сковыванию почво-грунтов и промерзанию до дна многих рек.

Мощность многолетней мерзлоты колеблется от 50-200 м в южных и юго-западных районах до 300-700 м - в северных. В течение короткого летнего периода многолетняя мерзлота успевает оттаять неглубоко, в среднем до 1-1,5 м. В разных частях зоны многолетней мерзлоты глубина деятельного слоя варьирует от 0,10-0,20 до 3-10 м.

Даже эти краткие сведения показывают, что климатические и мерзлотные условия не благоприятствуют развитию карста вообще, и, в частности, развитию современного поверхностного карста, хотя с другой стороны, мерзлота концентрирует сток, а низкие температуры повышают растворимость карбонатных пород, т.е. способствуют образованию карста.

В то же время геологические условия зоны многолетней мерзлоты, характеризующейся широким развитием сильно трещиноватых карбонатных карстующихся пород, весьма благоприятны для возникновения карста. Сочетание комплекса этих условий и определяет особенности и специфику развития карста в зоне многолетней мерзлоты. На огромной ее территории выделяется карст равнинно-платформенных и горно-складчатых областей, с преобладанием в первом случае подземных, а во-втором - поверхностных его форм. Среди горно-складчатых областей, охваченных многолетней мерзлотой, карст широко развит на Алтае, Горной Шории, в Западном и Восточном Саяне, Туве, Прибайкалье, Забайкалье, Джугджуре и Северо-Востоке СССР. Он развивается здесь преимущественно в известняках, мраморах и доломитах, слагающих древние свиты протерозоя и нижнего палеозоя.

Основную часть равнинно-платформенных карстовых областей занимают пластовые плато Средней Сибири и Якутки. Слагающие плато преимущественно нижнепалеозойские породы представлены в основном известняками, доломитами, мергелями и их разновидностями (известковистые доломиты, доломитизированные известняки и др.). Все эти породы часто сильно засолены и загипсованы. Наиболее распространены известняки, доломиты и мергели нижнего кембрия (алданский и ленский ярусы), а также среднего кембрия (майский и амгинский ярусы), ордовика и силура. Среди этих пород наибольшую площадь занимают известняки, имеющие, как правило, плотную структуру и значительные примеси песка и глины. Чистые разности известняков встречаются редко. Общая мощность карстующихся пород нижнепалеозойской осадочной толщи не превышает 1000-2000 м.

Породы эти характеризуются преимущественно почти горизонтальным или слабоволнистым залеганием с чрезвычайно пологим падением слоев. Для них, особенно известняков, весьма характерна диагональная система трещин северо-западного и северо-восточного направлений, а также ортогональная система широтных и меридиональных трещин.

Трещины образуют сложную перекрещивающуюся систему, играющую важную роль в развитии карста в многолетнемерзлых толщах пород. По ним находят себе путь надмерзлотные, межмерзлотные и подмерзлотные воды. Районы самой интенсивной трещиноватости, являющиеся обычно областями питания и разгрузки подземных вод, характеризуются наибольшей закарстованностью. Это характерно как для равнинно-платформенных, так и для горно-складчатых областей.

Все это указывает, что в мерзлых карстующихся породах имеются свободно циркулирующие трещинно-карстовые воды, расположенные на разных глубинах. Эти воды на территории Средней Сибири и Якутии (Сибирская платформа) обычно засолены и имеют повышенную минерализацию. Минерализованные источники в большом количестве встречаются в долинах многих рек, протекающих в зоне многолетней мерзлоты (Лена, Алдан, Амга, Оленек, Олекма, Котуй, Мойеро и др.). Кроме того, буровыми скважинами во многих местах (в долине Лены, Амги, Вилюя и др.) были вскрыты сильно минерализованные и соленые межмерзлотные и подмерзлотные воды и рассолы. Естественно, что все это должно быть связано с глубинными процессами выщелачивания известняков, гипсов и каменной соли, наличие которых доказано на широкой площади.

Вообще растворение и выщелачивание карбонатных пород в зоне многолетней мерзлоты происходит довольно интенсивно и почти повсеместно, причем величина химической денудации достигает значительных размеров. На это указывают повышенная минерализация вод деятельного слоя, сильная засоленность грунтовых вод и высокий ионный сток поверхностных и подземных вод. В течение года Лена, например, выносит в море свыше 55 млн. тонн растворенных веществ.

Таким образом, присутствие в мерзлой толще карстующихся пород надмерзлотных, а также минерализованных и засоленных межмерзлотных и подмерзлотных агрессивных вод во многом определяет специфические особенности развития карста в зоне сплошной мерзлоты. В пределах ее карст распространен крайне неравномерно, что объясняется как строением и характером самих карстующихся пород, так и существенным изменением мерзлотных и гидроклиматических условий в широтном направлении. В зависимости от этого зона сплошного распространения многолетней мерзлоты подразделяется на южную, среднюю и северную, а в зависимости от характера карстующихся пород на ее территории выделяются три основных типа карста: карбонатный, соляной и гипсовый, причем карбонатный карст развит наиболее широко.

В южной полосе развитие карста идет наиболее интенсивно, чему способствуют более благоприятные мерзлотные, гидроклиматические и гидрогеологические условия. Карст известен здесь на огромной территории бассейнов Лены, Алдана, Амги, Олекмы, Витима, Енисея, Ангары, Подкаменной Тунгуски, районов Приангарья и Енисейского кряжа. Карстующимися являются в основном кембрийские, а также ордовичские и силурийские известняково-доломитовые породы, содержащие часто соль и гипс. Одинаково хорошо выражены все три основных типа карста, представленных разнообразными формами как поверхностного, так и глубинного карста.

В средней полосе карст развит не так широко и менее разнообразно. Основные карстовые очаги приурочены здесь к водоразделам Вилюя с Нижней Тунгуской и Оленеком, а также к северным районам Подкаменной Тунгуски и Енисейского кряжа, где встречается карбонатный карст в известняково-доломитовых породах протерозоя и нижнего палеозоя. Кроме того, по Вилюю и его притокам (Мархе, Маркоке, Ыгетте и др.) в загипсованных отложениях нижнего палеозоя известен гипсовый карст, а в районе Кемпендяйских соляных структур широко развит соляной карст, связанный с отложениями верхнего и среднего палеозоя, содержащими соль, ангидрит и гипс. Гипсовый и соляной карст развивается здесь наиболее интенсивно, образуя специфические формы.

Северная полоса наименее благоприятна для развития карста вообще, а поверхностного в особенности, главным образом в связи с более суровой мерзлотой, а также общим ухудшением гидроклиматических и гидрогеологических условий. На огромной территории бассейна Оленека и прилегающих частей бассейнов Вилюя, Лены (Муна, Машарчина и др.), Анабара, Хатанги (Мойеро, Котуй и др.), а также в приенисейских районах (Норильское плато, западные предгорья плато Путорана и Сывермы и др.), сложенные в общем аналогичными карбонатными породами нижнего палеозоя, карст развит слабо. В северной полосе карст известен также в гипсоносных отложениях девона и карбона (бассейны рек Фокиной и Убойной, район Норильска, р. Имангда, плато Сыверма - гипсово-ангидритовое Мантуровское месторождение и др.) и соленосных отложениях и гипсах среднего и верхнего палеозоя на п-ове Юрунг-Тумус в Хатангском заливе. Из трех основных типов карста, известных на севере, интенсивнее всего развивается гипсовый и соляной карст.

Современный карст в зоне многолетней мерзлоты развивается своеобразно и сложно, он резко дифференцирован и делится на поверхностный и подземный (глубинный) карст. Современный поверхностный карст тесно связан с поверхностными надмерзлотными водами песчаных массивов террас и водами деятельного слоя. Мы называем его н а д м е р з л о т н ы м карстом. Он широко представлен воронками, блюдцами, ваннами, суходолами и другими формами покрытого и голого карста. Наиболее широко развиты формы покрытого карста, голый карст встречается реже, чем карст покрытый. Интересной разновидностью покрытого карста является отраженный карст в песках (Коржуев, 1959, 1961), перекрывающих террасы (Лены, Олекмы, Амги, Чары и др.), цоколь которых сложен трещиноватыми карстующимися карбонатными породами нижнего палеозоя. Характерной чертой надмерзлотного карста является также широкое развитие русловых и склоновых форм карста. Часто наблюдаются и рвы скалывания (отседания) склонов, сопровождающиеся примечательными цепочками активно развивающихся карстовых воронок (долины Лены, Алдана, Амги и др.).

Подземный карст занимает обширные площади водоразделов, и в отличие от поверхностного карста, меньше подвержен влиянию мерзлоты и колебаниям климата, поэтому развивается он свободно, круглогодично, почти не связан с широтной географической зональностью. Наличием подземного карста в ряде мест объясняется отсутствие заболоченности, что наблюдается в закарстованных районах, дренируемых карстовыми источниками (бассейны рек Мойеро и Вилюя, верховье р. Моркоки, западные районы плато Сыверма и др.).

Подземный карст связан с агрессивными глубинными минерализованными и засоленными межмерзлотными и подмерзлотными водами. Исходя из этого, мы предлагаем, наряду с поверхностным надмерзлотным карстом, выделять для районов со сплошным распространением многолетней мерзлоты подземный м е ж м е р з л о т н ы й и п о д м е р з л о т н ы й карст.

Таким образом, по нашим представлениям, вся толща мерзлых карстующихся пород подвержена карстовым процессам, причем протекают они в разных районах и на различных глубинах с различной интенсивностью и отличаются рядом еще не изученных специфических особенностей.

PERMAFROST KARST AND ITS TYPES

S. S. Korzhuev

SUMMARY

The problem of karst and permafrost has not been at all discussed in science until recently because of the widely spread opinion that karst cannot develop in frozen rocks. Latest discoveries have revealed karst in all permafrost places having karsting rocks. The accumulated facts festify to the existence of karst processes widely spreading in the entire territory of frozen rocks but not only in the sections free of permafrost (taliks and others).

These facts made it possible to conclude that permafrost in soluble karsting rocks can only retard the karst formation but does not exclude it. Three principal types of karst are distinguished depending upon the nature of underground waters: 1) above= permafrost, 2) inter-permafrost and 3) under-permafrost. The first type of karst is connected with the surface above-permafrost waters of sand masses and those of the active stratum. The two others are respectively related to the aggressive deep mineralized waters. The principal lithological types of karst are as follows: 1) carbonate, 2) saline, 3) gypsiferous.

Ba 025

KOTLIČ - A SPECIFIC DEPRESSION FORM OF SUBNIVAL ALPINE KARST

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In Yugoslav geographical literature the landform called "kotlič" (plural form: "kotliči", in transliteration: cotleech, cotleechy; pronounced with stress on the second syllable), a landform typical of alpine, glaciokarstic or subnival landscape, is first mentioned as early as in 1935 by A. Melik. Intensive research since the second War has established the existence of kotliči in nearly all parts of Southern limestone Alps in Slovenia as well as in some areas of the lower forested karst plateaus in the Dinaric Mountains.

While in Yugoslav- and particularly in Slovene-geography kotliči are recognized to be a specific alpine karst landform, in non-Yugoslav literature on glaciokarst kotliči are not individualized as a specific landform for which reason the phenomenon is treated by different authors under different names and not seldom in a rather confused way. From personal communication with H. Trimmel (1971) we found that in German the phenomenon of kotliči is called most often "Schachtdoline". In fact it is already O. Lehmann (1927, 215) who mentions depressions of a very similar kind to be found in Tote Gebirge. He also writes about Karrendolinen but it is not clear which of the landform he mentions might represent kotlič. Machatschek (1934, 84) mentions cylindrical depressions called "Schlott", along with Karrenbrunnen and Karrendolinen. Another author, Bauer (1954, 57-58), writes about Steinkisten as a specific kind of doline strongly dependant on the jointing of the rock. Cvijić (1960, 97) notes a special kind of doline - "Les dolines en fenetre". Zwittkovits (1966, 81) shows a typical profile of kotlič, the so-called Kesseldoline, but gives no explanation of the phenomenon. Haserodt (1965, 72) mentions Steilwanddolinen but describes them in terms not fully applicable to the phenomenon of kotliči. Identical landforms from Picos de Europa in the North of Spain are called by Miotke (1968, 51) "Karsteinbrüche" and explained as collapsed doline.

In view of the differences in the understanding and treatment of the landform "kotlič", it is the purpose of the present paper:

1) to elucidate and individualize the phenomenon of kotliči as a typical glaciokarstic landform determined by the subnival climate;
2) to discuss the distribution of kotliči;
3) to analyze the morphological complex of kotliči; and
4) to clarify the relation between kotlič and doline respectively between kotlič and pothole.

I

Literally translated from Slovene, the term "kotlič" means a small kettle. This term has already been used by Sweeting (1972) in his textbook on karst, while the landform itself being shown to the participants of an excursion into the Julian Alps arranged before the IV. International speleological congress in 1965. We have seen many of them also in Dachstein Mountains in the time of the International terminological conference on karst in Obertraun, Austria, 1971.

Technically, the kotlič is a depression in a compact and bare limestone surface. Generally, its vertical dimension equals that of its horizontal one; normally the walls are very steep or almost vertical, while kotliči of a more shallow kind have only smaller part of the slope that is completely vertical. The bottom of the kotlič often resembles that of a shallow dolina in case that it is filled with scree. Under ideal circumstances this means that on flat surfaces with horizontal strata we might expect regular developments of this landform. Under such conditions, again the shape of the upper edge should normally be rounded-off or square, while the shape of the depression itself is funnel-like. Ideally the relation between the diameter of the upper edge and the depth might be 1:1. As it happens, some forty instances of kotliči on the mountains of Kanin have a relation between the two dimensions expressible by the index 1,2, or the average diameter being 7.1 m and the average depth 5.9 m.

So far the process of the development of kotliči has not been studied in great detail; on the other hand, it is clear that the conditions in the depressions, especially under the circumstances of persisting snow, are nival-like. Miotke (1968, 56) clearly shows how the process of mechanical disintegration is important for the development of kotliči - because of the big diurnal changes in summer temperature, which is not rarely bellow the freezing point. On the other hand, we cannot agree with Miotke that kotliči or Karsteinbrüche should be on the whole results of collapses above underground water channels. Even if such examples are theoretically feasible, practically they are extremelly rare. In our view, kotliči are depressions resulting from conditions of a localy more marked microclimate and from locally accelerated mechanical disintegration as well as solution. The initial reason for their development represent small initial depressions in the rock through fissures, enlarged karren, which in winter has permitted relatively higher accumulation of snow. Within the entire process the solution of the rock functions as removing the scree from the bottom, respectively the solid rock- in a faster or slower way, depending on the thickness and the duration of the snow bung. Accordingly, all in all the kotlič is to be seen as a result of combined action of mechanical disintegration and chemical solution.

II

Kotliči are most commonly found either in relatively flat regions or in less inclined surfaces of old, flattened relief. Very often they are located on flat or little inclined pavements. The number of kotliči regularly increases with the decline of the slope, and vice versa. Another aspect is their vertical distribution. Since kotliči are karst landforms typical of barren, alpine glaciokarst of the subnival vertical zone, their lowest location is to be expected in the region of the upper forest line and litle lower. Such a distribution corresponds to the present-day conditions which are very likely also similar to those in the interglacials. In the Julian Alps kotliči are first found at the altitude of 1500 m, even if a few of them might be found at a somewhat lower altitude. Local conditions caused that the kotliči begin to appeare also much higher in some regions. Habič (1968, 155) mentions that in the high dinaric karst of Trnovski Gozd to the west of Slovenia there are at the altitude from 800 to 1200 m certain "transitional" kotliči, containing elements of the dolina landforms. Haserodt reports the beginning of Steilwanddolinen in Hagengebirge, the region under his study, to begin already at the altitude of 1400 m. In lower regions which were not glaciated, e.g. in Trnovski gozd, it is possible that kotliči are preserved as morphological remains from a period of prevalence of nival or subnival climate during glacial periods. As we shall see below, in glaciated areas and under special conditions we may get also kotliči from before the last glacial or prewürmien age. Also, there are certain indications that some kotlič-like phenomena can be found in altitudes below 1000 m; indicative of this is also information given by Cvijić. However, the circumstances under which such phenomena can develope will require further research.

Above the upper forest line and under the conditions of flat surfaces, the number and density of kotliči increase rapidly. In the Kanin mountains the greatest density is to be found at the altitude of only 185 om. On one hectare there are 21 kotliči. This is certainly an exception due to a very favourite conditions. The average density is much smaller, not bigger than 10 kotliči on one hectare, or even less (Kunaver, 1972, 321). There is no even distribution of kotliči at any particular height. Not only flat surfaces but especially the changes between flat and inclined surfaces favour their concentration, generally on flat steps at the foot of short slopes. Often these are places of collection of snow and in any case places of gathe ring the melting and rain water. On such slopes there is typical distribution of the karst landforms, namely from the Rinnenkarren to the Kluftkarren and the Trümmerkarren. Lastly where surface begin to be flat, especially on the outer side, the kotliči and potholes are numerous. Also this kind of concentration of kotliči is the expression of one kind of accelerated solution. Kotliči are very common appearance also on the lowest side of inclined pavements, which are natural collectors of water. Their frequency is much bigger in conditions, when the dip of the strata, or respectively of the pavements, is bigger than the inclination of the surface. The locations of kotliči are then at the foot of the pavement respectively of the head of the strata.

In the Julian Alps kotliči are a frequent appearance up to 2400 m; there are namely no higher flattend surfaces. In this zone and already a little lower snow is lasting very long, in the depressions mostly all the summer and not rarely all the year. Already a very efficient mechanical disintegration causes that the average kotlič gets a more shallow and wider profile. It could be expressed with an index of 1.4. In these conditions kotliči are much more influenced by the surroundings where additional scree is pouring down with help of snow and from local slopes. Therefore some depressions got already the transitional forms between kotliči and doline. The initial depressions are often more similar to rocky doline than to kotlič with vertical walls. Following the tendency of climatic deterioration it is normal to expect the diminishing of visible karst phenomena as well as of kotliči.

III

The relation between the dimension and the shape depends on the nature of the limestone and on the oroclimatic position in the vertical profile. First, the existence of the kotliči looks to be very much dependant on the thickness of the strata. In Julian Alps there is a predominance of the thick bedded upper triasic limestones of noric and rhetic age, known as a dachstein limestone, which normally carries the kotliči. On the other hand less frequent are they in non stratified limestones and particularly in thinly bedded limestones, where they are substituted with transitional forms or even with dolines. The tight dependance between kotliči and thickly bedded limestone seems to be one of the most important significance.

Interesting are also the influences of the dolomitisation of the rock. The admixture of the dolomite in the limestone causes easier mechanical disintegration in all vertical zones. In slightly dolomitic limestones the mechanical disintegration is more uniform and therefore also the shape is more regular, often of rounded and oval form. Another effect of such conditions is a shallownees of the depression resulting from a faster mechanical disintegration of the rock. Such kotliči are normally wider and less steep than kotliči in pure limestone. Similar efects on the shape and dimensions are caused by the strongly fractured rock.

Many influences could make the upper edge often of rectangular or square shape. The dependance on joints looks very important for the developing of kotliči, even if this influence is not always clearly visible. In more than half examples kotliči are located in places of visible joints or on crossings of the joints. Especially the last are often their locations. Closest dependance on the joints, especially on the master joints makes the groundplan most often elongated in the shape of elongated elypse or in the shape of a rectangle. There are not rare cases of a rows of kotliči, located on master joints.

Another factors which could influence the shape of the groundplan are the dip of the strata and the inclination of the surface. Where the kotliči are situated on inclined pavements the groundplans are most often elongated and the profiles are irregular. Extreme examples of irregularity are on the slopes with conformly situated strata. While the upper slope of kotlič is often the continuation of the inclined pavement in the form of structural steps lowering toward the bottom, the other, lower side is completely vertical and most often a projecting wall. In the groundplan of such kotliči, particularly if they are bigger and older, one can observe the convexe shape of the edge on lower side. This is the result of an accentuated disintegrational process, especially of the solution, on lower side of the kotliči which is logical because of gravitational influence on snow bung and because of exposition.

On the whole it exist much greater variability in dimensions and in the shapes in the same region of kotliči than of doline of lower karst.

IV

We are faced with the apparent problem of whether kotliči are a sort of doline or not, namely not only in morphological but also in morphogenetic meaning. Although this is not so important problem as to necessitate heated arguments we think that there are not many common elements which should join the two landforms. Kotliči are smaller in dimensions, have different shape of the profile and of the opening, they develope in regions with the absence of the soil cover, have been interrupted in the development by the glaciations and so on. Therefore it seems that this landform should be called with an indipendant name in the international karst terminology, which should avoid further misunderstandings and misleadings. The name "kotlič" has already been used in this way (Sweeting, 1972).

The second question is how to differentiate between an entrance to the pothole and kotlič? The bungs of snow very often prevent to see how is the nature of the bottom, particularly in midsummer. The deepest and also the biggest kotliči contain the snow also in autumn and sometimes all the year. With help of a great number of typical kotliči, which are free of snow early enough and in drier years one can see, that normally the bottoms are filled with scree or they are even in compact rock, half burried bellow stones. The potholes, on the other hand, begin very often with a narrower opening. Another type of potholes can also begin with openings which completely resemble the kotlič. A good example is the entrance to the Abisso Boegan on the italian side of the mountains of Kanin. In such cases the continuation of the pothole is normally much narrower than the entrance itself and it is located on one side of the bottom. We suppose that also the enlarged entrances to the potholes are results of the same process which causes the development of kotliči. In that case we have to deal with a combined landform. Very probably there exist a pretty great number of kotliči which are the enlarged potholes or at least enlarged fissures where the scree prevents to see what is the bottom in fact like. Nevertheless, every enlarged vertical depression with nearly equal dimensions of the width and the depth could be proclaimed as a kotlič except in the cases when the depth distinctly exceeds the diameter.

For further work it remains more detailed study of the nature of the bottom of all kotliči not regarding whether they are filled with snow or not.

There were not taken into account in the statistical treatment the biggest examples of the kotliči. They exceed in ~~diameter~~ ten meters and can reach up to 50 meters and more. In that cases the depths normally stay very much behind. This kotliči in any case express higher age than the smaller ones, not regarding whether they are filled with morenic material or not. Also the age of the smaller ones which are half or completely filled with this material and not rarely also eroded, is undisputable. On the other hand, of undoubtedly holocene age are smaller and initial kotliči which are to be found also on glacialy eroded surfaces. But we think that not all kotliči of the average dimensions are of the same age, it is of holocene or prelast glacial age. The reason for such supposition are the differences in the dynamics of their development which is due to changing conditions from place to place. We hope that this will be proved also with a concrete measurements in future.

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+The references will be completed before the paper will be read in section.

Ba 026

THE GEOMORPHOLOGICAL DEVELOPMENT OF THE NORTHERN PART OF THE SLOVAK KARST DEPENDENT ON THE TECTONIC STRUCTURE

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There exists a theoretically direct dependence in the relations between the geological and speleological levels of the karst exploration. Exactly said there should exist. In the case of systematic speleological research of the karst area there's nothing unusual if we meet - at a certain stage of the speleological exploration practice - an insufficient geological elaboration. The speleological research must become stagnant then, or contingent dependent on a hazard.

I have met this problem in my several years'lasting exploring work in the most extensive karst area of Czechoslovakia, in the Slovak karst.

The localities of this area - explored in detail - are either suitable as to the deposit view or paleontologically and stratigraphically important. The rest of the area has been explored quite unsufficiently.

In my review I allow to place before you esteemed collegues I have chosen the substantial informations arising out of a detail geological research of Slovak Karst's Northern part (it's the area from Drnava--Lúčka to Jablonov) on contact of the Mezozoik Groups of the south-gemeric unit with Spish-Gemer Paleozoic Group.

I am avoiding intentionally the results of the petrographic-lithological research of the coexisting carbonates rocks for the stand point of the karst microforms' genesis, and better concentrating on the tectonic structure research and on the differences of the basic structural units and tectonic elements. I apply the results to the geomorfological development of the area and refer to making full use of it for the next speleological research (not only in the proper research study, but for the karst areas in general).

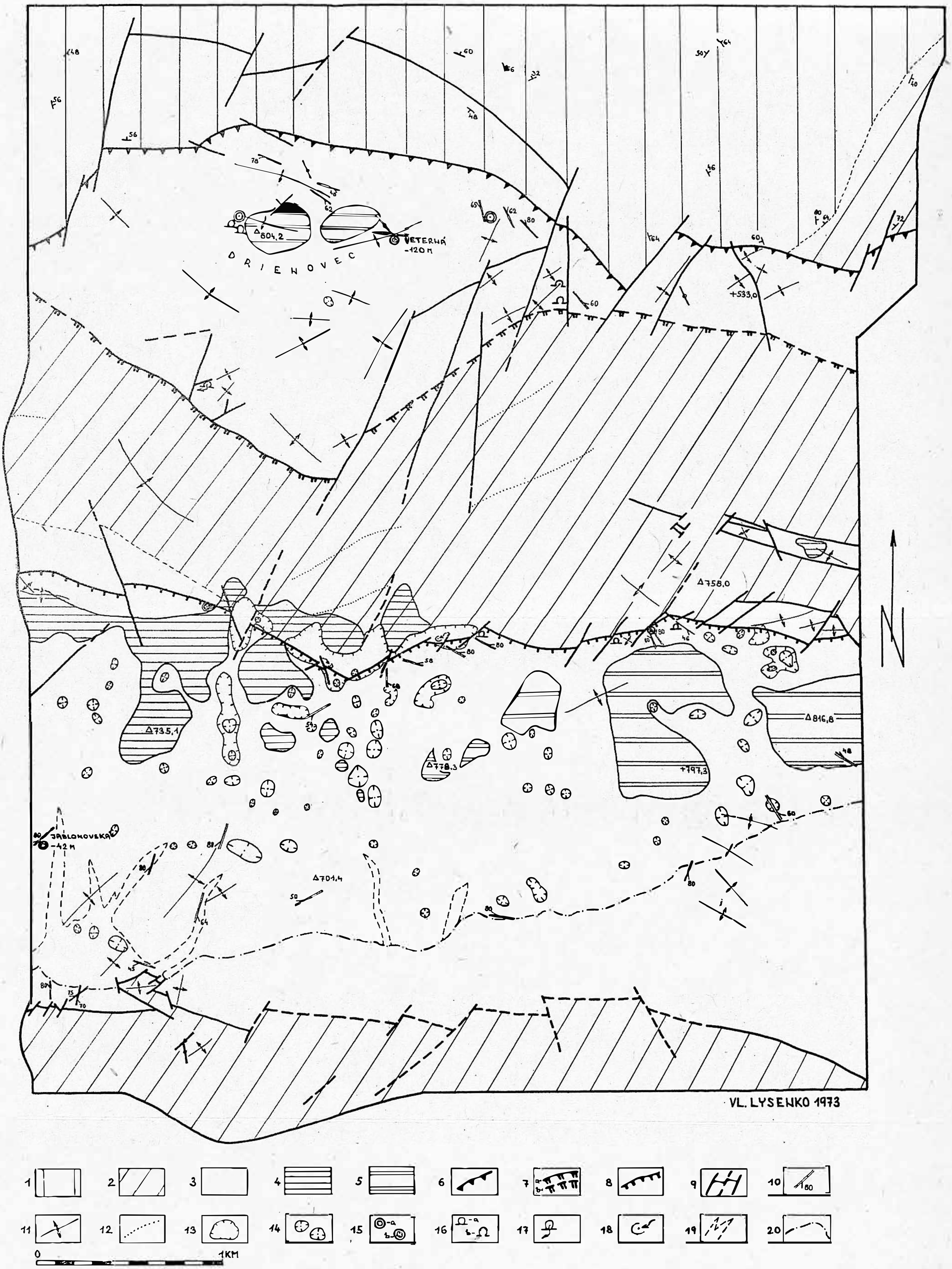
The Slovak Karst - as the most extending area of the Czechoslovak West Carpathians - forms a very complicated synclinore - the south-gemerid mezozoic tectonic unit. It's in the tectonic contact with the

Spiš-gemers Paleozoic Area (the so-called Rožňava line) in the North; continuing in the main to the South till the Ore-mining mountain chain in Northern Hungary. The conceptions on the Slovak Karst structure are different and according to the absence of the stratigraphical superfaces and to the unrealized total structural tectonic research even controversial till nowadays.

The researched area belongs mostly to the Silice-Turňa tectonic unit (the central and southern parts) and to the Hačava-Jasov unit (Drienovec and the area in the eastern line till Lúčka). There is the tectonic contact here between these both units, as well as between the Hačava-Jasov unit and Spiš-gemer Paleozoical Zone in the North. The rocks are represented here by 53 lithologic different types in the whole from the basal Triassic till the Jurassic Period.

In the studied area with a rather complicated structure I have determinated five partial structural units with both different and common structural characters separated by longitudinal fault lines and fault zones, I have dissected the subsidiary folded structures with the shear surface system and four main block faultings with one cross fault line. On the whole all the territory appears as a bilateral system with the former vergency to the North, the latter one to the North-East and North-West in the Northern part and to the South-East and SouthWest in the southern part. The originally one directional deformation proceeded in splitting into two lines with the majority of the North-West vergent deformations. In the former neoid movement phases the total throw dominated the tangential one. The structures rosen in this way penetrate one another and it´s impossible to separate them sharply. In the tectonic development of the are the deformation processes have be evidentally phased out, but there exist many interstages obliterating the phases´ limits. The particular deformations don´t appear suddenly, but they strengthen stage by stage the coming phase while the preceding one slowly disappears. The structures very often deflect; it´s seen in the radial systems´ formation of b-axes by the disjunctive deformation of the lower triassic series of strata and dislocations systems by the deformation of the carbonates median and surface Triassic event. Jurassic complexus. The situation is complicated even by the absence of the higher Mezozoik Era and Tertiary Period members.

The main anticlinal and synclinal structures with several folded amplitudes of East-Western direction as well as the longitudinal faults with reverse faults´ character have originated-according to my



Enclosure 1. Sketch to Show the Morfo-tectonic Structure of the Horný Hill among Drnava, Lúčka and Jablonov.

Explanations:

1) Paleozoic of the Spiš-Gemerides; 2) Lower Triassic; 3) Middle and Upper Triassic; 4) Remants of Surface of Planation (710-750 metres); 5) Remants of Surface of Planation (over 775 m); 6) Thrust Line (Mezozoic over the Paleozoic); 7) Thrust Line (Lower Triassic over the Upper Triassic): a - established, b - estimated; 8) Thrust Line; 9) Transverse Faults; 10) Expressive Faults; 11) Axis Line of Anticlines; 12) Axis Line of Flexures; 13) Sink-Hole Depression; 14) Sink-Holes; 15) a - Chasm, b - Collapsed Sinkhole; 16) Caves: a - entrance on the hill-side, b - entrance on the valley floor; 17) Spring Cave; 18) Ponors; 19) Old Erosion Furrows; 20) Margin of the Plateau.

opinion - in Cretaceous Period (Pre-senon Period). It must have happened including the origin of the longitudinal fault zones in tectonic labile ones on the limit of the competent and uncompetent series of strata in the partly squeezed main folded structures´ limbs. Even the origin of the Čremošná fault zone (the northern territorial bounds) and the successively sunken block Drienovec can be situated here.

The subsidiary fold, the appearance of chevron fold structures, the reverse faults with the North-Western and North-eastern vergency (of the Northern part), and the South-eastern and South-western vergency (of the southern part), as well as the appearance of the shear surface systems can have their origins in Laramide phase (Preeocen).

The proper dividing of the longitudinal fault zones and the appearance of the block tectonics with the transverse faults mostly of the North Western-Soust Eastern direction, accompanied by the normal faults and thrust faults, can be temporally classified to the Eocene-Oligocene Epoch. To the same time there can be classified the deflecting of some structures and faults of East-Western direction till the North-Western South-Western direction and shifting of the Horný Hill´s Eastern Block of the researched area towards the North with the contemporary appearance of the transversal fault zone in the North-Eastern South-Western direction.

The subsidiary block normal and thrust appeared also in Miocene Epoch. In the period of Slovak Karst Mesozoic uparching at the end of Tertiary Period (in Pliocene Epoch) there have appeared - especially in the edge zones some rejuvenating faults including local block tectonics of the homogenously developped automorphal horsts character. Finally in the opening Slovak Karst normal fault phases - evident in the crushed rock cirque valley head - there has been dying away the upheaval of the territorial part of the block Drienovec which is relatively higher regarding to the other area of the Hill Horný (analogically the eastern block of the Hill Horný to the western block).

The regularity and character of the regional tectonic structure seems to be a tectonic element´s copy to the field sculpturing. As the question is in the main the complex of carbonates, there is the inception of the surface and underground karst dependent upon the tectonics.

From this point of view there is the morphology of the independent block at Drienovec evoking a great interest. It´s formed by the upper

Triassic and Jurassic rocks with the younger Paleozoic. The double lined overthrust of the basal Triassic to the complex of Drienovec accompanied by the overthrust of the upper Triassic of Drienovec to the Spiš-gemer Paleozoic group was the cause of the compression and deformation especially of the South Western and South Eastern slopes of the block. The following pushing down of Drienovec as the individual tectonic block occured along the fault-zone Čremošná in the North and along the overthrust line in the South. After the block´s emergence there came the successive denudation - that´s true - but the proper character of the double-lined overthrust block remained saved and is perfectly morphologically evident. The South-eastern and South-western slopes are steeply diverted denudation fault slopes. The highest situated flatlying caverns (730 m, 750 m and 775 m over the sea level) can be considered as the evidence of the old denudation level connected with the period of the successive amplification of the epeiro-genetical movements - the thrust and sinking of the anticline zones. At the same time there have run the plateau stream (lakes) to the edge zones, existing as the fault zone at the Hill Horný. The flatlying caverns´ level can be compared with the analogical level of the caverns at the Northern edges of the Plešivec plain (the altitude being from 730 to 740 metres).

The thrust of the Drienovec block and the Western Horný Hill´s block pre-disposes the appearance of a large depression in the South--Western part of the Hill Horný´s area, successively drained to the North-Western part of the catchment area Turňa.

The appearance of the hanging erosion furrows on the southern edge of the plain (the short plain valleys) a little later in the western part, depends on the deep incised hollow Turňa. To this period (Middle Plioccene Epoch) characterised by the intense reduce of the erosion basis I include even the appearance of the sink lines in common with the submersion of the surface streams in the area of Horná Lipa - Mútná Studňa. The Mútná Studňa area has at the same time the character of the sink depressions on the border of the campil and middle Triassic. The depression was originating in the intersection longitudinal fault zone of the northern limb of the Hill Horný´s syncline and the transversal fault zone. It continues to the South (into the carbon complex of the middle Triassic area) with the sink lines in the direction to the North Northwest and South Southeast. The systems of the hyponomic hollows - having the function of the gulp in the time of the showers or spring melting - are typical for this depression. They are based on the dislocations directed from the North-West to the South-East and from the East to the West, draining the Northern part of the plain to the South.

From the other karst phenomena there are worth of mention the bogazy, erosion furrows and chasmes, precipice depressions, always genetically bound with the dislocations or the above mentioned fault lines, zones.

On the basis of this area researches I tried to exemplify the mutual dependence of the tectonics, the tectonic structure of the karst area and the genesis of the fundamental morphological forms of the karst phenomena. But this mutual relation isn´t the only matter. The detailed knowledge of the tectonic structure enables us to solve the genetic questions of the whole karst area more perfectly, enables us at the same time to determine the promising places for the speleological research, to identify the way of the surface research by bringing the tectonic elements to the topographical bases. In this way we discovered and uncovered several chasmes in the southern part of the Plešivec plain in 1968 (it´s near the Diviačia chasm), in this way I have located several caverns and a smaller chasm in the researched area.

On the top of it the detail tectonic study enables us to make even the character of the vertical karstification accurate. The subsidiary fold structions of the chevron fold type, inverted or eventually isoclinal, are for instance typical for the researched area. By means of the further deformations in the disjointed character there arise the fold reverse faults from these chevron folds, sporadically there occurs only the break of the fold structure in the fold nucleus.

The breaks in the fold nucleus are regularly opening to the depth and giving so a good precondition to the following karstification. The typical representative of the karstificated dislocation of that type is the Veterná chasm, 120 m deep, on the South-eastern slope of the Drienovec tectonical block.

I know I have only touched the whole problem in this brief account of mine. In spite of that I think it´s possible to hold the results of the detail tectonic research of the karst area for the first-rate matter within the framework of the systematical speleological research´s practising.

Without a perfect conception of the area´s tectonic structure there is the speleological research quite casual and the percentual success of the underground karst phenomena´s researches is essentially brought down in this way.

Résumé

La région étudiée - c´est la partie d´ouest du "Horný vrch" entre les villages Drnava, Lúčka et Jablonov - nous présente le rayon tangent du Mésozoique dans le Karst slovaque avec le Paléozoique "Spiš-gemère" posé au nord. En construction de la région, on peut différencier cinq structurelles individuelles unités, séparées d´elles par des lignes fragmentes oblongues et zones fragmentes, des structures uniques de plis avec des systèmes des plaines à détailler et quatre structures génerales à blocaux avec une zone transversale fragmente.

Bien que l´origine du mouvement tectonique en Mésozoique du Karst slovaque et bien aussi de la région étudiée on tient pour la Crétacé (Presenonien), c´étaient sentement les élévations et faiblesses des bloceaux uniques (au miocène) éventuellement la cesse de la soulevation des parties du nord en région-du bloc "Drienovec", qui ont posé la base pour la actuelle division. Les légalités et une caractère de la construction régionale tectonique se démontrent par la copie des éléments tectoniques pour la modelage de terrain. Et de plus, s´il s´agit au complèx des roches carbonates à la tectonique elle est dépendante aussi l´origine des révélations karstiques superficielles et souterraines.

Un exemple caractéristique, c´est un bloc unique de "Drienovec", construit par des minérals du Paléozoique plus jeunes. Avec ses pentes fragmentes-denudées, inclinées brusquement au sud-est et sud-ouest, c´est morphologique le produit expressif de la compression du bloc de deux compliquées directions causées par éboulisement du Triasique de dessus sur la complèxe "Drienovec". Dans les plus hautes parties du "Drienovec" sont conservé des restes des grottes horizontales, lesquelles on peut croire le document du vieux niveau denudé, comparables de paraitres niveaux dans la partie du nord de la "Plešivec plateau".

La plus basse gouffre de la région étudiée - "Veterná" (120 mètres), elle est fondée sur une dislocation dans la substance de plis tranchante. Semblablement, on peut, en dépendance à la prédisposition tectonique suivre la zone des plongeons dans le rayon "Horná Lipa - Mútná Studňa".

La connaissance détaillée de la construction tectonique nous facilite le résoudrement plus exacte de la géneze de toute la région karstique. Par ex., si on porte des situations tectoniques au bases topographiques, on peut établir rélativement exacte la continuation des connus systèmes souterraines, peut-etre établir la place, le rayon de grande éspérance pour les autres recherches spéléologiques, la découverte des gouffres etc. Uniquement avec la parfaite idée de la construction tectonique du territoire on peut tenir la recherche spéléologique pour le systématique, pas pour l´éventuelle.

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BASIC PRINCIPLES OF THE TYPOLOGICAL DIVISION OF KARST IN THE WESTERN CARPATHIANS

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No great attention has been paid to the questions of karst typology until the present time and works of this nature have appeared only sporadically in spite of certain foundations for typology given by the classic of karst geomorphology J. Cvijić (1924). There is a sufficient number of analytical works from the karst territories of all the world, which are devoted to the karst phenomenon, the synthetizing works, however, are lacking. The heterogeneity in theoretico-methodological approach in studying some areas did not give a sufficient possibility to compare and regional peculiarities of the territory studied appeared strongly here. In classifying the karst territories no unified criteria have been used, which would have a more general validity. A contribution to elucidate some problems was represented by the theory of climatic geomorphology, in which the role of climate is emphasized not only in the process of karstifying, but it gives a special impress also to relief forms (H. Lehmann 1954). The later works (V. Panoš, O. Štelcl 1965), however, call attention to the fact, that the differentiality of forms is conditioned by structuro-lithological properties of the territory. It is evident, that climate modifies karstifying process, on the other hand, however, we can meet with several karst types within the same climatic region. Thus, it is necessary to quest the causes of the phenomenon in further natural factors, although we must take into consideration in typology also the climatic as a zonal factor. The typological division by J. Roglić (1965) for karst and fluviokarst, which was made on the example of the Dinarian Karst, is to be taken into consideration in every region. In the conditions of the Western Carpathians most of the territories is to be placed to fluviokarst, but even territories delimited in this way have form differences. N.A. Gvozdecký's division (1965) according to the sort of karst cover is suitable to use in our conditions at a lower degree of division.

J. Michovská (1957), which was supported by the classical division by J. Cvijić, applied herself to the typological division of karst in Czechoslovakia. A progress was represented by the work by A. Droppa (1965). On the basis of recent knowledge in karst morphology, a division for the territory of Slovakia was made by E. Mazúr and J. Jakál (1969) and for the Czech lands by O. Štelcl (1972).

In this work we want to come back to the questions of the calssification proper in detail as well as to the study of conditions causing the different charakter of karst territories. We want to point out the problems of division within the climatic zones from the viewpoint of differentiation of karst territories, which is conditioned by morphostructural and other non-zonal elements.

Let us have a look namely at the Western Carpathian area, which will be a subject of this study. From the climatic point of view it can be placed to the moderate climatic zone and within its framework to the Central European karst region. In comparison with some Central European mountain regions the karst of the Western Carpathians can be understood as a special unit. The different development of the Variscan mountain ranges in relation to the Alpine-Carpathian ones found a reflection in the karst relief. Similarly, the not quite even development of the Alps and the Carpathians manifests itself not only in the wholly greater verticaldifferentiation of karst areas of the Alps in relation to the Carpathians, but also in a larger areal extent of the carbonic complexes in the Alps. For these reasons the karst of the Western Carpathians shows typologically rather peculiar. The main mountain ranges of the individual climatic zones would appear in this way as units of a lower taxonomic level, namely in this case e.g. the Alps, the Carpathians and the like would appear as units of the third order. Surely, it is necessary a comparative study to solve this question.

In the division proper of karst in the territory of the Western Carpathians we base on the fact that there are several mutually diametrally different types of karst. In their delimitation the climatic criterion would not be sufficient and therefore we need to take further criteria into consideration as well as to arrange their hierarchy according to importance. Occurrence of surficial and underground karst forms must serve as one of the main criteria. In the karst area we must trace the occurrence of karst forms, the configuration and riches of their occurrence, the completeness and degree of their development. In the second order we trace the conditions, which are the presupposition for development of karst phenomenon, and which determine the degree of its development.

Rock is an inevitable and self-evident presupposition for the rise of karst. The karstifying process is emphasized and speeded up by purity of rock and by thickness of karstifying complex. The extent of karst territory is determined by the very lithology. As there is the morphological division, it can be taken into consideration as a criterion at a lower degree of division. Even the same type of limestone, e.g. very pure Wetterstein one in different geomorphological positions, may have a different degree of karstifying and different occurrence of forms. On the other hand, when e.g. a karst plateau is built of this limestone together with dolomite, it is necessary to take this circumstance into consideration when divided at a lower degree.

Consequent to the above-mentioned, in the Western-Carpathian area it is necessary to note another decisive factor modifying the development of karst, which has been omitted so far. It is the role of relief, its morpho-structural properties, the morphological and tectonic development of karst territory as a whole, its extent and position to the non-karst territory. These elements play a great role in the rise of macroforms of relief, which may be denominated as a relief to be karstified. The development of karst phenomenon is strongly affected and directed by such rough relief features.

Upon the role of soils and vegetation it is to be looked from the viewpoint of palaeogeographical development of karst territories. In karstifying process their role was changing along with the changes of climate. The post-Pleistocene climatic conditions (apart from the high-mountain regions) are not different so much in the Carpathians that they should manifest themselves in relief. Thus we consider as basic criteria to delimitate individual subtypes of karst in the Western Carpathians:

1. occurrence and development state of surficial karst forms
2. occurrence and development state of underground karst forms
3. structuro-lithological charakter of karst territory
4. morphological nature of the landscape
5. nature of karst hydrography and of that in surrounding territories
6. climate of karst area
7. size of karst area

To better understand the typological division of karst in the

Western Carpathians, we consider as necessary to analyze briefly the individual elements affecting the development of karst and their time-spatial relations. We are not going to deal in detail with the role of these elements in karstifying in general, but we want to concretize them in the territory of the Western Carpathians.

GEOLOGICAL CONDITIONS OF KARST DEVELOPMENT

The large distribution of karst in the Western Carpathians is predestinated by rich occurrence of carbonatic rocks. The priority unit for the rise of karst are the inner Carpathians, the main building element of which are besides the crystalline complex and Palaeozoic also the thick Mesozoic strata of carbonates. Carbonatic rocks form also a narrow belt of klippen zone. The spatial distribution of limestones and dolomites of the Mesozoic age is given by tectonic conditions, which are the result of several orogenetic phases of the Alpine folding. From north to south the tectonic units may be observed as follows: the Tatrides, Ultra-Tatrides, Veporides, Ultra--Veporides, and Gemerides (Bystrický J. et al., 1969). Each of these units consists of the crystalline complex and sedimentary envelope, which is formed substantially by carbonatic rocks. In some units the sedimentary envelope is autochthonous (Tatrides, Veporides), in other tectonic units it separated and shifted to north in the form of nappes. The nappe structure is very striking in the northern group of core mountain ranges, especially in the Nízke Tatry Mts. The Gemeride zone of the Slovenské Rudohorie Mts. has a special position, where only the Mesozoic complex of the Gemerides with non--conspicuous nappe structure appears overlying the crystalline core of the Gemerides.

The original geostructures have no great importance in modifying the development of karst. Younger neoid tectonic development and erosion-denudational processes led namely to destruction of the original nappe structures and just this fact has played decising role in differentiated development of karst. The influence of nappe structure upon the development of karst asserts itself mostly by lithological differentiation only.

The most favourable to be karstifyied are carbonatic Triassic rocks, which are most spread. Very pure Wetterstein limestones are the main component especially in the Gemerides. They are most frequently massive or thick-sheeting and in places they form a complex with a thickness up to 1,200 metres. In the Subtatric nappes they are more slightly represented. Here pure Gutenstein limestones with a thickness of 200-250 metres are predominant, in places they alternate, however, with positions of dolomites. The purest ones are in the Krížna nappe. With Gutenstein limestones we meet also in the Gemerides, where they lie direct on the impermeable Werfenian underlying. Dolomites occur both in the nappes and in the Gemeride zone. The Subtatric nappes are built, however, to a considerable extent by the Lower and Middle Cretaceous complexes represented by marly limestones, the Calpionella and organogenetic as well as sandy limestones. In these the karst phenomenon is developed very slightly.

RELIEF AND ITS REFLECTION IN THE KARST PHENOMENON DIFFERENTIATED

The relief of the Western Carpathians may be considered as one of the basic elements conditioning the differentiated development of karst. The relief variety manifests itself both in vertical dissection, territorial inclination, in dissection of age, in genesis or development dynamics. The fact that karst areas are bound upon various physiognomico-genetic types of relief stand thus for a spatially considerably differentiated development of karst phenomenon. A great role is played also by the position of karst territory in relation to the non-karst territory, which reflects especially in relief development by means of hydrography. From the tectonic development decisive role in the development of karst may be ascribed especially to younger tectonic movements, which ran in the Neogene. In this period the Western Carpathians were already within the range subaerial destruction and the basic features of recent relief were being put down. The geomorphological development proceeded by stages in the Neogene. The lowering and levelling of mountain ranges was interrupted by several phases of tectonic movements with prevailing vertical component in contrast with tangential one. In this way an irregular mosaic arose with differently up-lifted individualized mountain blocks and with basins fallen in between them (Mazúr E. 1965). The subaerial destruction and above all uneven tectonic movements disintegrated in this way originally continuous nappe belts and within then also carbonatic complexes into differently large areas isolated from each other and differentiated considerably vertically and also by inclination according to their respectivity to the individual orographic wholes.

In the Sub-Carpathian basins the pre-Neogene complexes sank and so they are covered by a thick mantle of the Neogene and Quaternary. In the intermontane basins the pre-Neogene formations sank, too. They are covered by the Neogene and Quaternary sediments. Locally, however, non-large enclaves of carbonatic rocks with partly developed karst come to light. In places karst develops under this cover.

A great differentiation of karst areas may be observed in dependence upon morphostructural properties of the territory. These ones, in fact, determine the basic shape of karst territories.

One of the most typical mountain structures are wedge horsts with crystalline core symmetrically situated owing to one-sided uplift, so that carbonatic complexes appear in form of tilted structures along one side of the mountain range only (the Tatry, Nízke Tatry and Malá Fatra).

Another structural type, which is classically developed in the Strážovské Vrchy, is Appalachian structure. This is represented by undulate Mesozoic complexes without crystalline core or this one appears excentrically. In another place the Mesozoic complexes appear in form of horsts without crystalline core (northern part of the Malé Karpaty, the Chočské Vrchy) or as blocks preserved in form of non--large plateaus overlying the core (the Žiar).

A special structural type in the inner western Carpathians is the Rudohorie structure, which is the most favourable for karst to be developed. The Mesozoic complexes, in detail, it is true, with a complicated fold structure, appear substantially in horizontal to subhorizontal positions overlying non-karst rocks. In addition, they represent relatively well-preserved Neogene plateaus in a considerable extent (the Slovakian Karst, Muránska Planina, Slovenský Raj).

The least suitable structure for karst to be developed is the klippen zone, where karst rocks appear in form of isolated monadnocks morphologically strongly exposed.

In summing morphological conditions in the Western Carpathians we state that they are mostly not too favourable for karst to be fully developed, predominantly owing to tectonico-erosional destruction of originally more continuous Mesozoic nappe-fold structures into a mosaic fault-fold one, whence karst rocks came to extremely exposed positions and frequently under influence of non-karst morphological processes. Extreme inclinations, dissection of relief as well as influence of morphological processes in neighbouring non-karst areas allowed in this way even in areas with suitable lithological properties of underlying complexes a non-complete and one-sided development of karst phenomenon only, for instance, that of underground karst and so on. Areas of the Neogene levelled plateaus of the Slovenské Rudohorie and locally even those of the plateaus of horst mountain ranges have turned out to be most suitable for typical surficial and underground karst to be formed.

CLIMATE

From the climatic point of view karst of the Western Carpathians belongs mostly to moderate zone of the Central European climatic area. The climatic conditions are relatively favourable for recent forms of karst to be formed. The karst territories are situated in climatic zones Dfb and Dfc (according to Köppen's classification). In the individual territories in some places 700, in others 1,000 mm precipitation per year fall under average annual temperature of 6 to 8° C. Precipitation is distributed relatively evenly during all the year. More striking climatic changes show only in vertical direction, namely in the area above the upper timber line (approximately above 1,400 metres), which belong to ETG zone of climate. Average temperature reaches here 0-2° C and precipitation in places even 1,800 m.

WASTE COVER

In the Western Carpathians karst areas are mostly denuded, in places as far as rock underlying, or they are covered to various extent with soil cover preserved, predominantly of rendzina type. In the Rudohorie area remains of terra rossa are preserved on the plateaus. The tectonically subsided areas of karst have their karst surface covered with Neogene sediments, frequently also with Quaternary pebble coverings.

VEGETATION COVER

The vegetation cover is in most karst areas modified and in places even removed by anthropogenous activity. Especially karst areas are deforested and converted into pastures and meadown with a shrubby growth together with undergrowth of xerophilous and thermophilous vegetation. The other karst territories are mostly forested, in higher positions with needle-leaved forest, in lower positions with deciduous trees (oak-hornbeam woods). In the high-mountain karst areas dwarf--pine and sub-Alpine meadown appear.

TYPOLOGICAL DIVISION OF KARST

In dependence upon the very differentiated character of physico-geographical elements and of their correlations in the Carpathian area the karst phenomenon has developed very differently. The Central European karst of the Western Carpathians may be divided into two different groups, which may be forther divided into subtypes.

1. CENTRAL EUROPEAN KARST

1.1. Plateau karst

This type is developed in the Western Carpathians and as to the size of territory it occupies the largest areas. It is characterized by high-situated plateaus bounded by high abrupt slopes from the surrounding relief. The slopes encounter the plateau in a sharp edge. The plateau karst is bound only with one morphostructural type of mountains, namely with the old semi-massive block of the Slovenské Rudohorie. A considerable thickness, area and purity of karst rock (predominantly Middle Triassic limestones, to a lesser degree dolomites) as well as its moderately depressional deposition on an impermeable underlying complex and a relatively flat initial relief show as suitable conditions for karst to be formed. In this type the whole riches are developed as to the karst phenomenon. Here lapies, sinkholes, uvalas, blind and semi-blind valleys, dry valleys, karst basins (karst poljes), extensive cave systems (for instance the Domica-Baradlá 21 km), ponors, karst springs and fluviokarst forms of canyons are represented. The plateau karst is represented by three territories: Slovakian Karst, Muránsky Kras, and Slovenský Raj.

1.2. Dissected karst

This type is bound with mountain horsts, free folds, eventually with grabens - with basins of the Tatro-Fatrian area of the Western Carpathians. There are karst territories in comparison with the previous type, with less favourable conditions for karst to be developed and also poorer developed karst phenomenon. It is conditioned by a smaller thickness of frequently polluted karst rocks, mainly of limestones, in places with predominance of dolomites. Owing to this fact only some karst forms are represented in the various types.

1.2.1. Karst of monoclinal ridges

This subtype is bound with carbonatic rocks asymmetrically situated in the so called core mountain ranges in form of monoclinal structures, or appearing as self-standing monoclinal structures without any core. It may be characterized as a karst of mighty elongated ridges, separated by deep valleys, often of a canyon-like character. Such a nature of relief is a result of activity of allochthonous rivers coming from higher non-karst areas of core mountain ranges and from exposed morphological positions of carbonatic complexes. Such a surface is not favourable for surficial karst forms to be developed, of which scattered lapies only occur. The underground karst is, however, developed abundantly. The largest cave systems occur just in this karst subtype, namely in the areas built of pure limestones (for instance the Demänovská Jaskyňa Cave, Belanská Jaskyňa Cave and others). More weakly karst is developed in analogical structures built of non-pure Cretaceous limestones. Classically this type is developed in the Nízke Tatry, Belanské Tatry, Veľká and Malá Fatra, Malé Karpaty.

1.2.2. Karst of horsts and combined fold-fault structures

This subtype is bound with karst rocks, which are preserved in various positions on the mountain horsts or in the fold-fault structures. In this subtype we may trace different variants in the development of karst phenomenon in small distances. On the one hand even slight plateaus are developed, with well-developed surficial karst and underground spaces, and a typa analogical to the previous one on the other one. The surface is, as a rule, intensively dissected. Such a relief is in the Strážovské Vrchy with preserved small plateaus in the area of Slatinka and Mojtín. Larger islandlets of this type are found in tectonically uplifted blocks as the Žiar and a part of the Malé Karpaty are. The small plateaus and well-developed karst are bound predominantly with pure limestones with sinkholes, lapies, ponors, karst springs, and caves. On dolomites and the Cretaceous limestones predominantly fluviokarst is developed, for which dry valleys are characteristic.

1.2.3. Karst of basins

It is bound with tectonically subsided complexes of carbonatic rocks, which occur most frequently intermontane basins in depressional positions. In places karst comes to light, more frequently it is covered by Neogene or Quaternary sediments. Locally even exhumed karst occurs. These territories are drained in underground. Sinkholes and smaller caves are a frequent phenomen. Such karst territories occur in the Liptovská Kotlina, Horehronské Podolie, and Zvolenská Kotlina.

1.2.4. Karst of isolated klippen structures

It is bound with small islandlets of carbonatic rocks coming to light in form of the monadnocks of the klippen zone. They are built most frequently of the Jurassic limestones strongly folded. Their small area, extreme morphological position do not allow to the karst phenomenon to be fully developed. Small is occurrence of lapies and rarer more that of sinkholes. More frequent are slight caves - abris. The allogene rivers cut them by narrow passages.

2. HIGH-MOUNTAIN KARST

It is a special type from the viewpoint of climatic conditions. Thanks to favourable climatic conditions, here the karst phenomenon is developed intensively in a rich scale of forms. Especially the various types of lapies, further sinkholes and abysses are developed classically. In places a karst step-land in accordance with A. Bogli (1960) occurs here. Of the underground forms they are extensive cave spaces with vertical component dominant. This karst type appears roughly above a limit of 1,400 metres, scarcely it reaches, however, values about 2,000 metres. It occurs in the Belanské Tatry, Západné Tatry, Nízke Tatry, and Veĺká Fatra Mountains.

(From the Slovak translated by A. Krajčír)

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Ba 028

BASELEVEL AND STRUCTURAL CONTROL ON THE KARST HYDROLOGY AND THE GENESIS OF KARST GEOMORPHOLOGY

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A b s t r a c t. The genesis of karst areas depends upon several independent already highly complex factors such as the geological, the stratigraphy and structure of the local bedrocks, the climatic environments and their related vegetation covers and other factors.

But the true motor for development of the drainage pattern and the physiography is the existing of developing local relief energy, created by tectonic uplift or other caused changes of the local baselevel. The water sculpturing the physiography by erosion and or corrosion follows strongly the more or less steep gradient from higher to lower relief units. The drainage direction as well as the developing relief f o r m s (low reliefs or alpine mountains) are only m o d i f i e d by the geological and climatic factors. Keeping this in mind it is understandable that the local relief and the related physiography is highly dependent upon the incision rate of the master vallyes and their tributaries.

This is true not only in nonkarstic areas but also in carbonate terrains. The phreatic groundwater flow and the descending vadose waters, which are responsible for the subsurface solution of soluble rocks are both oriented to deeper vallye incisions. Owing to the fact the majority of ground water flow happens to be at the upper part of the moving water body (near the water table or the piezometric surface) and because here also the chemical solution power and the solution time is greatest, solution voids and cave passages will predominantly develop in a limited level range graded to the local baselevel.

As the genesis of surface erosion features and subsurface solution voids obey the same physical laws, the surface karst geomorphology cannot be analysed without exploring the underground hydrologic and solutional processes.

Different cave levels which can be connected with different valley terraces or marin benches, the indicator of former local baselevels, are obvious proofs of these genetic connections, which have existed during the successions of different high relief generations. The lenght of time which was available for each forming period at nearly stable baselevel is of great importance for the dominance of relictformes in a very complex developed recent physiography.

The theoretical conclusions are demonstrated using mainly North American and European examples.

Four main factors stood in the forefront of the scientific discussion about the genesis of the karst physiography:
1. **The relief** caused by tectonic uplift (the potential energy of height difference)
2. The stratigraphy (petrography) and geological structure
3. The climate, precipitation and temperature, the base for weathering and the vegetation cover.
4. The time during which the above factors are effective and their variability within the time.

In the early European literature the geological factors attained highest interest. Later since the "Düsseldorfer Vorträge", 1927, the climatic influence on the relief genesis, up to then mostly ignored, was recognized. In North America the climatic geomorphology and its results were ignored for a long time and even today many authors prefer the geological factors (stratigraphy, petrography and structure) in their geomorphic papers.

The importance of the base level (Erosionsbasis) for the relief genesis was already recognized by Powell, 1875, and Gilbert, 1877, and was minutely discussed by Davis, 1902, but was not applied enough in younger geomorphic fieldwork.

The time factor within the geomorphic complexity was already introduced by Davis, 1899, "Process cannot however complete its work instantly, and the amount of change from initial form is therefore a function of time." (p. 481).

Within this paper it shall be demonstrated that relief energy (height difference, potential energy) created by tectonic uplift or other positive displacement of the local base level, plays an outstanding role within the relief forming processes.

Beginning with a tectonic uplift the created higher relief gradient causes erosion acceleration of the existing rivers. Streams with larger headwater area and consequently higher water transit reach a faster entrenchment of the valley floor, so the bigger valleys get ahead the entrenchment of smaller tributaries. The master stream of the region functions as the base level onto which the valley floors of the tributaries are graded. The faster and higher the uplift of a region proceeds the faster, narrower and deeper the potent master stream will entrench, the less the deepening of the smaller tributary valleys can keep pace. So the tributary valleys become hanging valleys, especially if they are dry valleys.

When after the end of the uplift period the master river has reached its new entrenched equilibrium according to the new relief, the tributaries of first or higher order are still deepening their individual adjusted profile graded to the already deeper master stream. In karst terrains these new tributary gradients can be developed as cave gradients in the subsurface. Owing to the fact the denudation power is quite different in valleys with higher or lower water transit, the individually reached developing - stages of valleys are at the same time different too.

If the entrenchment within the master stream valley and the major tributaries become stagnant within a certain level range there will be only denudation and erosion above this level so the valley floors get wider but not deeper. At the same time small steep V-shaped valleys which are oriented to the local lower limit of erosion, still can erode deeper for a longer time. Depending on the situation within the relief, different developing stages can form and exist simultaneously.

The possibly for a longer time period stabilized l o w e r l i m i t of all existing erosion/corrosion is indicated by the level (gradient) of the deepest entrenched master valley which represents the local base level. All local surface or subsurface erosion/corrosion work down to this local base level but not beneath it.

A simple balance calculation shows that per quantity of runoff the dissolved and suspended load as well as the bed load is limited. As the amount of precipitation and the resulting runoff is also limited only a certain quantity of rocks can be weathered, eroded and transported per given time. The establishment of a new stream gradient during and after local uplift will be reached most economically by eroding a minimum of rock volume. The so entrenched narrow V-shaped valley will become wider and wider along the new equilibrium stream gradient if no further uplift occurs. It takes long time periods to weather, erode and transport the immense rock volume of the entire river basin down to the new base level after the water has already entrenched to its new base level gradient along a narrow valley course. (Extremely slow tectonic uplift could cause the development of initially wider valleys.) This is the reason, why the recent relief locally represents a not too much modified tertiary (pliocene) physiography. This applies the more clearly the further away the relief units exist from the master stream entrenchment (see also Büdel, 1971, p. 73).

Because the karst ground-water body is mainly developed along the course of the open flow or dry valleys, and it is here where the cave passages develope, the cave systems as well as the tributary valleys are graded to the local master stream. Along with a new entrenchment of the master stream after a tectonic uplift the karst-water-table also migrates deeper. If the karst-water stream is concentrated already in shallow graded cave passages, steep cave-canyons will form. They will be the connection to the future deeper situated cave level which will be graded to the new established base level of the local master stream. The cave canyons will be steep and narrow if the entrenchment happened fast, they will be wide if the deepening occured slowly.

The formation of a stationary karst-water-table which is sloping down to the temporarily fixed base level of the master stream will be reached first within the major tributaries. Farther upwards within the river basin the valley and cave gradients are somewhat steeper, the valleys narrower and the cave system is less developed in single major passages but shows a dense dendritic pattern of small conduits.

The aligned karst ground-water stream in a not too steep relief moves within a flat band which has an upper limit indicated by the piezometric water surface and a lower limit caused by the tightness of the joints and bedding planes. This karst ground-water band normally parallels the dry valleys down to the local base level. It is also here in the shallow phreatic environment where still aggressive water has the longest time to dissolve and enlarge karst crevices. Connections between two valleys of different altitudes across ridges are possible but not necessarily existing or are of low transit capacity. The outlet springs of the main karst water bands are mostly situated close to the mouth of the tributary valleys.

As has been shown erosion as well as karst ground-water alignment are controlled by the tributary courses and the local base level of the master stream. In order to demonstrate the special modifying influence of different stratigraphy and structure, the young pliocene period of entrenchment at Mammoth Cave, Kentucky, which was followed by a long time of stable base level shall be used as an example:

During the entrenchment of the Teays-River-system (younger pliocene) within the Central Lowlands of the USA into the Lexington erosion surface, the Green River at Mammoth Cave also deepened its valley course (Miotke, Palmer, 1972). The climate at that pliocene time probably was humid temperate (Potter, 1955). The Green River meandered in a wide shallow trough through the Lexington erosion surface when the Teays erosion period began. Synchroneous with the entrenchment of the Green River of about 30-50 m the tributary valley bottoms and the karst groundwater levels were lowered too. Beneath the already existing big cave passages large cave canyons were cut down to the new erosion level which became stabilized around 180 m above sealevel. At this altitude the local base level apparently became stationary for a very long time. The nearly horizontal cave systems at this level reached maximum sizes, the valleys developed wide valley floors and the Pennyroyal Plateau, encluding the Sinkhole Plain established a shallow sloping hilly karst plain. Reddish clayey cave sediments show great similarity to correlating residual soils on the same level or higher at the surface of the Pennyroyal Plateau and within the cuesta valleys and ridges.

The local developing relief forms, the local rapidity of the erosion down to the stabilized level around 180 m and consequently the volume of eroded and corroded rocks per time can be related to the resistance differences within the outcropping stratigraphy. Essential reason for the unequal surface lowering was the fact that the soluble St. Louis, Ste. Genevieve and Girkin carbonic limestones were locally covered by a series of nearly impermeable sandstones, shales and limestones. Whereas the sandstones and shales allowed predominantly erosion processes only, the limestone surfaces and subsurfaces were eroded and a d d i t i o n a l l y corroded.

The ratio between the suspended sediment load and the dissolved solids (residue at 180° C) of the Green River water at Munfordville, Kentucky, averages nearly one to one (U.S.G.S. Water Resources Data, Kentucky 1967-69). The dissolved load contains more than 60% calcium/magnesium-carbonates. High percentages of the dissolved load as well as a portion of the suspended sediments (60% clay) originate from corroded limestones. The sandstones being more eroded than corroded consequently are more resistant against denudation than the additionally soluble limestones which are probably weathered and their residuals carried away 30-50% faster than the sandstones. Therefore the sandstone capped Chester Cuesta is separated from the Sinkhole Plain

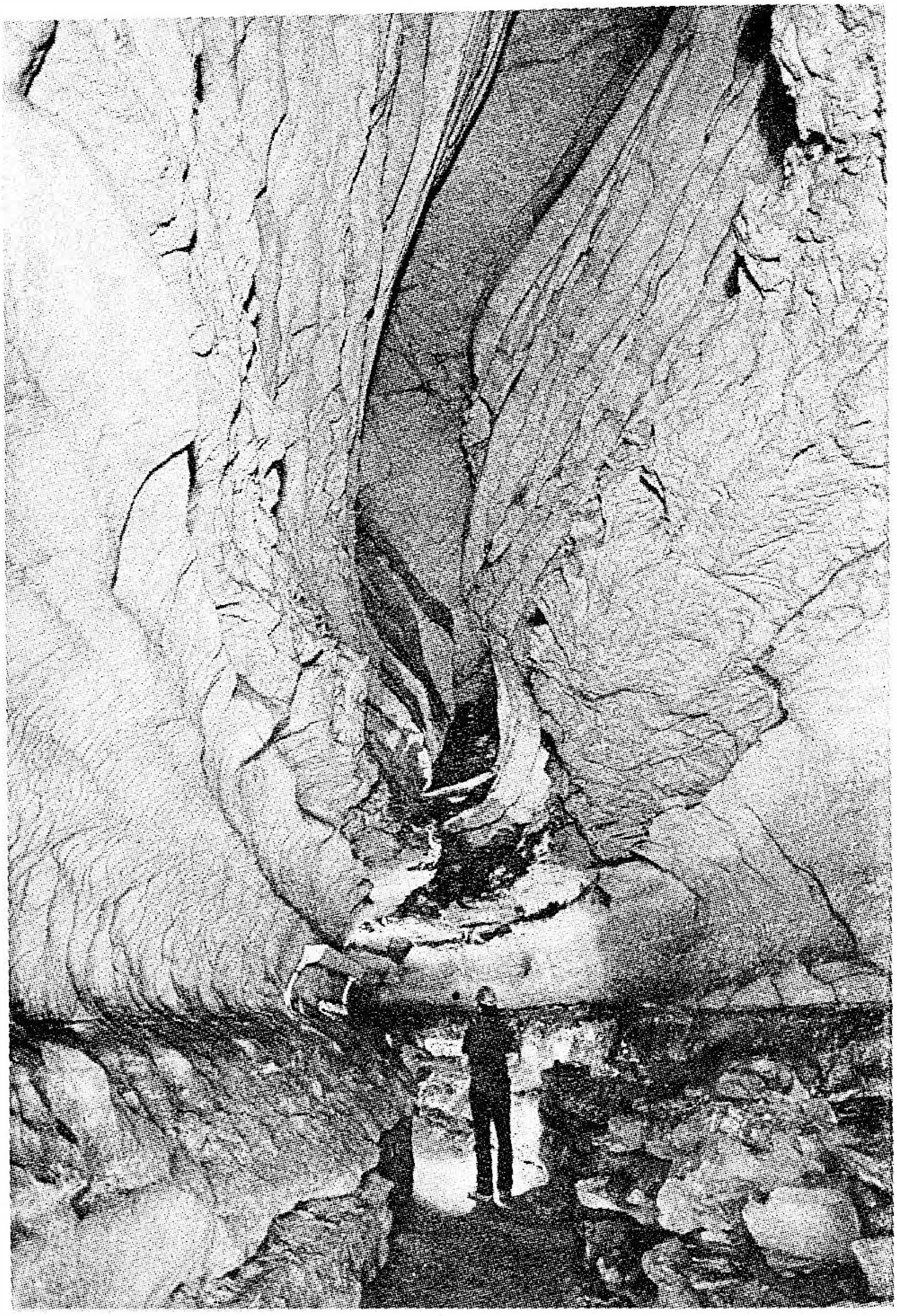


Fig. 1. Mammoth Cave National Park, Echo River Trail. Meandering canyon passage with scallops covered walls represents down cutting period. The passage shows accordance to the dip but actually cuts the strata along its route down to the Echo River base level.

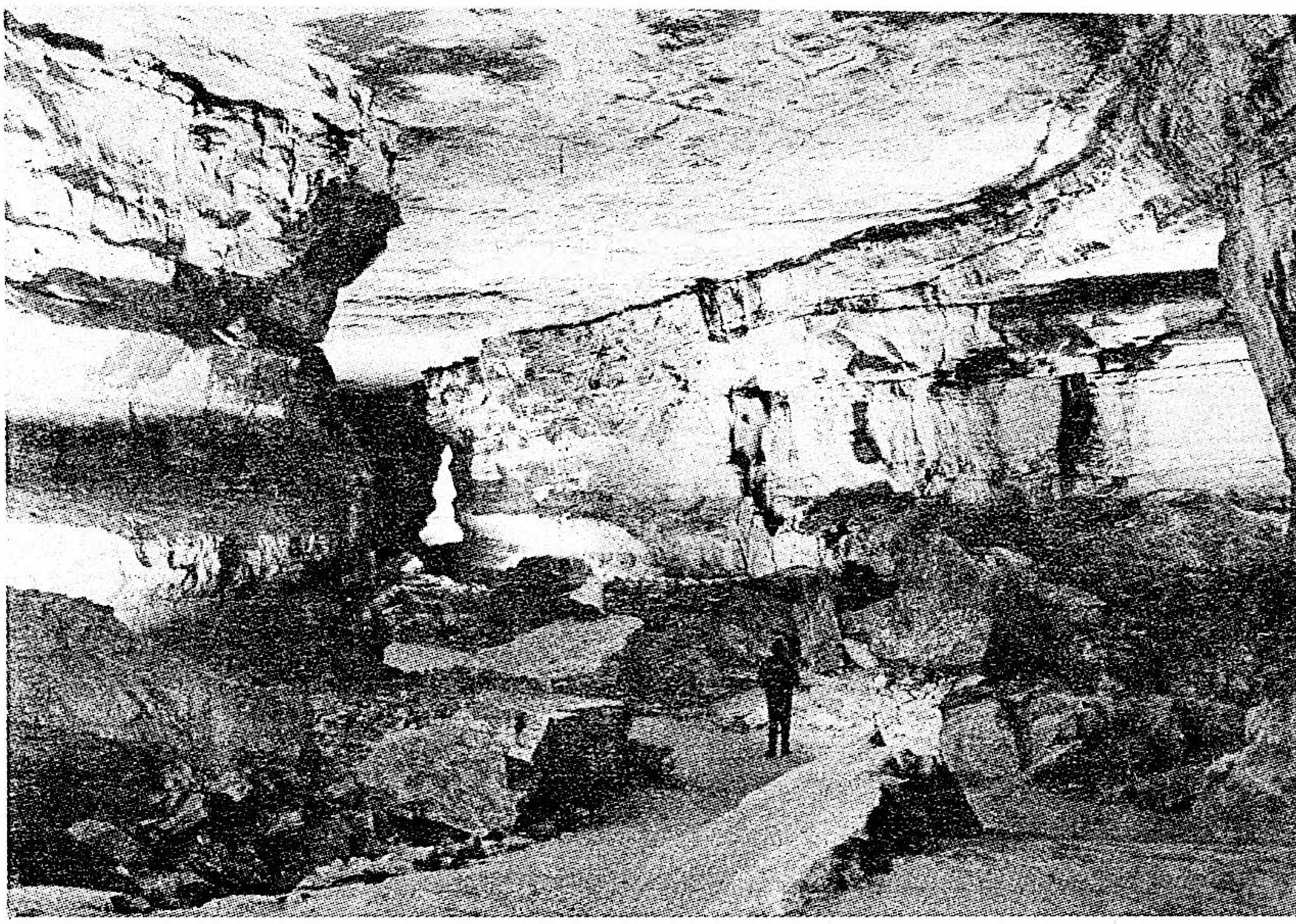


Fig. 2. Mammoth Cave National Park, Indian Avenue at Washington's Statue. Trunk passage at approximately 180 m altitude represents the Teays base level in late pliocene. The former main conduit was altered by later breakdown. Locally the ceiling along the stratum was formed by collapse of rocks. The passage floor was graded as a tpurist trail. Passage height approx. 9 m, width up to 15 m. Average ceiling-gradient 2,2 m/km (11,5 feet/mile).

(Pennyroyal Plateau) by the 60 m (max. over 75 m) high Dripping Springs Escarpment.

Around Mammoth Cave a series of later dry valleys which dissected the sandstone cap have developed wide valley floors at the level down to 180 m. These valley floors within the Girkin and Ste. Genevieve Limestones graded to the Green River base level which in that time (younger pliocene) was at 180 m.

After the sandstone cap was dissected the Girkin Limestones became eroded and more and more karstified. Big cave passages developed within the subsurface. When the valley incision and cave system had reached the stabilized lower limit of denudation (base level gradient) erosion and corrosion could not continue to deepen the valleys but worked to widen the valley floor on that level.
A very long time of slope erosion and corrosion reduced the sandstone

capped ridges and knobs which locally, after losing their protecting sandstone cap, became lowered down to flat hills.

The base level in the tributaries and the Green River valley were for the longest time nearly equivalent. The valley slopes of the Green River and the main tributaries suffered similar erosion and corrosion, because they had equal base level, an equal petrography and the same climate conditions. This is the reason why the tributaries in the Girkin/Ste. Genevieve developed valleys alike in width and shape. The big sinkholes along the margins of the ridges and knobs were enlarged by the same processes of slope denudation (erosion and corrosion) and weathering residuals were carried away through the cave system as in the dry valleys.

The pliocene (and recent) surfaces at Mammoth Cave are cutting the steeper dipping strata. Different relief forms and developing stages formed in close vicinity to each other due to variation in petrography causing different resistance against corrosion and erosion. All erosion and corrosion entrenched exclusively to the maximum depth of the local gradient to the Green River. This result is in contrast to the statement of Quinlan, 1970, that the morphology of the Central Kentucky Karst is determined by stripped structural surfaces.

The Chester Cuesta (mostly sandstone surface) north of the 60-75 m high Dripping Springs Escarpment is dissected by relatively narrow more V-shaped valleys. Within the eastward connecting area of Mammoth Cave the sandstone cap was already dissected since pliocene and earlier. Large cave systems in 180 m altitude and higher were developed during the young pliocene and earlier. Their position is parallel along the dry valleys and under the ridges. Large parts of the fossil cave system in that altitude are destroyed by later slope erosion/corrosion. Still farther east, where the sandstone cap was stripped much earlier, the flat plainlike area between the ridges and knobs became wider and wider until in the vicinity of Munfordville only remnant knobs were left which represent former divide areas. Within the Sinkhole plain locally flat hills are remnants of knobs which long ago lost their protecting sandstone cap.

Several phases of quaternary entrenchments, which followed the late pliocene erosion and corrosion did not completely alter the relict forms of the pliocene relief. V-shaped valleys and sinkholes dissected and dissect the older erosion surfaces. The Green River base level now in approximately 126 m altitude was lowered for 60 m since the end of pliocene. Quaternary cave passages correlate with river terraces of the same age (Miotke/Palmer, 1972). As for the tertiary erosion levels and correlative cave passages the quaternary erosion levels and their correlative cave systems are not related to "stripped structural surfaces" stated by Quinlan, 1970, (Miotke/Palmer, 1972). A certain accordance however is existing where erosion levels or cave passages cut resistant or less resistant beds.

The genesis of the Central Kentucky Karst shows that erosion and corrosion cannot proceed beneath a stationary lower limit which is given by the temporary local base level gradient. If the master stream gradient is stabilized by a long period of tectonic inactivity, valley floors having reached their aggradation profile increase their width but do not become entrenched any more. The local stratigraphy and structure will be cut by the valley base or by the karst groundwater system (caves). Modifying accordance recognized, the final level of the erosion/corrosion gradient is not determined by structural factors.

The correlations between base level, geological structure and climate conditions can be illustrated by the following analogy:

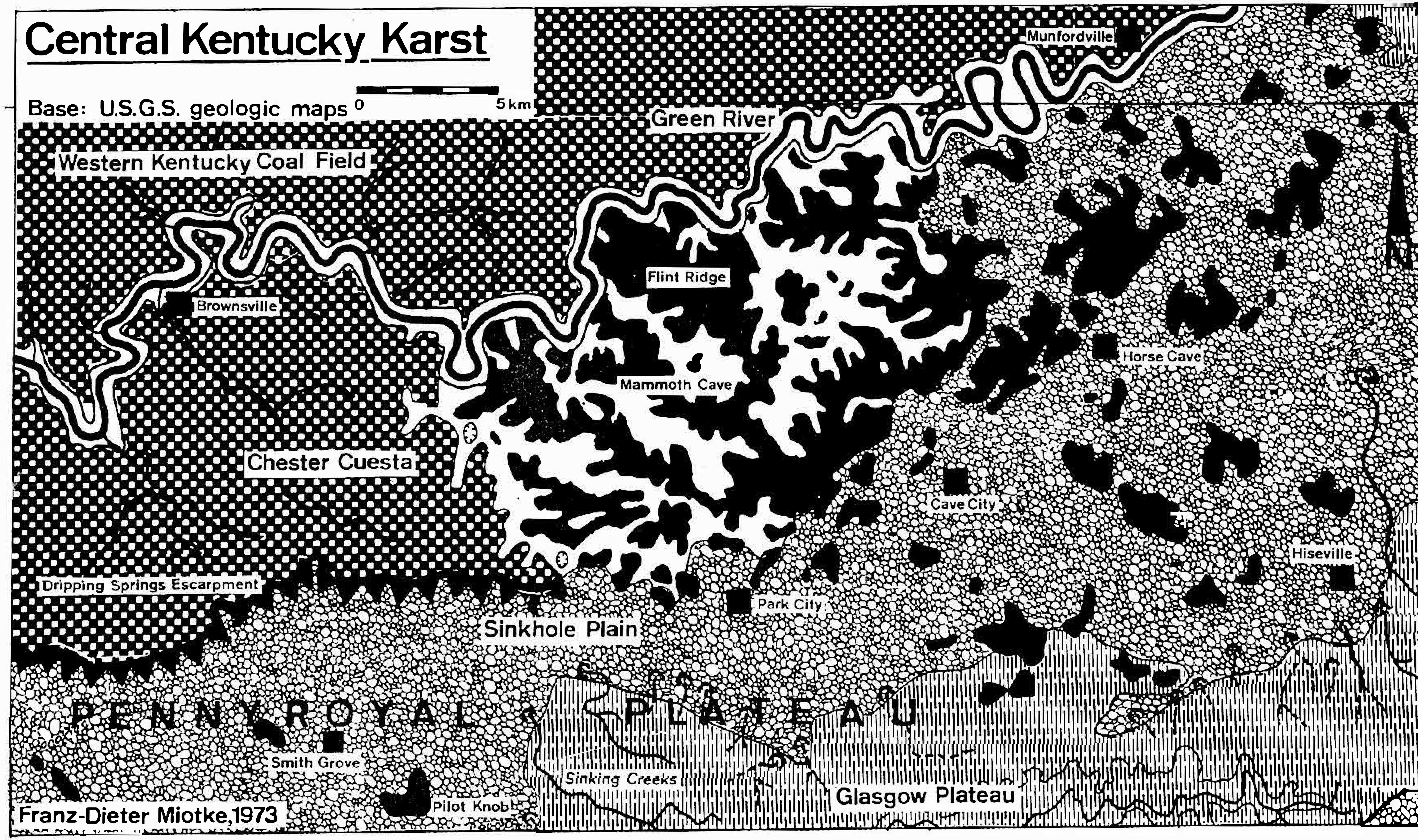
M o t o r — for all landforming processes, the existing or developing local r e l i e f e n e r g y, is created by t e c t o n i c u p l i f t or other caused changes of the local base level (height difference).

F u e l — for the motor causing erosion and corrosion is provided by the regional c l i m a t e conditions. Especially the precipitation and temperature (frost!) are the main factors for weathering and the vegetation cover.

B r a k e s — retarding erosion and corrosion activities, are the local s t r a t i g r a p h y (petrography) and g e o l o g i c a l s t r u c t u r e which determine the velocity and special form of landform development.

T i m e — The individually formed physiography resulting from the interference of those three factors (base level, climate, geology) will be most clearly developed the more time is available before the conditions change, especially the altitude of local base level (see also Miotke/Palmer, 1972, p. 6).

Any climate (provided that precipitation exists) working on any petrography and geological structure will create high mountain chaines, if the local relief energy is great enough (see subarctic



Chester Cuesta and Western Kentucky Coal Field	Chester Escarpment
black: sandstone capped ridges white: Karst valleys	Knobs, locally sandstone capped and flat knob remnants
Sinkhole Plain within the upper St. Louis and Ste. Genevieve limestones	Glasgow Plateau within St. Louis and other strata

Fig. 3. Central Kentucky Karst.

Alaska- and Middle American tropical mountains). On the other side no climate conditions or rock structures will prevent the development of hilly lowlands (plains) if the local height difference is small enough (see tropical Africa and arctic North America).

Providing enough relief energy (tectonic uplift) in which climate or geological structure so ever, no lowlands (plains, Flächen) can be developed nor preserved. This clearly indicates the dominance of the relief energy (height difference) within the complexity of geomorphic factors which recently Louis, 1973, emphasized too.

Any climate (if precipitation exists) will create a cuesta escarpment (Schichtstufe) provided that flat dipping strata of strongly different erosion and/or corrosion resistance and a not too great local relief energy exists. This demonstrates that geological structure is mostly more important for landforming than different climate conditions.

It must be clearly emphasized though that ranking the importance of geomorphic factors is only of use for analytical reasons.

GENERAL CONCLUSION

The major relief forms (high mountains, highlands, lowlands) encluding karst terrains are determined by the amount of tectonic uplift rather than climatic or structural factors. The velocity and special form of erosion (corrosion) and the specially developing relief forms are modified by geological and climatic factors though.

Long periods of denudation at stabilized local base level establish a relief which clearly reflects the erosion conditions and as a fossil relief dominates for a long time the succeding relief development.

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Ba 029

PHYSIOGRAPHY AND GEOLOGY OF THE HUASTECAN PROVINCE OF MEXICO

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The purpose of this paper is to report on the physiography and geology of that part of the Huastecan Province of México where are concentrated those caves inhabited by the eyeless characin fishes of the genus Astyanax.

Prior to our studies of these fishes, eyeless characin caves were known only from one specific range, the Sierra de El Abra of Tamaulipas and San Luis Potosí. Several such caves are now known from other parts of the Huastecan Province, but since the Sierra de El Abra remains the center of cave Astyanax concentration, it will be emphasized in this paper.

The Sierra de El Abra has long been known to be highly cavernous, but not until recent years has the true extent of its cavern development become apparent. It is now known to contain some of the longest and most complex cave systems in México. For example, surveyed length of passages in the Sotano del Arroyo now exceeds 6,500 m. Also some of the numerous pits located in the higher elevations, most of which we have presently seen only from the air, will rival in depth the deepest known pits in the Western Hemisphere. Also highly cavernous, but not studied at all until quite lately, is the Sierra de Guatemala, a much higher range to the north of the Sierra de El Abra. Several blind fish caves are now known from this range. The most recently discovered blind fish caves are located to the west of the Sierra de El Abra in the vicinity of the town of Micos, S.L.P.

The Sierra de El Abra lies approximately 150 km from the coast of the Gulf of México and extends for some 125 km in a generally north--south direction. Its greatest elevation, not known precisely, but between 450 m and 650 m, occurs just south of the Tamaulipas - San Luis Potosí border. Northward from this high point, the range gradually subsides until, almost sinking to the level of the coastal plain to the east, it again slopes gently upward to shortly merge with the rising Sierra de Guatemala. Southward from its high point, the range again gradually subsides finally to disappear into the Río Tampaón at an elevation of about 40 m. South of this river, El Abra Limestone makes two rather unimpressive reappearances, first as the Tantobal Dome, and, farther south, as the Salsipuedes Dome, a hilly area of low relief containing a spring which is a partial water source of the Río Coy.

The eastern face of the El Abra is well defined as a very steep escarpment rising above the coastal plain. The crest is almost flat and is very narrow ranging from about three km at the Canon Servilleta in the north to over five km just south of the Tamaulipas - S. L.P. border. The crest abounds with large sinks, some of which are scores of meters across, and pits whose black entrances speak of their great depth. The crest has largely defied attempts to locate its caves from the ground; dense vegetation restricts - almost prevents - exploration.

The western face slopes away into a valley, the Valle de Antiguo Morelos, bordered along most of its western side by the Sierra de Nicolás Pérez, but for a short distance in its southern portion by the Sierra de Colmena. Through this valley runs about 95 km of Highway 85.

The Sierra de El Abra lies on the boundary of two strikingly different physiographic provinces, the Gulf Coastal Plain to the east and the Sierra Madre Oriental to the west. The coastal plain is an almost flat plain which slopes imperceptibly eastward to the sea. The Sierra de El Abra and the two ranges to the west, the Sierra de Nicolás Pérez and the Sierra de Colmena form a relatively low interruption in the otherwise massive Sierra Madre Oriental which in the Sierra de Guatemala to the north reaches elevations in excess of 2,200 m and which to the south in the vicinity of Xilitla, S.L.P., has peaks of over 3,000 m.

The Sierra de El Abra, as well as other ranges having eyeless characin caves, is comprised of a dense, mid-Cretaceous limestone, the El Abra Limestone, which originated not as a single massive structure but rather as an aggregation of wave-washed shell banks, or "reefs", separated by interreef areas where calcareous muds were deposited (Bonet, 1963). The eastern edges of this reef complex faced the sea, and along this boundary fine material was removed by wave action leaving coarse shell to accumulate, forming a dense, essentially unbedded limestone, the Taninul Member of the El Abra Limestone. Originally this frontal wave-washed zone was about eight km in width. Farther westward, behind the reef front, there was less shell material and more lime mud and other fine particles which formed a bedded, backreef limestone, the El Abra Member of the El Abra Limestone. The El Abra "reef" thus grew for several millions of years resulting in the accumulation of hundreds of m of limestone as deposition in shallow water kept pace with sunsidance.

During much of Cretaceous time the El Abra reef formed the eastern edge of a large, shallow platform (Rose, 1963, Bonet, pers. comm.) extending to the north of Ciudad Victoria, Tamps., west to near San Luis Potosí, S.L.P., and south to the vicinity of Zimapán, Hidalgo. The clear, shallow waters of this platform were favorable for the growth of carbonate reefs, and numerous reefs similar to those of the eastern face of the platform, though generally smaller, developed on this platform to the west of the face. Late in the Cretaceous gradual uplift of the continental interior began, and clastic materials were brought into the El Abra area from the west. These clastic materials to the west of the El Abra reef face at first mixed with large amounts of calcareous sediments, but as uplift continued, terrigenous sediments increased in volume and encroached eastward onto the growing platform narrowing the zone of limestone deposition. Finally toward the end of Cretaceous time clastic deposits buried the entire reef, thus ending limestone deposition.

The clastic deposits contributed to three formations: the Agua Nueva, San Felipe, and Méndez. The Agua Nueva, formed first, is a thin-bedded, dark limestone containing relatively little clastic material. Above this and lapping further eastward over the reef deposits is the San Felipe Formation, comprised of flaggy beds of agrillaceous limestone characteristically about 20 cm in thickness separated by thin zones of yellow shales and marls that color the outcrop. The entire El Abra reef was finally overlain by the Méndez Formation, a generally indistinctly bedded, poorly resistant shale. To the east of the reef, this formation is a few thousand feet thick, but the reef itself was probably not deeply buried.

During the Laramide Orogeny, the Huastecan area was uplifted and warped into a series of north-south trending anticlines. These anticlines characteristically have much steeper dips along their eastern flanks, and the structure of the Sierra de El Abra conforms to this general pattern with dips on the west flank of 10^{o} to 20^{o} and dips on the steeper east flank of 30^{o} to 40^{o}.

Much controversy has surrounded the structure of the Sierra de El Abra, especially that of its steep eastern face. Hime, who did extensive work in the area before 1935, summarized the early work (1940, p. 339) as follows: "In earlier reports the eastern border of the Sierra de El Abra from Quintero [Tamps.] to beyond the Río Tampaón was mapped as a fault. Such a fault may be present locally; e.g., at Quintero between Mante and Canton [El Abra, Tamps.] but wherever there are good outcrops no such fault was visible, the Tamabra [El Abra Limestone] dipping normally under the San Felipe or Méndez beds." He concluded (1940, p. 344) "From there [the south end of the Sierra de Guatemala] the low El Abra range east of the Antiguo Morelos syncline forms the mountain front for 120 K as far as the Río Tampaón. It is a complex low Tamabra [El Abra Limestone] anticline with the steeper limb facing the plain." However, the steepness of the east face continued to suggest a fault, and Muir (1936, p. 35) emended Heim's cross sections to include a fault at the Hotel Taninul located near the southern pass through the Sierra de El Abra. Bonet (1953, p. 246) stated that the eastern face "... está constituída por un gran plano de falla, o mejor de una serie de fallas "en echelon" cuyo plano, que se aproxima a la vertical, es paralelo al plano del anticlinal y muy próximo a él ...", and he even suggested the possibility of a reverse fault (1956, p. 91) although a geologic map included with this publication indicated only an anticlinal structure. Other maps indicating the latter structure for the Sierra de El Abra are Murray's (1961) tectonic map of the coastal provinces in eastern México and the tectonic map of México of de Cserna (1968). Rose (1963, p. 61) stated "At the paso dé El Abra the massif is an asymmetrical anticline."

Other ideas have been advanced to explain the steepness of the eastern slope of the Sierra de El Abra. Heim (1940) realized that the El Abra reef represented the boundary between deep water and shallow water, and Rose (1963) felt that "The precipitous eastern front was merely an abrupt steep platform edge." This idea was further enlarged by Griffith, Pitcher, and Rice (1969) who stated that "As in some other prominent reef fronts, such as the Mississipian and Virgillian bioherms in the Sacremento Mountains of New Mexico and the Permian reef front of West Texas, the El Abra reef facies corresponds to the present escarpment." That is, erosion has removed the soft Méndez Formation that filled the area to the east of the reef, leaving the reef limestone standing above the coastal plain. However, if this were true then the wave-washed "reef" zone in the El Abra reef would had to have been no more than a few hundred m wide since the present exposure of Taninul Member along the escarpment is but a few hundred m wide. It is unlikely that the "reef" zone was so limited in width since wells drilled to the east of the Sierra de El Abra have encountered Taninul Member limestone (Rose, 1963), and to the north in the Sierra de Guatemala where the entire reef sequence is exposed, the Taninul Member is about 8 km wide.

The idea of faulting is appealing because of the steepness of the slope, and it is difficult to refute since exposures are generally poor. However, it is unlikely that a fault could follow exactly the undulating contact between the Taninul Member and the El Abra Member which is aligned with the undulating face of the scarp as we have noted at several locations along the length of the range. It is this alignment of the east face of the Sierra de El Abra and the western edge of the Taninul Member which indicates that the growth of the Cretaceous reef and the structure of the present Sierra de El Abra are related. It is likely that the growth of the El Abra reef along the edge of the platform was controlled by a deep-seated structure now buried beneath the Cretaceous sediments. This structure, possibly a relatively high area of basement rock, was able to resist deformation and formed the edge of the carbonate platform. Upon this structure grew many hundreds of m of massive reef limestone while structurally weaker limestone was deposited to the west and soft shales to the east.

It may be suggested that when the area was compressed during the Laramide Orogeny, the massive reef and its underlying structure strongly resisted deformation, and the weaker, bedded, backreef limestones were folded against the massive Taninul Member. The Taninul Member was deformed only locally where it integrated with the El Abra Member, and the western edge of the Taninul Member was rotated upward to form the steeply dipping eastern edge of the Sierra de El Abra. Bedding planes in the Méndez and San Felipe Formations adjacent to the escarpment agree with the generally indistinct bedding planes in the Taninul Member of 30° to 40° indicating that the Taninul dips are dips off of the eastern limb of the anticline and nor large scale cross bedding as might be expected to occur in the forereef talus formed originally a few km to the east. Further, the steepness of the slope of the escarpment has been enhanced in favorable localities as solution has removed material from the base of the escarpment. Concentration of water on the adjacent, flat coastal plain has caused the solutional encroachment of the plain into the scarp. For example, at the Nacimiento del Río Santa Clara this encroachment has progressed about 1/2 km as demonstrated by the extension of the Taninul Member eastward from the base of the escarpment.

The present surface of the range is an almost perfectly stripped structural surface. There has been so little modification of this surface that in places traces of drainage systems which once existed on the overlying impervious strata may still be seen from the air.

The broader anticline forming the Sierra de Guatemala rises out of the northern end of the Valle de Antiguo Morelos. It is physically continuous with both the Sierra de El Abra and the Sierra de Nicolás Pérez. North of Chamal, Tamps., the Sierra de Guatemala rises rapidly, and west of Encino, Tamps., it reaches elevations of about 2,200 m. The range then declines slightly toward the north where the narrow canyon of the Río Guayalejo crosses the anticline. The western boundary of the range is a relatively low valley which extends northward from Ocampo, Tamps., to the Río Guayalejo. The western slope is developed on the bedded El Abra Member, the eastern front on the Taninul Member. The latter member extends several km to the west, unlike its extension in the Sierra de El Abra, but its exact extent is not yet well known because of the great difficulty in moving about in this rugged range.

The limestone of the Sierra de Guatemala has in the past been variously designated as "Tamaulipas" and "El Doctor". Tamaulipas Limestone is, however, that thin-bedded limestone which was deposited in deep water to the east of the Cretaceous reef front and, in the Sierra de Guatemala, is restricted to the eastern edge of the range north of the Nacimiento del Rio Frio. The term "El Doctor Limestone" is so broadly defined that it essentially designates the whole collection of mid-Cretaceous reef limestones found in the Sierra Madre Oriental. We have chosen to apply the name "El Abra Limestone" to the rocks which comprise the bulk of the Sierra de Guatemala since they are identical in origin with those found in the Sierra de El Abra; indeed they are part of the same reef aggregation. We should also ass that another "reef" of El Abra Limestone existed to the southeast of the El Abra region. This reef, now entirely buried, is well known since its western front forms the world-renowned, oil--producing "Faja de Oro".

The region containing some of the more recently discovered characin caves, the "Micos Area", is not yet as well known as the two previous Sierras, but our recent work in the area permits some considerations. Immediately to the west of the Sierra de la Colmena in the vicinity of Micos, S.L.L., there is a narrow range extending from a wide area of limestone outcrop to the south. Structurally, this ridge is a northward continuation of the thrust fault which forms the frontal range of the Sierra Madre Oriental in the vicinity of Aquismón, S.L.P., 40 km to the south. Almost dying out in the Micos area, the ridge nevertheless continues northward to eventually continue with limestones to the west of the Sierra de Guatemala. This ridge is lithologically similar to the limestone of the Taninul Member. Although the flaggy San Felipe Formation overlies a thick--bedded El Abra Member 2 km to the west, it does not overlie this ridge. The absence of the San Felipe here is possibly due either to deposition of massive reef limestone at this locality while San Felipe was being deposited elsewhere, or to thrusting of a sheet of limestone of Taninul lithology into the Micos area from its original position to the west. Whatever may be the explanation, the absence of the San Felipe Formation from this ridge is of great consequence since this formation usually forms flanking slopes and hills which protect the El Abra Limestone from solutional attack.

In the intermountain valleys in the region of the Sierra de El Abra there still persist large outcrops of Méndez marls and shales now removed from the mountains themselves. Also persisting in some areas, especially along the western side of the Sierra de El Abra, is the relatively insoluable San Felipe Formation. The impervious Méndez and San Felipe are of great importance in the area since they have permitted the development of surface streams. El Abra Limestone, by contrast, is so permeable that it is essentially devoid of any surface drainage.

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Ba 030

DENDRITIC DRY VALLEYS IN THE CONE KARST OF PUERTO RICO

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INTRODUCCION

The karst topography developed on the limestone formations of Oligocene and Miocene age in northern Puerto Rico contains many dry valleys. Some of these seem to be related to jointing, but many have a pattern that resembles the dendritic drainage of consequent streams. The most perfectly developed dendritic patterns are in canyon-like dry valleys in the Lares Limestone of Oligocene age, west of the town of Ciales.

In the southern part of the Ciales area rocks of Cretaceous to early Tertiary age crop out, consisting mainly of volcanic and intrusive rocks. Most of these rocks are weathered into a thick soil mantle. They are overlain unconformably by the Oligocene San Sebastián Formation of clay, sand, and gravel. The San Sebastián is overlain by the Lares Limestone, which in turn is overlain by a thick sequence of limestone of Oligocene and Miocene age.

The Lares Limestone in the Ciales area consists of 250 meters of thin-bedded to flaky limestone and finely crystalline pink to yellowish-gray limestone. In the area of dry karst valleys farther west, south of Florida, the Lares is overlain on the hill crests by very friable pure calcarenite of the Cibao Formation, which has been indurated into an erosion-resistant limestone and forms prominent cliffs at the top of the canyon walls (Nelson and Monroe, 1966).

The Lares Limestone at most places has been dissolved and eroded to form a cone karst or cockpit karst (Kegelkarst) consisting of steep-sided hills surrounded by irregularly shaped closed depressions. In the area here described the depressions form continuous series of dry valleys rather than isolated depressions.

The area of dry valleys west of Ciales was designated by Lehmann (1954, p. 134, fig. 7) as typical of the type of kegelkarst he called "g e r i c h t e t e K a r s t", or directed Karst. He called attention to depressions between conical peaks arranged in long parallel lines trending south, especially in the Lares Limestone. He lists as reasons for the directed karst, the influence of the joint systems and outcrops of alternating resistant and less resistant strata.

DESCRIPTION OF THE DRY VALLEYS

Figure 1 shows the pattern of the dry valleys in the Ciales area. Two systems of dry valleys show on the map. The eastern system consists of valleys lined with swallow holes that trend north from the top of the valley wall of the Río Cialitos to a dry abandoned meander of the Río Grande de Manatí. The abandoned meanders of the river are also dry valleys, which are lined with swallow holes like those in the dendritic dry valleys. The longest of the dry valleys in this system starts at an altitude of about 310 meters and trends generally north northeast to an abandoned meander which has an altitude of about 85 meters above sea level, about 60 meters above the present valley floor of the Río Grande de Manatí. The dry valleys in this system are rock canyons averaging about 50 meters wide with walls about 70 meters high. As there is at present no through drainage in any of these valleys, all drainage is underground, except immediately up slope from swallow holes during heavy rainstorms.

The western part of the figure contains a long dry valley, which has several tributary valleys, and a number of shorter dry valleys. The longest valley trends generally west beyond the longitude of Florida and then bends abruptly north. The bottom of the long valley drops from an altitude of 290 meters at its southeastern end to an altitude of about 220 meters at the west, a drop of about 70 meters in 11.4 kilometers. The valley is a steep-sided canyon whose limestone walls range in height from 35 to 115 meters, averaging 75 meters. The width of the canyon at the bottom is mostly less than 100 meters, but at one place it widens to a maximum of about 200 meters. The bottom of the canyon is very irregular, as it is interrupted every 200-500 meters by swallow holes, commonly consisting of rather large basins having small vertical or steep-sided holes in the soil that has accumulated by washing down slope from the divides between the swallow holes. This mass of soil and alluvium is relatively thin, but its thickness is not known. The composition at most places consists entirely of clay, but in some of the depressions a few grains of quartz

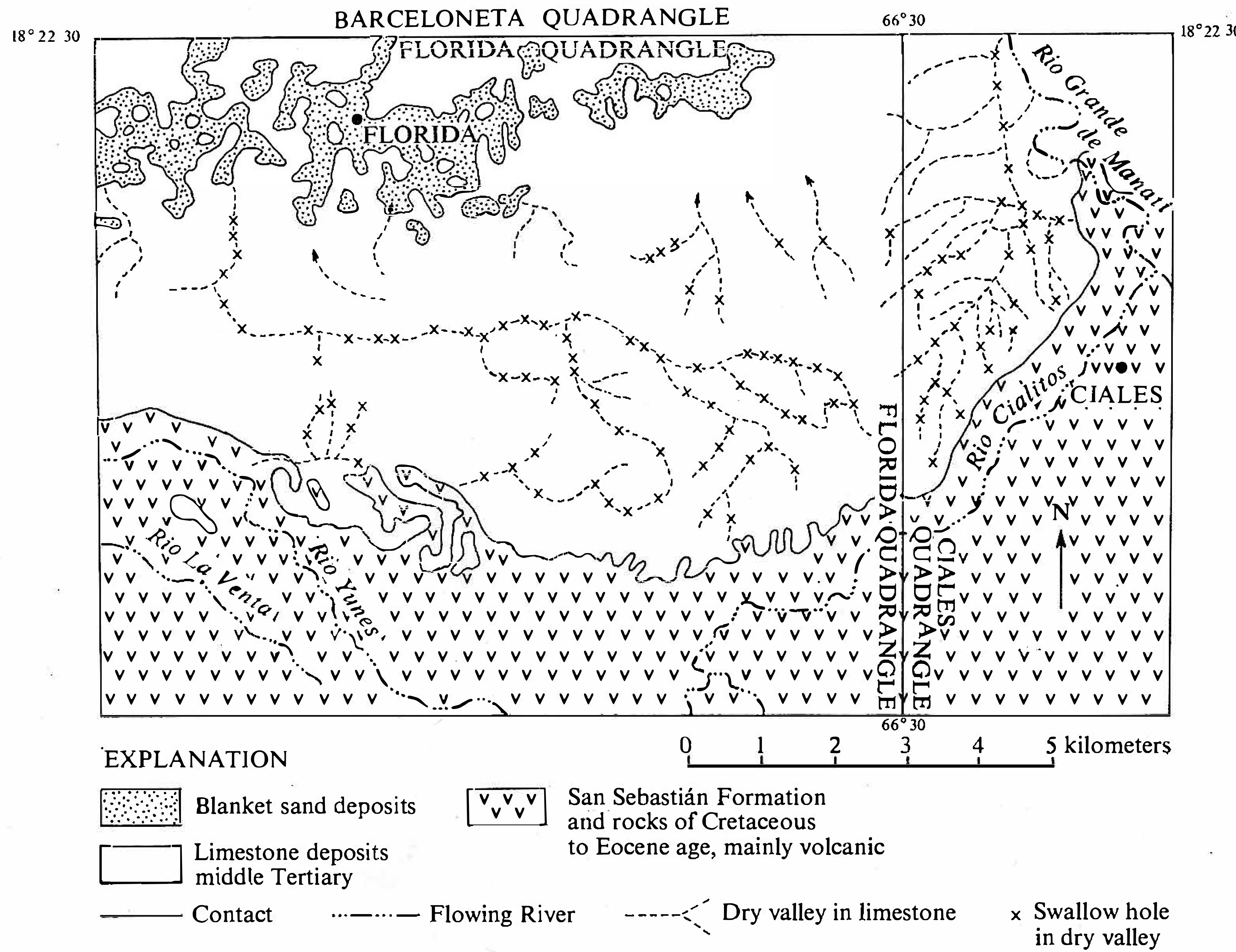

Fig. 1. Geologic map of area west of Ciales, Puerto Rico.

were observed. Between the swallow holes the soil cover is relatively thin and at many places bare rock is at the surface.

Hildebrand (1960) collected about 10 samples of the clay at the bottom of this series of dry valleys. He studied the samples by X-ray powder diffraction methods. He found quartz, anatase, and kaolinite in nearly all samples; other minerals found in some samples include boehmite, goethite, hematite, halloysite, oligoclase, sanidine, unidentified feldspar minerals, and organic matter. He believed that the deposits were derived from volcanic rock grains carried into the area from the mountains to the south.

PROBABLE ORIGIN OF THE VALLEYS

The origin of the valleys is undoubtedly related to the history of the Río Grande de Manatí, which acts today, and most likely in the past, as the karst base level of the area. After deposition of the entire sequence of marine limestone of Oligocene and Miocene age, the river carved a part of its present valley following a meandering course northward.

The dendritic pattern of the karst valleys suggests that the limestone was covered by noncalcareous sediments. The postulated cover must have been deposited at a time when the bed of the Río Grande de Manatí, 2 kilometers north of Ciales, was at an altitude of about 100 meters above sea level, or about 70 meters above the present level during the Pliocene or the very early Pleistocene. The cover of clastic material itself was probably an alluvial fan deposit washed off the upland of Cretaceous volcanic rocks wouthwest of Ciales. This upland now has a ridge crest altitude of 500-600 meters above sea level, but it has been deeply dissected by streams that appear to be extremely young in geomorphic terms. An alluvial fan was deposited on the limestone surface at an altitude of slightly less than 400 meters before the Río Cialitos had excavated its deep valley from the upland to the Río Grande de Manatí. The postulated alluvial cover was probably less than 20 meters thick& a dendritic drainage system developed rapidly having the pattern shown in figure 1. Erosion soon exposed the hard limestone and the drainage system that flowed to the Río Grande de Manatí began to entrench itself into the limestone. The form of the valleys was determined by the overlying drainage network, and the combination of steep-gradient streams heavily loaded with sediment caused fairly rapid erosion and entrenchment. As the water came in contact with the limestone, karstification began with some loss of water to the underground. As the underground drainage network developed more of the surface drainage went underground and swallow holes got deeper approaching the condition of today.

Presumably the Río Cialitos began as drainage to the Río Grande de Manatí on the more easily eroded beds in the lower part of the Lares Limestone, the San Sebastián Formation, and the underlying weathered rocks of the volcanic-intrusive complex. These rocks weather chemically faster than exposed hard limestone, for the limestone soon acquires a very hard surface crust (Monroe, 1966), which is resistant to solution and erosion and which sheds water rapidly during hard tropical rainstorms. The volcanic and intrusive rocks of Cretaceous to Eocene age do not form such a surface crust and erosion proceeds as rapidly as weathering can take place. The rapid differential erosion by the Río Cialitos soon produced a steep-sided valley at the side of which the indurated Lares Limestone formed a cliff face. Erosion of the ancestral Río Cialitos cut off all source of alluvium and a large part of the water supply for the dendritic valleys, and they received only the local rainfall. The underground drainage network could handle this quantity of water very easily, so that surface flow, except for a few hundred meters up stream from the swallow holes ceased.

In the area to the west a continuation of the alluvial fan covered the limestone, probably as far north as Florida. As no large river, such as the Río Grande de Manatí was present, drainge probably was generally toward the north. After a very little erosion a barrier to northward drainage was reached, when the erosion-resistant limestone member of the Cibao Formation was reached. Drainage was then diverted to the west until the cuesta of limestone was breached.

North of the dry valleys, near Florida, is the southernmost belt in Puerto Rico of the "blanket sands". Briggs (1966) believed that the parent material of the blanket sands was carried to the area by rivers, that the parent material consisted of debris derived from volcanic rocks, and that it was weathered by laterization processes into the present mass of sandy clay. It is likely that the anomalous blanket sands of the Florida area are the highly weathered residue of the alluvium of the ancient alluvial fan, eroded from the surface by streams and deposited in the lowland near Florida, which is a short distance south of another prominent cuesta scarp.

Cone karst is present in some areas in Puerto Rico not near such a trunk stream as the Río Grande de Manatí. In these areas the depressions seem to be alined for short distances, but no dendritic pattern was detected on aerial photographs or topigraphic maps. The alinement in these areas is probably controlled by joint systems as suggested by Lehmann (1954).

CONCLUSIONS

The alinement of karst depressions in dry valleys which form a dendritic pattern suggests that the valleys are superposed from drainage on a former cover of clastic material. Such a cover could have existed as alluvial fans deposited on the limestone during the later Tertiary before incision of the minor tributaries of trunk rivers.

Discovery of the dendritic dry valleys in Puerto Rico suggests that the cone karst areas of Jamaica, Java, and other tropical areas be reexamined to see whether such patterns are common to most areas of cone karst.

RÉSUMÉ

Les dépressions karstiques dans le kegelkarst de la circonscription vers l'ouest de Ciales situées dans la Formation Calcaire de Lares sont alignées en vallées sèches qui forment un dessin dendritique. Ces vallées enregistrent manifestement l'existence antérieure d'un manteau sédimentaire non calcaire qui fut deposé sur le calcaire pendant le tertiaire supérieur. Ces vallées furent erodées pendant le pliocène dernier ou au commencement du quaternaire, quand le niveau de la mer était pour le moins 80 mètres plus haut qu'à présent.

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Ba 031

LOS CAYOS DE SAN FELIPE: UN VALLE CARSICO INTRAMONTANO ANULAR

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INTRODUCTION

Entre los más pintorescos y bellos y, al mismo tiempo, más interesantes accidentes geográficos de la sierra de los Organos, en el Occidente de Cuba, se encuentra el curioso valle llamado L o s C a y o s d e S a n F e l i p e, depresión de forma casi anular abierta entre el extenso lomerío de arcillas pizarrosas y areniscas en cuyo centro se elevan abruptamente los mogotes calizos. Precisamente el nombre de L o s C a y o s alude al aislamiento de tales empinados mogotes solitarios, que como gemas orográficas se engastan entre el quebrado lomerío de forma más suave, cubierto por pinares.

Como sabemos los mogotes, de morfología cónica, se presentan como una sucesión de lomos de descomunales paquidermos por espacio de 90 km, desde Guane, en el extremo occidental cubano, hasta el valle del río Caiguanabo o San Diego, formando lo que pudiéramos llamar una de las capitales del carso tropical, con sus mogotes en forma de airosas cúpulas que encierran preciosos valles intramontanos, casi siempre rodeados de un lado por tales mogotes, y por otro, por las lomas pizarrosas, formándose así los v a l l e s c á r s i c o s i n t r a m o n t a n o s (sensu Núñez Jiménez), donde el drenaje se efectúa subterráneamente a través de las extensas y numerosas cavernas que van trasladando así, año tras año, los derrumbes y arrastres que arrancan las aguas en el seno del valle, ampliándolo, mientras que los mogotes se reducen por el proceso químico de la disolución cársica.

En medio de la majestad de esos valles, como en el de Viñales, se elevan, aislados, los mogotes solitarios.

Pues bien, alejados del espinazo de la sierra de los Organos, rodeada enteramente por las lomas redondeadas constituídas por arcillas

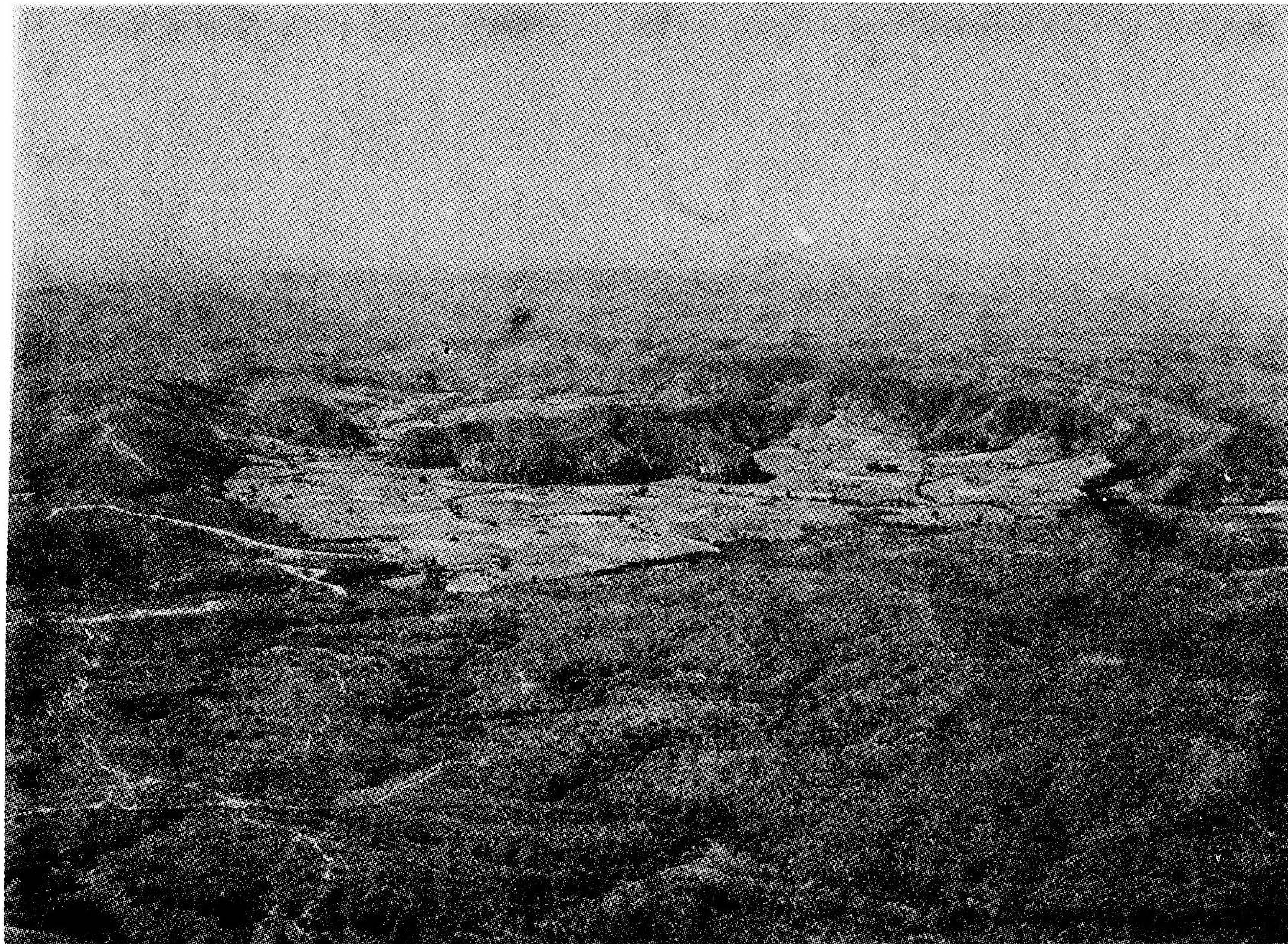

Fig. 1. Los Cayos de San Felipe. Al centro los mogotes calizos. Foto aérea dr A.N.J.

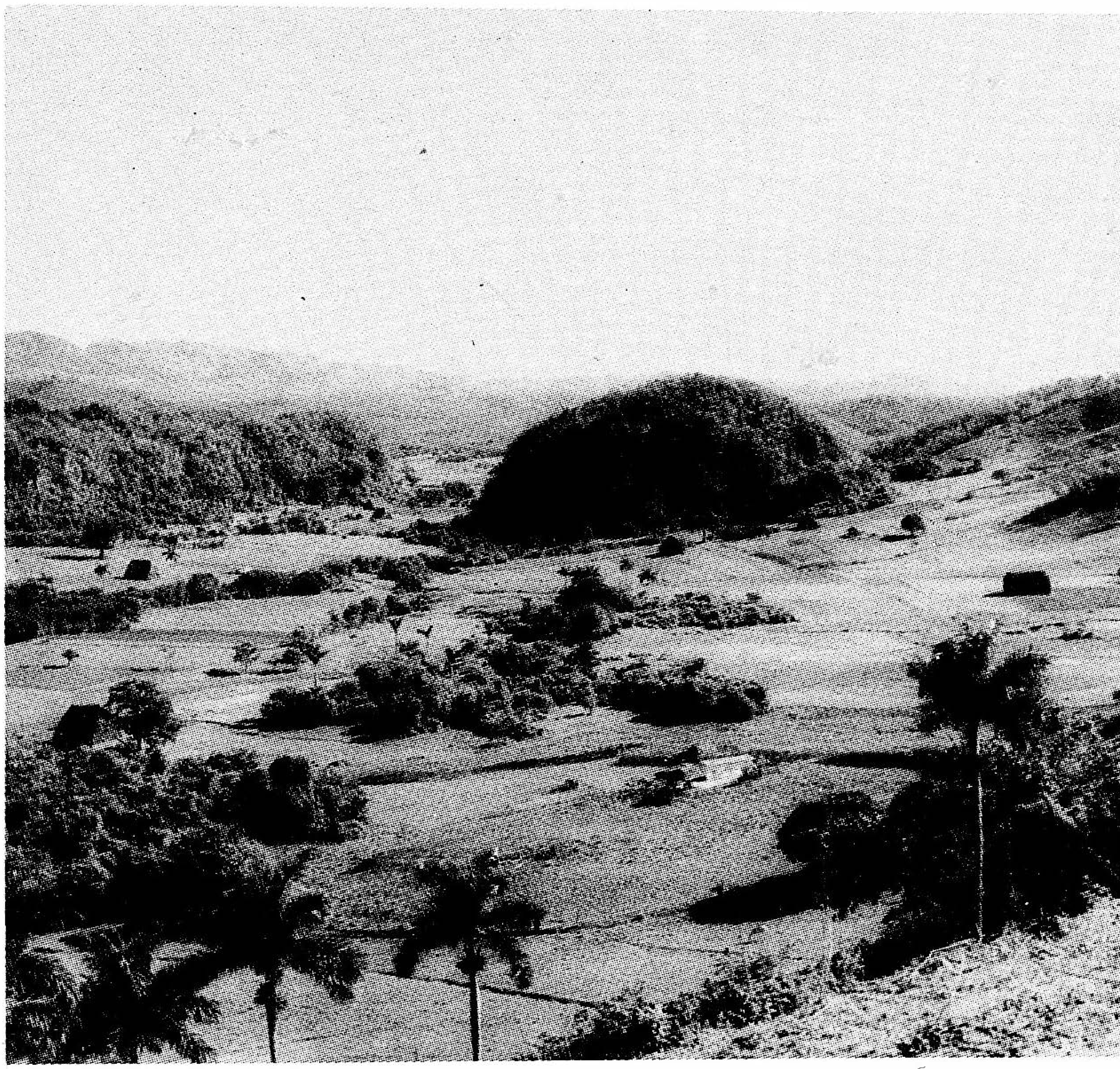

Fig. 2. La polja cársica marginal de Los Cayos de San Felipe. Foto A.N.J.

pizarrosas, se - yerguen grupos de mogotes, cubiertos por su típica vegetación tropical.

Por su aislamiento del eje de la sierra de los Organos, tales mogotes y los valles que se extienden a sus pies, recibieron por parte de los primeros colonos españoles el nombre de c a y o s (*)

(*) Es de destacarse que el nombre de L o s C a y o s d e S a n F e l i p e aparece ya en las mercedes de tierras otorgadas el día 27 de Agosto de 1666, aunque antes, el 3 de Julio de 1613 ya se había otorgado licencia para hacer allí una población (Bernardo y Estrada, Rodrigo, 1857).

y constituyen, por su alejamiento de las rutas usuales hasta hoy, uno de los paisajes menos conocidos de nuestro país.

Los c a y o s han sido utilizados por los agricultores para sembrar tabaco de alta calidad.

La primera vez que vimos L o s C a y o s d e S a n F e l i p e fue en 1959, cuando volábamos en helicóptero desde el valle de Viñales a la Sierra de Quemados. Pudimos contemplar así, entre el extensísimo e intrincado lomerío cubierto de pinares, un valle o depresión, que encerraba un grupo de bellísimos mogotes, tomando en aquella oportunidad, la fotografía que reproducimos como la figura 1 de esta monografía.

Excursiones posteriores por tierra, realizadas gradias a los caminos construídos por la Revolución, fue que pudimos llegar en 1967 a L o s C a y o s d e S a n F e l i p e; posteriormente hicimos varias excursiones en compañía de Leovigildo Gonzáles, Fernando Jiménez, Jesús Francisco de Albear y María Luisa de la Nuez de la Academia de Ciencias de Cuba y el eminente geélogo polaco Kazimierz Guzik.

SITUACION

El valle de L o s C a y o s d e S a n F e l i p e está situaco a 8,5 km al SW del pueblo de Vinales; a 7 km al Sur de la sierra del Infierno y a 7 km al E de la sierra de Quemado, donde se abre la G r a n C a v e r n a d e S a n t o T o m á s.

DESCRIPCION

El valle, de forma más o menos anular, tiene aproximadamente 1,5 km de largo y como hemos dicho, está rodeado como un anillo por lomas arcillosas y areniscas y en su centro se eleva una serie de mogotes, el mayor de los cuales, el C e n t r a l, tiene una base de 1 km, mientras que su altura máxima sobre la superficie del valle es de 90 m, siendo su altitud de 230 m sobre el nivel del mar. Otros mogotes más pequeños y aislados se alzan en el extremo SE del valle, algunos semiencajados en la formación arcillosa.

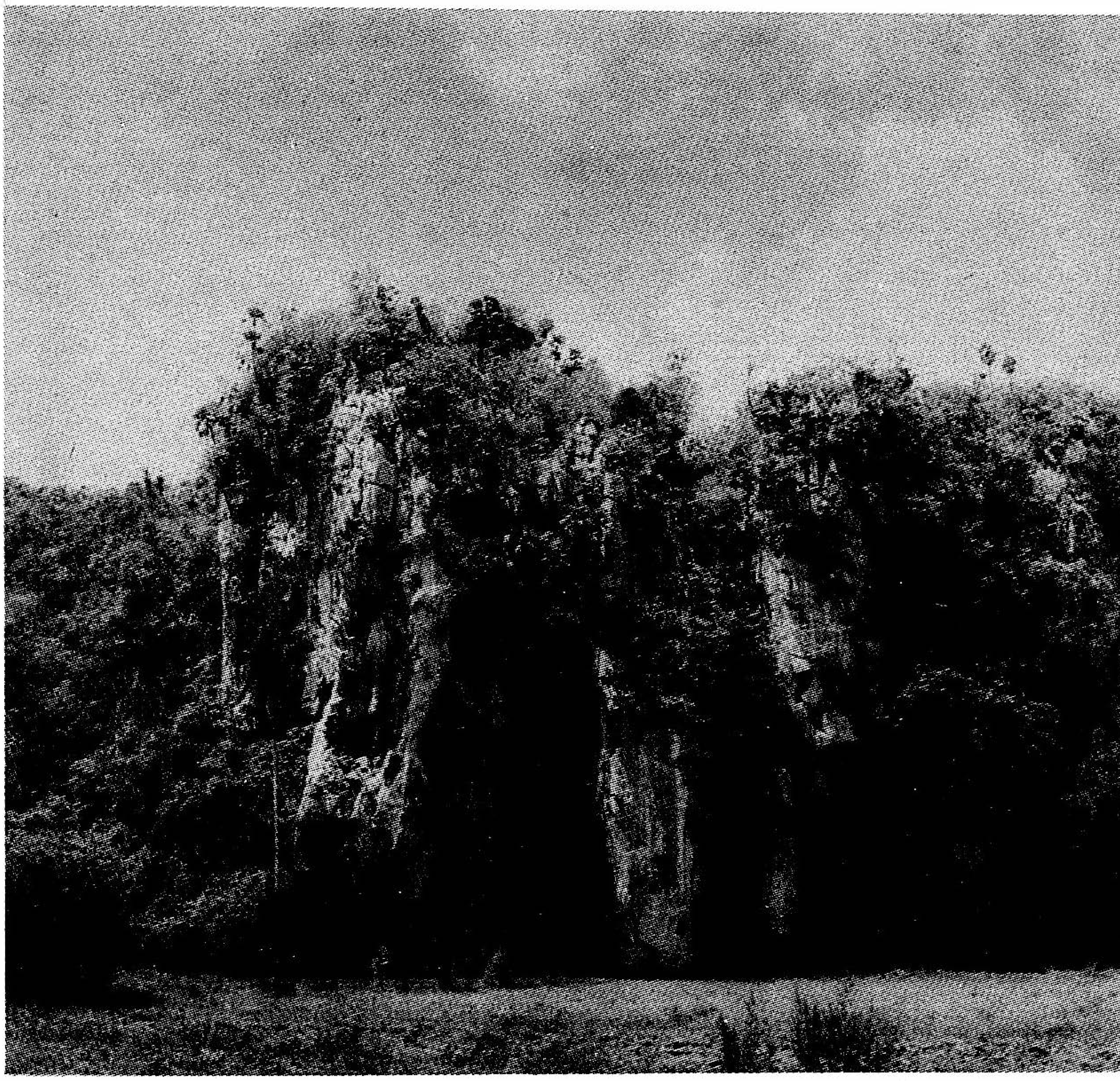

Fig. 3. Ladera del Mogote Central de los Cayos de San Felipe. Foto A.N.J.

La máxima altitud de las lomas arcillosas que rodean el valle llega a 302 m y tiene lugar en la ladera occidental.

Las elevaciones marginales arcillosas del extremo NW del valle se - abren para dejar paso/a las aguas del arroyo Rogero, que fluye de W a E por todo el valle, a lo largo de la base del M o g o t e C e n t r a l por su falda N, saliendo por el extremo del oriente, a través de un abra estrecha de duras areniscas cuyos estratos buzan 27° al W.

El Rogero recibe ínfimos afluentes en el propio valle. Así, por el N le cae el d e l a s B o c a s, y por el S el d e

Vargas, al cual le confluye a su vez el Chorrerón; ambos permanecen secos excepto en la época de lluvia.

El Rogero después de salir del valle lleva sus aguas al río Paso Viejo más adelante llamado Ajiconal, que al final fluye a la costa S.

Uno de los rasgos distintivos entre los valles de Viñales y Los Cayos de San Felipe, es que el drenaje del primero es en parte subterráneo, mientras que en el segundo el drenaje es enteramente superficial, aunque existen evidencias que el valle cársico intramontano de Los Cayos de San Felipe en tiempos remotos también tuvo su drenaje a través de cuevas abiertas en los mogotes, es decir que este último valle representa una etapa más antigua que el de Vinales.

Actualmente en el valle se han constituído las cooperativas agrícolas Niceto Pérez y Rubén López, organizadas por la Asociación Nacional de Agricultores Pequeños.

LOS MOGOTES

Claramente se ve que esos mogotes aislados que se levantan en el valle, formaban una masa continua y que comenzaron a quedar aislados unos de los otros gracias a las fallas que los quebraron, línea que marcó el camino para el ataque de la erosión física y química, que fue separando los bloques hasta aislarlos completamente.

En el paisaje de Los Cayos de San Felipe se puede ver el proceso evolutivo del fenómeno anterior. Así el Mogote Central, al más grande como hemos dicho, presenta su planta en forma lobulada: cada lóbulo se ve parcialmente separado por una falla, mostrando la tendencia a quedar aislados de la masa o núcleo.

Entre los lóbulos que marginan los abruptos farallones del gran mogote, quedan abiertas las ensenadas, así llamadas con precisión por los campesinos de la sierra de los Organos. A veces estas ensenadas pueden ser antiguas poljas o dolinas, semi-destruídas por uno de sus lados.

La más notable ensenada del Mogote Central es la del Congo, de unos 200 m de fondo, por unos 100 de ancho. Está situada en la ladera oriental del mogote; otra ensenada es la Perico Vargas, abierta en la ladera occidental.

El tan citado mogote presenta en su interior h o y o s a los cuales es dable llegar a través de cuevas que fueron antiguas corrientes fluviales. Algunos de esos h o y o s como el de Emilio, casi destruído por su ladera oriental, sirve a los campesinos para sus siembras de plátano y café (Coordenada 153-043) de la hoja 3483 IV (*).

A unos 100 m al SE del M o g o t e C e n t r a l y completamente separado del mismo, se alza el M o g o t e d e A n t o n i c a, también llamado L a C u r a n d e r a, que se reclina engastado en las suaves pendientes de las lomas arcillosas, mientras que su frente occidental sobresale sin contacto con las arcillas pizarrosas, es decir es un mogote en parte unido a las citadas alturas arcillosas, al igual que otros como los de C a r l o s R o d r í g u e z, situado en la ladera sudoriental, mientras que los del centro del valle se elevan como torres aisladas, caso del M o g o t e d e M á r m o l, llamado así por nosotros por haber constituído una cantera de donde sacaban bloques de fino málmol negro.

El proceso de la disolución de los mogotes se ve en toda su secuencia en L o s C a y o s d e S a n F e l i p e: su última expresión son los bloques o lentes de calizas a veces de sólo 1 m de alto que se alzan en el fondo del valle como d i e n t e d e p e r r o (lapiés).

LA CUEVA DEL HOYO

En el M o g o t e C e n t r a l exploramos la llamada C u e v a d e l H o y o situada en su extremo septentrional (aproximadamente en las coordenadas 153-047 de la hoja 3483 IV), elevada a unos 35 m sobre el suelo del valle y que presenta un sistema de cuatro galerías subterráneas superpuestas, que como pudimos comprobar fueron cauces sucesivos de un río ya desaparecido que en épocas muy remotas atravesó el mogote.

La C u e v a d e l H o y o corresponde al tercer nivel y es la única explorable, pues la otra, la superior y las dos inferiores, están casi completamente obstruídas por duros y muy antiguos conglomerados formados principalmente por cantos rodados cementados por arcilla y areniscas.

(*) Carta de Cuba, Instituto de Geodesia y Cartografía, Escala 1 : 50.000.

La C u e v a d e l H o y o tiene su boca de 6 m de ancho por 4 de alto, con 45 de largo.

Tan pronto se pasa del primer y amplio salón, le sigue una estrechez por la que se avanza a rastras, siguiendo entonces la galería con una altura de 1 a 2 m.

En el techo se observan formaciones secundarias como estalactitas y otras que las semejan, pero que son estructurales, es decir d e c k e n k a r r e n o l a p i é s del techo, modeladas por disolución sobre la roca caliza.

Adosadas al piso y a las paredes observamos grandes conglomerados fósiles, endurecidos, de origen típicamente fluvial.

Esta cueva nos condujo hasta un h o y o o dolina, de 33 m de ancho (de E a W) por 45 m de largo (de N a S).

En la pared del hoyo se ve la continuación de la cueva, tapiada por arrastres, probándonos que el primitivo río que generó la cueva pasaba antes por la masa caliza que luego, al desaparecer, desconectó el sistema subterráneo, dando origen al h o y o, formado por el derrumbe de las propias bóvedas cavernarias y por el proceso de profundización de la disolución, que hoy forma en su rocoso piso, grandes d i e n t e d e p e r r o, sobre los que yacen también los bloques rocosos desplomados. También en el caótico piso del h o y o observamos sumideros verticales.

El hecho de que en el piso del h o y o se vea la roca estructural caliza no cubierta por arrastres, se otro índice de que no fungió como cauce de los ríos subterráneos y a que dicho h o y o es posterior al de las cuevas superiores.

En la boca de la cueva más alta, por el lado de la pared occidental del h o y o, a unos pocos metros sobre la salida de la cueva que nos condujo hasta aquí, observamos dos proyecciones como plataformas, a manera de pisos superpuestos. constituídas por arrastres consolidados, indicadores de que en un momento dado la evolución de la cueva, después de haber estado colmada casi completamente por los conglomerados, hubo reactivación de la fluencia, la que erosionó parte de la masa conglomerática, dejando esas plataformas como entrepisos. A tales formaciones espeleológicas les hemos dado el nombre de p l a t a f o r m a s d e a r r a s t r e s.

El mogote, alrededor del h o y o presenta un complejo sistema de diaclasas y fallas casi radiales que desembocan y salen de esta dolina, algunas de las cuales dieron en parte origen a los cauces fluviales subterráneos.

LA CUEVA DEL CAYO

En la ladera NE del mogote de A n t o ñ i c a se abre la llamada C u e v a d e l C a y o (coordenadas 162-041) elevada a unos 10 m de altura sobre el valle, con un amplio salón de entrada, seguida de una galería de 30 m de largo, cerrado por conglomerados de origen fluvial.

Todo el piso de la cueva está cubierto por una capa conglomerática, que se interrumpe solo en el primer salón, donde se puede observar el interesantísimo accidente espeleológico de la p l a t a - f o r m a d e a r r a s t r e s. Las estalactitas sostienen en sus puntas grandes trozos de esa plancha o plataforma conglomerática, que se encuentra separada de la que cubre la galería descrita en el párrafo anterior, pero a igual nivel, indicándonos que por este nivel fluyó un antiguo río; la capa de arrastres formada por esa corriente, al desaparecer su fluencia, se endureció; el goteo de agua filtrado desde la bóveda superior formó estalactitas en el techo, a partir de las cuales se originaron estalagmitas sobre la mencionada capa endurecida de arrastres; posteriormente una corriente vadosa o estacional renovó la fluencia subterránea, filtrándose por debajo de la capa conglomerática, destruyéndola en parte, pero dejando los restos, que como pisos cuelgan hoy de las puntas - de las estalactitas.

Curiosamente las estalagmitas han quedado como suspendidas o colgadas sobre los restos de la capa parcialmente desaparecida y debajo de ésta se extiende el espacio hueco que media ahora entre la capa conglomerática y el piso estructural de la cueva.

OTRAS CUEVAS

Como ya dojimos, durante nuestros recorridos por el M o g o t e C e n t r a l pudimos conocer de la existencia de las siguientes diez cuevas situadas en su ladera occidental:

1. C u e v a d e l o s P i s o s, cercana al H o y o d e E m i l i o .(coordenadas 153-043)
2. C u e v a d e l H o n d ó n, situada a varios metros sobre el suelo del valle (coordenadas 153-045)
3. C u e v a d e l o s H u e s o s (coordenadas 152-046).

4. C u e v a d e P e r a z a, situada en el extremo NW del mogote, (coordenadas 154-046) /de la cual todavía los campesinos mantienen el recuerdo que un espanol de este nombre, situado en la boca de la cueva, tiroteó a las tropas del General Antonio Maceo en la Guerra de Independencia.(*)

5. Cerca de la cueva anterior se encuentra la C u e v a d e l H o y o, la cual ya hemos descrito.

6-7. En la ladera septentrional se suceden las cuevas números 6 y 7.

8. Le sigue la C u e v a d e l R í o (coordenadas 156-045) cuya amplia boca, situada sobre la margen S del arroyo Rogero, muestra la morfología de su primitivo origen fluvial.

9-10. Siguiendo la ladera N del mogote se suceden otras dos cuevas.

11. En la ladera N de la e n s e n a d a del Congo hay otra cueva. (Coordenadas 158-045.)

12. Casi en el extremo S del Mogote hay otra espelunca (coordenada 041-158).

13. También se observó otra cueva en la ladera N del mogote de C a r l o s R o d r í g u e z, en el extremo meridional del valle. La cueva puede ser situada en las coordenadas 157-032.

GEOLOGIA Y ORIGEN DEL VALLE

Los mogotes elevados en el centro del valle están constituídos por calizas de las formaciones J a g u a y V i n a l e s del Jurásico Superior (Oxfordiano Superior), y Kmmeredgiano - Titoniano inferior, respectivamente, mientras que las pizarras y arcillas se iden-

(*) "El día tres, (de Octubre de 1896), al amanecer, Maceo se dirigío a los pinares de S a n F e l i p e y Sumidero. Nuestra vanguardia tuvo pendencia con los guerrilleros de Isabel María y con los del Mogote y C a y o s d e S a n F e l i p e. Desde las once hasta las cuatro, se dio un descanso en Pinar de los Cayos; y tras una marcha corta, sin nueva hostilidad, se pernoctó en el asiento de San Felipe. A las siete de la mañana, después de haberse cumplimentado la orden del día anterior, relativa a la destrucción del veguerío de San Felipe, abandonado por sus dueños, se emprendió la marcha para cruzar otra línea fortificada, la de Santa Fe y Murguía, camino de Pinar del Río a Viñales" (Miró Argenter, J. - 1970).

tifican con la Formación S a n C a y e t a n o, del Jurásico Inferior o Medio.

La estructura de la serie de los mogotes muestra una estratigrafía monoclinal y en la ladera Sur occidental del M o g o t e C e n t r a l se aprecia un pliegue tumbado.

En la boca de la C u e v a d e l R í o el buzamiento es de 11° al SWS; en el M o g o t e d e M á r m o l es de 25° al W; los estratos del mogote de C a r l o s R o d r í g u e z buzan 5° al S; en el abra de entrada del río Rogero al valle, los esquistos S a n C a y e t a n o presentan estratigrafía buzando 25° al NNW; en el abra de salida, abierta entra las areniscas duras, el buzamiento es de 27° al W; en el abra del río de las Bocas las areniscas duras y oscuras buzan 55° al NNW; dicha formación yace debajo de las blandas arcillas S a n C a y e t a n o.

La estructura de pliegue tumbado y las otras descritas pudieran indicar un sistema de corrimiento o sobreempuje.

En las fotografías aéreas se observa un sistema de fallas orientado de NE a SW; una notable falla corta el flanco septentrional del valle y por ella fluye un arroyo semi-rectilíneo, afluente del Rogero; mientras que - otra falla orientada casi de N a S, se cruza con la anterior formando el lado oriental de L o s C a y o s d e S a n F e l i p e y por la cual fluye el arroyo de las Dos Bocas; en la línea de esa falla se sucede una alineación de mogotes (A n t o n i c a, E u g e n i o R o d r í g u e z, C a r l o s R o d r í g u e z y otros).

Los factores geológicos anteriores pudieran indicar que el valle tiene un origen inicial tectónico (*) donde un crucero de falla produjo una línea de menos resistencia, aprovechada por las aguas fluviales para efectuar, entre las duras calizas y las blandas pizarras, una erosión diferencial que produjo la forma negativa del accidente geográfico que estudiamos; las calizas, al ser como exhumadas de dentro de la formación S a n C a y e t a n o, comenzaron a ser carsificadas, adquiriendo así su forma mogótica.

(*) Hatten, 1957 y Rigassi-Studer, 1963, clasificaron a L o s C a y o s d e S a n F e l i p e como una ventana geológica.

SUMMARY

One of the most interesting and unknown features in the los Organos mountain range, western Cuba: the San Felipe Cays, is studied. This is a karstic intermountain valley, rather anular or ring-like in shape, formed by an - open plain among argillaceous and sandstone hills rising up, to 302 m around the valley. These hills belong to the sub-region known as Alturas Pizarrosas del Sur (San Cayetano Formation). At the center of the valley some black limestone mogotes rise (Jagua Formation).

The term cayo (cay) used for centuries by peasants to name this feature, seems to indicate the isolation of these solitary mogotes as well as of - this valley surrounded by slate hills.

The valley, some 2.5 kilometres in diametre, is crossed by several brooks which meet on its surface, 70 metres above sea level, and run out in a single stream by a pass opened through the hard sandstone hilles.

The mogotes, which are up to 230 metres high, rise at about 140 metres above the level of the vallend and show caves high above the ground of - obvious fluvial origin, at present fossil, (Type Cuyaguateje), indicating that the floor of the valley was originally at the height of those caves.

The mogotes also show the typical hoyos or dolines, resulting from collapse of former caves ceilings.

In general, the Cayos de San Felipe reproduces on a small seale the whole complecity of the conic karst (carso cónico) of the great Los Organos mountain range:

a) mogotes surrounded by argillaceous hills;

b) among the mogotes and those argillaceous hills, the famouse valleys appear among which and most famous of them all is the worldwide known Vinales;

c) fluvial caves (now fossiles) opened at several levels in these mogotes.

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HOYADA DE LA CATALINA

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SITUACION

La Hoyada de la Catalina está enclavada en la Cordillera de Guaniguanico, entre las sierras de los Organos al Oeste y la del Rosario, al Este, a unos 6 km al Sur del extremo occidental del Pan de Guajaibón, que con sus 692 m de altitud es la cumbre más alta del Occidente de Cuba.

Este interesante fenómeno cársico está situado en una intrincada región, taladrada de numerosas dolinas, furnias y cuevas.

DESCRIPCION

La Hoyada de la Catalina es una polja abierta entre sierras mogóticas y lomas arcillosas que encierran esta depresión en medio de la cual se elevan numerosos mogotes cónicos que vistos desde el aire semejan un campo de cúpulas.

El fondo de La Hoyada está situado a 175 m de altitud, mientras que las alturas circundantes alcanzan hasta 446 m de altitud.

La polja tiene unos 2.5 m de largo de Este a Oeste y una anchura de 1 km, siendo de forma muy irregular.

La Hoyada está marginada en su mayor parte por los abruptos farallones calcáreos de sus mogotes, donde se ensenorea la profusa vegetación tropical, así como también por las suaves pendientes de las lomas arcillosas, alfombradas de pinares.

Los mogotes se elevan solitarios sobre la superficie de la polja, así como en grupos y entre los mismos, en el fondo de la hondonada, se abren furnias que fungen como líneas verticales de drenaje.

El fondo aplanado de La Hoyada está cubierto por arrastres pluviales, procedentes principalmente de las lomas arcillosas, y en él se abren las citadas furnias verticales excavadas a través de los estratos calizos que forman el fondo estructural de la polja y sobre los que descansan los arrastres citados.

Algunos de dichos sumideros permiten su exploración inicial, pero a unos 8 m de profundidad ya los arrastres los cubren; no obstante en época de lluvias tales furnias dejan pasar las aguas al subsuelo, que tal vez deriven hacia la vertiente Norte.

El drenaje superficial ha sido sustituído por el subterráneo y la alta zona carsificada de hecho es la línea divisoria de las aguas: al Noroeste del quebrado territorio las aguas corren hacia el río Caimito, que lleva sus aguas a la costa septentrional; al Sudoeste y al Sur los ríos de Caiguanabo y otros, fluyen hacia la costa meridional.

Es de destacarse que el citado río Caiguanabo, el más caudeloso de la región, nace en las lomas arcillosas que marginan La Hoyada, para después atravesar subterráneamente la sierra de los Organos y salir a la llanura meridional del Occidente por donde llega a la costa Sur.

En la zona de La Hoyada de la Catalina el drenaje superficial es sólo estacional y en forma de pequeños arroyos que bajan de las lomas arcillosas y que cuando la creciente es grande, penetran al subsuelo a través de sumideros embudiformes verticales abiertos en el fondo de la polja.

Los mogotes que se alzan en medio de la polja tienen entre 20 y 60 m de altura sobre su base. Sus casi verticales farallones se ven extraordinariamente plegados, observándose estructuras tumbadas, sucesión de anticlinales y sinclinales, verticales, horizontales, indicándonos una estratigrafía de franco sobreempuje o de cabalgamiento.

Es de destacarse tamtién que dentro de las elevaciones calizas que marginan la polja se abren dolinas casi circulares de más de 200 m de diámetro, con sumideros verticales en su fondo, como la señalada con el nombre de Hoyo del Camino en nuestro corte geológico transversal de La Hoyada de la Catalina.

La Hoyada de la Catalina, descrita por primera vez por el autor (Núñez Jiménez, 1944) no es la única polja de la región, pues a sólo 1.5 km al Norte, se abre la Laguna del Billar cuyo fondo está a unos 200 m de

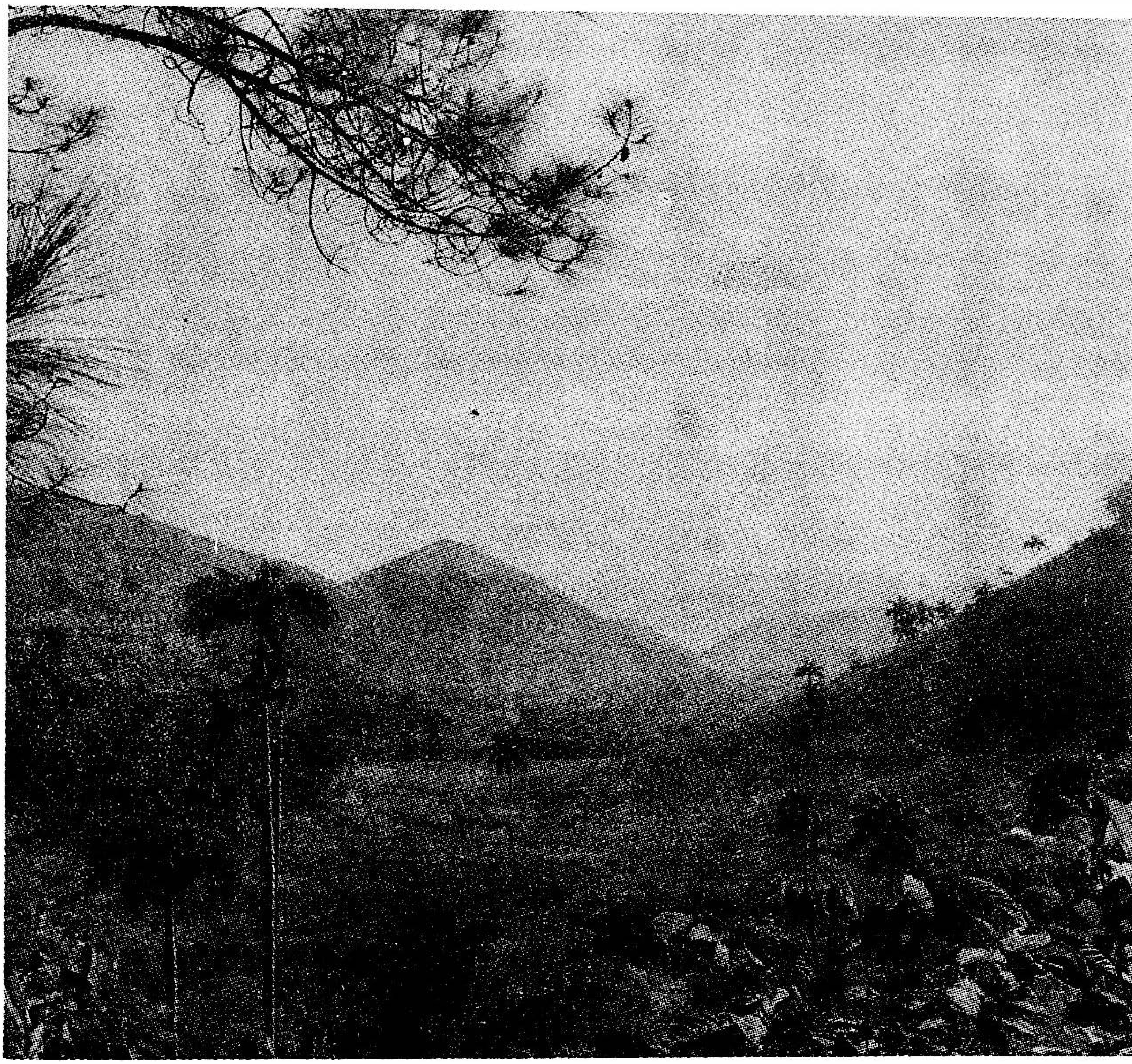

Fig. 1. Polja de la Hoyada de la Catalina. Foto A.N.J.

altitud mientras que - sus márgenes se elevan hasta 446 m; subiendo por el camino estrecho y escabroso - que va de La Hoyada hacia el Pan de Guajaibón se ven otras poljas en el lugar llamado Las Mil Cumbres donde se pueden observar furnias verticales inexploradas como la localizada en las coordenadas 547-241 de la hoja 3584 III de la carta de Cuba a escala 1 : 50.000; otras muchas se ven a ambos lados del camino mencionado.

El paisaje cársico se continúa por muchos kilómetros hacia el Este. En las zonas llamadas Miracielo se ven poljas todavía no estudiadas, al igual que en Sumidero, Vargas, Mameyal y a 15 km en dirección al NNE, ya en plena sierra del Rosario, se llega a la región de Quitacalzones donde se sucede un extrano paisaje de hoyos formados entre elevaciones formadas por una sucesión de estratos calcáreos y arcillosos, es decir que se apartan de las características de las estructuras y formas carsológicas de la sierra de los Organos.

GEOLOGIA

La Hoyada de la Catalina se encuentra ubicada en el gran anticlinorium de Guaniguanico, formado por calizas intercaladas en arcillas, pizarras y areniscas.

El valle del río San Diego de los Banos también llamado Caiguanabo, se toma como punto para la diferenciación de los dos grandes grupos orográficos de la cordillera citada: al Oeste, se extiende la sierra de los Organos y al Este la sierra del Rosario.

En lo fundamental la sierra de los Organos está constituída por potentes estratos de calizas complejamente plegados y fallados, que forman mogotes, a veces intercalados en las pizarras, mientras que la sierra del Rosario, está constituída por capas delgadas carbonatadas y arcillosas.

La zona estudiada aquí, ubicada entre ambas regiones geográficas y geológicas, presenta caracteres más cercanos a la sierra de los Organos.

La edad de las calizas que constituyen los mogotes que casi rodean La Hoyada no está bien determinada; posiblemente se trate del Jurásico Superior o Cretáceo Inferior; estas rocas presentan escasos fósiles, como radiolarios, algunos afines a la especie Globochaete alpina.

Son calizas sumamente plegadas, en estratigrafía de sobreempuje (overthrust).

Los estratos tienen como promedio unos 10 cm de grosor y son de roca gris a casi negra.

Las arcillas que constituyen las lomas parecen también del Jurásico y pueden identificarse con la Formación San Cayetano.

En el corte geológico realizado por el autor a través de La Hoyada de La Catalina, en línea de SW a NE, se observan primero, las lomas de arcillosas pizarrosas, donde se recuestan estratos calizos oscuros, que buzando al Norte monoclinantes forman los mogotes, entre los que se forma el H o y o d e l C a m i n o, una dolina, en cuyas paredes se observa un hermoso pliegue tumbado; en el fondo se ven estratos verticales perforados por una furnia; le sigue un mogote formado por estratos verticales y monoclinales que buzan al SW; el fondo de la polja continúa formado por estratos monoclinales que buzan 35^{o} al NE; siguiéndole un mogote de 20 m de altura que presenta estratigrafía anticlinal y después sinclinal asimétrica; el fondo de la polja continúa con estratos monoclinales con buzamiento de 50^{o} al NNW que están perforados por el S u m i d e r o D o b l e; más al NE los mogotes están más complejamente plegados, como el de C o r r a l i t o s, alcanzando las cimas del extremo noroccidental de la polja una altitud de 400 m.

ORIGEN DE LA HOYADA

El hecho de que la polja esté rodeada al Norte, Este y Sur por serranías calizas y que por el Noroeste la cierren lomas arcillosas, la convierte, según nuestra clasificación en un v a l l e c á r - s i c o i n t r a m o n t a n o, es decir, una polja originada por la combinación de procesos erosivos y de disolución.

Los primeros, los erosivos, actuaron sobre las arcillas a través de las aguas fluviales y pluviales, mientras que los segundos actuaron químicamente sobre las alturas calizas, reduciendo sus formas primitivas a los pintorescos mogotes, cubiertos de vegetación tropical, flora que acentúa la agresividad de las aguas atacantes. Al mismo tiempo la disolución atacó las propias entrañas de los mogotes abriendo en ellos ríos subterráneos a través de diaclasas, fallas y juntas de estratificación.

De hecho, los valles cársicos intramontanos, el más famoso de los cuales es el de Viñales, en la sierra de los Organos, se originan por erosión diferencial entre las calizas duras y las arcillas blandas, más el ataque de la erosión puramente química o disolución.

La zona de contacto entre las calizas y las arcillas fue el punto por donde comenzó a realizarse la apertura de la polja, que presenta su largo máximo o eje, de Este a Oeste; al avanzar la erosión diferencial algunos bloques de la serranía caliza quedaron aislados por el doble ataque de la erosión-disolución, lo que ayudado por factores estructurales y tectónicos (fallas, diaclasas, composición de la roca, estratigrafía, etcétera) quedaron como cúpulas aisladas o unidas a la serranía.

Los mogotes lograron, en parte, la verticalidad de sus paredes debido a los derrumbes de las bocas de las cuevas y solapones, originados al pie de esas elevaciones calizas, mientras que las cimas, atacadas por la disolución, modeló su morfología un tanto cupular.

DIFERENCIA DEL TIPO DE DRENAJE EN LOS VALLES CARSICOS INTRAMONTANOS DE LA SIERRA DE LOS ORGANOS Y DE LA REGION AQUI ESTUDIADA

La diferencia fundamental entre La Hoyada de la Catalina u sus valles análogos de la sierra de los Organos, clasificados por nosotros como valles cársicos intramontanos, es que los de esta última serranía, como el de Viñales, presenta su drenaje a través de las cavernas horizontales abiertas en los mogotes (es decir la línea de desague es horizontal, mientras que en La Hoyada el drenaje actual se realiza por el fondo mismo de la polja, a través de sus furnias o sumideros verticales.

Un dato de tenerse en cuenta es que, en gran medida, el fondo de los - valles cársicos intramontanos de la sierra de los Organos está formado por estructuras impermeables, como las arcillas pizarrosas, mientras que en el caso de La Hoyada, el fondo está constituído por estructuras calizas.

Sin embargo, en La Hoyada de la Catalina hicimos un descubrimiento que puede brindar mucha luz sobre la evolución de estos accidentes cársicos del conjunto de la cordillera de Guaniguanico.

Efectivamente en la ladera NW del mogote de la Manigueta (coordenadas 527-224, hoja 3584-III de la carta de Cuba a escala 1 : 50.000) formado por estratos calizos verticales, se abren dos cuevas superpuestas, horizontales, que a poco de adentrarse aparecen cerradas por cuantíosos arrastres fluviales muy antiguos, indicándonos primitivos ríos, ahora fósiles, que atravesaban el mogote, al igual que en el caso de los típicos v a l l e s c á r s i c o s i n t r a m o n t a n o s de la sierra de los Organos.

El anterior descubrimiento nos indica que originalmente L a H o y a d a tuvo un drenaje horizontal a través de los mogotes, para pasar en la actualidad al vertical a través de su fondo o parte llana, drenaje que combina con - avenida de aguas fluviales estacionales.

SUMMARY

East of Los Organos mountains (western Cuba), in a region that has not been thoroughly studied, where Rosario mountains originates, the H o y a d a d e l a C a - t a l i n a is located. It is a karstic intermountain valley (s e n s u Núñez Jiménez) - surrounded mostly by limestone hills of indetermined age (probably Late Jurasic to Early Cretaceous) as well as by slate hills of S a n C a y e t a n o F o r m a t i o n.

H o y a d a d e l a C a t a l i n a is 6 km South of the Western and of Pan de Guajaibón Hill.

The bottom of the H o y a d a is at 175 m of altitude aproximately, whereas the surrounding hills rise up to 446 m high.

Many conic mogotes, strongly folded, stand on the ground at the H o y a d a.

The main difference between H o y a d a d e l a C a t a l i n a and the typical h o y o s and karstic intermountain valleys at Los Organos, is that in this region the drainage is horizontal, by way of underground water streams piercing the sides of the m o g o t e s, whereas in the H o y a d a the drainage takes place through vertical sinkholes in the limestone surface of the valley.

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Ba 033

SUR QUELQUES ANCIENS TÉMOINS DE LA KARSTIFICATION DE LA RÉGION MÉRIDIONALE DES GRANDS CAUSSES

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Au cours de l'étude hydrogéologique de la région méridionale des Grands Causses (9) et d'une étude morphologique qui lui fit suite (6), nous avons noté l'existence de plusiers formations lithologiques superficielles ou souterraines qui témoignent de l'existence de plusiers phases dans la karstification des Grands Causses.

Nous avons distingué:

1° - Des dépôts de pierailles dus à la gélifraction piégés dans des grottes du Causse ou de l'Avant Causse pouvent être en rapport avec des éboulis de pente consolidés, réduits à des témoins plus ou moins importants, localisés souvent à des niveaux élevés au-dessus des vallées actuelles,

2° - Des cavités fossiles qui représentent des témoins d'une très ancienne karstification,

3° - Des formations carbonatées (tufs et travertins) isolées sur le flanc des montagne au-dessus des niveaux des vallées actuelles, parfois repris dans un système de drainage qui les dissout sans les alimenter.

I. SUR LA PRESENCE DE FORMATIONS DETRITIQUÈ DANS PLUSIERS RESEAUX ACTIFS DE L'AVANT-CAUSSE

I.1 LOCALISATION

Ces formations sont bien représentées dans deux grottes:

- La Grotte Perdue (commune de Versols, 178,2 x 699,9 EM Camarés), trop plein de la Dragonnière de Versols situé dans la vallée du Versolet, affluent dela rive droite de la Sorgues.
- La Dragonnière (commune des Costes Gozon, 73,2 x 86 EM Re-

quista), percée hydrogéologique dans le plateau des Costes Gozon, au NW de St Affrique (Aveyron).

I.2 DESCRIPTION DES FORMATIONS

- D r a g o n i è r e d e s C o s t e s G o z o n (8):

Dans la salle principale du réseau amont, un dépôt de piérrailles calcaires anguleuses a été entaillé en terrasse sur une épaisseur de 1,50 m par le ruisseau souterrain. Ces éléments anguleux, découpés dans la dolomite Hettangienne, ont un caractère homométrique (calibre centimétrique) et possèdent un émoussé de dissolution. Ils ont vraissemblablement été entrainés dans la cavité à la suite de la gélifraction des bancs dolomitiquea de surface.

- G r o t t e P e r d u e (8):

Au fond de la grotte, qui se développe sur un versant NE tout en restant proche de la surface, un cône de piérraille anguleuse, consolidé et fossilisé par une coulée de calcite, encombre la galerie. L´ouverture d´une bouche d´aven apicale (maintenant colmatée) est sans doute à l´origine de cette formation qui, du point de vue granulométrique, possède les mêmes caractères que la précédente.

I.3 INTERPRÉTATION

Ces dépôts de piérraille sont manifestment dus à la gélifraction des bancs dolomitiques de surface au cours des phases froides du Quaternaire, hypothèse confirmée par leur calibre centimétrique et leur homométrie.

Leur origine ancienne est d´ailleurs attestée par leur incision en terrasse dans la Dragonière des Costes Gozon et pa leur fossilisation dans la Grotte Perdue.

Ces formations ont le mérite de nous renseigner sur les conditions d´évolution de quelques réseaux de l´avant-Cause au cours du Quaternaire. Elles soulignent notamment les effets contradictoires des phases froides sur l´evolution de la karstification, effets pouvant sommairement se résumer comme suit:

- en surface: augmentation de la surface de contact offerte à la dissolution par débitage de gélifraction.
- en profondeur: obstruction partielle des conduits par ces

débris avec mobilisation de l'acidité des eaux au détriment des parois; mais parallèlement, accroissement des possibilités de façonnement mécanique.

Ce schéma ne s'applique bien sûr qu'aux cavités dont le système d'alimentation ou la morphologie a permis le "piégeage" de la pierraile: pertes ou avens formant regard sur un écoulement souterrain.

Il semble possible d'étendre ces observations à des formations identiques que nous avons examinées dans certaines grottes des Grands Causse. En particulier, on retrouve ce même type de formation dans toutes les cavités des deux rives du Trevezal (Montjardin, Montfleury, Pas de Joulié, Verrières ...). Il semble également possible de voir analogie entre ces dépôts détritiques et les éboulis de pente consolidés qui jalonnent les rives de la Dourbie, du Tarn et de la Sorgues et dominent le lit actuel de la rivière de plusieurs dizaines ou certaines de mètres (Cantobre, Tiergues, Moulin de Corp ...). Ils sont parfois recouverts par des formations carbonatées, comme dans les grottes (Creissels, St Affrique Tournemire ...). Il faudra un jour étudier les relations entre ces brèches extérieures et celles des grottes.

II. LES TRACES D'ANCIENNES KARSTIFICATION

Au Nord de la vallée du Tarn, sur les premiers contreforts du massif du Levézou, des lambeaux de grès Triasique surmontés de calcaire Hettangien reposent en discordance sur le cristallophyllien. Nous y avons découvert les traces d'une ancienne karstification:

- Un aven fossilisé au lieu dit "Carrière de Montjaux",
- Les restes démantelés d'une cavité karstique également fossilisée au lieu dit "Carrière de la Borie Sèche",
- Des conduits secondaires dans une troisième carrière.

II.1 L'AVEN FOSSILISÉ DE MONTJAUX

- Situation: (X: 83, 7, Y: 92, 3, Z: 810 EM St Beauzely)

L'aven a été dépagé par les travaux d'exploitation d'une

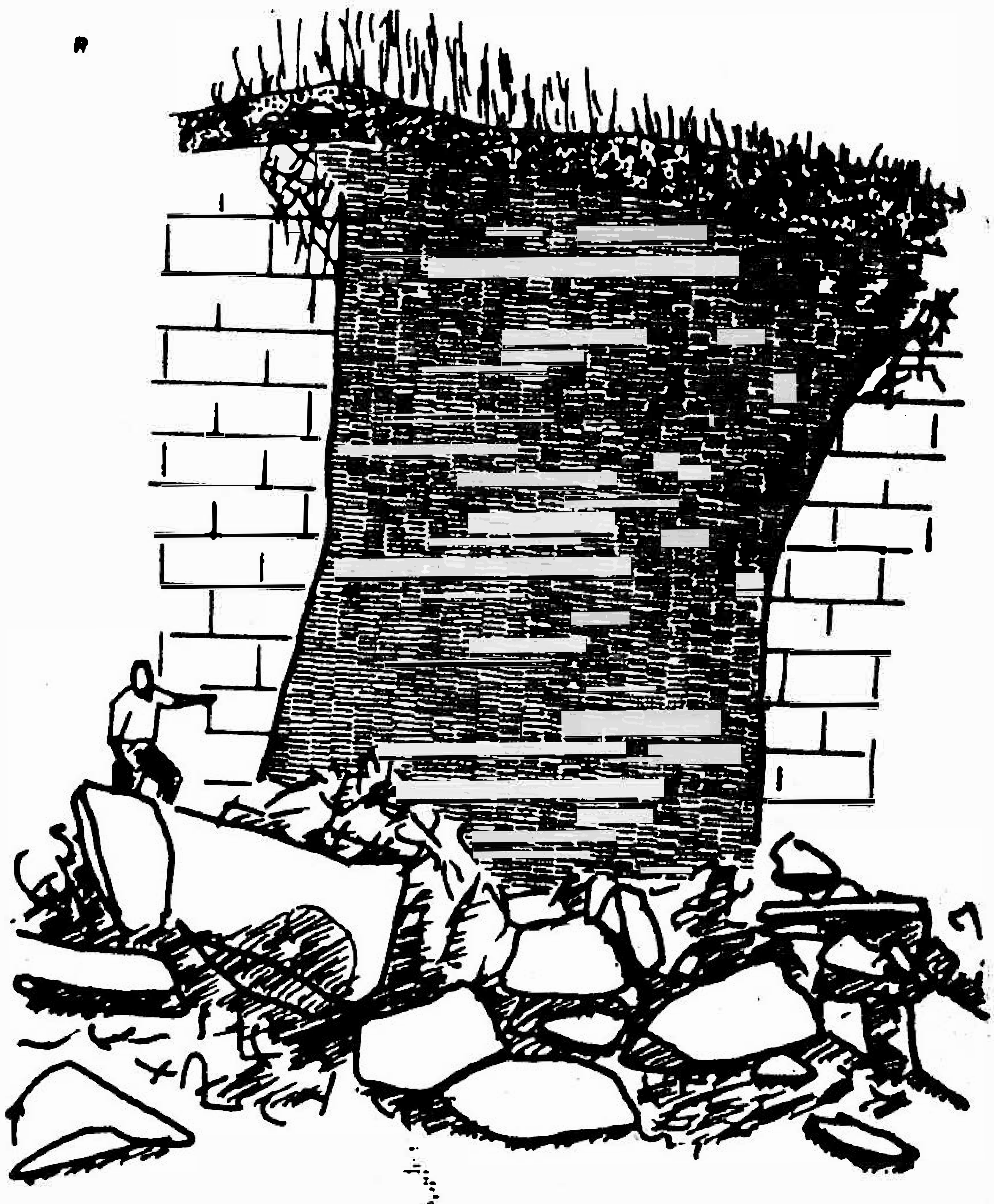
Fig. 1. Principaux tufs et travertins de l'Avant-Cuasse occidental du Larzac.

carrière de calcaire Hettangien à l'Est de Montjaux.

- D e s c r i p t i o n: (fig. 1, fig. 2)

Les dimensions de la partie visible de la cavité sont importantes: 3 mètres de largeur sur 5 mètres de hauteur. L'aven est entièrement fossilisé par une brèche beige à ciment calcaire assimilable à un "Sistre". Les éléments cimentés sont centimétriques et anguleux et possèdent un léger émoussé de dissolution. On distingue

Aven fossilisé de Montjaux (12)



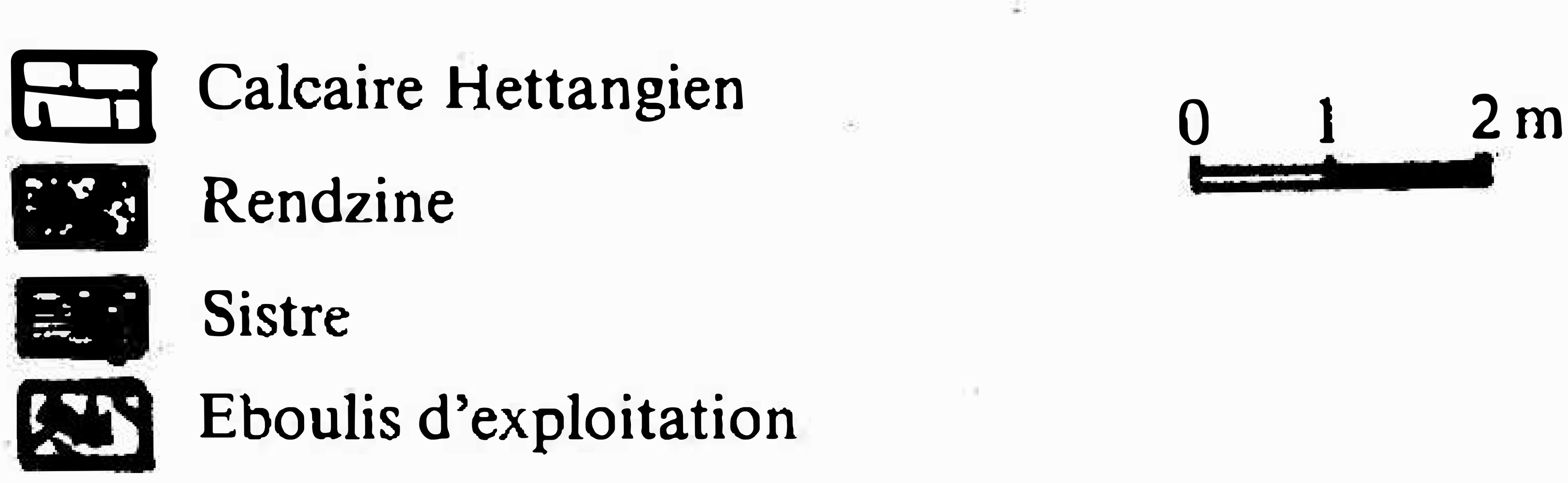


Fig. 2.

sur les parois de l'aven les traces caractéristique de l'érosion karstique.

On rencontre à la périphérie de l'aven l'extension du réseau représentée par des diaclases collectrices inégalement exploitées par la dissolution. Ces diaclases sont colmatées par un micro poudingue contenant quelques éléments de silice appauvrie et des pisolithes d'hématite.

Cavité de la carrière de la Borie Sèche

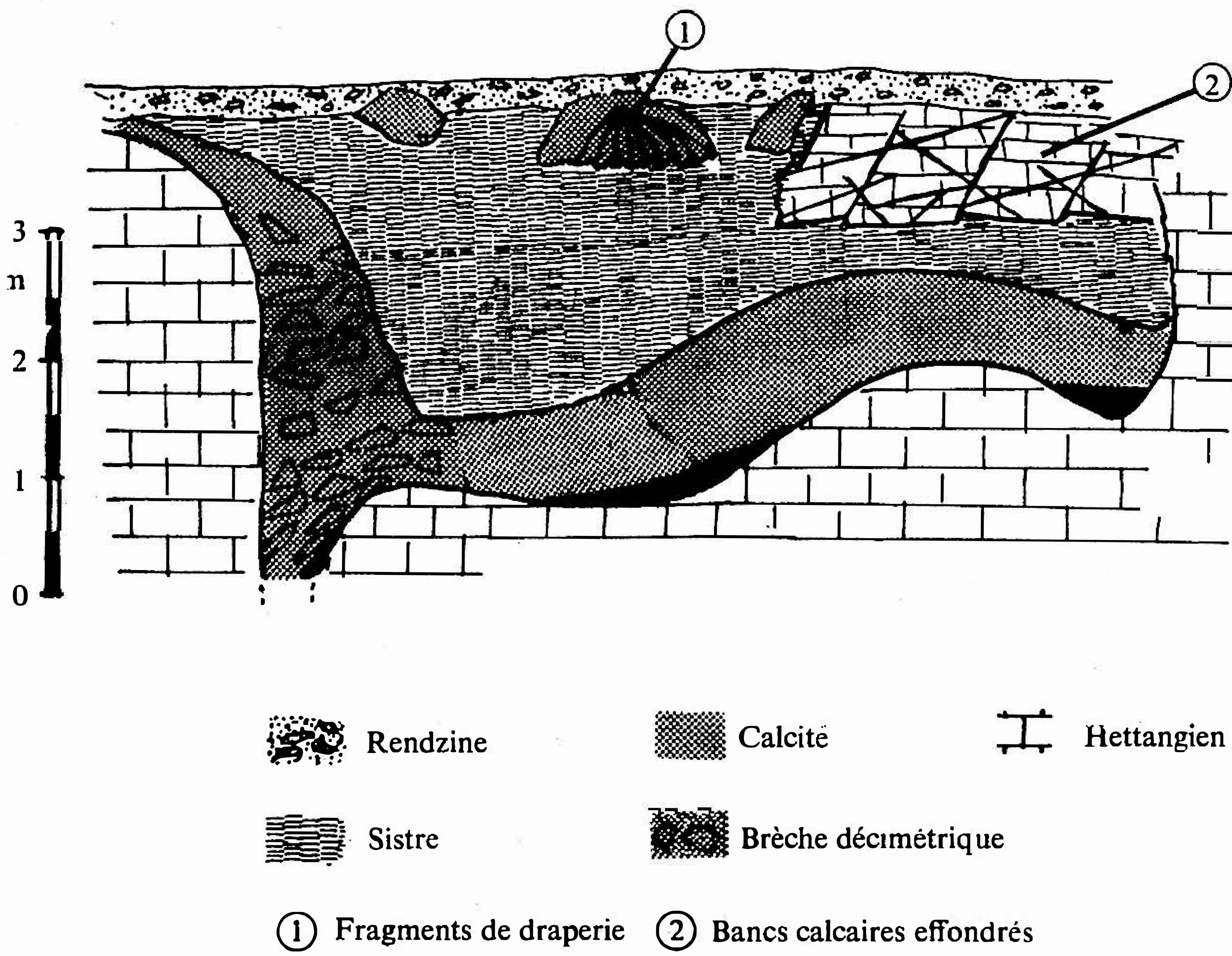


Fig. 3.

II.2 CAVITÉ DE LA BORIE SÈCHE

- S i t u a t i o n: (X: 45, 2, Y: 99, Z: 750 m)(EM Millau)

Dans une carrière de calcaire Hettangien au Sud de Montjaux.

- D e s c r i p t i o n: (fig. 3)

Large de 8 mètres, la cavité n'a plus que 3 mètres de hauteur, le plafond ayant été enlevé par l'érosion, ainsi qu'une partie du remplissage. Le revers du front de taille de la carrière montre de gros blocs de calcite à demi enfouis dans le sol qui permettent d'apprécier le travail de démantèlement et les dimensions primitives de la cavité.

Le remplissage est plus hétérogène que celui de l'aven de Montjaux. On peut ainsi distinguer plusiers niveaux:

- un micro poudingue brun identique à celui des diaclases de la cavité précédente. Cette formation colmate les points bas du réseau.

- un épais plancher stalagmitique de calcite rayonnante blanche repose directement sur les dépôts précédents en les fossilisant.

- une brèche à blocs décimétriques cimentés par la calcite rayonnante prolonge le plancher. L'accumulation des blocs selon une architecture cônique, avec triage des calibres, suppose une bouche d'aven apicale.

- une groize à matrice argilo sableuse et un sistre fossilisant le tout et enrobent de gros fragments de draperies.

II.3 CONDUITS SECONDAIRES

- S i t u a t i o n:

Dans une carrière de calcaire Hettangien au Sud de Montjaux et à une altitude plus basse que les cavité précédentes.

- D e s c r i p t i o n:

Ces petits conduits sont de section cylindrique et se développent sur un plan horizontal, selon un joint de stratification. Ces boyaux sont situés à quelques mètres sous la surface topographique et ne correspondent pas directement avec elle. Leur diamèter n'exéde pas 50 cm.

Leur remplissage est constitué par un micro poudingue identique à ceux rencontrés dans les autres cavités. Cette formation, épaisse de 15 cm environ, est fossilisée sous un plancher de calcite de la meme épaisseurs. Les conduits sont ainsi obstrués jusq'aux 2/3 de leur hauteur. Localement, on relève des bouchons et des placages d'argile brune noyant les formation précédentes.

II.4 ETUDE DES REMPLISSAGES ET INTERPRÉTATION

On peut distinguer trois styles de dépôts soit, de bas en haut:

1) Un micro poudingue contenant des éléments de silice appauvrie et des pisolithes d'hématite faisant penser aux résidus d'une couverture pédologique de type tropical.

2) Des cristallisation de calcite sous forme d'épais planchers stalagmitique.

3) Des dépôts de calcaire gélivé consolidés par un ciment carbonaté et s'apparentant à des "sistres".

Pour le moment, aucune de ces formations n'a livré de faune carastéristique, même au niveau des micromammifères. Le faible volume d'échantillons étudiés peut expliquer cett lacune.

L'étude des minéraux louds, faite par le professeur Demangeon à la faculté des sciences de Montpellier, a permi d'identifier:

- des Zircons cristallophylliens
- des Tourmalines
- des Rutiles
- des Grenats.

Il semble qu'il s'agisse de minéraux lourds en provenance du massif du Levèzou. Ces réseaux auraient dont été alimentés par des pertes de cours d'eau nés sur le cristallin.

Dès à present, nous pouvons dresser le schéma suivant:

1) Transgression triasique puis liasique sur le Levèzou.

2) Compartimentage par des failles jusq'au Miocène. Parallèlement, évolution pédologique du socle cristallin voisin en deux temps:

- sous climat chaus et humide, altération ferralitique et migration de la silice (Eocène)
- xous climat chaud mais de plus en plus sec, induration ferrufineuse partielle avec formation de concrétions ferriques (Eocène, début Oligocène).

3) Karstification sous climat humide (Oligocène). Les cavités piègent une partie de la couverture pédologique démantelée et entrainée par les cours d'eau issus du cristallin.

4) Cristallisation des planchers de calcite.

5) Démantèlement mécanique des parois des avens sous un climat frois quaternaire produisant de nombreux débris qui empatent la cavité. Abaissement général de la surface topographique qui rabote les formes hypogées. Ici encore, l'influence des climats quaternaires sur les circulations karstique est singulièrement négative.

III. LES DEPOTS CARBONATES ET LES ETAPES DE L'ENFONCEMENT DES VALLÉES

III.1 GÉNÉRALITÉS

Dans toutes les vallées de l'avant-Causse on rencontre de nombreux dépôts chimiques. Nous devons distinguer deux types: les tufs de source et les travertins (fig. 4).

- L e s   t u f s   s o u r c e (10):

Ils se sont accumulées contre en versant (tufs de Lapeyre, Vendeloues, St Rome de Tarn. etc...) ou dans les cirques qui indentent la cuesta bajo-Toarcienne (tufs de St. Beaulize, de Tournemire, etc...), mais toujours au débouché d´une exsurgence.

Certains sont encore actifs (tufs de St Beaulize, Tournemire, Moulin de Gissac, Vendeloues, Lapeyre, etc...). D´autres ne s´accroissent plus, mais attestent une origine récente (dépots fragiles et peu compactés, fémur humain (fossile) dans le tuf de St Rome de Cernon) et fossilisent souvent des formations de versant d´âge quaternaire.

- L e s   t r a v e r t i n s (5):

Ils empatent les vallées sur une épaisseur dépassant quelquefois les 30 mètres (plateau de France près de Millau, plateau de St Rome de Tarn et de Peyre). Très résistants sous le marteau, ils sont fortement compactés. Ce sont ces travertins, souvent karstifiés, emboités entre les différents niveaux de terrasses fluviales, qui retiendrons ici notre attention.

III.2 DESCRIPTION (FIG. 5)

Les plus interressants sont ceux qui fossilisent le débouché des vallées de la Levégède (St Rome de Tarn) et du Therondels (Peyre) audessus du Tarn (6).

Ces cours d´eau ont totalement ou partiellement abandonné leur ancien lit pour s´enfoncer le plateau de travertin en y creusant des conduits karstiques.

D´autre part, ces dépôts chimiques s´intercalent le plus souvent entre plusieurs niveaux de terrasses fluviales. On peut ainsi distinguer trois niveaux majeurs.

- u n   b a s   n i v e a u correspondant à une incision récente dans une nappe alluviale que les fortes crues recouvrent encore de limons. Située à une altitude relative de 2 m, cette formation passe latéralement à des dépots de pente.

- u n   h a u t   n i v e a u à une altitude relative de 35 m, constitué par les dépôts de travertin. A la hauteur des versants, des formations d´âge quaternaire fossilisent ces dépôts.

- u n   n i v e a u   a n c i e n, à une altitude relation

PRINCIPAUX TUFS ET TRAVERTINS DE L'AVANT-CAUSSE OCCIDENTAL DU LARZAC

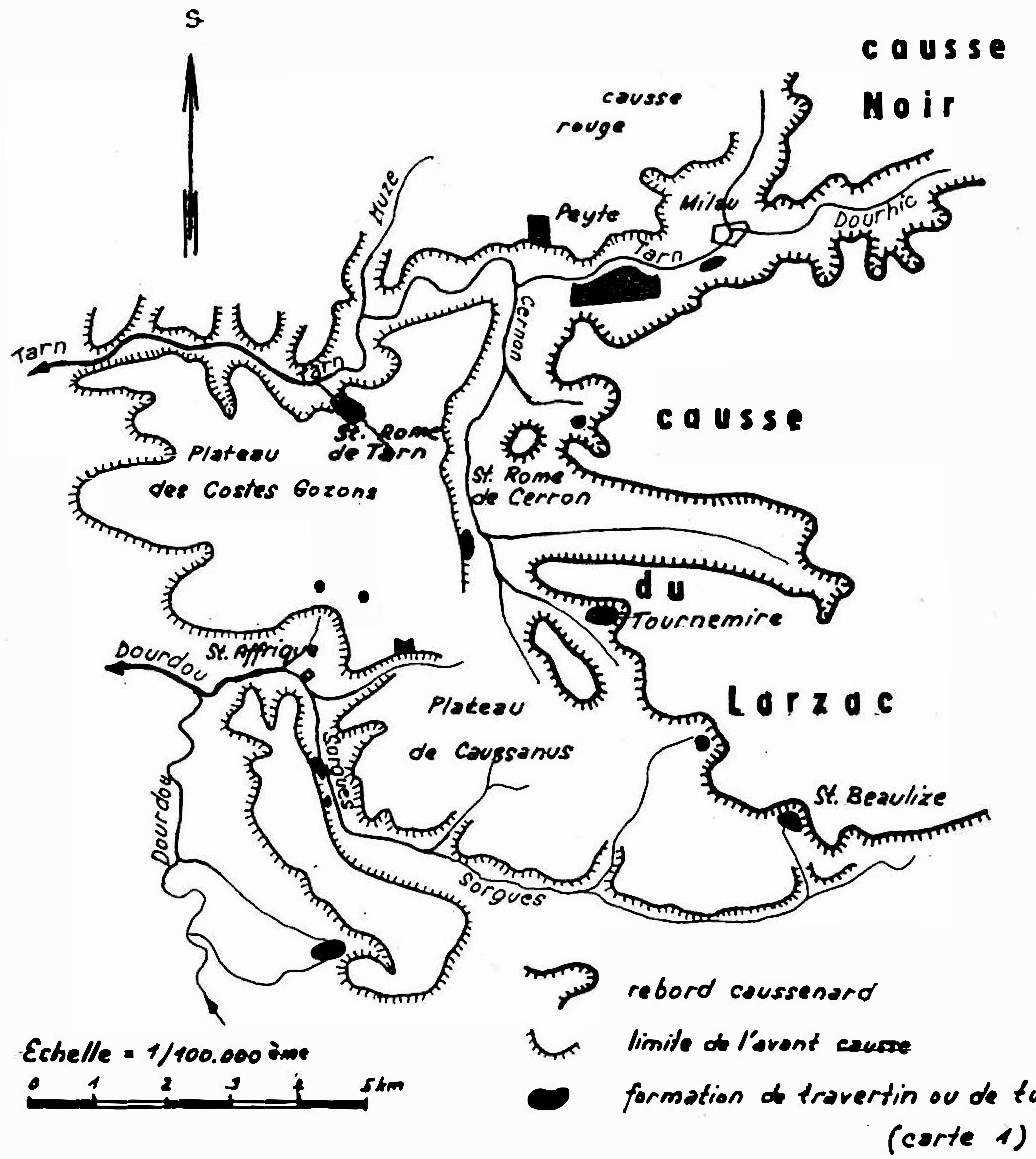


Fig. 4.

de 5 à 8 m, est fossilisé par le travertin. On y observe de bas en haut: des alluvions siliceuses; des dépôts de pierrailles libres; une brèche centimétrique de type "sistre".

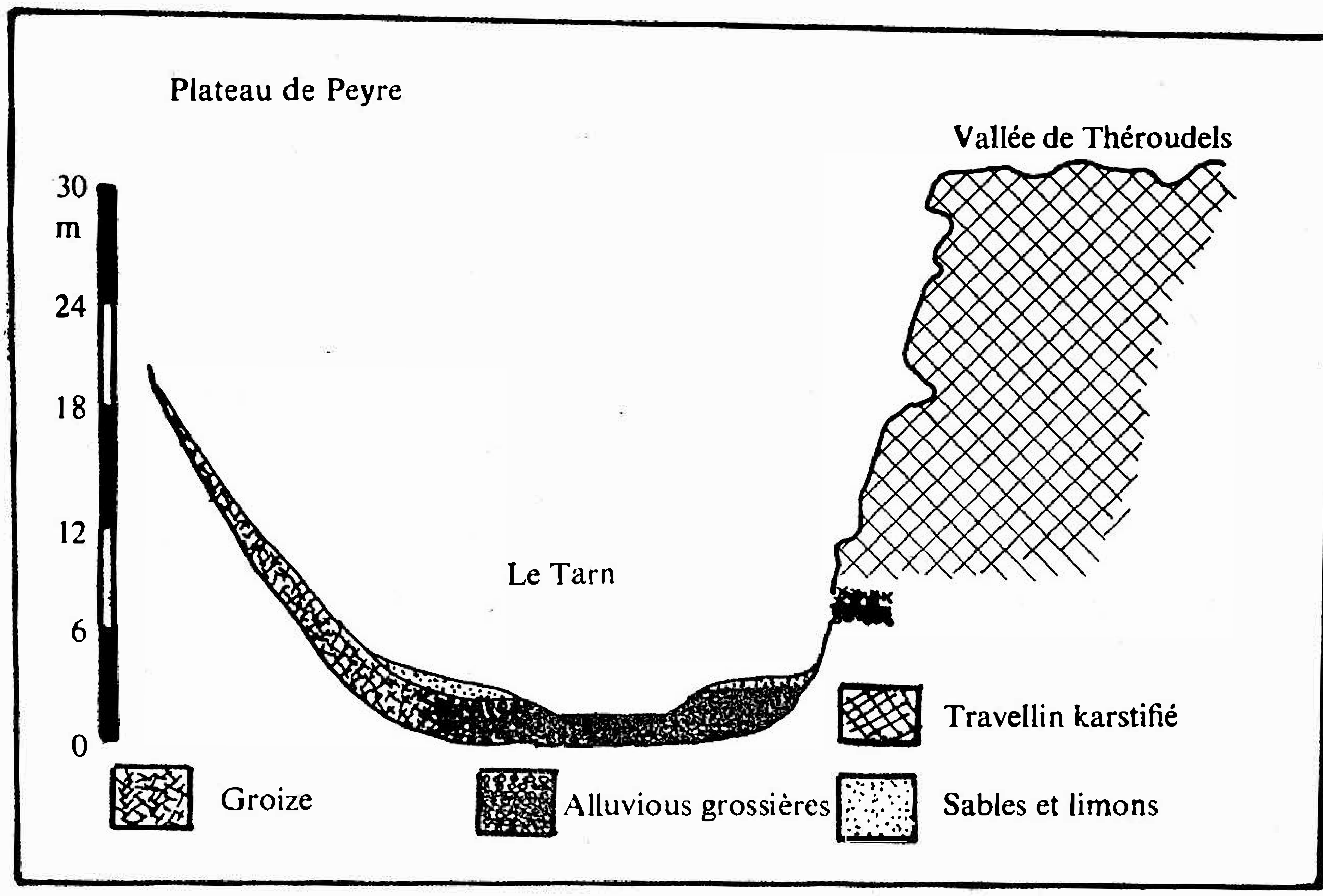


Fig. 5.

III.3 ELÉMENTS DE DATATION

En 1867, F. Samburcy et l'Abbé Rouquette découvrent une brèche osseuse dans une cavité du tuf de Peyre. Cette brèche, très riche, a livré du cheval, du renne, de l'ours et du mammouth. Une molaire de mammouth, identifiée par G. Astre, comme appartenant à l'espèce "Elephas Primigenius", nous indique que le tuf de Peyre existait déjà au Paléolithique supérieur et qu'il était karstifié. Sa mise en place remonterait donc, au moins, à l'interstade Riss-Wurm.

III.4 INTERPRÉTATION

Les éléments précédents nous permettent d'envisager les étapes de l'enfoncement des vallées:

1 - Creusement des vallées se terminant par une incision en gorge

jusqu'à 5 mètre au-dessus du niveau actuel. Pliocène, Villafranchien.

2 - Façonnement des versants par gélifraction. Gunz ou Mindel?

3 - Remblaiement de 30 m avec des alluvions et précipitations des travertins.

4 - Façonnement des versants donnant des vallées en berceau (Peyre) ou à fond plat (St Rome de Tarn) Riss.

5 - Phase de déblaiement puis d'incision jusqu'au niveau actuel. Les cours d'eau affluents du Tarn karstifient leur plateau de travertin pour aller rejoindre le nouveau niveau des écoulements. Würm.

6 - Alluvionnement et nouveau façonnement des versants. Fossilisation d'éléments de faune froide dans les cavités du travertin. Würm.

7 - Incision subactuelle dégageant une terrasse que les crues viennent encore napper de limons.

IV. CONSLUSION

L'évolution polygénique du karst caussenard nous apparâit à travers plusieurs témoins: des dépôts quaternaires dans des conduits encore actifs, et de vieilles cavités fossilisées et démantelées.

Les progrès de la karstification sont à relier avec l'enfoncement du réseau hydrographique subaérien. L'étude de quelques dépôts fluviaux caractéristiques nous a renseigné sur let étapes de cet enfoncement.

En l'absence de faune caractéristique dans les cavités fossilisées, il est difficile de les situer exactement dans l'histoire géologique. Toutefois, le karst de l'avant-Causse semble se diviser en deux niveaux principaux:

- à une altitude moyenne de 750 m, un haut niveau probablement Eocene-Oligocène représenté par les cavités fossilisées de Montjaux
- à l'altitude des vallées, un bas niveau représenté par l'émaillage des exsurgences dans tout l'avant-Causse, Sans liens apparents avec le précédent, il a été induit par l'enfoncement rapide du niveau de base local au Villafranchien qui a déterminé une réorganisation du drainage karstique.

Les climats quaternaires ont entrainé le colmatage de plusieurs cavités par l'accumulation des résidus de gélifraction. Ces débris ont pu être entrainés dans les cavités par gravité (avens) ou par l'intermédiare des cours d'eau (pertes). L'accumulation de pierraille, si elle n'a pas entravé les circulation souterraines, a paralysé temporairement le façonnement des conduits en mobilisant l'acidité des eaux; dans des cas limites elle a entrainé la fossilisation totale des vieux réseaux.

Nous tenons à exprimer nos remerciements aux membres du Spéléo Club St Affrique: Carel J., Caldier J.P., Parodi B., Inquimbert J.L., et à Messieurs A. Cazal, L. Balsan, à Monsieur le Professeur P. Demangeon.

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Ba 034

DARSTELLUNG EINIGER GIPSKARSTFORMEN IM ZECHSTEINAUSSTRICH DES SÜDHARZRANDES DER DDR (TEILGEBIET MOOSKAMMER)

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A b s t r a c t. Ausgehend von der geologischen Situation am Südharzrand und der Bedeutung des Gipskarstgebietes, wurden am Beispiel der Mooskammer verschiedene Kartierungen vorgestellt. Ziel dieser Arbeiten ist es, ein Karstgebiet komplex zu erfassen und darzustellen. Es soll damit eine gute Forschungsgrundlage über den Südharzer Gipskarst geschaffen werden.

Amateure haben sich auf lange Zeit ein sinnvolles, zielgerichtetes Programm vorgenommen. Es ist zu hoffen, dass dieses Anliegen auch weiterhin Erfolge zum Nutzen der Gipskarstforschung zeigt.

Das Harz-Grundgebirge ist weitgehend von einem Zechsteingürtel umgeben, der am Südrand des Harzes eine salinare Ausbildung aufweist. Durch die horstartige Heraushebung des Harzes in der saxonischen Orogenese kam es zum Ausstreichen der Zechsteinschichten, die parallel zum Harzrand liegen und ein flaches harzflüchtiges Einfallen haben. In einer Breite von wenigen hundert Metern bis mehreren Kilometern ist die salinare Abfolge in den bekannten vier Zyklen (Werra-, Stassfurt-, Leine- und Allerserie) vorhanden. Südlich des Zechsteinausstriches überdeckt der untere Buntsandstein der germanischen Trias diese salinaren Gesteine. Durch die kurz aufgezeigten geologischen Verhältnisse, sowie der morphologischen und hydrographischen Situation, dass die aus dem Harz kommenden Wässer in die Zechsteinschichten eindringen, kommt es zur Auflösung der Salze und Gipse in Oberflächennähe. Die Abb. 1 verdeutlicht diesen Prozess, bei dem die Landschaft morphologisch stark verändert wird. Harzrandparallel, wo neben dem Salz auch der Gips vollständig ausgeräumt wurde, haben sich markante Auslaugungstäler gebildet. Unterirdische Auflösung und Ausräumung führte zur Höhlen- und Schlottenbildung. Sie brachen vielfach

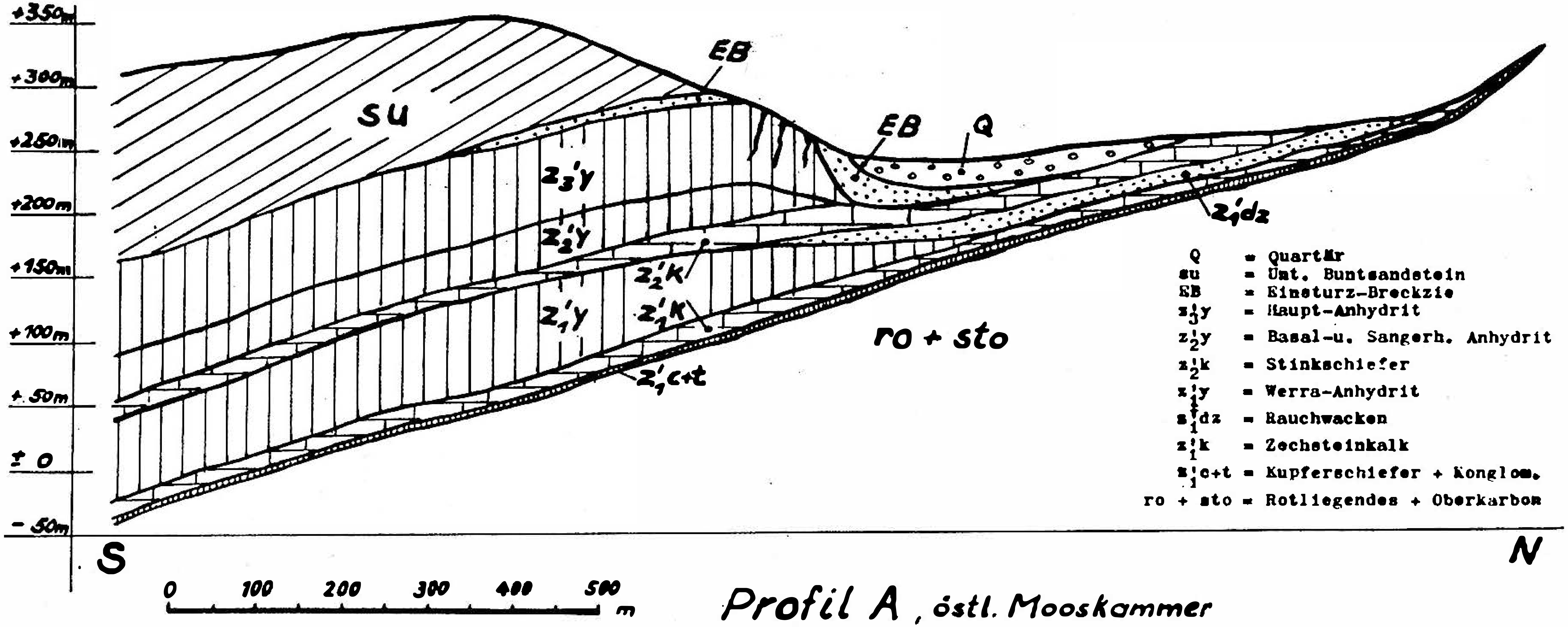

+350m
+300m
+250m
+200m
+150m
+100m
+50m
± 0
-50m
su
EB
EB
Q
z3'y
z2'y
z2'k
z1'y
z1'k
z1'c+t
z1'dz
ro + sto
Q = Quartär
su = Unt. Buntsandstein
EB = Einsturz-Breckzie
z3'y = Haupt-Anhydrit
z2'y = Basal-u. Sangerh. Anhydrit
z2'k = Stinkschiefer
z1'y = Werra-Anhydrit
z1'dz = Rauchwacken
z1'k = Zechsteinkalk
z1'c+t = Kupferschiefer + Konglom.
ro + sto = Rotliegendes + Oberkarbon
S
N
0
100
200
300
400
500
m
Profil A, östl. Mooskammer

Fig. 1.

infolge der geringen Tragfähigkeit des Deckgebirges relativ schnell zur Oberfläche durch und es entstanden Erdfälle. So hat sich am Südharzrand ein Gipskarstgebiet entwickelt, dessen Bedeutung zumindest für Mitteleuropa an erster Stelle steht.

Die wissenschaftliche Bearbeitung dieses Südharzer Gipskarstgebietes bezog sich im wesentlichen auf Einzeldarstellungen, so in der Hauptsache auf die Höhlen. Die bekanntesten Autoren waren Biese und Stolberg. Eine komplexe Bearbeitung des Periodischen See's bei Rossla führte Viete 1952/53 durch. Es muss aber festgestellt werden, dass es bisher keinen zusammenhängenden Kenntnisstand über dieses Karstgebiet gibt.

Amateur- Höhlen- und Karstforschergruppen haben sich die Aufgabe gestellt, den Südharzer Gipskarst komplex zu erfassen und zu bearbeiten. Dabei werden sie von der Bezirksstelle für Geologie Halle, als staatliche Dienststelle, unterstützt. Durch systematische Kartierungsarbeiten sollen alle Karstformen in ihrer Ausbildung und topographischen Lage erfasst werden. Damit wird eine Forschungsgrundlage geschaffen, die eine spezifische Bearbeitung des Gipskarstes am Südharzrand ermöglicht.

Am Beispiel "Mooskammer" sollen die Karst-Kartierungsarbeiten erläutert werden.

Die Mooskammer ist ein ca. 5 km langer, sich von Ost nach West erstreckender Höhenzug nordwestlich der Stadt Sangerhausen. Die Grenze zwischen den Karstgesteinen und dem Harz bilden Ablagerungen des Oberkarbons und Rotliegenden. In südlicher Richtung schliesst sich ein bis mehrere hundert Meter breites Auslaugungstal an, dessen Material aus Zechsteinkalk im Liegenden, Auslaugungs-Rückstandsgesteinen und quartären Lokkersedimenten besteht. Die Auslaugungsfront ist eine Steilstufe, die alle weiteren Zechsteinablagerungen, sowie den überdeckenden unteren Buntsandstein (su) beinhaltet. Teilweise wird der Steilhang durch sogenannte Einsturz-Brekzie (EB) überlagert. Auf diese relativ schmale Zone des hier benannten Nordabbruches der Mooskammer, einschliesslich des Buntsandsteines, verteilen sich die wesentlichsten Karstformen (Kockert). Sie sind eine Vielzahl von Erdfällen, von Abrissklüften, Spalten- und Verbruchsgelände und einer kleinen Höhle.

Für eine Übersichtskarte des gesamten Gipskarstgebietes ist die Mooskammer im Masstab 1 : 10 000 (Abb. 2) kartiert worden. Durch systematisches Ablaufen sind über 400 Erdfälle erfasst, die den grössten Teil der Karstformen ausmachen. Insbesondere der hier ver-

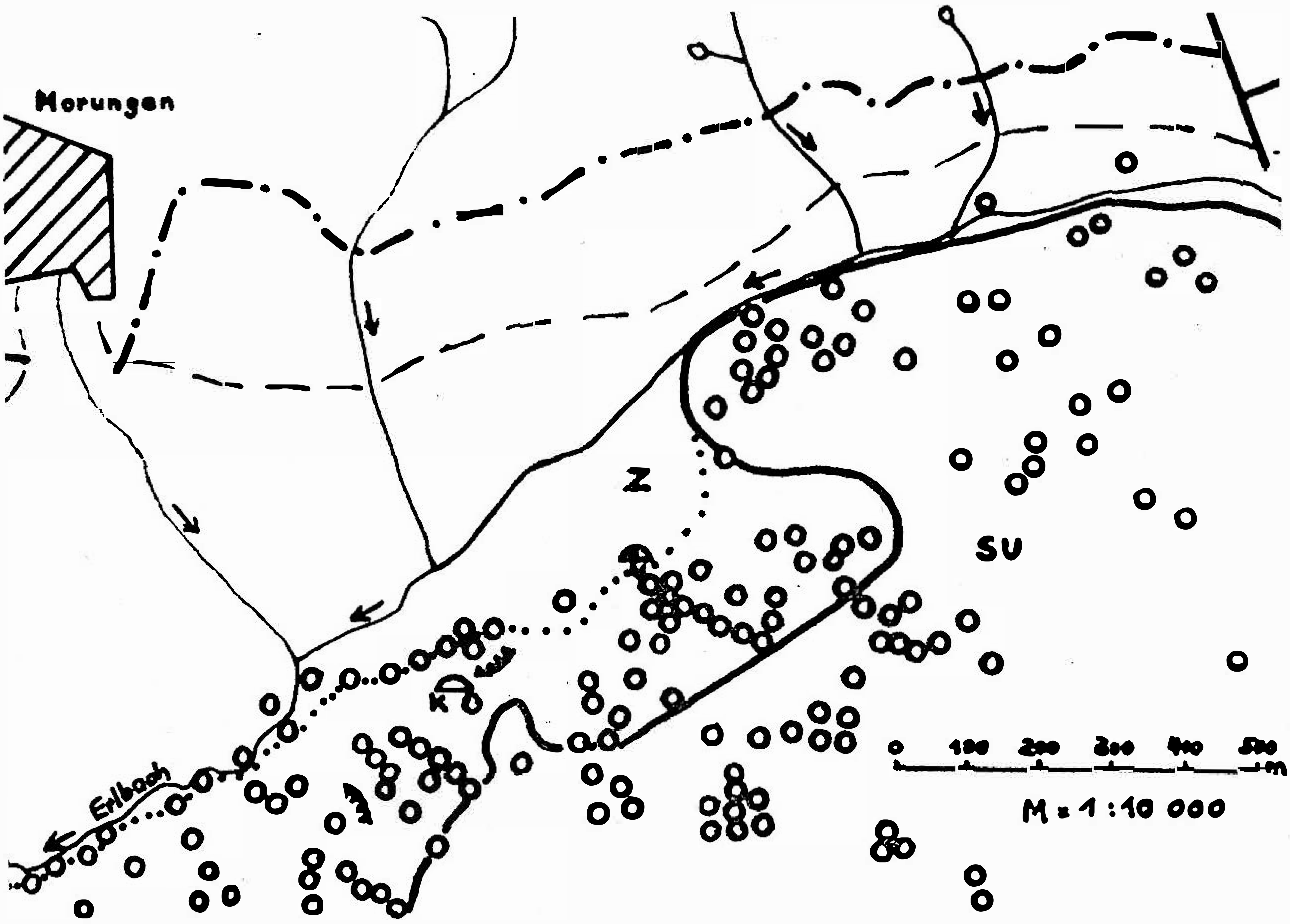


Fig. 2.

tretene Oberflächenkarst ist durch Kartensymbole (nach Fantasny) dargestellt. Gesteinsgrenzen, Hydrographie und die punktierte Auslaugungsfront, sowie die durch Kreise dargestellten Erdfälle neben untergeordneten anderen Karstformen vermitteln eine gute Karstsituation, ihre Formenentwicklung und räumliche Verteilung. Mit dieser Karte ist erstmals eine umfassende Karstübersicht gegeben, die auch den Kenntnisstand wesentlich erweitert.

Die Vielzahl der Erdfälle und ihre Formenentwicklung waren der Anlass, eine spezialisierte Karte zu zeichnen. Als Forschungsgrundlage für detaillierte Erdfalluntersuchungen, sowie zur Klärung anderer Karstzusammenhänge, entstand die karstmorphologische Spezialkarte "Östliche Mooskammer" (Abb. 3). Der gewählte Masstab 1 : 5 000 genügt gerade noch, um Erdfälle detailliert darzustellen. So konnten 170 Erdfälle, meist Alterdfälle, in den Grössen zwischen 1 m bis etwa 50 m Durchmesser in ihrer Form und Ausbildung charakteristisch erfasst werden. Für die Darstellung wurde die Schraffur verwendet, wie sie auf topographischen Karten für das Reliefbild üblich ist. Durch Erläute-

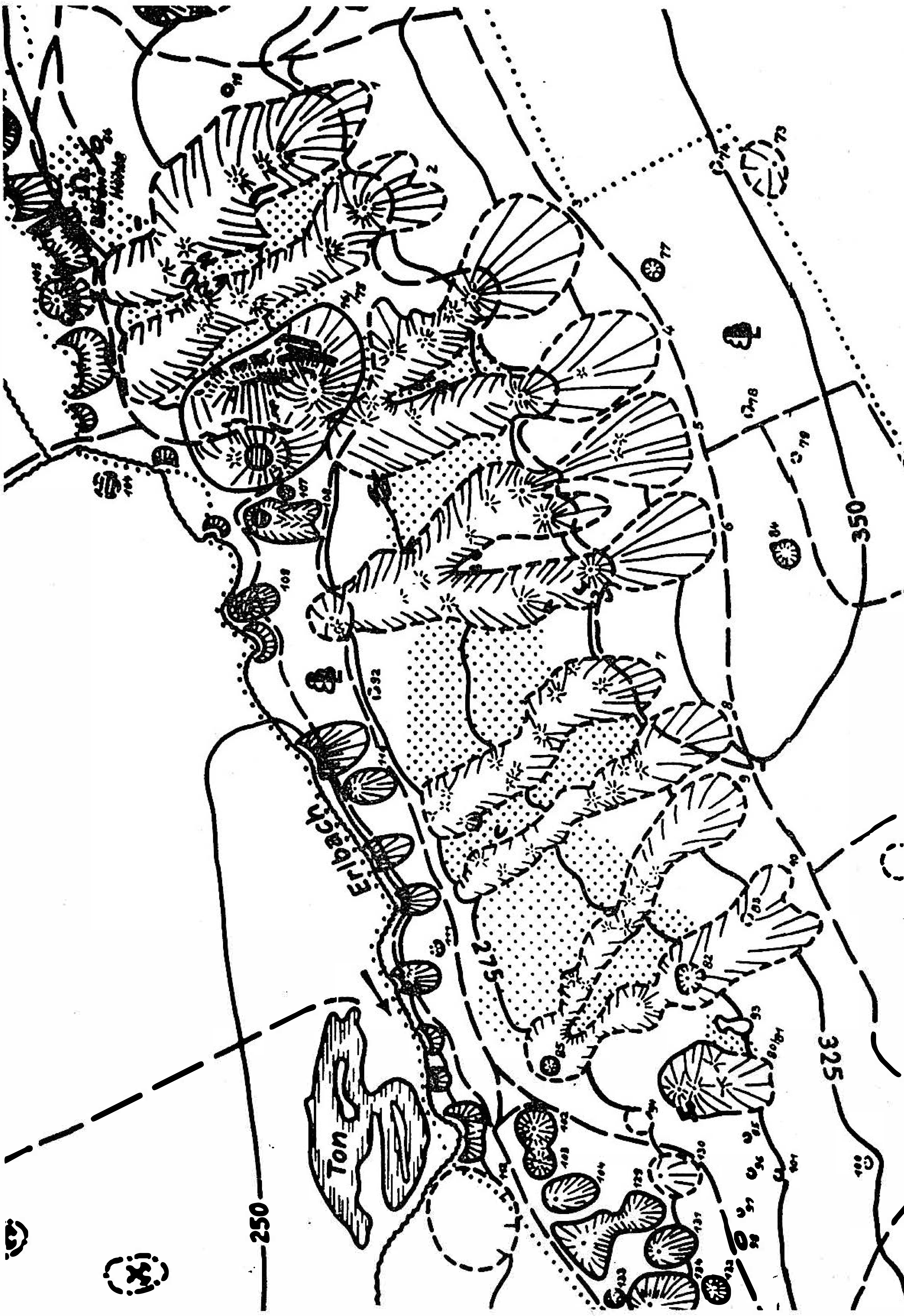


Fig. 3.

rung in der Legende wird die Ausbildung der Erdfallformen eindeutig unterschieden. Die Steilheit der Böschungen, ob Doppelerdfall oder Erdfall mit Nachbruch sind Beispiele der Unterscheidungsmerkmale. Alle Erdfälle sind nummeriert, da gleichzeitig mit der Kartierung Kennwerte für weitere Auswertungen festgehalten sind. Auffällige Erdfallformen sind die sogenannten Randerdfälle. Sie liegen auf der unteren Hangkante und dem gegenläufigen Einfallen des Morunger Auslaugungstales. Durch Einfliessen von Lockermaterial sind sie vom Morunger Auslaugungstal her zugeschwemmt und nur noch halbseitig auf dem Hang vorhanden.

Im westlichen Teil des Kartierungsgebietes sind 10 Erdfalltäler bestimmend im Kartenbild. Ihre Entwicklung ist sicher mit dem Nordabbruch der Mooskammer und der dadurch entstandenen Zerrung und Abkippung in Verbindung zu bringen. Bemerkenswert sind jeweils mehrere Erdfallzentren in den Erdfalltälern. Besonders in den Bereichen zwischen den Erdfalltälern sind Spaltenzonen vorhanden, die mit dem Nordabbruch der Mooskammer im Zusammenhang stehen. Im erfassten Bereich bildet die Karte eine gute Ausgangsbasis für die Klärung weiterer Karstzusammenhänge. Durch die reihenweise Anordnung von Erdfällen könnten z.B. tektonische Linien konstruiert werden.

Aufbauend sind weitere Erkenntnisse über die Form und Volumen der Erdfälle in Verbindung mit der Geologie erreicht worden (Wadewitz). Eine Karte, die den Zusammenhang zwischen Geologie und Erdfallvolumen darstellt (Abb. 4), ist ein weiterer Schritt bei der Erforschung des Gipskarstes. Auf der Grundlage einer geologischen Kartierung von Kriebel ist die Geologie, speziell des Zechsteins übertragen worden. Die Darstellung der Erdfälle und Erdfalltäler, gestaffelt entsprechend der Grösse des Volumens zwischen ... 10 m^3 und 300 000 m^3, bringt eine gute Aussage in Verbindung mit der Geologie. Die Profile A (Abb. 1) und B sind eine gute Ergänzung zur Karte. Die geologische Situation im Zusammenhang mit der Verkarstung wird anschaulich gezeigt. Bedingt durch die unterschiedliche Steilheit des Einfallens der Schichten am Ausstrich hat sich der Karst entwickelt. Flaches Einfallen mit grosser Angriffsfläche des Wassers in Oberflächennähe führen zur Ausbildung von Auslaugungstälern mit anschliessender Steilstufe. Steiles Einfallen mit wenig Angriffsfläche, zumindest in Oberflächennähe, lässt die Verkarstung erst im grösseren Umfang in der Tiefe einsetzen und kann zur Schlottenbildung führen (Profil B).

Interessante Karstformen, die auf der karstmorphologischen Karte

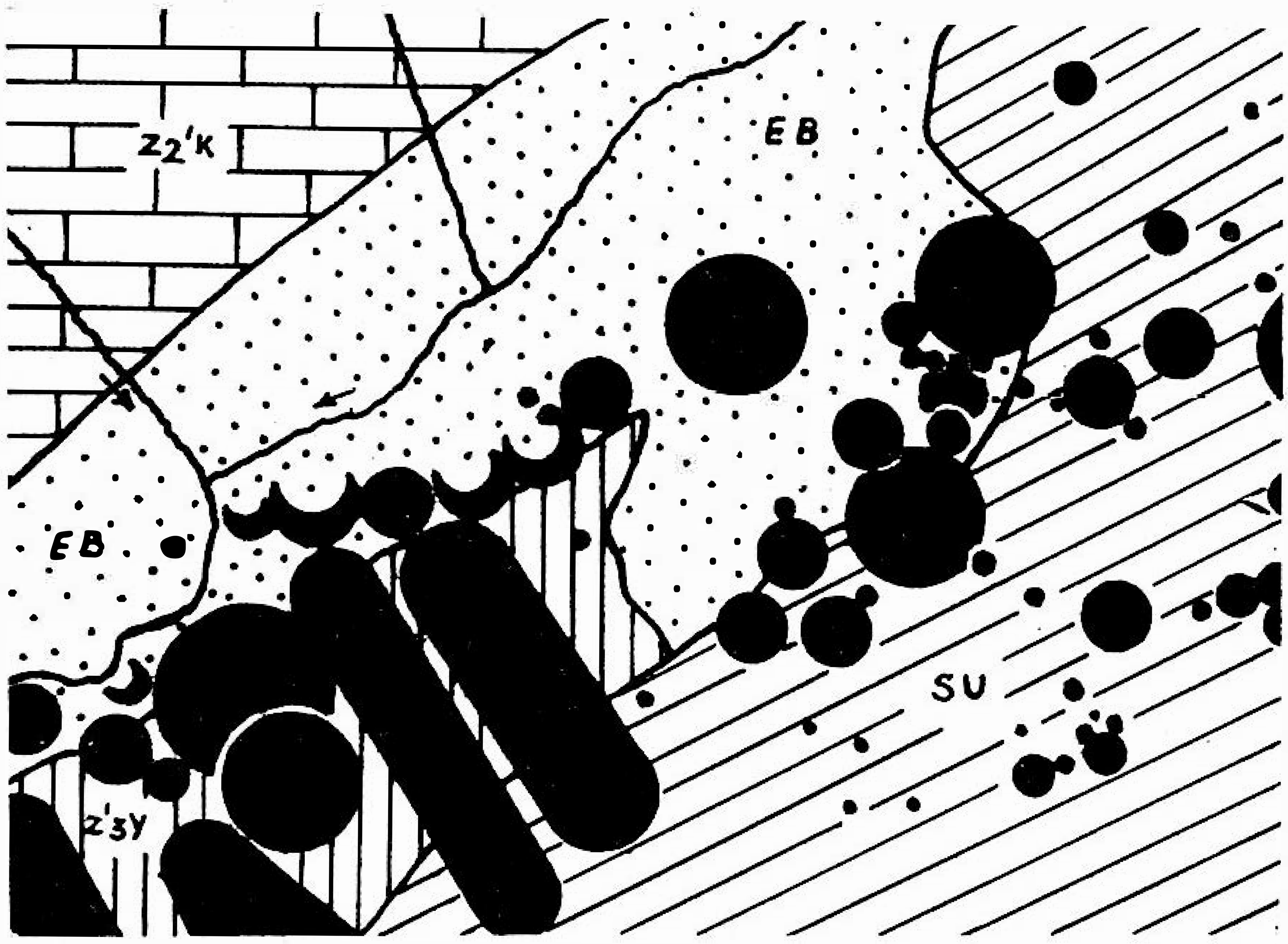


Fig. 4.

kaum in ihrer Bedeutung zum Ausdruck kommen, aber wichtig für spezielle Untersuchungen sind, wurden im Masstab 1 : 250 kartiert. Charakteristisches Beispiel ist der sogenannte "Pferdestall" (Abb. 5), als grösstes Karstphänomen in der Mooskammer. Er umfasst zwei übereinanderliegende Erdfälle, die im Zusammenhang mit grösseren Abrissklüften stehen. Die Klüfte, die bis auf etwa 20 m Breite geöffnet sind, haben eine Höhe bis zu 15 m und eine Längsausdehnung bis zu 40 m. Höhenschichtlinien im 2-m Abstand bilden die Grundlage der Geländedarstellung, die mit dem Messgerät "Dalta 020" vom VEB Zeiss Jena vermessen wurden. Die Felspartien sind in ihrer Gestalt durch Schraffur herausgearbeitet. Das Gestein ist der Hauptanhydrit des Zechstein 3 = Leineserie. Die Genese des Pferdestalles konnte mit dieser Kartierung nachgewiesen werden.

In den Abrissklüften konnten die Schichtverkippungen gemessen werden. Da der Pferdestall im Nordabbruch der Mooskammer liegt, fallen hier die Schichten in Nordrichtung ein, dass ist gegensätzlich des Normaleinfallens zum Thüringer Becken. Ein langjähriges Messprogramm in den Abrissklüften soll Auskunft über mögliche Bewegungen geben. Mit Stahlmessbändern und einem eigens dafür konstruierten Messgerät werden Abstandsdifferenzen mit 1/10 mm Genauigkeit gemessen. Die Entfernungen zwischen den Messpunkten betragen bis zu 22 m. Messergebnisse sind wahrscheinlich erst nach einigen Jahren zu erwarten. Um eine Aussage zu erhalten, werden jährlich 2 Messungen durchgeführt.


Pferdestall in der Mooskammer
südlich Morungen / Südharz
aufgen. 07.70 ... 02.71
OWBO AG Geologie Leipzig
N
0 10 20 30 40 50
Meter
251,8
270
Fig. 5.

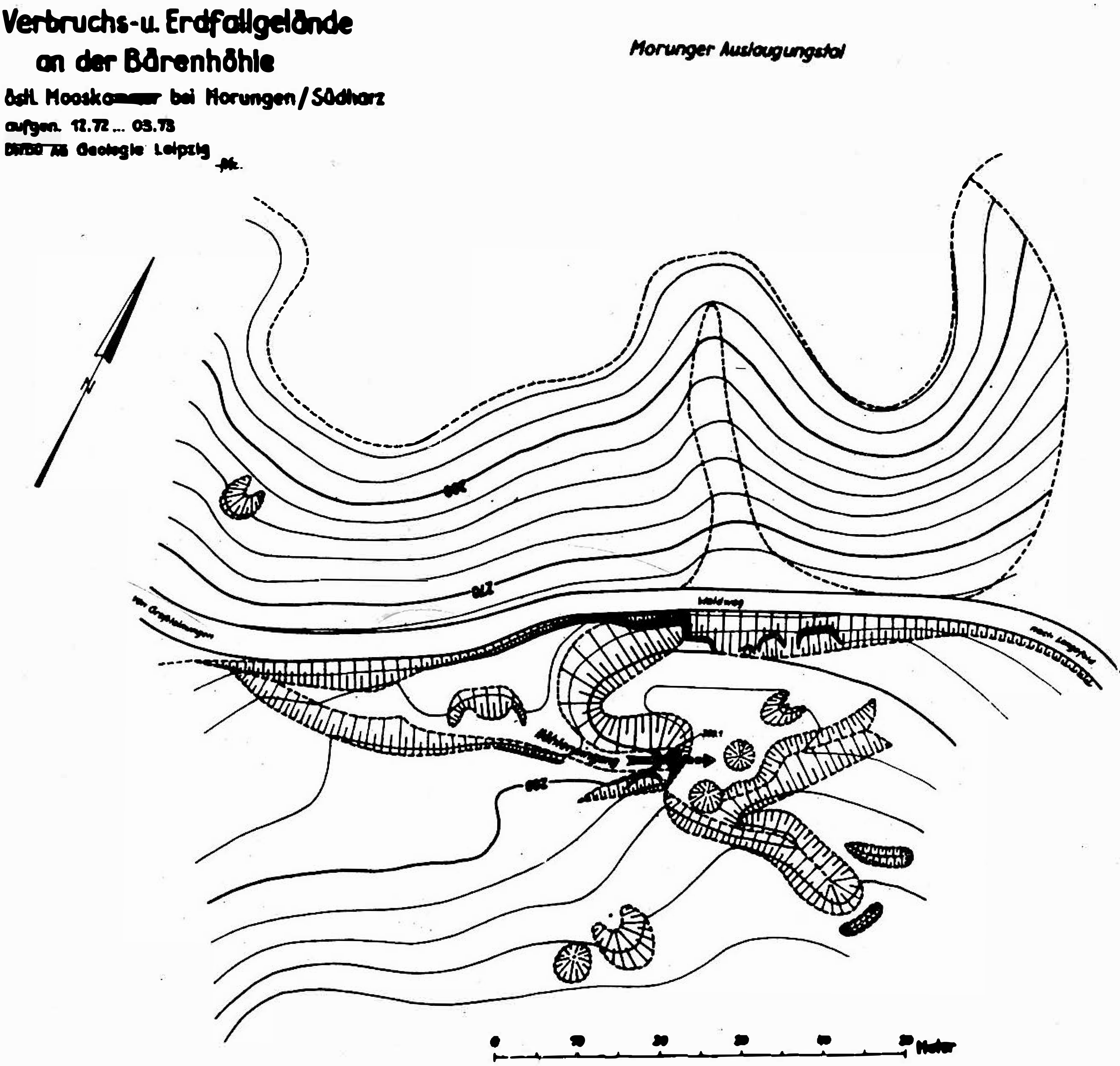
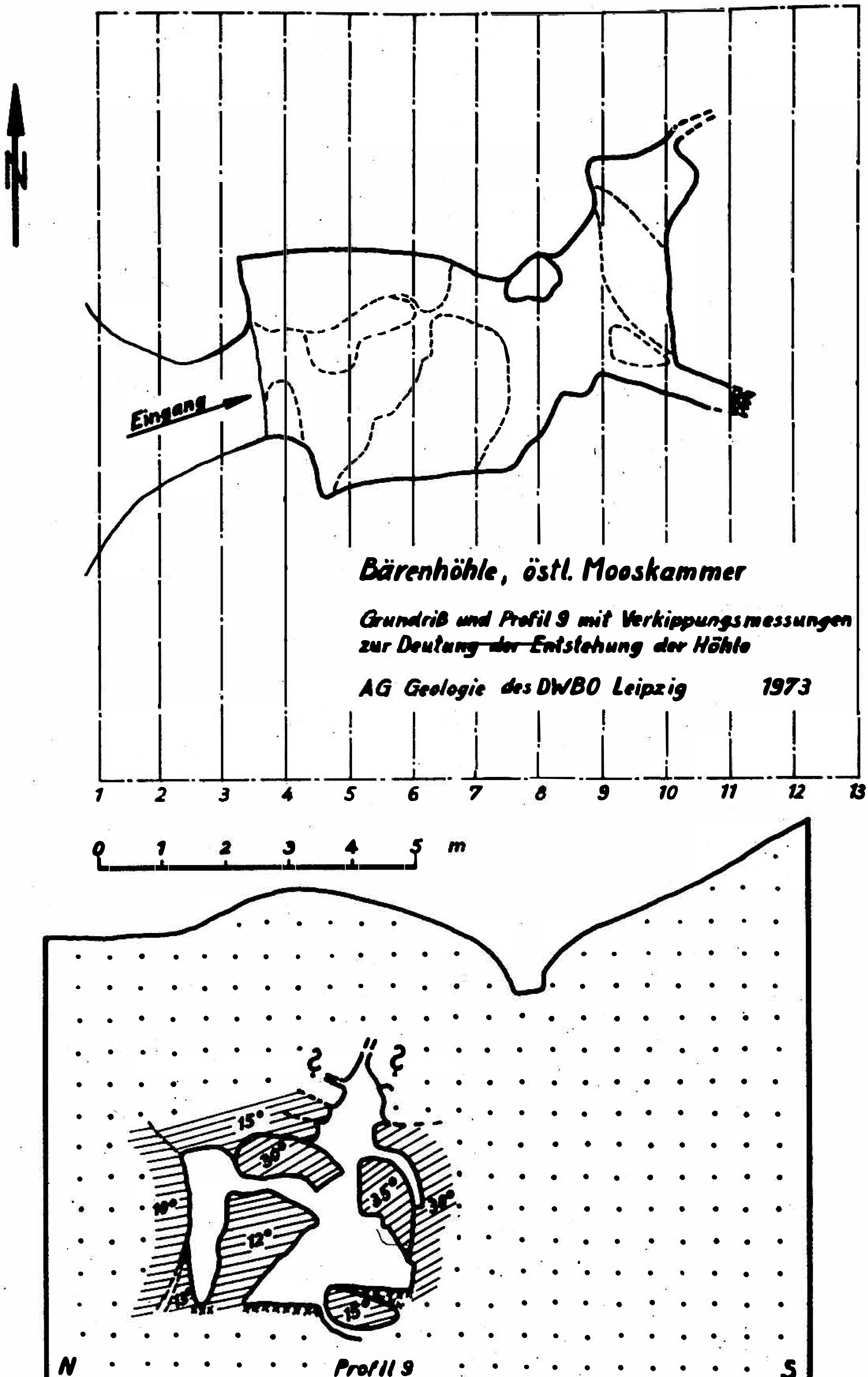


Fig. 6.

Eine weitere detaillierte Kartierung im gleichen Masstab ist das "Erdfall- und Verbruchsgelände an der Bärenhöhle" (Abb. 6). Zwei Randerdfälle zeigen das ansteigende Gelände am Mooskammerhang, welches von Spalten durchzogen ist. Mit Schraffen sind Steilstufen und Spalten, sowie kleine Erdfälle dargestellt. Die Beziehung der kleinen Bärenhöhle zum Gelände sollte nachgewiesen werden. Die Bärenhöhle wurde im Masstab 1 : 50 kartiert. Mehrere parallele Schnitte durch die Höhle und Oberfläche (Abb. 7) mit der Einzeichnung der Verkippungswinkel einzelner Blöcke im Höhlenprofil beweisen die Entstehung der Höhle.



N
Eingang
Bärenhöhle, östl. Mooskammer
Grundriß und Profil 9 mit Verkippungsmessungen
zur Deutung der Entstehung der Höhle
AG Geologie des DWBO Leipzig 1973
1
2
3
4
5
6
7
8
9
10
11
12
13
0 1 2 3 4 5 m
15°
30°
35°
30°
18°
12°
15°
15°
N
Profil 9
S

Fig. 7.

Es ist eine Einsturzhöhle im Hauptanhydrit (Z 3), die durch den Nordabbruch der Mooskammer entstanden ist.

Profile in unterschiedlichen Masstäben ergänzen die Kartierungen. Sie zeigen einmal die Morphologie der Karstlandschaft oder einzelner Karstobjekte. Besonders die Formen von Erdfällen können durch Profile gut belegt werden.

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Ba 035

ТИПЫ КАРСТА ПРЕДБАЛКАНА В БОЛГАРИИ

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Карст в Болгарии имеет значительное распространение. Он охватывает 22,7% территории страны и развит на различных по возрасту, мощности, карбонатному содержанию и условиям залегания карбонатных породах.

В Старапланинской геоморфологической области карстом охвачено около 19,8% всей территории. Наибольшее распространение он имеет в северной части этой области, называемой Предбалканом. С юга Предбалкан ограничивается главным старапланинским поясом, охватывающим структурно-геоморфологические котловинные понижения, долинные расширения или фацетированные склоновые откосы, расположенные к северу от Старапланинской фронтальной линии.

На севере Предбалкан отделяется от Дунайской платформенной равнины разломом древнего заложения.

Площадь Предбалкана - 14,390 кв. км, что составляет 13% от территории страны. Карстом охвачено 22,5% его площади. В геологических формациях карст распределяется следующим образом: меловые известняки (валанж, апт, маастрихт) - 67,8%, сарматские известняки - 20%, юрские известняки - 8,3%, триасовые известняки - 3,9%.

Карст Предбалкана значительно отличается от равнинного карста на Дунайской платформе, несмотря на то, что и в этой части страны карстовые процессы протекают на почти тех же самых растворимых карбонатных породах (исключая триасовые известняки), которые слагают и Дунайскую равнину. Можно провести следующие отличия:

1. Карстовые явления и процессы в Предбалкане, в противовес таковым на Дунайской равнине, приурочены к сложным тектоническим структурам - антиклиналям, синклиналям, моноклиналям, нарушенным разломами, ступенчатыми сбросами и флексурами. Здесь в развитии карста ведущая роль принадлежала неогено-четвертичным движениям, дифференцированным во времени и пространстве. В свою очередь, сравнительно более высокая средняя высота над уровнем моря Предбалкана создала условия для более глубокой эрозионной расчлененности. В сочетании со

значительной мощностью окарстованных пород (в ряде случаев до нескольких сот метров) она является причиной существования глубоких пропастей, длинных многоэтажных пещер и сложной циркуляции грунтовых карстовых вод.

2. Карст в Предбалкане преимущественно голый. Только там, где карстовые районы покрыты лесом, карст перекрыт тонким почвенным слоем. Здесь типичны глубокие, иногда до 2-3 м, карры в различных стадиях развития (Стражанское плато и т.д.), обширные карровые поля, различные по форме воронки, простирающиеся по направлению основных тектонических трещин, длинные (до 3 км) увалы (Ябланицкое бырдо, "Стражата" и т.д.), небольшие карстовые поля (Брестницкое).

3. Относительно более высокие суммы осадков в Предбалкане способствуют более интенсивному развитию карстовых процессов.

Основными критериями при определении карстовых типов в Предбалкане послужили его структурно-литологические особенности, геоморфологическое развитие, эволюция и морфологические особенности поверхностных и подземных карстовых форм и гидрография карста.

Рельеф Предбалкана холмистый (71,7%) и низкогорный. Для него характерны карстовые плато - синклинальные (Стражата, Драгоица и т.д.), антиклинальные (Беляковское, Арбанасское, западная часть Преславскс-Планины и т.д.) и моноклинальные (Деветакское и т.д.).

О широком стратиграфическом, тектоническом и морфологическом разнообразии карстовых образований в Предбалкане свидетельствуют следующие наиболее характерные примеры типов карста в антиклинальных, синклинальных и моноклинальных структурах: (рис. 1).

1. КАРСТ В АНТИКЛИНАЛЬНЫХ СТРУКТУРАХ

Карст, развитый в антиклинальных структурах, составляет 29,4% от карстовых образований в Предбалкане.

Между реками Вит и Панега в мощной (до 450 м) титонской мантии поднимающейся к востоку Ботубской антиклинали, расположен Панежский карстовый район (рис. 3). Его денудационный уровень (450-600 м) изобилует многочисленными увалами, длиной до 2400 м и глубиной до 50 м, воронками, размещенными на различных уровнях, обширными карровыми полями и конусообразным карстом. На высоте 510 м над уровнем

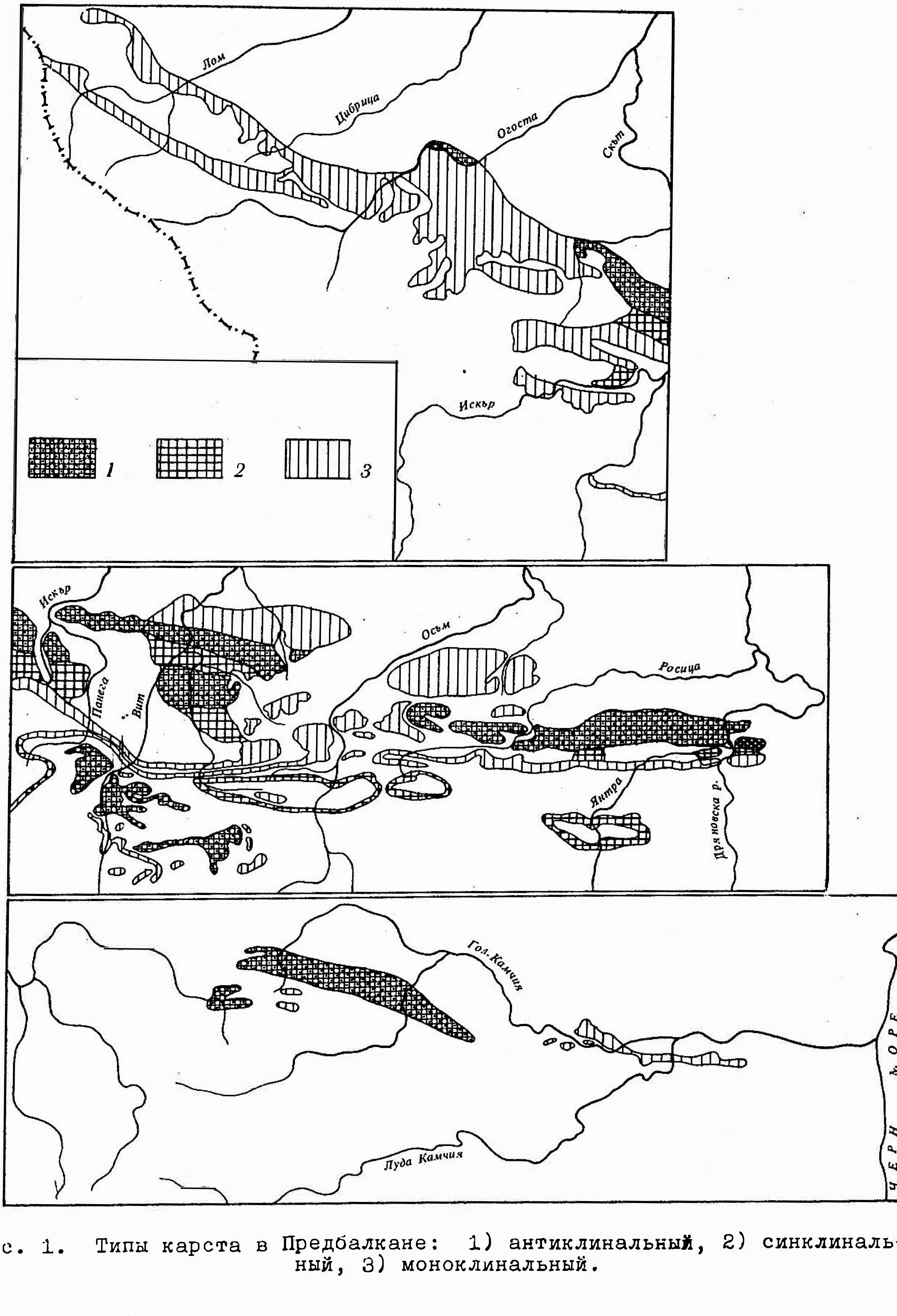

Рис. 1. Типы карста в Предбалкане: 1) антиклинальный, 2) синклинальный, 3) моноклинальный.

моря находится вход в живописную электрофицированную пещеру "Съева дупка". Из известных пропастей наиболее глубокая "Бездънния пчелин" (105 м). Здесь расположено небольшое Брестницкое карстовое поле. В северной части этого карстового поля вытекает наиболее крупный карстовый источник "Глава Панега" (1620-4.000 л/сек). Значительную часть своих вод этот источник получает подземным путем из реки Вит.

Карстом охвачены аптские ургонские известняки, слагающие мантию плоской Тырновской антиклинали, рассеченной глубоким (до 280 м) проломом Янтры. Сарматопонтическая денудационная равнина Беляковского и Арбанасского плато (409 м) характеризуется широким развитием поверхностного карста (карровые поля - кайряки, воронки и т.д.). Пещеры расположены на нескольких уровнях, наиболее высокий из которых находится в Дервенском проломе Янтры на высоте 220 м над уровнем реки, а наиболее низкий отмечает положение водной Мусинской пещеры, образованной на северном сбросовом склоне Беляковского плато на высоте 120 м над уровнем моря.

На северном сбросовом склоне этого плато расположены крупные карстовые источники, такие как Мусинский карстовый источник (со средним дебитом 392,5 л/сек), "Кая бунар" (40-460 л/сек) - южнее с. Хотница.

Карст характерен и для западной части Преславска-Планины, лежащей западнее р. Голяма Камчия. Он развит на валанжских известняках, слагающих мантию Преславска-Планины (рис. 2). Поверхностные карстовые

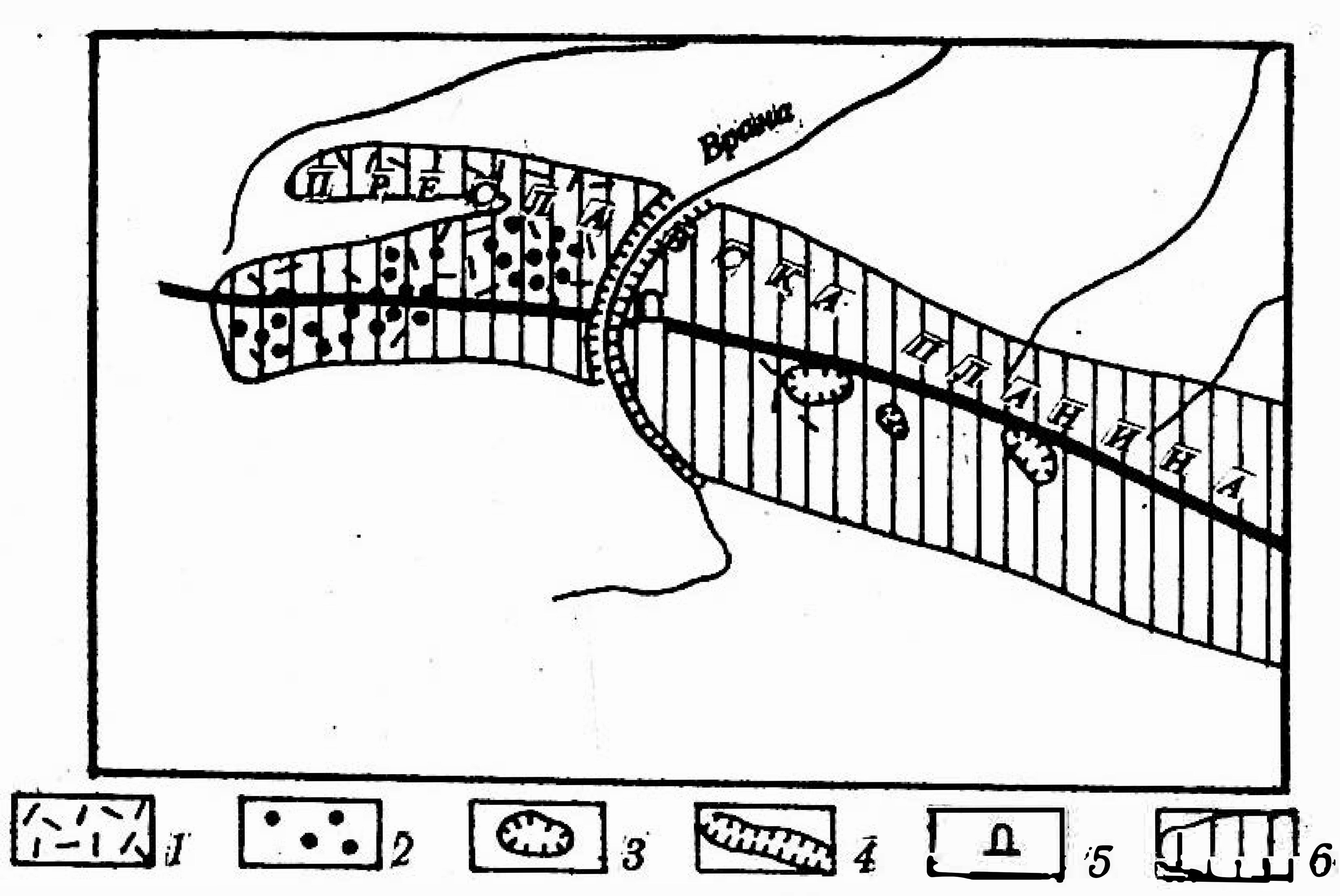

Рис. 2. Картосхема антиклинального карста в Преславска-Планина: 1) голый карст, 2) воронка, 3) увал, 4) каньонообразная врезанная долина, 5) сухая пещера, 6) антиклинальный карст, 7) антиклиналь, выраженная в рельефе.

формы наиболее типичны для свода антиклинали, где сармато-понтической планацией была образована денудационная поверхность на высоте 500-600 м. По ней распространены обширные валоги и увалы - "Чьорне" (800/325 м), "Пропастна" (750/750 м) и т.д., дно которых изобилует понорами. Из многоэтажных пещер наиболее известная Дервентская около с. Пролаз, вход в которую расположен на высоте 160 м над руслом Враны.

2. КАРСТ В СИНКЛИНАЛЬНЫХ СТРУКТУРАХ

Этот тип карста распространен сравнительно реже. Им охвачено 9,2% карстовых образований в Предбалкане.

Юротипный рельеф Предбалкана представлен глубоко денудированными структурами, простирающимися с северо-запада на юго-восток в западной части и с запада на восток в восточной. Примером типичной синклинальной структуры для западного Предбалкана является Салашская. Карст в этой синклинали, образованной между Предбалканом и Главной Старапланинской цепью, развит в триасовых и главным образом, в юрских (титонских) известняках.

Своеобразен карстовый район Предбалкана между реками Искыр и Осым, эволюция которого тесно связана с тектоническими и неотектоническими движениями в области простирающейся с северозапада на юго-восток Луковитской синклинали и особенно с эволюцией поперечного к синклинали витско-тектонического понижения. Здесь карст распространен в мастрихтских известняках.

К востоку от р. Вит мастрихтские известняки слагают часть северного крыла Батульской антиклинали и мантии Агленского и Садовецкого поднятий, а также и плоские понижения между этими двумя структурами. Слабо наклоненный окарстованный мастрихтский комплекс, мощностью до 90 м, в общих чертах погружается к западу, к руслу Вита. Поэтому карстовые источники расположены преимущественно по правым берегам врезанных долин Вита и правых его притоков Каменицы и Катуницы. Такими источниками является "Батово" у с. Дерманци (15-370 л/сек) и "Езерото" у с. Петырница (80-500 л/сек). Для этого карстового района характерны не только каньонообразные врезанные участки (до 80 м) речных долин, но и многоэтажные пещеры. Карстовые процессы наиболее интенсивно развиты по своду поднятий, где тектонические напряжения наиболее сильные, а трещины наиболее многочисленные и глубокие.

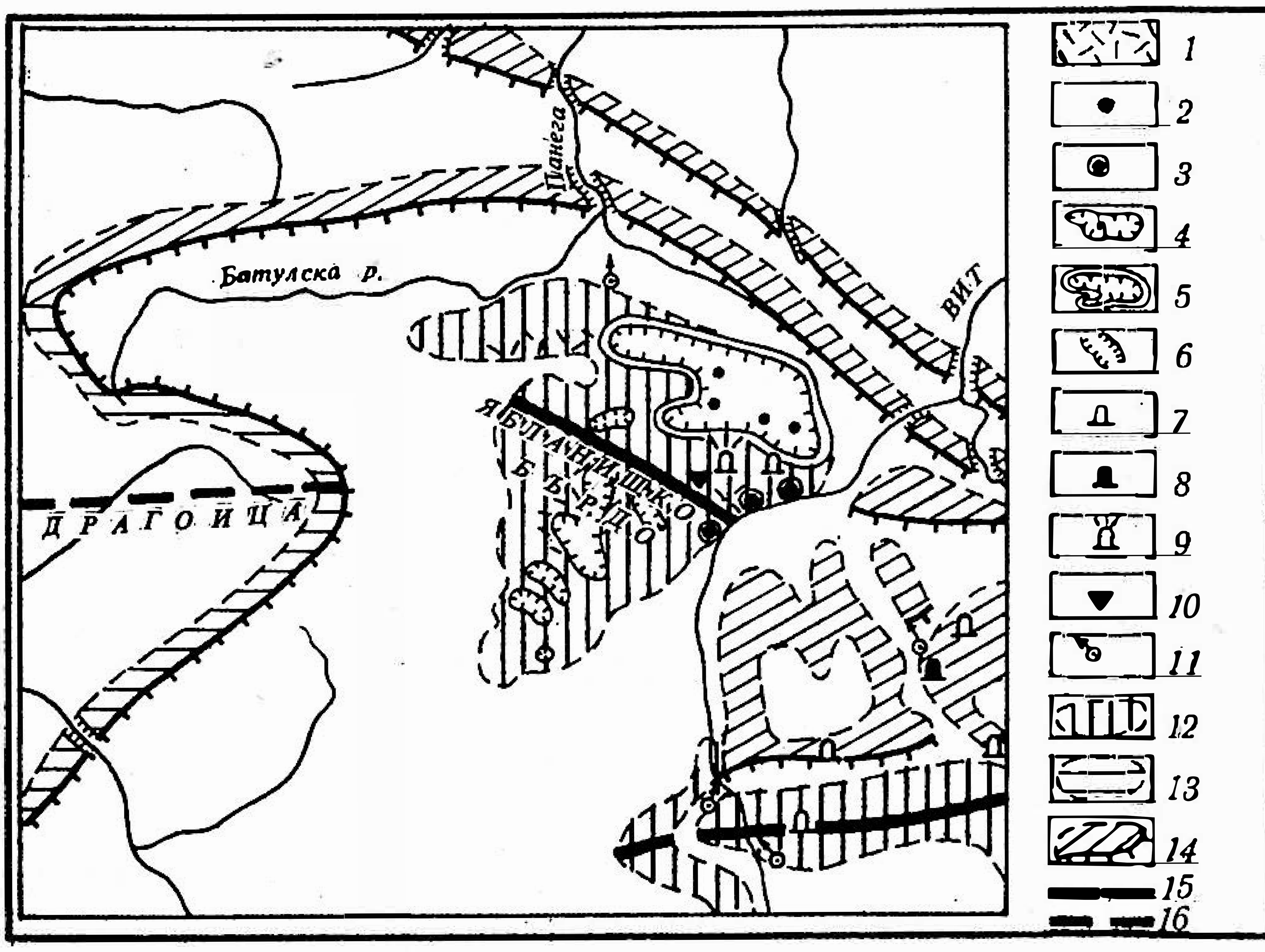

Рис. 3. Картосхема антиклинального и синклинального карста: 1) голый карст, 2) воронка, 3) понор, 4) увал, 5) карстовое поле, 6) каньонообразная врезанная долина, 7) сухая пещера, 8) водная пещера, 9) Электрофицированная пещера, 10) пропасти, 11) карстовый источник, 12) карст в антиклинальной структуре, 13) карст в синклинальной структуре, 14) карст в моноклинальной структуре, 15) антиклиналь, выраженная в рельефе, 16) синклиналь, выраженная в рельефе.

Восточнее с. Бежаново расположена пещера Парниците (длиной 2950 м), перед которой образованы каменные мосты.

Западнее р. Вит комплекс мастрихтских известняков, мощностью до 120 м, образует мантию различных по величине структур, погружающихся к востоку по направлению к р. Вит. Поэтому крупные карстовые источники располагаются на левых берегах Панеги и Вита.

Эволюция приискырской части Карлуковского карста тесно связана со стадиальным развитием Искыра в плейстоцене. Эта река, несмотря на восточный наклон Карлуковской синклинали, выполняла роль локального базиса для развития карстовых процессов. Об этой свидетельствует тесная связь между высотой террас Искыра в районе Карлуковского карста и уровнями пещер на правом берегу реки.

Наиболее интенсивное карстообразование наблюдается на плато "Стражата", образованном в погружающейся к востоку Стражанской синклинали (рис. 4), сложенной главным образом несколькими горизонтами

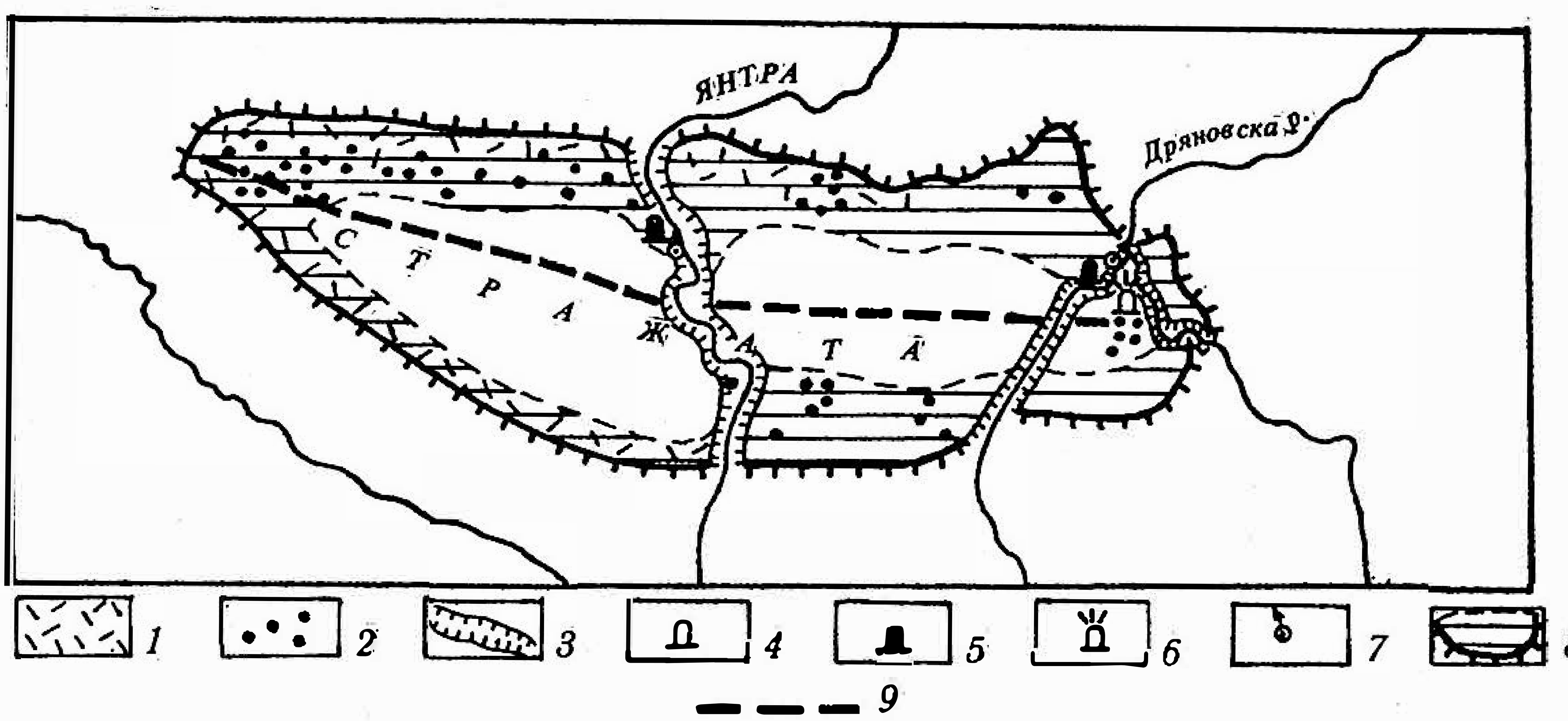

Рис. 4. Картосхема синклинального карста плато "Стражата": 1) голый карст, 2) воронка, 3) каньонообразная врезанная долина, 4) сухая пещера, 5) водная пещера, 6) электрофицированная пещера, 7) карстовый источник, 8) карст в синклинальной структуре, 9) синклиналь, выраженная в рельефе.

аптско-ургонских известняков и пересеченной поперечно каньонообразными долинами Янтры и Дряновской реки.

Сармато-понтическая поверхность этого плато волнообразна, благодаря наличию более 35 воронок и увалов (величиной до 680/480 м) с глубиной до 40 м. Для периферийных районов плато "Стражата" характерны обширные карровые поля.

Восточный наклон ургонских известняков обуславливает сток грунтовых карстовых вод через две водные пещеры. Пещера "Извора" образована на левом берегу Янтры на высоте 11 м над уровнем реки почти непосредственно по оси синклинали. Сток с восточной части плато (междуречье Янтры и Дряновской) осуществляется главным образом через Дряновскую пещеру, вход в которую расположен на высоте 11 м над Дряновской рекой. На высоте 35 м над рекой расположен вход и во вторую пещеру "Бачо Киро", электрофицированную и имеющую длину 2400 м. Обе пещеры образованы точно вдоль оси погружающейся к востоку Стражанской синклинали.

3. КАРСТ В МОНОКЛИНАЛЬНЫХ СТРУКТУРАХ

Это наиболее широко распространенный тип карста. На него приходится 61,5% карстовых образований в Предбалкане.

Для Западной Стара-Планины характерны окарстованные моноклинали,

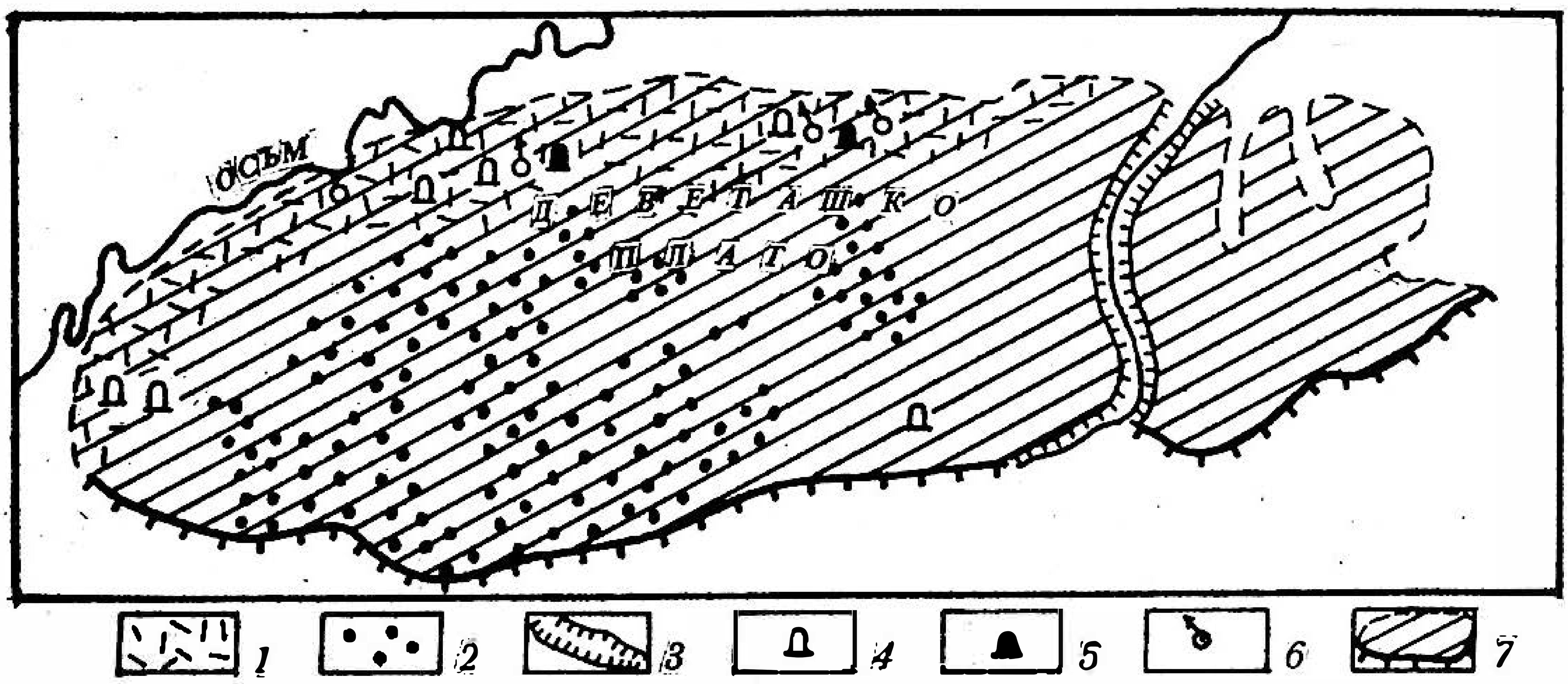

Рис. 5. Картосхема моноклинального карста Деветакского плато: 1) голый карст, 2) воронка, 3) каньонообразная врезанная долина, 4) сухая пещера, 5) водная пещера, 6) карстовый источник, 7) моноклинальный карст.

части глубоко денудированного Белоградчикского антиклинория. На северном крыле этого антиклинория находится уединенная "Рабишка могила", в которой в плиоцене была создана пещера "Магура" (длиной 2500 м), в настоящий момент электрофицированная. Ряд окарстованных моноклиналей носит название "венцов". Примером такового является Белоградчикский венец, в котором оформлена "Неприветливата пропаст", глубиной в 126 м.

Южное крыло Белоградчикского антиклинория слагают окарстованные титонские известняки моноклиналей: "Ведерника", "Широка-Планина", "Веренишкото бърдо".

К востоку от Огосты расположена типичная гомоклиналь "Милин камък". Здесь окарстовыванию подвержены аптские ургонские известняки, которые рассекаются слабо наклоненной к югу левантинской денудационной поверхностью. В южной части "Милин камъка" находится третья по длине пещера "Понора" (3500 м). Поблизости расположена пещера "Младеновата" (1640 м) и живописный каменный "Божи мост".

К востоку от р. Осым в северной части среднего Предбалкана простирается обширное Деветакское карстовое плато (рис. 5). Сармато-понтическая его денудационная поверхность наклонена слабо к северу (470-380 м) и образована в аптских ургонских известняках. Оно изобилует многочисленными воронками, плотность которых местами достигает до 43 на л кв км (с. Тепава). Обширные карровые поля распространены на северных периферийных участках плато и вокруг воронок. В этом карстовом районе насчитывается около 48 пещер, расположенных в 4 этажа. Из них наибольщую длину имеют следующие пещеры северного склона Деветакского плато: "Водопада" (995 м), водная пещера "Урушката маара" (1600 м), расположенная южнее с. Крущуна, и Деветакская пещера (1400 м) - северовосточнее с. Деветаки.

Подвержены окарстовыванию баремские и аптские известняки параллельно расположенных моноклиналей северного крыла Севлиевской антиклинали. Между Севлиево и Тырново на этих моноклиналях образованы каменные "венцы" и голые карровые поля.

В последние годы в связи с изучением полезных ископаемых, гидротехническими, промышленными, дорожными и другими видами строительства на изучение карста в Болгарии обращается все большее внимание. При комплексном исследовании карста Предбалкана необходимо обращать специальное внимание и на неотектонические движения, которые до значительной степени обуславливают закономерности его развития.

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Ba 036

THE PROBLEM OF SURFACE MODELLING BY SOLUTION, A CASE STUDY

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Long before Corbel's provocative thesis in 1957 karst geomorphologists calculated solution rates from the chemical load of rivers. Since his work it has become a well known and commonly used method: The volume of dissolved rock removed by a river in a known time from a known catchment area is related to this area and expressed in the dimensions m^3/year/km^2 or - which is numerically the same - in mm/1000 years.

Results obtained in different climatic and petrographical regions do not show a regularity as unequivocal as expected by Corbel. This gave rise to the opposition of several authors: Ranging from Bögli's objection in 1960 that karst morphology is less interested in the "output" of a karst landscape than in the processes going on within it, up to the criticism of Beckinsale (1972) who considers it to be more reasonable to establish the relation between the rock volume removed by solution and the total volume of soluble rock involved in solution instead of relating the volume to an area.

In spite of all objections the erosion rate calculated by Corbel's formula seems to be a useful standardising concept. Sometimes it is significant in a strictly literal sense - on exposed rock surfaces for instance or in loose material (clastokarst) - sometimes it is to be considered as a more abstract index allowing, for example, small scale comparisons between different catchment areas[1].

The differentiations of the erosion rate[2] proposed by several authors seem to be of a certain advantage over the original single-figure-index, but they are either impracticable at all because they contain non-quantifiable elements or they are at least much harder to determine than the simple solution rate. This is valid for:

- the differentiation of surface and subterranean solution by Corbel himself as well as for

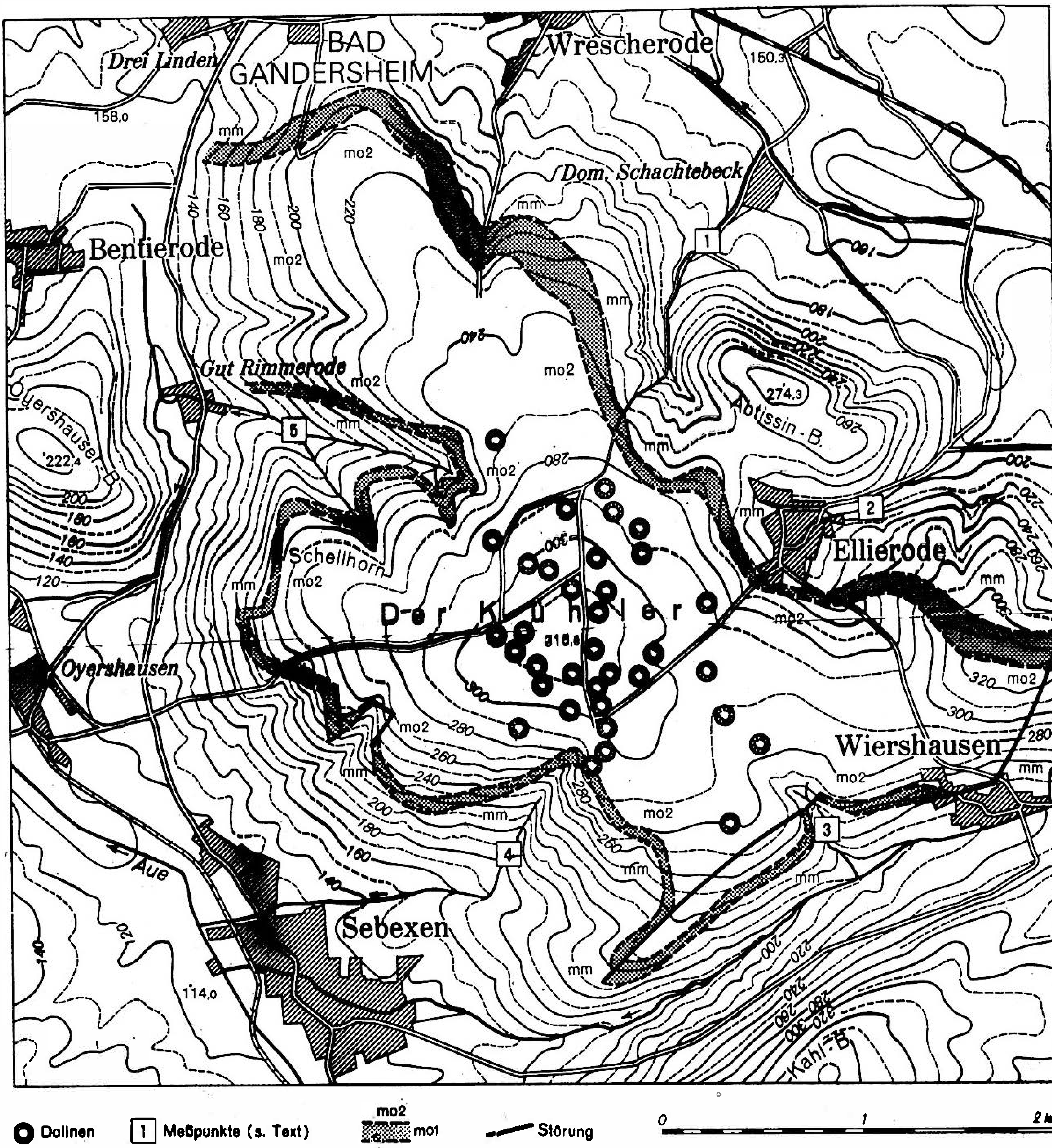

Fig. 1. Map of the Study Area - Extract of the Geology, Location of Dolines and Sample Points.

1) To do justice to Corbel it must be said that he did indeed recognize these difficulties and some of the reservations of his critics. Even in his first publication in 1957, where he used this method, he wrote "Rappelons que ... la couche de calcaire que est enlevée annuellement ... est f i c t i v e puisqu'elle correspond à une érosion qui s'exerce non seulement en surface mais aussi à l'intérieur de la masse rocheuse." (1957, p.498). - Corbel's apparent errors in the domain of climatic morphology do not depend on this method but they are caused by insufficient data and by a premature interpretation of the facts.

2) I prefer to call it solution rate in the following.

- the differentiation between the solution-deposition-metabolism within an area and the definite removal of dissolved rock. This was objected by Bögli (1960) and Williams (1968),
- the distinction of "karstic" and "non-karstic solution" (according to Rohdenburg & Meyer 1963) as well as for
- the delimitation of the rock volume affected by solution proposed by Beckinsale 1972.

In this paper I shall propose one more solution index that seems easily calculated and morphologically more relevant than the simple rate of erosion.

This will be demonstrated by discussion of a small area of interstratal karst (a term proposed by J.F. Quinlan 1969, in German we call it "unterirdischer Karst" according to A. Penck 1924), on Middle Muschelkalk Gypsum.

The area called "Kühler" is situated near Bad Gandersheim; this is 60 km SSE of Hannover, in Northern Germany. As shown in figures 1 and 2 it is an Upper Muschelkalk plateau isolated in all directions by valleys so that the relatively impermeable Middle Muschelkalk crops out everywhere except in the NW.

The more or less flat lying Lower Muschelkalk (mu) consists of 100 m of bedded limestone, the Middle Muschelkalk (mm) of about 40 m of marls with some 25 m of gypsum in its middle, the lower part of the Upper Muschelkalk (mol) consists of 10-15 m of sparitic limestone and the upper part (mo2) of 40 m of impure limestone. A loess cover of 1-3 m mantles the eastern half of the Kühler. This eastern part is arable land, the western part of the top and all steeper slopes are covered by beech tree forest. There is no significant surface runoff.

The Kühler is situated in a region affected by considerable dislocations. Nevertheless the Middle Muschelkalk does not seem to allow the perched groundwater to penetrate into the Lower Muschelkalk. Under these conditions one may suppose that the whole runoff passes through the springs. The NW end of the area is not considered here; there may be some underground outflow through the gently dipping Upper Muschelkalk, but this is speculative. Also, the constriction between the springs above the sampling points 1 and 5 makes a northward directed underground overflow from the centre of the Kühler improbable.

A comparison of the measured runoff and the calculated one based on the known climatic data (730 mm of precipitation - 480 mm of evapotranspiration = 250 mm of runoff) showed a perfect conformity: there

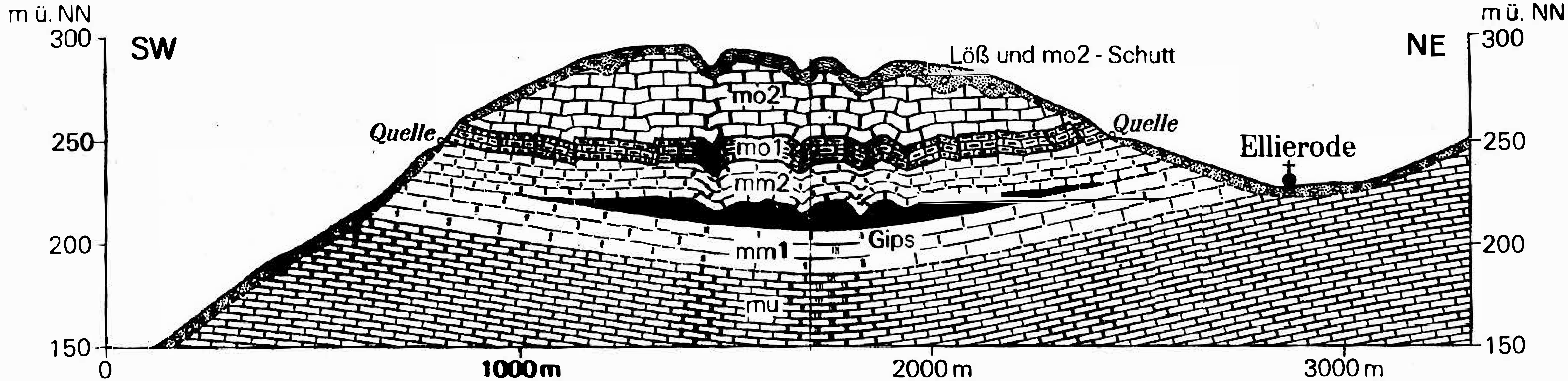

Fig. 2. Generalized Profile of the Kühler (between Sebexen and Ellierode, exaggeration of heights 5x).

cannot be an important deep outflow because it can be excluded absolutely that water from outside the considered catchment area appears in the springs.

There are very few areas in the limestone regions of the German "Mittelgebirge" where conditions for analysing catchment areas in detail and for establishing a water balance are as favourable as here. - Confining catchment areas seems to be the main problem in large scale studies in karst hydrology.

Water gaugings and analyses were made 16 times with irregular intervals during one year (1968 to 1969) at the 5 points indicated. The total runoff value was 1,6 . 10^6 m^3/year, the average solution load was 152 ppm $CaSO_4 \cdot 2H_2O$ and 270 ppm $CaCO_3$. This is equivalent to a solution rate of 17 mm of gypsum and 25 mm of limestone per 1000 years. Extrapolating the present solution rate over the entire Holocene period, a gypsum volume of 170 000 m^3 and a limestone volume of 250 000 m^3 will have been removed from one square kilometre. This corresponds to an average surface lowering equivalent of 42 cm.

The only karst forms on the plateau - like top of the Kühler are some 35 dolines with sigmoid slopes, diametres of 8-90 m, and depths of 2-8 m. By several drillings in this area and by analogy to other and better-known dolines in similar geological, morphological and hydrological situations - there are more than 1000 dolines in the Upper Muschelkalk of Lower Saxony - it may be affirmed that these dolines are of post-glacial age and that they do not depend on limestone solution but that they are collapse dolines genetically related to Middle Muschelkalk gypsum, as suggested in figure 2. The 35 dolines have been measured and the volume of all of them can be calculated being slightly more than 24 000 m^3. The volume decrease by break-down of the Upper Muschelkalk rock and by slope denudation in the dolines has deliberately not been taken into account.

A comparison of this doline volume with the amounts of dissolved gypsum mentioned above leads to the unexpected conclusion that only about 1-2% of the total gypsum solution during the Holocene produced proper karst landforms. The amount of limestone dissolved is even larger, but it has not produced any known karst forms at all.

This ratio demonstrates the discrepancy between the surface lowering and the surface modelling effects of solution. In this and many other cases of the solution of Mesozoic and younger rocks the "surface lowering" may be understood in its literal sense - not only considering "geological" times. In loose or poorly consolidated material, in densely fissured rocks, in interstratal sulphate and halite karst - these rocks are often enclosed between slightly consolidated pelites - the effect of solution is essentially a diffuse and undifferentiated surface lowering: the most important erosion process (in the sense of "Abtragung" in German) is completely unnoticed by geomorphologists.

In conclusion, I wish to state that as a supplement to the solution rate, the surface lowering / surface modelling ratio seems to be an interesting index from two points of view: firstly in order to characterize the morphological effect of solution on different rocks, under different covers, and - I am sure - under different climatic conditions; and secondly maybe it can serve to characterize the actual situation of karst morphology, being both a landform science and a process science, interested in the solution process even in regions where it does not produce any karst forms.

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Ba 037

О КАРСТОВЫХ ЯВЛЕНИЯХ РАЧИНСКОГО ХРЕБТА (ЗАПАДНАЯ ГРУЗИЯ)

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Исследуемый район, являясь составной частью Рачинского хребта, занимает территорию площадью 650 км^2 известняковой полосы Западной Грузии. С севера район ограничивается ущельем р. Риони. Рачинский хребет асимметричного строения. Его южный склон местами представлен отвесными обрывами, высотой 200-400 метров. Более обширный северный склон включает в себе несколько небольших диагональных хребтов (Поцхвреви, Хихата, Накерала).

Поверхностный сток района относительно незначителен. Гидрографическая сеть, в связи с сильной закарстованностью района, не густая, реки немноговодные. Левые притоки р. Риони (Хеора, Барула, Крихула, Шараула) берут начало на Рачинском хребте и местами образуют глубокие каньонообразные ущелья.

В климатическом отношении район расположен в субтропической полосе Западной Грузии, хотя сложные орографические условия вызывают значительную разницу между климатическими показателями (М.О. Кордзахиа, 1960). Особо высокой влажностью и большим количеством осадков отличается Накеральский хребет высотой 1300-1400 м над у.м. (2000 мм/год).

В геологическом строении района принимают участие местами обнажающиеся среднеюрские отложения - байосская порфиритовая свита и батские глины и песчаники. Выше по разрезу следует верхнеюрская (кимериджская) пестроцветная свита, на которой расположены нижнемеловые отложения. Низы валанжин-готерива представлены кварцево-аркозовыми песчаниками, переходящими выше в среднеслоистые доломитизированные известняки. На эти отложения залегают барремские толстослойстые известняки, занимающие большую часть исследуемой территории. За барремскими известняками следуют мергелистые известняки апта, мергелистые глины и мергели альба и глауконитовые песчаники сеномана. Выше по разрезу идут турон-сенон-датские и палеоценовые известняки. Далее следуют терригенные отложения верхнего палеогена-неогена и отложения четвертичной системы.

По схеме геотектонического районирования Грузии, разработанной П.Д. Гамкрелидзе (1964), исследуемый район входит в подзону Рачинско-Лечхумской синклинали Гагрско-Джавской зоны, относящейся к складчатой системе Южного склона Большого Кавказа. Район представлен, в основном, пологоскладчатыми структурами, осложненными частыми дизъюнктивными нарушениями, придающими району блоковое строение.

Известняковая часть Рачинского хребта представляет собой классический район горного карста. Известняковые толщи, являющиеся ареалом развития карстовых явлений, характеризуются господствующими падениями на север под углом 10-40°.

Поверхностными и подземными карстовыми формами особенно изобилует Шаорская котловина (1160 м от у.м.) и окрестности гор - Поцхврези (2405 м), Хихата (2243 м), Сацалике (1997 м), Накерала (1570 м). Накеральское плато считается районом наиболее интенсивного развития карста в СССР (Н.А. Гвоздецкий, 1965).

Карстовые формы представлены депрессиями, пещерами, колодцами, шахтами, воронками (диаметром до 150 м и более, глубиной до 60-80 м), каррами. Глубина многочисленных карстовых колодцев варьирует от 10 до 20 метров при диаметре 0,5-1,5 м. Пещеры в основном горизонтальные и обводненные. На южной отвесном крыле Накеральского хребта, на абс. выс. 1300 и 1435 м открываются Цхраджварские пещеры. Общая длина первой из них, выработанной в барремских толстослойстых известняках (ургонская фация), составляет 468 м (Ш.Я. Кипиани, В.М. Джишкариани, 1973). II и III пещеры выработаны на контакте барремских и нижненеокомских известняков. Севернее, в ущелье р. Шараула нужно отметить Цахскую пещеру, богатую натечными образованиями и пещеры Шараула и Цивцкала. Рекой, вытекающей из пещеры Цивцкала, питьевой водой снабжается (путем откачки) г. Ткибули.

У северных отрогов Рачинского хребта, в восточной части Шаорской котловины, почти на одинаковом гипсометрическом уровне открываются горизонтальные пещеры с небольшими озерами в конце и вытекающими из них карстовыми источниками (пещеры Сакишоре, Кидобана, Долабиставии). В восточной части территории, на Шкмерском плато находится интересная, изобилующая натечными образованиями горизонтальная пещера Ушолта, по дну которой протекает подземная река Черула.

В карстовой воронке около с. Шкмери, представлено озеро диамет-

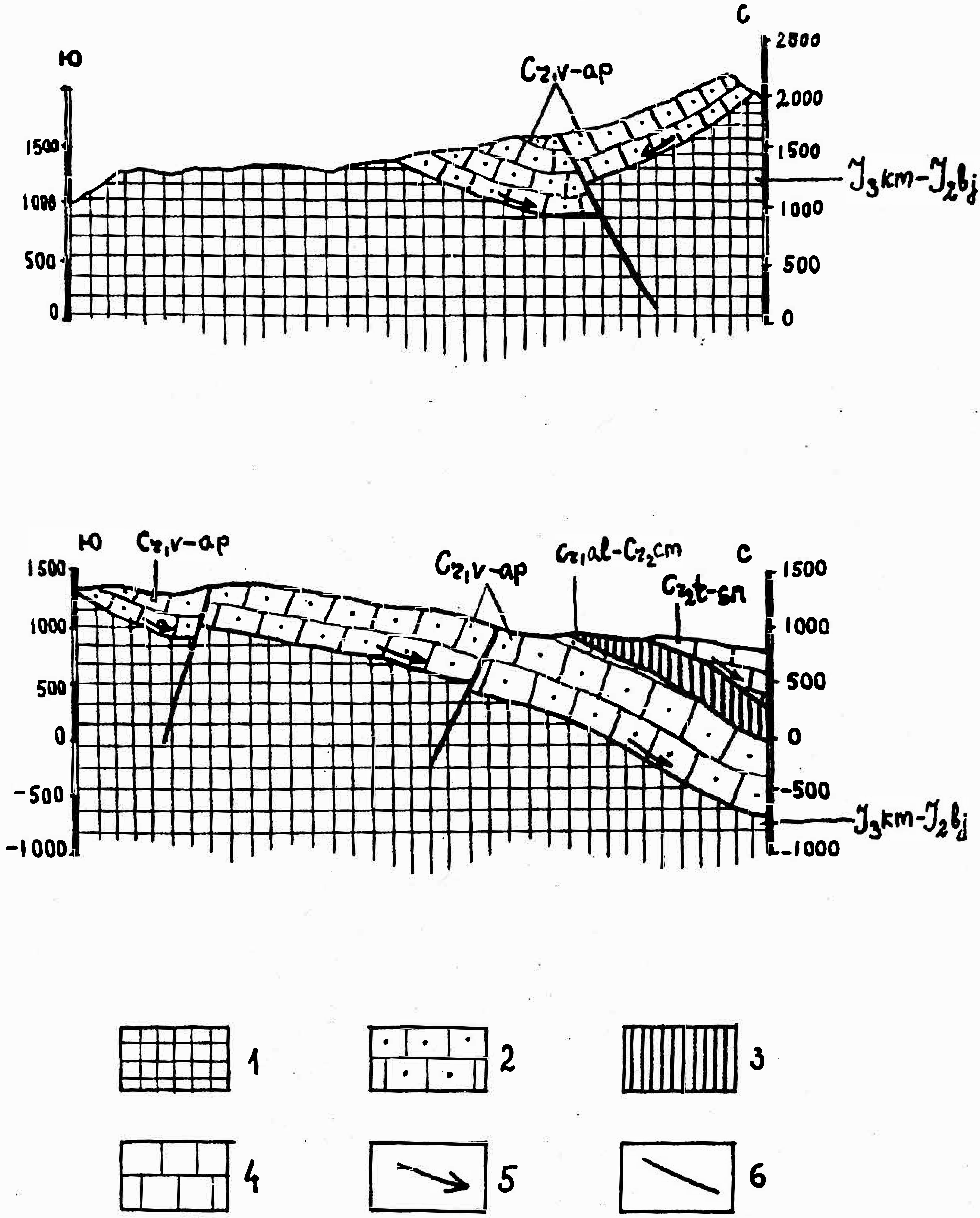

Рис. 1. Схематические гидрогеологические разрезы по меридианам гор Поцхврези (а) и Сацалике (б): 1. Нижный водоупорный горизонт, глины, песчаники, туфобрекчии кимериджа (пестроцветная свита), а также отложения средней юры. 2. Нижный водоносно-карстующийся горизонт, средне- и толстослойстые известняки, доломиты и доломитизированные и мергелистые известняки валанжин-баррем-апта. 3. Верхний водоупорный горизонт, глинистые мергели и песчаники альба и сеномана. 4. Верхний водоносно-карстующийся горизонт, слойстые известняки тырон-сенона. 5. Направление подземных водотоков. 6. Разрыв.

ром 15 м, воды которого дают начало реке Хеора. В 400 м от озера, на южном склоне хребта Поцхвреви выходит довольно мощный карстовый источник "Клдисцкаро".

Нужно отметить также вертикальные ледяные пещеры Сакинуле и Схвава, которые крестьянами использовались для хранения продуктов.

Из большинства известных на исследуемой территории пещер (до 20) выходят карстовые источники.

Район характеризуется сложными гидрогеологическими условиями. На основании анализа литологии и тектонического строения отдельных участков территории, нами выделяются следующие водоупорные и водоносно-карстующиеся горизонты (см. рисунок):

1. Нижный водоупорный горизонт - представлен, в основном, глинами, песчаниками и туфобрекчиями кимериджа (пестроцветная свита), мощность которой в центральной части составляет 500-800 метров, а в крайне восточной части (Шкмерское плато) - 100-200 м.

2. Верхный водоупорный горизонт - представлен глинистыми мергелями и песчаниками альба и сеномана, широтно простирающимися по северной периферии исследуемого района. Мощность горизонта варьирует от 20 до 150 м.

Водоносные горизонты:

1. Нижный водоносно-карстующийся горизонт - представлен валанжин-баррем-аптскими средне- и толстослойстыми известняками, доломитами и доломитизированными и мергелистыми известняками. Общая мощность горизонта варьирует от 200 до 1000 м, является основным карстующимся горизонтом и составляет около 70% исследуемой территории.

2. Верхний водоносно-карстующийся горизонт - представлен верхнемеловыми (турон-сенон) слойстыми известняками и распространен в северозападной части территории - в бассейне р. Шараула, в центральной части - между селениями Знаква и Схвава, а также в крайне восточной части - на Шкмерском плато. Мощность горизонта 50-150 м.

Вторичные тектонические дислокации сыграли важную роль в формировании обособленных карстовых водотоков. Наглядным примером этого положения служат находящиеся недалеко друг от друга выходы мощных подземных рек Цивцкала и Шараула (к северо-западу от с. Никорцминда), режим и химизм которых различны.

В отличии от массива Арабика в Абхазии (Т.З. Кикнадза, 1972), для исследуемой территории сбросы сыграли основную роль в межбассейном распределении атмосферных осадков. Нашими исследованиями подтверждается положение о том, что формирование, перемещение и разгрузка карстовых вод в горных областьях происходит в границах определенных массивов, имеющих обособленные гидрогеологические водосборы (Г.Н. Гигинейшвили, 1973).

Инфлюацированные во многочисленных поверхностных карстовых формах атмосферные осадки после подземной циркуляции разгружаются в виде карстовых источников гидродинамических зон горизонтальной (источники пещер Цивцкала, Сакишоре, Кидобана, Долабистави и др.) и сифонной (источники на дне Шаорской котловины, оз. Хариствали на Шкмерском плато, воклюз около пещеры Сакишоре и др.) циркуляции. В классификации карстовых источников Г.А. Максимовича (1963) выделен тип подвешенных карстовых вод, примером которого может служить источник "Клдисцкали" на Шкмерском плато.

Разгрузка карстовых вод приурочена к зонам тектонических нарушений и к контактам известняковых толщ с водоупорными горизонтами, в местах эрозионного расчленения последних, а также к днищам долин.

Карстовые воды на исследуемой территории гидрокарбонатно-кальциево-натриевого-магниевого типа с общей минерализацией 200-500 мг/л, при pH 7-8, температура колебляется в пределах от 5 до 8 °С. Дебит крупных источников варьирует от 50 л/сек до 0,5 м^3/сек.

В межбассейном распределении атмосферных вод и их подземной циркуляции наряду с тектоническими нарушениями важное значение имеет наличие гидрогеологических водоразделов, часто не совпадающих с топографическими. Выявление и уточнение распространения последних необходимо для дальнейшего изучения гидрогеологических условий развития карста исследуемой территории.

ON THE KARST PHENOMENA OF THE RACHA RANGE (WESTERN GEORGIA)

K. Rakviashvili

SUMMARY

Karst phenomena of the Racha range (Central Caucasus) being developed in Barremian limestones represent the classical type of mountain karst. The numerous sink holes, wells and depressions are located in the area. The caves are mostly horizontal and watered.

On the basis of analysis of lithology and tectonic framework of various sections of the investigated territory the author singles out two impermeable and water-bearing karstic horizonts.

Thickness of the principal water-bearing karstic horizont is up to 1000 m.

The secondary tectonic dislocations are of the main importance in the distribution of underground-water. This thesis is confirmed with the existence of underground rivers with different regimes and chemism with neighbouring outlets at the same hipsometric levels.

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Ba 038

BEMERKUNGEN ZU SENKUNGS- UND ERDFALLERSCHEINUNGEN IN SALZKARSTGEBIETEN DER DDR

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A b s t r a c t. Nach Darlegung der allgemeinen ingenieurgeologischen Problematik in Salzauslaugungsgebieten wird eine Deutung über die Möglichkeit des Auftretens von Erdfällen über Salzkarst diskutiert.

Grosse Erdfälle treten in den Senkungsgebieten des Salzkarstes der DDR in der Zerrungszone am Rande von Senkungsmulden auf. Eine Grundvoraussetzung für den weiteren Ausbau der ingenieur-geologisch-geomechanischen Modellvorstellungen ist die Durchführung und Auswertung von Senkungsmessungen und die Entwicklung weiterer Messverfahren zur Beobachtung der Entwicklung von Senkungsformen.

1. PROBLEMSTELLUNG

Eine Hauptaufgabe der Ingenieurgeologie in den Südwestbezirken der DDR besteht in der Erforschung der Gips- und Salzkarsterscheinungen mit der Zielstellung Kriterien für die ingenieurgeologische Einschätzung der Karstgebiete für das Bauwesen und den Bergbau zu erarbeiten. Der Gegenstand der Betrachtungen soll hier nur der Salzkarst sein. Im Bereich des Salzkarstes tritt eine grosse Formenfülle auf, und es sind viele wirkende Faktoren zu berücksichtigen. Als die wichtigsten den Prozess beeinflussenden Faktoren wurden von von Hoyningen-Huene und Reuter (1963) genannt: Gesteinsart, geologisch-tektonische Verhältnisse, hydrogeologische Verhältnisse, Löslichkeit, Zeit und Klima. Wenn auch die wichtigsten Lösungs- und Bewegungsvorgänge prinzipiell bekannt sind, so wird doch durch das Hangende des Karstgebirges, insbesondere infolge seiner Inhomogenität und Anisotropie, der Senkungsvorgang derart modifiziert, dass nicht sicher vorausgesagt werden kann, wann und ob ein Ereignis als quasiplastische Verformung oder als katastrophaler Einbruch ablaufen wird. Die Erscheinungsformen des Salzkarstes, wie Randspalten, Schollenverkippungen, grabenbruchartige Einsenkungen, Dolinenbildungen u.a., sind grundsätzlich geomechanisch erklärbar; allerdings sind bis heute fast in allen Fällen noch keine geeigneten Messmethoden und -programme entwickelt worden, um die Bewegungsvorgänge in diesen Formen exakt erfassen zu können.

2. IST DIE VORHERSAGE VON EINBRÜCHEN ÜBER SALZKARST MÖGLICH?

Nach TGL 168 - 1002 sind Geländeschäden in Salzkarstgebieten so zu beurteilen, dass ein wenig oder noch gar nicht beanspruchtes Deckgebirge nach der "Unterlaugung" grosse Spannungen aufnehmen kann, ehe es zu einem Bruch kommt. Dadurch ist die Entstehung von grossen Hohlräumen möglich, die sich zu Erdfällen entwickeln können. Bei einem vielfach abgesenkten und demzufolge stark beanspruchten Deckgebirge, wo das Hangende des Salzes infolge der Senkungen zerbrochen ist und als Schollenmosaik vorliegt, ereignen sich demgegenüber mehr oder weniger gleichmässige Senkungen als Folge von laufend stattfindenden Partialbewegungen an den Grenzen der Teilschollen der hangenden Schichten. Diese Vorstellungen sind geomechanisch gesehen durchaus real und sie werden durch die geologische Geschichte der Senkungsgebiete scheinbar auch gestützt, indem in alten Senkungsgebieten, in denen mächtige jüngere Schichten abgelagert wurden, Einbrüche nicht bekannt geworden sind.

Für die akuten Auslaugungsgebiete der DDR (z.B. im Senkungskessel von Rollsdorf und im Bereich der Senkungskessel von Volkstedt/Eisleben) ist eine solche Aussage nach den bisherigen Erfahrungen entweder gar nicht oder nur mit Toleranzen von mehreren Kilometern möglich gewesen. Für die praktische Ingenieurgeologie und das Bauwesen bedeutet dies, dass die Aussage damit bedeutungslos wurde. Nach neueren Untersuchungsergebnissen bieten sich gewisse, auch geomechanisch begründete Kriterien über das Einschätzen der Erdfallgefahr über Salzkarstgebieten an.

In der Bergschadenslehre werden die Senkungen über bergmännischen Abbauen auf der Grundlage der sogenannten Trogtheorie beurteilt. Ganz ähnlich wie bei den bergbaulichen Senkungsmulden werden auch bei den Senkungsmulden in Auslaugungsgebieten Pressungs- und Zerrungszonen beobachtet, die im Gelände und vor allem bei geschlossener Bebauung mit ihren Schäden gute Demonstrationsobjekte für die Bewegungsvorgänge darstellen. Im unbebauten Gelände lassen sich die Ränder von Senkungsmulden durch konzentrische oder Randspalten gut verfolgen. In Auslaugungsgebieten haben diese Spalten in hydrogeologischer Hinsicht eine grosse Bedeutung. Auf ihnen findet eine Wasserzirkulation statt, und es kann in ihrem Bereich zu einer verstärkten Auflösung der Salze kommen. Die Folge der höheren Auslaugungsintensitäten sind grössere

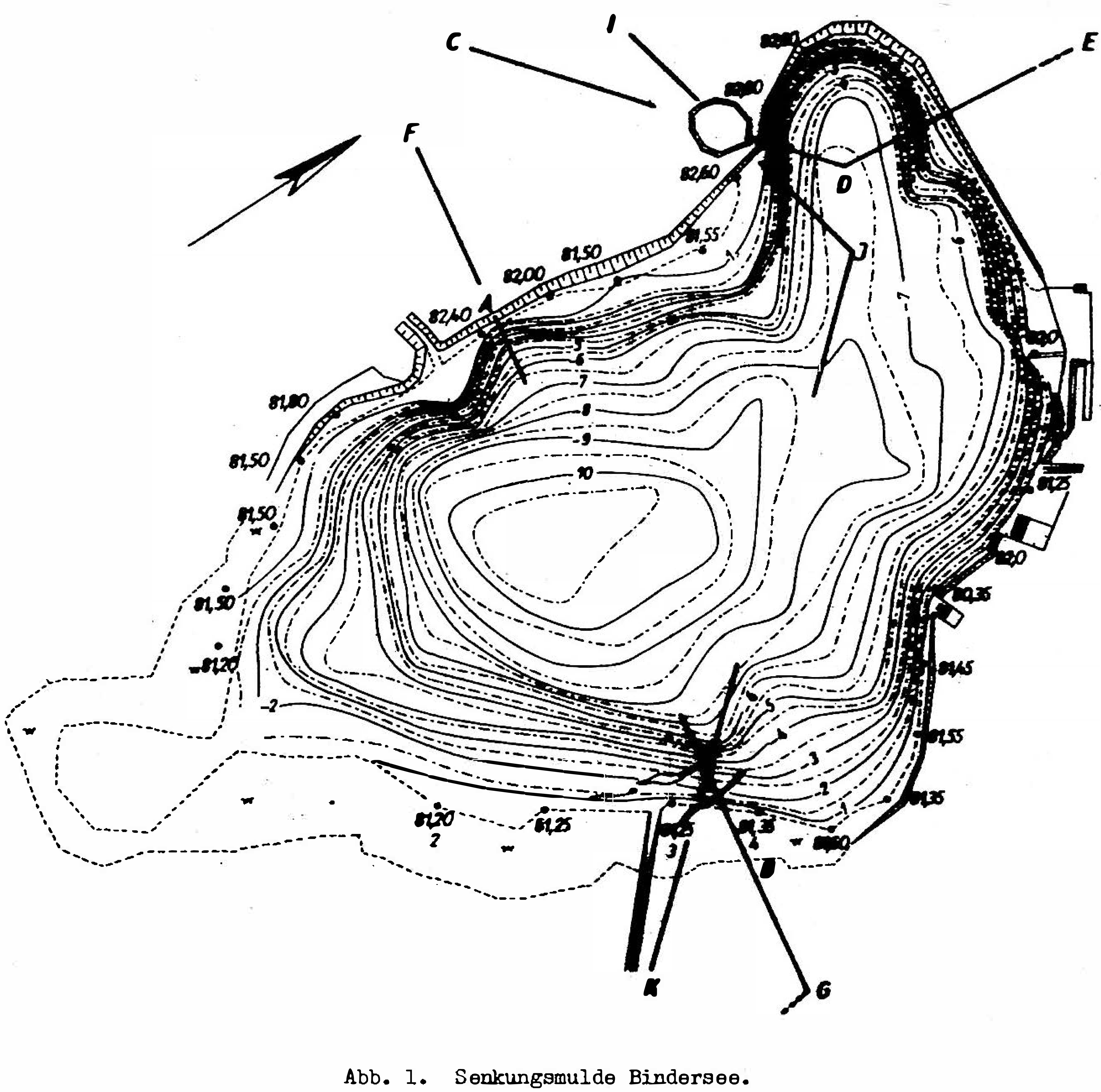

Abb. 1. Senkungsmulde Bindersee.

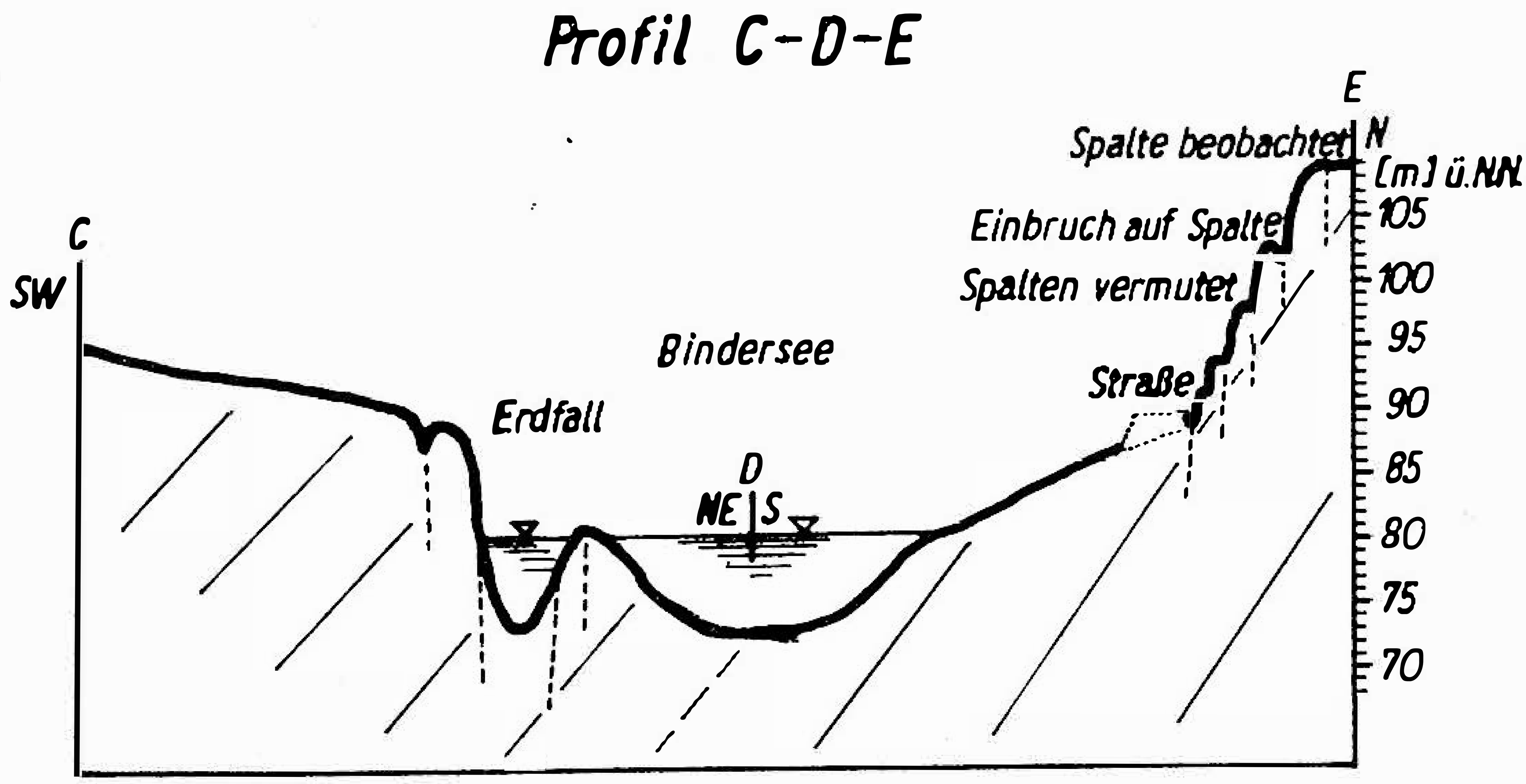

Abb. 2. Schnitt durch den Bindersee bis zum Hang östlich der F 80.

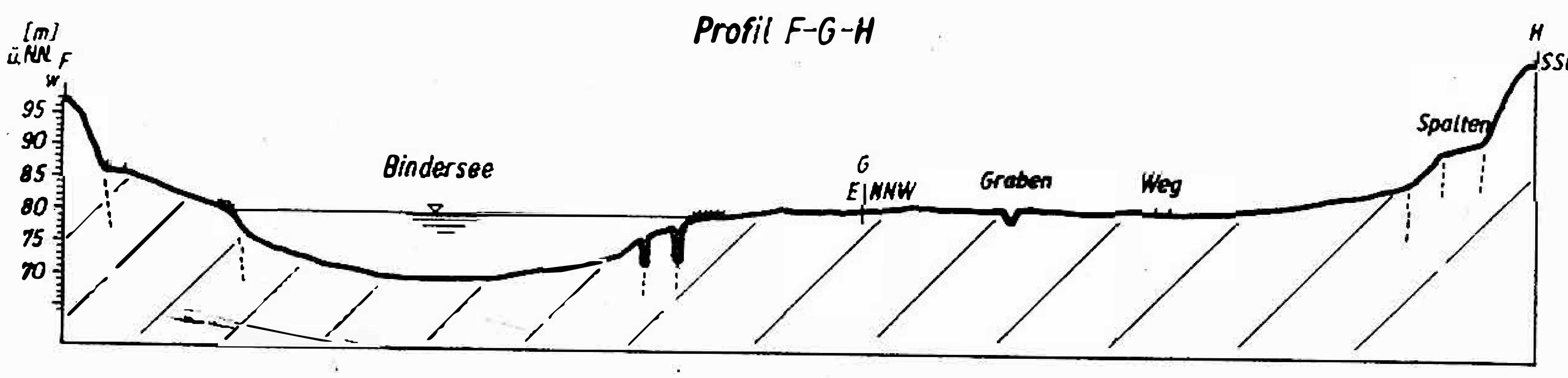

Abb. 3. Schnitt durch den Bindersee bis zum Erdfall Teufelsspitze.

Senkungsgeschwindigkeiten. Offensichtlich stellen im Salzkarstgebiet der Mansfelder Mulde solche Gebiete mit stärkeren Senkungen verschiedenedene junge Seen dar (Abb. 1); aber auch an anderen Stellen lassen sich Senkungsmulden in diesem Sinne deuten. Wenn man die Schnitte im Bereich einer dieser Seen (Abb. 2 bis 4) betrachtet, erkennt man, dass das Seegebiet tatsächlich eine gegenüber der Umgebung schneller sinkende Teilmulde darstellt. Nach der Trogtheorie treten an den Rändern jeder Senkungsmulde Zugspannungen auf, als deren Folgeerscheinungen sich Zerrungsrisse bilden. Mit Zunahme der Senkungsintensität werden die Zerrungen grösser, und die entstehenden Risse gewinnen als hydrogeologischer Faktor an Bedeutung. Dies bedeutet, dass neben der verstärkten Lösungstätigkeit im Bereich der Risse eine Schwächung der Gebirgsfestigkeit erfolgt (Verringerung der Reibung). Am Rande von

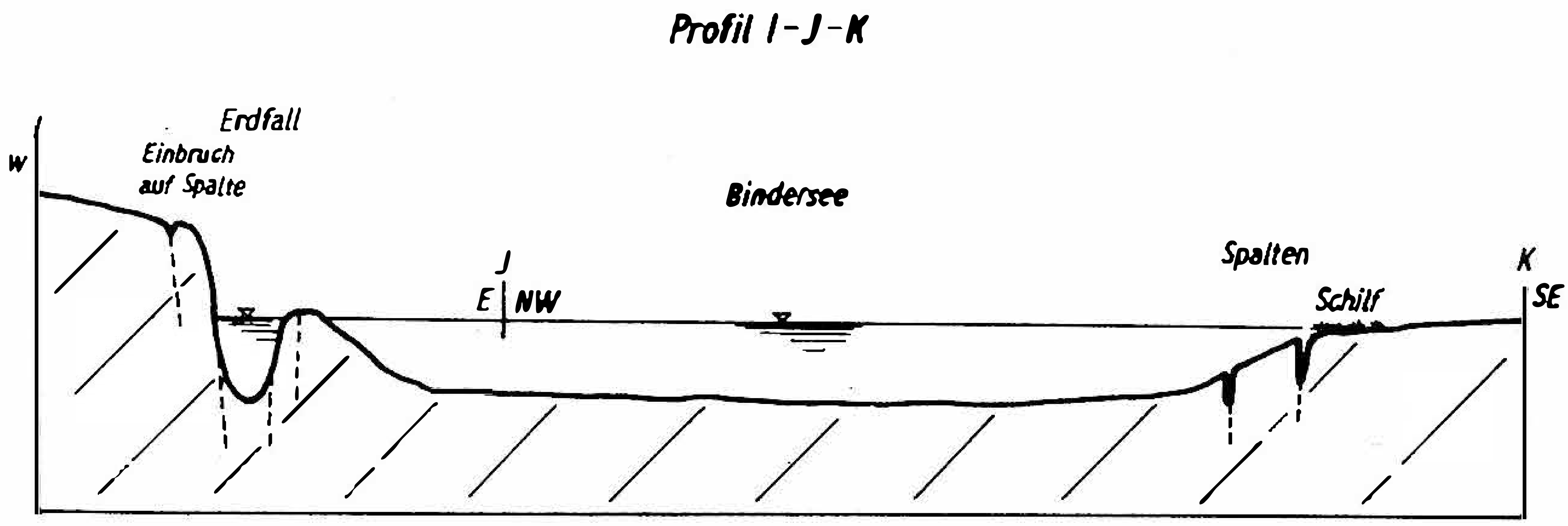

Abb. 4. Schnitt durch den Bindersee.

Seen, wo reichlich Wasser vorhanden ist, werden diese Faktoren besonders wirksam, so dass es in einem bereits vielfach abgesenkten Deckgebirge in den Bereichen mit den grössten Zugspannungen Erdfälle entstehen. Diese Art der Entstehung der Erdfälle lässt sich an mehreren Beispielen eindeutig belegen.

Wenn man eine Senkungsmulde an einer anderen Stelle betrachtet, lassen sich die dort stattfindenden Senkungsvorgänge, die an den Rändern der Mulde als grabenbruchartige Senkungen vor sich gehen, zwanglos in das dargelegte Modell einfügen.

Alle bruchartig verlaufenden Erscheinungen im Salzkarst treten offensichtlich im Berich der grössten Zugspannungen, d.h. in der Zerrungszone nach der Trogtheorie, auf. Ob sich der Prozess als Spalte, als "Grabenbruch" oder als Erdfall abgespielt, hängt ausser von der Senkungsintensität im wesentlichen von den geologisch-tektonischen und hydrogeologischen Bedingungen ab.

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Ba 039

OBSERVATIONS ON SOME GREAT SOLUTION RUNNELS WITH NESTED SOLUTION PANS OF THE VENETIAN PREALPS

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Numerous solution forms have been imposed during the Postglacial age on rock-cut terraces, modelled by the Würm Ice Sheet, in the South of the Adige valley (Val Lagarina);

These were the starting point for a study of Rundhöckerkarst type landscapes as a whole (Sauro 1973). Of the forms examined, two deep rectilinear runnels stand out because of their peculiarities. They begin with a solution pan (kamenitza) fed by one or two minor tributary runnels and continue as alternating runnel and enclosed pan tracts as far as an engulfing cavity. Beyond the lip of practically every pan follows a slightly inclined runnel which ends, suspended above the back edge of the next pan. The runnel pans are situated in the central zone of the erosional terrace in the rock near Canale. This zone, sloping approximately 15° towards south 30° west and slightly undulating with clear signs of glacial moulding, is, in contrast with the surrounding areas, almost completely lacking in vegetation of any type having only little pioneer turf and a few rare busches.

The most westerly runnel (more central on the terrace = runnel A) is also the one which, being nearer the area totally covered by vegetation found uphill (about 10 m from the lower margin of the talus heaps), appears to be mostly exposed to the influence of this (the bringing of various organic and inorganic residues). It consists of a 8 metre long runnel, 20-40 cm wide, 15-40 cm deep and with a direction from N 30 E to S 30 W, which collects the waters of a 22 m^2

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*) Research carried out under a programme financed by the Consiglio Nazionale delle Ricerche.

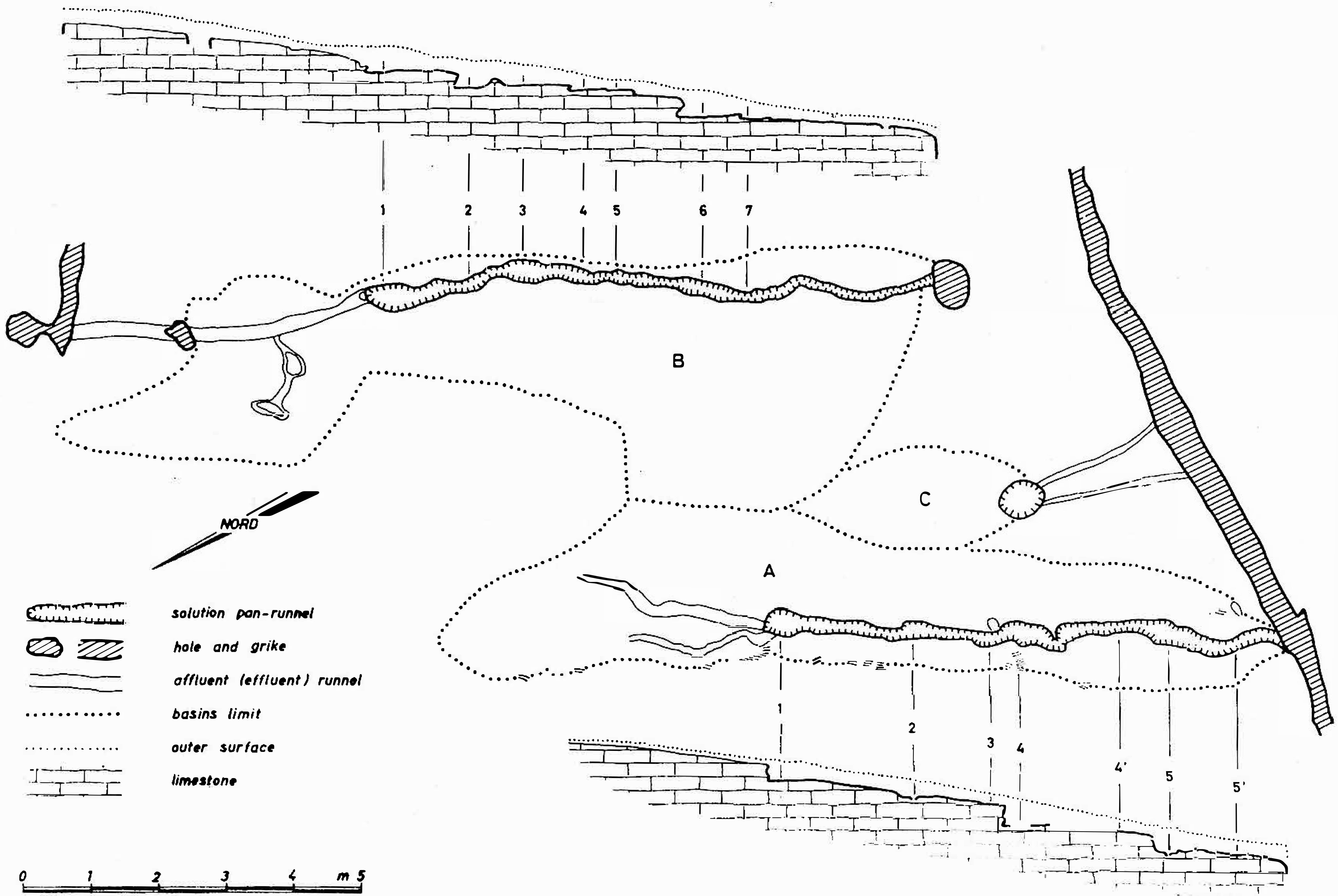

Fig. 1. Planimetrical sketches and longitudinal profiles of the two solution pan runnels. The dotted line indicates the limits of the respective basins. A third basin (C) is also drawn belonging to a solution cup.

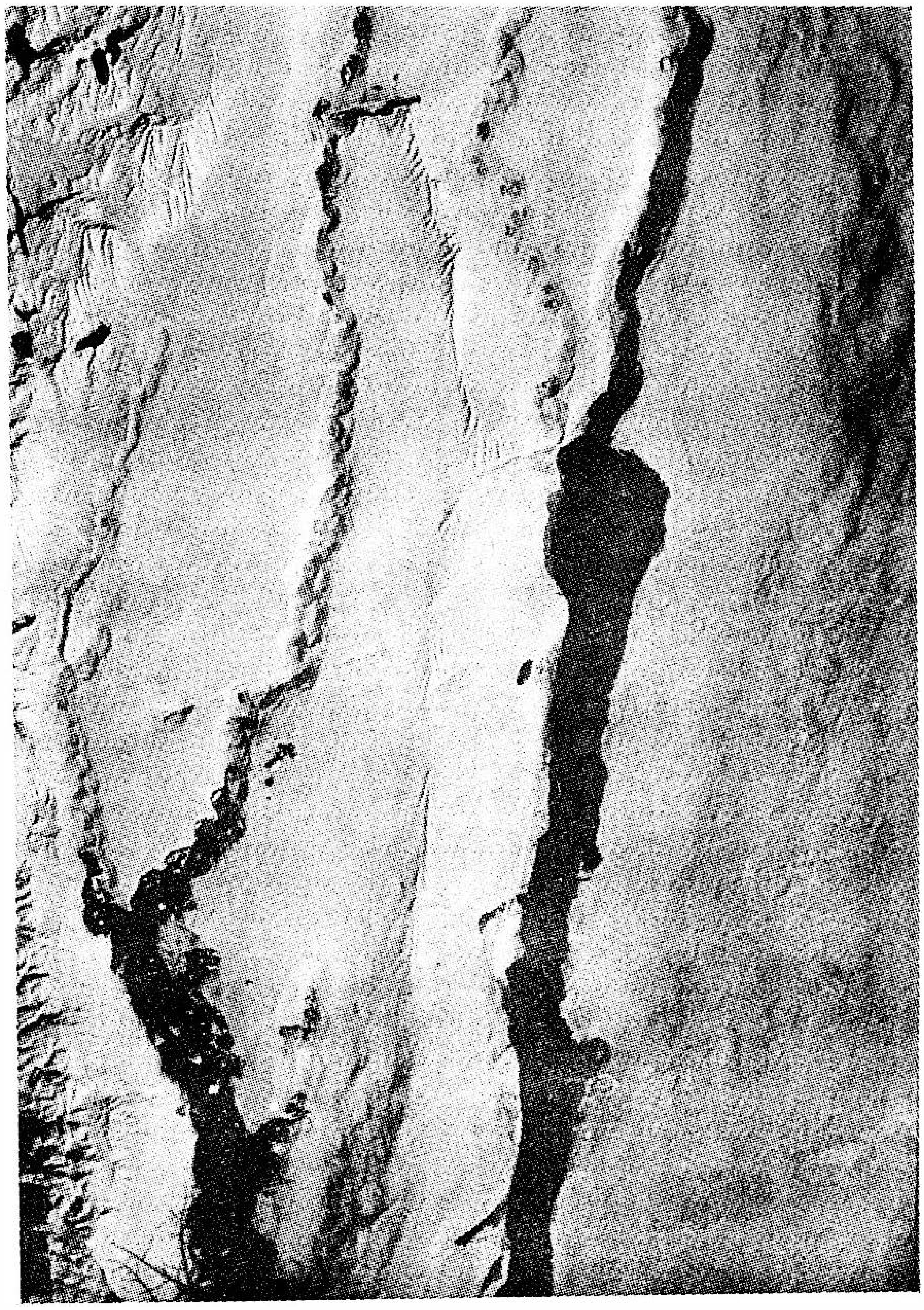

Fig. 2. The first tract of runnel A as seen from 5 metri above. Two meandering runnels join in the initial pan. Groups of solution flutes follow tracts of the watersheds.

basin, lengthways like the runnel and clearly dissymmetrical (the left slope is about 3 times wider than the right). Two tributary meandering runnels from the first pan are left sharply suspended on the back edge of this. Five pans in all are found in the main runnel (1A, 2A, 3A, 4A, 5A) of which 3A appears directly suspended over 4A. The runnel ends in a rather wide grike with an east-west trend.

The sum of the lengths of the pans represents about 38% of the total length of the runnel.

Runnel B is situated about 4 metres further to the east of runnel A, in relation to which it is subparallel but more southerly. Infact, the highest part of the drainage basin of runnel A borders on the low part of the one of runnel B. Uphill from the basin of runnel B, which measures about 30 m^2 and is also dissymmetrical (the right slope being much wider than the left), a 15 metre long depression can be seen which is anactive because drained by numerous holes and crossed by grikes and which contains traces of old pans. Runnel B contains 7 pans (1B, 2B, 3B, 4B, 5B, 6B, 7B) the first of which receives only one tributary. The sum of the lengths of the pans represents over 45% of the total length of the runnel (8,5 m) which ends in a solution pipe. A small elliptical basin (4 m^2) is found enclosed below between the two basins of runnels A and B, dependent on a great solution cup.

Ledges are to be found on the side of every pan. They are at different heights and correspond to old levels of the lip, that is, to the various levels assumed by the surface of the water at the start of successive periods of deepening and widening of the pan as a semi-free form (with water).

In the above mentioned note I have maintained that:

1) The two great pan runnels can, in their complex, be considered as the result of the particular development of the initial pans. This development would have been conditioned both by the relatively large dimensions of the drainage basins and by their morphological positions such as to reduce the bringing of extraneous materials. Such conditions favour the formation of an important effluent from the initial kamenitza and in general the individualization of solution pans. Therefore the long runnels with their nested pans, which continue the initial kamenitza would along with these, represent, also genetically, a unique form made up of a "mother" pan with the relative effluent containing several "offspring" pans.
2) The superimposed ledges represent cyclic factors. From top to base, every new ledge testifies to a preceding phase of infilling of the great runnel by soil. The soil would, in fact, have accelerated the deepening of the lips, tending to transform the infilled cavity into a single great runnel. After the washing away, the stagnant water in the pans would have determined the development of a new ledge below the proceding one, up to heights corresponding with those of the new levels of the lip. A concave notch found between two ledges would therefore, always from the top to bottom, correspond to an evolutionary period of the pan as a semi-free form (with

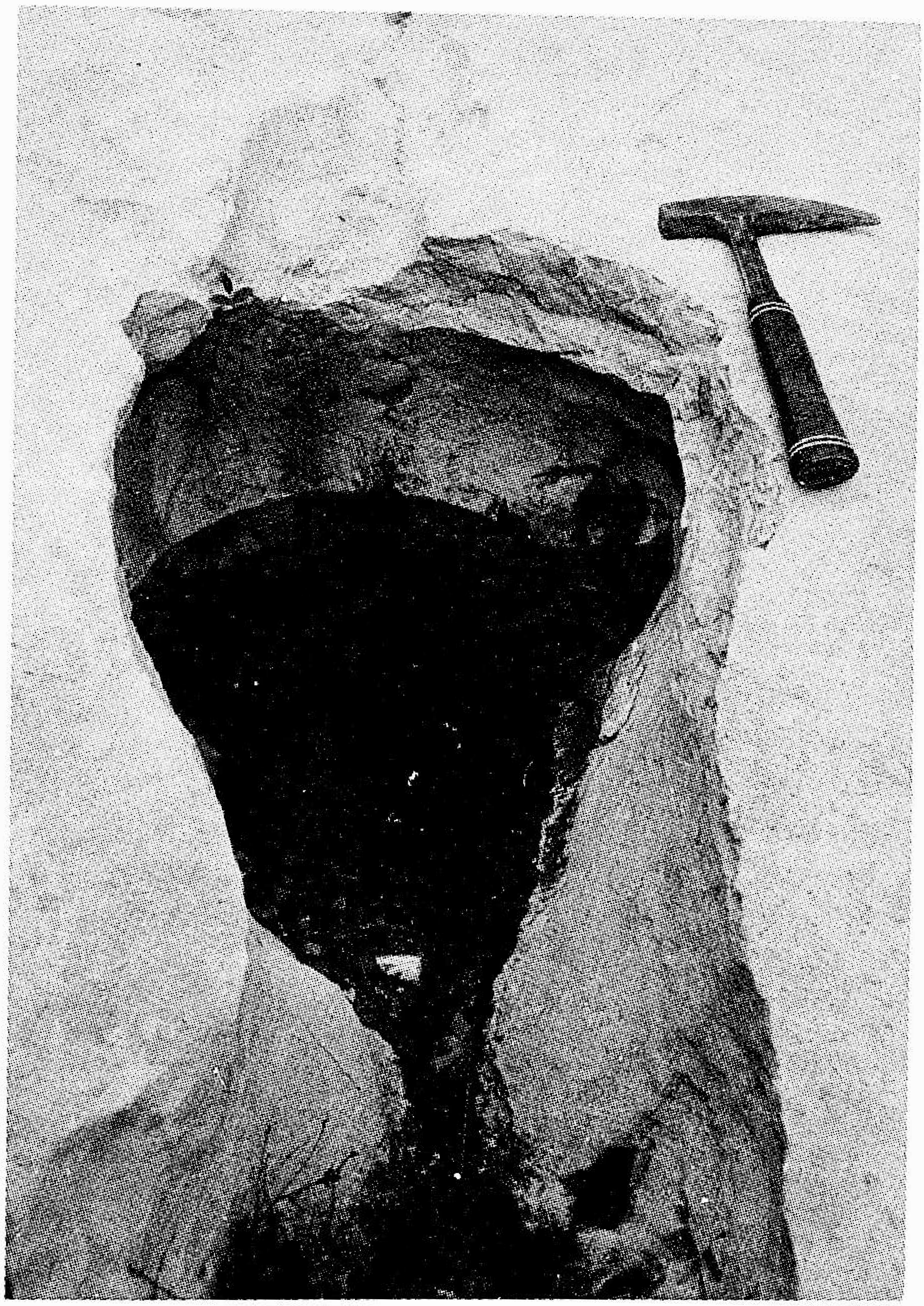

Fig. 3. The initial pan of runnel A. The suspended tributary runnels and ledges situated at different levels can be seen.

water) followed by a period of infilling with soil (a covered form) until its washing away.

For such hypotheses to be confirmed, I have considered the following to be necessary:

a) a more accurate analysis of the two forms;
b) research on similar forms in other areas and a comparison between them in the light of the different local morphological and, eventually, micro-climatic conditions.

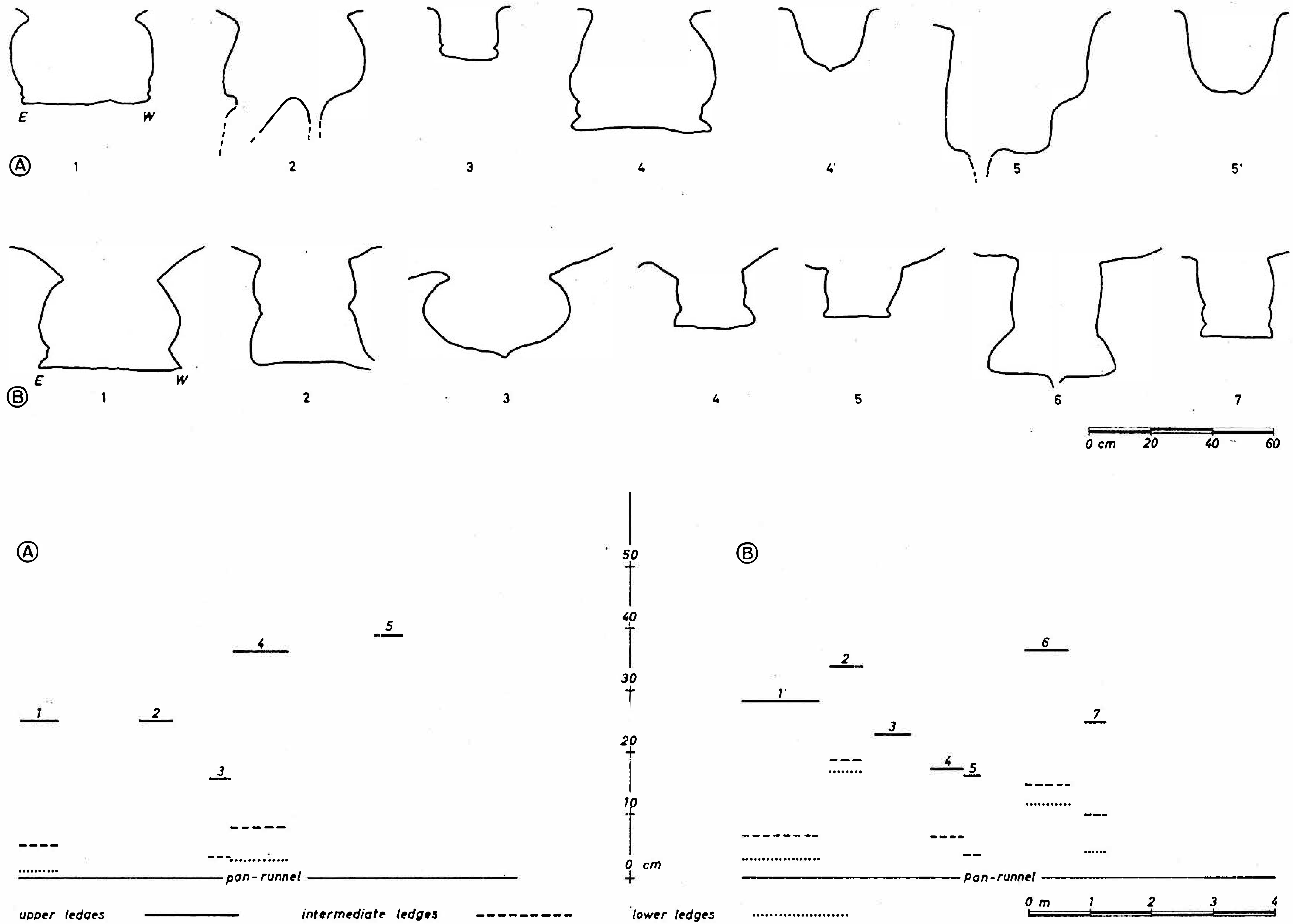

Fig. 4. Transverse profiles of the pans of the runnels A and B (see the previous figure) and diagrams showing the positions of the ledges on the inside of the pan runnels in their longitudinal developpment. The upper ledges are shown by continuous lines, the intermediate by dashed lines and the lower by dotted lines.

At the time of this study the two solution pans, both of runnel A (2A and 5A) and runnel B (2B and 6B) were filled in with soil cove red by turf. These are the only pans to exhibit crevices of a certain importance on their bottoms, which do not, however, appear open but are probably already absorbent (certainly in pan 6A). The height of the lips of the solution pans appears in general to be very low (about 2-4 cm in pans 1A, 4A, 1B, 6B) with the exception of pan 2B whose lip (over 10 cm high) probably constitutes a relict tract of the runnel suspended over the successive pan, now inactive. All the other pans are practically without a lip and are clearly suspended above the successive pans (eg. 3A, 3B and 4B).

Besides an upper ledge, only slightly lower than the drainage basin level, the pans may show 1 or 2 lower ledges, the lowest of which is only slightly higher than the levels of the lip. The distance between the upper and intermediate ledges (about 20 cm) is, with the exception of pan 2B, clearly greater than the distances between the intermediate ledge and the lowest one (4 cm) or between the lowest and the pan base (2-4 cm).

In general, in both runnels, the first and last pans appear deeper and with clearly distinguishable ledges in comparison with the intermediate pans. As is shown on the appended graphs a correlation is possible between the various ledges belonging not only to the pans of one runnel but also of the other. This indicates that, independently of localized factors, the two runnels have, on the whole, been subjected to the same type of evolution with corresponding episodes of infilling by and washing away of the soil.

After all, even in the light of the data discussed in my previous note (Sauro 1973), the comprehensive evolution of these solution forms could be conjectured in this way:

1) An older principle phase, particularly favourable to the formation and development of the great solution pans of the pavement and also some great solution pan runnels (runnel B must have been notably more extensive uphill). An episode of expansion of the vegetation layer with infilling of most of the depressions would have closed this phase.
2) An intermediate phase beginning with an episode of washing away of the soil contained in the pans. In those still active, there is development of new ledges corresponding with the new levels of the lips. A new episode of infilling follows.

3) A recent phase beginning with an episode of outwash of soil and continuing as semi-free erosion in the kamenitza.

The presence of soil in 4 pans could perhaps be explained, other than on the basis of the local microclimatic situation, by considering the depth attained by these depressions. I have noticed how, in normal conditions, rainwater which runs in the pan runnel forms a small cascade inside every kamenitza helping to clean it of detritic fragments. This could also in part, explain the greater depth and morphological individuality of the first and last pans compared with the intermediate ones.

In fact, the first pans receive little detritus and residue of dissolution, possessing a relatively small drainage basin whilst the cleaning action of rainwater is more active, or was more so in the past when the runnels were less deep, in the last pans.

In the karst of Trieste, in the locality Grotta del Gigante studied by S. Belloni and G. Orombelli (1970), I have been able to observe numerous kamenitza with superimposed ledges. Here, in general, the uppermost ledge is not clearly distinguishable whilst an intermediate and lower ledge often appear clearly. None of the pans present supplementary ledges. The ledges can be joined in 3 groups for the distances in relation to the base: 1st group with distances of 2-3-5 cm; 2nd group with distances of 6-12 cm (with a prevalence of 8); 3rd group with distances of over 15 cm.

The values of the three groups lend themselves to be correlated with those of the lower, intermediate and upper ledges of the solution pan runnels of the southern Adige Valley.

In the light of such facts and considerations it does not appear improbable, therefore, that these solution forms have been conditioned in their development by the climatic vicissitudes of the Postglacial and can also be used in future as useful morphoclimatic and morphochronological indicators.

RÉSUMÉ

On décrit soigneusement des microformes de corrosion creusées sur des roches moutonnées.

Chaque forme se compose d'une profonde rigole où de nombreux nids de poule (kamenitza) se sont nichés.

On éxamine les formes et sourtout les profils trasversaux des nids de poule, qui montrent des corniches à des niveaux differents.

On essaie de reconstituer le développement de ces formes.

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Ba 040

DIE EIGENSCHAFTEN DES KARSTES IN DEM ANINAGEBIRGE (RUMÄNIEN)

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An der südlichen Extremität der Westkarpaten befindet sich das grösste und dichteste Karstgebiet von Rumänien. Dieses Gebiet erstreckt sich von der Stadt Reşiţa in Norden bis zu der Donauschlucht in Süden auf eine Fläche von 807 qkm. 600 qkm aus dieser Kalkoberfläche gehört den Aninagebirgen. Diese Gebirge erreichen eine höchste Erhebung von 1 160 m mit der Leordişspitze. Auf diesen Kalksteinen entwickelt sich die ganze Mannigfaltigkeit der Karstformen, die in verschiedenen Entwicklungsetappen sich befinden.

Die Kalksteine der Aninagebirge haben sowohl eine Jura- als auch eine Kreidezeitalter und sind in Synklinalen und Antiklinalen geordnet, die ungefähr parallel, fest gefaltet und tektonisiert sind.

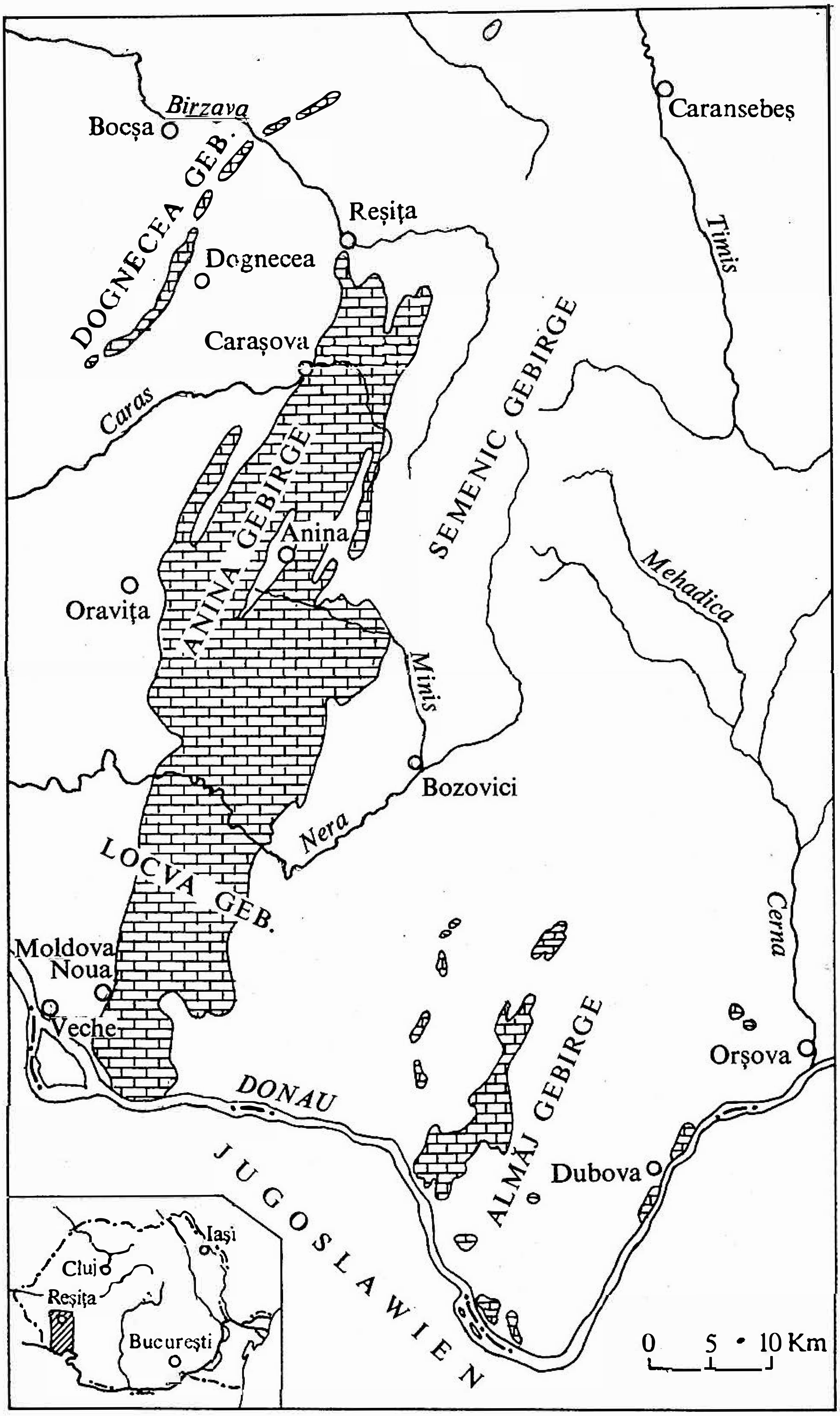
Der Jurateil wird von einem Kalkpacket gebildet, in dem zwei Mergeleinlagerungen sich befinden (Oberdogger und Obercallovian und Unteroxfordian). Die Kreide hat auch in seinem Fundament ein Mergelpacket (Berriasian - Valanginian) Die Mächtigkeit dieser Kalksteinen erreicht eine Grösse von 1 200 m.

Als eine Folge dieser geologischen Struktur wird das Relief von einer Aufeinanderfolge von parallelen Rücken und Tälern gebildet. Unter diesen sind langgestreckte Kalkhochebenen wie z.B. die Hochebenen Iabalcea, Colonovat, Bradet, Cirneala, Poiana Florii u.s.w. eingelagert, die eine Höhe von 400 bis 800 m besitzen.

Weil das Relief in seiner Gesamtheit der Struktur sich nicht anpasst, gibt es häufig Fälle von Reliefumkehrungen. Trotzdem kann man feststellen, dass die Haupttäler (oder grosse Abschnitte deren) die Richtung der Synklinalen und die hervorragenden Rücken die Richtung der Antiklinalen oder der Antiklinalflügel folgen.

Alle Kalkhochebenen werden aber auf die Synklinalflächen gepfropft.

Der wichtigste Karstprozess erfuhren die Kalksteine der Kreidezeit. Auf diesen Kalksteinen entwickelt sich die ganze Mannigfaltig-



Bocşa
Birzava
DOGNECEA GEB.
Dognecea
Reşiţa
Caransebeş
Timis
Caraşova
Caras
SEMENIC GEBIRGE
ANINA GEBIRGE
Anina
Oraviţa
Mehadica
Minis
Bozovici
Nera
LOCVA GEB.
Moldova Noua
Veche
Cerna
ALMĂJ GEBIRGE
Orşova
DONAU
Dubova
JUGOSLAWIEN
Iaşi
Cluj
Reşiţa
Bucureşti
0 5 10 Km

Fig. 1.

keit der Karsttypen. In diesen Kalksteinen wurde sich 70% der Gesamtzahl der Höhlen, die 67% der Gesamtlange des Streckennetzes enthält. Im Vergleich dazu enthalten die Kalksteine der Jurazeit den Rest der Höhlen und des Streckennetzes. Diese Tatsache erklärt sich dadurch, dass unter gleichartigen Bedingungen was den Karstprozess betrefft, die Kalksteine der Kreidezeit einen grösseren Inhalt vom Kalzium-Karbonat (90-94%) im Vergleich zu den Kalksteinen der Jurazeit (79-93%) besitzt. Es darf auch berücksichtigt werden, dass die Oberfläche der Kalksteinen der Kreidezeit grösser sei und dass die Entwicklung der Hochebenen auf diesen Kalksteinen die Wasserinfiltrierung begünstige.

Was die Höhlenstrecken betrifft, es wird festgestellt dass diese zum grossten Teile auf Faltungen und zwar in deren Richtung erschienen. In derselben Art und Weise werden einige Karsttypen der Oberfläche, insbesonders die Dolinen und die Dolinentäler, was ihre Entstehung und Richtung betrifft sehr stark von den tektonischen Linien beeinflüsst. Unterirdisch entsprechen die Strecken und Räume der Höhlen den Dolinen der Oberfläche.

Die Kalkoberfläche der Aninagebirge ist von Caraşfluss mit seinen Nebenflüssen Buhui, Jitin und Girlişte, von Minişfluss mit seinen Nebenflüssen Ponor und Valea Morii und von Valea Rea Fluss entwässert. Alle diese Flüsse sind autochton und werden von den Karstgewässer versorgt. Nur Nerafluss, der den Kalksteinstreifen guerscheidet, ist allochton.

Wegen den Kalksteinen wurde das Gewässernetz desorganisiert. Die Gewässer verlieren sich in ihrem Bett, auf der Basis einer Kalkwand oder unter dem Gewölbe einer Höhle. Deswegen haben drei grosse Kalkhattiggebiete (die Hochebenen Iabalcea, Bradet und Poiana Roşchii) keinen Oberflächenabfluss. Gleichfalls entstanden durch die Reorganisation des Gewässernetzes in der Tiefe unterirdische Flüsse (Ponicova, Ponor, Buhui), die durch Höhlen auf ihre ganze Länge gefolgt werden können.

Die Karstflüsse sind in den Kalksteinen der Jura- und Kreidezeit eingelagert und werden aus den atmosphärischen Niederschlägen versorgt. Der Mittelwert der jährlichen Niederschlagmengen beträgt 1000 bit 1200 mm. Diese Karstflüsse werden in der Industrie und als trinkbares Wasser verwendet. Sie üben einen negativen Einfluss auf die Bergwerke.

In der feitspanne 1958-1969 wurden 11 Färbungen mit Fluoreszein durchgeführt, um die Wasserzirkulation des Karstgewasser der Aninagebirge kennenzulernen. Zusätzlich wurden alle Angaben genutzt, die auf der Grundlage der Grubenarbeiten und der Bohrungen sich ergaben.

Als durch die Verbreitung des Fluoreszeines keine Wasserverluste auf der Oberfläche stattfanden, wurde das Wasser mit Fahrezengen abgefördert und in Dolinen beschüttet. Auf dieser Art und Weuse wurden positive Ergebnisse erzielt.

Die Angabenanalyse hebt hervor, dass in Aninagebirge die drei hydrologischen Zonen aus dem Karst sich befinden (Aerationzone, die Zone der ständigen Zirkulation und die Zone der allgemeinen Tränkung).

In den Kalksteinen der Jura- und Kreidezeit befinden sich drei Mergellagerungen, die sich als undurchlässiges Gestein sich verhalten. Ungeachtet dieser Tatsache können nicht diese Mergellagerungen den Wabberdurchtritt bis zur Basis der Kalksteine verhindern, weil die zahlreichen Verwerfungen eine Verschiebung der Schichten in Senkrichtung bewirkte. Das schliesst aber nicht die Anwesenheit suspendierten Gewässers aus, das sich auf der Sohle einiger durch Mergel abgedichteten Synklinale sich befindet.

Der Wasserdurchbruch aus der Kohlengrube Anina in Kalksteinen bei einer Tiefe von 700 m als während 17 Tage 150 000 Kubikmeter Wasser mit einem Druck über 50 at abfloss, und der Verlust der Bohrschlammes in den Karsthöhlungen heben den Karstprozess in der Tiefe hervor, der bis 900 m unter dem Schwarz Meeresniveau erreicht.

Ba 041

РЕГИОНАЛЬНЫЕ ОСОБЕННОСТИ ПОВЕРХНОСТНОГО И ПОДЗЕМНОГО КАРСТА В СРЕДНЕМ ПОВОЛЖЬЕ

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В пределах обширной платформы, занимающей европейскую часть СССР - Русской равнины, территория Среднего Поволжья выделяется широким развитием современных и древних (погребенных) карстовых форм, прекрасно выраженных в рельефе полями впадин разнообразной величины, глубины, зачастую округлой и эллиптической формы.

Среднее Поволжье площадью до 400 тыс. кв. км является полем широкого развития древних пермских отложений, слагающих тела Приволжской и Вятско-Камской возвышенностей, Бугульминско-Белебеевского плато, плато Высокого Заволжья и плато Самарской Луки. Рассматриваемая территория тектонически представляет Волго-Уральскую антеклизу с обширными полями карста (до 120 воронок на л кв. км), линейно вытянутыми вдоль речных долин или в их верховьях, в пределах тектонических структур третьего порядка (брахиантиклинальные и куполовидные складки), сложенных карстующимися породами казанского яруса пермской системы.

Анализ пространственного распространения карстовых явлений показывает, что современные карстовые формы приурочены к положительным морфоструктурам платформенного типа, валам, сводовым поднятиям (Окско-Цнинский, Горьковско-Алатырские, Вятские, Соко-Шешминские дислокации, Жигулевско-Пугачевский вал). Особенно ясно поверхностный карст выражен в пределах усложнения крупных тектонических структур (валов, сводов) малыми структурами, относимыми по рангу к структурам третьего порядка. В пределах положительных морфоструктур, представляющих обычно ступенчатые по рельефу плато, карстовые явления обусловлены в долинах рек близким залеганием к дневной поверхности или выходами на поверхность трещиноватых карбонатных пород (известняков, доломитов и их разностей), имеющих прослои и линзы гипсов. Комплекс карстующихся пород достаточно мощен, он достигает до 40-60 м, причем наиболее активно протекают процессы современного карстования в зоне сезонного колебания подземных вод, связанных с водотоками - реками. В пределах речных долин карст зачастую расположен асимметрично, то-есть он является принадлежностью левобережья рек, представляющих комплекс аккумулятивных террасовых толщ, цоколем которых являются сильно закарстованные и эродированные доломитово-известняковые, гипсово-ангидритовые породы пермского возраста. Ярким примером являются долины Волги, Оки. Глубина вреза рек определяет современный этаж закарстованных пород. Значительно глубже эрозионных врезов закарстованные этажи горных пород пермского, каменноугольного, девонского возраста отмечаются бурением (полости, водообильность с дебитом скважин до 200 л/сек). Однако этажи глубинного карста, неотраженные в рельефе являются по динамике карстовых процессов в основном "мертвыми". Они порождены древними эпохами карстования, происходившими в иных палеогеоморфологических и палеогеографических условиях.

Карстовые явления отражают неотектоническое дифференцированное развитие территории Среднего Поволжья. Современный карст не наблюдается в областях относительного тектонического опускания, выраженных в рельефе низменными равнинами (с абс. высотами 120-180 м) Заволжья. Карст активно развивался в пределах поднимающихся блоков платформы (Приволжская возвышенность, Жигулевский массив, Бугульминско-Белебеевская возвышенность, Соко-Самарское плато).

Особенности процессов карстования зависят от литологического состава карстующихся пород, перекрытых рыхлыми отложениями четвертичного возраста и некарстующимися коренными породами. Для территории Среднего Поволжья важно отметить литологическое разнообразие карстующихся пород и четкое проявление этого фактора в морфологическом и гидрографическом разнообразии поверхностного и подземного карста. Преобладает на 75-80% карбонатный карст, но гипсовый карст проявляется ярче. Гипсовый карст выражен в пещерах, в закарстованности днищ крупных речных долин, в создании озер, в частности "голубых озер" (Горьковская область - долина р. Пьяны и Татарская АССР - долина р. Казанки). Подземный карст выявляется аномалиями модуля подземного стока и реками, имеющими подземное питание при прорезании закарстованных горных пород. Формы подземного карста имеются в пределах долин Волги, Ика, Пьяны (пещеры). Пещеры приурочены к контактам сульфатно-карбонатных толщ и формируются в основном в результате выщелачивания гипсово-ангидритовой толщи.

Для Среднего Поволжья типично сочетание карбонатного и гипсово-ангидритового карста (Гвоздецкий, 1954; Родионов, 1963; Ступишин, 1967, 1972). Гипсы и ангидриты образуют нижний этаж современного карста, который вскрывается глубокими речными врезами Оки и Волги.

Гипсы и ангидриты слагают артинский и сакмарский ярусы нижней перми, а также и кунгурский ярус, сильно эродированный на рубеже нижней и верхней перми. Реки, достигающие гипсово-ангидритовой поверхности, создают обширные впадины - озера, представляющие важную и ценную особенность географического ландшафта (Лаптева, Ступишин, 1968). Верхний этаж современного карста является этажом доломитов и известняков. Наличие гипсовых прослоев до 10 м и более в карбонатном разрезе создает своеобразие и направленность карстового процесса, проявляющееся в выработке подземных полостей в контактовой зоне доломитов и гипсов (Сюкеевские пещеры, Юрьевская пещера - в долине р. Волги).

Для верхнего карбонатного этажа карста в Среднем Поволжье следует выделить два литологических варианта карста, а именно карст в однородном карбонатном разрезе и карст в неоднородном карбонатном разрезе (Ступишин, 1967, 1972). В первом случае разрез состоит из известняков или доломитов и карстовый процесс проявляется избирательно, приурачиваясь к определенному пласту наиболее податливому к растворению. Для неоднородного карбонатного разреза типично переслаивание доломита и известняка, причем карстовому процессу подвергается крупнокристаллический известняк (Ступишин, 1972), а образование межслоевых карстовых полостей приводит к обрушению слоистых и сильно трещиноватых доломитов с образованием брекчии, которая затем цементируется вторичным кальцитом, поступившим за счет растворения вышезалегающих прослоев крупнокристаллического известняка.

Важное значение в пространственной ориентировке цепей карстовых провальных форм имеет ориентировка трещин в карстующихся породах как и в других районах Советского Союза (Гвоздецкий, 1954). С господствующей ориентировкой трещин в карбонатных породах связана ориентировка малых эрозионных форм: оврагов, балок, малых долин, а с ними и ориентировка карстовых форм. В особенности такая зависимость четко проявляется в рельефе Приволжской и Вятско-Камской возвышенностей, где ориентировка трещин в закарстованных породах отражена в ориентировке малых эрозионных форм и цепей карстовых поверхностных провалов. Наблюдаются случаи когда эрозионная форма, балка или долина, вызвавшая появление поверхностного карста в результате развития карста перерождается в карстовое поле.

Среднее Поволжье в своих недрах хранит погребенные этажи древнего карста. При глубоком бурении вскрываются закарстованные глубинные толщи карбонатно-сульфатных пород. Этажи древнего карста в отложениях верхнего девона, нижнего карбона, нижней перми отражают континентальные эпохи, вызванные тектоническими поднятиями, которые видимо были связаны с процессами в пределах Уральской геосинклинали. Палеоклиматические и ландшафтные условия палеозоя значительно отличались от современных. Территория Среднего Поволжья в нижнем и среднем палеозое не представляла единой суши, а распадалась на острова, окруженные мелкими теплыми водными пространствами. Острова слагались известняками, зачастую древними коралловыми рифами. В условиях теплого и влажного климата процессы поверхностного выщелачивания происходили в широких масштабах. Судя по данным глубокого бурения карстовые процессы захватывали толщу растворимых пород до 100 м и более. На существование аналогичных ландшафтов карста к востоку от Среднего Поволжья указывает Г.А. Максимович (1963), который выявленный бурением останцовый рельеф в девонских породах характеризует как формы рельефа тропического карста.

Аналогичные ландшафты с палеозойским карстом имели место в нижнемезозойское время в Среднем Поволжье (юг Самарской Луки). Этот карст был изучен по материалам бурения и описан А.В. Ступишиным (1960, 1967). Погребенная под отложениями мезозойских толщ поверхность карбонатных пород - доломитов имеет сложный типичный карстовый рельеф с господством котловин до 1-2 км протяженностью при глубине до 20 м. Кроме воронок - провалов обрушения имеются воронки выщелачивания. Карстовые воронки осложняют склоны карстовых котловин. Они фиксируются на поверхности карбонатных останцов. Относительные перепады высот в пределах закарстованного участка достигают 53 м. Облик карстового ландшафта свидетельствует о развитии форм обнаженного, задернованного карста, причем закарстованность карбонатной толщи происходила как с поверхности (сверху), так и изнутри при содействии процессов обрушения породы в подземные полости. Имелись и древние карстовые озера, котловины которых выполнены озерными глинами ("переволокскими") мощностью до 20 м.

В прикладном отношении современные карстовые явления представляют серьезную опасность при хозяйственном использовании территории и в особенности скрытые подземные полости в растворимых карбонатных породах. Пещеры несмотря на небольшую величину интересны в научно-познавательных и туристических целях.

REGIONAL SINGULARITIES OF SURFACE AND SUBSURFACE KARST IN MIDDLE VOLGA REGION

A.V. Stupishin, N.N. Lapteva

SUMMARY

The Middle Volga region which covers the area of 400,000 sq. km is situated within the boundaris of the Volga - Ural anteclino. The ancient rock of the Permian system is deformed due to the differential tectonic development. Contemporary karst is confined to positive morphostructures represented by elevations or plateaus. Karst tends towards river valleys dissecting positive morphostructures. Contemporary karst comprises dolomites, limestones, gypsums, anhydrites and chalk sediments of the upper chak. Two levels are distinguished in karst: the upper - carbonate and the lower - gypsum-anhydrite. Ancient buried karst (paleokarst) belonging to Paleozoic and lower Mezozoic era has been uncovered. Ancient karst developed under warm and humid climatic conditions. The study of the Middle Volga region karst is of great practical and theoretical value.

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GEOMORPHOLOGICAL CHARACTERISTICS OF THE KARST REGIONS IN THE CZECH SOCIALIST REPUBLIC

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The karst regions on the territory of the Czech Socialist Republic cover a total area of 240 square kilometres (J. Michovská, 1957). They found in small, but numerous districts surrounded by non-carbonaceous rock of various types. Every region possesses its typical features, being the result of the action of a whole number of factors. The basic relief differences between the individual karst regions are given by their appurtenance to several morphostructural systems with a different geological composition and geomorphological development.

Karstifying rocks are on the one hand Prepaleozoic crystalline limestones and marbles of varying chemical composition, in places with a considerable silicate admixture. They are deposited in differently thick layers and lenticles reaching a thickness ranging from several centimetres to one metre, exceptionally even to 100 metres. They are complecately and minutely folded, the thicker layers being strongly jointed. On the other hand these are Odrovician to Lower Devonian Limestones, more poorly metamorphosed, reaching in place a high chemical purity and considerable thickness. The younger Devonian Limestones usually occupy a larger area, are poorly metamorphosed to non-metamorphosed, very poor, and reach considerable thicknesses. They easily are subject to karstification. The Western Carpathians include cliff limestones of the klippen zone. They occupy a small area, reaching great thicknesses.

Limestones occur in altitudes from 200 to 1000 metres. Their major part falls into the temperate zone. Only in the higher border mountain land they fall into the cold zone (E. Quitt, 1970). Precipitation varies about 600 mm, only in the mountainous regions it rises to 850-900 mm. It is evenly distributed with an inconspicuous maximum in the summer months. The average annual temperature lies between 7 and 8 °C, in the uplands and the mountainous regions it drops below 5 °C.

The morphostructural properties of the territory together with the geomorphological processes and whole number of other conditions are the causes of differentiation of the individual karst regions. Their typological division is at present problematic, because there does not exist a uniform, generally accepted classification of karst regions. This is due to the fact that at present there does not exist any uniform view on the very essence of karstification. Disagreement of view reflects itself also in the below listed classification which, in fact, respects the modern views on the genesis of the karst, but cannot set the general acceptance of the proposed classification as its aim. It shows only one of the ways how to solve this problems. It proceeds from a whole number of criteria, through the observation of which we have arrived in the territory of the Czech Socialist Republic, at the division of the following types and subtypes of karst:

A. Central European karst of the temperate zone
- I. Karst of plains
- II. Scattered karst
  1. Fold-fault structures
     - a) in the region of linear megafolds
     - b) in the region of domes strongly affected by tectonics
     - c) in the region of block and horst structures
     - d) in the region of isolated blocks
  2. Complicately folded structures (Barrandien)
  3. Klippen structures

I. KARST OF PLAINS

This type included karst regions where almost all surface and underground karst phenomena are well developed (lapiés, sink-holes, grabens, uvalas, blind and semi-blind valleys, karst rand polje, karst valleys - canyons, cave levels developed in several horizons interconnected by precipices and chimneys with rich dripstone decor), characteristic karst hydrography and typical soils. Present are karst forms of several generations, including fossil conical karst. The perfect development of karst forms was made among others, also by a relatively large range of thick, very pure non-metamorphosed limestones of Devonian age, their great tectonic disruption and the high position of the karst surface over the local erosion base level.

Only the Moravian Karst belongs among this type in the territory of the Czech Socialist Republic (R. Kettner, 1960; V. Panoš, 1962; O. Štelcl, 1964).

II. SCATTERED KARST

This category comprises karst regions of a small area separated from one another by non-carbonaceous rocks. They have less favourable conditions for karstification (smaller area, in places strongly metamorphosed limestones, lesser thickness, frequent impurification of limestones and the like) for the development of karst forms and karst hydrography. They are scattered over a considerable area of the territory of Czechoslovakia. The scattered karst is developed in several geological structures, in various geomorphological units from which a whole number of subtypes result. The overwhelming part of karst regions belongs among it.

1. THE KARST OF FOLD-FAULT STRUCTURES

Forms 4 subtypes differing from one another:

a) Karst in the region of linear megafolds. This karst arose on Prepaleozoic crystalline limestones, forming a whole number of occurences considerably limited in area. The limestones form an integral part of several geomorphological systems and subsystems (the Bohemian-Moravian Highlands, the Šumava Mts., the Středočeská pahorkatina, the Železné hory Mts.), mostly of an upland character. In the relief they do not come into play in a more conspicuous manner. Usually they form round elevations, or rocky valley sides. Surface karst phenomena are very few in number. Most frequent are grikes, lapiés, corroded fissures, while sink-holes occure less frequently. Underground karst formations, inasmuch they occur at all, reach small sizes and are poor in dripstone décor. Usually they are filled with sediments, some with limonite. The karst hydrography is insufficently developed. Karst phenomena are concentrated in the Šumava region and its foot-hills, in the drainage areas of the rivers Horní Otava and Berounka (M. Prosová, 1950; J. Kukla, P. Batík, 1959), in the Bohemian-Moravian Highlands they are well developed in the surroundings of Chýnov (J. Kunský, J. Hlávka, 1948), Ledeč nad Sázavou and near Vápenný Podol in the Železné hory Mts. (F. Skřivánek, 1957).

b) Karst in the region of domes strongly affected by tectonics. This karst is developed in several domes geological structures, which were jointed by younger tectonic movements and geomorphological development to such an extent that today they form two geomorphological regions of a higher order - the Eastern Sudeten and the northeastern part of the Bohemian-moravian Highlands. Odrovician to Lower Devonian carbonates are found in many places. Generally they occupy a small area, in places they are strongly karstified. For their small area they do not play a major role in the relief. V. Král (1958) divided the region of the eastern Sudeten into the following four groups:

The Sněžník-Jávorník Region is characterized by poorly karstified limestones, forming narrow strips, geomorphologically little pronounced. Surface karst phenomena are few in number, usually they are covered with solifluction material and debris of non-carbonaceous origin. In the underground, small, narrow caves very poor in dripstone décor have been found. Several abundant springs point to the existence of karst hydrography.

The Branná Zone. Surface and underground karst formations of several generations are richly developed in limestones belts running from the valley of the Upper Morava near Hanušovice to Vápenná. The most prominent locality is Na Pomezí. In the surroundings of Supíkovice, remains of a fosil conical karst were found under the accumulations of the continental glacier (T. Czudek, J. Demek, 1960; V. Panoš, 1964).

The Vrbno Region. This region occupies the area between Zlaté Hory and Vrbno. It is very poor in karst phenomena. Surface karst phenomena are almost missing, in the underground small fissure caves poor in dripstone décor have arisen. The karst hydrography too, is imperfectly developed.

The fourth group comprises a whole number of further limestone occurences only insignificantly affected by karst processes (V. Král, 1958).

The region of the northeastern part of the Bohemian-Moravian Highlands is very poor in karst phenomena. The latter occur on long limestone strips, running in the structural directions of the Svratka and Dyje dome. Geomorphologically they are little distinct. They usually form the highest parts of flat elevations, or short, rocky ridges with imperfectly developed lapiés and corroded fissures. In places the limestones are covered with a differently thick layer of weathering products and sediments, altogether veiling karst phenomena. The underground karst formations too, are imperfectly developed (P. Ryšavý, 1950; J. Turnovec, 1967).

c) Karst in the region of block and horst structures. This subtypes included karst areas considerably limited in size on crystalline limestones in the regions of the Krkonoše (Giant Mts.), the Jizerské hory Mts. and the Krušné hory (Ore Mts.), as well as on limestones of the younger Devonian in the Podkrkonošská pahorkatina. The karst regions form an integral part of several geomorphological units with a gently undualated relief. The latter was strongly affected by Saxonian radial tectonics and divided into a system of blocks assuming different positions. The surface karst phenomena are few in number. They are represented only by lapiés and isolated rocks. Caves of small size arose only in places. The karst formations were described at Bozkov (F. Skřivánek, K. Valášek, 1960), Poniklá and at Jitrava (J. Rubín, F. Skřivánek, 1963). In the region of the Krušné hory (Ore Mts.) no karst phenomena have been described as yet.

d) Karst in the region of isolated blocks. This subtype is found in a whole number of mutually isolated blocks of Devonian limestones in Central Moravia. The variety of karst forms strongly resembles the karst of plains. The only differences residing in that the individual karst regions are much smaller in size, developed independently of one another, and therefore, are characterized by various groups of karst phenomena.

The limestone blocks have gone through a long and complicated geomorphological development, ranking them into several geomorphological units, mostly of a highland character. Usually they form more or less distinct elevations, representing structural forms –

monadnocks, stripted of the surrounding, less resistant non-carbonaceous rocks. Their karstification proceeded in several stages under varying conditions. The karstified limestones were fossilized in places by weathered products and marine or terrestrial sediments, concealing their karst character, e.g. the karst in the surroundings of Hranice na Moravě (J. Tyráček, 1962), of Maršov (J. Skácel, 1954), of Vratíkov (V. Panow, 1962). The most outstanding karst formations are found in the environs of Tišnov, Javoříčko (J. Loučková- Michovská, 1964), Mladeč, Čelechovice, Grygov (J. Šrot, 1950; J. Janásek, 1954), etd. In number of caves, important archaeological and paleontological finds have been made.

2. KARST OF COMPLICATELY FOLDED STRUCTURES

The described type of karst has arisen on complicately folded Barrandian limestones. Silurian and Devonian limestones possess the character of outstanding lithofacial intercalations, placed into layers of another type. In the relief, the influence of geological structures of different resistance of the individual layers to weathering and denudation is reflected. The relief is gently undulated with low rounded ridges and elevations, running in the direction of the geological structure. The river Berounka cuts across them and forms a deep canyon-like valley. On the steep slopes there are numerous caves. Karstification proceeded in the individual limestone strips isolately (J. Michovská, 1957). Therefore, no differentiated development of karst forms occured. The odlest expression of karstification are depressions (sand pipes) filled with remains of paleogene fossil tropic soils (V. Homola, 1950). The overwhelming part of surface (lapiés, sinks, karst canyons, etc.) and underground karst formations (caves) are of a younger date.

3. KARST OF KLIPPEN STRUCTURES

The karst of this type depends on small occurrences of carbonaceous rocks projecting prominently over the surrounding relief in the form of monadnocks. The carbonates are of Jurassic age and rise in the blocks of the nappes of the flysch zone of the outer Carpathians. They form the Pavlovské vrchy, a group of isolated cupola-shaped hills in the Štramberská vrchovina, and isolated hills near Nový Jičín, Valašské Meziříčí, Kurovice and Cetechovice. Some occurrences like Skalička and Jasenice are only exotic blocks.

The intensity of karstification is the reflection of the paleogeographical position of the individual klippes. The surface forms are usually represented by lapiés, sinks, while the caves formed underground are mostly of fissure character. The dripstone décor is missing or very poor. Only in the Štramberská vrchovina the limestones have reached a higher degree of karstification (M. Prosová, 1952).

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ABOUT KARST IN GENERAL AND SWEDISH KARST IN PARTICULAR

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Almost from the beginning of speleology it has been unual to describe the character of a cavernous landscape by the term Karst, and the author introducing this term was the Jugoslavian researcher Jovan Cvijić (1865-1927) who in his work "Das Karstphänomen" (Wien 1893) transferred this common national expression into international terminology. Since antiquity Karst has been the name of the manifold broken Dinaric plateau of limestone which gives a special character to the Slovenian, Kroatian and Macedonian landscape. The word is certainly of Celtic or pre-Celtic origin, the Celtic "kare" being the same as the Grecian "Chalis" and the Latin "calx" or simply chalk or limestone.

In the literature Karst signifies a limestone territory with fissures, dolines and other depressions, caves, and swallows, with mainly subterranean waters - or in other words a typical erosional landscape but where the principal work of erosion has been corrosive. An abundance of different papers have been written about the classical term Karst, treating e.g. the eternal question of how limestone is progressively dissolved, both on the surface and in underlying layers. Karstology and its problems present more and more interesting goals to among others geographers, who many years ago created a special commission of their international union in order to follow the study of karstic phenomena, the commission remaining active untill in the year 1965 this task was overtaken by a commission of UIS, the International Union of Speleology.

This special commission has directly or indirectly arranged attractive symposia, from which some detailed proceedings have been published: "Phénomènes karstiques", Paris 1967, "Problems of Karst Denudation", Brno 1969, "Karst Denudation", CRG Ledbury 1972, "Karst in Carbonatic Rocks", Moscow 1972, and "Papers of the Symposium of Karst-Morphogenesis IGU", Szeged 1973, among others. Karst problems are being even more intensively studied by geographers, geologists, mineralogists, meteoro- and climatologists, students of chemistry and physics, entomo- and bacteriologists and indirectly also by archeologists and paleontologists and other specialists. This ever-spreading research has already resulted in such a huge quantity of different theses that simply enumerating them here would be an overwhelming task. As such studies are beyond the purpose of the present paper, those interested are referred to the special literature of each category. Nor it is the purpose of this paper to deal with the chemical-physical aspects of karstology. The sole intention here is to give a descriptive account of the different characteristics, a sort of typology of karst, with special reference to Sweden.

The assumption of karstology by the UIS (the International Union of Speleology) has been mentioned above, and a subcommission of this organization has proposed the following terminology for dealing with a karst:

1. (real) KARST is a type of landscape where subterranean drainage occurs through solidified soluble rocks, i.e. karstifiable minerals, and where characteristic subaerial and subterranean features, i.e. karstic phenomena can appear.
2. PARAKARST is a term originated in Italy, referring to the appearance of weakly-developed karstic forms in badly karstifiable rocks.
3. PSEUDOKARST is the term for a landscape with forms similar to a karst, but developed in non-karstifiable, non-soluble rocks.

If one applies the term (real) karst strictly, Sweden however has very little to demonstrate. Aside from the limited limestone rocks of Gotland and Oeland, small occurences of chalk in Scania and some solitary limestone and marble deposits in Middle Sweden, and some winding pre-Cambrian limestone streaks in Northern Sweden, only a few phenomena similar to karst occur in rare sandstone beds. On the other hand, there is an abundance of features similar to karst in other non-karstic rocks. Therefore, some researchers consider that karst-like features in this sandstone, a conglomerate of small siliferous grains, generally very poor in calcium, don´t belong to karst phenomena but should be assigned to a group of their own. A well-known Italian speleologist, Professor Franco Anelli at the University of Bari, previously chief for the caves of Postumia-Postojna during the Italian occupation, and nowadays chief for the Castellana Caves in

Apulia, some years ago proposed a wider usage for the term karst.

On the basis of contributions by two world-renowned researchers, M. Gortani: "Per lo studio idrologica e morfologico delle regione carsiche e semicarsiche italiane", Trieste 1933, and O. Lehmann: "Die Hydrographie des Karstes", Leipzig & Vienna 1932, Anelli attentively followed the development of the question and the world-wide discussion which it soon aroused. In 1963 he published an epoch-making work: "Phenomeni carsici, paracarsici e pseudocarsici" in Annali del Museo Geologico di Bologna Ser. 2 Vol. XXXI, a theme which he developed more clearly afterwards by oral and written communication. But up to now only a few researchers have expressed their agreement with his ideas, while the majority of speleologists still cling to the classic conception of the term karst and believe, that one absolutely cannot speak about a karst in any other sense than that of Cvijić.

But even such non-corrosive phenomena as abrasion, evorsion, and not less, clastic downfall in caves ("incasion" in the use of Bögli and others) are features of real karst. Inasmuch as such phenomena occur regularly in other rocks than limestone, some researchers conclude that many karstic features are by no means limited to limestone regions. Anelli, in a lecture at the 3rd International Congress of Speleology i Vienna 1961, pointed out that such features can appear i e.g. solitary limestone cliffs, in many coarsegrained, poorly soluble sorts of limestone, in firmly-banked, stratified or slate-like limestones, in several kinds of sandstone, in gypsum and in tufa and similar rocks. Therefore, with agreement from French researchers among others, he proposed including such karstic phenomena in the subdivision called P a r a k a r s t.

In an earlier paper: "Nomenclatura italiana dei fenomeni carsici" in Le Grotte d'Italia Vol. II Castellana Grotte 1957-58, Anelli also used the term P s e u d o k a r s t for a third group of karstic features. Some students, for example G. Cramer, F.P. Savarenskij, C.B. Floridia and W.R. Halliday had already tackled this question, especially the latter in an article "Pseudokarst in the US" in Bulletin of the NSS Vol. XXII 1960, and progress of the matter was considered very urgent, even after Anelli's very helpful lecture. Many examples of karst-like forms had been found in solidified lava, especially in the USA and in Iceland. Certain phenomena in gneisses, granites and other such non-limestone rocks, caused by geologic movements, heat, frost-wedging, weathering, chemical influences and other agents, were namely impressively similar to results of karstic procedures in soluble stone. Here I would also mention the Swedish geographer Dr Gunnar Rasmusson, who, besides his explorations of a real karst in Lappland and one on Lofoten in Norway, also published the study "Karstformen im Granit des Fichtelgebirges" in Die Höhle Nr 1 1959, based upon similar observations in H. Wilhelmy: "Klimamorphologie des Massengesteines", Braunschweig 1958, pointing out features of corrosion in Archean, non-soluble rocks due to the cover of vegetation.

In spite of the fact that many speleologists still keep the original meaning for the term of karst, more and more intensified international cave-research has forced acceptance of a wider sense of the term, and nowadays many students also agree upon the necessity of using the terms Parakarst and Pseudokarst for phenomena outside the limits of the classical conception. This was evident from discussions at the conference about terminology held in the Austrian town of Obertraun in the autumn of 1971, arranged by UIS.

The cause of reluctance to deviate from the original usage of the term "karst" surely lies in Cvijić's development of his own conception, especially as it appears in his work "La géographie des terrains calcaires", Beograd 1969, published after his death. In this book he deviates from the original term, which he now calls "holokarst" (from the Greek "holos" = whole or complete) and distinguished this holokarst from "merokarst" (from the Greek "meros" = defective, incomplete). In this system a karst must be a real, complete karst or a defective one. This terminology was further developed afterwards by several authors, for exemple a well-known Spanish speleologist, Professor Noel Llopis Llado (1911-1968) who introduced the terms "holofossil" and "merofossil" and thus classified karst regions to their age.

According to this system a real karst, i.e. a paleokarst must be the result of long erosion of a limestone landscape, which has passed through all the different forms of development possible, and now is finished, complete or fossil. It may still be lying open, or it may be covered by other forms. A merokarst, on the contrary, is only rudimentary and mostly still in development. The two types are distinguished by different types of sediments, which Llopis classified with the precise terms "allochtonous" or "autotochtonous", i.e. substances from the outside or solutional deposits from the place itself. However, faced with an increasing number of different features, he also was forced to accept certain transitions, for example a feature which he called "karst rajeuni" or "rejuvenated karst", whereby the process of solution can reappear either in a holo- or merokarst.

In the gradual progress of research the literature has been enriched with other distinctions: it has been found urgently necessary to distinguish between a nude and a covered karst (Llopis), an arctic and a subarctic (Corbel), a thermal and a glacial (Ermoelev & Svensson), a tropical and a subtropical (Lehmann), a coastal and other regional karst (Panoš & Štelcl) and so on. Despite these and other terms, many conscientious researchers feel that the proposal by Anelli signifies a basic, rational classification of different karstic regions, which many be further divided or defined ad infinitum in order to cover the meaning of any author. It is always easier to subdivide the clear system of karst, parakarst and pseudokarst into special parts, than to have to search for the right expression for something out of a chaos of individual terms.

For Sweden, I have especially pointed out this fact in an earlier study: "Urbergsgrottor - Caves in Archean Rocks", in Archives of Swedish Speleology Nr. 9, Norrköping 1969, wherein I also mentioned some foreign papers, e.g. Bouquet-Marti-Michel: "Cevités en terrain non calcaire", Chikishev: "Types of karst in URSS" and Starka: "Jeskyne Drapova". However, it is also a well-known fact that the far-northern climate has an evident effect upon the development of a normal karst. On the Norwegian side of the Scandinavian peninsula it was early understood that the multitude of young phenomena of erosion, particularly caves, depend partly upon forms originated during the glacial time and from resting glaciers and derive partly from active and rapid postglacial erosion. This understanding led to the suggestion of a special type of karst, namely the arctic or subarctic karst. Norwegian researchers like G. Horn, L.Natvig, J. Oxaal and others have described and discussed this very form in many publications.

In regions of permafrost or "tjäle" occuring in the far-northern countries, some karst-like forms can appear, where by erosion the tjäle plays the same role as a solid rock or earth layer, but with the important exception that tjäle and permafrost can thaw with increasing temperature, and the bottom frozen layer thereby becames subject to rapid erosion. H. Svensson has related in a study: "Thermokarst" in the Swedish Geographical Yearbook 1970, that the Russian M. Ermolaev introduced this term as early as 1932 for "those forms of terrain and land which appear by melting of the land-ice". To those forms belong above all the collapse of earthy layers, but also the development of niches, karren and similar effects of erosion. In this connection I must mention the theory by R. Ciry: "Des grottes cutanées" in Annales de Spéléologie Vol. XIV Part 1-2 1959, which is also based upon the appearance of erosional phenomena under certain conditions in tjäle. This theme is further developed in another paper by H. Svensson: "Glaciation and Morphology" in the Communications from the Geographical Institution at the University of Lund 1959.

But one researcher has never spared any labour in penetrating problems concerning the arctic and subarctic karst landscape, namely the well-known French glaciologist and speleologist Dr Jean Corbel (1920-1971), active in the CNRS (Comité National de Recherches Scientifiques). His foremost work is his voluminous doctorate thesis at the University of Lyon: "The Karsts du Nord-Ouest de l´Europe et de quelques Régions de Comparaison - Étude sur le Role du Climat", Lyon 1957: 539 pages of densely-printed text with 100 photographs of his own and innumerable sketches designed to demonstrate landscapes and details.

After many months stay on the Spizbergen Islands and on the islands of the northern Norwegian archipelago, and in the Lapplandian region of Norway, Sweden and Finland, very often in terrain not visited nor even described earlier, by means of a detailed study of the landscape during different local meteorological and climatic conditions, giving himself time to penetrate also the most minute karstic details, Corbel produced his extensive work of research which has been esteemed as every karstologist´s New Testament. In this paper only his general conclusions as to the development of the arctic landscape can be mentioned. For Sweden, however, we must regret that this very sharpsighted observer - maybe for lack of time - has not even skimmed the particularities of the Swedish topography in question, and has almost completely overlooked the results of recent Swedish karst studies.

To summarize the above-mentioned conclusions of Corbel, firstly he demonstrates the importance of differences in temperature between the arctic and temperate zones. At 0° the quantity of dissolved $CaCO_3$ is no less than six times the amount dissolved at a temperature + 40 centigrades. Secondly, the bacterial flora of the severe northern climate has far less capacity to dissolve rock than in the warm zones, Thirdly, he demonstrates the influence of the sour water from peat beds in the numerous moors. Fourthly, the sea water in the North is far more aggressive against the coastal limestone cliffs than in temperate and warm zones, and, fifthly, the limestone beds have been protected from denudation by huge morainic covers in certain regions. Finally, he presumes a very early process of karstification, perhaps as early as Oligocene, of the mother-stone, from which the greatest part was eroded however before the appearance of the inland ice in the Pliocene, Pleistocene and Quaternary Epochs. Below the mighty ice-cover very little happened, and the actual karstic phenomena are therefore very young but have developed rapidly owing to the cold climatic circumstances. Corbel gives proofs for this quick erosional procedure in the hollowing-out of the morainic cover and in the small and quickly changing, mostly superficial caves. He also discusses a sort of relict, for exemple of earlier limestone plains, but here he makes the mistake of confounding in text and photograph the porphyric hill of Hoverberg in southern Jemtland with a limestone relict.

After some short notes about a single small Swedish cave "Guldhalet" in Nerike and the big limestone beds on the islands Oeland and Gotland, for which he usually describes the climatic circumstances, he compares Oeland with the plains on Spitzbergen and other Norwegian islands. His great book gives indeed no proof at all that he even wished to study the few Swedish caves known at that time with the same interest and ardour as he had devoted to Norwegian caves. One cause for this omission could be that he had encountered many Norwegian researchers also interested in speleology, whereas his Swedish colleagues were more meteorologists, geographers and geologists--morphologists, dealing with other things than caves.

As I have written in a study: "Some Remarks on Swedish Speleology" in Geograf. Annaler 47 Ser. A 1965:1, however, nowadays there are so many Swedish geographers and geologists also interested in speleology, and so many scientific papers appearing from our universities, that Sweden is by no means to be considered a Terra incognita, in spite of the impression given by Corbel. And, on this occasion I would direct attention upon two recent Swedish papers: "The Problems of Karst Topography" by Professor Sten Rudberg in Övre Ältsvaten Expedition published by SSF the Swedish Speleological Society, Stockholm 1970, and "Preliminär svensk Grottbibliografi" by Rabbe Sjöberg, published in 1972 by the same society.

Personally, I found it curious that Corbel, at the same time as he praised the work by the scientific team Gislén-Brinck in Gotland, did not himself penetrate this or other Swedish karsts, and, after asking him, I got the impression, that he had in some sense overstrained himself in Spitzbergen, Norway and Great Britain, so that there was very little energy left over for Sweden. I would just point out that against 40 pp. about Spitzbergen and Björnöya, more than 150 pp. about "La haute Laponie" and 20 pp. about "Norvège méridionale", only 16 pages are written about northern Sweden and Finland altogether, with 7 pp. about the rest of Sweden.

Nevertheless I regret that Corbel did not spend a little more of his time, forces and attention on Swedish Karst phenomena, and I am quite sure it would have contributed to a broader and more detailed work. In any case he would have had a better backgrund for his somewhat hasty study: "Les phénomènes karstiques en Suède" in Geogr. Annal. Nr 3-4 1952. In the same year, however, he had written a better paper: "Karst et Glaciers en Laponie" in Révue de Géographie de Lyon Vol. XXVII, where he described Swedish climatology in the North very well, along with the well-known geological three broad landscape "steps" from the high mountain range Koelen down to the northern Baltic sea.

However, it is a fact, even with the limited idea of arctic and subarctic karsts covered by Corbel, that Sweden does indeed possess many interesting karstic phenomena. And, if one widens the term to include Parakarst and Pseudokarst, many opportunities will be found to observe curious formations in our northern country. In an earlier paper: "Karstic occurences in Sweden" in Archives for Swedish Speleology Nr. 4, Norrköping 1964, I have already dealt with this theme. Here I would just describe shortly some essential features in each Swedish province, classified according to the three forms of karst just discussed.

1. SCANIA

a) Real Karst. The 200 m long Balsberg cave near the town of Christianstad is the biggest cave in Southern Sweden, and its surroundings show all the classical marks of karst, such as dolines, depressions, holes and corroded stone lumps in a thin morainic layer above the cave on the top a the wooded hill of Bals-Berg. Those interested are referred to one detailed study of this

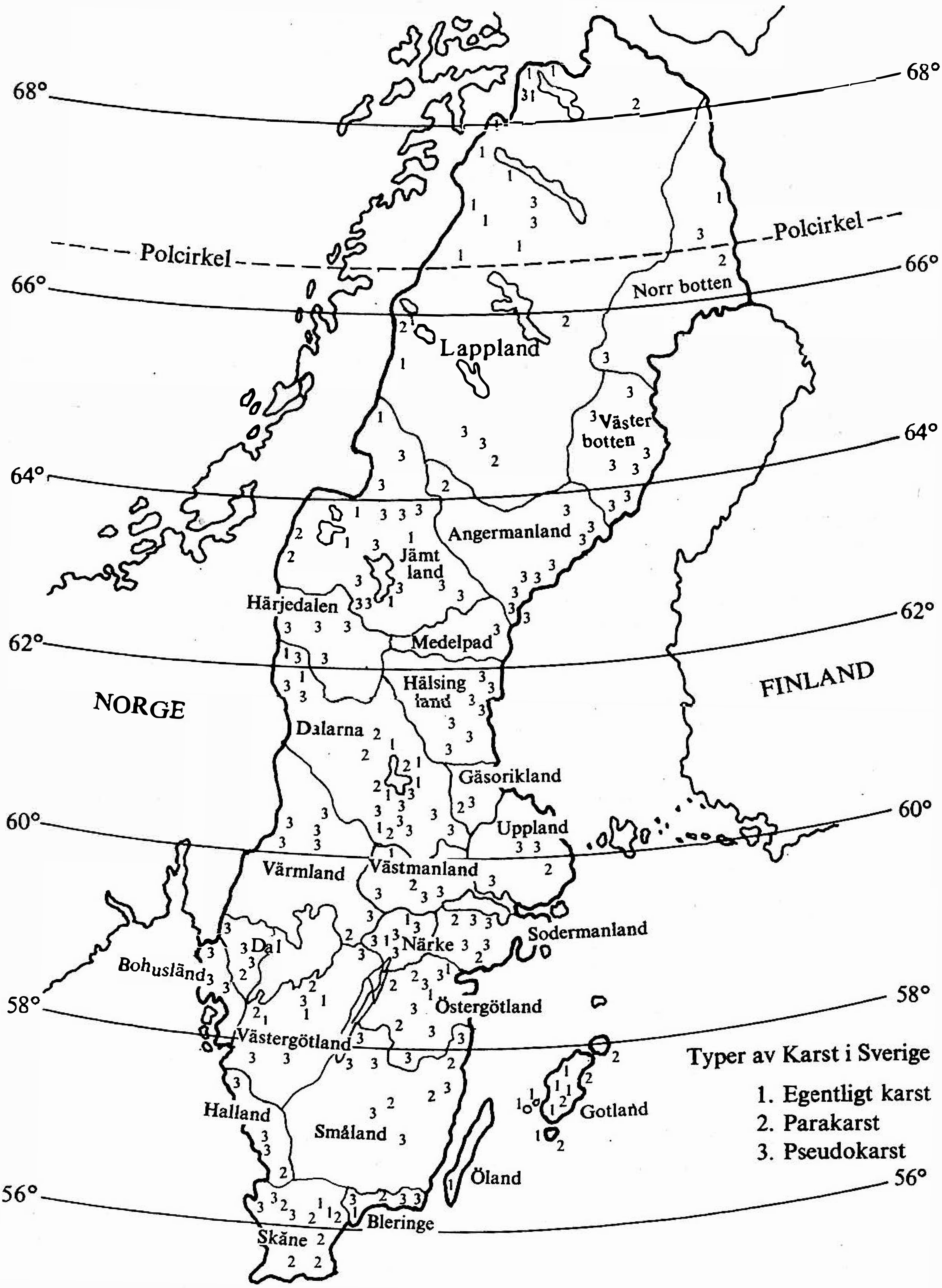

Fig. 1. Swedish Karst.

cave: "Balsbergsgrottan" in Archives of Swedish Speleology Nr 7, Norrköping 1967. Here I will just mention that the cave is eroded in a cliff of Danian formation and should properly be classified together with karstic phenomena in such young sedimentary rocks as chalk and gypsum. The complicated hydrology of the cave has been thoroughly studied during the few last years by J. Akerman from the university of Lund.

Ever since the area was first settled, building stones and material for an excellent mortar have been extracted from Balsberg. A multitude of quarries exist in the numerous finds of chalk in the province, and it is still possible to find some karst features in and around quarries, in spite of the fact that nowadays most of the chalk lies deep under buildings, village communities, towns and cultivated fields.

b) P a r a k a r s t. On the island of Ivö in the lake of the same name kaolin has long been worked in big quarries, and there one can study a sort of Paleokarst, formed out of the broken-up and crushed Fenno-Scandian Archean granitic shield, in which the feldspar has been ground to the finest kaolin powder. More evident parakarst phenomena occur in sandstone, schists and slates in places e.g. Övedskloster, Bjärsjölagard, Frualid in Torpaklint, Andrarum etc. Perhaps some forms in the Cambrian sandstone in Torekov could also be put into the same class.

c) P s e u d o k a r s t. Many other phenomena of karst character exist in the province of Scania, which are neither real Karst, nor of Parakarst nature, but are formed in other, crystalline, non-limestone, not even limestone-like minerals. The peninsula Kullaberg north of the city of Helsingborg consists principally of gneiss with fragments of other, mostly eruptive minerals. The coarse-grained gneiss is easily broken up by weathering and frost-wedging and is further subject to considerable abrasion by waves at the water-line. The water from rain and melting snow disappears quickly in small fissures and recumulates slowly in caves or bigger fissures. In winter-time it freezes in the neighbourhood of the outer cliff-walls. The ice forces the gneiss to burst into pieces, which fall down in to the sea or land on the bottom floor of coastal caves. By this procedure and material, some narrow strips of shore are created and many caves widened yearly. Some parts of the rocky peninsula give the impression of a real karst, but are typical exponents of pseudokarst.

Similar forms appear in Skäralid and in Klöva Hallar, i.e. in the powerful Precambrian shield of basalt, and in other places still mightier features appear in e.g. Hovs Hallar at the northwestern end of the hill of Hallandsas.

2. BLEKINGE

a) R e a l   K a r s t. Possessing the same character as the north-eastern Scania, this province shows some small karsts of chalk i Broaryd, Mörby, Istaby and on the peninsula of Listerlandet, where among other phenomena there is a little cave at the bottom of a well, in surroundings of typical karst forms.
b) P a r a k a r s t. Some phenomena in the kaolin finds at Mölle-björke are of this type.
c) P s e u d o k a r s t. But, on the other hand, several narrow canyons formed from fissures in the great Archean granitic rock shield are of pseudokarst type. There are also many caves and cave systems among blocks and in burst rocks at e.g. Ronneby and Lyckeby, where the labyrinths Skafteskär and Rävaskär have very karst-like appearances.

3. HALLAND

a) R e a l   K a r s t. In this province - a landscape without open limestone or chalk layers - the only existing layer of chalk lies at considerable depth at the town of Laholm, there are consequently no karst phenomena. The weathered Archean rocks and schists at Knäred show only some slight occurrences of parakarst type.
b) P s e u d o k a r s t. Phenomena of this type are more frequent. In the granitic cliffs at Tylösand exhibit the same forms as in Hovs Hallar, and there are some small caves in Östra Krarup, Sibbarp and Kvibille. A karst-like landscape also exists in and around a big cavernous cleft "Börsas hal" at Hällesaker.

4. BOHUSLAEN

As in the above province the Archean landscape of this district offers no examples of real karst forms, and only a few of parakarst type. Nevertheless, it is possible to find some parakarst phenomena in the Cambrian sandstone of Brefjället at Ljungskile and in some finds of quartzite. The considerable shell banks in Bräcke at Uddevalla, which may be the biggest in the world, might also show some marks of parakarst.

P s e u d o k a r s t. However, some forms of this third type of karst appeare in much-fractured and weathered granites and gneisses, especially in the usual "klovor" in the coastal cliffs, which are clefts into which huge blocks are squeezed. There are some cleft caves in Jörlanda, Hunnebostrand, Veddeberg, Fröland, Kviberg and other places, and several examples of giant´s cauldrons or marmites are known in the province.

5. DALSLAND

This small province doesn´t differ much from the foregoing one. Its rocks are mainly granites and gneisses, many of them greatly weathered. Archean limestones and Cambrian sandstones are rare and are often found together with fragments of eruptive rocks. Some caves are known in Steneby, Mon and Fjällbo, and also some giant´s cauldrons.

6. WESTGOTLAND

a) R e a l K a r s t. This province holds rocks capables of developing karst forms, and along a little brook at Karstorp, 5 km north of the town of Skövde, six small caves with dripstones have been found in a typical bit of karstic territory. In quarrying the Ordovician limestone in the mountain Billingen, some karst forms have also been found.

b) P a r a k a r s t. The frequent occurrence of old sandstones, slates, schists and diabase beds speaks for the possibility of finding small para- and pseudokarsts, and the famous caves in Kinnekulle, such as Brattefors and Mörkklev and Apostle Cave at Rabäck show some clear karst forms, as does also the small cave of Skanshal at Grävsnäs. An interesting phenomenon appears in the huge relicts of Halleberg and Hunneberg, where very old sedimentary layers have been protected - as in Kinnekulle - from erosion and weathering by means of a thick, firm cap of diorite. Tectonic movements have caused clefts in this upper shield, and guided atmospheric waters, and therefore weathering and erosion into the underlying layers of Ordovician limestone and alum schists, and now there is a net of deep and narrow "devil´s holes" in these hills.

c) P s e u d o k a r s t. The biggest cave in the province is that of Öglunda at Varnhem, a karst-like feature formed in diabasic rock. Similar forms appear in the hill of Mösseberg, and in the Archean rocks of Tiveden there is a multitude of caves and clefts of pseudokarst nature. Some of the country´s biggest giant´s cauldrons are to be found in the valley between the lakes Anten and Mjörn, and at Marbäck and Knutstorp.

7. SMAOLAND AND OELAND

a) R e a l K a r s t. The island of Oeland is a place where one would have high expectations of finding some sort of karst, because of the island´s mighty beds of Cambro-Silurian limestone. But in this very hard, banked Orthoceratite chalk only some small and slight superficial karstic marks exist. Since ancient times it has been known that two or three springs discharge their water in the coastal cliffs, and these suggest the existence of subterranean drainage for Alvaret and other parts of the high inland plain of the island. Of these I will just mention the well-known spring in Lundkälla and the rich water vein in Resmo, Mörbylanga, which was noted and described already by von Linné in 1741.

In a paper about Oelandian dolines Dr H. Svensson from Lund published in the Swedish Geographical Yearbook 1963 the suggestion that in the surroundings of Resmo, a system of subterranean cavities may be hidden, even perhaps an analogy to the famous caves of Lummelunda on the island of Gotland. But hitherto it has not been possible to enter the rocky, narrow water tunnel. Corbel has expressed the opinion that there must exist an ancient, preglacial karst on the island.

Other parts of the provinces in question present a landscape solely of Archean rocks with one curious exception: an occurence of Cambro-Silurian limestone on the border of the lake of Hummeln between Kristdala and the town of Oscarshamn, with no marks of karst character at all.

b) P a r a k a r s t. In the geologically well-known sandstone beds of the Visingsö formation on the island of this name in lake Vetter, there are some caves and small karst features, and in the same class are the interesting More Kastell in Fogelfors and the cave of Svaltorp at Forsaström.

c) P s e u d o k a r s t. Much larger in scope, however, are the clefts and fissure-caves together with small caves among erratic blocks, and the many giant's cauldrons which characterize very big areas of the provincial districts of Jönköping and Calmar. The long canyon of Skurugata at Eksjö, and similar wide fissures in the granitic basic shield, such as Väggeberg, Hälleberg and Sigge kista are of impressive size. Glacial blocks formed numerous caves, e.g. Vista Kulle, Flishult, Pelarne, Göljhult and many others, which are all pseudokarst forms, as are the marmites in Marbäck, Huskvarna, Stockatorp, Wenzelholm etc.

8. GOTLAND

This mighty old relict of principally Silurian limestone of great thickness, which covers the Fenno-Scandian Archean rockshield, demonstrates, in contrast to other Swedish provinces, many big examples of erosional phenomena. This peculiar character of Gotland has been pointed out by all Swedish and foreign authors dealing with the well--known island in the Baltic sea. As early as 1741 von Linné noted the subterranean stream in Lummelunda, together with relict formations called "raukar", caves, springs and different sedimentary minerals in several parts of the island. Professor H. Lundqvist has expressed these features best in his official description for the geological maps of Visby and Lummelunda (SGU Ser. Aa Nr 183 Stockholm 1940) where he writes: "The cause for the remarkable conditions of drainage in Gotland is the fact that the rock carries many lines of fissure, which are widened by solution of the limestone. We have here an evident parallel to the karst territories of Southern Europe. Those fissures and holes meet in the depth looser horizontal layers. The water rushes down in the fissures and clefts and follow the horizontal layer to the outflow, where it appears either as real brooks (as in Lummelunda and Kolens kvarn) or as springs e.g. in Lully Hill."

Another famous geologist, H. Munthe, had earlier published a paper entitled "Coastal caves and nearly related geological phenomena i Sweden", Stockholm 1920, but had overestimated the significance of the caves there due to coastal abrasion. Describing the cave of Lummelunda, he declares: "That cave is to be considered as a combination of a coastal cave and a cave of solution" but completely fails to mention the remarkable subterranean water passage from the lake of Martebomyr over 1300 m to the subaerial brook in Lummelunda hund. However, this subterranean water-course has been known for many reds of years, and there are many reports about it before and after that of von Linné.

Professor T. Gislén from the University of Lund inaugurated, in 1924, a long series of investigations of the subterranean waters on Gotland. He returned to the island in 1933 for the same purpose and again in company with his colleague P. Brinck for several periods during the years 1945-1947. Their researches resulted in two papers: "Subterranean waters on Gotland, with special regard to the Lummelunda current I-II", Lund 1948 and 1950. This is the first detailed scientific report of undeniable karst-like phenomena on the island.

In the years 1920-1940 I came into contact personally with the curious landscape around the lake of Martebomyr and the mill of Lummelunda and soon became aware that here was an object of interest for Sweden and even for other countries. Most people, however, didn´t believe me, among them certain geologists and directors of tourism, in spite of the fact that the known outer cave with the reappearing current clearly showed not only perfect marks of erosion but also some remarkable dripstones. I therefore dedicated time, forces and money to pursuit of the matter. From the very beginning, I was enthusiastically aided by the miller, Captain T. Hermansson, and the owners of the terrain, the brothers Rolf and Thor Ödin, who when they were schoolboys, had entered the cave farther than people thought possible.

Such personal exploration, such penetrating, of course, unveils more about a hidden subterranean landscape, and especially about the nature of karst, than any investigation from the surface. I was surprised at the often incorrect and superficial conclusions stated by other Swedish and foreign researchers. For instance, in the year 1943, a French geologist, Georges Chabot, published a report about Lummelunda, apparently based on a superficial examination at the end of a trip, devoted to describing karstic phenomena in Estonia. He writes in this paper: "Naissance d´un karst: l´ile de Gotland dans la mer Baltique" in Annales de Géographie Vol. LII Nr 289, that deeper karstic marks are lacking, because he found only some slight subaerial crevices, and was convinced that the sole exception were a small preglacial karst.

Before Corbel´s great work about the Karsts of North-Western Europe, Corbel has published a little study: "Les phénomènes karstiques en Suède" dans Geogr. Annal. Nr 3-4 1952 where he lightly touches on speleology in Sweden. In this paper he concentrates himself only on some superficial phenomena and contents himself with mentioning an insignificant little spring at Kolens kvarn, instead of studying the karst terrain of Lummelunda more carefully. It is rather incomprehensible that scientific research has passed over the clear signs of sinkholes and the doline landscape in that place for such a long time, and that so few have taken the chance to investigate the subterranean drainage through the mighty current, especially after the above-mentioned successful analytic work by the team Gislén-Brinck.

In the very latest years, however, the picture has changed considerably. Guided by Dr Gert Knutsson, two students from Chalmer´s Technological Institute at Gothenburg, N. Andersson and A. Gusting, made a thoroughgoing investigation of the subterranean drainage, the result of which was published in 1962. Another native researcher, Dr Carl-Fredrik Lundevall of the National Museum of Sweden in Stockholm, used to work as a journalist, and in this capacity had several times visited my work in Lummelunda. Among other things he had written a great article "350 millions of years deeper in the rock", illustrated by excellent photographs by the world-famous artist Lennart Nilsson, in the popular weekly "Vecko-Journalen" Nr 29 1955. Since than Lundevall has pursued scientific investigations of the terrain in question, published in several papers, among them: "Karst-morphological investigations in the district of Lummelunda", "Karst phenomena in the Lummelunda area" and "A newly-discovered cave system at Lummelunda", the last two appearing in Geogr. Annal. Vol. 47 1965 and Vol. 48 A 1965.

It is to be hoped that this inexhaustible landscape will offer many more objects for further investigations by young students. The students of the gymnasium of Visby have always shown interest in the caves of the island, and in 1954 three boys from the gymnasium found a creep-passage into parts of the Lummelunda cave, which I and my assistants had so far been able to reach only by diving in deep and narrow water-tunnels. The passage of these boys opened a better, though still difficult route to inner parts of the cave, which were eventually opened to tourists in 1959, through an artificial tunnel.

The above-mentioned work by Gislén-Brinck includes some other subterranean waters on the island: Muske myr in Sundre, the brook of Mölnare in Klinte, springs in Etelhem and Östergarn, another brook in the castle garden of Visby and a similar one from Hästnäs to Kolens kvarn, and finally some sink-holes in Bro. But there are still many other phenomena of this type all over Gotland to be investigated. My catalogues of Swedish caves contain hundreds of caves in Gotland alone, but only a few of them can be classified under "karst". The majority of these caves are in solitary limestone butts, and especially in the coastal cliffs, where not erosion but abrasion has gone to work.

b) P a r a k a r s t. In spite of the assertion by Corbel that the limestone of Gotland is very propitious to karst forms, it is advisable to be aware of the great difference between the limestone layers. The limestone is very often in an impure form, which normal erosion <u>cannot</u> conquer, and of which many stretches of coast show proof in the form of "raukar", the curious pillar-like relicts of impure limestone. Those raukar are most numerous on the island Farö, in Slite and on the little southern island of Heligholmen. There are also parakarst features in the marble-hard Orthoceratite limestone of the hills of Hoburg and Torsburg. More pronounced, however, are the marks of parakarst nature in some sandstone beds at Sudret, which von Linné studied in 1741 and observed their unusual capacity of absorbing water.

Aside from these the geological structure of Gotland doesn't allow any pseudokarst.

9. OSTROGOTLAND

a) R e a l K a r s t. The landscape of this province on the Swedish mainland is a typical Archean one, with principally granites and gneisses. Either the original overlying sediments have been completely planed off by glaciers, or the Archean rocks have been preserved high above ancient seas so that no sediments were ever laid down. It is therefore difficult to imaging it containing real karst forms. Ther' are some bands of Cambro-Silurian limestone situated deep in the earth's crust under Ostrogotland, but they cover only one-tenth of the total area and seldom appear at the surface. However, the wide fertile plain in the middle of the province lies directly on top of such layers. In Gistad, chalk has long been quarried for agricultural purposes, and in Kolmarden the quarry of Marmorbruket has delivered a famous green marble for many hundreds of years.

In this same place, in a narrow strip of chalk, lies the single real karst cave of the province. This small, winding cave has been eroded by a little brook, and demonstrates a miniature karst.

b) P a r a k a r s t. There are several karst forms around the chalk- and sandstone quarries at the foot of the hill of Omberg, and the old sandstone beds in Lemunda, Norra Freberga, Tjällmo and Hällestad have been quarried for mill- and grindstones for a long time. But an outstanding example of parakarst is the famous Pelargrottan in Malexander, where a thin bed of quartzite, super- and subposed by eruptive granite, has been curiously eroded into low holes between short thick pillars.

c) P s e u d o k a r s t. Most karst phenomena in Ostrogotland appear in crystalline rocks such as granites, gneisses, gneiss--granites and different porphyries. Even if some geologists would hesitate to call such features karst forms, anyone who sees them must wonder about the character of such features as the famous Trollgatera (Ogres's lanes) in Grythult, a subterranean labyrinth formed by fissures and clefts in the Archean granite shield. In this landscape there are several such subaerial and subterranean clefts, deep, even knife-cuts, in Swedish called "skuror" (scores), and the origins of these phenomena are still discussed, some students suggesting glacial pressure, others suggesting tectonic movements.

Many caves show peri- and/or postglacial development, for example Torekullakyrka in Rämninge and Rövarmon in Vanga, caves in the forest of Stjärnvik, in Stralsnäs and in Höversby. There are also many giant´s couldrons, for example the 12 m deep, 3 m broad Devil´s Cauldron in Tjällmo.

10. SUDERMANLAND

a) R e a l K a r s t. As in Ostrogotland, the bedrock in this province consists mainly of Archean rocks, especially gneisses. Some granites and leptites also occur, and some rare strips of limestone. In many places there are abundant finds of ores, e.g. iron in Kantorp and in the island of Utö, copper, cobalt and other minerals in Tunaberg. In the chalk quarry of Oaxen a big cave of erosion was destroyed a long time ago, but there is still an impressive cave of erosion on the peninsula of Hornö, with a little real karst.
b) P a r a k a r s t. In the rare formation of sandstone on the island of Granholmen in the Melar lake, it is possible to study parakarst phenomena, which also appear in a curious little cave in the northern part of the town of Nyköping.
c) P s e u d o k a r s t. Pseudokarst caves and clefts, however, are numerous in the Archean rocks, e.g. Smedtorp, Vingaker and Mellösa as well as on the border of the lake of Baven and on the islands of Hartsö, Mörkö and Hölö.

11. NERIKE

In this province - as the most of Sweden- being dominated by Archean rocks, there are not so many karst-forms of any sort present. The bedrock consists principally of Cambro-Silurian limestones, sandstones and schists. Gneiss is a frequent mineral, together with Porphyries, granites and leptites with many veins of ore.

Here I must point out that the Swedes, being accustomed to the hard Archean bedrock of their country, don´t expect many own speleological phenomena in their rocks, even including limestones, because these formations most often are of Archean.origin och nature, i.e. long before the formations of Devon, Carbon, Perm, Trias or Jura were laid down, and which now carry more less famous karsts, caves and cave systems in the world. To the geologist, however, the following enumeration of the minerals in each province will give a key to understand the difficulties of Swedish speleology and the rarity of its objects.

a) R e a l K a r s t. Some small limestone occurrences contain caves, for example at the lake of Älvslangen, there are two erosional caves, Klingtjärn and Jacob-Jons. In and around the little cave named "Guldhalet" (= Hole of gold) in Garphyttan, described by Corbel, is a small karst area, and in all three there is subterranean drainage.

b) P a r a k a r s t. In the Orthoceratite chalk in Lanna and other places as well as in the schists of Yxhult and Kvarntorp, there are some slight parakarst phenomena.

c) P s e u d o k a r s t. More evident are forms of this type, especially in and along the long faults which run through the whole Archean rock shield. Examples of pseudokarst may be seen in Kilsbergen and Fellingsbro and other places, such as in the fault's breaking-up zone in Stenkälla and Garphytteklint. Many giant's cauldrons of all forms and sizes exist in the ancient stream-bed of Sveaälv in Degerfors.

12. WERMLAND

Although this province is geologically interesting for its many and rich mines, it is almost a blank spot to speleologists. There are, however, several other interesting geological features, for example the mighty belts of quartzite with much feldspar together with Cambric sandstone in the valley of the river Svartälven. Some few caves are known in Amot, Sunne, Skillingsfors and Ekehärad.

13. WESTMANLAND

Having almost the same landscape as the foregoing, this province doesn't show any evident karst features. There are some chalk quarries in Sala and Riddarhyttan, and some quartzite with feldspar in Kila, but no karst occurrences, so far known.

Small pseudokarst forms, however, can be studied in Sevalla, Västerfärnebo, Anderbenning and on the little island of Skarpan in the Melar lake.

14. UPLAND

In the considerable Archean beds of this province, there are leptites with rich ore veins, porphyries, granites, schists and quartzites, which show some slight subaerial pseudokarst. It is possible that deep below the surface, a Cambrian paleokarst is hidden. Almost all of the valley of Fyris lies on mighty layers of Archean chalk. On the islands of Ekerö in the Melar lake, and around the lake of Erken, are finds of Jotnian sandstone. A few pseudokarsts exist in some places, e.g. Gillberga gryt in Edebo, Pukebergs Cave i the neighbourhood of Enköping, and two "Robber´s caves" on the border of the lake of Vällen. There are also some giant´s cauldrons, notably a big one below the county hall of Haga in Stockholm.

15. GESTRIKLAND

This province, also a typical Archean rock landscape with orecarrying leptites, granites and gneisses, with some veins of diabase, gabbro and amphibolites, presents only a few karst features, around small caves in Ockelbo and Järbo. Underneath the surface layers lie beds of Jotnian chalk and sandstone. A little crystal cave is reported from the Storrede mines in Hofors.

16. DALECARLIA

This province presents a varying geological picture with all sorts of minerals, such as ore-rich leptites, granites and gneisses, quartzite, conglomerates and schists. Containing also considerable beds of several kinds of limestone and sandstone, it shows some evident karst features.

a) R e a l   K a r s t. Around the lake of Siljan and in Särna, Boda, Skattungsbyn and Elvdalen there are many finds of limestone and chalk. The existence of caves here has been known for many hundreds of years, e.g. the famous cave of Jätturn with typical karst features at Rämshyttan. A sort of karst exists around the lake of Ljugarn in Bingsjö and some partly subterranean brooks exist in Töfsingan at the lake of Grövelsjön and in Gravan in Skattungsby among other places.

b) P a r a k a r s t. In the mighty 180 km-long layers of sandstone from Malung through Elvdalen and Särna up to the Norwegian boundary there are numerous caves, e.g. Gwenna in Däraberg and Styggforsen in Boda.

c) P s e u d o k a r s t. Phenomena of this class can be studied in Eländegraven in Idre and in many ravines and canyons like Dragbergs gatu and Frostbrunna in Stora Tune, Studentrännan in Hykleberg at Elvdalen and Trollgatorna at Grangärde.

17. HELSINGLAND

This province, built upon Archean rocks such as granites, gneisses, leptites with ore-veins, porphyries, schists, quartzites and chlorites, has no cavities or karstic forms other than small clefts in the long, large faults, running across the landscape. e.g. Hallbo Vall at the lake of Dellen, and Solleberget, Laforsen and Sotegrottan in Hanebo.

18. MEDELPAD AND ANGERMANLAND

Here the previously described type of Archean landscape is still valid. Beside granites, gneisses and ore-bearing leptites, there are mighty moraines with stone-filled hills (drumlins) and deeply incised river valleys. The well-known Swedish archipelago along all the coast exhibits also here many small and big islands, and in some islands Archean sandstone still is preserved by a cover of diabase showing fissures and clefts. The mountain range at Holing and Tasjö contains rich layers of quartzite. The caves known in Granö are hollowed out in Ordovician schists.

The most remarkable cave known in the provinces is in the granitic hill of Skuleberg, and it is further another big cave named Räckebergakyrkan at Torsböle. This cave has been hollowed out in granite by ice and shows erosional marks from glacial streams. In all the places showing the pseudokarst, the features are very like real karst, but are developed in insoluble rocks.

19. JEMTLAND AND HERJEDAL

Given the foregoing descriptions, one must agree that real karst forms are rare in an old Archean country like Sweden. One must indeed pass over nearly all the country as far North as up to Jemtland in order to meet such phenomena. However, in other respects, geographically and geologically the intervening provinces are interesting: the marks of the enormous uplift and overlapping during the Caledonian Era ca. 350 millions of years ago, described by professors Arvid Högbom and Bror Asklund, are still visible. In many places, old layers are pushed up upon younger formations, and by descending into subaerial or subterranean clefts and fissures, one arrives at curious canyons with subterranean waters and innumerable marks of erosion.

Between layers of limestone there appear Archean rocks: granites, schists, gabbros, syenites, diabase and other porphyric rocks. In Herjedal there are mighty layers of quartzite. The limestones are built out of Cambrian and Silurian sediments, and in many places they are metamorphizised into hard white or grey marble. They appear principally in the high mountain range forming the Norwegian boundary, in the river valleys, and around the lake of Storsjön.

a) R e a l K a r s t. An early studied karst region of the province Jemtland is the valley of Bjurälven, which extends down to the lake of Leipik. A little Norwegian river makes an abrupt turn and disappears below the divide of Kollen, continuing its subterranean flow into Sweden, where it has formed a karst with all the usual marks and forms, such as dolines, sinkholes, dead valleys, and caves.

A similar but smaller karst area appears on the border of the lake of Gysen, where two brooks alternate subaerial with subterranean flow, forming water-filled tunnels and low but long caves. Also, in Hackas there is a similar karst area, with long erosional caves beginning on the bottoms of wells.

b) P a r a k a r s t. In the old quarries in Ånge and Offerdal, as well as in the surroundings of Tandsbyn and Husa, there are some parakarst features.

c) P s e u d o k a r s t. In the Archean rocks there are many caves which show karstic phenomena. The well-known cave is Hoverberg in Berg is a big cleft, measuring 170 m, in porphyric rock, and there are similar caves at Hede, Bydalen, Pilgrimstad, Hammerdal, Rätansbyn, Hällsjö, Görvik and other places. Glacial phenomena appear in such places as a famous Ice cave at Frösön, Östersund, in the brook of Labbas at Hammerdal, and between Hunge and Bräcke. Many giant's cauldrons can be seen in Ragunda, Hede and in the canyon of Hällingsa.

20. WESTERBOTTEN AND NORRBOTTEN

As in the other far-northern coastal provinces, the bedrock is principally Archean, often of the oldest formations in the world, such as porphyries, granites, gneisses, together with orerich leptites. There are also several phyllite bands of conglomerates, schists and Archean sand- and limestones, all of them partly covered by huge moraines. On the borders of the Torne and Muonio Rivers are some finds of Archean limestone, which is quarried in Kolari on the Finnish side, and ought to carry some karst marks also on the Swedish side. A sort of parakarst appears in the hill of Luppio at Övertornea.

P s e u d o k a r s t. The provinces in question are also rich in pseudokarst phenomena, especially around Nordmaling, where there are many caves in the hills of Storris, Mossarotland and Lusberg. The area around the town of Umea shows many considerable clefts and caves, recently discovered by the Swedish speleologist Rabbe Sjöberg, such as Anna-Lotta and Gittstugugrottan. There are several giant's cauldrons on the shores of the nearby river of Umeälv.

21. LAPPLAND

Geologically this big province constitutes the two or three broad upper steps, described by Corbel and others, gradually sinking in vast forest-belts from the mountain-range at the Norwegian boundary down to the northern bay of the Baltic Sea. The bedrock consists of Archean rocks, the oldest parts of which seem to lie in the region of the river and town of Skelleftea, and consist of porphyries, characterized by rich ore-carrying leptites and gabbros, which are particulary abundant in Kiruna. There are also several granites, especially a fine-grained beautiful one on the border of the lake of Hornavan. Relicts of pre-Cambrian limestones and quartzites appear as schists in narrow bands, which have been broken up many times by seismic and tectonic strongs movements, which have influenced the former morphology. In huge faults in the Archean rock shield, the narrow bands of limestone and schists wind horizontally and up and down.

a) R e a l K a r s t. But these limestone bands, and even some quartzite bands, make it possible to find the same karst and para-karst and pseudokarst forms as in the province of Jemtland. And in fact the karstic occurrences in the corner of Jemtland between Lappland and Norway continue further north. Professor G. Beskow did an early investigation of the subterranean brook and caves of Southern Storfjället, which are similar to phenomena appearing in the region of Tärna.

Following the mountain-range along the boundary with Norway, one finds typical karst-forms from the latitude of 65° until 68°30′ north, beginning with the mountains of Röding and Rönäs, and continuing over the cave-rich territory of Artfjäll with the newly discovered caves of Sotsbäck (1600 m long), Mieskatjakko and Langfjäll, and numerous other real karst features, most of them only suspected but not yet fully investigated. Above the Polar Circle there were formerly some pretty karst phenomena around the mighty waterfalls of Stora Sjöfallet, but these are now inundated by a big power dam. In the mountains around Kvikkjokk, Sulitelma and Stipok, some members of the Swedish Society of Speleology have recently discovered numerous caves and karst forms.

Further north, at the latitude of 68°, many discoveries have been made around the lake of Torneträsk. In 1954, Dr Gunnar Rasmusson investigated the 1200 m long, and soon internationally-known cave of Lullihatjarro at Djupviken, and since than there has been a long list of further discoveries of real karst nature in this same region. Contrary to the opinion of Corbel about the rarity of noticeable caves above the Polar Circle, several new expeditions have found more and more facts of considerable karstification in these regions. In one recent paper, L.G. Hellgren of Chalmer´s Technological Institute of Gothenburg has thoroughly described the results of geological-hydrological investigations around Lullihatjarro. Other students (G. Knutsson, L. Carlsson, M. Nord, M. Lindström, A. & R. Lindén and others) have made equal discoveries at Björkliden, in the same region around Abisko and the lake of Torneträsk.

b) P a r a k a r s t. It is too early to classify all new discoveries of parakarst nature, but there are some interesting phenomena, for example the "Devil´s Cleft" in a canyon southeast of the iron mines of Koskullskulle, Altarliden Cave at Rusksele, and some caves in the region of Asele.

c) P s e u d o k a r s t. Considering the fact that real karst and parakarst phenomena appear in the rare occurrences of limestone, quartzite and schists, there must be many other karst-like features in the generally Archean rock shield of the landscape. But little about this is yet known, except for the existence of some caves at Avasjö, some burial caves of the Lapps at western Abel-Water in Tärna, many caves around Asele, and caves in Kvikkjokk, Vuoskelvagge, and Peripakte, in the boundary mountain-range.

RÉSUMÉ

Avant relaté l´histoire du terme KARST dès la publication de J. Cvijić en 1893, et les contributions des autres auteurs, comme p.e. N. Llopis Llado, dans le sens de Holokarst, Merokarst etc., on veut ici rappeler la discussion sur des formes karstique diverses, aussi dans des roches non-calcaires, particulièrement par O. Lehmann, M. Gortani, W. Halliday e.a., synthétisée par F. Anelli dans les termes nouveaux de karst, Parakarst et Pseudokarst.

La commission de terminologie de l´Union Internationale de Spéléologie vient de définir les phénomènes karstique comme suit:

K a r s t (m), Région karstique (f): type de région constituée par des roches compactes et solubles (roches karstifiables) perméables en grand et dans laquelle peuvent apparaitre des formes superficielles et souterraines caractéristiques (phénomènes karstique).

P a r a k a r s t (m): terme employé surtout en Italie pour désigner une région dont les formes karstiques sont peu caractéristiques dans des roches peu karstifiables.

P s e u d o k a r s t (m): région présentant des formes analoques à celles du Karst dans des roches non karstifiables.

Dans la Suède et autres contrées arctiques et subarctiques existe un karst spécial, un Karst arctique ou Thermokarst, mais la plupart des phénomènes se développent dans des roches non-calcaires appartenant aux types de Parakarst et particulièrement Pseudokarst. Dans la suite l'auteur décrit les phénomènes divers de chaque province suédoise.

ZUSAMMENFASSUNG

Die Geschichte der Begriffe Karst wird erzählt und analysiert, wobei die verschiedenen Theorien mehrerer Nachfolger von Cvijić, der den Ausdruck Karst im Jahre 1893 selbst introduzierte, weiter behandelt werden, z.B. die Diskusionen von O. Lehmann, M. Gortani, W. Halliday u.a., worin gewisse neue Ausdrücke entstanden, die von F. Anelli später ausgeschieden und differenziert wurden, und zwar hauptsächlich als P a r a k a r s t und P s e u d o k a r s t.

Die Subkommission für Therminologie der Internationalen Union für Speläologie UIS hat folgende Definitionen aufgestellt:

K a r s t (autentischer Karst) ist ein Landschaftstyp (Gebiet) in dem unterirdische Entwässerung in verfestigten löslichen Gesteinen (verkarstungsfähigen Gesteinen) erfolgt, und in dem kennzeichnende ober- und unterirdische Formen (Karsterscheinigungen) auftreten können.

P a r a k a r s t ist ein ursprünglich im italienischen Sprachgebiet verwendeter Begriff für den schwach ausgeprägten Karstformenschatz in schlecht verkarstungsfähigen Gesteinen.

P s e u d o k a r s t bedeutet eine Landschaft mit karstähnlichen Formen in nicht verkarstungsfähigen Gesteinen.

In Schweden und anderen arktischen und subarktischen Ländern existiert öfters eine Spezialform des Karstes, nähmlich ein arktischer oder Thermokarst, aber grösstenteils erscheinen Karstphänomene in anderen Gesteinen als in den seltenen Vorkommen von Kalksteinen. Aus diesem Grund wird eine Beschreibung der schwedischen Karsttypen vielfach andere Form als jene des klassischen Karstes behandeln, d.h. Parakarst und ganz besonders Pseudokarst. In der folgenden Aufzählung erklärt der Verfasser die diesbezüglichen speziellen Erscheinungen jeder einzelnen schwedischen Landschaft.

Ba 044

LIMESTONE EROSION UNDER SOIL

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INTRODUCTION

This paper attempts to relate the rate of limestone erosion under soil to soil type. It also attempts to relate bedrock morphology to soil type and rate of erosion. The paper is concerned mainly with clint form and not the formation of grikes nor limestone pavements in general. The data are largely drawn from fieldwork in Co. Clare, Eire.

Five soil types covering limestone were studied: calcareous brown earth, humus rendzina, acid brown earth, limestone ranker and peat bog soil. Ultimately, if sufficient data are gathered to characterise each of these soil types in terms of erosion loss, it may be possible to predict erosion loss within a limestone basin from a study of the distribution of soil types.

Erosion rates measured range from a mean value of 0.0003 mm/yr under calcareous soils and increase to 0.025 mm/yr under acid mineral soils, rising to around 5.0 mm/yr under acid peat soils. There is a concomitant increase in bedrock dissection.

THE LOCUS OF EROSION

Solutional removal of calcium carbonate from the soil/bedrock profile cannot necessarily be equated with bedrock lowering. In the case of bedrock erosion it has been shown by Williams (1966), Trudgill (1972a) and Trudgill and Atkinson (in press) that calcareous soils act to protect the limestone bedrock. Active bedrock erosion only occurs under acid soils. However, it can be emphasised that while bedrock erosion is minimal under calcareous soils solution does occur at some position in the soil profile.

It is also not necessarily possible to equate solution loss in the soil with a contribution of calcium carbonate to percolation waters in the cave system. The calcium carbonate dissolved in the soil may be reprecipitated further down the soil profile or within the bedrock below the soil. The retention of calcium in solution in percolation waters appears to depend upon the concentration of carbon dioxide in the ground air in percolation cracks (Atkinson, 1971 and personal communication; see also Trudgill and Atkinson, in press).

It is therefore seen as important to differentiate between solution with surface lowering under acid soils and solution without bedrock lowering under calcareous soils. In either case the entry of calcium into the cave percolation system may be influenced by other factors not discussed in this paper.

A further complication under acid soils is that the bedrock surface may be attacked for some time without immediate surface lowering. The process of decalcification of the surface is evident in some sub-soil limestones. A crumbly layer, over 2 mm and up to 1 cm thick is frequently visible. These crusts commonly have about 1/3 to 2/3 of their calcium carbonate removed (as compared to the sound limestone below). Clearly, surface lowering will be taking place but the precise definition of the "surface" is not possible. The several different zones of solution and erosion are illustrated in fig. 1.

THE AGGRESSIVENESS AND SOLUTION LOAD OF SOIL WATERS

Data exist in the literature relating to the solution load and saturation status of waters from different soil types. Tab. 1 presents some data (from the Mendip Hills, Somerset), from which principles of a general nature can be extracted.

Of the soil waters sampled it can be clearly seen that the water which has percolated through acid soils has a low solution load and a high potential for further solution. As a contrast water percolating through calcareous soils, while having a variable solution load, was mostly saturated on arrival at the soil/bedrock interface. Runoff waters from areas covered by humus soils showed a high solution load but the solution potential of the water was largely used up after passage over limestone from the soil covered area.

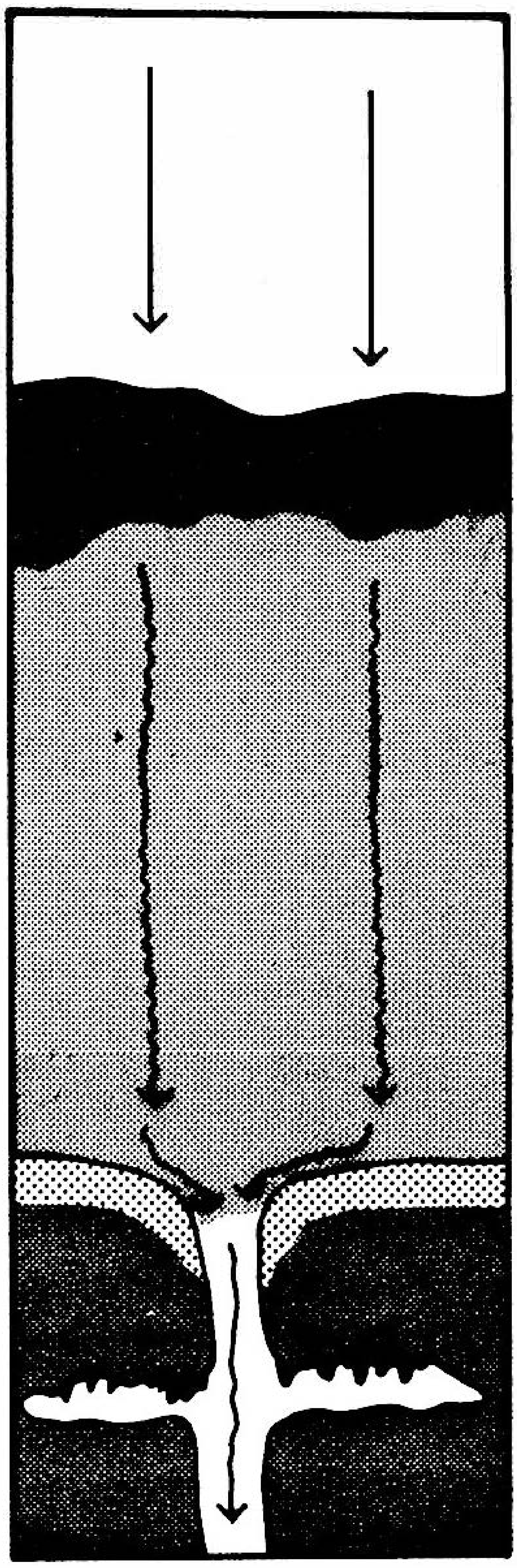

Fig. 1. Solution, deposition and transport in the soil profile.

MORPHOLOGY AND EROSION REGIME

The first step of the study in Co. Clare, Eire, was to attempt to identify any relationship that may exist between soil type and bedrock (clint) form. Three factors were seen as important here:

1. The history of glacial erosion.
2. The nature of the present erosion regime.
3. Lithology.

The flat, scoured surfaces produced by glaciation have been subsequently modified by erosion under soil (and also by rainwater and

T a b. 1. Solution Load of Soil Waters (Figures in mg/L $CaCO_3$)

Soil Type	$CaCO_3$ Load	Potential	Aggressiveness
A. Water samples from the soil profile			
Acid brown earth	53	195	142 *
Acid brown earth	44	183	139 *
Calcareous brown earth	265	270	15 *
Calcareous brown earth	60	65	5 *
Calcareous brown earth	180-250	180-250	0 **
B. Water samples from water draining from soil over limestone			
From acid humus soil	225	270	45 ***
From humus rendzina soil	120	120	0 ***

*Atkinson, 1970
**Newson, 1970 (See also Trudgill and Atkinson, in press)
***Author

lichens on soil free sites). The land forms are thus glacio-karstic (Williams, 1966). The striated glacial surfaces are only completely preserved under thick calcareous drift. The bedrock forms have been classified firstly according to genetical interpretation. Secondly, lithological variations are seen to act within broader classes associated with erosion regime. The classification proposed is as follows (the morphology is illustrated in fig. 2).

I Surfaces produced by glacial erosion and little modified by subsequent weathering

a) Subaerial surfaces (soil free).	Undulating/even surface of clints.
b) Surfaces under a protective cover of a calcareous nature.	Undulating/even/striated.

II Surfaces produced by glacial erosion but subsequently modified by ~~weathering~~

a) Surfaces under brown earths.	Undulating/even.
b) Surfaces under humus rendzinas.	Undulating.
c) Surfaces under acid brown earths.	Cuspate.
d) Surfaces under acid peaty rankers.	Arcuate form.
e) Surfaces under peat bogs.	Runneled and arcuate forms.

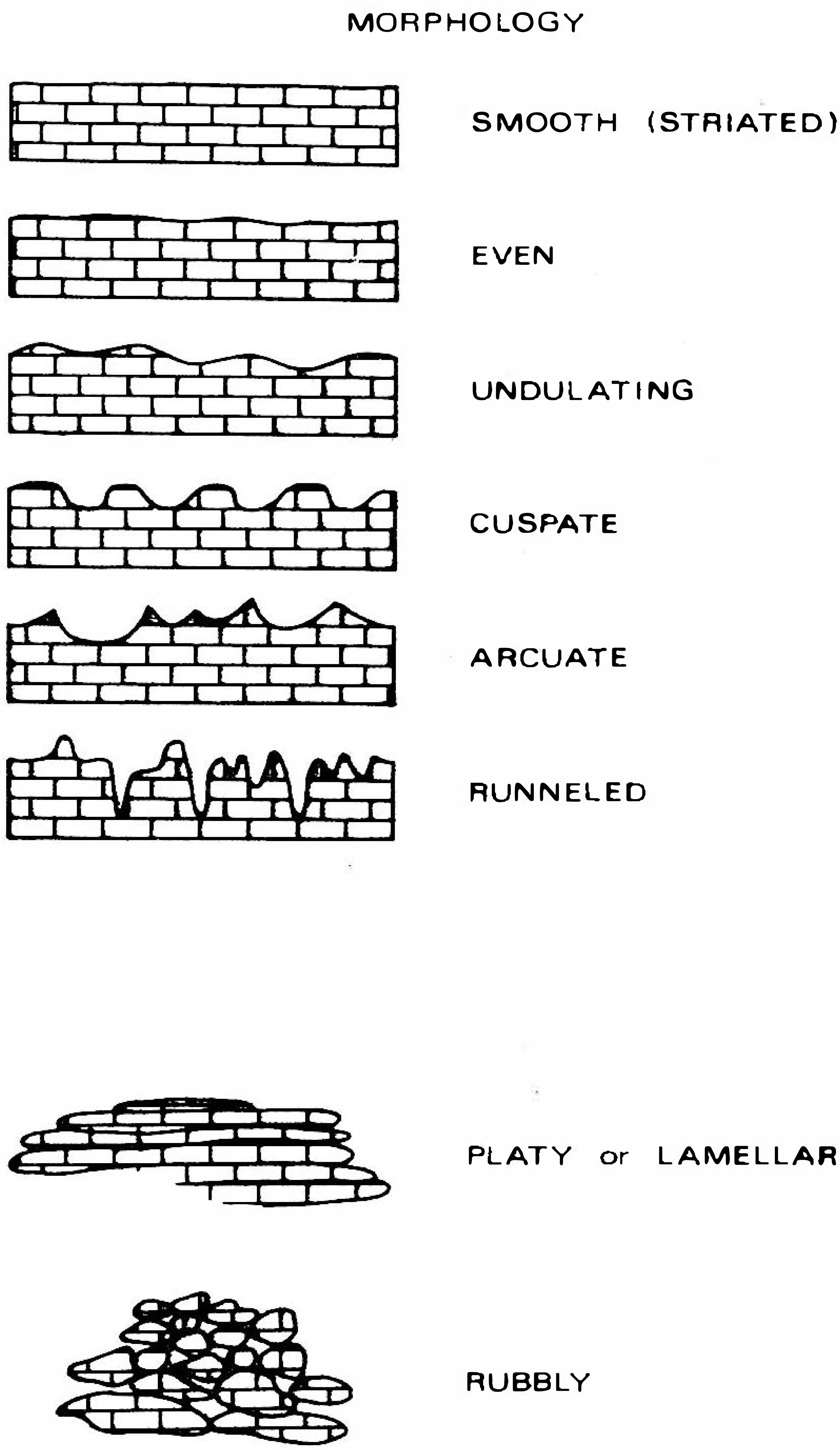

Fig. 2. Morphology types.

III Variations in surface form produced by lithology

a) Platy surfaces associated with stylolites.

b) Rubbly surfaces associated with weak, fossiliferous and rubbly limestones.

These lithological forms can dominate the influence of erosion regime on lithology and can account for many of the variations seen below one type of soil cover.

The above classification is a broad, intuitive one based on field observation. Further work is needed on variations under one soil type, especially in terms of lithological variations, before a more complete interpretation of morphology is possible.

SOIL TYPE AND EROSION RATE

In the literature there are few records on the rate of surface lowering under soil (see for instance Sweeting 1966). Such data that do exist tend to confirm that high erosion rates occur under peaty soils and acid soils in general, as might be expected from a knowledge of solution processes. Micro-erosion meters (High and Hanna, 1970, Trudgill 1972b and Trudgill and High in press) have been used by Newson (1970) to estimate subsoil erosion rates on the Durness magnesian limestone in Scotland. Some selected data are presented in tab. 2.

T a b. 2. Erosion rates under a soil cover (surface lowering)

Soil Type	Rate	Comparable Subaerial Rate	Source
Gravelly soil, pH 6.5	0.495 mm/yr	0.297 mm/yr	Newson 1970
do.	0.427 mm/yr	0.248 mm/yr	(micro-erosion meter) (Scotland)
Peat	5.0-8.2		Sweeting, 1966 (Yorkshire)

Erosion rates under non-calcareous soils thus appear to be over twice those on a soil free area. In both cases pedological data are lacking. In Co. Clare, Eire, erosion rate was estimated and soil studies were made in an effort to relate erosion rate more specifically to soil characteristics.

Erosion rates have been estimated by the insertion of limestone tablets in the soil under field conditions. Before emplacement the tablets were weighed to six decimal places. After field insertion of 18 months they were reweighed and erosion rates were calculated on a weight loss basis. Since the surface area of the tablets and the density of the limestone are known it is possible to express the rate of erosion in terms of surface loss in millimetres. The weight loss is converted to a volume loss (Volume = weight divided by density) and the volume loss is distributed over the surface area of the cylindrical tablets. In this way an erosion rate equivalent to mm/yr can be estimated. (The method is also used and described in Gams, 1969, Newson, 1970, Newson, 1971, Trudgill 1972b and c and Trudgill and High in press).

At each site of tablet insertion the soil profile was studied. Samples of soil were taken and analysed for % calcium carbonate and pH. Soil type, vegetation and depth of tablet insertion were also noted. Water samples have also been collected from the study sites. These were analysed for solution load of calcium carbonate. Aggressiveness was measured by pH change (Picknett, 1964) rather than by titration (Stenner, 1969) as the sample volumes were too small to be used for two titrations. The data on erosion rates and soil characteristics are reported in tab. 3 and are illustrated in fig. 3.

T a b. 3. Erosion rate and soil type (tablet erosion)

(Samples for analyses immediately above active site of erosion - see fig. 3 and tab. 4)

Soil Type	Vegetation*	% $CaCO_3$	pH	Depth**	Erosion rate (mm/yr)
Acid brown earth	Festuca-Agrostis	0.02	6.0	15 cm	0.0084 - 0.02534
Humus rendzina (1)	"Herb rich mat"	2.0	7.0	4 cm	0.00473 - 0.00502
Humus rendzina (2)	Thymus	0.1	6.5	5 cm	0.00269 - 0.00558
Calcareous brown earth	Sesleria	11.0	7.9	12 cm	0.00012 - 0.00136
Peat Bog	Calluna	0.00	4.5	35 cm	1.8372 - 5.2976
Limestone ranker	Calluna	0.00	7.5	30 cm	2.9327 - 5.3268

*Nomenclature: Clapham, Tutin & Warburg, 1962.

**Depth of whole profile (see fig. 3 for erosion rate and depth).

***Mixture of Sesleria, Helianthemum, Plantago, Thymus, Briza and Hieracium.

% $CaCO_3$ on a Collin's Calcimeter (Bascomb 1961).

pH by electrometric laboratory analysis (sticky point on air dried soil).

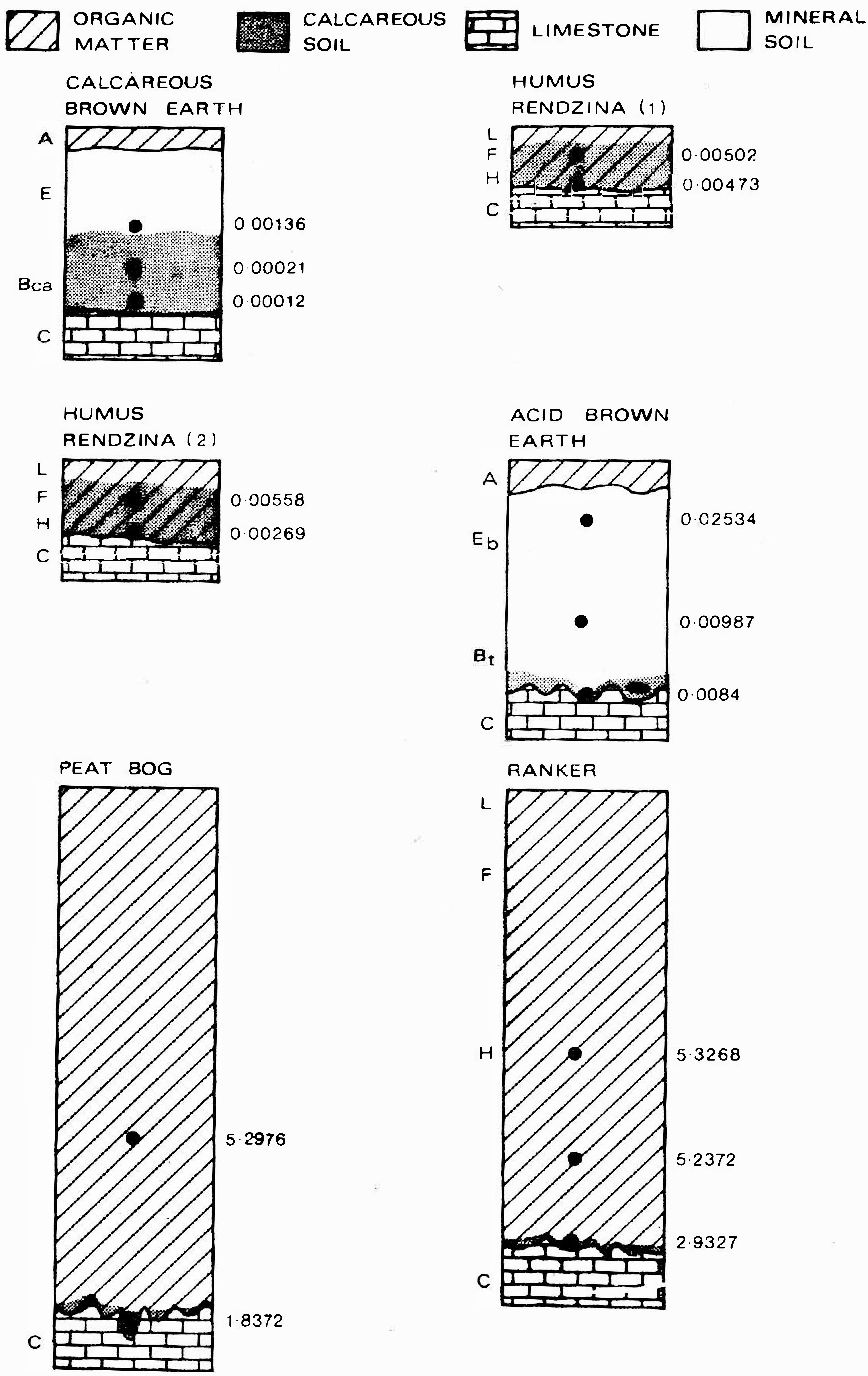

Fig. 3. Erosion rates in soil profiles (rate in mm/yr).

Erosion rate increases from a calcareous brown earth to acid brown earth. Of the organic soils, the rate increases from humus rendzina to peat soil. Thus erosion rate is highest in those soils with a low calcium carbonate content, a low pH and a high organic matter. When it comes to explaining individual differences, rather than overall trend, the matter is a little more difficult.

There is a relationship between erosion rate and percentage calcium carbonate in the soil (fig. 4) but this is mainly a gross difference between the calcareous brown earth and the others. However, when the erosion rate is compared with the solution load and aggressiveness of the soil waters samples a clearer picture emerges. The erosion rate appears to be influenced by the aggressiveness of the water (fig. 6) and by the overall solution load (fig. 5), but there are insufficient data points to make a rigorous interpretation.

If the erosion rates for erosion at the active site of solution are studied (tab. 4 and as indicated in fig. 3) a more consistent overall trend may be seen. The active site of solution is defined as the upper limit of carbonate detectable on a Collin's Calcimeter (Bascomb, 1961).

T a b. 4. Erosion rate at site of active solution

Calcareous brown earth	(soil profile)	0.00136 mm/yr
Humus rendzina (1)	do.	0.00502 mm/yr
Humus rendzina (2)	do.	0.00558 mm/yr
Acid brown earth	(soil/bedrock interface)	0.0084 mm/yr
Peat	do.	1.8372 mm/yr
Ranker	do.	2.9327 mm/yr

These values show a better correlation with soil water aggressiveness than the overall range of figures do (see fig. 6).

CONCLUSIONS

The following present day erosion regimes can be identified as far as bedrock erosion (surface lowering) is concerned.

1. Protective - calcareous cover. Erosion rates .0001 to .001 mm/yr.

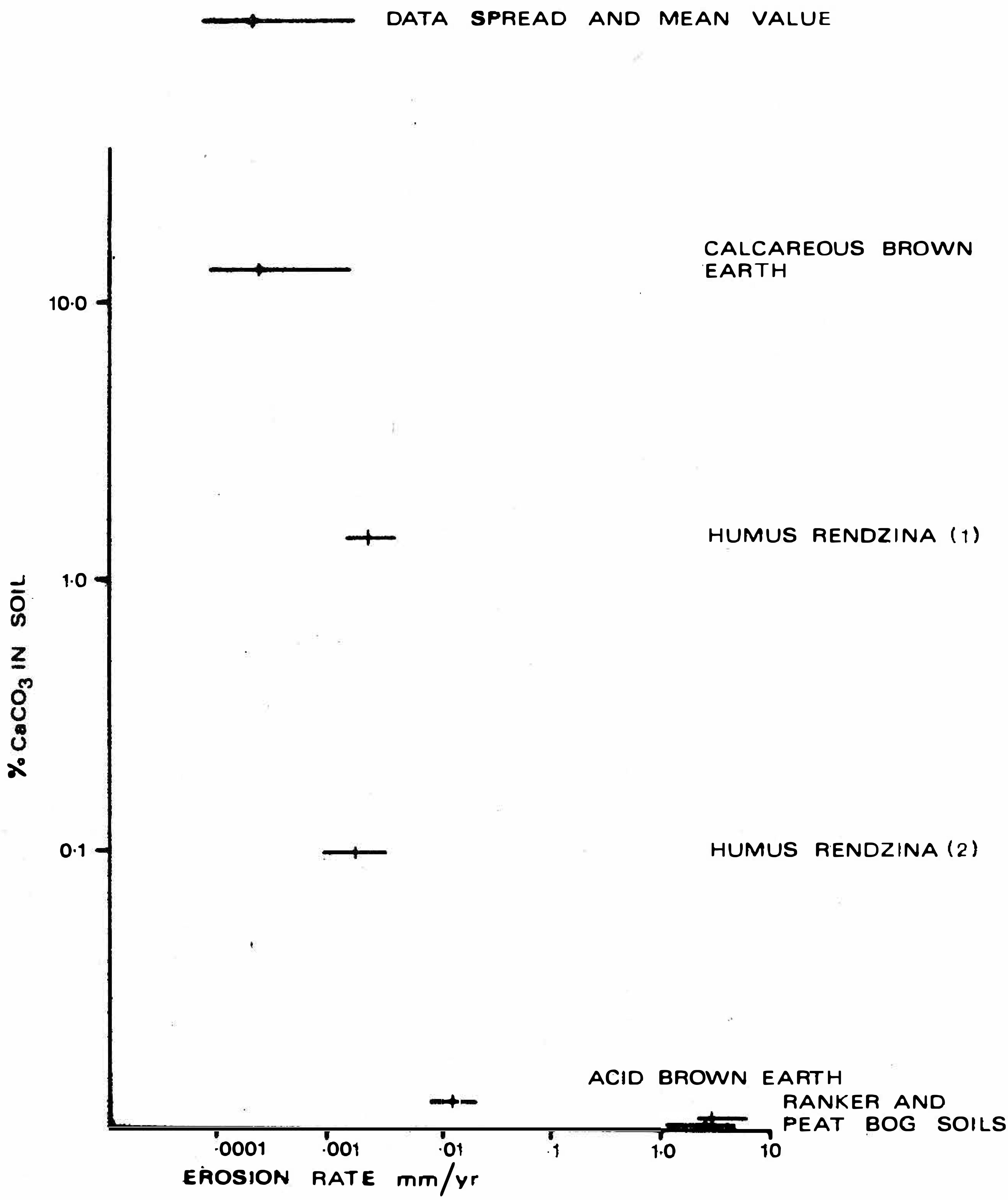

Fig. 4. Erosion rate and soil calcium carbonate content.

2. Pluvial - soil free limestone; erosion by <u>rain</u> water <u>and</u> lichens. Erosion rates .001 to 0.3 mm/yr.

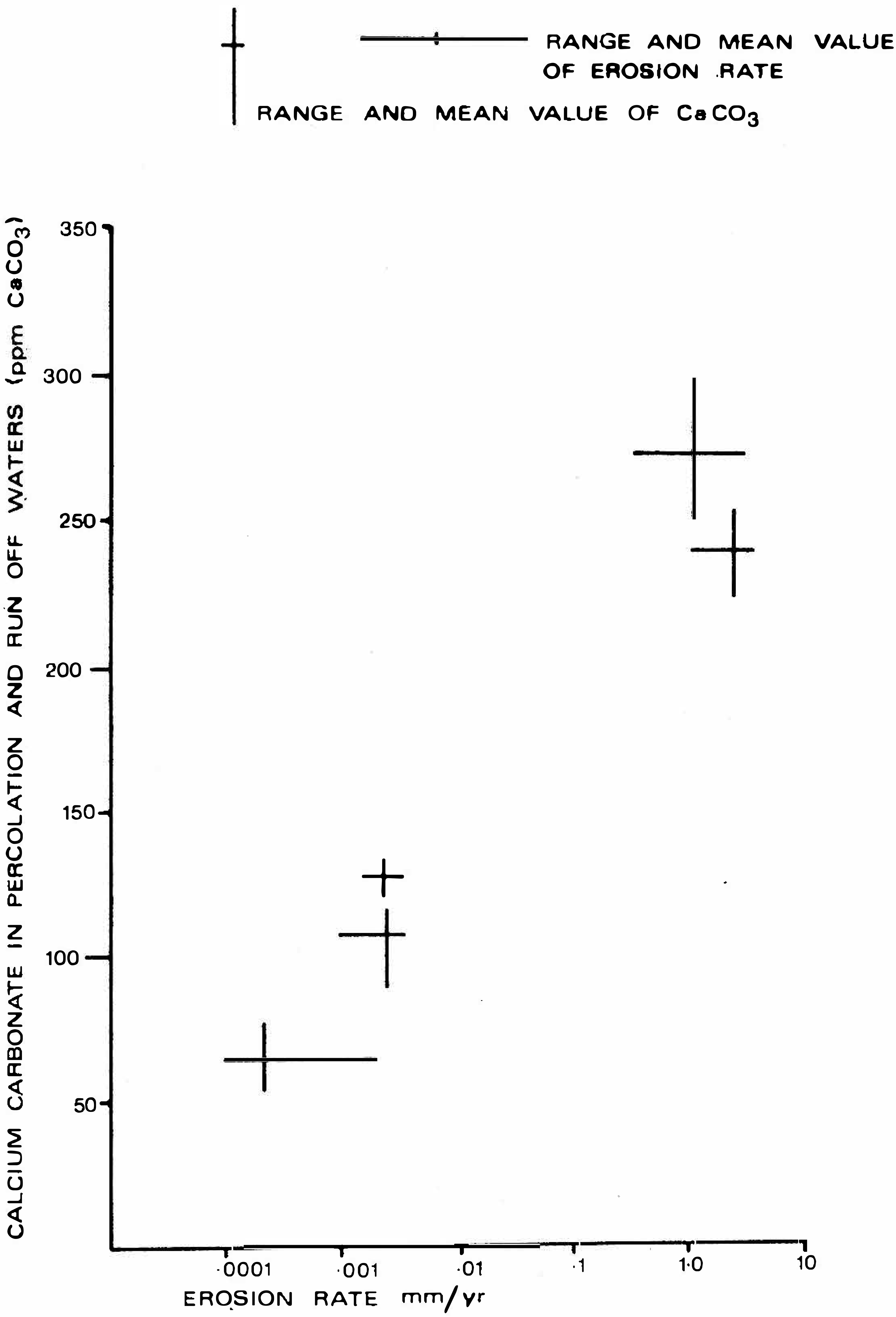

Fig. 5. Solution load and erosion rate.

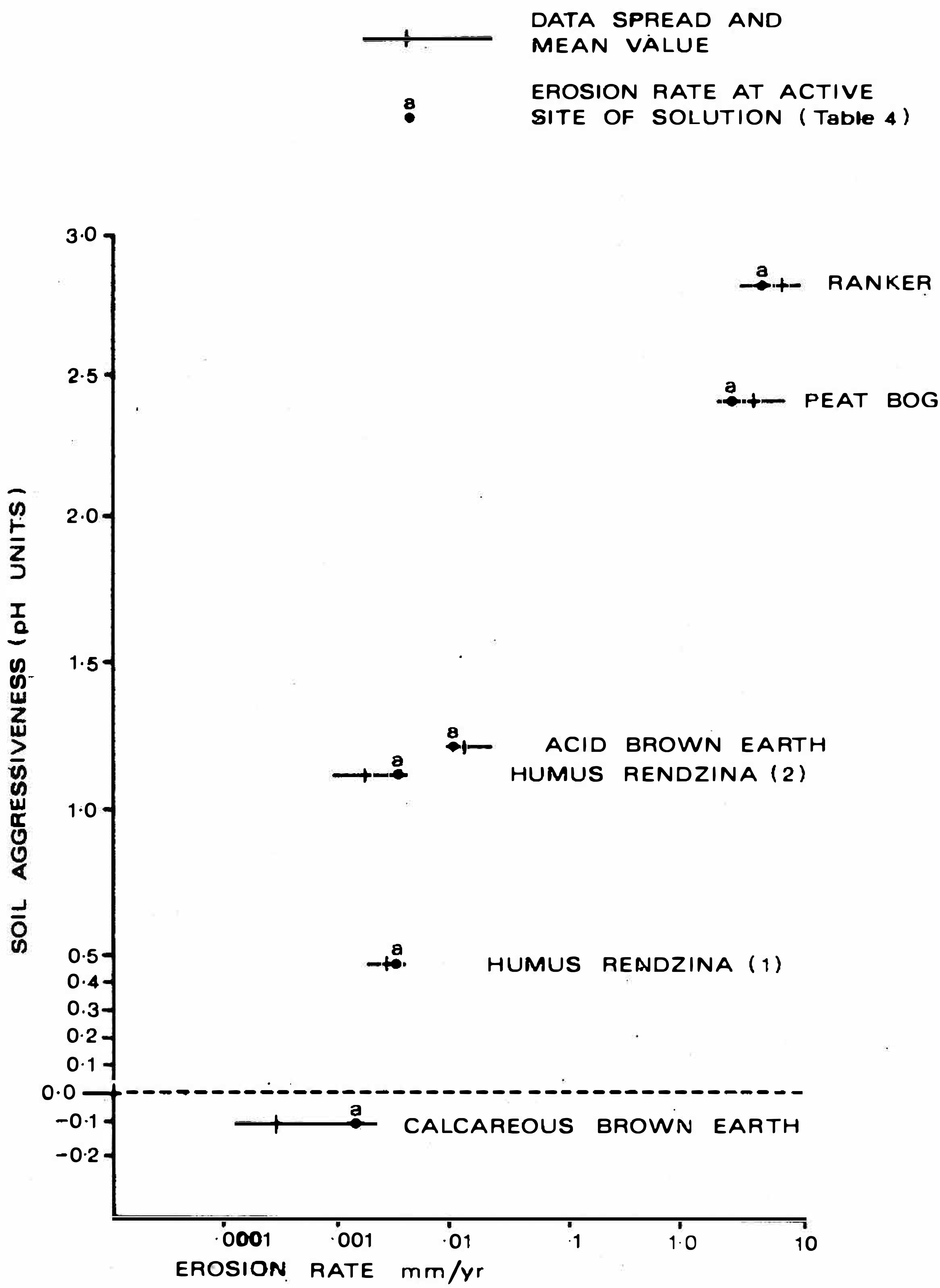

Fig. 6. Erosion potential and actual erosion.

3. Pluvial Enriched - Aggressiveness of rain water enriched by hydrogen ions and carbon dioxide from the soil. Acid soils (including those thinner soils with low water retention). Erosion rates .001 to 1.0 mm/yr.
4. Corrosive Soaking - The limestone is soaked in permanently aggressive water. Acid peaty soils, including peat bogs. Rapid solution, bedrock decalcification. Erosion rates 1.0 to 10 mm/yr.

From regimes 1 to 4 erosion rate and bedrock dissection increase.

From this paper it is argued that clint morphology (degree of dissection) is adjusted to the present erosion regime and the rapidity of the erosion rate. The erosion rate is adjusted to the erosion potential. More work is needed on the role of soil type to elucidate the influence of the spatial variability of soil. Such work and detailed work on lithology would consolidate knowledge of the role lithology in explaining differences of morphology within one soil type.

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Ba 045

ERDFALL - FORM - UND VOLUMENBERECHNUNG ALS GRUNDLAGE ZUR ERFASSUNG DER ZUSAMMENHÄNGE ZWISCHEN ERDFALL UND GELÄNDE

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A b s t r a c t. Die Annäherung der Erdfallform durch die allgemeine Parabel ermöglicht eine einfache Kennzeichnung für Form und Volumen. Die damit in einem bestimmten Gebiet erfassten Erdfälle werden statistisch und mit ihrer geologischen Umgebung verglichen.

1. KENNWERTE DER ERDFALL-FORMEN

In der Literatur ist es üblich die Form der Erdfälle (EF) zu beschreiben, wie z.B. schüssel- oder brunnenförmig oder diese durch Höhenlinien bzw. Schnitte zu charakterisieren [1 ... 4]. Für bestimmte Untersuchungen ist es vorteilhafter die Erdfallform in Kennzahlen zu erfassen. Mit Hilfe dieser Kennzahlen lassen sich statistische Untersuchungen oder andere Vergleiche aussagekräftiger durchführen.

Im folgenden wird die Form eines einzelnen EF aus seiner Höhe h und dem Radius r in einer senkrecht stehenden Schnittfläche dargestellt. Zur Veranschaulichung ist in Abb. 1 ein am Hang liegender EF mit seinen vertikalen Schnitten dargestellt. Bei ungestörten EF sind die Halbschnitte, abgesehen von den Randhöhen, annähernd deckungsgleich, bilden also eine einheitliche Kurve. Es zeigt sich, dass sich diese Kurve gut durch die allgemeine Parabel annähern lässt:

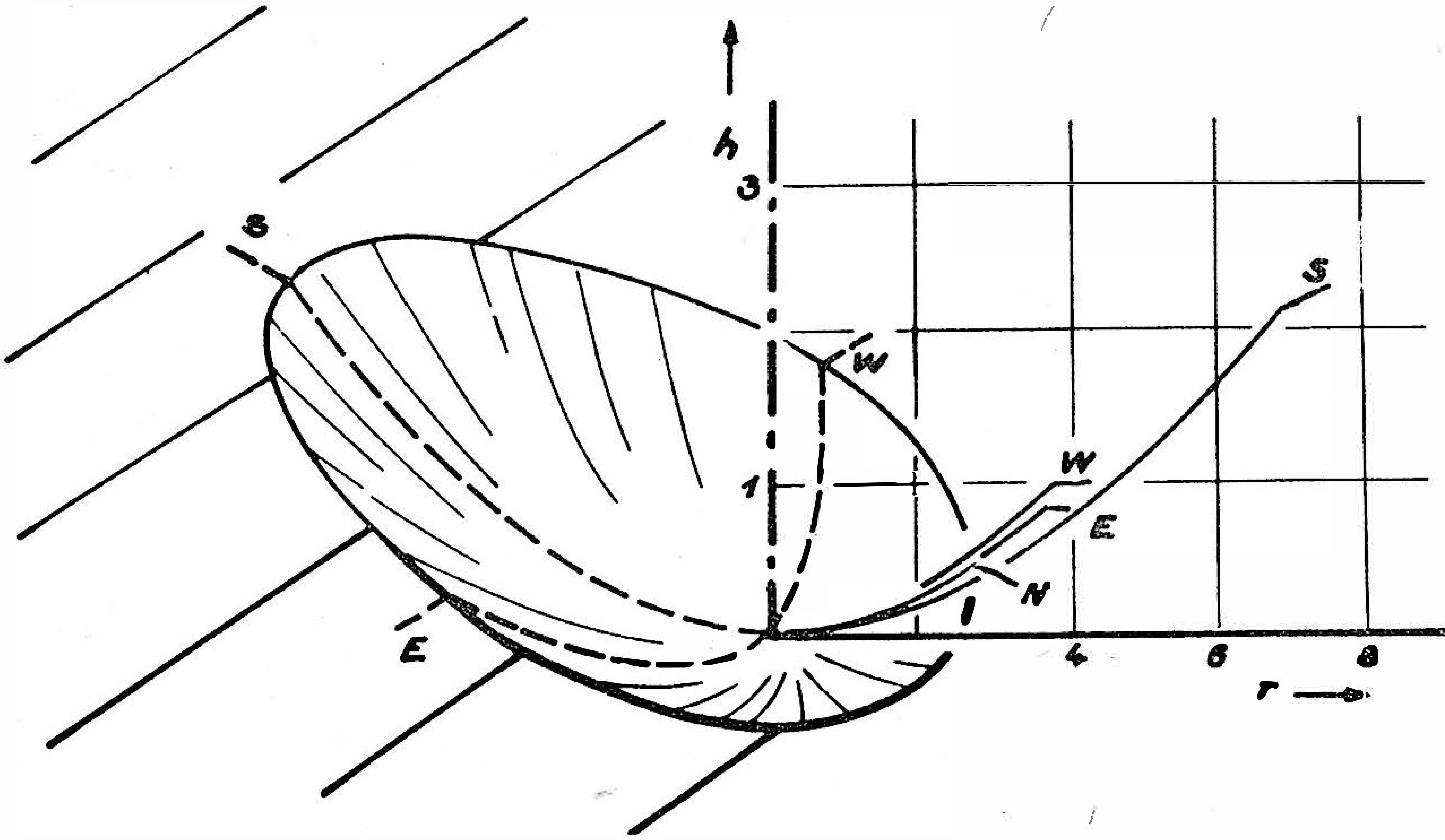

Abb. 1. Darstellung der Erdfall-Form durch Halbschnitte.

$$h = a \cdot r^b \qquad \text{mit} \quad a = \frac{1}{R^b}$$

h = Höhe
r = Radius
b = Durchbiegung der EF-Wand
a = normierende Konstante

Abb. 2 zeigt diese Funktion für R = 20 m dargestellt. Der Parameter b d.h. die Durchbiegung zeigt deutlich für den Wert 1 den trichterförmigen, meist aktiven EF, dessen Zentrum dann die fliessenden Lockermassen abzieht. Grosse b-Werte (b . 4) weisen auf junge EF hin, deren Einbruch noch nicht verschliffen wurde. Die Mehrzahl der EF liegt bei b = 1,5 ... 2,0.

Abb. 3 zeigt als Beispiel die Annäherung an ein über 20 m hohes und 45 m langes Halbprofil eines Doppelerdfalles mit Abweichungen, die kaum über 50 cm zwischen den gemessenen und den aus 2 Messdaten errechneten Werten liegen.

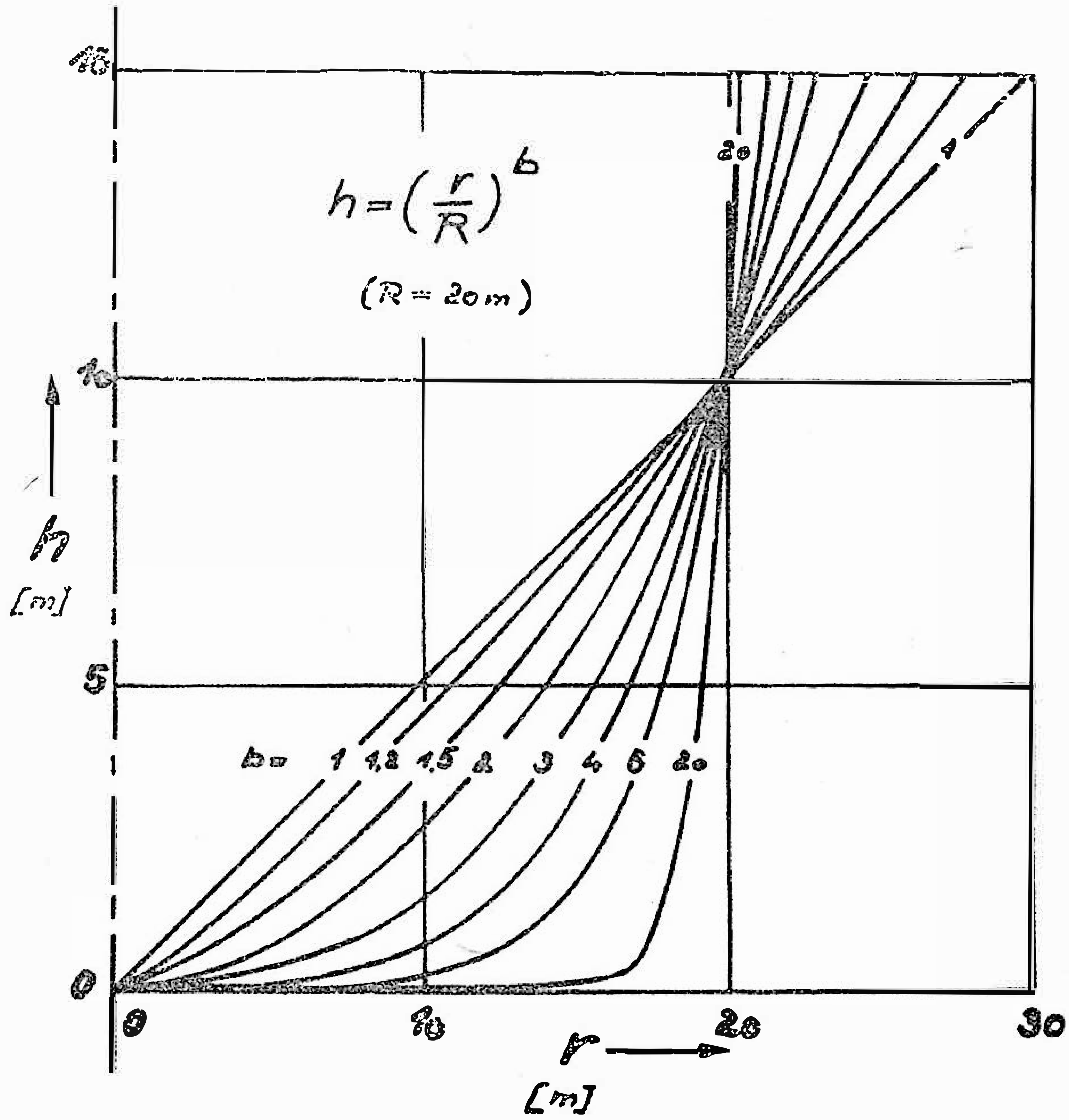

Abb. 2. Änderung der parabelförmigen Näherungsfunktion durch Variation der Durchbiegung b als Parameter.

2. VOLUMENBESTIMMUNG

Ausser der Form ist das Volumen des EF eine wichtige Kenngrösse. Dazu wird die EF-Höhe h_o als die senkrechte Höhendifferenz vom tiefsten zentralen Punkt des EF bis zur ehemals unverbrochenen Oberfläche angenommen. r_o ist der mittlere Randradius des EF.

Das Volumen wird nun durch einen Kegel angenähert:

$$V_k = r_o^2 \cdot h_o \cdot \frac{\pi}{3}$$

Steigend mit der Durchbiegung b und der Schräglage am Hang entsprechend $\frac{r_i}{r_a}$ muss das EF-Volumen V durch folgende Korrekturglieder vergrössert werden.

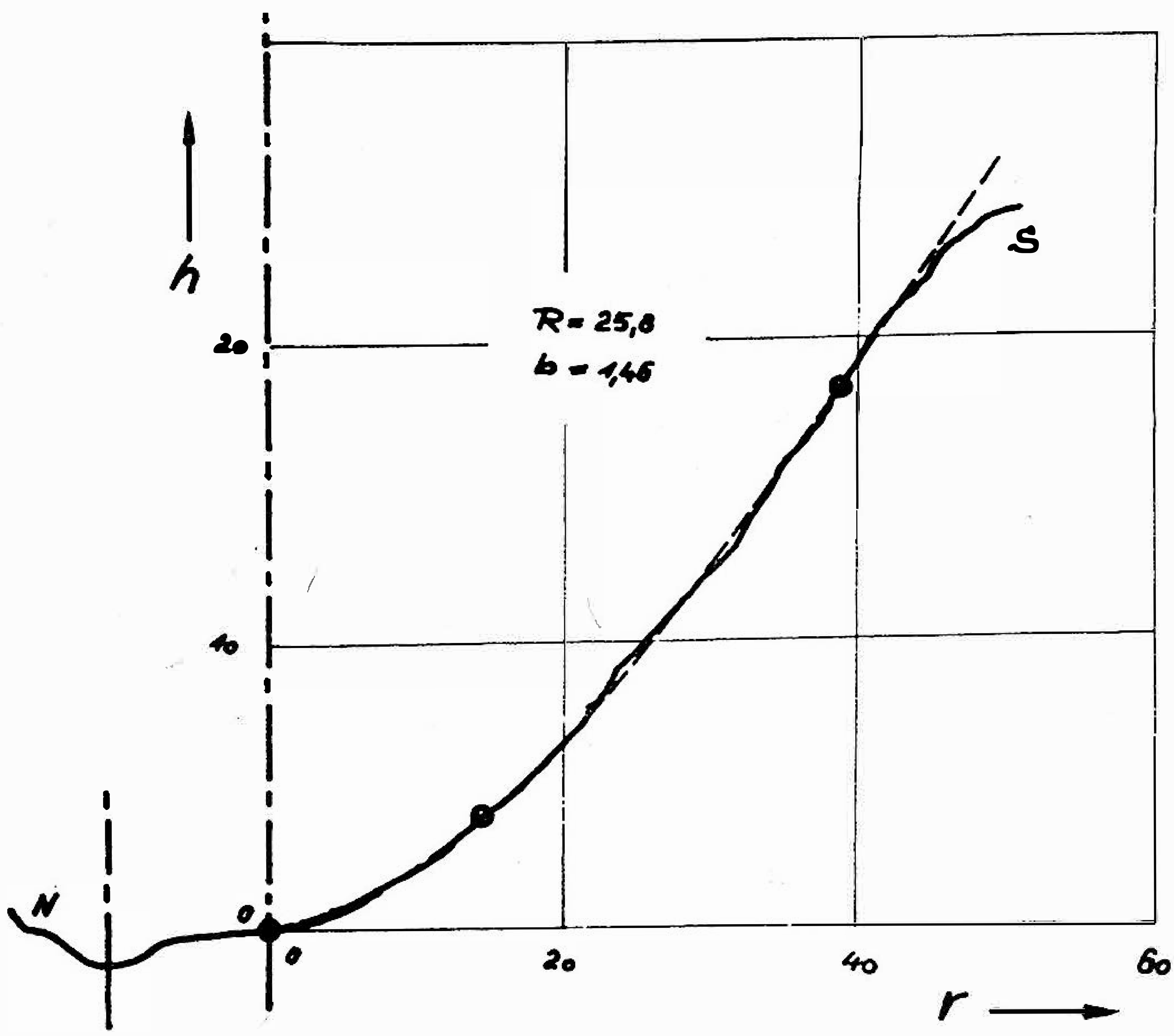

Abb. 3. Beispiel der günstigen Annäherung an einen (Doppel-) Erdfall mit 2 Messwerten (vom Ursprung gemessen). Abweichungen im Durchschnitt kleiner als 0,5 m.

K_b ist der Korrekturfaktor für die Durchbiegung:

$$K_b = \frac{V}{V_k} = \frac{3\ b}{b+2}$$

K_s ist der Korrekturfaktor für die Schräglage:

$$K_s = f\ (r_i,\ r_a)$$

r_i = kleinster EF-Radius
r_a = grösster " "

Da diese Funktion viel Rechenaufwand erfordert, wurde sie als Tabelle zusammengestellt.

Berücksichtigt man ausserdem das Volumen des abgerundeten Randes als Ring, bestimmt zu V_R, so ergibt sich die Volumenformel

$$V = r_o^2 \cdot h_o \cdot \frac{\pi}{3} \cdot K_b \cdot K_s + V_R$$

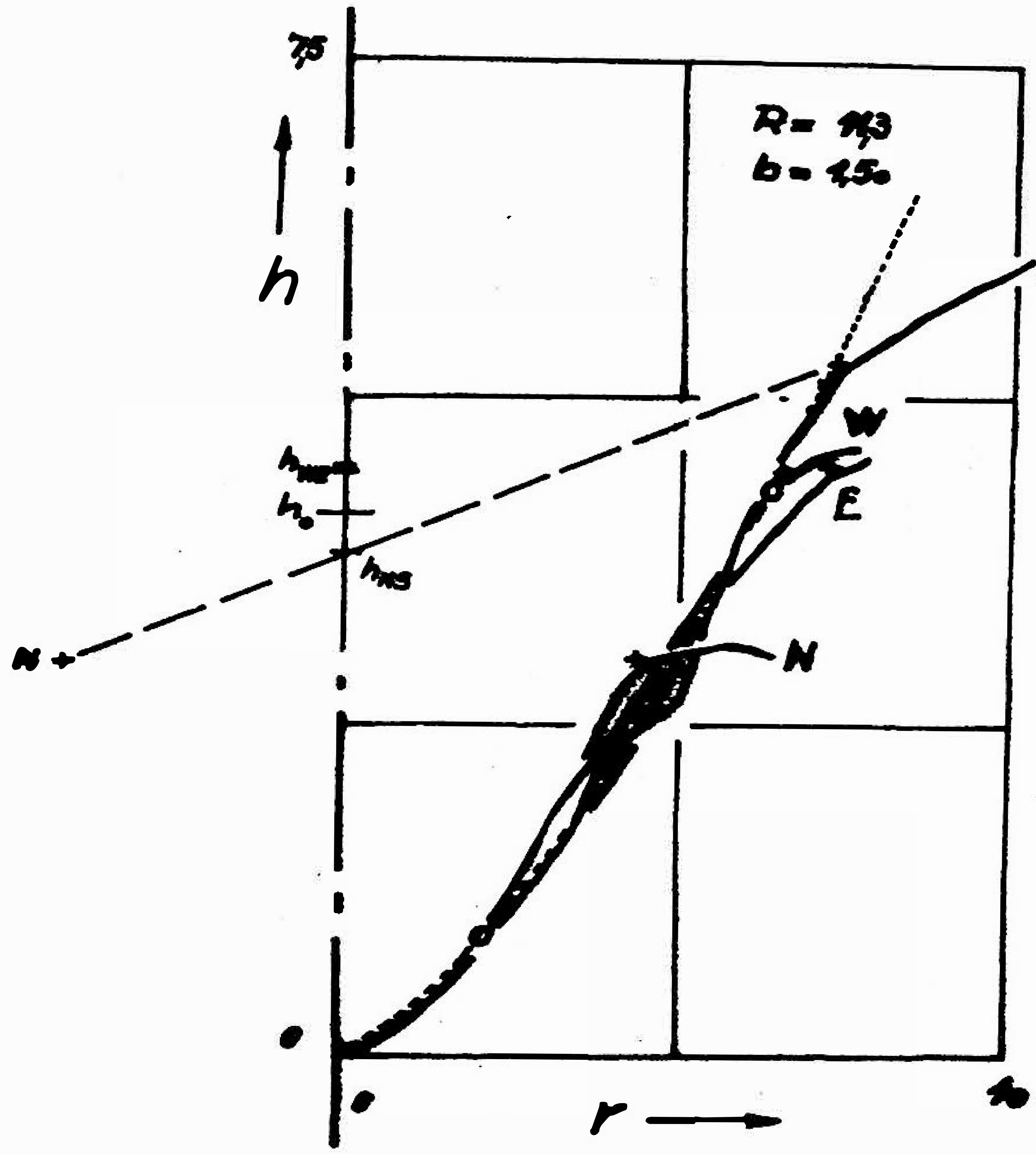

Abb. 4. Beispiel zur Höhen- und Volumenberechnung eines Erdfalls.

Als Beispiel für die zu erwartenden Grössen dient ein EF, dessen Halbschnitte in Abb. 4 mit den zwei Messpunkten und der Näherung aufgetragen sind. Das Gesamtvolumen ergibt sich zu

$$V = \overset{V_k}{140} \cdot \overset{K_b}{1,29} \cdot \overset{K_s}{1,13} + \overset{V_R}{1,5} = 205 \ m^3$$

Der Fehler der Volumenangabe kann zu 10 ... 20 % für EF mit geringen Formstörungen abgeschätzt werden.

Auf weitere Einzelheiten der Form- und Volumenberechnung wie Ableitung der Bestimmungsgleichungen, der Korrekturen, Rechenbeispielen an besonderen Formen wie z.B. die Tiefe von Wasserfüllungen, die Anwendung auf Erdfalltäler (Scheibenzerlegung) sowie über die praktische durchführung im Gelände u.ä.

muss an dieser Stelle verzechtet werden. Sie sind zur Veröffentlichung an anderer Stelle vorgesehen.

3. ERGEBNISSE VERGLEICHENDER BETRACHTUNGEN

Diese Berechnungen wurden in einem Teil des Südharzen Gipskarstes praktisch eingesetzt. Die dabei erhaltenen Aussagen können zu folgenden Ergebnissen zusammengefasst werden.

Die Form einzelner EF ist oft auf wenige Dezimeter genau mit der Parabel anzunähern, d.h. sie ist mit guten Kenngrössen erfassbar. Abweichungen sind leicht zu erkennen und weisen auf Störungen durch Nachbarn oder andere Besonderheiten wie Nachbrüche hin.

Der frische EF hat meist im Schnitt eckige Form, d.h. b-Werte 4. Mit der Alterung bzw. dem Verschleiss runden sich die Wände und führen zu b 2.

Aktive EF, d.h. EF mit Bodenabzug sind trichterförmig b = 1,0 ... 1,2, müssen aber nicht jung sein.

Zeigt der EF eine grössere Steilheit im Unterteil, so erfolgte meist ein Nachsetzen der liegenden Lockermassen oder eine neue Aktivierung. Die Nachbruchverhältnisse sind oft regional ähnlich, z.B. beträgt im mittleren Teil der Mooskammer der Nachbruch um 3 % des Ausgangsvolumens, im Ostteil des bewaldeten Gebietes herrschen dagegen 25 % vor.

EF im landwirtschaftlich genutzten Gebiet sind nach der angegebenen Methode kaum erfassbar, da ihre Ränder verfälscht sind. Sie weichen stark von der Parabelform ab.

In unmittelbarer Nähe grösserer EF findet man oft kleinere (hier Satelliten genannt). Diese sind wahrscheinlich durch die Zerrspannungen am Rand relativ schnell entstanden, daher oft steil. Da das Spaltenvolumen von Randklüften sehr bedeutend sein kann, wie im vorhergehenden Bericht von S. Pfeiffer bei der Bärenhöhle bzw. dem Pferdestall näher beschrieben wurde, führt deren Verfüllung dabei zu EF bis mittlere Grösse. Umgekehrt kann ein EF durch seinen Verbruch eine erhöhte Laugaktivität in unmittelbarer Nähe hervorrufen, die dann ebenfalls zur Satellitbildung führt. Dieser Unterschied kann von grossem Interesse für die Ingenieurgeologie sein. Leider ist es nicht möglich anhand der äusserlichen Satellitenform auf eine der beiden Entstehungsursachen zu schliessen.

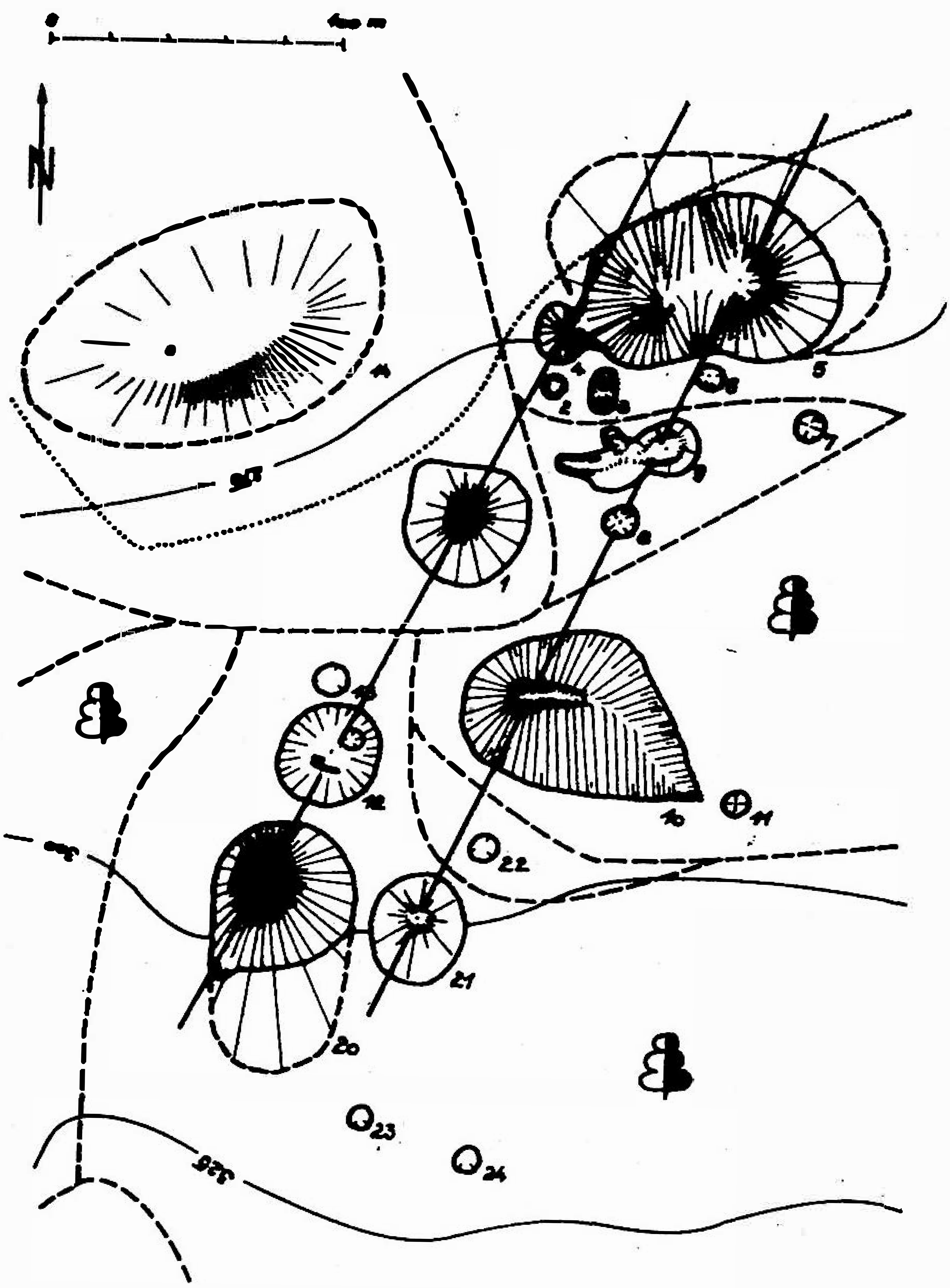

Abb. 5. Ausschnitt aus der morphologischen Karten der Mooskammer (Südharzrand) mit Zuordnung von Erdfällen zu 2 Reihen.

Interessante Zusammenhänge wurden mit Hilfe der Kenngrössen sichtbar, ~~wenn man~~ die Lage gleichartiger EF zu einander ~~betrachtet.~~ Abb. 5 zeigt die relativ sichere Zuordnung mehrerer EF zu 2 Reihen. Die linke Reihe umfasst mehrere offene aktive EF (b = 1), die im untersuchten Gebiet sonst nicht häufig sind. Die rechte umfasst EF mit ähnlichen Nachbruchverhältnis, wie sonst in dieser Umgebung auch kaum vorhanden. Eine Begründung für diese Reihenbildung z.B. durch Aktivitätswanderung von Ost nach West ist nicht beweisbar. Zusammenhänge mit tektonischen Störungen, ob über- oder untertage konnten nicht gefunden werden. Da

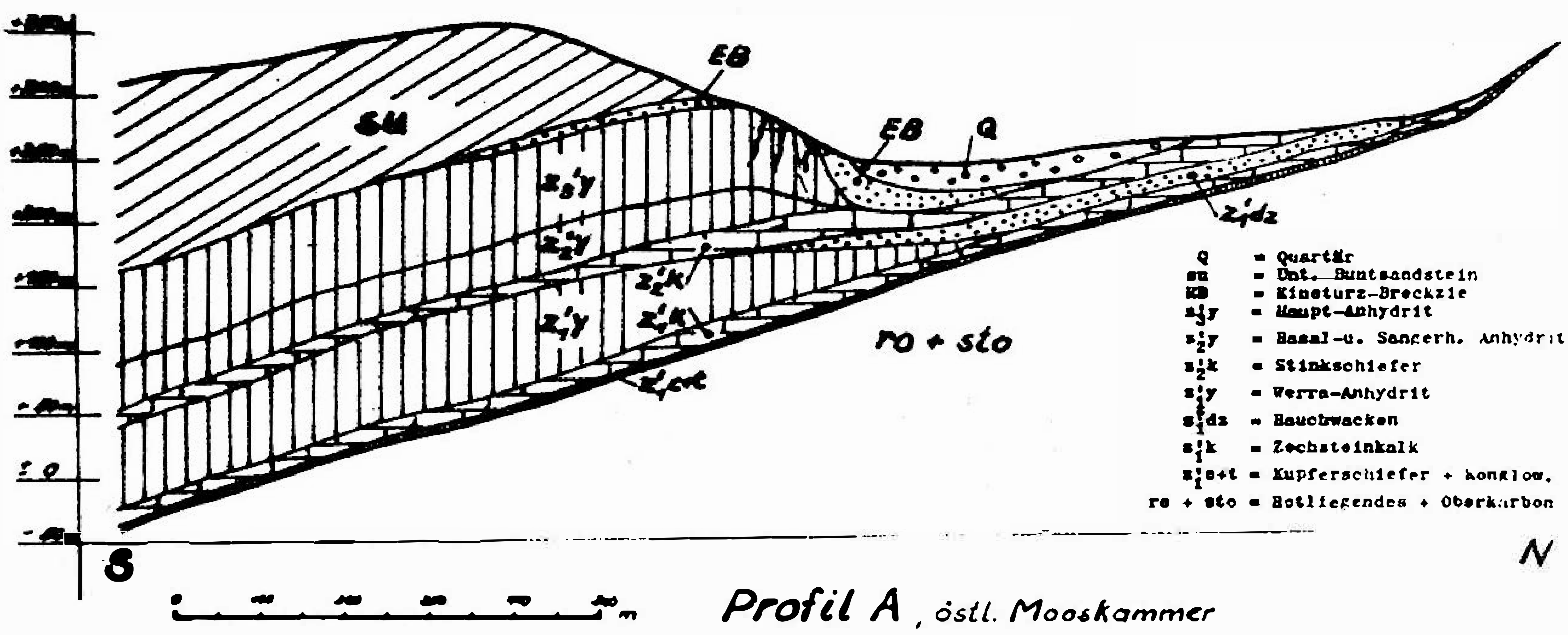

Abb. 6. Schnitt durch den Westteil des aufgenommenen Mooskammergeländes zur Erläuterung der Ablaugung.

die allgemeine Richtung der Störungen etwa um 45° nach links gedreht verläuft, ist kaum ein Zusammenhang zu erwarten, d.h. die tektonischen Störungen sind in diesem Gebiet zumindest für die EF-Bildung von untergeordneter Bedeutung.

4. ZUSAMMENHÄNGE MIT DER GEOLOGIE

Als Grundlage für die Geologie des beschriebenen Geländes diente die geolog. Neukartierung von Kriebel, 1962.

Im konstruierten Schnitt A (Abb. 6), durch den Westteil der Mooskammer gelegt, wird der Verlauf der lösenden, den Nordhang herabfliessenden Oberflächenwässer betrachtet. An der Grenze des Hauptanhydrits (Z_3' y) zur Einsturzbreccie (EB: Gipsbrocken und Laugreste des 3. und 4. Zyklus) versickert das Wasser bis zum Stinkschiefer (Z_2' k). Auf diesem wird das Wasser weitergeleitet und löst Teile der Einsturzbreccie und den Fuss des Hauptanhydrits auf. Die geringere Festigkeit der Einsturzbreccie kann zu EF an dieser Grenze führen. Da die EB aber gleichzeitig die Talsohle bildet, wurden die EF von der Talseite bei Hochwasser mit Lockermassen eingeschwemmt. Es blieben die sichelförmigen Reste der Bergseitigen EF-Wände übrig. Die EF müssen mittleres bis grosses Volumen gehabt haben, sind aber so verfüllt, dass eine Abschätzung nicht möglich ist. Da die nördlich liegenden Gesteine kaum löslich sind, ist die Grenze Einsturzbreccie/Anhydrit etwa auch gleichzeitig die nördliche EF-Grenze. Im östlichen Teil der Mooskammer werden die auslaufenden Anhydrit-Zungen vom Buntsandstein überdeckt, damit liegt die nördliche Grenze der EF dort im Buntsandstein.

Die Frontauslaugung an der Grenze Einsturzbreccie/Hauptanhydrit auf dem wassersperrenden Stinkschiefer führt zu einer Unterhöhlung und als Folge zu einem Absenken mit Brüchen parallel zum Hang so-wie zur Überkippung. Entsprechende Spalten sind fast im gesamten Gelände des Hauptanhydrits zu finden. Die allgemein mit etwa 10^0 gegen Süden einfallenden Schichten fallen an der Nord-Hangkante bis zu 4^0 nach Nord ein. Es ist zu vermuten, dass anfangs das Wasser eines kleinen Erosionstales in einen an der Hangkante liegenden Spalt (u.U. hervorgerufen durch einen Rand-EF) verschwand und einen neuen EF provozierte. Durch Abziehen von Lockermassen und damit seitliche Erweiterung seines Einzugsgebietes verhinderte er die Ausbildung eines Nachbar-EF. Der durch das Tal aktiv gehaltene EF trug zur Ablösung der Front verstärkt bei, d.h. schaffte neue Spannungen, Abbrüche bzw. Spalten, die zu einer Rückverlegung des Tales durch einen neuen EF in südlicher Richtung führte. Durch diesen sich mehrfach wiederholenden Vorgang ist die eigenartige Erdfalltal-Bildung erklärbar. Die obersten EF der Erdfalltäler liegen nur wenige Meter im Buntsandstein.

Die EF ziehen sich in der Hauptsache als ein Band von etwa 200 m Breite (Ausreisser bis auf das 4fache) durch das untersuchte Gebiet. Die EF-Dichte liegt bei etwa 50 ... 150 EF/km^2. Dabei ist die Dichte der mittleren und grösseren EF im Hauptanhydrit etwas grösser als im Buntsandstein.

Addiert man streifenweise das Massendefizit durch die EF so ergibt sich ein durchgehender Querschnitt von etwa 30 m^2 im östlichen Teil, 20 m^2 im mittleren Teil und bis zu 400 m^2 im westlichen Teil. Setzt man die durchschnittliche Breite des EF-Bandes zu 200 m (knapp!), so ergibt sich ein durchschnittlicher Massenentzug von nur 15 cm im östlichen, 10 cm im mittleren und maximal 2 m im westlichen Teil. Bei einer Schichtdicke des Hauptanhydrits von über 50 m sind diese Werte unbedeutend, auch wenn die vielen Erdfälle in der Natur sehr beeindruckend sind.

Durch diese Abschätzung ist zu vermuten, dass die Ablaugung des Anhydrits von unten in der gesamten Frontbreite und die darauf erfolgende Senkung des Hauptanhydrits u.U. in vielen Stufenbrüchen die

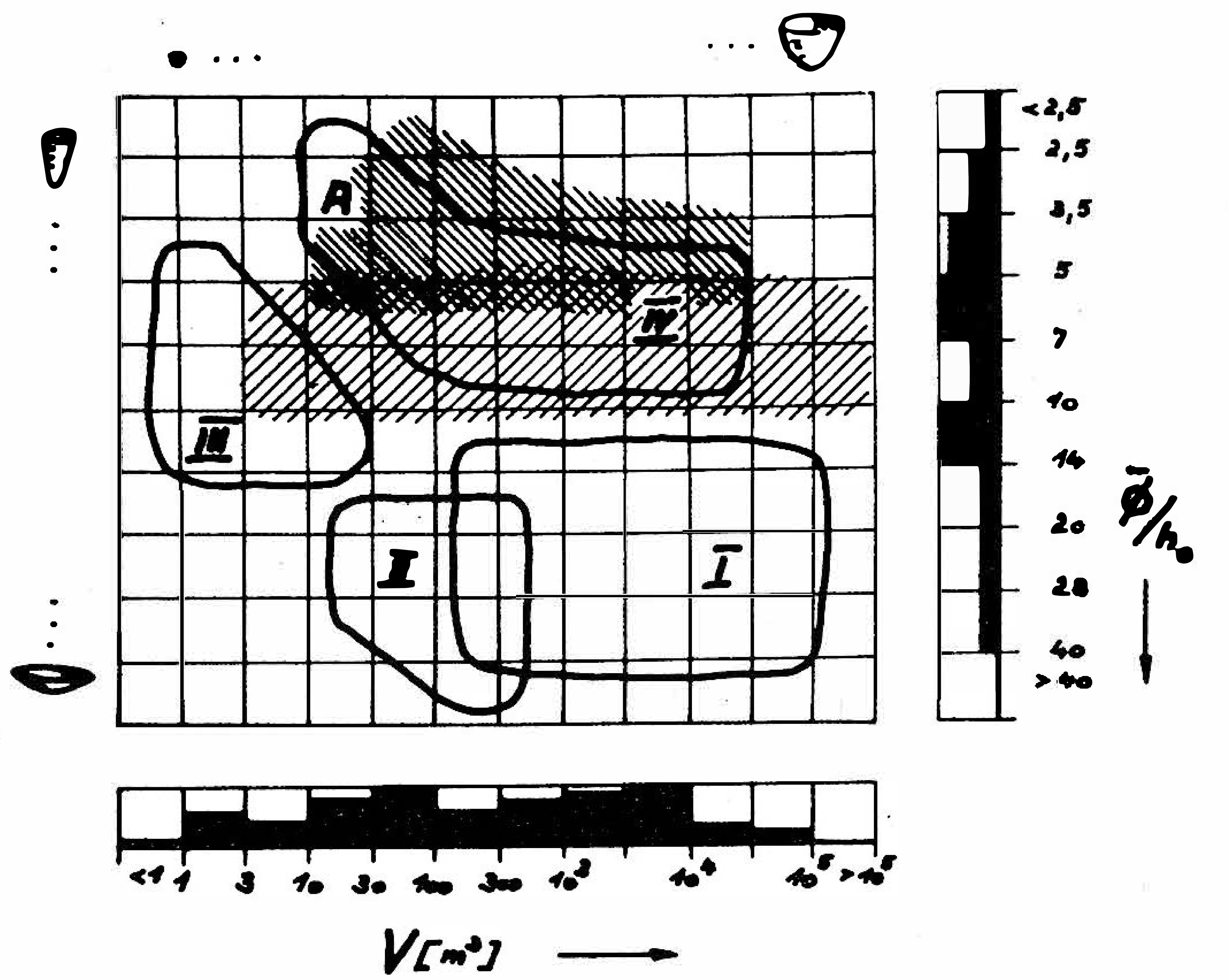

Abb. 7. Häufigkeitsverteilung der Erdfälle in Abhängigkeit vom Volumen bzw. dem Verhältnis der mittleren Durchmesser zur Höhe.
Verteilung der Erdfälle im Volumen-Steilheits-Diagramm unter Berücksichtigung der geologischen Bedingungen: SU = Buntsandstein: I landwirtschaftlich genutztes Gelände, II planes Gelände im Wald, III einzelne Erdfälle am Hang, IV grössere Erdfälle am Hang und A = Satellitenhäufung, EB Erdfälle im Gebiet der Einsturzbreccie, Z_3' y Erdfälle im Gebiet des Hauptanhydrits.

Hauptursache für die Herausbildung des Laugtales ist. Die Erdfälle haben zur Formung dieses Laugtales wenig beigetragen.

In einer Auswertung (Abb. 7) wurde die Steilheit der EF über ihn Volumen eingetragen, unter Berücksichtigung der Lage und des Oberflächengesteins. Als Ergebnis kann zusammengefasst werden:

I. Die mittleren und grossen EF im landwirtschaftlich genutzten Gelände (Buntsandstein) sind eindeutig flacher (im Durchschnitt etwa 4x breiter bei gleichem Volumen) als die des Waldes. Kleinere EF im genutzten Gelände sind nicht vorhanden bzw. "zugeackert".

II. Eine Gruppe mittelgrosser EF im Buntsandstein hebt sich vom Hauptanteil ab. Es sind flache EF, die etwa 2/3 der EF im planen Gelände des Waldes ausmachen.

III. Einzelne kleine EF im Buntsandstein haben einen mittleren relativen Durchmesser. Die EF in der Nähe grosser EF (Satelliten), die etwa gleiches Volumen haben, sind wesentlich steiler: A.

Vergleicht man mit den umgebenden (Oberflächen-!) Gesteinen, so sind die Durchmesser-Volumen-Verhältnisse d.h. das EF-Aussehen ähnlich. Die EF in der Einsturzbreccie sind durchschnittlich nur wenig steiler, die im Hauptanhydrit durchschnittlich etwas flacher als die Hauptmenge der EF, die den Buntsandstein (IV) durchbrochen haben.

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Ba 046

THE METAMORPHOSIS OF KARREN IN THE NORTH OF ENGLAND

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Abstract. This paper examines some of the evidence for sub-aerial modification of karren, especially of those generally assumed to have been formed beneath a cover of soil and/or glacial deposits. Special attention is paid to the modification of rundkarren by the development of kamenitzas, some of which have dissolved alternative outlets, provisionally termed plugholes, and leaving small "natural bridges". A shorter treatment is given to the modification of kluftkarren and rillenkarren (which are much less common).

The basic problem in geomorphology recognized by early workers such as Hutton and Lyell is that one must work backwards from the present to interpret the past. This is most difficult when one seeks an explanation of landforms which do not appear to be produced to-day. In examining modified landforms it is even more difficult to determine which are original features. The task is somewhat easier where changes that have occured during the late Pleistocene and Holocene can be directly associated with datable deposits. Comparative studies may also throw light upon such problems. It is also important that an agreed terminology should be used and one that does not group together forms of dissimilar detailed form and possibly origin. In the case of karren the author will follow the terminology of Bögli (1960) and Bauer (1962) and only use English equivalents where they may be directly related. The main types of karren to be examined will be rundkarren, hohlkarren and kluftkarren for which there is now widespread agreement that they were formed beneath a vegetated soil and/or glacial drift cover. This is the major premise from which most of the discussion flown. It is the modification of these forms after exposure which is the author's main concern.

The study of karren was carried out mainly within three areas of the Pennines and adjacent hills, namely the Peak District. N.W. Yorkshire and the low hills of North Lancashire adjoining Morecambe Bay. All three areas were glaciated, but much of the Peak District remained free of ice during the Last Glaciation and probably during the Penultimate Glaciation, using the terminology of Zeuner (1959), apart from minor invasions from the northwest. Much of the Peak District is blanketed with an acolian deposit derived from the surrounding Namurian rocks up to depths of 70 cm or more (Pigott, 1965). Sheet glaciers were active in the Yorkshire Dales and in North Lancashire during the Last Glaciation, removing complete beds of limestone. Many workers however consider that the action was not intense, though Waltham (1970) has advanced the view that the valley floors were extensively excavated during this period. The Peak District forms a plateau ranging between 250-350 m in height and with some hills up to c. 500 m, but the plateau is deeply dissected by river valleys up to 150 m deep and by a network of dry valleys. The general vegetation is cultivated grass for hay and pasture, with little bare limestone except on the valley sides and isolated karren blocks, e.g. at the head of Back Dale (south of Buxton) and Dowel Dale near the headwaters of the Dove. These show modified rundkarren, kamenitzas and relict rillenkarren. Deep kluftkarren associated with curved joints in reef knolls are to be found on the east bank of lower Dovedale resembling bogaz, but these are probably much older forms than are discussed in this paper. The precipitation of this area is on average about 1000-1500 mm per annum. In North-West Yorkshire, on the other hand, occur some of the best karrenfelder, especially upon the flat surfaces flanking the inner valleys. These are usually called clints in English when they stand up proud, with either flat surfaces of dendritic systems of rundkarren, bounded by kluftkarren, known as grikes. These rectangular, flat blocks are generally referred to as pavements, though it is better if this term is confined to the flat topped forms. Intermediate forms are hohlkarren with flat spaces between the karren. These plateaux at bout 400 m above sea level are partly covered by till and much of the latter is overlain by peat. Over much of the latter is an Eriophorum-Sphagnum bog fringed with Nardus stricta, with fescues, closely cropped by sheep, on thin soils, immediately over the limestone. During the past century there has also been a decline in the amount of juniper scrub growing in the grikes (Sweeting, 1966). This area experiences over 1500 mm of precipitation in the form of rain and snow on average. Westwards from this area there are isolated low hills rising up to 300 m such as Hutton Roof Crag, near Kirkby Lonsdale and surrounded by drift-covered Triassic deposits. Even further west and close to zhe coast are lower hills only some 150 m high surrounding small basins, some of which are true p o l j a. Hutton Roof Crag is unusual in possessing steeply dipping limestones which have been scoured by ice and reveal the best collection of r i l l e n k a r-r e n in Britain. The other north of Carnforth is covered by woodland, much of it of a scrubby or coppied character, growing from the exposed k l u f t k a r r e n, and between these the surface of the limestone is exposed in both bare pavements and pavements dissected by r u n d k a r r e n and h o h l k a r r e n. In addition there are large grooves cut across the beds which at first sight appear to be minor folds in the cleared beds, which Mr. Peter Ashmead, who first introduced the author to this area, considers to be of glacial origin.

In North Lancashire the r u n d k a r r e n are typically rounded in cross-section, both across the grooves and the interfluves. Some are part of complex dendritic systems draining towards the marginal k l u f t k a r r e n, but these are in the minority, simply branching systems are the norm and often there is a flat top between the rounded shoulders of successive karren. Where they appear to be little modified by exposure their long profiles are generally smooth and continuous downwards and they drain freely after rain with no pools remaining. Usually there is only a minor incision where the k a r r e passes into a grike; but where there is a parallel series with a short overland flow the interfluves change from round shoulders into sharp divides like r i l l e n k a r r e n, whilst retaining the rounded channel, e.g. at Throng End, north-west of Yealand Redmayne (see also fig. 1). However few of the r u n d k a r r e n retain the simple form which is taken to be the original one and which is revealed by removing turf and the associated soil. The main difference is that on immediate exposure the runnel is stained brown with humid acids.

The main modification is the formation of pools or k a m e n i t z a s at the base of the groove, usually roughly oval in form, sometimes with pointed ends, though in once case a triangular shape

Fig. 1. Rundkarren, near Hale Moss, North Lancashire, England, showing little modification other than a sharpening of the ridges. Faint rillenkarren appear on the sides of some of the karren.

was seen where a minor crack had been exploited by solution, and this crack formed the base of the triangle, with the apex pointing cownslope. Frequently the edge of the pool is crenelated and undercut and "strandlines" are to be found marking stages in drying out. Flat-bottomed pools are uncommon, such as Sweeting and Williams have reported from Ireland and Yorkshire. Often the pools appear to have exploited a narrow crack along the axis of the groove and produced a V-shaped cross-section. In some cases this had proceeded sufficiently far to provide an exit either into the next pool in the karre (fig. 2) or by a more direct route to an adjacent grike, sometimes even reversing the direction of drainage. The first type produces a small natural bridge a few centimetres wide, whilst the other forms a type of plug-hole for the basin (fig. 3). These drained pools were often found on blocks whose surface was badly pitted in an irregular fashion (see fig. 3). Some pools were found with water in them, others had dried organic deposits filling them upon in one case to a depth of 3-4 cm.

Fig. 2. Rundkarren, near fig. 1. showing modification by the development of kamenitzas, as well as "plu-holes" and small-scale "natural bridges".

Yet others had vegetation growing on soil, beneath which corrosion was no doubt active once more, helping to increase the depression. Miss Sweeting reports depressions in some of the Yorkshire r u n d k a r r e n and infers that they were original. It will be interesting to test this on newly exposed forms. Even if slight depressiond do occur, there is little doubt that they are extended by later modification by pool action. This is comparable to the effect of doline formation in a dry valley such as occurs in Jugoslavia.

R u n d k a r r e n are even commoner in Yorkshire, where R.J. Jones (1966) confirmed the close connexion between their formation and vegetated areas underlain by soils and glacial driftand showed conclusively that r u n d k a r r e n and k l u f t k a r r e n both passed under the drift from adjacent cleared areas. Miss Sweeting has also confirmed this. A more casual inspection by the author revealed a much less frequent occurrence of k a m e n i t z a pools and where they were found, they were much smoother in outline, a though often showing solutional undercutting. It would be of interest

Fig. 3. Rundkarren, close to fig. 3, with a complex "plug-hole" draining to a nearby kluftkarre. The general surface shows considerable roughening by solution and frost action.

to determine whether r u n d k a r r e n show any slope limits; such forms have been noted on slopes estimated to be of at least 15°, but most are on blocks with only a few degrees of inclination. In the Peak District r u n d k a r r e n are much rarer and only to be found on isolated blocks and these appear to be very degraded. In one case at the head of Back Dale they appeared to have a slope of c 30°, but were interrupted by marked basins filled with acidic vegetation. The adjacent interfluves were also pitted. The clearance of over-burden on the edges of quarries does not usually produce much beyond a general roughening, a though one old Geological Survey photograph shows marked "piping" developed in deep grikes in Millers Dale.

Modification of r u n d k a r r e n and h o h l k a r r e n by running water is more difficult to establish except on the edges and even here some authors, such as Bauer, suggest that such forms resembling r i l l e n k a r r e n, but with rounded grooves may form beneath soils or by water draining from soil in rundkarren. Some of the hohlkarren show sharp edges where they intersect the pavement surface instead of the normal rounded shoulders and this may be due to undercutting and retreat of the karre wall by lateral corrosion. Such forms usually have rather flatter floors as well. Dr Sweeting has also described runnels which appear to be formed by running water which cut diagonally across clint blocks. They are 50-100 cm wide, and up to 50 cm deep and may be up to 10-15 m long and examples occur near Borrins Moor Rocks near Alum Pot.

It is generally assumed that the original form of kluftkarren walls formed beneath a soil cover was smooth, though there are few reports of direct observations from freshly excavated sections. Most of the exposed sides show fretted features, roughly horizontal and etched out by solution. In other cases the slight depressions are slightly polygonal and are described as "cockling" (Sweeting 1966). These two forms are very common in Yorkshire on the sides of clint blocks standing pround above the surface. More clearly defined cockles have been found covering the roof and walls of Plas Heaton Cave, Denbighshire and these may be due to the action of water films condensing on the rock surface. Frost action is often mentioned in the literature but there is little angular debris below them, though the surface may be flaked by such action (Sweeting, 1972). In wintry conditions the lodging of snow in the grikes will tend to reduce the effects of frost. Rillenkarren can sometimes be seen on the sides of grikes, but these are rare and usually only very faint.

The rarest karren in Britain are rillenkarren and trittkarren, the latter only being reported from Ireland. Rillenkarren are best exposed on Hutton Roof Crag, Lancashire, on steeply dipping slabs, crossed by a diamond pattern of grikes. Williams (1966) has pointed to the apparently newer irregular grikes that cut across these karren and which indicate that they were formed after the grooves had been cut by running water since the sharp rills continue below the lip of the opening. Also the sides of the rillenkarren have been etched by solution, though on a smaller scale than on the sides of the clints. This seems hardly compatible with active use, again suggesting that these are fossil forms. An even more degraded form of rillenkarren was found on an isolated limestone block near Moscar Farm, Parsley Hay, Derbyshire, where the surface is covered by lichen, though the angular ridges and V-shaped rills remain distinct.

Perhaps the most difficult matter to resolve is whether the various karren attributed to solution below a soil and drift cover are still being exposed or covered over. R.J. Jones (1966) marshalls considerable botanical evidence to support progressive removal of the cover and Clayton (1966) puts forward a theoretical scheme, with supporting evidence for the entrainment of fine material in the grikes leading to localised surface lowering in the form of dolines or shake-holes and incipient grikes. Certainly examples can be found ranging from narrow fissures grass-floored passages wider than the clint blocks. In some of the latter cases the outlines of the grikes have become distinctly sinuous, or have become circular basins (R.J. Jones, 1966). Against this Dr Sweeting (1966) can produce direct evidence of grass creeping over pavements and of turf levels rising substantially in certain grikes around Ingleborough. Some of the r u n d k a r r e n adjoining drift are bounded, on the side away from the drift, by a selvage of flat-topped pavements as can be seen above Malham Tarn. Jones considers this to be the normal pattern, and suggests that the flat areas have remained uncovered for a long period. If this is accepted the one must ask why these flat surfaces are so little altered by sub-aerial erosion. Probably the flatness of these blocks, especially if they are almost horizontal, militates against concentrated flow and the production of runnels by water of low agressivity. A further complication is that in some of the Yorkshire areas such flat surfaces occur close to thin patches of drift which appear to be retreating. However, Marjorie Sweeting has evidence of such areas actually being recolonised by grasses. There is general agreement that they are relict features. In North Lancashire they are also common in an area where one gains the impression that the soil has been eroded in relatively recent times. That area also has a lot of angular limestone debris in the k l u f t - k a r r e n which passes into areas where the surface is composed largely of such material and in a few cases, as shown in fig. 1 this material also occupies some of the r u n d k a r r e n.

The author has attempted to review the evidence for the existence of fossil or relict karren in the Pennines and to indicate some of the features which may be taken to be modifications to the original forms. Of these, the most obvious is the development of k a m e n i t z a s in the floors of gently sloping r u n d - k a r r e n which may proceed sufficiently far to cause wholesale disruption of the grooves, and tending towards a much greater roughness and diversity of the micro-relief. Modification by running water is also present to some degree, though in the case of relict *rillenkarren*, these appear to be little used for surface run-off and are being modified but at a much slower rate than the *rundkarren*.

The writer would like to acknowledge his debt to Dr Marjorie Sweeting for her work in the Pennines, and above all for her quantitative contributions. He also wishes to thank Mr Peter Ashmead for introducing him to the Morecambe Bay sites and Miss Helen Warwick for help with translations from German literature.

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Ba 047

PSEUDO-KARST OF THE KLUTLAN GLACIER, YUKON TERRITORIES, CANADA

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A b s t r a c t. Pseudo-karst features of the Klutlan Glacier are the result primarily of the downwasting and removal of ice by melting. This development is contrasted to that of true karst on limestone by solution. The evolution of specific glacial pseudo-karst landforms is described, and it is concluded in general that the similarity of morphological forms of downwasting glaciers and downwasting limestone karst is the result of converging effects of the two different processes of melting and solution.

The Klutlan Glacier is located at the northern edge of the Icefield Ranges near the Yukon/Alaska boundary (Rampton, 1970). The terminal debouchment described here lies in an east-trending valley, the glacier and morainal debris occupying an area about 9.5 kilometers wide and 24 kilometers long. The elevation at the upper end of the area is about 1500 meters and at the terminous about 1000 meters. Maximum ice thickness in this area probably exceeds 100 meters. The upper one-third of the glacial debouchment has a free ice surface, while the lower two-thirds is covered with morainal debris representing at least six major periods of glacial surge marked by six arcuate morainal deposits differentiated by lineations, landform texture, lithology, limnology, and plant cover. The most recent glacial surge occured within the last 10 years, while the oldest represented by the moraines was probably more than 550 years ago. In the terminal debouchment area the free ice surface and each of the six major moraines have distinctive suites of pseudo-karst landforms. This pseudo-karst landscape evolves on the ice and the morainal debris through processes of 1) ice-melt by sunlight, warm rain, and warm stream waters that flow into the glacier from the valley walls, 2) the erosive action of flowing water, and 3) gravitational collapse.

Clayton (1964) describes "Karst Topography on Stagnant Glaciers" in the general area under investigation as though it is formed by general karst processes, i.e., by the solution of ice. However, study of the Klutlan glacier shows that these landforms evolve under the action of processes quite different from the solutional activity that is definitive of karst. The melting of glacial ice combined with the erosional activity of water flowing on and through the ice and morainal debris forms a pseudo-karst landscape that in morphological form greatly resembles true karst landscapes formed by the solution of limestone. In this paper I give brief descriptions of the evolution of some specific pseudo-karst features of the Klutlan Glacier, and conclude with the generalization that all similar landscapes on stagnant glaciers are pseudo-karst formed by ice-melt and erosional processes as described here.

In most general terms, glacial pseudo-karst landscapes evolve under the actions of processes that 1) remove all of the ice from the area, 2) remove large quantities, particularly the fine fractions, of morainal rock debris from the area, and 3) lower, transport, redistribute, and redeposit the morainal debris remaining within the area. The landscape change thus effected is spectacular. A mass 100 or more meters thick consisting of ice with a relatively smooth surface containing a scatter of as little as 0.5% or rock debris is reduced to a mantle of rock debris seldom as thick as 10 meters. In gross, therefore, there is a distinct analogy between an ice mass that downwastes to its bedrock floor to deposit there that portion of enclosed rock debris that does not melt and wash away, to a limestone mass that downwastes to a lower contact with impermeable beds or a base level to deposit at that level the portion of the insoluable fraction that does not dissolve and wash away. In karst landscapes near to or carried to completion, the most impressive landform is the vast plain or gently closed depression resulting from regional downvasting as the limestone beds dissolve almost completely away. Such a planar landform is also the greatest result of the melting away of glacier ice. It is therefore instructive for anyone studying morainal features left by valley (or continental) glaciers to imagine how the valley (or region) was once filled with ice, and then to think how the enclosed rock debris would belowered, sorted, transported, and some if it finally deposited on the valley floor as the ice downvastes by melting. During the Klutlan Glacier studies, such thought experiments (Watson, 1965) could be checked in the terminal debouchment area of the glacier where at least six stages of development are exhibited from that part of the glacier with a free ice surface in the upper regions to morainal debris resting on bedrock in the lower regions.

Limestone dissolves in water that comes from outside the limestone mass and that flows on beyond it, carrying away the solute. The most obvious difference between downwasting limestone and downwasting ice is that ice does not require an inflow of water either for reduction or transportation. Under the application of the sun's heat alone, H_2O in the form of ice will melt and flow away in the form of water. The first glacial pseudo-karst forms, then, are those formed by the melting of bare glacial ice. Ice melting differentially on the uneven surface of a glacier gathers in low areas where the water itself contributes to further melting down of the basin. Because the volume of ice is greater than that of the water derived from it, the basin can hold more water than is contributed by the ice melted out to form the basin. Such lake basins on the glacier surface have vertical walls and often greatly resemble collapse sinkholes. They enlarge laterally by undercutting the walls which collapse. In this way the basins coalesce and sometimes break through valley or crevice walls to drain. Most, however, appear to have drains into the ice out of their bottoms. They have flat floors, and when drained sometimes resemble karst windows or p o l j e s.

Water enters the ice mass from the surface through vertical shafts or g o u f f r e s. These are often called m o u l i n s in the literature of glaciology, which is an incorrect designation to the extent that it implies that the grinding or milling action of loose rocks formed the opening. These shafts generally originate from the initial vertical flow of water down fracture intersections or other zones of weakness. All have horizontal drains at the bottom which convey water into extensive cave systems that form along fracture and joint planes in the ice. Some shafts remain nearly circular in shape while others elongate into waterfall canyons. They attain depths of as much as 50 meters on the Klutlan Glacier. Great quantities of rock debris are swept into shafts to form cones of debris as high as 20 meters on their floors. As the general ice surface downwastes around such cones, they eventually stand as towers over the surface, the former ice walls that surrounded them having been melted away.

Surface streams on ice flow in deep, inset canyons, often with highly meandering courses because of initial sinuosities on the ice surface. The water slides around smooth curves, leaving symmetrical ice cones and cutting deep under the outer ice walls. Such streams sometimes cut beneath meander necks to form natural bridges, and some sink into the ice mass itself to become subsurface streams. In the upper region of the Klutlan debouchment where morainal debris is seldom thicker than 10 or 20 centimeters, a valley over 30 meters deep terminates abruptly in a wall of ice in which two large cave passages are exposed. The upper is about 6 meters in diameter, and the lower is some 6 meters wide and over 12 meters high. Both are floored with a pavement of semi-rounded gravel and cobbles. These cave passages are exposed from above 100 meters farther down glacier by downwasting. These exposed passages are probably typical of large cave systems enclosed in the Klutlan Glacier.

Water from two major tributaries, one flowing from each valley wall, flows down to the Klutlan Glacier and plunges into and under the ice. The swallow hole of the tributary from the south wall was investigated and found to narrow down to 3 meters wide and 0.5 meters high about 30 meters into the ice. The cave entrance is about 5 meters high and 10 meters wide, with ice collapsing actively all along the passage investigated.

Warm rainwater and tributary water must melt a considerable amount of ice. As it is channeled along cave passages in the ice, it must cut downward rapidly, forming canyon passages. Any vertical access to lower regions would be quickly utilized, so that a major amount of flow would soon reach the bedrock floor under the ice. Deposition of rock debris in cave passages with bedrock floors and ice walls and ceilings remain as e s k e r s after all the ice has been removed.

There are major water inputs into the Klutlan Glacier along the south side, but the major rise from the glacier is on the north side, which means that there is extensive flow under the glacier from south to north. The Generic River that drains the Klutlan Glacier is fed by several rises on the north side of the glacier, the largest being about 10 meters wide with an ice ceiling at water level (in July, 1971).

Where morainal debris is up to several meters thick on the

Klutlan Glacier, surface streams often sink into the ice as the valleys fill with sliding rock debris and the water course melts down deeper and deeper under the outer ice walls. One such cave passage was investigated to a depth of about 5 meters below the surface stream valley floor, and was observed to have an extremely unstable rock debris and iceblock wall along one side.

On the lower portions of the Klutlan Glacier where morainal rock debris reaches several meters in thickness, there are large numbers of dry closed depressions on hill tops that are formed as the ice melts away from under the mantle. Linear collapses occur because of water flow on the ice under the mantle or the intersection of cave passages by the downwasting of ice. Many lake basins are funnel shaped as their bottoms fall out through the melting of the underlying ice, causing the debris-mantled margins of the lake to collapse into the water. The undersurface outlets of lakes in the morainal debris of the lower portions of the Klutlan Glacier can often be traced along dry valley beds with many sinkholes along their courses. As the ice melts rapidly, some lakes fill and drain rapidly because of the vagaries of undersurface flow and debris collapse. Although many of these collapse and undersurface drainage features seem exactly to resemble true karst forms, it is perhaps worth remarking once more that they are primarily the result of the melting of a rock matrix (ice), not of its solution.

Ubiquitous topographic reversal is present in downwasting and depositional detail at every stage of ice melting until the ice is completely gone. In a gross sense, the gently concave morainal surface remaining on the bedrock floor is the result of a grand topographic reversal from the original gently convex glacier ice surface 100 or more meters above. Towers of morainal debris were originally deposited in the bottoms of vertical shafts in ice, and some linear mounds of debris were deposited on the floors of cave passages in ice.

As long as some ice core remains beneath the morainal rock debris, pseudo-karst landforms continue to develop. This is because it is easier for water to flow along and through ice than it is for it to flow over and through the rock debris. Water melts channels and caves rapidly in ice, disrupting surface drainage lines through undersurface capture and collapse. Only when all the ice has melted away do surface lines of drainage begin to be integrated, after which erosion destroys most of the pseudo-karst landform features.

In conclusion, the evolution of the pseudo-karst landforms on the Klutlan Glacier has been shown to be the result primarily of the melting of ice, a process quite different from solution which results in true karst landscapes. The similarity of the morphological forms of downwasting glaciers and downwasting limestone karst, therefore, is the result of converging effects of the two different processes of melting and solution.

NOTE

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Ba 048

KARST AND CAVERN DEVELOPMENT IN THE GROS VENTRE MOUNTAINS

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A b s t r a c t. The Gros Ventre Mountains are an east-west range measuring about 30 km by 10 km located in central western Wyoming. Elevations range up to 4000 m. Several areas of intensive karst development occur in the alpine and sub-alpine environments of this area. Solutional areas are of two distinct types: (a(flat or gentle sloping areas of nearly horizontal limestone with well-developed surface karst forms, and (b) areas of cavern development in steep, youthful valleys, usually where steeply dipping limestone borders a fault.

The Tosi Creek Basin, near the eastern end of the mountains, is a very well developed area of the first type. The bedrock is the Mississippian Madison formation consisting of pure limestone with a few thin, interbedded, impure limestone layers. Denudation is by solution except for frost shattering and mechanical transport of the impure layers. Karren develop on all exposed surfaces in forms which are dependent on slope and snow cover. They range in size up to K l u f t k a r r e n 12 m deep and over 1 m wide. No large caves are found to develop in this terrain.

The second type of area is represented where faults extend aoross valleys containing steeply bedded limestone immediately downslope from the fault. At the fault, the bedding is vertical. Cave passages are developed along joints parallel to the fault and are greatly modified by running water.

The Gros Ventre Range is located in the west-central part of the state of Wyoming within the Middle Rocky Mountain Physiographic Province. The range is centered near 43°30′ N, 110°30′ W and trends N60°W. The better-known Teton Range lies some 50 km to the northwest and the Wind River Range stretches to the southeast. The Hoback River forms the southwest boundary and the Gros Ventre River the northeast boundary of the Gros Ventre Range (fig. 1). The base of

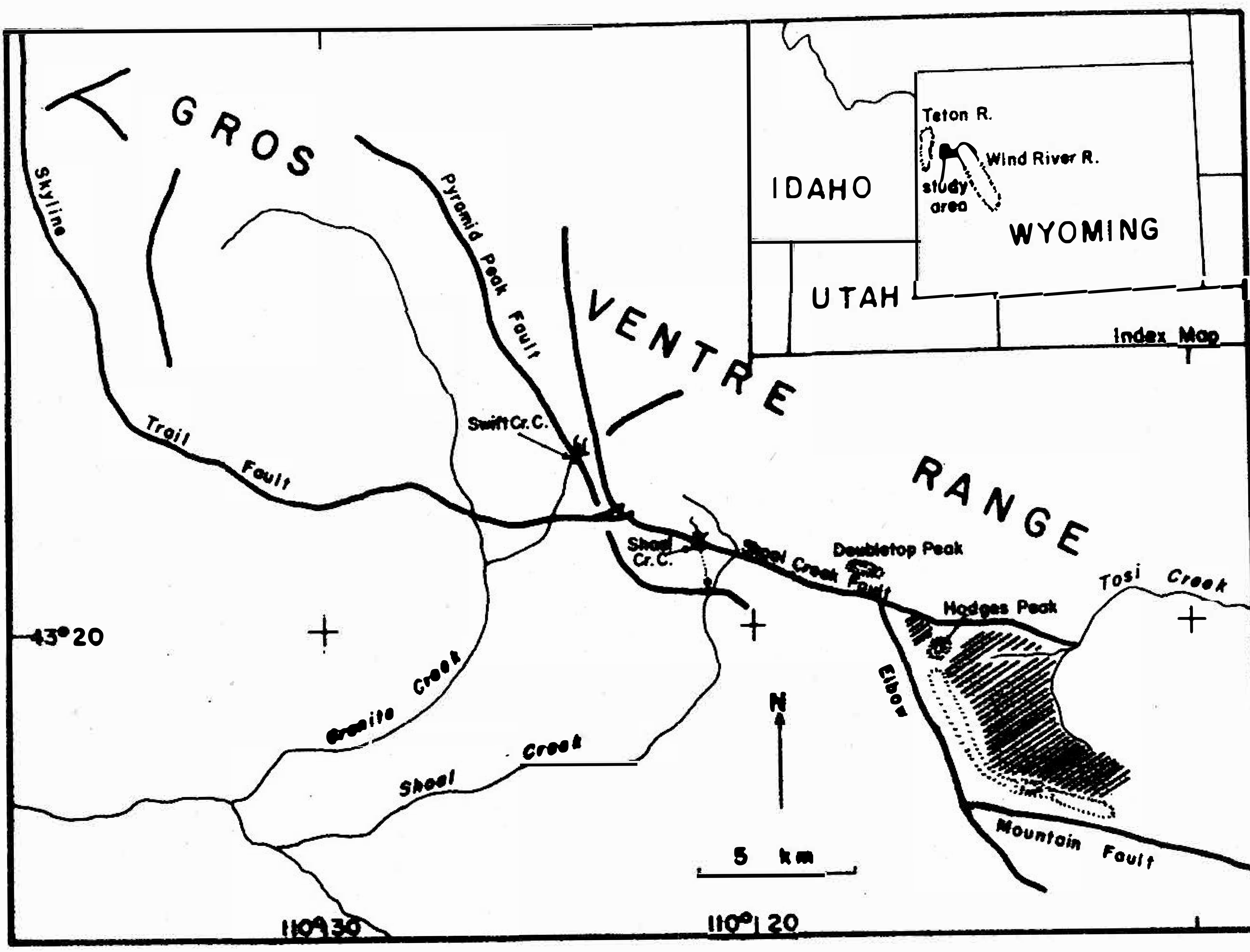

Fig. 1. Map of the study area. Heavy lines indicate faults, light lines indicate drainage. Tosi Creek Basin and the small basin near Hodges Peak are shown by diagonal shading.

of the Gros Ventre Range is at an elevation of 1800 m and its peaks rise to 3500 m.

The entire Gros Ventre Range is about 55 km long by 25 km wide; the central peaks portion, where the Precambrian and Paleozoic rocks are exposed is 10 by 30 km. Almost the entire area is national forest land, part of which is used for stock grazing. Rainfall (between 30 and 60 cm annually) is insufficient for cultivation without extensive irrigation.

Structurally, the Gros Ventre Range is part of an asymmetric anticline with one limb dipping gently to the northeast. The southwestern front of the range is bordered by major faults and is broken into three blocks by "trapdoor" faults (Nelson and Church, 1943; Horberg, Nelson, and Church, 1949). The locations discussed in this paper are near the boundary between the western (Skyline Trail) and the center (Shoal Creek) fault blocks, and on the eastern (Elbow Mountain) fault block (fig. 1).

Numerous studies have been made of the structural and stratigraphic geology of the range and its vicinity, but only one paper on its karst development is known to the authors. This paper (Keefer, 1963) discussing the Tosi Creek Basin prompted the present study. The only other paper discussing karst in western Wyoming is that by Stellmack (1968).

Karst development has occurred in several areas of the Gros Ventre Range, all of which may be classed as alpine or sub-alpine environments. Snow persists in sinkholes at least until late August. Solutional areas are of two distinct types: (a) flat or gently sloping basins of nearly horizontal limestones with well-developed surface karst forms, and (b) cavern development in steep, youthful valleys, where steeply dipping limestone borders a fault.

The Tosi Creek Basin, near the eastern end of the mountains, is a well-developed example of the first type. The basin slopes gently from an altitude of 3200 m at its southwest corner (near Tosi Peak) to 2800 m at its northeast corner where tosi Creek leaves the basin. The exposure of the limestone (Mississippian Madison group) covers about 3 by 5 km. The horizon found here is at the base of a paleokarst or solution-brecciated zone, indicating the top of the Lodgepole formation. (See Houlik, 1973, for a summary of the stratigraphy of this area.) The slope of the basin follows the dip of the limestone which is about 8° to the northeast. Superimposed on this slope is a local relief of usually 10 to 20 m (fig. 2).

The limestone consists of two types: (a) dark brown, medium to thick bedded, very pure (except for chert nodules and layers) (the "dark unit"), and (b) buff, very thin bedded, impure (the "buff unit"). Analysis of the dark unit shows only a trace amount of insolubles and about 2% dolomite. The buff unit contains on the order of 5% clays and quartz and a like amount of dolomite. Effervescence in HCl of the dark unit is very strong, that of the buff unit is slight and very slow to start. Bulk permeability and porosity of the buff unit is significantly greater than that of the dark unit. Denudation and surface expression of the two rock types also differ.

The buff unit weathers principally by mechanical means, no solution features being present. Judging from the character of the accumulations of broken fragments of this rock and the angularity of

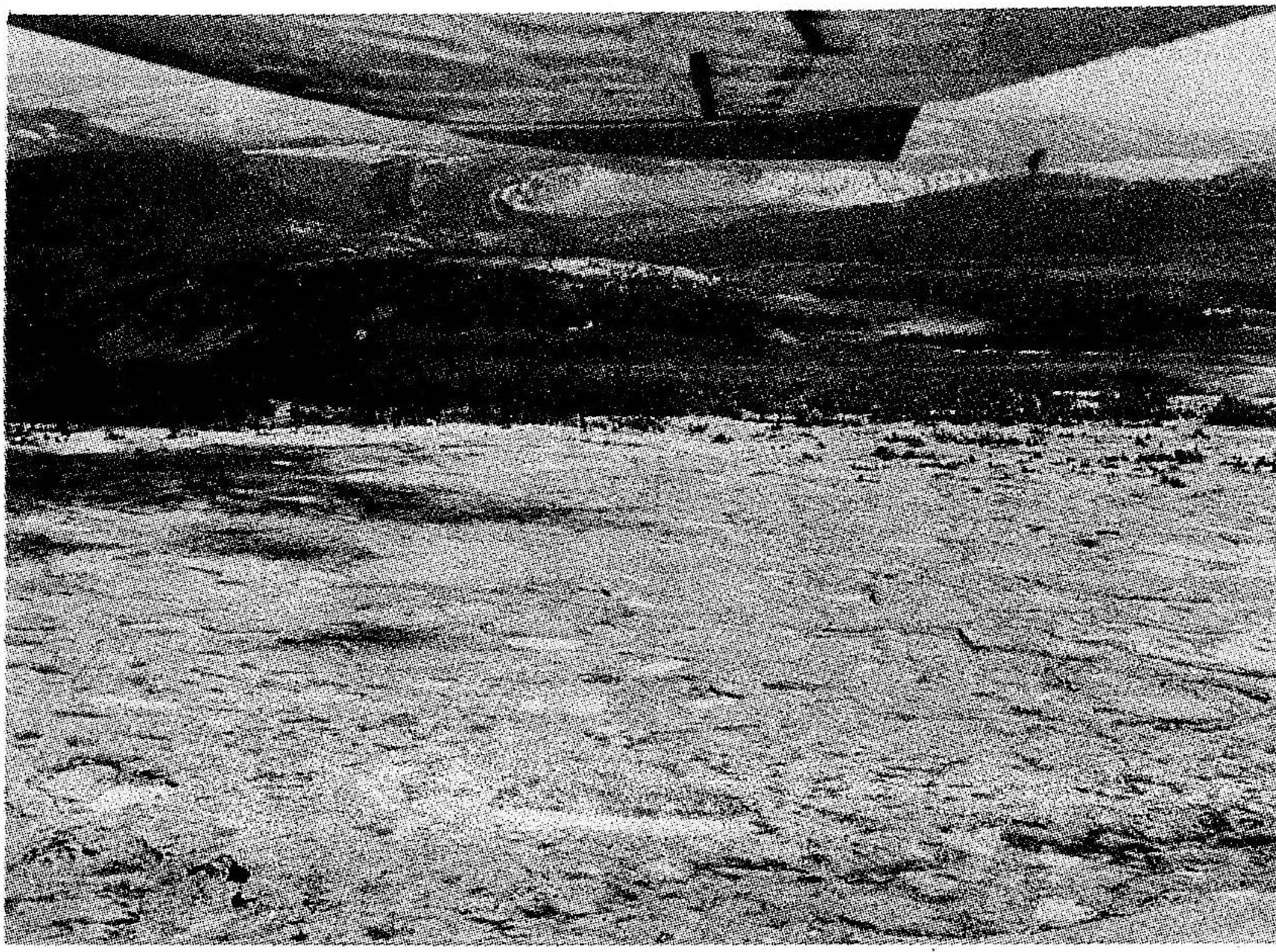

Fig. 2. Oblique aerial photograph of part of Tosi Creek Basin, looking east.

the fragments, frost action appears to be the dominant weathering mechanism of this unit.

The principal denudational agent of the dark unit is solution. All the surface karst features (karren and "sinkholes") in the basin are on this rock type. The sinkholes are chiefly dolines with only a few collapse sinks in evidence. The dolines average 30 to 50 m in diameter and 5 to 10 m deep, and cover nearly the entire basin. Several are soil-filled and can be clearly seen as circuler grassy areas from the air.

The karren found on the dark unit are the best developed the authors have seen in the United States. All of the *freien Karren* of Bögli (1960) are represented. The most common forms are *Rinnenkarren*, with *Mäanderkarren* and *Kluftkarren* also well represented. These features, as well as the sinkholes, are illustrated and described in greater detail elsewhere (Werner, in preparation).

Only two small caves were found in the basins. One was a solution tube 2 m long connecting two ponors in Tosi Basin. The benesis of this tube is unclear since there has been much collapse. The other cave is located in the basin north of Hodges Peak (see fig. 1). The cave entrance is directly beneath a layer which is unaffected by solution (its composition is not known). Passages extend downward about 3 m and horizontally for about 10 m.

A distinctly different type of karst development has been found in two places along faults: (a) on the northwest-trending Pyramid Peak Fault, and (b) on the west-trending branch of the Shoal Creek Fault. In both cases, the Madison limestone is exposed downslope of the fault with only non-carbonate rocks upslope. The limestone has been upturned to the vertical at the fault, but soon attains the regional attitude of 15^{o} from the horizontal within half a kilometer of the fault. In at least two locations where these conditions occur caves have developed (fig. 2).

The southwest flowing branches of Swift Creek cross the Pyramid Peak Fault at an elevation of 3000 m and flow off the crystalline rocks onto the Madison limestone. The limestone forms a scarp 60 m high along the fault line. As streams cross the fault, short canyons are cut through the limestone (see fig. 3).

The easternmost stream sinks entirely into two caves. The lower cave is at the base of a pit 5 m wide and 15 m deep. The cave terminates immediately in frost-spalled breakdown. In the wall of the canyon 30 m upstream from this cave are three entrances leading to a second cave, which follows a set of joints trending N18^{o}W (parallel to the fault). The cave is rather small, having a length of 100 m and a depth of 32 m. Passages are chiefly joints enlarged to 1 to 2 m wide and 10 to 15 m high. The passage is delineated by a series of snow-filled sinkholes (fig. 3).

Five km east of Swift Creek Valley is Shoal Creek. The Shoal Creek Fault (trend = N72^{o}W, displacement = 800-1000 m) crosses the valley at approximately right angles. Here a cave has formed in the Madison limestone downslope of the fault. The cave entrance (at 2960 m) is at the base of a sinkhole 15 m deep and 20 m wide. A side branch of Shoal Creek flows into the cave. A considerable amount of frost-shattered limestone in fist-size pieces lies on the first 10 m of cave floor. Beyond this, the cave consists of a single passage 10 to 15 m high and 1 to 3 m wide. This passage contains the stream and can be followed downstream for 200 m to a breakdown termination. The cave is

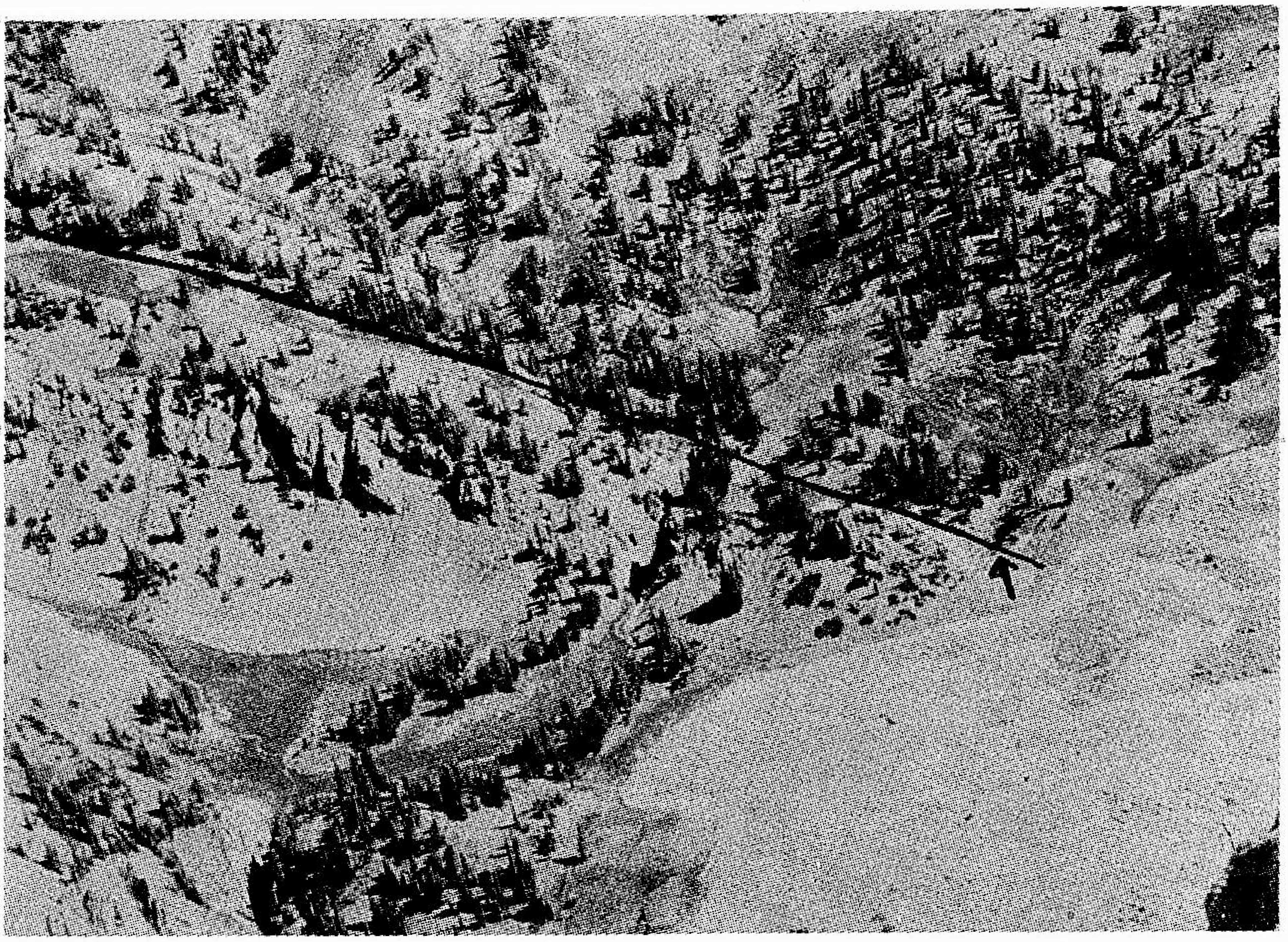

Fig. 3. Oblique aerial photograph of the Swift Creek Caves area. The cave entrance is indicated by the arrow at the upper right, the heavy black line is the trace of the Pyramid Peak Fault. North is to the left.

developed in the upper part of the Madison limestone on a set of joints which are perpendicular to the Shoal Creek Fault. The joints are closely spaced and the cave passage occasionally switches from one joint to the next. The cave stream has been traced to a spring 1250 m away from and 250 m lower than the entrance. Further descriptions and maps of the caves may be found in Medville and Plantz (1973).

CONCLUSION

There are two distinct sets of conditions which produce distinct types of karstification in the Gros Ventre Mountains of central western Wyoming. In the first, exemplified by Tosi Creek Basin, nearly horizontal limestone is exposed on a topographic surface with essentially the same attitude as the rocks. There are no streams entering the terrain; the principal water source is melting snow. This fairly even distribution of water onto the surface has produced a considerable amount of solution to create an impressive display of surface karst forms. Subterranean solution is probably equally widely distributed so that many small channels form, but none of cave dimensions. A notable exception occurs beneath less soluble layers, which may have the effect of directing a concentration of flow into one subsurface channel.

The second set of conditions is exemplified by Shoal and Swift Creek Caves. Because of drag-folding and the proximity of a fault, fracturing and jointing are more intense (and more significant hydrologically) than in the basins. Water flown onto the limestone as streams (about 1/2 m^3/s). Since there is no carbonate uphill from the fault, the water is still agressive and, upon reaching the highly fractured limestone, solution occurs in a relatively small area forming caves.

The orientation of cave passages is controlled by a combination of primary fracture direction and hydraulic gradient. At Swift Creek Cave, the major orientation is along fractures parallel to the fault, rather than downdip and downslope along the primary hydraulic gradient. Since water travelling either towards the west or the south is following a component of the hydraulic gradient, the preferential direction would be that which offers greater permeability and thus a cave would develop along the more prominent fractures. In this case, that is parallel to the fault.

A Shoal Creek Cave, the major passage orientation appears to be downdip (at right angles to the Shoal Creek Fault), even though present topography indicates that the primary hydraulic gradient should be parallel to the fault. However, inspection of aerial photographs shows a distinct lineament over 10 km long which passes through the cave entrance and follows the passage trend. This was not field-checked, but, since scarps can be seen along some segments, it is probably a fault. In that case, the cave may be formed along fractures parallel to a fault.

The two cave examples indicate that passage development occurs along fractures associated with faults because of higher permeability there. This is not necessarily the direction of greatest hydraulic gradient.

Thus, two examples of karst less than 15 km apart illustrate differences which can occur because of topographic and structural conditions under similar climatic conditions on the same rocks. In Tosi Creek Basin there is primarily surface development, at Swift and Shoal Creeks there is primarily subterranean development.

LE DÉVELOPPEMENT DU KARST ET DES CAVERNES DANS LA CHAINE DU GROS VENTRE, WYOMING, É. U. A.

E. Werner, D. Medville

RÉSUMÉ

La chaîne du Gros Ventre est orientée d'est en ouest. Elle fait 30 kilomètres de long sur 10 kilomètres de large et est située dans le centre-ouest de l'état du Wyoming. Certains pics s'élèvent jusqu'à 4000 mètres d'altitude. Il existe plusiers régions, situées dans les parties alpines et sous-alpines de cette contrée où le développement du karst est intense. Les régions favorables à la dissolution du matériel sous-jacent comportent deux groupes distincts: (a) des régions plates ou légèrement en pente composées de calcaires de surface presque plate et comportant en surface des formations bien développées de karst; (b) des régions propices au développement de cavernes dans des vallées jeunes et de forte pente, généralement situées là où des calcaires tombent à pic le long d'une faille.

Le bassin du Tosi Creek, situé près de l'extrémité orientale de la chaîne, est une région très bien développée du premier groupe. La roche de fond est de formation dite de "Mississippian Madison", qui consiste en calcaire pur lardé de quelques minces couches de calcaires impurs. L'érosion se fait par solution sauf lorsqu'il y a destruction par le gel et par le transport mécanique des couches impures. La formation de lapiés se produit sur toutes les surfaces exposées sous des formes qui dépendent de l'inclinaison et de la quantité de neige. Leurs dimensions peuvent atteindre jusqu'à 12 mètres de profondeur et un mètre de largeur (Kluftkarren). Aucune grande caverne ne peut se former sur ce terrain.

On trouve le second groupe là où les failles traversent des vallées contenant des assises escarpées de calcaires en abord immédiat avec une faille. L'assise est verticale devant la faille. Les passages, situés le long de cassures orientées parallèlement à la faille, ont subi de grandes modifications sous l'action de l'eau courante.

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Ba 049

RELICTS OF TERTIARY KARST FORMS IN LATER RELIEF OF THE LANDSCAPE

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Attempts to determine karst denudation within climatic zones of temperate geographic latitudes generally meet a number of dicculties. The limestones there are undergoing recent corrosion and the intensity of denudation has been fairly accurately defined by various authors (comp. I. Gams 1966; O. Štelcl 1969). The strength of these processes is, however, but low, as compared with those in cool or even frigid zones.

Even preliminary observations of fossil karst forms indicate that in some mountainous regions with a temperate climate, the Younger Tertiary karst processes occurred on a large scale. Big caves and other structures were built in the same areas during the Pleistocene, reasonably suggesting that in a moderately cool climate the limestones were also strongly corroded.

The karst areas in Poland (in the lowlands, highlands and mountains) permit a more exact determination of the scale of karst processes hoth during the Tertiary (under a temperate warm, intermittently even a sub-tropical climate) and during the Quaternary (under a temperately cool, intermittently even a frigid climate). During the Pleistocene, nearly all of Central and Northern Poland was covered by Scandinavian glaciers, or mountain ice fields. It is, therefore, possible to determine the scale of karst processes during the glacial and interglacial periods.

Recent karst in the temperate climatic zones is that most inadequately known. This is due to various causes. Our interpretation of the intensity of corrosive processes is based foremost on the chemical analysis of karst waters. Under definite conditions these data are sufficient but fail in age determination of earlier forms. Here, the criterion of time must be taken into account along with climatic variability, intensity of surface erosion due to vertical movements, etc. Putting it shortly, results of recent water chemical analyses should be treated with greatest caution in geological interpretations.

Geologically dated fossil forms are of much greater importance for the interpretation of karst events. It must be stressed, however, that classical forms of this type have been preserved very sporadically. Hence, they may only be an index of the intensity of karst processes during early geological periods. The scale of the corrosive processes may be more accurately determined by diverse geological investigations.

The karst forms of Poland are known from various areas: from the Paleozoic to the Cenozoic (R. Gradziński, Z. Wójcik 1966). Pre-Tertiary forms are practically without significance in recent morphology. Theironly major concentration is known from the Silesian Highland (S. Gilewska 1961), but the karst Liassic pits there persist under classical sediments in the Tertiary made subordinate to younger relief.

Nearly all major fossil karst forms known in Poland came into existence during the Tertiary. The Paleogene ones are not so well fully documented as the Neogene forms. About 80 per cent of the investigated classical fossil karst structures (pits with deposits, caves) are of Miocene and Pliocene age. These structures have been only very slightly modified even within areas penetrated by glacial thaw waters.

An analysis of the fossil karst forms from the Miocene (intermittently with a sub-tropical climate) and from the Pliocene (temperate warm climate) indicate optimally favourable conditions prevailing then for the development of karst forms. Big caves (the Czarna Cave in the Tatra Mts. is 6 km long) and karst pits and uvalas etc. of considerable size formed at that time. Since young Tertiary karst forms play an important role in the present relief it may be reasonably supposed that the most favourable climatic conditions for karst development were those of a warm climate.

Quaternary karst structures are known from various regions of Poland. No caves have been reported from the Polish Lowland (absence of major ups and downs). But in many places there are small karst pits filled with residual clays and moraines (R. Gradziński, Z. Wójcik op. cit.). An examination of these forms has shown that they did not come into existence under conditions of a cool glacial climate favouring corrosion but under the temperate climate during the inter-glacial periods. On the other hand, caves formed (the Kasprowa

Niźnia cave, 2 km long) is mountainous areas (in the Sudetes and particularly in the Tatras) at the close of the glacial periods. This was connected with the penetration of waters flowing out of crevices in glaciers on limestones at the level of valley bottoms (Z. Wójcik 1969). However, caves associated with conditions of corrosion in the Tatra Mts. during the glacial periods are not so well developed as those formed during the warm climate of the Pliocene.

To supplement the above remarks it should be added that the karst highland areas modeled during the Quaternary have many features in common with the development of the relief in lowlying regions (uvalas, karst pits) as well as in mountainous places (caves, but distinctly smaller than those in the Tatras). Karst forms of greater size have formed here also during the Neogene.

Thus, it may be concluded that karst relief in Poland developed mostly during the younger Tertiary to be slightly re-modeled in later times. The most important changes this relief has suffered are abservable in mountainous areas. Hence, the forms that are of importance in the recent karst relief are mainly relict forms (though re-modeled in many cases). They developed in a different climate, the conditions most favourable for the development of major karst structures being those prevailing in a temperate climate of the Neogene.

Time was the factor which significantly influenced the formation of major karst forms during the Tertiary. The rate of the corrosion processes in the Tertiary was much slower than in mountainous areas when crevices in limestone rocks were being penetrated by glacial thaw waters. In the latter case, processes of corrosion did not last longer than a maximum of several thousands of years while during the Tertiary the slow corrosive action, even of isolated forms, may have been at work over a million years. In a warm climate, with intermittent low humidity periods, major structures may slowly form, even under weak denudation (it being accepted that other agents, eg. humus acids, did not accelerate the action of corrosion).

Observations which the wirter was able to make in many countries of Central Europe indicate the existence there in the Tertiary of optimum developmental coditions of major karst structures. In many cases the karst relief of these regions is an assemblage of relict forms, but slightly re-modeled during the Quaternary. Karst relief in high-mountain areas was the only one to suffer more important modifications. For instance, the Tertiary karst forms that have persisted in the Alps are sporadically encountered. Generally they represent fragments of old, horizontally developed caves.

The disappearance of older structures in many highmountain regions (particularly in the Alps) is connected not only with the penetration of aggressive thaw waters in limestone massifs. Vertical movements of great intensity are noted in the youngest Tertiary. The uplifting of highmountain massifs resulted in stronger erosion during the Quaternary. The young Tertiary vertical movements also led to a growth in the energy of corrosive action (subsurface and above the surface) in many highland areas, eg. in the karst regions of Slovakia, Moravia and Czechoslovakia.

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