16th INTERNATIONAL CONGRESS OF SPELEOLOGY

Proceedings

VOLUME 1




Edited by

Michal Filippi

Pavel Bosák

16th INTERNATIONAL CONGRESS OF SPELEOLOGY

BRNO 2013 CZECH REPUBLIC

WHERE HISTORY MEETS FUTURE

16th INTERNATIONAL CONGRESS OF SPELEOLOGY

Czech Republic, Brno

July 21–28, 2013

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Cover photos (some photos were adjusted/cropped)
Top left – José Bidegain, on his way for the recovery Marcel Loubens' body. Author unknown. For details see the paper by A.A. Cigna.
Top right – "Walking Mammoth" – a prehistoric drawing from the Kapova Cave, Russia. Photo by O. Minnikov. For details see the paper by Y. Lyakhnitsky et al.
Bottom left – "Astronaut" David Saint-Jacques (CSA) collecting microbiological samples for the scientific programme of the ESA CAVES course. Photo by V. Crobu. For details see the paper by Bessone et al.
Bottom right – The long-legged cave centipede Thereuopoda longicornis – a typical species of Lao caves. Photo by H. Steiner. For details see the paper by H. Steiner.

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The names of the Committee members are given along with their home countries and fields of research they represented as convenors.

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Preface

Dear readers, the Proceedings volumes you are holding in your hands were issued within the 16th International Congress of Speleology (hereafter 16thICS) on July 21–28, 2013 in Brno, Czech Republic. Let us welcome you to its reading.
In total, over 320 contributions (over 250 oral presentations and over 70 posters) by more than 750 authors have been received to be included within the Congress Proceedings. This represents over 2,300 received e-mails and a similar number of responses during the last 6 months, approximately 4,300 electronic files and over 1,450 printed pages of the text. To put it simply, "really, really much interesting stuff concerned with cave and karst subject". The author's guidelines stipulated that the particular contributions should not exceed 6 pages of text and we were delighted to find that most authors prepared contributions close to this upper limit. Only very few contributions did not exceed one page of text. This illustrates a clear willingness of the cavers and karst scientist to share their discoveries and research conclusions.

The presented contributions (abstracts/papers) stand for both oral and poster presentations as indicated in the headings. Contributions in each session are arranged alphabetically by the last name of the first author. All contributions were reviewed from the viewpoint of technical quality and scientific content by members of the scientific committee and invited reviewers. The authors had the opportunity to revise their papers in response to reviewer's comments and we were pleased to see that the reviews have improved the clarity and readability of the contributions. However, profound improvement of the English language could not be arranged due to the shortage of time and insufficient human resources; the authors themselves are therefore responsible for the linguistic level of their contributions.

Thirteen thematically different sessions and six special sessions were scheduled within the call for your contributions to cover the whole range of subjects to be discussed within the wide scope of the 16thICS. The low number of contributions for some of these "detailed" sessions necessitated their merging with others. As a result, eleven original and three joint sessions are presented within the Proceedings. The contributions were grouped into three separate volumes. The purpose of this arrangement was that each particular Volume is filled with a certain logical hierarchy of topics, and that related topics are presented together. It was also the intention that the content of each Volume is topically balanced and contains both generally interesting (popular) topics with rich photographic documentation and hardcore scientific topics dominated by tables and plots.

Volume I starts with three plenary lectures representing three global topics related to 16thICS subject. Further it contains papers concerned with history of research (session "History of Speleology and Karst Research"), archeology and paleontology (sessions "Archaeology and Paleontology in Caves"), topics focused on management and preservation of caves and karst areas and other social-related aspects (sessions "Protection and Management of Karst, Education"; "Karst and Caves: Social Aspects and Other Topics"). In the last mentioned session you can also find a small part devoted to extraterrestrial karst. Volume I is ended by a relatively large portion of biology-oriented papers placed within the session "Biospeleology, Geomicrobiology and Ecology".

Volume II contains the traditionally heavily attended session "Exploration and Cave Techniques" and by the related session "Speleological Research and Activities in Artificial Underground". These exploration topics are, we believe, logically supplemented with contributions from the field of "Karst and Cave Survey, Mapping and Data Processing". The content of the second Volume is completed with a somewhat more specialized session "Modelling in Karst and Cave Environments" and with session "Cave Climate and Paleoclimate Record". The last mentioned session probably better fits to the end of Volume III, but it was placed into Volume II in order to reach balance in the extent of the individual volumes.

Volume III also starts with traditional, heavily attended topics organized in two sessions: "Karst and Caves in Carbonate Rocks, Salt and Gypsum" and "Karst and Caves in Other Rocks, Pseudokarst". These topics are supplemented by the related session "Speleogenesis". This last volume of the Proceedings is ended by the study of cave minerals, included in a specific session "Cave Minerals".

It is clear already from the previous ICS meetings that the range of the published topics becomes wider and wider, including localities in the whole world but also – owing to the access to high-quality spacecraft images – from other planets. The range of the instrumental, analytical and software methods employed in cave and karst research is remarkable and shows that the topic of "cave & karst exploration" attracts an ever increasing number of researchers even from already established scientific disciplines.

Let us also say a few words about the selection of the cover photos for the Proceedings volumes. The idea was to select such photos which would best represent all topics (especially those enjoying the highest interest) in each particular volume and be of high technical quality. Since we believe the cover page is a place for a serious presentation of the inner content, we made our selection from photos used in the presented papers. In one case the additional photo was requested to get a better representation of the topic. For our purpose, we decided to place several photos on the cover page of each volume. We hope that you enjoy them.

We wish to take this opportunity to apologize for the all mistakes which might have possibly originated within the operations with different versions of the manuscripts and other related files and e-mails which passed through our computers. We believe that everybody find their interesting reading in the Proceedings and we wish that the whole publication (Volumes I–III) becomes a valuable record of the 16th meeting of enthusiasts addicted to the fascination of the underground world.

Finally we wish to thank all the authors for their contributions. Enormous thanks belong to the reviewers and especially convenors (members of the scientific committee) of the particular sessions for their time and effort in the improvement of the overall message of the texts. We also wish to thank Michal Molhanec who significantly helped with the on-line form for the contribution submission, to Jiří Adamovič who repeatedly helped us with the improvement of our English, and to Jan Spružina, Zdeněk Motyčka, Jana Holubcová, and Renata Filippi who contributed to the preparation of the Proceedings.

After the few introductory words, let's now enjoy the papers from localities all over the world, presenting all forms of activities in karst, caves and other related surface and subsurface environments!

Michal Filippi and **Pavel Bosák**
Proceedings editors

Plenary Lectures

FROM OLOMOUC 1973 TO BRNO 2013: A REVIEW OF PROGRESS IN PHYSICAL SPELEOLOGY DURING THE PAST FORTY YEARS

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In the forty years between the Olomouc and Brno congresses our exploration and knowledge of the world's natural solutional caves has increased enormously. There have been exciting new discoveries in every region, with particularly great expansions in eastern Asia and Latin America. There are 22 mapped cave systems longer than 100 km in the May 2013 list of longest caves (including two that are largely or entirely underwater), and more than 300 longer than 15 km which is sufficient to provide abundant genetic information. More than 160 caves have been descended to depths greater than 750 m, twelve of them being > 1,500 m. What has been learned from these advances in caving? This paper presents the author's personal assessments of some of the significant advances that have occurred in our understanding of physical speleology.

1. Speleogenesis

1.1. Meteoric water caves

We have a much better appreciation today of the morphologic and genetic range of solutional caves that are found in the karst rocks, and are able to distinguish between them more clearly. The principal type (quantitatively dominant in most caving regions) is the unconfined (or *hypergene*, *epigene*) meteoric water cave system. In the 1950s and 1960s the foremost genetic problem was seen to be the relationship between these systems and local water tables. This was substantially resolved in 1971 by recognition that four different basic geometric relationships can and do occur in Nature, plus combinations of two or more of them. The 1973 Olomouc congress proceedings also include a first formal hardware model study of how the plan patterns of hypergene caves develop. By 1975 physical model studies of the range of their recharge geometries had been completed and causes of the development of complex patterns of passages such as the Holloch, Switzerland, were well understood. The solution kinetic basis for the cascading sequences by which such patterns are built was elucidated in 1977 and after. Later refinements have emphasized the importance of epiphreatic passage creation in alpine systems.

1.2. Hypogene caves

Ascending water (*hypogene*, often *thermal*) solutional cave systems are more widespread than was recognised in 1973, and are now much better differentiated. Understanding of the role of inter-formational groundwater flow in cavern morphogenesis has been greatly enhanced by studies in the giant gypsum maze caves of the Ukraine and Moldavia. At the Olomouc congress there was discussion of the potential genetic significance of sulfuric acid produced by oxidation of pyrite in bedding planes but no real inkling of the explosion of understanding that was to come after 1978 with recognition of the distinct H_2S class of water table notch caves that may be found in carbonate rocks: work primarily in the western USA has predominated here, including perhaps the most spectacular individual cave discovered in the past forty years, Lechuguilla (1986) in the Guadalupe Mountains, New Mexico. The H_2S studies have also drawn our attention to the importance of condensation corrosion (CO_2-driven as well as H_2S) in all caves, epigene, hypogene and marine. I think that understanding is still lacking for shaft-type hypogene caves and hypogene solutional overprinting on complex paleokarst such as is found at Budapest, in the Jewel and Wind maze caves of South Dakota and in parts of Lechuguilla.

1.3. Marine mixing zone caves

A third distinct class of solution caves that we now recognise is that of fresh water/marine mixing zone cavities. They have been well explained in a sequence of conceptual models based on examples in young limestones in the Caribbean and Pacific. Coastal caves in older, harder and deformed, limestones tend to be more complex mixtures of epigene development with marine overprinting related to changing sea levels.

2. Computer simulations of cave genesis

The advent of much cheaper computing with PCs in the 1980s opened up computer modeling of groundwater flow and cave genesis in soluble rocks. The early focus was upon testing the cave plan hardware model results of 1971–5, which were confirmed and then extended by addition of local mixing corrosion and other effects. In 1997 addition of a code allowing standard deviations up to 2.0 about the mean aperture within a given fracture significantly advanced our understanding of differences in genesis on joints and bedding planes. Modeling of cave system development in depth has not yet been successful because it has not reproduced the cascading effects. Modeling of hypogene speleogenesis is in very early stages. A challenge I propose for future modellers is to take an intersecting 3D network of fractures and bedding planes with standard deviations ranging 0.2–2.0 in aperture and attempt to reproduce the real caves that we climb and crawl in – computing is so much cheaper now than it was at Olomouc!

3. Mud and other crud: Clastic deposits in caves

Since 1973 there has been an immense amount of new work on deposits in caves. Neglecting the distinctive facies of entrance zones, studies of clastic materials (the clay, silt, sand, pebbles, boulders, etc. that make us happily filthy and bruised) have largely proceeded along the conventional lines of sedimentary classification. In the author's opinion there are now too many slightly differing classifications being proposed, newcomers not troubling to familiarise themselves with the previous literature: UIS might strike a sub-commission to propose a standard framework, based on facies concepts for my preference. There has been distinguished work on the weathering of cave walls and clastic sediments, particularly in the ancient caves of Australia and Slovenia. The nature and mechanics of breakdown are now well understood, chiefly from work in the USA; this does not make me any less uneasy when crawling through a boulder choke.

The physical dating of cave clastic sediments has advanced in fits and starts. The first major achievement was the measurement of paleomagnetic profiles in the late 1970s in clay sediments in Mammoth Cave, Kentucky, which detected two magnetic reversals and gave an initial and reasonable chronology for that great system. It has been extended to Tennessee, and widely applied in central Europe by a Czech and Slovenian team headed by the President of this congress. The problem of convincingly locking the sequence of magnetic excursions and reversals measured in a cave to the global magnetic record based on precisely dated lavas remains. More recently "cosmogenic dose" (or ^{10}Be:^{26}Al) dating of quartz sands and pebbles has been applied in North America, where it firmed up and extended the paleomagnetic chronology in Mammoth and some other caves, and in Siebenhengste in the Alps. The method is limited to the past five–six million years at present, and will always give the maximum residence time for a sample at a given site rather than establish its true time there: however, it has the greatest promise for clastic dating at present.

4. Cave minerals

Beyond question, interest in the precipitates in caves has drawn more scientists into physical speleology than any of the other subjects discussed above (or, probably, more than all of them combined). At the 1997 speleo congress at La Chaux de Fonds, the UIS and National Speleological Society of America launched "Cave Minerals of the World", an international effort involving thirty two contributors from fifteen different countries. The number of different minerals confirmed in that volume exceeded 200. There have been some breathtaking individual discoveries such as the giant gypsum crystals of Naica Cave, Mexico, the improbable "Chandeliers" of Lechuguilla, and the enormous stalagmites and flowstones of the river caves of China, Malaysia, Laos, etc. Russian speleologists have taken the lead in describing the ontogeny (competitive construction of crystals) in calcites, aragonites and gypsum, Romanian speleologists in studies of ice in caves. Standing in a class of its own has been the recognition that in some H_2S caves common clay minerals in the limestone may react with the acid to produce hydrated sulfates such as alunite, a compact and hard crystalline substance that can be dated by the $^{40}Ar/^{39}Ar$ radiometric method. This is a means of dating the true time of genesis of the host cavity. It was applied to the H_2S caves of the Guadalupe Mountains in 1997 to show a convincing range of ages, oldest to youngest, from 12 million years ago down to the present. It is unfortunate that its geologic range of application is quite limited – at the present time at least.

5. Dating and paleo-environmental studies of calcite and aragonite speleothems

The precise dating of calcite and aragonite stalagmites and flowstones, and study of the oxygen and carbon isotope, trace mineral, and other ratios in them to extract past temperatures and other paleo-environmental information, has been the principal focus of speleothem studies. ^{14}C dating was applied first but has a limited time range and other problems. In 1973 the applicability of what is the chief method today, $^{230}Th/^{234}U$ (uranium series) dating had just been established by a statistically sufficient number of ages from a handful of labs, with the first geomorphic application (the age of an antecedent river canyon in the Northwest Territories, Canada) being published that year. The $^{230}Th/^{234}U$ methodology of the time was crude, however, requiring large amounts of sample with comparatively high U content and two weeks on a radiation counter to obtain just one age with ±10 % error. The breakthrough that launched what must be described as "the modern bandwagon in speleothem studies" came with successful application of mass spectrometry to the counting problem, first for corals in 1986/7 and then for stalagmites (and even ostrich egg shells) in 1989. Today one gram of sample or less will suffice, an age can be obtained in as little as twenty minutes on the machine and the age range of the method is extended from 350,000 to ~600,000 years B.C.E. The cost of establishing your lab has increased by an order of magnitude too, of course.

In 1975 the first published U-dated records of O isotope patterns that extended over one glacial cycle or longer, from stalagmites from West Virginia and the Canadian Rockies, showed reasonable correlation with the O isotope paleoclimate patterns then being discovered in deep sea sediments. In 1976 the first report on remnants of the precipitating water in stalagmites (their fluid inclusions) appeared; "flu inc" studies have continued ever since but remain tantalising in their promise of precise cave paleo-temperatures that never quite convince me. In 1979 it was shown that many speleothems preserve chemical and detrital paleomagnetic records, allowing expansion of measured timescales to 780,000+ years in samples from the Canadian Rockies and elsewhere. Alternating periods of growth and then cessation with minor weathering began to permit better definition of the ice ages in mountain regions. In the 1980s annual or seasonal banding in stalagmites began to be recognized via an increasing number of phenomena. There were lighter-darker calcite pairs in flowstones deposited in a 19th Century Belgian canal tunnel, the alternation of calcite and aragonite at microscopic scale in ‘mites from South Africa indicating wetter and drier seasons respectively and, most widely applicable, the demonstration with Bulgarian samples that many speleothems carry important luminescence signals originating from soil organic acids. Luminescence studies yield very high temporal resolution and can bring the researcher to the interface with biospeleology. Following the introduction of U series mass spectrometer dating there has also been an explosion in studies of modern drip rates, water chemistry and isotopes in caves in many different environments to better interpret the past deposits. Teams today seek and find correlations with NAO, El Nino, ENSO regional climatic events, etc. The statistical analytic methods being applied have become very sophisticated.

6. Back into “deep time”

In conclusion, it should be recognized that caves are the longest lasting elements in a landscape because parts of them are protected inside the host rock. Filled paleokarst caves are known in Archean and all younger rocks. Uranium in speleothems in caves will eventually decay to stable lead. The first successful Pb/U dating of limestones was reported in the 1980s and was achieved in a speleothem in 1996. This method can date the oldest rocks and landforms on Earth. An age of ~90 million years for the earliest phase of cave development in the Guadalupe Mountains was published in 2000 and there are hints of much greater ages from the ancient karst landscapes of Australia.

THE MORAVIAN KARST IN THE ANTHROPOLOGICAL PERSPECTIVE

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Although the Moravian Karst is our main karst region with the longest caves, its greatest originality rests in its anthropic dimensions. The process of prehistoric settlement was influenced by two factors, i.e. positively by a mild climate and presence of natural shelters, and negatively by the ca 10 km distance from the nearest river. The densest occupation is documented in the Middle Palaeolithic and in the Magdalenian. Very important for the human image of the Moravian Karst are also the phenomena relating to the dense settlement of this territory in the historic periods and to the proximity of Brno city as a centre of research.

1. Introduction

Since this introductory paper deals with humans in the Moravian Karst, not with its geology and karsology, only some basic data relating to this region will be mentioned. The Moravian Karst with the area of 85 square km lies in the southern part of the Drahany Upland, at the average height 450 m above sea level. It consists of Devonian limestones and some of its valleys are filled with Miocene sediments. It is the largest and most developed karst territory in the Czech Republic that is divided into three parts: northern with the underground Punkva River, central with the Jedovnický and the Křtinský brooks, and southern with the Říčka Brook (Balák and Flek 2009).

2. The Palaeolithic occupation

In principle, the process of prehistoric settlement was influenced by two factors, i.e. positively by a mild climate and negatively by the ca 10 km distance from the nearest river (the Svitava). Together with non-preservation of intact ante-Saalian sediments this has caused that the traces of Lower Palaeolithic are found missing. The oldest finds from the Kůlna Cave (Fig. 1) originate from the end of the Saalian glacial period (Valoch 1988). These are several flakes and cores showing the use of the Levallois reduction strategy. For the Eemian interglacial there is a rich industry of the Taubachian occurring, which features microlithic tools and – apart from the dominant spongolite – a considerable representation of quartz among the raw materials. Both of these raw materials occur also in the immediate vicinity of the cave, although the main sources of Cretaceous spongolite are located 10 km westward in the valley of the Svitava River. The third and last Middle Palaeolithic culture the bearers of which have settled in the cave is Micoquian. It comprises mainly smaller bifaces with a thick base, at times of asymmetric shape, bifacial knives and a number of side scrapers. The oldest layer containing such implements, i.e. 9b from the transition of Eemian and lower Vistulian, yielded also 2 leaf points. The richest layer 7a was deposited in a relatively mild climate, although still much colder than that of today. Reindeer were the main game animals, and the remains of mammoths (almost exclusively tusks and molars) probably originated only from gathering. A great proportion of bones bear traces of cutting, or were utilised as retouchers. Roughly modified adzes made of reindeer antlers and a rib with sharpened ends represents the first bone tools. There are about one tenth of retouched implements among ten thousand lithic artefacts. The prevailing spongolites were brought to the cave in a slightly modified form; numerous cortical flakes attest to this. With the exception of local coarse raw materials, or contrariwise the most distant imports all stone materials (spongolite, Jurassic chert, quartz and quartzite) were processed by the same method, mostly until the total exploitation of the core. However, chopping tools were manufactured almost exclusively from pebbles of the local Culmian graywackes. Perhaps the most distant import may be a handaxe made of Central Slovakian (?) or Hungarian andesite. Raw materials of a more distant provenance appear in the form of retouched tools more often. The eagerly anticipated remains of Neanderthals appeared in the form of a parietal bone fragment, the right part of upper jaw with 4 teeth, and 3 deciduous teeth, perhaps lost in exfoliation. Radiometric date from 49 to 43 thousand years BP was acquired from burnt bones found near the jaw.

Figure 1. Kůlna Cave before the war.

The fauna from the most recent Micoquian layer 6a indicates very rough (cold and dry) climate. A Neanderthal mandible and a scarce lithic industry come from the Švédův stůl Cave in the southern part of the Moravian Karst. Although the two mentioned cave sites are best known due to the finds of Neanderthal remains, many more Middle Palaeolithic localities are found in the open field in the area of the Boskovice furrow, ca 10–15 km to the west (Bořitov, Doubravice, Černá hora etc.), where rich outcrops of spongolite occurred. It is difficult to make an estimate, to what extent Neanderthals intentionally sought after these areas of raw material resources, and to what extent it is only the effect of increased clarity of the remains caused by the quantity of chipped raw material.

Only a small number of scarce tools, mainly leaf points discovered in the caves Pod hradem, Rytířská (Fig. 2) and Pekárna, which apparently served as hunting stations, were preserved from the Early Upper Palaeolithic period. These belong to the Szeletian culture, the bearers of which have probably been Neanderthals still. Just as inconspicuous are the traces of presence of the so-called mammoth hunters that rendered Moravia famous through sites like Předmostí and Dolní Věstonice. In contrast to the preceding cultures, the Gravettian hunters have not settled in the margins of uplands, but consistently along rivers to have a view of broad river valleys. This was probably connected with the movements of mammoth herds (these pachyderms could not move very far from rivers because of their large demands of water) and the need of inter-group communication of hunter bands during seasonal mammoth hunts. Large depots of Northern flint attest to such contacts (Oliva 2007). The local sources of cherts ceased to be of interest at that time, and the Svitava River valley rising towards hilly region was not a favourite mammoth corridor. The radiocarbon dates from the classic phase of the Gravettian (Pavlovian) originate only from the Pod hradem Cave, but the associated lithic industry is inconspicuous. An assemblage with large retouched blades of spongolite from layer 6a in the Kůlna Cave can be dated as Late Gravettian, i.e. around 22 thousand years noncal. BP. Auerochs and bizons were supposed to prevail in the game fauna but the dates acquired directly from their bones are much more recent – thus we probably have to do with a contamination of layers. A roll made of tusk and decorated with dots and platelets of ivory with parallel grooves were unearthed during older excavations (Valoch 1988, Fig. 17).

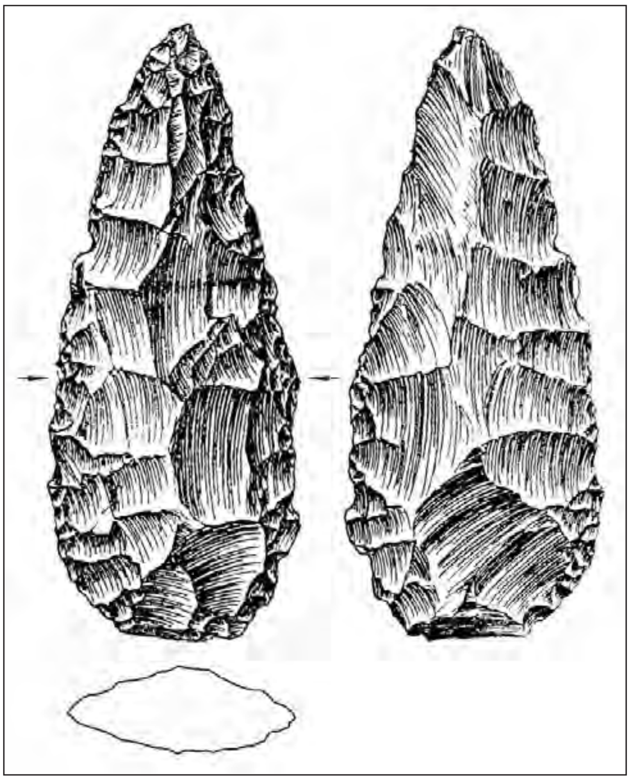

Figure 2. Leaf point from the Rytířská Cave.

Contrary to Gravettian, the entrance parts of the caves attracted the reindeer and horse hunters of the last great Palaeolithic civilization, the Magdalenian. Nearly all the sites are located in the valleys or their parts, through which some brook flows even. The most important of these are the Pekárna and the Kůlna caves. Especially the Pekárna Cave with its quantity of relics and unique works of art counts among the foremost sites of this culture in general. Engravings of animals and magical marks on spoon-like items made of lower jaws of horses and complete scenes carved into horse ribs belong to unique objects in Europe (Valoch 2001). Hunter equipment has improved by the introduction of thrower of spear and harpoon, i.e. a weapon with a separable point (provided with a blood groove or backward teeth), which was intended to remain in the animal body and to cause exhaustion through blood loss. Although most of the raw materials come from the glacifluvial sediments in Silesia, the interest in local sources has revived – a proof of this is an intense production of blades from the local chert in the so-called Southern branch inside of the Býčí skála Cave (Oliva 1995). This is why the absence of any trace of the Magdalenian in the exploitation area for spongolite in the Boskovická Furrow is surprising, even more so that open-air settlements are found in the surroundings of the Moravian Karst. If reindeer and horses occurred in the valleys and on the plateaus of the Moravian Karst, they had to move around this area so much the more.

The occupation of the Kůlna Cave has continued until the Final Palaeolithic (layers 4 and 3: Valoch 1988, 21–24), whereas for the Mesolithic it has not been corroborated so far.

3. Later prehistoric periods

The Neolithic is only represented by the developed phase of the Linear Pottery Culture (LBK). The ceramics with the so-called Notenkopf ornamentation was found mainly in the caves Výpustek, Barová and Koňská jáma. A shard depicting a human face originates from the latter situated in the northern part of the Moravian Karst (Fig. 3). In the Výpustek Cave, the LBK vessels were found in a very damp and draughty corridor with a difficult access, i.e. in a place entirely unsuitable for occupation. Researchers from the 19th century mention thick layers of sinter with fireplaces, pottery, and animal bones. The effect of the draught has perhaps fanned the fires during some kind of ceremonies. One pot contained burnt human bones; therefore this used to be a burial place as well (Wankel 1871; Hochstetter 1883). Of other Neolithic cultures, the traces of the Late Lengyel and the Jevišovice cultures occurred in the caves (Skutil 1970). A pattern carved into the ceiling of the Southern branch in the Býčí skála Cave discovered by M. Oliva in 1994 probably dates back to the period of the Baden culture (Oliva 1995, 36).

In the Bronze age, the stay in the caves can be hardly linked with aridization, as it is maintained e.g., for the Urnfield Period (Jäger and Ložek 1978). Exactly the karst areas belong among the driest; only the interiors of the caves themselves are humid. Although aridization could have made the long-term stay in the damper parts of the caves more pleasant, humans have always avoided occupation of such caves. The reason to dwell in the inhospitable parts of the caves could not have been the move of humans after fertile soil either, especially not within the karst. If the population really suffered from aridity, the dampness of the karst caverns could have possessed psychic and symbolic meaning, and some parts of the caves might have become the scenes of various ceremonies. It is a question whether reasoning about the purpose of the stay in a cave based on the character of the objects left behind is indeed as groundless as it is sometimes stressed. As a rule, most of the profane functions (as a shelter for shepherds, casual hunters, woodcutters, outcasts, threatened people) do not leave behind any pottery, the carrying of which is very impractical and usually unneeded. It is symptomatic that exactly the caves most suitable for human occupation yield very small numbers of such finds. However, vessels of any kind (drinking cups, bowls for food, storage jars to hold sacrificed products etc.) were necessary in places, where some special activity required also formalisation and representativeness of the equipment. Obviously, such activity is more likely performing of ceremonies than occasional overnight stays of several individuals. Pottery is also important as grave goods, as isolated graves from the Early (Hadí, Kůlnička caves) and Middle Bronze Age (pod Kůlničkou Cave) prove (Stuchlík 1981). Therefore, even if the caves have been used mainly for profane purposes, which is probable, the majority of the documented finds would testify to rather non-profane activities, and archaeological perspective would thus make the rendered picture markedly distorted. An exception probably is the Pekárna Cave, situated at the southern margin of the Moravian Karst, adjacent to the region that used to be densely settled in prehistoric times. At the times when people were threatened, they might have taken a refuge in this prominent and hospitable cave, taking all their equipment inclusive of utensils with them (Červinka 1926).

Figure 3. Shard of LBK wessel with the human face, width 10 cm, Koňská jáma Cave.

In the Hallstatt Period, the Moravian Karst might have attracted people as a source of iron ore, although there are no exploitation or metallurgy activities known from that period. Among the not too numerous relics from that time the famous ritual centre in the Býčí skála Cave stands out, regretfully explored by J. Wankel too early (1871–1873). The original interpretation of the finder that it is a burial of a chief on a chariot, accompanied by damaging of property and human sacrifices, especially of young women, has gradually been abandoned. Each of the chariot wheels has a different diameter, men prevail among the dead, the alleged altar is grinding slabs. J. Nekvasil (1969) has linked this ceremonial madness with the panic aroused by the incursions of the Scythians. At present this eerie find is regarded as a long-term ritual centre, to which crops and riches used to be brought from far and wide and where humans, perhaps captives, used to be buried, and maybe even killed (Parzinger et al. 1995; Golec 2007).

There are no La-Tène finds occurring in the Moravian Karst, and only a bronze brooch originating from the Roman period was discovered in the Kůlna Cave (Podborský 2012).

4. Historical times

In the Old Slavonic period (end of 8th to 11th century) production of iron developed but settlements were still missing (Souchopová 1986). The oldest occupation of the deserted village Bystřec near Jedovnice does not fall before the 13th century (Belcredi 2006) and was made by colonists from Lower Austria. The villages in this area were founded both by the bishops of Olomouc and by the local nobility, whose fortified castles on the rocks have distinctly marked the landscape of the Moravian karst. It is clear that the castles and caves in the deep dry valleys became the refuges of outlawed knights and brigands. Well known is the Hladomorna (i.e. Dungeon or Oubliette) Cave connected by a small corridor in its ceiling with the Holštejn fortified castle; as late as in the 19th century numerous human bones inclusive of child bones used to be found there. A medieval fortification has also been discovered in the big portal-type Rytířská Cave (the Knight's Cave). Without doubt, tales about fairies (e.g., in the Balcarka Cave) and devils emerged already in the Middle Ages; the activities of the latter within the karst area are supported by the numerous toponymic names (e.g., Devil's Bridge, Devil's Gate, Devil's Windows etc.). Apart from agriculture and pasturage, an important part of economy continued to be ironmongery. Iron ores were extracted mainly near the Rudice village, and ironworks were founded in the towns Adamov and Blansko in the 19th century. Towards the end of the 19th century, especially the northern part of the karst was so overgrazed by sheep that it was reminiscent of the Balkan landscape (Fig. 4).

The reports by the Renaissance and Baroque scholars regarding the finds of fossil bones in the cave loam constituted the early stages of scientific research in the Moravian Karst. These bones were rightfully considered very ancient, "antediluvian", and their curative properties were likened to the wholesome effect of unicorn bones. In 1669, Johann Hertod of Todtenfeld metered the depth of the abyss in the Sloupské Caves in the Lord´s Prayers he was able to recite before the stone he threw reached the bottom. The first to descend into the Macocha Abyss was the Minorite Lazarus Schopper in 1723. Johannes A. Nagel, the court mathematician, set on the journey to the Moravian Karst at the command of the Holy Roman Emperor Francis I in 1748. The most outstanding caver and speleoarchaeologist of the 19th century was undoubtedly dr. **Jindřich (Heinrich) Wankel** (1821 Prague – 1897 Olomouc), who has proven the contemporaneity of humans with cave bear and unearthed the ritual centre in the Býčí skála Cave. The first list of caves was created thanks to his continuator **Martin Kříž,** a lawyer; for this purpose the caves were systematically localized in the karst valleys, numbered, measured and described, and the largest of them even schematically mapped. **Jan Knies** of the following generation had merit in exploration of smaller caves; in this way he discovered the majority of the Magdalenian sites. At the very beginning of the 20th century **Karel Absolon** (1877 Boskovice – 1960 Brno) has started offensive speleological exploration of the Moravian Karst. His most significant exploratory and mainly organizational achievement was the discovery of the Punkva Caves in 1909 and making the bottom of the Macocha Abyss accessible, both through the dry track and the "waterway" (the Punkva stream) in 1933. In the central and southern part of the Moravian Karst in the period between the wars mainly German amateurs (engineers H. Bock and K. Feitel) were active, who succeeded in passing the siphon at the end of the Býčí skála Cave and penetrating into new spaces. Since 1948 the Speleological Club of Brno has been carrying out versatile exploration activities in the entire karst area. Their greatest achievements include the penetration into the large domes of the Rudice Cave System and mainly the discovery of the Amatérská Cave system on the collecting channels of the Punkva River below the plateau. As regards archaeology, the most important research was performed in the Pekárna Cave (K. Absolon in the interior in 1925–1930; B. Klíma in front of the entrance in 1961–1964) and in the Kůlna Cave (K. Valoch 1961–1976).

Figure 4. Landscape near Ostrov overgrazed by sheep. Photo A. Wiesner about 1905.

5. Conclusion

Although the Moravian Karst is our main karst region with the longest caves, its greatest originality rests in its anthropic dimensions. We have in mind not only the world-famous archaeological sites, but also the phenomena relating to the dense settlement of this territory in the historic periods and to the proximity of Brno as a centre of research. The former is connected with a rich verbal folklore (legends) and popular names of all more prominent caves, the latter with the extraordinarily long and manifold tradition of the research.

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THE CAVES THAT MICROBES BUILT – THE FRONTIER OF CAVE AND KARST SCIENCE

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Life in caves can take many forms, from pigmentless, eyeless animals, such as fish, salamanders, spiders, and beetles, to colorful, passage-covering slime and microbial biofilms floating in water. Cave animals have been the subject of study since the sixteenth century in Europe and China, although the formal discipline of biospeleology has existed only since the middle of the nineteenth century. Most biospeleological investigations focus on understanding the distribution of cave-adapted animals in the subsurface, their population sizes and dynamics, life cycles, and the genetic basis of adaptation to darkness and extreme environmental conditions, such as nutrient and energy limitation and oxygen deprivation. However, there is still much to be learned about obligate cave fauna, nutrient cycling, and cave ecosystem dynamics. Oddly enough, investigations of the microbial diversity and ecology from cave and karst landscapes could improve our knowledge of life in caves overall. Early biospeleologists considered microbes that colonized caves to be merely a subset of surface microorganisms, predominately serving as secondary organic matter degraders and food sources for higher organisms. The discovery of chemosynthetically-based ecosystems at the deep-sea hydrothermal vents, in groundwater, and in caves, toppled the dogma that all life on earth was dependent on sunlight. It is now well known that reactive air, water, and rock interfaces in the subsurface contain abundant and active microbial biomass. Because subsurface habitats can exist for thousands to millions of years, microbial activities can significantly affect ecosystem development by cycling nutrients and degrading or producing organic matter that serves as the energetic base of the ecosystem. In essence, these microbial activities drive the biodiversity we observe in caves today. But, microbial activities also alter solution geochemistry and overall cave geology by causing rock dissolution or mineral precipitation. Consequently, not only do microbes impact how cave ecosystems function, as well as how cave-adapted animals likely survive and persist through time, but the actual habitats themselves are being modified and formed by microbial processes. Current technological and experimental advances that incorporate metabolic assays, isotopic labeling, and genomic, transcriptomic, and proteomic approaches now permit the study of microbial diversity and functional activities in ways that were impossible decades ago. Exciting discoveries will continue to increase our knowledge of cave ecological and geological processes, and eventually lead to better ways to protect and conserve these novel places.

1. Introduction

The cave habitat is divided into three major zones based on light intensity: entrance, twilight, and dark zone. Each zone has specific physicochemical and nutrient conditions that control the types of organisms present in that zone. Biospeleologists who first began investigating the life of caves were predominately interested in the strange and exotic animals that they found throughout caves. *Troglobites* are obligate cave-adapted terrestrial animals, and *stygobites* are obligate groundwater-adapted animals. Obligate cave- and groundwater-adapted animals have evolved unique characteristics suitable for the subsurface habitat. Some of the organisms that live in caves and aquifer are able to move freely in and out of a cave (e.g., *trogloxenes*, such as bats and cave crickets), whereas other organisms (e.g., microbes) are more likely to be dependent on transport or translocation to move them into or throughout a cave.

Cave and karst habitats can have nearly constant temperatures and stable geochemical conditions, although some sections of a cave may change rapidly, such as in a stream due to seasonal or periodic flooding, or even within the entrance zone from daily changes in light. The diversity and metabolism of organisms that can and will colonize these habitats are affected by the juxtaposition of physicochemical conditions, changes in extreme circumstances (i.e. during a flood), availability and speciation of redox-sensitive elements, and the types and loading of carbon and other nutrients.

Figure 1. Water droplets condense on the hydrophobic surfaces of colorful microbial biofilms on a cave wall in Slovenia.Usually, such macroscopic biofilms can be white, yellow, orange, or pink in color, especailly if they are from within the dark zone. If near the cave entrace, biofilms can have a dark green to pale green and even purple color. Each of the colors can be correlated to specific microbial groups.

In general, cave and karst fauna can have rich diversity, with representatives of roughly a third of the recognized bacterial phyla, half of the recognized archaeal phyla, and broad representation among the microbial eukaryotes, although knowledge of microeukaryotic diversity is fairly limited. Because microbes colonize virtually every surface and interface with all zones of a cave system (Figure 1), including in cave streams with dynamic geochemical interfaces (Figure 2), understanding microbial diversity and function is central to all of the karst-related sciences.

Figure 2. White filamentous microbial mats in the sulfidic cave stream from Lower Kane Cave, Wyoming (USA). The microbial mats extend from a spring in the cave for more than 20 m along the stream.

This extended abstract summarizes a plenary lecture that highlights the history of cave and karst microbiological studies, the importance of microbes to cave ecology, and describes how microbes influence geological and geochemical processes in caves. The abstract concludes with future prospects that will continue to push the frontiers of cave and karst sciences from microbiological research.

2. History of Cave and Karst Microbiological Studies

The earliest microbiological studies of cave and karst habitats examined sediment and water by using microscopy or enrichment and isolation culture-based approaches. From the 1900s–1940s, many cave deposits were considered to have a microbiological origin, even if researchers could not prove it until more recently, including cave nitrate (saltpeter or saltpetre) deposits, carbonate moonmilk, and other speleothems. Some iron- and sulfur-oxidizing bacteria were identified from caves, and these groups, specifically sulfur-oxidizing bacteria, were implicated in the sulfuric acid-promoted dissolution of limestone as early as the 1930s. In the 1960s through 1980s, based on what was known of microbial diversity from culture-based approaches available at that time, cave and karst microbes were thought to be a subset of surface (e.g., soil) microbes flushed into caves from meteoric drip waters, surface streams and air currents, or carried into the caves by animals. Consequently, the ecological role of most microbes in caves was assumed to be primarily as secondary degraders and food sources for higher organisms. The role of microbes as primary producers in caves was not established until the mid-1990s from geochemical, isotopic, and ecological work done in the Movile Cave, Romania. The Movile Cave was discovered in 1986, following soon after the discoveries of chemosynthetic ecosystems at the deep-sea hydrothermal vents.

Prior to the research done in Movile Cave, which also coincided with the development and application of molecular genetics techniques in the 1980s and 1990s, earlier investigators relied heavily on routine methods developed from medical microbiology. Many microbes were discovered by these techniques, and for many years these were the only methods to obtain information about microbial diversity and nutrient cycling from karst settings. Nonetheless, even when the metabolic requirements are known, laboratory enrichment and pure culture isolation has been difficult because many of the cave and karst habitats are oligotrophic and culturing selects for fast-growing rather than slow-growing groups. In fact, it is estimated that less than 1% of known microbes are culturable using current techniques.

More recently, advances in molecular techniques have made it possible to circumvent culture-based problems and to identify microorganisms based on the evolutionary relationships of genes isolated from materials originating from caves and karst. Unlike animals, microbial classification is complicated by different levels of genetic relatedness and the extent of gene flow within and between taxa (i.e. horizontal gene transfer). This has resulted in a limited assessment of microbial diversity from caves. Since the 1990s, cave and karst microbiological studies have kept pace with new technology and most research has focused on the census of microorganisms colonizing a particular habitat. By comparing all of the known gene sequence data from caves around the world, related microbial groups are found in geographically separated cave systems. This suggests that colonization of the subsurface is not an isolated phenomenon. Consequently, the genetic diversity of cave and karst microbial communities may be particularly important to characterize and understand microbial species and ecotype concepts because of the global distribution of caves having similar physico-chemical constraints from cave zone to cave zone, and from cave to cave in different regions.

Recently, new research directions attempt to understand what microorganisms are doing to the cave physically (e.g., geochemical and geological impact) and to the cave ecosystem functionally. Broadly speaking, however, most research is still descriptive, using molecular surveys and culture-based analyses of habitats. The future of cave and karst microbiology research, and potentially most of the cave sciences, will improve by connecting phylogeny to function and by utilizing a combination of culture-, genomics-, and proteomics-based analyses. Through the biochemical evaluation of genes, enzymes, and metabolites, our knowledge of the ways that microbes shape their habitat and of the role that the cave and karst habitat has in selecting the metabolic and functional types of microbes within that habitat will improve.

3. Ecological Roles of Microbes in Caves

Photosynthesis is not possible in the dark zone. Therefore, most cave and karst ecosystems are assumed to be dependent on *allochthonous* material (brought into the cave) from wind, drip waters percolating through the epikarst from the surface, stream drainage, or even as guano. The most common type of allochthonous material is as dissolved and particulate organic matter. A range of allochthonous organic matter can occur in caves, as anyone knows from encountering leaves, tree trunks, and even automobiles deep inside caves (Figure 3). In some shallow cave settings, including in lava tubes, plant roots ("rootsiscles") can also penetrate cave passages or aquifers, which can have rich (micro)biota.

Figure 3. Pile of organic matter, ranging in size from fine to course particulate material in a Kentucky (USA) cave entrance. Cavers are behind the pile for scale. Just like on the surface, where microorganisms (e.g., bacteria, fungi) are responsible for the majority of decomposition of organic matter, microbes are also important to breaking down organic matter in caves.

Microbes are also responsible for processing organic matter, although the flow of carbon and energy in cave ecosystems has been poorly investigated compared to open surface streams. Most microbes in epigenic cave systems are degraders and food sources for animals. But, since the 1990s, increasing evidence suggests that microbial primary productivity (i.e. chemosynthesis) augments cave ecosystem carbon and energy budgets. There are now more than a dozen caves worldwide, most being hypogenic systems, where energy sourced from microbial chemolithoautotrophic primary productivity supports cave ecosystem (Figure 4). Chemolithoauto-trophy sustains large population densities of obligate troglobitic and stygobitic animals at several trophic levels, with Movile Cave being the exemplar chemolithoauto-trophically-based cave system. If the base of these ecosystems is impacted, such as from changes in water quality, then the ecosystems would likely collapse. This fact makes conserving the entire karst system at the level of the groundwater basin and watershed, and not just the cave, critical for protecting these fragile systems.

4. Geomicrobiology of Caves

Microbes profoundly impact geochemical and geological processes in karst, even if we currently cannot recognize or understand all of the microbial geochemical and geological forces in subsurface settings beyond where we can explore and experiment. Microbes affect the geological and geochemical systems due to their metabolism, from obtaining carbon, along with other nutrients, to gaining energy. Carbon for cellular growth originates by either converting inorganic carbon (CO_2, HCO_3^-) to organic carbon as an autotroph, or assimilating organic carbon initially produced by autotrophs. Heterotrophs use existing organic carbon for cellular energy and their carbon sources.

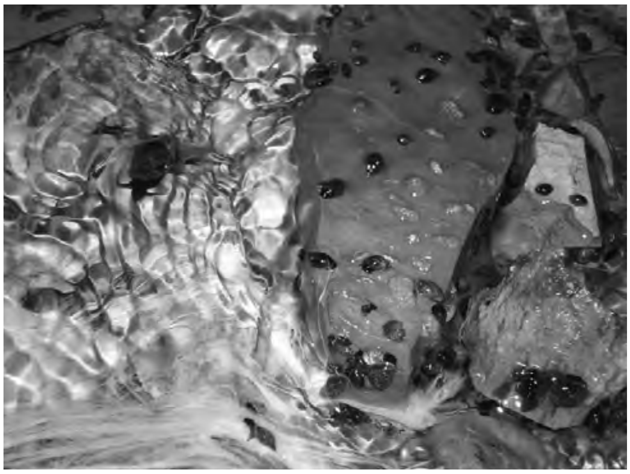

Figure 4. Physella spelunca *coexisting with microbial mats in the sulfidic stream from Lower Kane Cave. The snails have isotopic compositions that demonstrate they consume carbon sourced from microbial chemolithoautotrophy.*

The physiological mechanisms for capturing chemical energy are diverse, and the distinction between a chemosynthetic and a photosynthetic organism is based on whether the initial energy source comes from inorganic chemicals (*litho*) or light (*photo*). Microbes that gain energy through chemosynthesis and fix inorganic carbon are *chemolithoautotrophs* (literally "self-feeding rock-eaters"). During chemosynthesis, microbe gain energy by transferring electrons from one chemical (electron donor) to another (electron acceptor) that originates from groundwater or rocks and minerals. Inorganic electron donors can include, but are not limited to, molecular hydrogen or reduced sulfur compounds. Microbial dependence on oxygen is also important. *Aerobes* require oxygen, which serves as the terminal electron acceptor for oxidation of reduced sulfur compounds (e.g., sulfide, thiosulfate), iron oxidation, or ammonia oxidation. In reducing environments, *anaerobes* do not require oxygen, and use alternative electron acceptors for respiration in the following order: $NO_3^- \rightarrow Mn^{4+} \rightarrow Fe^{3+} \rightarrow SO_4^{2-} \rightarrow CO_2$. Consequently, microbial harvesting of energy from rocks and from water influences the mineralogy of the habitat and geochemistry of the system. This means that cave and karst settings provide unique sites to explore geomicrobial interactions compared to other subsurface environments because the habitats can be explored by humans or easily by remotely operated autonomous vehicles.

Although geomicrobial processes have been studied since the 1900s, recent studies provide evidence that microbes are responsible for metal and nutrient cycling in caves and lava tubes, including iron and manganese, nitrogen, sulfur and carbon, as well as for processes related to mineral (i.e. carbonate) precipitation and carbonate dissolution in epigenic and hypogenic systems. For example, microbes cycling iron and manganese in caves form metal-rich deposits (Figure 5), and active carbon metabolism (e.g., respiration) affects carbonate formation rates of speleothems. In essence, microbes are responsible for physically and geochemically shaping their habitats.

Figure 5. Microbial colonies formed on Mn coatings from a cave in Tennessee (USA). The tip of the finger points to bare limestone and microbial colonies on the limestone that have black centres, suggestive that the colonies may enhance Mn mineral formation on limestone over time.

Most geomicrobiology studies can be generally categorized as: (1) studies that attempt to understand the abundance, diversity, and activities of microbial communities; (2) studies that attempt to relate microbial diversity to ecosystem function; and (3) studies that attempt to use microbes to explain mineralogical phenomena, like precipitation or dissolution of minerals or deposits. The majority of cave and karst geomicrobiology studies fit into the first category, which means that the future of geomicrobiological research should focus on the other two categories.

5. Conclusions

Ongoing research in cave and karst habitats is revealing rich and diverse microbiota that warrant greater attention outside of the field of microbiology. Microbes serve as the foundation of different cave and karst ecosystems because of the decomposition of organic matter and from chemolithoautotrophic primary productivity. Obviously, microbiological research from caves has changed our perception that all life on earth is dependent on photosynthesis. But, it is also possible that microbiological research can also change our perception of the extent to which geochemical and geological processes are impacted by microbes. From current research, microbes do not simply passively colonize subsurface habitats, such as aquifer rocks or speleothems, without having a significant effect on the mineralogy, lithology, and geochemistry. Going forward, we need to move beyond observational investigations that focus on categorizing microbial communities from caves and karst, and instead advance our understanding of the geomicrobial and biogeochemical roles of microbes by using sophisticated experimental and analytical methodologies. From these discoveries, it will be possible to quantify process rates and mechanisms that are controlled by microbial ecophysiology and functional activities. It will be possible to truly measure the rates of specific metabolic reactions to demonstrate how fast, and to what extent, microbes build (i.e. form) and modify caves. This is the new frontier of cave and karst science.

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Session:

History of Speleology and Karst Research

SPELEOLOGY OF GEORGIA

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Georgian mountainous karst region is one of the unique in the world. Due to karst-creation standard conditions the maximum depth of karsting exceeds 4,000 m. The similar hydrogeological potential has only the mountain regions of Mexico, Indonesia, Turkey and China. According to the data of September 12, 2012, number of researched caves exceeded 1,300 in our country, out of which 820 (63 %) cavities are vertical and 480 (37 %) – subhorizontal. It is remarkable that out of more than 1,000 m deep 60 karst caves of the world 6 caves are found in Georgia, they are: world # 1 "cave-champion" – Kruber cave (2,197 m deep), Sarma cave (1,830 m), Tovliana-Mezheni cave (1,753 m) Pantiukhin cave (1,508), Iliukhin cave (1,275 m) and Dzou shaft in Gagra and Bzipi massifs.

1. Introduction

By an active participation of our expedition groups in high mountain limestone massifs of Georgia the water-bearing system of Napra-Mchishta (Bzipi massif) was revealed, which is also one of the deepest (2,345 m) in the world, whereas the depth of Iliukhin-Reprua (Arabica) hydrogeological system reached 2,307 m. Today similar hydrogeological systems can be found only in Mexico ("Cheve" 2,553 m) and China.

Lowland karst caves are distinguished mainly by sub horizontal, watery, often multistory labyrinth caves and water-abundant karst river outlets including one of the largest (3,285 m) in capacity (≈1.5 million m^3) Akhali Atoni Cave System and many entries labyrinth type cavity of Tskhaltubo (Kumistavi) discovered in early 80s, researched part of which exceeded 15 km.

Geophysical researches conducted in 1982 proved existence of unknown (without natural entrance) karst cavities full of air and water in the amphitheatre-like depression of the Mchishta at the depth of 50–70 m below surface. In the 300 m long siphon corridor of complex morphology, where the strong stream of the Mchishta River (9.5 m^3/sec. – mean annual and 200 m^3/sec. – during flood, maximum depth of water reaches 46 m. Such long and deep siphons are very few in Eurasian continent. Besides, none of the water abundant underground rivers of Georgia (Mchishta, Tsachkhura, Tsivtskala et al.) have been studied entirely.

Western Georgia karst outcrops lie along the southern slope of the Greater Caucasus mountain range extending some 325 km from the Psou River to the Ertso Lake area. The total area of karst rock outcrop amounts to about 4,475 km^2, or 6.4 % of the total area of Georgia. According to the hypsometrical data the karst belt is characterized by a sharply delineated vertical zonation, from the coastal area (with its submarine springs) to 2,757.6 m a.s.l. (at the Peak of Speleologisis on the Arabika Massif).

Figure 1. Speleological map of Georgia.

2. Methods

For investigation visual, yearly geomorphological and climatological observation data were used. According to them speleological map was composed in GIS system. Distributions of Georgian caves according to sub provinces are given.

3. Results and discussion

On the basis of the results of complex geographical and speleological investigations the karst of Western Georgia is subdivided into:

a) the middle and high mountain limestone massifs (>1,000 m a.s.l.), comprising the Arabika, Bzipi and Gumishkha high mountain and the Okhachkue, Kvira, Gaucha, Mingaria, Askhi, Khvamli, Racha and Kudaro middle mountain limestone massifs;

b) the foothills and intermontane plain (low mountain) limestone massifs (<1,000 m a.s.l.). From the Gagra area to the Psirtskha. Gumista, Chaama Tsebelda and Panavi limestone massifs in Abkhazia; the Urta and Unagira limestone massifs (Ekismta, Abedati and Nakalakevi) in Samegrelo; in the Kvemo Imereti region – the Sataplia-Tskhaltubo and Okriba massifs (Kutaisi-Navenakhevi and Okriba-Argveta) and the Zemo Imereti structural plateau together with all of the Chiatura district;

c) the clasto-karstic massifs of the plain, represented by the Bach-Otkhara and Duripshi plateaus, the Jali and Tsebelda conglomerate massifs (in Abkhazia) and the vast clasto-karstic regions of Central Samegrelo (Tintilozov 1976) – (Fig. 1).

According to data available on November 2012, the number of the caves investigated in Georgia exceeds 1,300, whereas in the 1960s the number of recorded caves barely exceeded 300 (Kipiani et al. 1966; Tatashidze et al. 2009). The total length of the explored caves is 240 km and the depth of the known systems is more than 61 km. 65,5 % of the caves investigated lie in the middle and high mountain massifs (1,900–2,400 m a.s.l.); 30.4 % caves are in the foothills and intermountain lowland and 4.1 % are developed on the limestone conglomerates of the plain (Fig. 2).

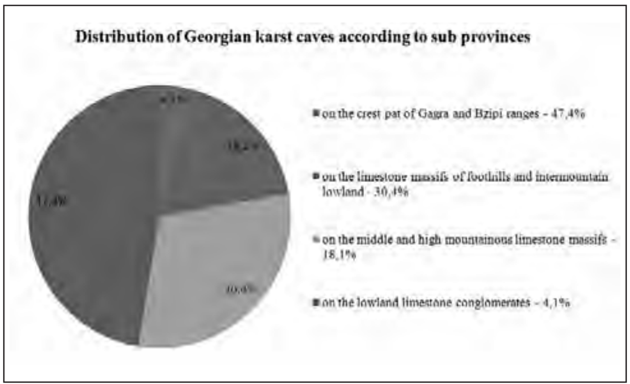

Figure 2. Speleological map of Georgia.

Some 326 caves (67.7 %) out of 480 registered horizontal caves are about 100 m long. 120 caves (24.9 %) are from 101 m to 500 m. 25 caves (5.4 %) are from 501 m to 2,000 m and 9 caves (2 %) are more than 2,000 m long (Fig. 3).

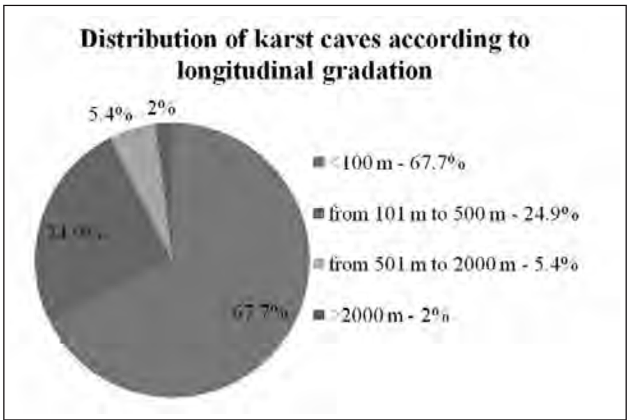

Figure 3. Caves according to longitudinal gradation.

Among the 826 vertical caves cuttently registered in Georgia, 724 (87.6 %) are 100 m deep, 88 (10.6 %) are from 101 m to 500 m deep. 7 (0.9 %) are from 501 m to 1,000 m deep and 8 (0.9 %) are more than 1,000 m deep (Fig. 4).

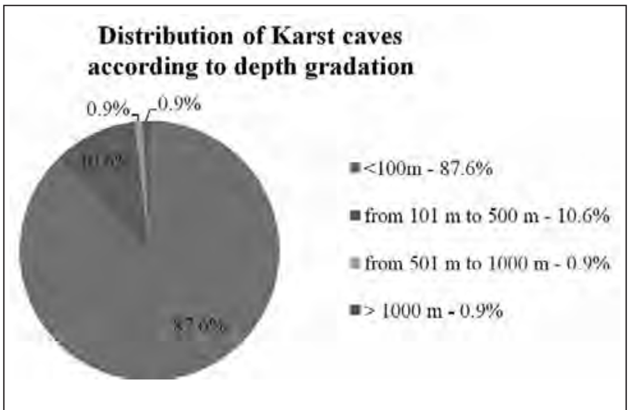

Figure 4. Caves according to depth gradation.

In Georgia Interest in caves begins from late past periods, but for 60th of 20th century in scientific literature only 60 well explored horizontal caves and pits were known (Kipiani et al. 1974).

The most important discovery was made in 1961 in Akhali Atoni vicinity, when unknown underground emptiness (void) were found with 50,000 m^2 area and 1.5 million m^3 volume. Republic authority with recommendation of management of Institute of geography passed a resolution for organization of public services and amenities on this monument. With this resolution was founded further development of speleo tourism in Georgia.

Significant speleological discoveries were made on Tskaltubo limestone massif in the beginning of 80th of last century. Expedition group of institute of geography had found many entrance labyrinth types Tskaltubo (Kumistavi) cave system, which now is made for tourists according to modern standards.

4. Discussion and Conclusions

There are few karst regions on the earth, which hydrogeological potential is more than 2,000 m. As it is turned out, there are great perspectives of deep penetration into the karst provinces of Mexico, Indonesia, India, Georgia and Turkey. It is proved in our country, yet in 60s of the last century – in the Arabika limestone massif (in the range of Gagra) number of deep mines and karst shafts discovered and partly investigated by Georgian researchers (Maruashvili et al. 1961; Tintilozov et al. 1965; Kiknadze 1972).

A valuable contribution was made by the speleosections and amateur speleologists' expeditionary units of different cities of Russia and Ukraine (Voronezh, Dnepropetrovsk, Kiev, Krasnoyarsk, Moscow, Novokuznetsk, Novosibirsk, St. Petersburg, Simferopol, Tomsk, Cheliabinsk, etc.) to the discovery and research of the deepest karst caves of Georgia. (Iljukhin 1974, 1978; Kasian 2005; Kiselev 1987, 1990).

As it is proved by studies, the limestone massifs of Bzipi and Arabika (Abkhazia, Georgia), in which the world's deepest shafts are formed, are clearly distinguished by the perspectives of depth penetration (Fig. 5).

Figure 5. Large cave – abysses location scheme on the Bzipi and Arabika limestone massifs.

At present there are 89 karst abysses on our planet with the depth of more than 1,000 m. 17 out of them are located in Austria, 16 – in Spain, 13 – in Italy, 9 – in Mexico, 7 – in Georgia, 7 – in Slovenia, 6 – in France, etc. (Gulden 28. 03. 2011). An absolute world record was established when the record depth of more than 2 km (2,197 m) was overcome in the Krubera (Voronja) Cave (Abkhazia, Georgia) on the limestone massif of Arabika.

We have basis to assume that development of speleo investigations in Georgia is optimistic and realistic. From world's ten deepest karst caves 4 are situated in Georgia. First three position occupy Kruber (2,197 m), Sarma (1,830 m) and "Iluzia-snow-Mejeni" (1,753 m) caves situated in high mountain limestone massifs (Table 1).

Table 1. World's deepest caves (Gulden 2012).

#	Cave name	Depth (m)	Length (m)	Country (Region)
1	Krubera (Voronja)	2,197	16,058	Georgia (Abkhazia)
2	Sarma	1,830	6,370	Georgia (Abkhazia)
3	Illyuzia-Mezhonnogo-Snezhnaya	1,753	24,080	Georgia (Abkhazia)
4	Lamprechtzofen Vogelschacht Weg Schacht	1,632	38,000	Austria (Salzburg)
5	Gouffre Mirolda/Lucien Bouclier	1,626	13,000	France (Hautle Savoie)
6	Reseau Jean Bernard	1,602	20,536	France (Hautle Savoie)
7	Torca del Cerro delCuevon (T.33)-Torca de las Saxifragas	1,589	7,060	Spain (Asturias)
8	Shakhta Viacheslav Pantiukhina	1,508	5,530	Georgia (Abkhazia)
9	Sima de la Cornisa – Torca Magali	1,507	6,435	Spain (Leon)
10	Cehi 2	1,502	5,291	Slovenia (Julian Alps)

Georgian karst caves are the deeper than the deepest karst abysses (Lamprechtsofen depth 1,632 m; Mirolda 1,626 m; Jean Bernard 1,602 m), which were assumed as an "underground poles" for many years.

Georgian investigators (Z. Tatashidze, T. Kiknadze, J. Jishkariani and others) have proved experimentally the existence of world's deepest karst hydrogeological systems in Georgia (Lapra-Mchishta 2,345 m and Iliukhin Reprua 2,307 m) which are sensational perspectives for speleological discoveries.

Nowadays from more than 100,000 karst caves registered longer than 50 km length are 57, more than 100 km length are 20 caves. World largest horizontal bottom caves are Mammoth (USA, length 627.6 km), Jewel (USA, 257.5 km) and Optymistychna (Ukraine, 236.0 km). Areas of those massifs, where world's longest caves are situated quite smaller than Bzipi (150 km^2), Askhi (200 km^2) and Arabika (100 km^2) watershed basin areas on western periphery of Georgian karst zone, where Mchishta, Tsachkhura and Tsivtskali underground rivers flow (Table 2).

Table 2. Some data about development of world longest caves.

#	Cave name	Current total length (km)	Area of the massif holding the cave (km^2)	Maximum extent of the massif (km × km)
1	Mammoth Cave System (National Park)	627.6	35–45	10.5 × 8.5
2	Jewel Cave (National Monument)	257.5	6.5	6 × 2,5
3	Optymistychna (Optimisticeskaja) (qypsum)	236.0	1.5	1.9 × 2.2
4	Mchishta, Georgia	?	200	25 × 25
5	Tsachkhura, Georgia	?	150	10 × 15
6	Tsivtskala, Georgia	?	100	13 × 11

5. Conclusion

An investigation result gives us opportunity to assume existence of giant cave systems in Georgian abounding underground river basins. There are several tens unstudied underground monuments in Apkhazeti, Samegrelo, Racha and Imereti regions. During the last 50 years a lot of work was done, but hence we do not know much about Georgian the most interesting underground phenomena. For abounding in debit underground basins are still inaccessible for investigators (Shavtskala, Tsachkhura, Rechkhi and others)

Studies conducted until present not only confirmed the prognosis of Georgian researchers about the truly great prospects of Speleology in our country (Tintilozov 1988; Tintilozov et al. 1987; Tintilozov et al. 1988; Tatashidze et al. 1993), but by the obtained results Georgia strongly embedded among the countries with the first degree speleo-resources in the world.

Acknowledgments

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THE HISTORY OF SPELEOLOGICAL PROGRESS IN TURKEY

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The number of caves in Turkey is estimated to about 40,000. Ca. 3,000 of them were investigated by the end of 2012 and about 200 are studied annually. Cave research in Turkey dates back to 1927 but continuous work began in 1955, when Temuçin Aygen and his friends initiated the scientific exploration of caves in Turkey. This individual effort continued until 1964, when the Cave Research Society was founded that speeded up cave research once more. Today, caving and cave science are carried by government research institutes, associations, university clubs and independent groups. Clubs and associations studying caves decided to form a Federation in 2008 and became the Speleological Federation of Turkey in 2009. The SFT today initiates cave studies and organizes cave rescue and speleological training workshops. With commissions on cave rescue, documentation, standardization and cave protection, the SFT continues its studies according to UIS standards.

1. Introduction

40 % of Turkey's surface area consists of carbonate and sulfate rocks prone to rapid erosion (Nazik et al., 2003). This shows that Turkey is very rich in terms of karst and caves. Many authors estimate the total number of caves in Turkey to be around 40,000. Approximately 3,000 caves have been studied by the end of 2012.

As all over the world the interest for outdoor sports has recently increased in Turkey. As a consequence, caving activities and speleological studies have increased as well.

Here we give a short history of cave studies in Turkey, followed by an introduction to the Speleological Federation of Turkey, founded in 2009.

2. The Speleological History in Turkey

In Turkey, cave research started rather late. According to the records, the first cave study is the one carried out in 1927 by Professor Raymond Hovasse from Istanbul University in the Yarımburgaz Cave in Istanbul on its biology (Pancarcı and Ünlü, 2003). The second study was conducted by Professor Cemal Alagöz from Ankara University and called "Karst Phenomenon in Turkey" (Alagöz, 1944). Later in the years 1949 and 1950 K. Lindberg from Sweden did research on the fauna of some caves in Anatolia and published it in Annales de Speleologie in France with the title of "Notes on a few Turkish Caves" in French (Pancarcı and Ünlü, 2003).

The first team to investigate a cave in Turkey was that of Temuçin Aygen and his friends that studied the Konya Maraspoli Cave in 1955. Until 1965 many caves were investigated under Aygens leadership. In 1964, upon the establishment of the Cave Research Society caving studies speeded up (Pancarcı and Ünlü, 2003). University clubs and associations founded afterwards increasingly contributed to the speleology of Turkey. Technical abilities were developed more and more and serious expeditions into the deeper caves were initiated.

Until the mid '80s only three groups (Cave Research Association, Boğaziçi University Cave Research Club, and General Directorate of Mineral Research and Exploration) carried out speleological research with almost no communication between the groups; communication was only among individuals. After the early 1990s when the first deep cave exploration was done by the Turkish cavers, caving in Turkey accelerated and new student clubs and communities were founded.

The First Speleology Symposium in 1990, in İstanbul, was the first truly national meeting of Turkish cavers. At the beginning of the symposium the groups had a chance to introduce themselves and their research. The Cave Research Community, the Boğaziçi University Cave Research Club, the General Directorate of Mineral Research and Exploration, the Nature Researches Association, the İstanbul Technical University Diving Club and the Zonguldak Cave Research Club participated in the symposium. This was the first glimpse on a national federation but its prospects were not seen promising at that time. At the end of the symposium it was decided to settle first for a communication web among cavers.

In 1992 the Boğaziçi University Cave Research Club had an accident in Düdenyayla and the Cave Research Community joined the group in the rescue. After that the importance of communication among the groups and the necessity of a cave rescue group were understood well.

In 1993 a panel was held in İstanbul on the "The problems of Turkish Caving and Suggested Solutions". Here a national union was mentioned for the first time under the name "Turkish Cavers Union". As a result of this meeting the "Turkish Caving Groups Coordination Board" was founded and the prime goals of the group were defined as to provide inter-group communication and coordination, to have a rescue organization, to establish a Turkish cave inventory and to organize communication with foreign groups because of an increasing number of unauthorized explorations by foreign cavers.

With the proclamation prepared and presented by the Cave Research Community and the Boğaziçi University Cave Research Club during the Second Speleology Symposium held in Ankara, the foundation of the Turkish Cavers Union was announced and a legislation proposal was presented. The association was accepted by the other groups participating in the symposium. The proposal contained the definition and the goals of the association, terms of membership, composition of an executive council, and rules and missions of the procedure. A short text announcing the foundation of the association informed caver groups abroad.

The first meeting of the Turkish Cavers Union was held on 14th January, 1995, in Ankara leading to the commissions on standardization and rescue.

After the meeting in 2004, the work of the Union accelerated. In regular workshops cave rescue was trained. To some of these cave rescue teams from Bulgaria, Belgium, France and Slovenia were invited for cooperation and training. After the meeting in Eskisehir in 2004, SRT techniques were practiced in Olympos, Antalya. Following this, cooperative rescue was trained with Bulgarian cavers in Oylat, Bursa, in March 2005. Belgian, French, and Slovenian cave rescue teams were invited at different times and cooperation and training was organized. These activities strengthened the Union and meetings were held annually: İstanbul 2006, Eskişehir 2007, İzmir 2008 and Antalya at the end of 2008.

During the last general assembly of the Turkish Cavers Union it was decided to become a federation. As a result, the Speleological Federation of Turkey was founded 17th November, 2009.

3. Speleological Federation of Turkey (SFT)

The SFT unites caving communities and university clubs. The SFT's prime missions are:

- To provide communication among caving groups;
- to maintain a national cave rescue team;
- to protect our caves and karst landscapes;
- to defining training standards; and
- to represent Turkish cavers at national and international platforms.

By end of 2012 six associations and nine university clubs are members of the SFT. In addition the SFT cooperates with the General Directorate of Mineral Research and Exploration, the Ministry of Forestry and Water Affairs, and the Directorate of Nature Conservation and National Parks.

The administrative board of the SFT is formed by representatives of all associations and university clubs. Its main duty is coordination among groups. The tasks of the federation are performed by the following commissions:

- The Cave Rescue Commission organizes national rescue trainings, coordinates with national and international search and rescue organizations and manages S&R operations in case of caving accidents.
- The Cave Protection Commission determines possible threats on caves, prepares and performs action plans on cave protection, and conducts courses on cave protection.
- The Training and Documentation Commission keeps training standards updated, formulates documents and organizes publications within the federation.

These are the current members of the SFT and the organizations working in close cooperation with it:

- **Mağara Araştırma Derneği (MAD) / Cave Research Association**: It was the first caving organization to be founded in Turkey, Ankara, 1964. It cooperates with other clubs during cave expeditions both nationally and internationally and conducted many cave meetings. It keeps the Turkish cave inventory and trains new cavers. It still plays an important role in Turkish caving and is active in Ankara and Bursa.
- **Boğaziçi Üniversitesi Mağara Araştırma Kulübü (BÜMAK) / Boğaziçi University Cave Research Club:** This is the first university caving club, founded in 1973. It conducted many successful expeditions into deep caves, such as reaching the endpoint of Peynirlikönü Düdeni at 1429 meters depth, still the deepest cave in Turkey. It is still active in İstanbul.
- **Maden Tetkik ve Arama Genel Müdürlüğü Mağaracılık Birimi (MTA) / General Directorate of Mineral Research and Exploration Caving Unit:** This is the first governmental speleological organizing, established in 1978. Until now it is pioneering the Turkish cave inventory, and provided a great deal of information, helping other institutions, associations, university clubs and groups. It is active in Ankara.
- **Hacettepe Üniversitesi Mağara Araştırma Kulübü (HÜMAK) / Hacettepe University Cave Research Club:** Founded in 1988, it surveyed many caves, organized symposia and caving photography contests. It is active in Ankara.
- **Dokuz Eylül Üniversitesi Mağara Araştırma Kulübü (DEÜMAK) / Dokuz Eylül University Cave Research Club:** It was founded in 1994 and is active in İzmir.
- **Eskişehir Mağara Araştırma Derneği (ESMAD) / Eskişehir Cave Research Association:** It started cave research in 1995 and became an institution in 2006. It is active in Eskişehir.
- **Ege Üniversitesi Mağara Araştırma Kulübü (EMAK) / Ege University Cave Research Club:** It was founded in 1996 and is active in İzmir.
- **Toros Mağara Araştırma ve Koruma Derneği (TAMAK) / Toros Antalya Cave Research and Conservation Association:** It started as Toros Outdoor Sports in 2002 and became an association in 2008. It is active in Antalya.
- **Ankara Üniversitesi Mağara Araştırma Birimi (ANÜMAB) / Ankara University Cave research Unit:** It was founded in 2004 and is still active in Ankara.
- **Akdeniz Üniversitesi Mağara Araştırma Kulübü (AKÜMAK) / Akdeniz University Cave Research Club:** It was founded in 2006 and is active in Antalya.

- **İstanbul Teknik Üniversitesi Mağara Araştırma Kulübü (İTÜMAK) / İstanbul University Cave Research Club:** It was founded in 2007 and is active in İstanbul.
- **Ege Mağara Araştırma Derneği (EGEMAK) / Aegean Cave Research Association:** It was founded in 2008 and is active in İzmir.
- **Boğaziçi Uluslararası mağara araştırma Derneği (BUMAD) / Boğaziçi International Cave Research Association:** It was founded in 2008 and is active in İstanbul.
- **İzmir Mağara Araştırma Derneği (İZMAD) / İzmir Cave Research Association:** It was founded in 2008 and is active in İzmir.
- **Anadolu Üniversitesi Doğa Sporları Kulübü (ANADOSK) / Anadolu University Outdoor Sports Club:** It was originally founded in 2000 and established a caving unit in 2008. It is active in Eskisehir.
- **Doğa Koruma ve Milli Parklar Genel Müdürlüğü Mağara Koruma Birimi (DKMP-MKB) / Directorate of Nature Conservation and National Parks Cave Protection Unit:** It was founded as a unit affiliated with the Ministry of Forestry and Water Affairs, in 2008. It is active in Ankara.
- **Uludağ Üniversitesi Mağara Araştırmaları Topluluğu (UMAST) / Uludag University Cave Research Group:** It was founded in 2012 and is active in Bursa.

The alphabetical order of clubs and associations in the SFT are listed in Table 1. These clubs and associations add nearly 200 caves to the inventory every year during the expeditions they organize.

Table 1. Associations and university clubs in the SFT.

Name	Type	Year of Foundation	No.of Members
AKÜMAK	Univ. Club	2006	30
ANADOSK	Univ. Club	2000	11
ANÜMAB	Univ. Club	2004	12
BUMAD	Association	2008	30
BÜMAK	Univ. Club	1973	60
DEÜMAK	Univ. Club	1994	36
EGEMAK	Association	2008	25
EMAK	Univ. Club	1996	45
ESMAD	Association	1995	35
HÜMAK	Univ. Club	1988	30
İTÜMAK	Univ. Club	2007	42
İZMAD	Association	2008	30
MAD	Association	1964	73
TAMAK	Association	2002	16
UMAST	Univ. Club	2012	20
Total			495

The Federation is also a member of international unions and federations. Since 2006 SFT, which has been a member of Balkan Speleological Union (BSU), participates in the Balkan Cavers Camp which is organized every summer. SFT had this camp in Antalya Olympos in 2006 with the attendance of 250 cavers.

The federation holds regularly a national cave science symposium. The last one was in Eskişehir, 1st Balkan Speleology Symposium and 6th National Cave Science Symposium in November 2012. (www.speleolojisempozyumu.org). Also, the federation publishes a magazine called SpeleoTurk since 2004.

Figure 1. SFT Logo.

The official web site of the SFT is www.tumafed.org. The logo of the SFT is shown in Figure 1. The contact person of the SFT is the General Secretary Meltem Pancarcı (meltempan@yahoo.com, +90 506 3307560).

4. Summary

Caving and speleological research accelerated noticeably after the 1990ies in Turkey. Caving associations and university clubs at first joined under the umbrella of the Turkish Cavers Union (TCU) in 1998 and then founded the Speleological Federation of Turkey, 17th November, 2009. Cave training standards were improved and national training camps, and workshops and symposia on cave science were conducted. A group for cave protection was established and the SFT is working with related ministries on rewriting cave protection laws in Turkey. Furthermore a national cave rescue team was established. SFT is open for cooperation with cavers from abroad.

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Türkiye Mağaracılık Federasyonu. http://www.tumafed.org

A HISTORICAL DATASET: MARCEL LOUBENS AND THE GOUFFRE DE LA PIERRE ST. MARTIN

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This brief article reports about a significant documentation, quite relevant to the history of speleology, eventfully found quite recently: seventeen photographs, dating back to the 50's of the last Century, and concerning the incident of Marcel Loubens in the "Gouffre de la Pierre Saint Martin".

1. Introduction

Some years ago in a flea market, an envelope with 17 pictures was found, with a written note on it: "Photos sent by the French Consulate in Florence on May the 17th 1955".

In June 2012, two commemorative plaques in memory of Beppo Occhialini and Giulio Racah were set on the wall of the Corchia Show Cave entrance, the sa called Antro di Corchia, a cave system in the Apuan Alps (Italy). Occhialini and Racah carried out many explorations in the Corchia Cave, during the '30s of the last Century. This event called the attention to the old photos, forgotten in a drawer. It seems to the owner of the photos rather appropriate to deliver such memories to the 16th International Congress of Speleology, especially for their intrinsic historical value.

Figure 1. The boundary stone between the French and Spanish border, which gave the name to the pothole.

Figure 2. Marcel Loubens at the entrance of the pothole "Gouffre de la Pierre St. Martin" in August 1951.

Figure 3. The preparation of the Loubens' rescue inside a shepherd's hut.

Figure 4. After the cable failure and Loubens' fall, the Lyon scouts try to descende by ladders (August 1952).

Figure 6. The special container for the recovery of Loubens' body is transferred to the camp at the entrance of the doline. In front Norbert Casteret (right) and José Bidegain, behind Robert Lévi and George Lépineux.

Figure 5. August 1954: the Loubens' body recovery operation starts. Three tons of various equipment are parachuted on the top of Soum de Lèches. A special container for the recovery of Loubens' body was also used.

Figure 7. Robert-J. Lévi (left) and Norbert Casteret (middle).

Figure 8. The Lyon scouts move from Picq Atheray towards the pothole for the recovery of Loubens' body.

Figure 9. The doline at the top of the pothole.

Figure 10. Assembling of the winch.

Figure 11. The engineer Corentin Queffélec at the winch board.

Figure 12. The preparation for the descent: waterproof caving suit, helmet and harness.

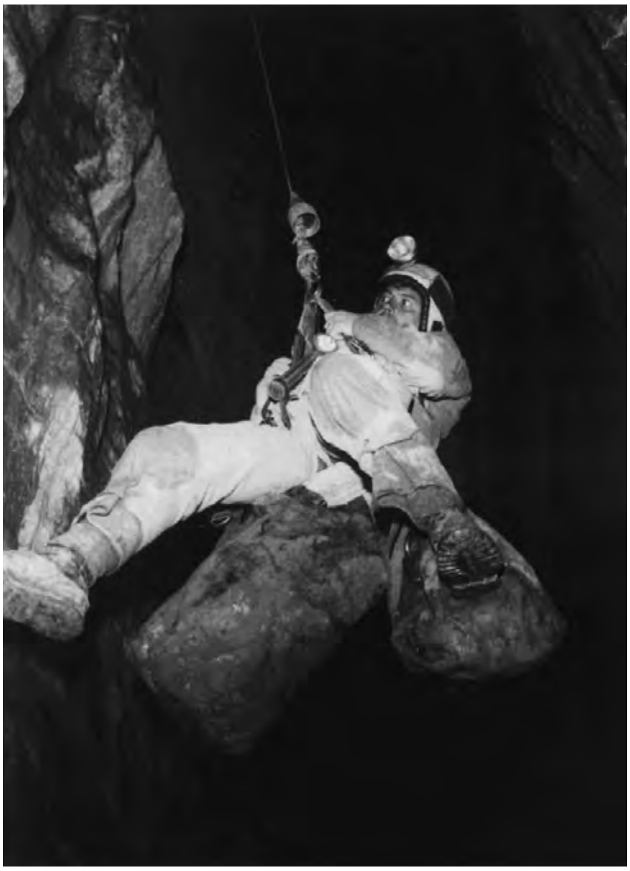

Figure 14. Jacques Labeyrie descending into the pothole.

Figure 13. Norbert Casteret, the first one to enteri the pothole.

Figure 15. The container for Marcel Loubens' body descending the pothole.

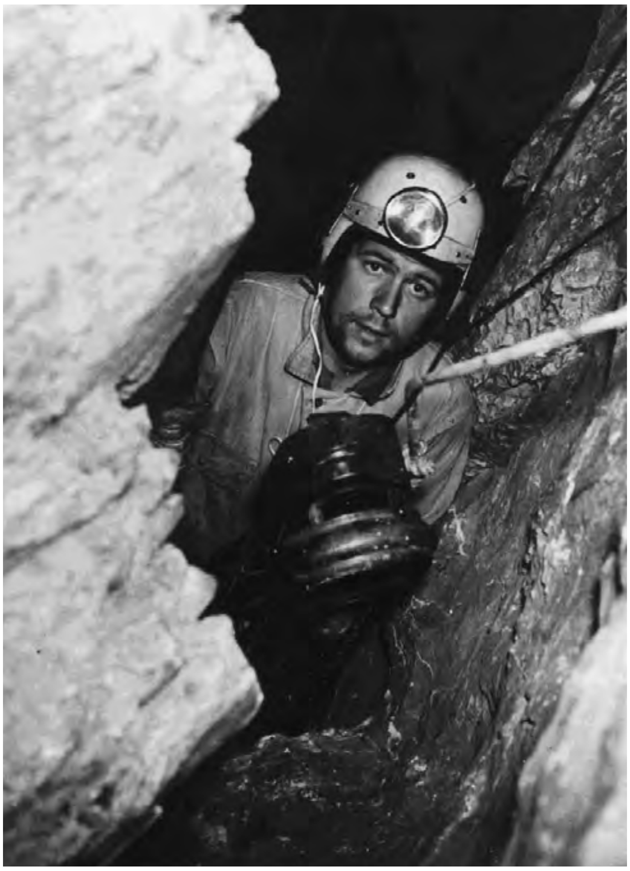

Figure 16. José Bidegain, who will recover Marcel Loubens' body, going down with his descender.

Figure 17. The first grave of Marcel Loubens with the inscription written by Beppo Occhialini: ICI MARCEL LOUBENS A VEÇU LES DERNIERS JOURS DE SA VIE COURAGEUSE (Here Marcel Loubens lived the last days of his brave life).

Acknowledgments

The contribution of some friends was instrumental in preparing this note: Margherita Cigna, Francesco De Sio, Fabrizio Fallani, Daniela Pani.

THE ALBURNI MASSIF, THE MOST IMPORTANT KARST AREA OF SOUTHERN ITALY: HISTORY OF CAVE EXPLORATION AND RECENT DEVELOPMENTS

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The Alburni Massif (Campania, southern Italy) is a karst mountain extremely rich in caves and other karst landforms, situated between the valleys of the rivers Calore and Tanagro. After some initial activities at the turn between the 19th and 20th centuries, systematic speleological explorations were carried out in the early 50s by the Commissione Grotte "Eugenio Boegan". During the following decades, the push toward further explorations reduced, until, in the late '80s the will to explore together gave life to AIRES, an association joining cavers from many different grottos. The main outcome of this co-operation was a book, entirely dedicated to the Alburni caves, which is still today the most important reference to study the area. In the 90's, the activities went on, even though not within the framework of a co-operated action. Nevertheless, several important exploration results were obtained. Recently, it was again decided to make a joint effort in order to better plan and carry out research in the Alburni; thus, the Alburni Exploration Team was born, and since 2009 all the activities in the area are duly coordinated, and the news about any discovery is shared with all the interested cavers in real time, also by means of a dedicated website. The present article describes briefly the history of explorations in the Alburni Massif, following the main phases of research, and then focusing on the activities carried out in the last years. Aims of the paper are to present to an international audience the potentials of this karst area, to attract the interest of other cavers, and disseminate the information about karst and caves of Alburni to the local population, as a fundamental step toward protection and safeguarding of this precious natural environment.

1. Introduction

The Alburni Massif (Fig. 1) is located in the Apennine Chain of Italy (Campania region), and represents the most significant karst area of Southern Italy. The name Alburni takes its root from a word meaning white, due to the main color characterizing the area, related to exposure of the carbonate rocks. The massif has been the object of several cave expeditions, due to a greawt variety of karst landforms, including some hundreds of caves. After a period of relative still in the exploring activities, in recent years a new phase was started, thanks to the re-established co-operation among the main grottos working in the area.

This article describes the history of the main phases of caving research and exploration in the Alburni Massif, aimed at highlighting the importance of this karst area, and to show the many potentialities it has for further developments; following a geological and morphological introduction to the area, the main activities carried out during the years will be described, and the new (still on-going) research mentioned, before concluding the article with future perspectives for caving activity in the area.

2. Geological and morphological setting

The Alburni Massif is in the heart of the Cilento and Vallo di Diano National Park, between the valleys of the rivers Calore and Tanagro, and represents a karst ridge extremely rich in dolines, ponors, caves, and swallow holes. The karst nature of the area is illustrated by the presence of over 400 caves explored so far (Table 1). Among these, the most

Figure 1. The Alburni Massif seen from NW (photo: F. Maurano).

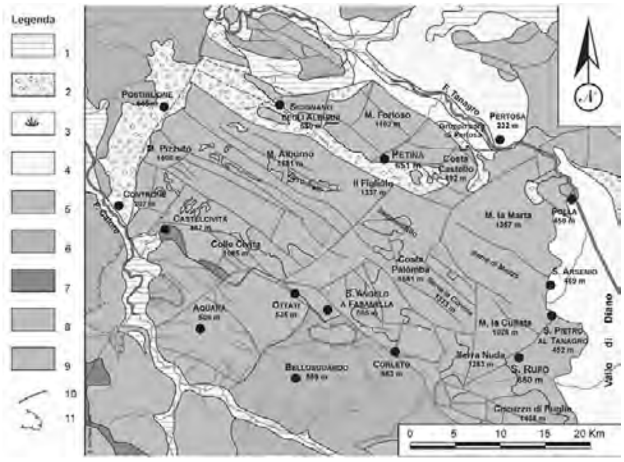

Figure 2. *Geological sketch of the study area. Key: 1) alluvial deposits; 2) debris; 3) lacustrine deposits; 4) conglomerates (Pliocene); 5) marly limestones and quartz sandstones; 6) varicoloured clays; 7) limestones and marls; 8) Mesozoic limestones; 9) dolostones and dolomitic limestones (Upper Triassic – Jurassic); 10) fault; 11) overthrust.*

famous are represented by the show caves of Castelcivita, the longest in Southern Italy with a total length of 5.4 km, and of Pertosa, about 3 km long (Parise 2011). Covering a total area of about 280 square kilometers, the massif is one of the many carbonate ridges of Southern Italy, mostly consisting of limestones and dolomitic limestones of Mesozoic age, originated in carbonate platform environments. Karst features are mostly concentrated within the Cretaceous sequence, with overall thickness over one thousand meters. Apart from the Mesozoic deposits, more recent, Miocene terrigenous formations can be found laterally to the limestones along the sides of the massif, and as filling materials within structural basins developed at the highplain.

Table 1. Main caves in the Alburni Massif. The star in the last column indicates spatial development of the cave.

Cadastral no.	Name (m)	Depth	Development (m)
Cp 94	Fumo	443	1,590
Cp 255	Gentili	437	2,036 *
Cp 472	Piani S. Maria III	422	1,850
Cp 1406	Campo	403	1,542 *
Cp 244	Gatti I	402	657
Cp 253	Vitelli	385	1,800
Cp 487	Ossa	291	250
Cp 92	Madonna del Monte	288	435
Cp 671	Confine II	266	461
Cp 93	Melicupolo	259	154
Cp 86	Piani S. Maria I	253	755

As concerns the geomorphological setting, the Alburni Massif can be described as a monoclinal structure gently dipping to the SW; delimited by fault scarps (main systems N 030°, N 070°, and N 120°), the massif shows a summit plateau, developed in elevation between 1,000 and 1,500 m a.s.l., where many closed basins of karst origin can be identified. A great variety of surface and subterranean karst landforms has developed in the area, and represents the main character of this mountain.

Basal springs are distributed at the SW and NE sides, with mean discharges ranging from 3 to 7 m^3/sec (Celico 1979).

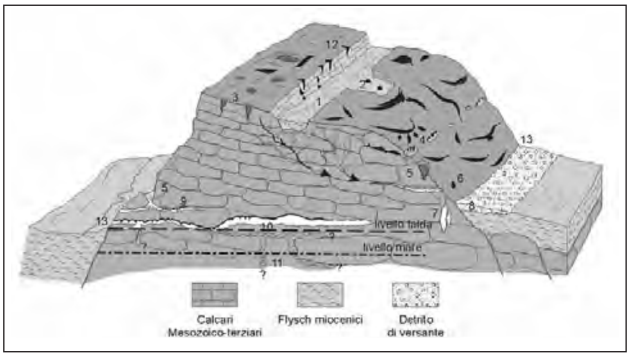

Figure 3. Morphological sketch of the Alburni Massif (after Santangelo and Santo, 1997). Key: 1) swallow holes along fault walls; 2) swallow holes in valleys; 3) surface solution shaft; 4) intrastratal caves; 5) collapse sinkhole; 6) spring; 7) inverse erosion shaft; 8) cave due to lateral spreading; 9) fossil hanging phreatic conduits; 10) phreatic conduits related to the present water table; 11) water table karst conduits; 12) vertical shaft along fracture; 13) basal spring.

Location of these springs between elevation from 260 to 70 m a.s.l. shows that the overall thickness of potentially karstifiable limestones exceeds one thousand meters (Santangelo and Santo 1997).

In addition to classical karst caves in the Mesozoic limestones, it has to be pointed out that different types of caves can be observed, which also include those produced by landslides in the slope breccias deposits ("lateral spreading caves" according to Santangelo and Santo 1997).

Several caves open in correspondence of swallow holes, as described by Santangelo and Santo (1997): vertical inputs from perforated overlying beds, and lateral inputs from adjacent impervious rocks (contact ponors), represented by the clays of the Miocene flysch formations. As concerns the morphological position of the swallow holes, these are mostly located along fault scarps or at the lowest points of endorheic valleys and basins.

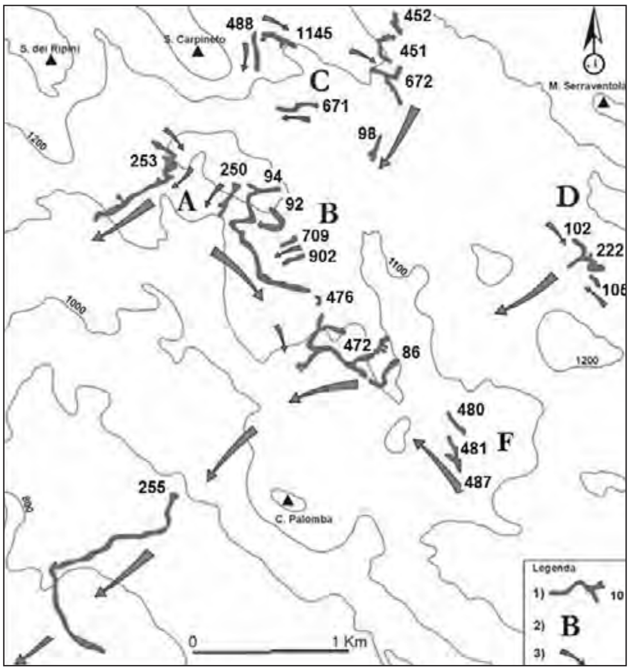

Figure 4. Network of the main karst systems in the central sector of Alburni. Key to symbols: 1) caves (numbers indicate the entry in the Campania register); 2) main endorheic basins (see Table 2); 3) underground flow direction, by cave explorations and tracing tests.

Progressive development of erosional processes in many cases caused the downward migration of the input sites, which resulted in the presence of both inactive (the oldest and highest) and active (the youngest and topographically lowest) ponors. There is an overall dependence of the size of ponors (and the related subterranean karst systems as well) with that of the feeding catchments: the dimensions of the inactive ponors are larger than those of the active ones, which should derive from wider areas collecting water and transporting it toward the input points.

entered 300 m into the cave. They were not able to find their way out, and were rescued only eight days later. One of the brothers died soon after, and the other went insane.

The Castelcivita karst system became a show cave in 1930, and two years later also at Pertosa the cave was opened to the public. At this latter site, however, the first lighting system was installed only 30 years later, due to a dispute between the municipalities of Pertosa and Auletta (Russo et al. 2005; Parise 2011).

Table 2. List of the main caves in the central sector of Alburni Massif (shown in Figure 4), and their main characteristics. In the last column, the first letter indicates position of the cave access at the valley bottom (v) or along a faults scarp (f), and the second (in upper case) the endorheic basins, as shown in Figure 4.

Cave no.	Cave	Length (m)	Depth (m)	Catchment basin (km^2)	Activity	Location (see Fig. 4)
Cp 253	Vitelli	1,800	385	-	inactive	f in A
Cp 92	Madonna del Monte	435	288	0.12	active	f in A
Cp 250	Fra’ Gentile	335	232	-	inactive	f in A
Cp 94	Fumo	1,590	443	1.14	active	f in A
Cp 709	R. Lombardi	108	147	-	inactive	f in A
Cp 86	Piani S. Maria I	755	253	0.25	active	f in B
Cp 472	Piani S. Maria III	1,850	422	0.81	active	f in B
Cp 476	Gravaccine	54	51	0.37	inactive	f in B
Cp 902	Stretta	235	113	-	inactive	f in B
Cp 451	La Pila I	700	122	0.34	active	v in C
Cp 452	La Pila II	265	153	0.37	active	v in C
Cp 672	Inverno	1,420	201	-	inactive	f in C
Cp 488	S. Carpineto	500	117	0.23	active	f in C
Cp 1145	Cavaggione	300	226	-	inactive	f in C
Cp 98	Confine I	240	216	0.44	active	f in C
Cp 671	Confine II	461	266	-	inactive	f in C
Cp 102	Parchitiello I	565	205	0.25	active	v in D
Cp 222	Parchitiello II	4	7	-	inactive	v in D
Cp 105	T. Aresta	144	116	-	inactive	v in D
Cp 480	Varroncelli I	160	118	0.27	active	f in F
Cp 481	Varroncelli	100	127	-	inactive	f in F
Cp 487	Ossa	250	291	-	inactive	f in F
Cp 255	Gentili	2,036	437	1.03	active	

Karst appears to be controlled by a combination of lithological and structural features, starting from the local structural setting and the relationship between bedding and water flow direction (Fig. 4).

3. History of explorations

3.1. Man and the caves in the Alburni Massif

Even though with less remains than those found in many other caves located near the coasts of Campania, some Alburni caves testify to the frequentation by man since Paleolithic times (Pellegrini and Piperno 2005). This in particular occurred for the most accessible sites, located at the foothills of the massif, and/or close to water sources.

Apart from the prehistoric frequentations, as concerns the main topic of this article, that is caving explorations, the pioneering activity actually began during the 19th century, and had a tragic end (Boegan and Anelli 1930): in 1889, two brothers from a nearby town entered the Castelcivita cave using oil lamps to explore the system, still unknown at that time. Carbon dioxide from a lateral branch of the cave system extinguished the lamps after the two had

3.2. Beginning of the caving activities

At the beginning of the 1920’s, the Commissione Grotte “Eugenio Boegan” from Trieste, the oldest grotto in Italy, began its caving activity in the Alburni Massif. Since that time, with an increasing pace in the 50’s and 70’s, the explorations were carried out systematically, producing remarkable results in terms of numbers of explored caves. The surveys were published in several articles. These provided the first documents showing the remarkable features of the Alburni Massif, and the exploration potentials of the area (Vianello 1965). Thus, many other cavers from different parts of Italy became to be interested to cover this area in their activities.

In 1950, the Gruppo Speleologico CAI Napoli began to work in the area, especially carrying out scuba diving explorations. The above mentioned grottos were followed later on by Circolo Speleologico Meridionale and, in the years 1960–70s, by other grottos from Latium: namely, Circolo Speleologico Romano and Speleo Club Roma. In the late ’80s, after some years of minor activity, the change to new exploration techniques led to abandonment of cable ladders. Nylon ropes and new, more reliable and lightweight gear allowed to carry out better explorations within the abysses of the Alburni Massif.

Three grottos (Gruppo Speleologico Martinese, Gruppo Speleologico Dauno and Gruppo Speleologico CAI Napoli) were the most active at that time and began to co-operate during the explorations. At the same time, they also produced a survey register, where all the informations about the outcomes of each survey were recorded. Toward the end of the ’80s, to stress the joint will to explore together, AIRES was born, as an association covering different grottos and aimed at obtaining the best from joint explorations and researches. In this way, the Alburni Massif became an important meeting point for all Italian cavers.

The main outcome of this crucial period in the exploration history of the area is the book "Alburni Mountains – speleological researches" (Bellucci et al. 1995). It is still today the main reference for anybody interested in exploring the Alburni caves. During the middle ‘90s further cavers are attracted to the Alburni. As a consequence, new results are obtained in caves such as Grava del Casone Vecchio, Auletta, Piani di S. Maria, and Grava d'Inverno. In the time period 1994–96, systematic explorations were carried out in branches of Grava II dei Gatti, and the overall cave topography increased three times (from 500 to 1,500 m of development).

In 1997, at Grave del Casone a 140-m deep shaft was found and explored and new ways of continuation in the karst system were hypothesized. Unfortunately the following exploration camps were not able to produce significant results. During the 1998 summer camp, remains of a cave bear were found at the grotta Milano; the remains were later recovered in November 2005 in collaboration with the Earth Sciences Department of "Federico II" University in Naples (Meloro 2007).

During the 2001 summer camp the Piani di Santa Maria karst complex was examined, and previously known caves were connected (Proietto and Buongiorno 2001). In two years (2002–2003) exploration activities performed mostly in winter times were carried out at Grava dell'Auletta by cavers from Campania, Apulia, Molise, Latium and Umbria; the exploration efforts allowed to double the original depth of the cave (Buongiorno 2003; Russo et al. 2003). New caves have been found in the meanwhile (2005) in the massif, adding further data and information to the overall evelopment of karst in the area: Grava di Cesare (23 m deep) and Grava di Matteo (85 m deep).

3.3. Scuba diving explorations

Notwithstanding the huge karst potential in the Alburni Massif, scuba diving explorations have been limited so far to a quite small number of caves. This because many sumps end in lakes of small size, with unpassable narrow conduits, or water flow moving within passages with gravel and sand deposits. At this regard, we recall here the dives at Serra Carpineto and at Falco, carried out between the end of the ‘80s and the early ‘90s by GS Neretino.

Most of the scuba diving explorations, on the other hand, were interested in the springs located at the massif foothills: Old Mill and Ausino in the Castelcivita territory, and Auso at S. Angelo a Fasanella. At Castelcivita the first attempts date back to the ‘60s, but only in the following decade the research became systematic, thanks to the efforts by CAI Napoli. A tragic event, however, marked the beginning of a still period, when in 1973 three divers (Giulio de Julio Garbrecht, Giandavide Follaca and Sergio Peruzy) lost their lives at the Old Mill resurgence. After this tragedy, the scuba diving activity by CAI Napoli re-started only in 2005. Nevertheless, some activity was produced by other divers from different parts of Italy: in the early ‘90s a group from Foligno succeeded to link Castelcivita and Ausino caves. In about the same years, M. Bollati, L. Casati and J.J. Bollanz brought the Old Mill explorations to a depth of 117 m, with an overall development of 450 m. In 2001 the activity went ahead, again thanks to L. Casati and Z. Zenkak, who were able to increase the development of the explored cave to 550 m, with a branch rising upward to -85 m.

Explorations at the Auso started in the ‘90s and had no significant outcomes initially. This was due to the impossibility to open a passage in the slide deposits in the main basin. During the same years, the lucky discovery by GS Martinese of an inclined phreatic conduit ending with a 10m-deep shaft flooded at its bottom (Lo Mastro, 2010) has to be noted. A preliminary inspection, carried out without the use of tanks, resulted in the identification of a large passage, with an estimated length of some 30 m. In 1993 R. Onorato and in 1994 M. Diana explored the passage and, through a large room, came out in another air-filled cavern leading back to the slide deposits in the basin. The last explorations are dated 1998, when a team composed of M. Diana, R. Malatesta and G. Caramanna, entering the new passage identified in 1994, surveyed about 200 m of air passage, and found a new submerged gallery of about 30 m, that remained unexplored so far.

3.4. The Alburni Exploration Team (AET)

During a national cave meeting in 2008, the idea of joining again the efforts was shared by cavers from Apulia and Campania. Immediately after, it was decided to give life to the Alburni Exploration Team (AET) as a natural follow-up of AIRES. An important point was the will to directly involve the local populations, both to disseminate the results reached and to add further value (that is, the karst caves) to this territory, very rich of natural beauties.

Figure 5. Grava d'Inverno: the meanders in the newly explored sectors (photo: F. Maurano).

The main explorations carried out in the last years by AET are those at Grava d'Inverno, Grava del Campo, Grava dei Vitelli, and Grotta del Vento.

Tens of cavers have worked in the time period 2006–2008 at Grava d'Inverno, carrying out an exploration that, even though mostly sub-horizontal, had several degrees of difficulties due to the many narrow passages, the presence of mud, and several areas with breakdown deposits. Nevertheless, the final outcome resulted in greatly extending the known development of the cave, reaching 201 m of depth, and a length of over 1.4 km, which makes Grava d'Inverno one of the longest caves in the massif (Maurano et al. 2009).

Grava del Campo was one of the many swallow holes clogged by sediments at its bottom; however, a small climb allowed in August 2008 to find a narrow meander through which, after a number of steps, a further winding sector, with sharp bends, was reached. The difficulties to move in that part of the cave were overcome by the evidence of further voids ahead, testified by the strong air current. Thus, after much work to widen the passage, at the end of the summer 2009 a caver went through and explored alone the two successive shafts beyond the narrow passage. Continuing the exploration later resulted in finding alternating shafts and horizontal passages, until the final meander, ending in a sump at the depth of 403 m, was reached. Grava del Campo represents today the fourth deepest cave in Campania, and is over 1.5 km long.

Figure 6. Grava del Campo: coming out from one of the narrow passages (photo: G. Pinto).

Grava dei Vitelli was discovered in 1962 by CGEB and was later object (1987–1990) of explorations that brought its development to 1,880 m, with depth of 385 m (Bellucci et al. 1995). In 2009, at a depth of 270 m, some cavers have performed a 30-m high climb, finding new spaces consisting of meanders and conduits alternating with small rooms with breakdown deposits and some shafts. After some 500 mt of development, for a difference in elevation of +100 m, cavers are today blocked by an intermittent sump. During the explorations, a remnant of a red deer antler was found.

Starting from field observations and analysis of the main caves in the area, in the last years GS Martinese has worked in the sector of the massif where three of the most important caves (Madonna del Monte, Fra' Gentile, and Fumo) are located. The three caves are likely parts of a single karst system and should connect to a basal underground river, so far never reached. With such an aim, detailed surveys allowed in 2010 to identify an important fault, and a work of identification and mapping of the dolines in the area brought to discover what seemed a fossil cave: 30-m deep, it ended clogged by mud and sediments, but with an open crack on one side, from which a very strong air current came out that gave the cave its name: Grotta del Vento (Wind Cave). The obstacle was finally removed with much work, reaching new underground void. From there a narrow passage (passed after many days of hard work), led to a tectonically-controlled shaft that was estimated to be about 150 m deep. At around half of its depth, the shaft is divided in two sectors by a wide rock terrace; this passage allows, on one side, to connect to Grava del Fumo, in a 100 m-deep shaft (Fig. 7). Thus, Wind Cave is the fossil sector of the same system of Grava del Fumo.

As demonstrated, even though this area has always been one of the most frequented by cavers, further possibilities of explorations still exist, and hopefully will result in the future to discover and understand the functioning of the hydrologic system of the Alburni Massif.

4. Conclusions

The Alburni Massif is without any doubt one of the most remarkable karst areas of Italy and has been too often underestimated in the past, in terms of it karst potential. The history of speleology briefly described in this paper documents that the activities carried out in the area have often had no continuity, with many efforts produced individually by small group of cavers. On the other hand, remarkable results have been reached when carefully planning the activities (also on a sound scientific basis), and concentrating the efforts on a single cave or karst system. In this latter regard, the recent foundation of the Alburni Exploration Team and the derived will to strongly move toward a common goal, is very important and hopefully will yield other, important results in the near future.

At the same time, we would like to close this article by highlighting a very crucial aspect that so far was never been dealt with in such a manner: that is, the communication with the local population. It is aimed at disseminating the results of the caving activities, by involving as much as possible the local communities in speleological activities, and in transferring to them the importance to safeguard and protect the very peculiar and fragile environment represented by karst, both at the surface and underground, in an attempt toward living in a sustainable way in karst areas.

Acknowledgments

The researches and explorations carried out in the Alburni Massifs would had not been possible without the passionate work and the fatigue of many cavers from different parts of Italy that over the years made it possible to reach the results described here. We warmly dedicate the present article to all of them.

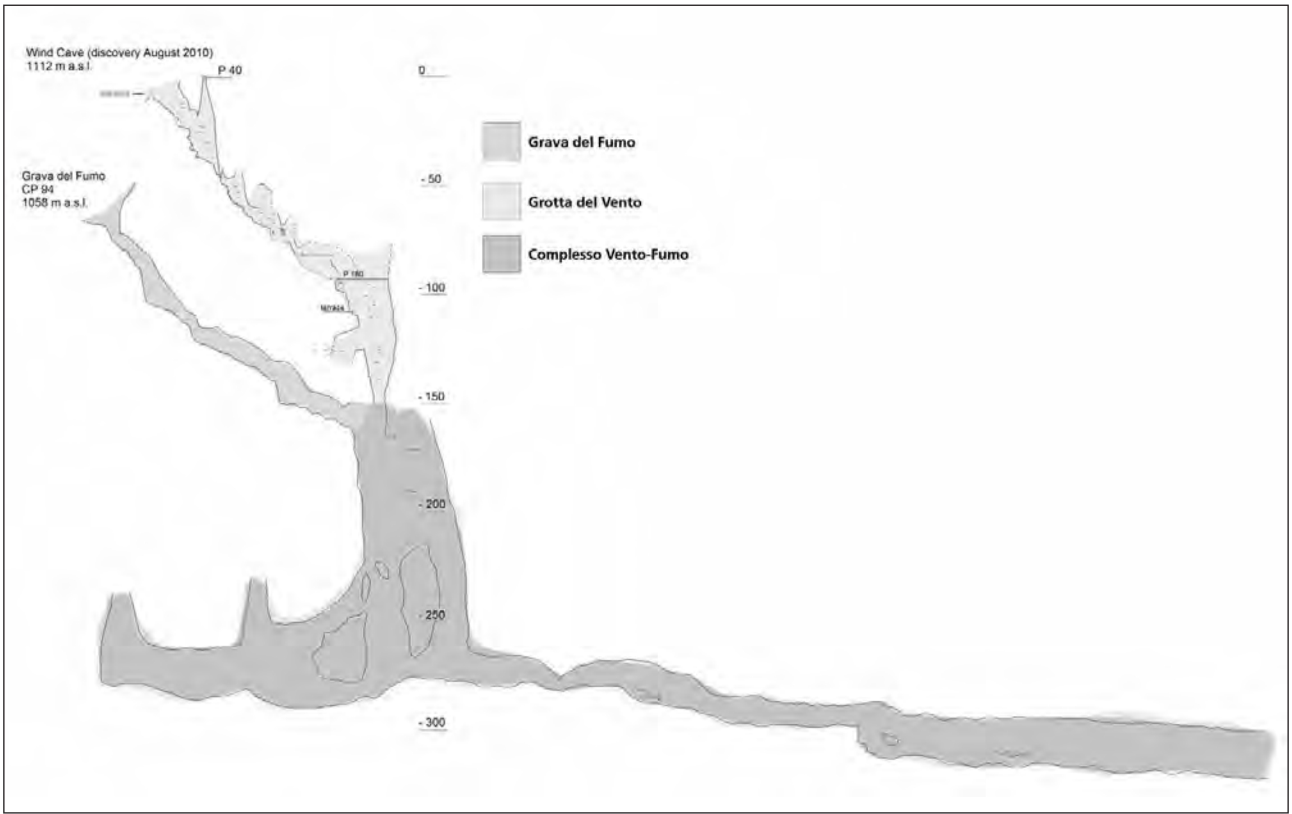

Figure 7. The system Grava del Fumo – Grotta del Vento, that now is the deepest karst cave in Campania (-443 m). Drawing: O. Lacarbonara.

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A MASTERPIECE OF HISTORIC CAVE SURVEYING: SEVERAL REPRESENTATIONS OF MIREMONT-ROUFFIGNAC CAVE (DORDOGNE, FRANCE), XVIII–XIXth CENTURIES

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Miremont-Rouffignac is a horizontal cave, more than 4 km long; it seems like a true maze. Here we present three unpublished surveys which have been drawn up between ca. 1765 and 1824. They have just been re-discovered and they are really spectacular. When Martel came to Miremont-Rouffignac in 1893, at least five different maps of the cave had already been drawn.

1. Introduction

The cave of Miremont-Rouffignac is known at least since the end of the XVIth century and was often visited. Miremont is a horizontal cave, more than 4 km long; it seems like a true maze in which visitors were afraid of losing their way. To avoid such accidents, visitors tried to draw the map of the cave as they advanced further and further (Delluc, 1981). At the same time, engineers tried to draw up accurate surveys, possible in an effort to link them to the surface cadastre.

Cave science historians (Bouchereau 1967 and 1970; Bitard 1978; Shaw 1992; Guichard 1993; Choppy 2002) have noticed for a long time that the cave of Miremont has been surveyed early on but many questions remained unanswered. This paper presents three unpublished surveys which have been drawn up between ca. 1765 and 1824. These have just been re-discovered and they are really spectacular.

2. Three unpublished surveys

The first of these maps is preserved in the French National Library in Paris; it is an anonymous small map (22 × 16.5 cm), well coloured. The author of this map has not yet been identified, neither the circumstances of its survey. The accuracy of this map is very good, including the narrow access to the underground little river (Fig. 1).

The second map was discovered in the Archives of the Departmental Board at Périgueux: larger than the first one (73 × 51.8 cm), it is a very detailed map, showing 28 cross sections and a profile of the entrance (Fig. 2). At least two copies of this map exist and have been published, one by the local painter Bouquier, the other one by the famous engineer Bremontier.

These first two maps were most possibly drawn up between ca. 1765 and 1778; they still pose many questions about authors, dates and circumstances.

The third map is a bit later. It was surveyed in 1824 by Fayard, Marty and Fayolle (Fig. 3). It is kept in the public library in Périgueux. A copy is kept in the Archives of the Departmental Board at Périgueux (published in Delluc 1987). It is also a large coloured map (71 × 50 cm), with an interesting attempt to integrate the geometrical map with a landscape view of the cave entrance.

These coloured maps were made very carefully and accurately. They are witness of a great semiological inventiveness in the art of cave mapping: how to link together map and profiles, how to distinguish dry galleries and underground rivers, how to draw the cave fillings…

At least two more surveys were conducted during the XIXth century: one by Couasnard and Lapradélie in 1840–45 that was lost and never relocated (quoted by Martel 1894, but who didn’t see it), another one by the priest Hippolyte Brugière about 1880. Finally, when Martel came to Miremont-Rouffignac in 1893, at least five different maps of the cave had been drawn, an exception in the history of cave science! Martel, with Rupin and Lalande, spent two days to draw up even a sixth one (Fig. 4).

3. Conclusions

For all these reasons, Miremont-Rouffignac appears to be a major place in the history of speleological investigations and especially for cave surveying. Possibly only Postojna in Europe could be compared with Miremont-Rouffignac.

Acknowledgments

We gratefully thank Jean Bouchereau, Jean-Pierre Bitard and Francis Guichard, the grand old gentlemen of caving in Périgord for their decisive help. This research has given us the opportunity to make their acquaintance and to have with them instructive and glowing discussions: old surveys, new friends!

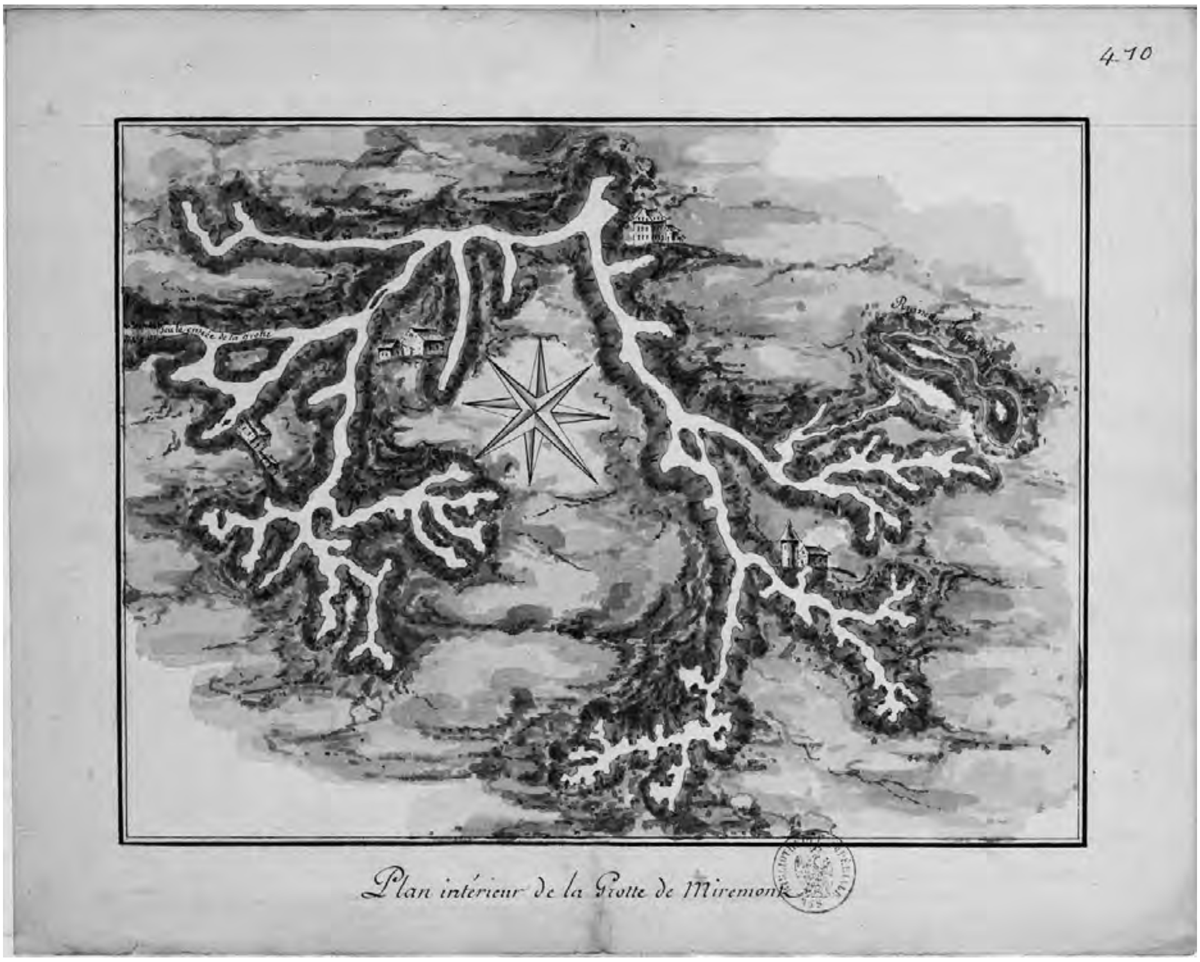

Figure 1. This anonymous little map (22 × 16.5 cm) is preserved in French national Library in Paris. The author has not yet been identified.

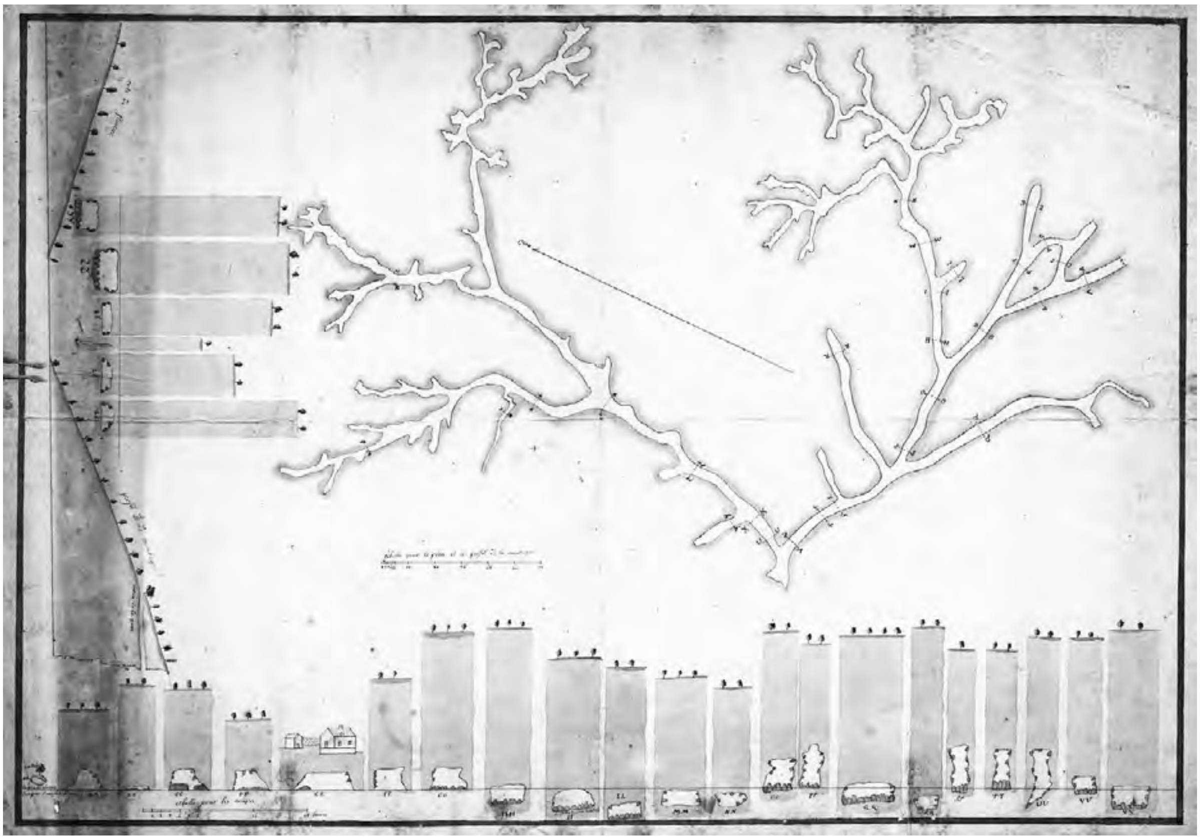

Figure 2. This map has been discovered in the Archives of the Departmental Board at Périgueux (73 × 51.8 cm). It presents a large map, including 28 cross-sections and a profile of the entrance. The author has not yet been identified.

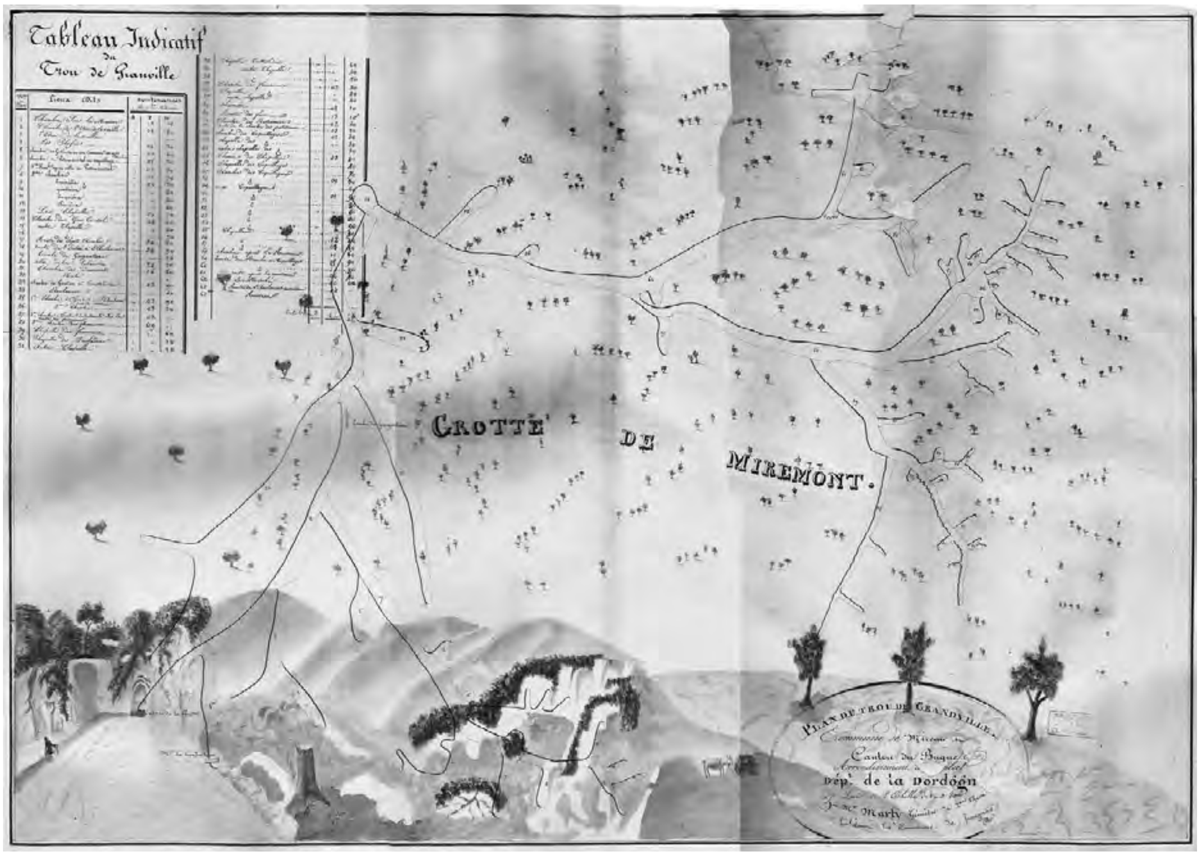

Figure 3. This coloured map (71 × 50 cm) has been surveyed in 1824 by Fayard, Marty and Fayolle. It is kept in the public library at Périgueux (with a copy in the Archives of the Departmental Board at Périgueux).

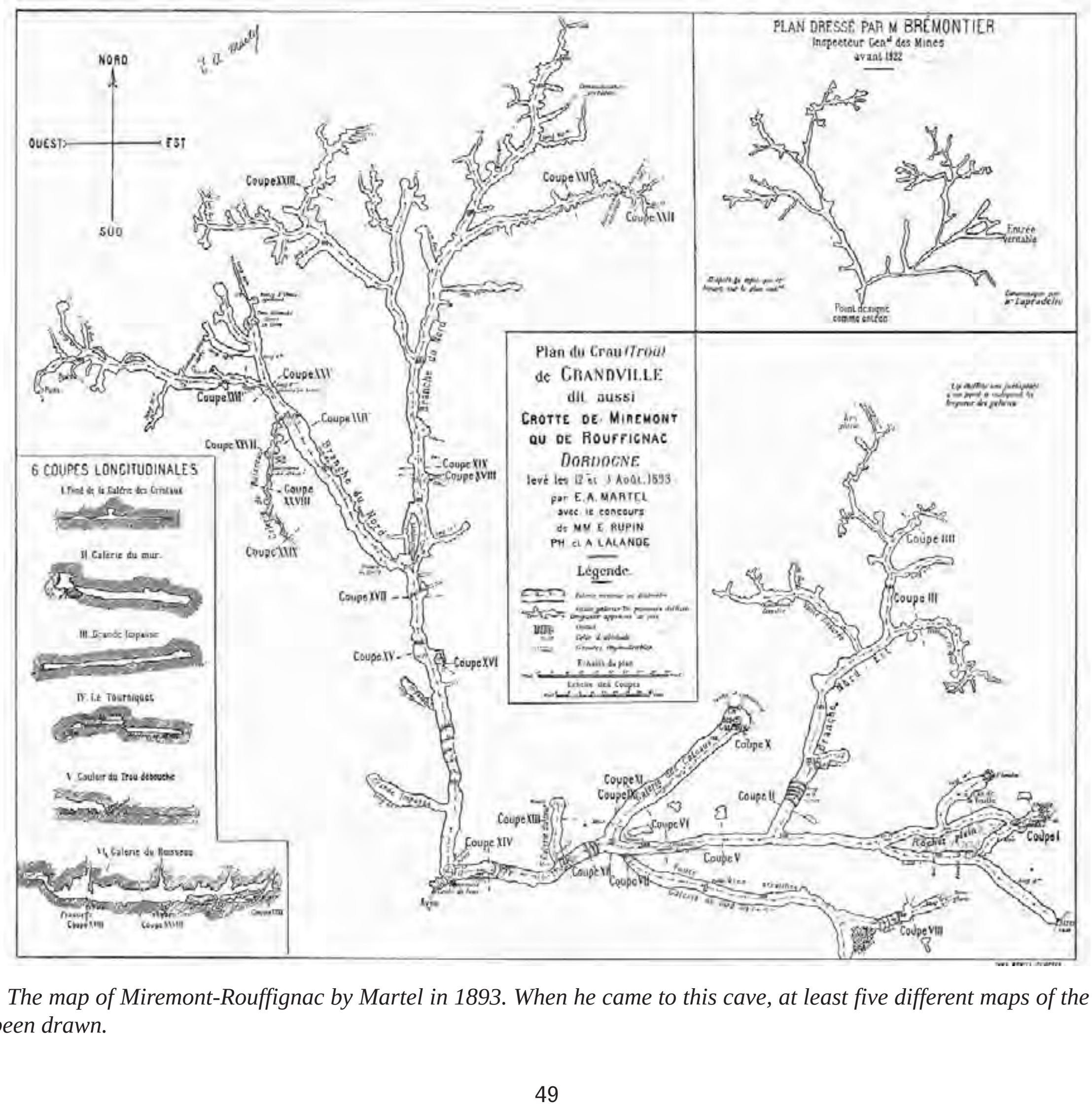

Figure 4. The map of Miremont-Rouffignac by Martel in 1893. When he came to this cave, at least five different maps of the cave had already been drawn.

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SPELEOLOGICAL DEVELOPMENTS IN IRAN SINCE ISEI 2008

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The Iran Speleology Association (ISA) founded by Changiz Sheikhli, a veteran caver, and his friends in 1946 was a head start in developing the activity of caving and speleology in Iran. It was a small group of cavers but with a respectable number of achievements. Unfortunately, due to political reasons and war, Iranian cavers became separated from the international community of cavers resulting in improvised caving and climbing techniques – a dangerous trend that actually cost several lives.

The International Speleological expedition to Iran (ISEI) in 2008 was a great opportunity for the Iranian cavers to reconnect their caving community to the international caving and speleological community. Several national cave meetings inspired by ISEI finally led to the establishment of the Iranian Cavers and Speleologists Association (ICSA) which is considered the true descendant of the ISA. During the past five years after ISEI 2008 Iranian cavers have made appreciable progress in caving techniques and the number of cave discoveries and surveys has increased a great deal.

Joining the UIS in 2013 will be the next objective of Iranian cavers and speleologists in the attempt to have more cooperation with the international caving and speleological society.

1. Introduction

Iran Speleology Association (ISA) founded by Changiz Sheikhli, a veteran caver, and his friends in 1946 (Fig. 1) was a head start in developing the activity of caving and speleology in Iran. It was a small gathering of cavers which had appreciable achievements. Unfortunately due to political reasons and war, Iranian cavers got separated from the international community of cavers which resulted in improvised climbing techniques in caves – a dangerous trend which cost several lives.

Figure 1. ISA board of directors in 1946.

In 2007, after a visit paid to Iran by Fadi Nader, UIS general secretary, having a meeting with Ms. Leila Esfandiari, Mr. AfshinYousefi and Mr. Kazem Faridyan, the countdown to start a great speleological event began. Damavand Club sponsored by the Cultural Heritage Organization hosted 14 members of UIS from five different countries and the International Speleological Expedition to Iran (ISEI) was held in 2008 under the excellent joint leadership of Mr. Javad Nezamdoost and Dr. Fadi Nader (Fig. 2).

Figure 2. ISEI2008 logo.

2. Achievements and activities

ISEI 2008 was a gathering of enthusiastic Iranian cavers which resulted in uniting them nationally. This unity was first visible five months later in Ghar Baton near Mashhad at a national gathering of cavers and continued to be felt at several other similar gatherings in different regions in Iran until March 2010. Then a national caving gathering led into a poll to elect the board of founders to establish the Iranian Cavers and Speleologists Association (ICSA).

After a year of effort and cooperation the ICSA was finally registered with the Ministry of Internal Affairs as an NGO, an event that was celebrated in the presence of more than 100 cavers from different cities of Iran in March 2011 in Shemshak Hotel near Tehran. There the first ICSA board of directors was elected, namely:

Javad Nezamdoost (ICSA President)

Ghasem Ghaderi (Vice President)

Yousef Vaghef (Financier)

Majid Saghafi

Saeed Hasheminezhad

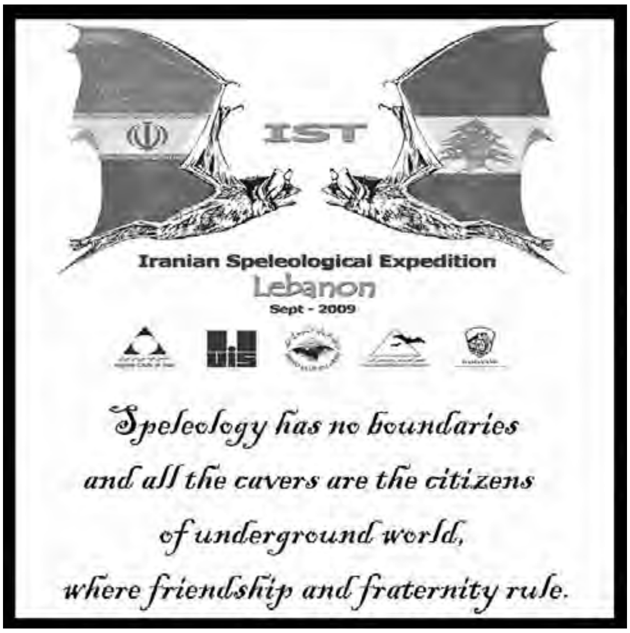

Figure 3. Iranian cavers' motto participating in IST200.

The following meetings were held before and after the official registration of ICSA:

1. Ghar Baton in Sarayan, Mashhad – March 2009
2. Ghar Hampoeel in Maragheh, Tabriz – July 2009
3. IST – Lebanon – September 2009 (Fig. 3)
4. Ghar Parau, Kermanshah – September 2009
5. Ghar Yakhmorad, Cave Rescue Maneuver, Tehran –February 2010
6. Shemshak Hotel, Tehran – March 2010 (ICSA Board of Founders Election)
7. Ghar Hampoeel, Cave Rescue Maneuver, Tabriz – April 2010
8. Ghar Qalaichi, Bokan – July 2010
9. Ghar Jahanbin, Hafshejan – September 2010 (discovering the deepest pit)
10. Day of Clean Caves – September 2010 (the polluted caves in 20 different cities were cleaned)
11. Ghar Angareh-mino, Shiraz – August 2010
12. Akhlomad Valley, Mashhad, self-rescue gathering – December 2010
13. Shemshak Hotel, Tehran – March 2011 (ICSA Board of Directors Election)
14. Salt Domes Expedition, Qeshm Island, Shiraz – April 2012

During most of these gatherings it was attempted to train new cavers and familiarize them with caving techniques, cave mapping and self-rescue techniques (Fig. 4). The gathering in Shiraz was a great chance to meet and attract several speleologists and involve them in caving activities, e.g., Mr. Ezat Raeesi, a well-known Iranian geologist. Mr. Ghasem Ghaderi, ICSA Vice President, is also a geologist who is active in training Iranian cavers in geology.

Establishing good relations with cavers and speleologists of other countries has been a concern from the onset. The recent cooperation of ICSA cavers with geologists of Oxford University to visit and sample some Iranian caves is a good example. Hosting the UIS officers during the Salt Domes Expedition in 2012 was another example. It was also a genuine act of assisting and cooperating with Iranian geo-scientists.

Figure 4. Author descending the first shaft of Ghar Bolour. Photo by Vahid Ashrafi.

A new development among Iranian cavers is that caves are now actively searched for in order to discover new caves and entrances. For example, Ghar Jahanbin was considered the deepest single pit in Iran 140 m deep. Now a pit 208 m deep has been discovered and explored! Several further caves were discovered and surveyed by new cave mappers based on UIS standards (Fig. 5).

There are now also several active websites and weblogs concerned with caving and speleology:

Iranspeleo.com
Irancaves.com
Persiancavers.blogfa.com
& …

It is undeniable that it was the great impact of ISEI2008 and following activities which motivated the Iran Mountaineering and Sport Climbing Federation (IMSF) to activate its Caving Working Group (CWG). Eight months after ISEI2008, five trainers were sent to Poland to participate in a cave training course to learn caving techniques based on the ones practiced in the world of caving and to discard the techniques adopted from rock climbing. Now CWG works as an active department to train cavers and has a close cooperation with some geologists. Arranging a cave rescue training for Iranian cavers with French instructors in September 2012 was another attempt by IMSF to broaden its technical knowledge base.

Another achievement of ISEI2008 and the following activities is the foundation of the National Speleology Working Group ordered by the President's Office in 2009. This working group which considers management of caves in Iran consists of delegates of several national organizations. The president of this work group will be the delegate from the Environmental Conservation Organization. Although there was first only one seat reserved for one NGO delegate both the ICSA and the IMSF now have delegates to represent Iranian cavers.

Figure 5. Map of Ghar Shamsham, one of the first maps sketched according to UIS standards.

3. Conclusion

From the outset it was tried hard to maintain friendly contacts with cavers world-wide in order to keep Iranian cavers and caving techniques up-to-date and to keep pace with international developments. ISEI 2008 was a fruitful attempt which resulted in practicing modern caving techniques and putting a distinctive line between caving and rock climbing in caves!

Recent cooperation of ICSA cavers with geologists of Oxford University to visit and sample some Iranian caves as well as hosting the UIS officers during two fruitful expeditions in Iran have illustrated the Iranian thirst to have more cooperation with the international caving and speleological community. Now, after five years, Iranian speleologists and cavers are ready to join UIS in order to be an active member country.

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50 YEARS OF CAVE RESCUE IN HUNGARY

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The first registered cave rescue operation in Hungary was in 1927. Later in 1932 a cave rescue accident was the reason to establish the first Rescue Society of Counties and Cities. Because of the increasing number of cave accidents the Cave Rescue Service was established within the framework of Hungarian Speleological Society in 1961. The official establishment gave a significant progress and we begun to develop our common equipment base. A few years later we lost the Hungarian Speleological Society for the Hungarian Red Cross because of a change in legal background. Joining to the speleo-education system we published the cavers' safety regulations in 1983. In the same year we had organized the 5th International Cave Rescue Conference in Aggtelek where 16 countries participated. In 1989 the 10th UIS Congress was held in Budapest and on that occasion the UIS Cave Rescue Commission held a symposium as a pre-congress event where 21 countries were represented. The legal background had changed again by the end of 1980's and we left the Hungarian Red Cross and went under the authority of the Hungarian Nature Friend Federation as a member society. Our legal status changed into an independent society on the occasion of the political transition and our new name has been Hungarian Cave Rescue Service (HCRS) since 1991. As an independent organization we have created contracted cooperations with the Police, Ambulance, Civil Protection, Fire Service, Ministry for Environment Protection, Hungarian Speleological Society, and Hungarian Nature Friend Federation. Our target was to cover with our activity as large a part of our country as we could. Therefore we established two country branches: North Hungarian Branch of HCRS with its center at Aggtelek and South Hungarian Branch of HCRS with its center at Pecs. On the base of the experiences of some cross border rescue activities we have created close contacts and regular collaborations with Horská Záchranná Služba (HZS) from Slovakia, Salvaspeo Corsa Romania and Salvamont Bihor also from Romania and Górskie Ochotnicze Pogotowie Ratunkowe (GOPR) from Poland. In 2007 we organized the 11th International Cave Rescue Conference in Aggtelek again. 26 countries participated. During the Conference an important document was born: the Aggtelek Agreement. The Hungarian Cave Rescue Service had celebrated its 50th anniversary of establishment in Pal-volgyi Cave at 29 April, 2011. Now the HCRS has more than 100 members who are all volunteers and we are able to do a cave rescue operation anywhere in our country independently of other organizations.

1. Accidents and rescue operations before HCRS

Hubert Kessler is the person who suffered the first registered cave accident in year 1921. He was 14 years old when he went alone to a cave with a ladder made from clothes-rope and broomstick. He had dropped down his hand light which stopped working. He had no other lighting equipment, not even a match. He rambled for many hours and only by luck did he find his way out.

The first registered rescue operation occurred in autumn of 1927. Participants of an International Speleological Congress went to visit Almasi vertical cave in North Hungary. Hubert Kessler and Gyula Kiss took a metal ladder into the cave and went down 40 meters and they waited for the visitors there. One of the 30 participants at the cave entrance unluckily kicked down a stone that fell into the cave. Kessler and Kiss leant to the wall but a piece of the stone hit the back of Kiss who blacked-out. Later he regained consciousness, but he could not speak and was helpless. A rope was sent down from the surface and Kessler made a sitting loop on it and Kiss was pulled up by the people on the surface.

Later in 1932 seven scouts went to a cave splitting into two groups close to the entrance. The four-member group came back to the surface but the three-member group did not. The four scouts informed the local authority about their lost friends. The authority sent cavers and firemen into the cave to find the three scouts. The firemen used a fanfare for the searching. Because there was no result after 24 hours of searching, the gendarmerie looked for Lajos Barbie who knew that cave well. Finally he found the scouts in the part of the cave which was explored by him six weeks earlier. That event was the reason to establish the first Rescue Society of Counties and Cities.

2. Establishment of Cave Rescue Service

There are no other large cities in the world where one can find so many caves which are so easily accessed by public transport than in Budapest. After the 2nd World War caving became more popular year to year in the early 1950's. A notable step in that progress was the reestablishment of the Hungarian Speleological Society in 1958. Another organization for cavers was the Hungarian Nature Friend Federation. More and more people went cave exploring to look for some adventure. Caves were open then so it was easy to enter them. As a result of that popularity children got lost more frequently. The caves were unknown to police and the fire brigade so that they regularly asked for help from experienced cavers. Within a short period of time a well-functioning alert system was formed between authorities and cavers. Soon it became clear that a well-organized rescue team was in need with standard and experienced members to increase the efficiency of rescue operations (Taródi 2011).

It is interesting that the final step in the establishment of the Cave Rescue Service was a false alert. It concerned two lost students in April, 1961. Almost all of the cavers were looking for them for a week without any result. That long search needed good organization and teamwork. Finally the two students turned up in Yugoslavia where they went to leave Hungary for western countries. On purpose they left false information about themselves that they were in a cave to deceive the searchers.

The lesson was that cavers can be in demand of similar wide range searches any time. After that operation Dr. Gyorgy Denes discussed the situation with speleoclubs and organized the Cave Rescue Service within the framework of the Hungarian Speleological Society, where he was the General Secretary at that time.

3. The first two decades (1961–1980)

The official establishment was a significant progress for the Cave Rescue Service. The Civil Protection gave us a storage room in mid-1960. Earlier all of us were using our personal equipment but after the establishment we began developing our common equipment base. The Police provided transportation, communication and logistic possibilities during rescue operations. In return we helped not only the Police but the Civil Protection and the Fire-service with search of lost people in difficult places and in case of special accidents. We began training regularly and learnt first aid (Fig. 1).

Figure 1. Cave rescuers in the 1960's.

Because of legal changes we lost the Hungarian Speleological Society for the Hungarian Red Cross. There were some serious accidents, but the main activity was to search for persons lost in caves. It became a question of status among cavers to become a member of the Cave Rescue Service within the caving community. Therefore we could select the best candidates. It was a peculiarity of that age that we could not accept those volunteers who had no access to a phone, so that many able cavers could not become a member of the Cave Rescue Service.

Some memorable events happened at that time. In autumn of 1961 three young boys disappeared, but it was not sure if they were in a cave at all. Fortunately one of their friends knew about their earlier caving adventures and he called the Cave Rescue Service. After some questions it became clear in which cave the boys could be. Four hours after the alert and six days after the boys disappeared we found them in a less known passage of the Matyas-Hill Cave. They had entered the cave with only one electric hand light, but it had been dropped and crashed. They suffered severely because of the cold, but more seriously because of lack of water. They had tried to drink their own urine, but that was not the solution. Later they heard some water drops and barely found the source of the noise. They tore out their trouser pockets, knotted them with laterite and when that became wet they pressed that water into their mouths. At the time we found them they already thought that they were practically dead. They had to stay for one month in hospital and luckily regained their health.

In the same year there was another serious accident when a young girl suffered a spinal injury in Meteor Cave. We managed to bring her to the surface and she finished her caving career as a happy mother a few years later.

In the same cave a young boy fell down about eight meters suffering a serious head injury. We brought him to the surface such that his condition did not get worse, but unfortunately he died in hospital two months later.

The danger of losing orientation was illustrated by an event which happened in 1975. Four young boys went caving without notifying anybody and nobody looked for them. Cavers found them six weeks later and the Cave Rescue Service could only recover their remains (Fig. 2).

Figure 2. Recovering four dead boys in 1975.

4. Next period from 1980 to 1991

The UIS Cave Rescue Commission held its 4th Conference in Zakopane (Poland) in 1979 and Hungary was asked to organize the next Conference due in 1983. At the same time Dr. Gyorgy Denes was elected as the General Secretary of the Commission. We decided to organize that event in Aggtelek. At that time our decision was not risk-free because political consent was needed for all international activities, especially to organize an international event. There was no possibility to ask for that consent in Zakopane, but we managed to obtain it after we arrived home.

The early 1980's was the period when many caves were gated. At the same time vertical caving techniques changed from ladders to using rope techniques. Parallel, a well-organized speleo-education system came into existence and we published caving safety regulations in 1983. As a result of that progress the search for lost children became less often but injuries often were more serious. So a reorganization of the Cave Rescue Service became necessary. We functionally divided our activity into "peace" and "rescue operation" time. During "peace time" the president conducted activity democratically but during rescues the operation leader conducted the activity in hierarchical order (Horváth 2011).

That was the situation when we began to organize the 5th International Cave Rescue Conference with 16 countries participating: Austria, Belgium, Bulgaria, Czechoslovakia, France, Germany, Great-Britain, Hungary, Italy, Portugal, Romania, Soviet Union, Spain, Switzerland, United-States, and Yugoslavia. More than 50 presentations concerning cave-rescue equipment, problems, methodology, first aid, rescuer training, accident origin statistics and cave rescue organizations were given. Dr. Gyorgy Denes was elected as Vice-President (Dénes, 1983).

The 10th UIS Congress was held in Budapest (Hungary) in 1989 (Hegedűs 1989). On that occasion the UIS Cave Rescue Commission held a Symposium as a pre-congress event. 21 countries participated: Australia, Austria, Belgium, Bulgaria, Canada, Czechoslovakia, France, Germany, Great-Britain, Greece, Hungary, Italy, Norway, Poland, Romania, Soviet Union, Spain, Sweden, Switzerland, Venezuela, and Yugoslavia (Fig. 3).

Figure 3. André Slagmolen (left) on the Symposium.

The legal background changed again by the end of the 1980's and the Hungarian Nature Friend Federation took over the patronage from the Hungarian Red Cross. Our legal status changed into an independent society on the occasion of the political transition and our new name is Hungarian Cave Rescue Service (HCRS) since 1991.

5. HCRS between 1991–2011

As an independent organization we contracted cooperations with the police, ambulance, civil protection, Fire Department, Ministry of Environment Protection, Hungarian Speleological Society, and Hungarian Nature Friend Federation. Our target was to serve as large a part of our country as possible. To do that we established two country branches: North Hungarian Branch of HCRS with its center at Aggtelek and South Hungarian Branch of HCRS based in Pecs (Fig. 4).

Figure 4. The branches of HCRS.

In 2002 we had to manage two large rescue operations in addition to some smaller ones: In the evening of the 25th of January, 2002, a cave diver had an accident in Rakoczi Cave of Esztramos Hill, North Hungary. That area is a part of the Aggtelek National Park. The cave is known since the early 1920's when it was found by miners. The first survey was made in 1958. Since that time its exploration has been almost continuous both above and below the water level. Nowadays the total length of the passages amounts to 650 meters and the vertical dimension is 87 meters (44 meters below water level).

On that 25th of January ten divers entered the cave for training and photography, divided into three groups. They went into different passages of the cave because the cave's standing waters does not move and stirred-up mud takes a long time to settle. Visibility decreases quickly during each dive. It takes about one month for the water to clear up again.

The first two groups returned from their dive without any problem, but one member of the third group lost his way. He was the last in his group and at a narrow point the guiding rope slipped from his hand and he could not find his way in the muddy water. He swam back into clearer water where he spotted the surface above his head. He rose up and found himself in a very little chamber, but with breathable air. It was a totally unknown part of the cave because the water level was lower than usual and had left the small chamber high and dry. He dived four times to try to find his way back, but he did not manage to locate the dive line, because the 18 meters deep passage was narrow with zero visibility and his air reserve was very small.

The first rescue divers began looking for him immediately, but they could not find him. Later the rescuers heard his crying through the cracks of the rock. That was why they didn't stop the rescue activity. Soon it became clear that they needed more people to solve the situation, so they alerted the Police and the HCRS. The extended rescue operation began and altogether 289 persons participated (64 divers – 55 Hungarians, four Slovaks, five Czechs; and 122 cavers – 89 Hungarians, 28 Slovaks, and five Czechs). There were 286 dives altogether. Fifty-five participants from police, army, companies, municipalities, authorities, fire-departments, ambulance, etc. assisted as well (Adamkó and Hegedűs 2002; Hegedűs 2003).

After 118 hours we rescued the lost diver and brought him to the surface alive (Fig. 5).

Figure 5. The rescued diver after 118 hours in the cave.

In October of the same year a Hungarian speleogroup with experienced cavers went into the Valea Rea Cave, Bihor Mountains, Romania. Their aim was to explore and survey unknown parts of that cave. At 10 o'clock a.m. of 26th October a 32 year old member was injured by a falling rock that broke his right leg causing two open traumata. This happened three kilometers in the cave and 170 meters below the entrance. The Romanian cave rescuers and the HCRS were alerted at 2 p.m. At first medical service was provided to the injured by Romanian and Hungarian doctors. Finally 26 Romanian, 52 Hungarian and four Slovak cave rescuers and 14 other supporting organizations worked for more than 40 hours to bring the victim to the surface. Aggravating circumstances were bad weather and heavy rain in the previous days, because the cave itself is a sinkhole. The rescue base (Fig. 6) was 50 kilometers away from the nearest village and the cave entrance was eight kilometers away from the rescue base, a foot-path not passable for cars.

After the rescuers brought the caver to the cave entrance it took more than two hours to carry him to the rescue base by foot. Romanian ambulance was waiting for him and brought him to the state border where he was put in a Hungarian ambulance, taking him finally to the hospital.

Luckily the injured speleologist regained his health completely and even joined the HCRS later.

On basis of these across-the-border rescue experiences we decided to look for formal collaboration possibilities and currently we have close contacts and a regular collaboration with Horská Záchranná Služba (HZS) from Slovakia, Salvaspeo Corsa and Salvamont Bihor from Romania, and Górskie Ochotnicze Pogotowie Ratunkowe (GOPR) from Poland (Hegedűs 2011).

Figure 6. Rescue base in the Bihor Mountains.

In 2007 we organized the 11th International Cave Rescue Conference in Aggtelek again, with 26 countries participating (Fig. 7). The main topics were organizational aspects of cave rescue, contributions of cave rescue squads to civil protection during disaster, medical aspects from examples of actual rescue operations, cave rescue exercises or training courses, equipment and radio transmission (Hegedűs 2007).

During the Conference an important document was born: the Aggtelek Agreement. The representatives of the 26 countries agreed on certain basic recommendations concerning cave rescue operations. The point was to form rescue teams and to let them operate on a basis legally approved by state authorities. Thus the document, endorsed by our speleological federations, may serve as a support in the negotiations between rescue managers and administrations (Urbain 2011).

Figure 7. Stamp issued on occasion of the 11th International Cave Rescue Conference.

During the Conference Dr. Gyorgy Denes was elected Honorary President of the UIS Cave Rescue Commission.

We celebrated the 50th anniversary of our establishment in Pal-volgyi Cave on 29th April, 2011 (Fig. 8). The participants of that event were our collaboration partners, supporters, old members and many of the rescued persons. The HCRS saved altogether 500 lives during more than 200 rescue operations within 50 years.

Figure 8. A group of the cave rescuers during the 50th anniversary of the Hungarian cave rescue.

6. Nowadays

Today the HCRS has more than 100 members, including seven medical doctors, plenty of rescue and medical equipment and material, plus office and storage space. In this way we are able to conduct cave rescues with an ample logistic background anywhere in our country independently of other organizations. We are organizing education and training on a regular basis. In 2012 we revised the safety regulations of caving that is a part of the speleo-education system. The HCRS members are volunteers and most rescues are on their own cost.

The insurance background of cavers is unsettled in Hungary even for rescuers during operations. Our financial background is also unsettled. The number of sponsors is decreasing from year to year and it is difficult to break even with the costs of rescue operations. We are trying to find regular sponsors. We are widening the range of our activities with others organizations such as the education of firefighters, search and rescue of lost persons in difficult terrain, or assisting paragliders in trouble etc.

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MAGYAR BARLANGI MENTŐSZOLGÁLAT

ATHANASIUS KIRCHER'S CHAPTER XX "ABOUT CAVES, FRACTURES AND THE INNUMERABLE PASSAGES OF THE EARTH" AND THE GROTTO OF ANTIPAROS FROM "MUNDUS SUBTERRANEUS", 1678, TRANSLATED FROM LATIN

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The early literature on caves includes also Latin texts. Apart from short notices of caves in Renaissance and Baroque books, texts dealing with specific caves are rare. Four of those deal with the Baumann's-Cave, Harz. Those of Eckstorm (1589, publ. 1620), Lachmund (1669), and von der Hardt (1702) were translated and published by our group; the text contained in Leibniz' *Protogaea* was already published by Engelhard, 1949. Here we report on the translation of a fifth text, i.e. that of Cornelius Magni describing the first documented visit of the Grotto of Antiparos headed by Count Nointel, French Ambassador to Constantinople, during Christmas of 1673. It is documented in *Mundus Subterraneus* by the Jesuit polyhistorian Athanasius Kircher. In the first edition of his book, 1665, Kircher included only a three-page section on caves (Lib. 2, Cap. 20) but added Magni's letter to it in the third edition on 1678 (possibly already in the second edition) both in Italian and in Latin, thus expanding Cap. 20 to twelve pages. The letter itself, in spite of its length, does not contain many real details and is therefore given only in summary. We suggest that this letter was of immense value to Kircher, as it described a real, recently discovered cave. It therefore served to back up his model of the hydrological cycle that postulated that water was heated by the central fire of Earth and driven up underneath the mountain ranges to feed the sources of rivers.

1. Latin Cave Texts

Caves caused curiosity early on in the history of science (e.g., Shaw, 1992). Little known are the early Latin texts referring to specific caves. The Baumann's-Cave, Harz, Germany, one of the best documented caves in early literature, is the object of several texts in Latin. After Agricola, Matthesius (citations not fully verified) and Gesner briefly mentioned the Baumann's-Cave in the middle of the 16th century, it was Heinrich Eckstorm who wrote the first longer report about the cave in 1589 in Latin (published 1620), albeit without ever visiting the cave. He was followed by Johannes Letzner who visited the cave in 1599 (or shortly later) who gave the first account in German. More German descriptions were to follow in the 17th century, notably those published by Merian in 1650 and 1654. In 1669 Lachmund published a short Latin description in *Oryktographia Hildesheimensis*, based on a visit in 1666. Leibniz visited the cave at the end of the century, but his report was published only 50 years later in his famous *Protogaea*, 1749 (Engelhard, 1949). In 1702 the last of the Latin reports was published by von der Hardt in *Acta eruditorum*, the most important German scientific magazine at that time. It was for the first time accompanied by a map and longitudinal sections of the cave based on a rough survey. The detailed description of all the formations (cross-referenced with the map) established a canon of curiosities shown to visitors for almost two hundred years. The map was copied by Leibniz (1749) and Linné (1779). The texts of Eckstorm, Lachmund and von der Hardt were translated and published by us (Kempe et al., 2004; refer also to this paper for references of the publications mentioned here) while the Leibniz text had been translated earlier by Engelhard (1949) (reproduced in Kempe et al., 2004). Apart from these texts, several others, albeit short, Latin texts relate to caves, specifically dealing with the bones found in the caves, such as Horst (1656). These sources have been dealt with in Kempe et al. (2005).

2. Kircher and the Mundus Subterraneus

One further substantial Latin text deals with caves in general and with one cave in particular (the Grotto of Antiparos). That text is contained in the famous *Mundus Subterraneus* by Athanasius Kircher, first published in 1665 (Fig. 1). G. Naumann and B. Dunsch have translated this text into German. Its full length will be published elsewhere, since it is far too long to be reproduced here.

Athanasius Kircher (Fig. 1) was born in Geisa, a small town in the Rhön/Thüringen/Germany, 26 km NE of Fulda on May 2nd, 1602 and died November 27th, 1680 in Rome (Vonderau Museum Fulda, 2003). He was one of the foremost Jesuit scientists of his day and a true cosmopolitan and polymath, interested in many different subjects. Kircher studied at Geisa, Fulda, Paderborn (where a large karst-spring may have triggered some of his ideas about the water cycle and where he joined the Jesuit Order in 1618), Cologne, Koblenz, Aschaffenburg, Heiligenstadt, Mainz and Speyer. 1622 he had to escape the approaching protestant troops under Duke Christian of Braunschweig-Lüneburg to Cologne. While crossing the frozen Rhine, he broke through the ice and barely managed to save his life. In Heiligenstadt, Kircher became a teacher of mathematics, Hebrew and Syrian and was ordained in 1628. In the following year he became professor of mathematics and ethics at the University of Würzburg. In 1631 Kircher was forced once more to escape from protestant (Swedish) troops, and went to Avignon. Then, in 1633 he was appointed mathematician to the imperial court at Vienna, but also received a professorship for mathematics, physics and oriental languages at the Collegium Romanum in Rome. In 1637 he traveled to Malta, and on his way back to Rome in 1638 he witnessed the devastation caused by recent eruptions of Mount Vesuvius (which he also scaled), again an experience kindling his geological interests. In 1645 he was relieved of his lecture duties to concentrate on his research and publications. His oeuvre is vast: Between 1631 and 1680 he published 44 books containing enormous amounts of copper etchings done according to his instructions. Throughout his life, he corresponded with hundreds of colleagues, of whom nearly 800 are still known by name, and he collected all sorts of natural and artificial objects that were displayed at the Museum Kircherianum in the Collegium Romanum, a must-see for all visitors of the Holy City at the time. After the annulment of the Jesuit Order in 1773, the museum fell into neglect and in 1874 the remaining items were distributed to other Museums in Rome, Turin and Florence.

Mundus Subterraneus was the only book that saw three editions during Kircher's lifetime (1st ed. 1665; Fig. 2). It encompassed two folio volumes with twelve books. Each text page has two columns, accompanied by keywords on both margins (Fig. 3). The 3rd ed. (1678) comprises 346+487 pages. It is available as a one-volume facsimile reprint since the International Geological Congress in Florence, 2004. Both editions are also available on the internet (http://ouhos.org/2011/09/14/athanasius-kircher-mundus-subterraneus-1665/).

Even though the title suggests a comprehensive book on caves, it is actually a textbook on physical geology, dealing with many aspects of the planet Earth.

Figure 1. Portrait of Athanasius Kircher when he was 53 years old. (Source: Wikipedia).

The work is published in folio, containing twelve books with their titles (abbreviated) and contents (in modern words) (length according to 3rd ed.):

Volume I:

1. Centrographicus (mathematical geography) 55 pp.
2. Geocosmus (how the Earth functions) 76 pp.
3. Hydrographicus (oceanography) 46 pp.
4. Pyrographicus (volcanology, but also dealing with winds in a second section) 67 pp.
5. De Lacuum, Fontium, Fluminumque Origine (fresh water) 68 pp.
6. De Quarto Rerum Naturalium Elemento quam Terram dicimus (geochemistry) 31 pp.
7. De Mineralium seu Fossilium… Natura (sediments, soil) 20 pp.

Volume II:

8. De Lapidosa Telluris Substantia (palaeontology, petrography, mineralogy, gemology and subterraneous animals, such as dragons, etc.) 124 pp.
9. De Venenosis Lethiferis Fructibus (poisons or deadly substances: minerals, plants, animals) 56 pp.
10. Metallurgia sive Ars Metallica (metals, mining, processing) 66 pp.
11. Chymiotechnicus (chemistry and alchemy) 96 pp.
12. Polymechanos (miscellaneous) 161 pp.

Book 2 contains the cave texts. The book starts with a view to the moon and the sun and proceeds with an over-view of continents, mountains, rivers, and the hydrological cycle. According to Kircher's thinking, it was driven by subterraneous heat: The meteoric origin of ground water had not yet been discovered. All of the mountain ranges are thought to contain vast empty spaces that collect water driven up by heat (Fig. 3).

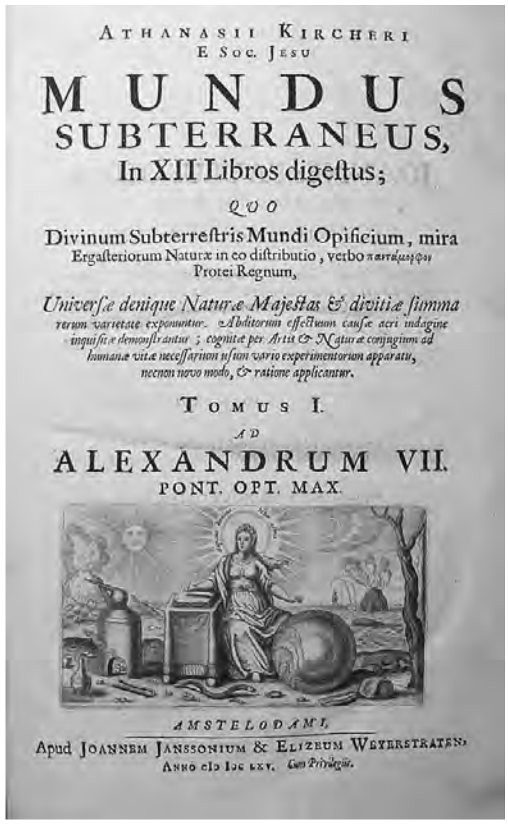

Figure 2. Titel of the first edition (1665) of Mundus Subterraneus *(after the original copy owned by the Universitäts- und Landesbibliothek Darmstadt).*

Similar caverns are supposed to exist underneath the Himalaya, southern Africa and in the Andes. These central caves are not the only virtual caves. Kircher postulates the existence of large subterraneous "*canales*" that connect various lakes and marginal seas with each other. One of these connects the fearsome maelstrom "*Vortex Norwegicus*" with a vortex in the "*Sinus Bothnicus"* below Norway and Sweden (Figure p. 159, 3rd ed.). Through another one ("*Canalis subterranea in Charybdin*") southern winds press water underneath Sicilia into the Charybdis, the famous Homerian current in the Strait of Messina (Figure p. 101 3rd ed.). Most prominent are "*canales*" that connect the *Mare Nigrum* (Black Sea) with the *Mare Caspium* underneath the Caucasus, and it in turn to the *Mare Persicum*. Another channel system connects the *Mare Mediterraneum* with the *Mare Rubrum* (Red Sea) along the later Suez Channel and the *Mare Rubrum* with the *Mare mortuum Asphalticum* (Dead Sea) ("*Canalis subterranea bituminosa*") (Figures on pp. 86 and 87 of 3rd ed.). Since the Suez Channel has been built and the Red-Dead Channel is in the planning to halt the further sinking of the Dead Sea level (e.g., Abu Ghazleh et al., 2009), both of these "*canales*" may actually come into existence, albeit not constructed by nature.

Figure 3. Page 71 of the first edition with the etching showing the Alps and its subterraneous cavity feeding the alpine rivers.

The text relating to "real" caves is found at the end of the Liber secundus. The "*Caput XX, De Antris, Hiatibus, & innumeris Terrae meatibus*" ("Chapter 20, about caves, cracks and innumerable passages of Earth") has only three pages in the first edition of *Mundus Subterraneus* but twelve pages in the third edition (pp. 120 to 131). This is because Kircher added a letter written by Cornelius Magni from Parma written to him on Naxos on 31st December 1673 (pp. 122–131) about the visit of the Grotto of Antiparos. Magni was a member of a tour initiated by Count Nointel, the French ambassador at Constantinople (Istanbul).

This letter appears to be of such importance that Kircher published it both in Italian and in Latin.

Magni was the author of several travel books, i.a. of "*Relazione della città d'Athene, colle provincie dell'Attica, Focia, Beozia, e Negroponte, ne tempi che furono queste passeggiate da Cornelio Magni L'Anno 1674*, Parma 1688" and "*Quanto di più curioso, e vago hà potuto raccorre Cornelio Magno nel secondo biennio da esso consumato in viaggi, e dimore per la Turchia, seconda Parte*, Parma 1692."

3. Kircher's Text on Caves in General

Kircher starts this chapter by citing Jacobus Gaffarellus (Jacques Gaffarel, 1601–1681; librarian of Cardinal Richelieu) who, in his work "Mundo Subterraneo", divided caves into five categories: Divine, human, animal, natural and artificial. In detail, the divine group ("*Divinas*") contains caves where angels have appeared (such as the Grotto on Mons Garganus where St. Michael appeared) or the Indian Temple caves, the catacombs in Rome, oracle caves and caves of fauns, dryads and nymphs, among others. In addition to that, it also contained virtual caves like those of hell or other religious fictions. The group of the human caves ("*Humanae Cryptae*") comprises grottos of giants, the Muses or Sybilles, shown in Mediterranean countries, like in Cumae near Naples. Into this group he also counts hermitages like the grotto of St. Paul on Malta and the Cave of St. Beaume (Maria Magdalena) in France. Animal caves ("*Cryptae Brutales*") are dens of lions, wolves, bears, snakes and dragons, among others. The natural caves ("*Cryptae Naturales*"), "which come in many kinds", have natural powers associated with them, some of which are medical; others are full of metallic vapors, fumes and water, yet others contain ice and crystals like the one on Mons Seranus. Others are Aeolian, blowing air or have "*resolutiva, restrictiva, congelativa*" (dissolving, adstringent, freezing) powers. The final type ("*Artificiales Cryptae*") contain caves dug by humans, like the grotto of Posillipo (near Naples) or those near Syracuse, or underground quarries for marble and other minerals.

In the second part of the chapter he deliberates more on the natural caves that are those that the "divine wisdom" installed in the interior of earth for the natural necessities. Some of those are open to humans at the surface, others are inaccessibly deep in the interior of the geocosm, coming in three kinds, internal branching nets of "*Hydrophylacia, Pyrophylacia, Aerophylacia"*, i.e. those that contain water, fire (magma) and air. The multitude of those open to the surface and leading "into the abysses of bottomless depths" give rise to the rhetoric question of how many there would be in the "inner marrow of Earth"? The inherent powers of some caves derive from those deep in the interior, either water- or fire-filled, changing in relation to the rocks through which they rise. Therefore some caves are endowed with the "*succo petrificio*", the petrifying juice (see also Kempe et al., 2004), turning everything into stone, i.e. producing speleothems. Others induce the "power of foresight (as some think)" or cause chastity or libido on the contrary. Some are narcotic or induce insomnia and others are full of oil, blood-colored fluids, asphalt, salt, vitriol (nitrates) or naphtha. In any case, it seems as if each cave has a different character according to the material through which the channels rise.

In the third part of the chapter Kircher discusses several caves reported by antique authors, beginning with the "*Specus Corycianus*" (near Korghoz, Cilicia, Turkey) as described by Mela, Solinus, Pliny, and Strabo. This cave "is larger than can be easily described". It opens up in a mountain above the coast, where an abyss leads down 1,500 steps through greenery, ending in a cave with a mighty river that has not been explored.

Next, Kircher cites Aelian's "Various Histories" and his description of a plutonic abyss in "Aryan India" (Persia to India) into which the Indians drive 3,000 (Aelian actually says 30,000) "various animals, sheep, goats and cattle". They cannot be seen at the bottom, but their voices are heard, and every day more animals are sacrificed.

Another example is the story of a deep pit near to the last one, related by Seneca in a moralizing context in his "Natural Questions" (5.15.1), who himself cites, according to Kircher", "Asclepiodorus" (in Seneca, correctly, "Asclepiodotus"). Into it King Philipp II of Macedon sent miners to explore if "the old greed has left anything for future generations". The miners, equipped with material to last for several days, gave reports of huge rivers and immense masses of water. Seneca comes to the conclusion, referred to by Kircher, that the Earth is hollow in many parts: "Believe that exists below what you see above". "Below Earth laws of Nature exist that are less known to us, but nevertheless existing". "Just as the ocean spreads across Earth", "the interior of Earth has fresh water in surplus" and even more so, as "Earth opens towards depth".

Kircher continues that subterraneous caves are of diverse shape, caused either by chance or by Nature: Some are very high, others extensive or of bottomless depth, or have many entrances. All of them, however, have "nature" as "author", endowed with properties almost corresponding to the local conditions.

After these conclusions Kircher goes back to Strabo and quotes more reports on caves, namely a cave near Metaurus that runs underground in a riverbed, then a cave in Mauretania along the coast, seven stadii, i.e. about 1,330 m, long, open to tides, and another one 130 stadii, which would be ca. 25 km, long between Palea and Andeira which was transgressed by a goat. He then begins to quote more recent reports, among them the book of the missionary PLro Pais (Pedro Paez, 1564–1622) who had visited Ethiopia and written about the sources of the Nile, postulating subterraneous contacts with those of the Niger. Finally Kircher turns to Ramusius (Giovanni Battista Ramusio, 1485–1557) and his three volumes on travels. According to that work gigantic caves collect water underneath the Andes so that the miners have never heard of anything more terrible. Among other stories a boat is mentioned, that traveled 140 miles underground: A story even Kircher admits not to believe.

One of the interesting conclusions from all these citations of older sources is that Kircher has not seen many caves himself. The only one is the Monte Serana cave at Trevi/Umbria about which he says "*me vidisse memini*" ("which I remember to have seen"). We know that he has been to Malta, but he does no mention that he saw the caves there. Interesting is also the fact that he apparently counts volcanic conduits ("*Pyrophylacia"*), into the class of natural caves.

4. The Antiparos Letter by C. Magni

The longer part of the chapter XX on caves in the third edition is devoted to the letter of Cornelius Magni about the Grotto of Antiparos. In its introduction, Kircher reports how Magni visited him in Rome, enroute to the orient and how he urged his friend to send him a report about the cave because the printer, van Waesberge in Amsterdam, was waiting for the second edition. This suggests that the letter was already included in the second edition, whose date of appearance is, however, still unknown to us.

Magni had in fact written this letter already a few days after his cave visit, but did not have had the opportunity to deliver it. It was written in Italian and Kircher reproduces it both in Italian (left column) and in Latin (right columns).

Magni starts the letter with an address to "most esteemed father" and continues to praise extensively his sponsor, the Count of Nointel (Charles Marie François Olier, Marquis de Nointel, 1635–1685, Ambassador since October 1670 until 1680 of Ludwig XIV at the court of Mehmed IV., who reigned 1648–1687 in Constantinople), who invited Magni to the voyage into the Archipelagos (Aegean Islands, more specifically the Cyclades). Within two months they visited Tenedos, Lesbos and Mytilene, Chios and Mykonos, Delos, the former treasury, the rich Naxos, and finally Paros, that offers safe and easy anchorage, causing many pirates to stay there during storms and winter. Once they reached Paros, the ambassador heard about a gigantic statue in a cave on the neighboring island, Antiparos (35 km^2) and decided to visit there on December 22nd. The party found a house where a priest lived, and the Count sent his young librarian (most likely the orientalist Antoine Galland, 1646–1715, later famous as the French editor of the stories of *1001 Nights*) to reconnoiter. He came back elated, and the Count immediately left with the party to walk four miles through plains and hills, reaching a small mountain where they found the gaping entrance to the cave.

Twenty paces in, they came across a gigantic statue, a large stalagmitic column, twenty hands (ca. 4 m) tall. Depending on the angle of view, one could recognize a giant, its head "artfully carved" with forehead, eyes, nose and beard, but with a body of an "ill-conceived miscarriage". Behind that, another, similarly tall column came into view along with other smaller formations. In the background of this "cave theatre", a dark opening, a hole of about three hand-spans width, was found. The Count inquired from the locals what was beyond. An 80-year-old man was the only one who thought that the dark pit would end in an unplumbed lake. Stones thrown in seemed to vanish after leaving a lot of noise. The Count then sent one of his sailors down with a torch. After 15 min, he came back reporting that he had proceeded 50 feet and had seen many flowstone formations, of which he brought some pieces. Even though it was already quite late in the day, Magni also wanted to go down, and with the help of a rope he climbed "courageously" down the first man-high step. Six steps in, he looked up into the “wide cavity of a cave of enormous extension” persuading him that “the entire mountain was empty and cavernous”. His voice would “propagate for more than a mile” and the many dripstone features would merit a more intensive inspection. The “slow downward gliding taught him the immeasurable size” of the abyss, but with trust in the rope and his sailor-guide he reached a “short, flat, small room” with another column wrapped with festoons and tubelets. After his eyes had adjusted, he progressed another few paces finding himself at a cliff 30 hand-spans deep (6 m?). Being ordered back, he retraced his steps and reported to the Count. Since dawn set in, further exploration was postponed until the following day. On the way back Magni lost his direction and covered twelve miles instead of four before reaching the house for the night.

Next morning His Excellency ordered a ladder, ropes, sailors, candles, torches and provisions from the “pirate ships in harbor” at Paros. Back at the cave Magni helped to rig the entrance with the ladder. Then ten sailors with candles in their hands were sent in to light the descent. Now the Count himself climbed down, partly holding on to the rope, partly being guided and carried by the sailors. He rested at the place Magni had reached the day before and inspected all the formations there. Meanwhile the sailors had descended along different routes and illuminated the cave, appearing like “the demons that are painted in the background of images of hell”. After everybody had been brought down by the ladders, they discovered that they were standing in a “kind of huge theater” with a rectangular stage and curtains. The “appearance of these things filled His Excellency with such enthusiasm that he decided to stay not only for hours, but for full days and nights”. Furthermore, he wanted to conduct a Christmas service in the cave. To this end he ordered 500 wax candles, 20 torches, and a number of lamps at Paros. Within the theater a frozen mass 15 palms high (1.5 m?) rose, forming a kind of pyramidal taber-nacle. The altar for the service of the holy night was to be erected at its foot. The stalagmites nearby served as torch-holders. Magni takes many sentences to describe the scenery with all the dripstones and draperies. Some of these form a “seat or throne” eight palms across (1.6 m?).

Meanwhile, many Maltese Knights and others had landed on Paros and came over to join the service. Three priests were available as well. One of them had a portable chapel decorating the altar. The sailors climbed into every corner to place lights there. One of them discovered a hollow formation which served as a much admired lamp, symbollizing the star of Bethlehem. Another formation, held by two columns, was illuminated and looked like the crib.

Nevertheless, the bottom of the cave had not yet been reached. Next to the theater a descent opened up. It was followed for 50 paces down and led into a small room. Its floor was not composed of solid marble like elsewhere, but was so soft due to the water collecting there, that a stick could be sunk for six or seven hand-spans (1.3 m?). Of all the wonders of frozen water three or four stones that were holding each other up were especially remarkable, since they were covered with protrusions like mushrooms that “broke at the slightest touch”. The Count collected a certain amount of them.

The service started with the Matutin, followed by the midnight service and, after two hours of rest, by the morning service. Not much later, the sun hit the entrance of the cave giving its upper part a golden hue. “A really exceptionally beautiful sight”, as Magni commented. The sailors had brought various war-machines and fired those several times during the “*Gloria in excelsis*”, both at nightfall and in the morning. The sound reverberated through the cave as if it had been produced by large guns.

On the way out to sunlight, they discovered an old, partly weathered inscription in Greek letters at the entrance. As much as one could read, it reported about a certain Antipatros who had come here at the time of Alexander III of Macedon (356–323 BC). It is not apparent whether they also visited the cave’s interior. The Count had ordered to put up an inscription as well to commemorate his own visit. Magni then wonders why throughout all those years during which the Venetian fleet had been present nobody had had the desire to visit the cave.

Magni then measured the length of rope that was used. It was 60 sailor paces or Roman cannae long (a Roman canna, or stick, is 2 to 2.3 m long, the descent therefore had a length of over 120 m). With this rather scientific remark the description of the cave ends, followed by a lengthy explanation of why the letter had been delayed.

5. Further Reports

Cornelius Magni was not the only one to write a report about this visit. Count Nointel wrote one himself, however it was only published as late as 1892 by M. H. Omont. This report is accompanied by two drawings, one of the entrance and one of the interior of the cave. The second picture shows how the participants rope down into the cave on the left, while to the right the Christmas dinner, the altar where the mess has been read and the night biwak of the ambassador on the floor are depicted.

The next person to visit the cave and to write about it was the botanist Joseph Pitton de Tournefort (1656–1707), who visited the cave in 1700–1702 (Tournefort, 1717) publishing a picture of its interior.

Salmon and van Goch used the Nointel and Tournefort reports in their treaties on the Ottoman Empire, 1749. It also contains a copper etching of the grotto, but it appears not to be based on Nointel’s sketches.

The grotto was therefore well known in the travel literature of the 18th century when Marie-Gabriel-Florent-Auguste Comte de Choiseul-Gouffier (1752–1817) visited the cave in 1776–77 and published three large, superbly done copper etchings of it in his opulently edited two volume folio opus “Voyage pittoresque de la Grece” (1782, 1809 and 1822). The first volume was the result of a geographical demanding round trip through the Aegean which included his visit to the Grotto. The first etching contains a map of the cave including ground view (Fig. 4), longitudinal section and scale. The second one depicts the entrance of the cave and the third one a view of the interior. At the entrance, one can clearly see the rope that helped to descent the first step as it is wound three times around the corroded stalagmite. 14 people armed with torches are seen as they prepare for the adventure, all very lively depicted. Two locals in costumes are seen standing by, watching the scene skeptically, one of them smoking a long-stemmed pipe. To the right a building is seen set into the entrance of the cave. The picture of the interior shows 17 people; eleven are seen at a distance working their way down along on ropes and ladders, six stand at the bottom of the large hall. They are already occupied with scientific investigations, as is indicated by the knotted rope of the person to the left and the sitting figure holding a sheet of paper. A corpulent man with a mustache, most probably Count Choiseul himself, is seen en-face, giving orders to the drafter. All visitors wear either short jackets or long coats, simple trousers or more stylish knickerbockers and long socks. The realistic depiction of the stalactites and stalagmites, and their lighting from the torches is most admirable. More torches are for later use deposited in the foreground. These etchings were later copied first by Rosenmüller and Tilesius (1805) and then by Bertuch in the 6th volume of his famous “Bilderbuch für Kinder” (1807).

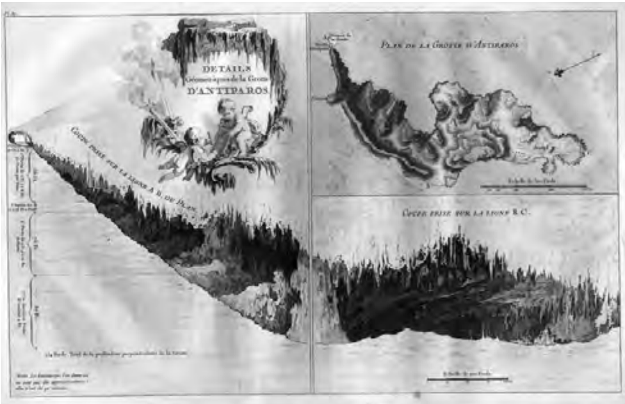

Figure 4. Map of the Grotto of Antiparos by Choiseul-Gouffier (1782) (Collection S. Kempe).

The last visit of literary interest was that of Lady Elisabeth Craven in May 1786. On invitation of Count Choiseul she visited the cave and wrote extensively about it in her travel book (1786). She was not only the first woman in the cave, but also the first one to write about a cave visit in literature (Kempe et al., 2006).

6. Conclusions

It is interesting that only two caves dominate the Latin text corpus about caves, the Baumann’s Cave and the Grotto of Antiparos. Both are, according to today’s standards, rather small caves, the first one being just 150 m long (in its historic section) the second one measuring about 100 × 30 m. Kircher’s eagerness to print the lengthy Antiparos description of C. Magni was apparently guided by one big weakness of *Mundus Subterraneus*: the lack of substantial evidence that his model of the global water cycle through caves in the interior of the Earth is valid. Chapter 20 in Book 2 lists only a small number of caves (and most of them from antique sources) and is only three pages long originally. The enthusiastic report of Magni, with some of its exaggerated phrasing, was therefore a welcome addition to substantiate Kircher’s global model.

Acknowledgments

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NAZI MILITARY USE OF GERMAN CAVES, DR. BENNO WOLF AND THE WORLD CAVE REGISTRY PROJECT

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Dr. Benno Wolf was the mastermind of German speleology in the pre-World War II time, an eminent speleologist and an early activist for nature protection. He maintained international connections and was an honorary member of the British Speleological Association. Dr. Benno Wolf was also an instigator of the German cave registry and in 1923 called for a uniform, systematic structuring of registry documents. In particular, Dr. Wolf possessed a valuable and extensive private library of cave literature that served him as the basis for his work on a world cave registry. This was to cost him his life as the transfer of the Nazi arms production into bomb-proof underground locations awakened the interest of the Nazi henchmen for his cave material. In spite of being a protestant, Wolf, of Jewish origin, was interred in the concentration camp Theresienstadt and died there in 1943. Long time forgotten, the most important German caving award today is named after Dr. Benno Wolf as a symbol of the troubled history of German speleology and environmental protection.

1. Introduction

"Those expert at preparing defenses consider it fundamental to rely on the strengths of such obstacles as mountains, rivers and foothills. They make it possible for the enemy to know where to attack. They secretly conceal themselves under the nine-layer ground."(Tu Yu, A.D. 735–812; from Leith 2009).

Battles were fought in various geographical and geological settings since mankind invented arms (Underwood and Guth 1998; Rose and Nathanail 2000; Zečević and Jungwirth 2007). In the course of World Wars I and II and the following Cold War, the role of Military Geosciences became more and more important.

According to Tietze (1993), Military Geography can be regarded as "Security Geography" and characterises the simplest and most deep-seated relationship man has with his living space, the desire to protect it from other men or to aggressively acquire new land from other people. Understanding of terrain becomes in this instance a powerful weapon. Thus, Military Geography can be considered as a form of applied geography, understood here in its widest sense, including cartography, climatology, geology, geomorphology, geodesy, remote sensing etc. and the whole spectrum of human geography (Tietze 1993).

Military Karstology and Speleology play a special role in karst areas. Day (2004, 2010), Kranj and Travassos (2009), Travassos (2009), Lučić and Travassos (2010) and Travassos (2012) discuss examples of military use of karst and caves in Jamaica, Slovenia, Bosnia and Herzegovina, and other parts of the world. Since Military Geosciences started to develop, researching the underground cavities serving as potential shelters to regular armies, guerrillas, armament factories or storages and civilian population came into the military-strategic focus.

Osama bin Laden and the recent military actions in Afghanistan have brought into the public's eye the landscapes, but also the geology and caves of this country. "*Geology's underlying role in recent events is particularly apparent because our adversaries have moved below ground. The military needs "geologic intelligence" on the locations and characteristics of caves, and on how resistant tunnel entrances may be to conventional and penetrating bombs. Geology has become particularly important in the search for Taliban and Al Qaeda forces in Afghanistan, where the U.S. Geological Survey (USGS) estimates there are more than 10,000 caves, both natural and manmade*." (Leith 2009).

In Military Speleology, the role of caving clubs and cave registries is of interest. Much has been written on military geologists and their work, but the active or passive role of cavers and caving clubs and the use or misuse of their cave registries in Military Geosciences is often unclear. The secret services of many countries are active in collecting "Mil-Geo" and cave data (Knolle 2011). One of the most interesting and tragic cases of this kind is the speleological work of Dr. Benno Wolf, his life and his death in a Nazi concentration camp (KZ).

2. Who was Dr. Benno Wolf?

Benno Wolf was born 1871 in Dresden, Germany. He had Jewish ancestors but he and his parents – both physicians – were christened Protestants. Wolf studied law in Berlin where he also passed his state examination in 1895. In the same year he also obtained his PhD in Leipzig. In 1908, he became a judge at the district court at Elberfeld. Later on, Wolf moved to Berlin, where he functioned as a judge at the court Berlin II. From 1912 on, Wolf additionally worked for the Prussian nature conservation bureau with a focus on legal questions.

Since 1898, Wolf was intensively involved in caving and cave research and soon became a well known speleologist. Not only were his achievements in the technology of cave exploration noteworthy as being ahead of his time, for example in Slovenian vertical caves, where he was member of the caving clubs Hades and Touristi Triestini, but he was also recognised as an authority in scientific cave research and had many national and international contacts.

In Berlin, Dr. Benno Wolf had attracted as an interdisciplinary net-worker a group of nature conservationists, geo and bio-scientists as well as patrons and supporters, and inspired them with his enthusiasm for cave research. He was present when the Hauptverband Deutscher Höhlenforscher (*Main Association of German Speleologists)* was founded in 1922 in the Steiermark (Styria/Austria). Dr. Wolf was even elected as its first Vice President. Back in Berlin he founded in addition the Gesellschaft für Höhlenforschung und Höhlenkunde Berlin (*Society for Cave Research and Speleology Berlin)* in 1923. Dr. Wolf was elected as the first secretary of the society (Wolf 1924). Its membership list is a venerable who-is-who of the speleological network that Wolf initiated, including such prominent names as Dr. Walther Arndt, Prof. Dr. Barsch, Dr. Kurd v. Bülow, Prof. Dr. Ludwig Diels, Prof. Dr. Paul Dienst, Prof. Fraatz, Prof. Dr. Götze, Prof. Dr. Otto Hamann, Dr. Max Hilzheimer, Prof. Dr. Krause, Prof. Dr. Paul Krusch, Prof. Dr. Georg Kyrle, Prof. Dr. Lehmann, Prof. Dr. Nöller, Dr. Werner Paeckelmann, Prof. Dr. Josef Pompecky (then 1st President of the society), Prof. Dr. Arthur Schlossmann, Prof. Dr. Walther Schoenichen, Dr. Walter Schriel, Dipl.-Ing. Friedrich Stolberg, Prof. Dr. Weissermel, Prof. Dr. Fritz Wiegers, Prof. Dr. Wunstorf, Prof. Dr. Ernst Zimmermann and institutions including the Zoologisches Institut und Museum der Universität Berlin and the Staatliche Stelle für Naturdenkmalpflege. Wolf had also won the support of sponsors and promoters such as the factory owner Heinrich Kortkampf and the factory director Ludwig Posselt. Even the cave administration of the Heimkehle (Southern Harz Mts.) became a member, not knowing that the cave would be acquired later by the Nazi armament.

Dr. Benno Wolf was also an instigator of the German cave registry and had begun calling for a uniform, systematic structuring of registry documents in 1923. In particular, Wolf possessed a valuable and extensive private library of cave literature that served him as the basis for his work on a world cave registry – a project hardly thinkable today. This work was to cost him his life as the transfer of the Nazi arms production into bomb-proof underground locations awakened the interest of the Nazi henchmen for his cave material.

Wolf secured experts from home and abroad for the cave information project, obtained money for research purposes and published a first world-wide cave animal catalogue (Wolf 1934–1937, 1934–1938, 1939a, b, 1941).

After more than 21 years of professional involvement in Prussian natural conservancy he became a victim of anti-Jewish discrimination. 1933, Dr. Wolf was expelled from the civil service. Also in 1933, the well-known geologist and speleologist Walter Biese left Nazi Germany for political reasons and immigrated to Chile via Switzerland, because his life was believed to be in danger (Spöcker 1961).

Probably because of his many international contacts within Europe and overseas, and perhaps to give him some help against the Nazi prosecution, Wolf was named a British Speleological Association honorary member in 1936.

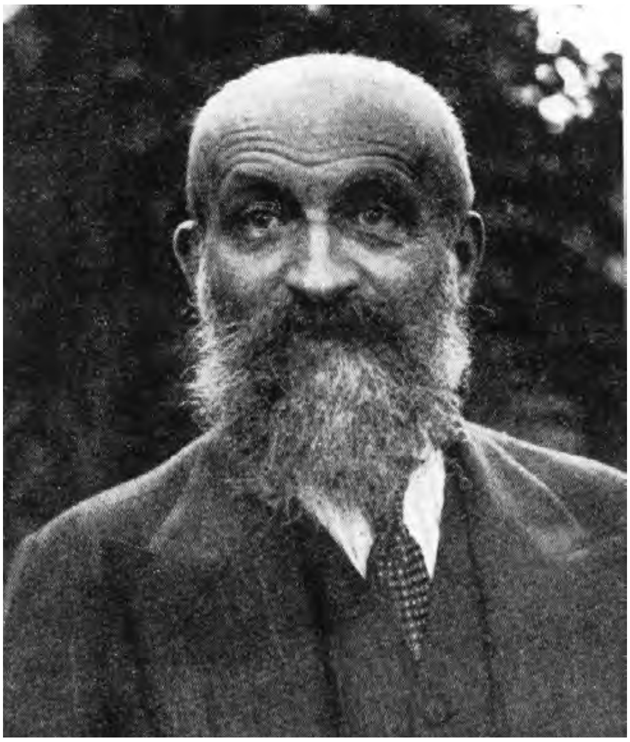

Figure 1. Dr. Benno Wolf, about 1930. Photo F. Mühlhofer.

Wolf edited the Mitteilungen über Höhlen- und Karstforschung, the journal of the Hauptverband Deutscher Höhlenforscher, until 1937 and was the Chairman of the Hauptverband for many years. To avoid endangering the Association with too much political exposure, Wolf had turned the chairmanship over to his most active patron, the factory owner Julius Riemer, before it was too late. But of course everyone knew that Wolf was still the inofficial head of the German cave researchers (Kater 2006; Knolle 2012).

In May 1941, all German and Austrian speleological clubs were forced to merge and to form a "Reichsbund für Karst- und Höhlenforschung" in Salzburg. This new Reichsbund stood under the direct influence of the SS-Ahnenerbe organisation. From now on Dr. Benno Wolf was left more or less on his own.

In order to confiscate Wolf's library of cave literature for the SS Ahnenerbe cave research institute and its armament goals, Wolf, aged 71, was arrested by the Gestapo on July 6, 1942, and deported on the 17th Elderly Transport out of Berlin to the concentration camp of Theresienstadt. There he died half a year later, on January 6th, 1943, as a result of inhuman imprisonment (Stoffels 1995c). None of his cave research colleagues at home or abroad were able to help him – they did not even know where he was.

3. Underground weapon production

3.1. Natural Caves

From 1940 on, allied bombers flew first attacks on German cities. From year to year these attacks became more massive and dangerous for the Nazi war production. As one of the answers to this situation, the military looked for bomb-safe shelters for their weapon production. In 1943, Hitler and Göring gave orders to transfer war technology into caves, cellars, and mining sites. Hundreds of potential caves and caverns were listed by geological and mining authorities and an underground reconnaissance was done in the entire German Reich area.

Three secret service reports, written after the end of war, give a profound overview of the Nazi activities in natural caves. In the three-volume report “German Underground Installations” (British Intelligence Objectives Sub-Committee 1945) the projects were analysed and described. Vol. 1 reports on “Unique Design and Construction Methods”, Vol. 2 on “Adaptations of Existing Facilities” and Vol. 3 on “Installations of General Interest”. Nearly all projects were in artificial underground cavities. In Vol. 2 the Dechen Cave is mentioned (Nr. 50, S. 31): *“An ammunition storage in a cave located in a hill on the north side of the ISERLOHN-LETHMATHE road. The cave is a natural, winding cavern with two entrances… The cave is extremely damp and has numerous stalactites and stalagmites. This cave was formerly a tourist attraction and is owned by Iserlohn Kreisbahn A.G.”* (Orthography slightly corrected).

Another report “Engineering Geology in Germany” (Joint Intelligence Objectives Agency 1945) contains four papers. Amongst others, the Mittelwerk-Nordwerk and Woffleben projects in the South Harz area are described. The paper summarises: *“Hills of anhydrite and gypsum seem to be almost ideal construction sites for large underground factories, both from the economic and military standpoints.”* This is the reason why the Nazis concentrated so much of their underground weapon production in the South Harz area.

Most interesting under caving aspects is paper No. 4 “*Source data for investigation of German and French underground factories*.” In alphabetic order, underground production and storage sites are listed, among them (orthography slightly corrected):

- *“11. Baumannshoehle, near Goslar. Series of caves in Harz Mts, 8 miles SE of Goslar. Used by Junkers Flugzeug u. Motorenwerke A.G. Ref.: Shaef Report No. 5, 25 April 45 on Evacuation of Intelligence Targets.*
- *83. Iserlohn/Letmathe. Map ref., 4416/Q2/9407. Reported ammo. dump in Dechen-Höhle Grotto north of Iserlohn-Letmathe road. Grotto has surface are of 60,000 square meters. Ref.: Fatherland No. 17.”*

Another report “Underground Factories in Central Germany” (Combined Intelligence Objectives Sub-Committee 1945a) describes 13 underground war production sites, most of them in the South Harz karst area. Nr. 12 has five pages, accompanied by a cave map of *Heimkehle Cave* and an aerial photograph. It describes project A5, the production of airplane landing gears and tools by the Junkers-Werke in the Heimkehle Cave near Rottleberode: “*This small factory is located in a natural cave which formerly had some reputation as a tourist attraction… Conversion of the cave to industrial use was seen to have involved leveling and flooring the cave with concrete, the erection of shops with walls of brick or precast concrete blocks, and roofed with wood and tarred paper; and the excavation of three short tunnels – all brick lined… The labour force for operating the plant numbered 650, of which 500 were employed on production. The monthly output was 250–300 undercarriages.”* (Orthography slightly corrected). This project was also called “Thyra-Werk” (Fig. 2).

Nearly 80 % of the labour working here was forced labour. For more information on the situation of the cave today (Fig. 3), an interesting show cave again (see www.hoehle-heimkehle.de). The cave contains also a small monument in honor of those who were killed there (Fig. 4).

In the end, natural caves proved not to be ideal for underground military production because of their moist air provoking corrosion, irregular shape, variable ground water levels, instable geological character, and their often remote location.

Figure 2. Aspect of Heimkehle Cave in WW II. From Baranowski (2000).

Figure 3. Heimkehle cave today. Photo Ernst Schuhose.

Figure 4. Monument to the victims of Nazi forced labour in the Heimkehle Cave. The flat floor in the foreground was once the floor of the Junkers factory; the brick wall in the back was part of the effort to stabilise the cave roof during the WW II operations. Photo Stephan Kempe.

3.2. KZ Mittelbau-Dora

The underground concentration camp (KZ) Mittelbau-Dora became more widely known (www.dora.de). The secret Nazi "Mittelbau" in the Kohnstein Mountain at Niedersachsswerfen near Nordhausen (Thuringia) was probably the biggest underground war plant in 1945 worldwide – the entire tunnel system finally amounted to 120,000 m^2.

Following the allied attack on Peenemünde and its V-weapon production, this new plant in the South Harz karst area was installed in 1943 in a partly pre-existing and later on massively enlarged artificial tunnel system in upper Permian anhydrite (Werra Series). Exploration and geotechnical work was done by the pro-Nazi geologist Dr. Walter Schriel.

At the same time, an above-ground KZ, named Mittelbau-Dora, was built, in the first phase as a satellite camp of the KZ Buchenwald. In December 1943, the first three V2 rockets were completed, followed by 52 more in January 1944. Parallel to the V2 rockets, and the V1 (flying bombs) production more plants moved underground to this place in the course of WW II, e.g., the Junkers Flugzeugwerke from Dessau. In 1943, this KZ registered 108 victims; however, this figure grew to 34,000 at the end of 1944. All inmates were forced to work under inhuman, horrible circumstances. It is estimated that about 20,000 of them were killed by labour or by violence of the guards.

Following the evacuation of the KZ in April 1945, US soldiers entered the tunnels and found the underground factory. Even though the existence of the Mittelbau tunnel plants had been detected by intelligence, the allied knowledge about Dora-Mittelbau was poor – at least up to the first big air attack on London.

The Nazi "wonder weapon history" became widely known after 1945 by the US operations "Overcast" and "Paperclip" that implemented German armament knowledge into the US rocket program – personified by Wernher von Braun. Later on, the Red Army came to Thuringia and still found so much technical material and Nazi personnel, that this improved the USSR rocket program very effectively as well. Thus, world history was written in these anhydrite tunnels in the South Harz. A very small section of the tunnel system is open now for the public within a guided walk through the KZ area.

4. Post-1945

German cave research suffered tremendously under the Nazi's political and military misuse of the discipline (Schaffler 1991; Stoffels 1995a, b; Kater 2006; Knolle et al. 2007; Knolle 2012).

In 1947 R.G. Spöcker initiated the foundation of a new and politically unencumbered German cave research society, the Deutsche Gesellschaft für Karstforschung.

Spöcker was very adamant about dealing with the brutal and unjust events of the past; in one passage in the minutes of the founding meeting in Nürnberg from September 13, 1947, it states, *"SPÖCKER thanks all those who were active in the society and recalls in particular those no longer living. Most specially, the President for many years, state district court Judge Dr. BENNO WOLF, Berlin, who died in the concentration camp Theresienstadt, Herr Prof. Dr. ARNDT, Berlin, who was executed by the henchmen of the Third Reich and the former Chairman Prof. Dr. HILZHEIMER, Berlin, as well as all those who had to forfeit their lives in the war years. In honour of the dead the participants of this meeting will now rise."* (Spöcker 1947).

This new cave research society, however, soon faded away. The Verband der deutschen Höhlen- und Karstforscher e.V. (VdHK; www.vdhk.de), founded in 1955, did not initially come to terms with the past, but individual cave researchers repeatedly built on the work of Dr. Wolf.

In 1995, in Iserlohn-Letmathe at the annual general meeting of the Verband and after years of research within the Society, Dr. Benno Wolf was unanimously honoured posthumously – 52 years after his death. The protocol records:

- *Agenda Point 9: Motion to honour Dr. Benno Wolf*

Unanimously, the posthumous naming of Dr. Benno Wolf as honorary member of the Association was passed. Those present rose from their seats to hold a minute's silence for the cave researcher who lost his life in a concentration camp.

- *Agenda Point 12: Founding of a Dr. Benno Wolf Prize*

It was unanimously voted to create a Dr. Benno Wolf Prize for outstanding research achievement (motion: F. Knolle, J. Obendorf, J. Götz and the association board).

With these decisions the VdHK finally honoured a person who, in spite of his great achievements for German and international cave research and nature conservancy, had been, up to then, almost totally forgotten.

5. Conclusions

Unfortunately, memorial work of Nazi victims in Germany is still incomplete. The Nazi offenders themselves were at first occupied with assisting each other in whitewashing their crimes. They repeatedly played down their involvement in the crimes and, where possible, withheld evidence. Many unpublished papers, incriminating documents and other objects of evidence, if not already deliberately destroyed during the war or at the end of it in 1945, were "lost" or have remained, until today, unobtainable.

The Verband der deutschen Höhlen- und Karstforscher e.V. itself was not innocent – recognising Dr. Benno Wolf and his work should have begun much earlier (Spöcker 1986). An active Nazi, Prof. Dr. Gustav Riek, was even named an honorary member of the VdHK in 1968.

A look at historical publications since 1945 awakens the impression that cave researchers of Jewish ancestry like Dr. Benno Wolf have been "actively forgotten". We are confronted up to now with excuses, legends and prefabricated memory gaps – and in that way have provided us with the difficulty of having far too little evidence to contradict the fabricated tales of the Nazi generation.

Only two small caves bear the name of Benno Wolf. The Dr. Benno Wolf Prize has, however, developed into a successful memorial project and has also radiated into German nature conservation – the fate of Dr. Benno Wolf is now discussed more widely. The German Stiftung Naturschutzgeschichte (Nature Conservation History Foundation; www.naturschutzgeschichte.de) has become active and the German Bundesumweltministerium (Federal Ministry for the Environment; www.bmu.de) supported appropriate projects; see also Frohn and Schmoll (2006).

To honour Dr. Benno Wolf a private initiative has laid a memorial plaque in front of his former home in the Hornstraße 6 in Berlin-Kreuzberg in 2005. These plaques have been laid by the sculptor Günter Demnig as slightly raised paving stones bearing the names of Nazi victims. On the brass name plates on the upper sides of the paving stones the names and biographical data of the victims as well as date and place of deportation are engraved. Another memorial plate ("Berliner Gedenktafel") was installed in 2008 at the Haus am Kleistpark, where Wolfs natural conservation working place was from 1912 to 1933.

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STORY OF THE DOLOMITE – D. DE DOLOMIEU OR B. HACQUET?

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Abstract. The author describes the discovery and research of the rock nowadays called dolomite by two eminent researchers, the chemist and geologist Balthasar Hacquet and the geologist Déodat de Dolomieu. The first one described the rock from the karst in the nowadays Slovenia in 1778 and called it *Stinkstein.* The second one sampled the rock in Stubaier Alps and described it in 1791 as "pierres calcaires très peu effervescentes avec les acides". Dolomite was probably mentioned already in Linnaeus' Systema Naturae (1768) and later in publication of G. Arduino in 1779. In 1792 Nicolas-Théodore de Saussure published the paper "Analyse de la Dolomie" where he named this rock the dolomite in the honour to D. de Dolomieu.

Abstrait. L'histoire de dolomie – D. de Dolomieu ou B. Hacquet? L'auteur décrit la découverte et la recherche de la roche qui furent effectuées par deux chercheurs éminents, le chimiste Balthasar Hacquet et le géologue Déodat de Dolomieu ; il s'agit de la roche qui s'appelle aujourd'hui la dolomie. En 1778, le premier décrivit la roche du karst de la Slovénie actuelle et l'appela *Stinkstein* (la roche puante). Le deuxième trouva cette roche dans les Alpes de Stubai et la décrivit en 1791 comme "les pierres calcaires très peu effervescentes avec des acides". La dolomie fut mentionnée probablement déjà en 1768 dans le Systema Naturae de Linné et un peu plus tard par G. Arduino en 1779. En 1792, Nicolas-Théodore de Saussure publia l'article "Analyse de la Dolomie" où il nomma cette roche la dolomie, en l'honneur de D. de Dolomieu.

1. Introduction

Baltazar (Balthasar, Balthazar, Belsazar) Hacquet de la Motte was born in 1739 or 1740 in France and died in 1815 at Vienna. In older sources Le Conquet (Brittany) is mentioned as his birth place while some recent publications suggest Metz or its surrounding (Gauchon 1999; Šumrada 2003) where he started his school. He was a surgeon in different armies, at last in the Austrian one. With the help of Van Swieten, the doctor of the empress Marie-Therese, he came as a surgeon to Carniola where he spent 20 years (1766 to 1787). During the first years he was a surgeon at Idrija mercury mine, replacing the well known physician and naturalist Giovanni Antonio Scopoli (1723–1788), who lived there in the years 1754–1769. In 1773 Hacquet moved to Ljubljana where he held different positions, being professor of chemistry and of obstetrics and secretary of Agricultural Society of Carniola among the others. Finally he left "bigoted and uncultured" Carniolians and took the offer of the new founded University at Lvov (Lviv) to become the professor of natural history and medicine there. He travelled a lot, especially through Southern, Eastern and Central Europe, from Grossglockner to Moldova, from Bosnia to Poland. He studied rocks, minerals, geology, waters, relief, plants and even human activities, mining activities and metallurgy especially, folklore and languages even. Hacquet's latest bibliography (Južnič and Kranjc 2013) enumerates about 140 of his articles and books. For Carniola, for Slovenia and for karstology and speleology the most important is his tetralogy O*ryctographia Carniolica oder Physikalische Erdbeschreibung des Herzogthums Krain, Istrien, und zum Theil der benachbarten Länder* (Oryctographia Carniolica or Physical description of Duchy of Carniola, Istria and partly neighbour countries) published on 623 pages in 1778–1789 in Leipzig. In this and other of his works he often describes rocks and their analyses (Kranjc 2003).

Ten years younger of Hacquet was Dieudonné Sylvain Guy Tancrède de Dolomieu usually known as Déodat de Dolomieu (Dolomieu, Isère, 1750 – Chateauneuf 1801). Like Hacquet he started with military career as a member of the Knights of Malta. He spent his spare time taking research excursions throughout Europe collecting mineral specimens and visiting mining areas. His particular interests included mineralogy, volcanology, and the origin of mountain ranges. Although Dolomieu was greatly interested in volcanoes, he became convinced that water played a major role in shaping the surface of the Earth through a series of prehistoric, catastrophic events. Dolomieu was not an uniformitarian geologist. His contemporary, James Hutton (1726–1797), did not publish the principle of uniformitarianism until 1795. Dolomieu was an observationalist and spent much time collecting and categorizing geological data. Unlike Hutton, no scientific principles or theories are credited to him, although he left his permanent mark on geology in another way (Wikipedia, Gratet de Dolomieu). In 1779 he became a "corresponding member" of the Academy of Sciences of Paris, and about 1797 its "Founder Member" (Zenger et al.1994).

2. First descriptions of the dolomite

Hacquet was not just a traveller and he was not just writing down the diary and impressions of his travels, he was researcher, a chemist as he called himself. During his travels he gathered samples of rocks, plants, and water and carried them home for detailed inspection and analyses. It was not an easy task; for the analyses he took (or sent) home a sample of few buckets (Austrian "bucket" has about 56 litres) of water. How seriously he researched rocks can be seen from the 1st volume of his *Oryctographia carniolica:* there are 12 pages of description and discussion about 17 analyses of a sandstone sample (Hacquet 1778). It is not surprising that he, as a keen observer, found in the field already that there is a type of limestone quite different than the other. In the first book of *Oryctographia carniolica* (Hacquet 1778, 65) (Fig. 1), describing his travel across Istra (Istria) Peninsula, he remarks: "*I came to Lipica. Here* *for the first time I found very black Stinkstein, Lapis suillus* (stinking rock)*"*. In the third book of Oryctographia he is talking about Podpeška Jama cave (its survey was published in Valvasor's *Die Ehre…* in 1689 already) and its geology (Hacquet 1784, 166): *"…Aller Orten waren die Wände der Grotte, so wie der Boden sehr glatt, schmutzig-braun und ohne Tropfstein. Als ich den Stein untersuchte, fand ich, daß es blosser Stinkstein (Lapis suillus) war. Valvasor,… hat auch bemerkt daß diese Höhle keinen Tropfstein hat… Auch ich wußte nicht, daß der Stinkstein untauglich sey, Tropfsteine zu bilden, die blosse Erfahrung überwieß mich hier; denn in dieser Grotte, so gut wie anderwärts, sieht man, daß aller Orten Wasser von oben herunter tröpft; folglichfehlt es an den Erzeugungsmitteln nicht. Es hat also das Ansehen, daß das Wasser nicht im Stande sey von diesem Stein viel aufzulösen, wegen des Phlogiston, das mit dem Kalksteine verbunden ist*." ("Everywhere the walls as well as the floor of the grotto were very smooth, dirty brown and without flowstone. As I inspected the stone, I noticed that it was pure Stinkstein (*Lapis suillus*). Valvasor did also notice that this cave has no flowstone. … I also did not know that stink stone was incapable of forming flowstone, the first hand experience taught me this here, because one sees in this grotto, as any other, that water drips everywhere from above, so that there is no lack of the means to generate (flowstone). It therefore appears as if the water is not capable to dissolve much of this stone, due to the Phlogiston, that is bound with this limestone.") (Translated by S. Kempe).

Hacquet mentioned this rock also in some other parts of the text: *"…hill at Nazarje, where the monastery lies, are clay strata and Stinkstein…"* (Hacquet 1778, 112); *"… between Bistra and the springs of the Ljubljanica there is limestone only, somewhere changed into the Stinkstein; this lapide suillo is of grey or black colour somewhere."* (Hacquet 1778, 155); *"…on the Karst there is a lot of limestone belonging to Stinkstein, so hard to produce sparks by a steel. It is fine-grained, grey coloured with addition of some iron. It effervescents slightly with the acid only when it is crushed. It is specific to contain a lot of petrifications. The rock is maybe also bituminous."* (Hacquet 1789, 41). From the text and analogy it is obvious that Hacquet's *Stinkstein* is a special rock, a special kind of limestone or carbonate rock. In 1779 when Hacquet visited Tyrol (he described this travel in 1780) (Hacquet 1780), he surely fell upon the *Stinkstein* too. So it is possible to say that Hacquet discovered a new kind of rock – *Stinkstein* or *Lapis suillus.* Nowadays there is no rock with such a name. What happened, why not?

Similar to Hacquet, Dolomieu was also a great traveller, even greater. During some mineralogical excursions in the Tyrolean Stubaier Alps, west of the Brenner Pass, Dolomieu recognized an abundance of rocks that resembled the limestone but were only weakly effervescent with acid. At first he thought his acid had lost its strength, but he noted that, when powdered, these rocks reacted with small effervescence and completely dissolved. On returning to Italy, in the calcareous mountains overlying the basement in the Bolzano – Trento area, he noted that beds have similar characteristics to those in the Stubaier Alps but were horizontal and contained shell impressions. In 1786 Dolomieu donated calcareous acid-resisting limestone to his friend Felice Fontana, the director of Florentine Cabinet of Physics & Natural History. Even before, during the autumn 1784, when travelling through Ljubljana, Dolomieu visited also Hacquet. Dolomieu described their meeting in his letter of September 6, 1784 to Picot de la Peyrouse at Toulouse: "*J'ai vu à Laibach le docteur Hacquet, qui publie une immensité d'ouvrages de minéralogie et de botanique ; je ne vous en ai pas parlé parce que je ne savais pas que vous eussiez été en relations avec lui. Il a de l'esprit, des connaissances mais il me paraît qu'il ne digère pas assez ses idées et ses systèmes, et qu'il se hâte trôp de décider sur le moindre aperçu. En général tous ces Allemands sont très savants et presque tous les Italiens fort ignorants˝*. (At Laibach [Ljubljana] I saw Dr. Hacquet who publishes immense works on mineralogy and botany; I did not mention him to you because I did not know that you are in contacts with him. He has the spirit and the knowledge, but I think that he does not digest his ideas and systems and that he jumps too quickly to the conclusions at the slightest indication. In general, all these Germans are connoisseurs and nearly all the Italians are great ignorants) (Šumrada 2001, 69). Did they discuss this unusual limestone too? Up to 1790 Dolomieu and Hacquet corresponded but their contacts abruptly ended because of political situation after the storming of the Bastille.

On January 30, 1791 Dolomieu sent the letter from Malta to Picot de la Peyrouse. It was published in July 1791 under the title "Sur un genre de pierres calcaires très peu effervescentes avec les acides et phosphores-centes par la collision" (On a Type of Calcareous Rock that Reacts Very Slightly with Acid and that Phosphoresces on Being Struck) in Rozier's Journal de Physique (Dolomieu 1791) (Fig. 2). In this letter Dolomieu in fact adopted Hacquet's description of a Tyrolese calcareous acid-proof rock, but without mentioning his name (Južnič and Kranjc 2013). He introduced the new concept that limestone and dolomites were formed in the universal ocean before the time of precipitation of the Secondary Mountains, and hence before the occurrence of marine organisms. A year later (1792) in the same Rozier's Journal de Physique Nicolas-Théodore de Saussure published the paper "Analyse de la Dolomie" (Saussure 1792). Saussure named Dolomieu's rock "dolomie" in the latter's honour, as Dolomieu's descriptive term was so unwieldy (Zenger et al. 1994) and the name of Hacquet was passed over in silence again. So the new discovered rock was born and baptised.

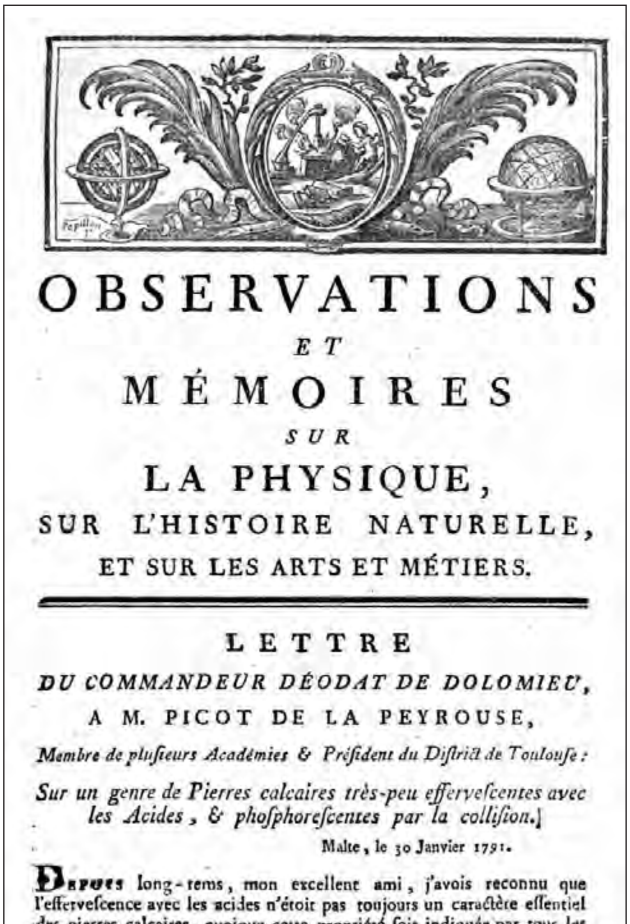
But was it really new and Dolomieu the first to describe it? It is clear that Hacquet mentioned this unusual limestone rock at least in 1778, in *Oryctographia carniolica*, 13 years before the basic description of de Dolomieu and 14 years before Nicolas-Théodore de Saussure coined the name Dolomite. Regarding Hacquet's descriptions or better mentioning of *Stinkstein* it can be said that there are some queer features. In the first book of *Oryctographia* Hacquet published 17 analyses, which he performed himself, of sandstone (it has to be Eocene Flysch) found in Brkini Hills (South-eastern Slovenia). Due to results he proposed the new name for this rock: *Mittelstein*; sometimes additional adjective has to be needed: *Sandiger Mittelstein*. The same 17 analyses, they seemed to be a standard, he used to research Idrija's mercury ore, as stated in the second volume of *Oryctographia*. At Bohinj he found "variegated jaspis", similar to petrified "Coburg wood" and performed four chemical analyses of it. And for the new found rock, the *Stinkstein*, there is nothing apart from few remarks. In the first book of *Oryctographia* (1778, 65) he stated: "*…near Lipica I found for the first time the Stinkstein…*". This statement can have a double meaning: the first, that he has fallen upon *Stinkstein* for the first time (ever in his life); and the second, that he has found it for the first time in Carniola or just the first time along his travel from Kras towards Učka Mountain in the Eastern part of the Istra (Istria) Peninsula. In any case it is unusual that he did not analyze it or that he did not mention where or when he previously published the results. To Tyrol where from Dolomieu brought his specimen of (later named) dolomite, Hacquet travelled later, after publishing the first volume of *Oryctographia*. From the year 1766 to 1778 included, he published 29 articles and a book – the first volume of *Oryctographia.* The most (eight) of articles are dedicated to veterinary science, six to medicine, three each to fossils, mining and travelling, two articles to botany and metallurgy, and one article to geology, zoology and statistics. Considering the titles only, it does not seem that any of the mentioned publications can include analyses or description of the *Stinkstein.*


ORYCTOGRAPHIA CARNIOLICA,
oder
Physikalische Erdbeschreibung
des
Herzogthums Krain,
Istrien,
und zum Theil der benachbarten Länder.
Erster Theil.
Leipzig,
bey Johann Gottlob Immanuel Breitkopf, 1778.

Figure 1. Frontispiece of the first volume of Hacquet's Oryctographia carniolica (1778).

3. Conclusion

In the twelfth edition of Linnaeus Systema Naturae (1768) (Zenger et al. 1994) is an unreferenced Latin quotation of a *marmor tardum* from the surroundings of Roedburg, a white marble that effervesces very slowly. It can be recognized as dolomite. Hacquet mentioned few times dolomite under the name *Stinkstein* given by him in the first and the fourth volumes of his *Oryctographia* (1778, 1784). It is not known (yet) if he did, and if, where he did publish detailed description and results of this rock analyses. A year later (in 1779), G. Arduino published an article on chemical observations on fossils where he mentioned a "*vein of white brecciated marble*" (Arduino 1779). According to his description and analysis the rock would be termed the dolomite. In 1791 Dolomieu published the article "On a Type of Calcareous Rock that Reacts Very Slightly with Acid and that Phosphoresces on Being Struck" in Rozier's Journal de Physique. In 1792 in the same journal Nicolas-Théodore de Saussure published the paper "Analyse de la Dolomie" where he named this rock *dolomite* in favor of its "discoverer" Dolomieu. It is not an easy and a pleasant task to judge. In any case, B. Hacquet found that the rock we call nowadays dolomite is a special rock and he published this in 1778, without being remarked or cited by his contemporaries.


OBSERVATIONS
ET
MÉMOIRES
SUR
LA PHYSIQUE,
SUR L'HISTOIRE NATURELLE,
ET SUR LES ARTS ET MÉTIERS.

LETTRE
DU COMMANDEUR DÉODAT DE DOLOMIEU,
A M. PICOT DE LA PEYROUSE,
Membre de plusieurs Académies & Président du District de Toulouse :
Sur un genre de Pierres calcaires très-peu effervescentes avec les Acides, & phosphorescentes par la collision.]
Malte, le 30 Janvier 1791.

Depuis long-tems, mon excellent ami, j'avois reconnu que l'effervescence avec les acides n'étoit pas toujours un caractère essentiel des pierres calcaires, quoique cette propriété soit indiquée par tous les
Tome XXXIX, Part. II, 1791. JUILLET. A 2

Figure 2. The title page of Dolomieu's article on dolomite (1791).

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"GIVING US AN IDENTITY" – THE CONSTRUCTION OF MEMORY IN THE HISTORY OF SPELEOLOGY

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On the basis of constructivist cultural studies the paper discusses the process of historicization in the field of speleology and cave exploration. The analysis is based on the method of discourse analysis and contextualized from a historical and sociological point of view.

The main focus lies on the end of the 19th and the beginning of the 20th century, when speleology was institutionalized as private clubs and governmental organizations and a collective identity of the explorers was formed. To ensure higher reputation within the scientific community, the discipline was historicized. With a coherent and obligatory narration of speleology the caving groups were able to generate self-supporting identities, which let the cave explorers feel as successors of a long tradition and legitimated contemporary ambitions. The process of musealization, collective celebrations like jubilees and the heroization of deceased speleologists played an important role for the cementation of memory. Preserving the narration of speleology, museums retain and reify memory as moments of greatness for subsequent generations. Jubilees and anniversaries of speleological institutions or clubs became welcome occasions for perpetuating and remodeling obligatory concepts of the history of science. The heroization of past cave explorers provided an opportunity for identification and instrumentalization of the commemoration.

The results suggest that traditional research interests in the history of speleology should be reconsidered. In many cases the history of speleology is still seen as an apologia of the research history. Instead, outstanding exponents of the discipline and discoveries should be contextualized. The self-definition and -description of cave explorers and the scientific discipline are not historical constants. They have been discussed permanently throughout history.

1. Introduction

Why we are studying the history of science? What are our aims when drawing an obligatory picture of the past and focusing on particular questions, while we ignore other historical problems? For which purpose are we talking about "great speleologists", "fathers of cave science", their long-lasting "achievements" and the "starting point" of our discipline?

Franz Kraus (1834–1897), author of "Höhlenkunde", writes one of the first articles about the history of speleology for the daily newspaper "Neue Freie Presse" of Vienna (see Figure 1). In his article he places special emphasis on the positive effect of historiography for the collective memory:

"The history of caves still lies idle, because nobody has yet tried to arrange a systematic assorted and academic composed tableau of the results from different researches. […] [The Speleological Club in Vienna] will have an honorable position, when cave exploration in Austria can be considered as completed and somebody tries to write a history about it." (Kraus 1879, pp. 4)

From the late 1980s onward sociologists like Hannah Arendt have often stated that history and traditional historiography were outdated and at their end (Arendt 1994). New trends are focusing on the construction of collective and personal identity through memory, cultural and social implications and functions of historical narration. In the United States of America this dispute is generally known under the term "science war" and should be seen as a part of the postmodern criticism of science. In his paper "Historiography of Science" Michael Aaron Dennis adjudicates programmatically on the changed self-concept of the history of science:

"No longer is the history of science the story of individual researchers confronting a 'nature' that must be persuaded to reveal its secrets. Instead, the new historiography has made the identification of the natural and its boundaries one of the prime areas of inquiry. What has taken place is nothing less than a redrawing of the boundaries separating the natural and the artificial." (Dennis 1997, pp. 1)

Natur- und Völkerkunde.

Zur Geschichte der Höhlenforschung.

Es gibt nur wenig Dinge, die nicht schon ihren Historiographen gefunden hätten. Von der großen Geschichte der Menschheit an bis zur Geschichte irgend eines Kleingewerbes oder eines Dragoner-Regimentes ist Alles bereits emsig notirt und registrirt, und spätere Forscher haben nichts mehr zu thun, als nach dem bekannten Recepte zehn Bücher aus dem reichen Schatze der deutschen Literatur herauszuholen und ein elftes daraus zu schneidern.

Nur die Geschichte der Höhlen liegt insoferne noch brach, als man es noch nicht unternommen hat, ein systematisch geordnetes, schulgerecht aufgebautes Tableau der Resultate vereinzelter Forschungen zusammenzustellen. Das Werk von Dawkins widmet den Höhlen als solchen nur eine Einleitung von etwas über 50 Seiten, während der Rest mit vergleichenden biologischen Studien angefüllt ist. Fraas, Gümbel, Quenstedt und noch viele Andere haben einzelne werthvolle Beobachtungen publicirt, allein der geistige Zusammenhang unter der Fülle von Material wurde bisher noch nicht hergestellt.

Dawkins machte es sich sehr bequem mit der Entstehungsgeschichte der Höhlen. Er wählte sich eine Theorie, die ihm für jene Höhlen zu passen schien, die er gesehen, und nahm dieselbe als allgemein giltig und unumstößlich an, obwol man zugeben muß, daß er an einer Stelle noch von anderen Ursachen spricht, die ebensogut einzelne Höhlenbildungen erklären können, wie: Wellenschlag, Volumen-Verminderung der Gesteine &c. Im späteren Theile seiner Einleitung schweigt er jedoch alle diese Möglichkeiten todt, und seine Theorie lautet: Der Höhlenbildungs-

Figure 1. Kraus' paper on the history of cave exploration.

Even if the dispute is still going on, a return to secured scientific truism and a historiography of banal scientific achievements is implausible. However, the history of science has reflected these new positions and investigated how traditional conceptions of the development of the sciences are affected in order to make sense of actual scientific practices.

For Franz Kraus the basis for a prosperous development of the field is a collective and combined narration of speleology. So a historiography of cave science not only has the role as a generic basis for the distribution of meaning, but also gives identity to each caver and gives significance and legitimation to such activity. In this regard an entanglement of – what Hans Reichenbach has called – the "context of discovery" and the "context of justification" can be noticed (Reichenbach 1962, pp. 231).

Even today the link between exploration and justification in scientific practice is probably closer than many natural scientists would admit. Franz Kraus' message, cited above, refers to the meaningful function of the history of speleology. The view back to the beginning and origins of the cross-disciplinary field of speleology often acts as an affirmation of the own identity, as a confirmation of the *status quo*.

The sources for this sort of instrumentalization go back to the end of the 19th century, when the foundations for the history of cave science were laid.

2. Construction of a collective identity

At the beginning of the 19th century caves were seen as areas of artistic inspiration and as archives of natural history. On the basis of a modified perception of nature, scientists and travelers of the urban civic elite penetrated deeper and deeper into the subterranean worlds. They discovered not only the depth of subjectivity, but also recognized caves as the location of empiricism.

Since 1880 cave exploration has been institutionalized as governmental institutes and private clubs. Thus at the end of the 19th century speleology in Europe went through a radical change. Urgent karst-hydrological problems, such as drinking water supply and water engineering, became quickly the scope of speleology. In the former territories of the Austro-Hungarian Empire, the karst landscapes of Trieste, Carniola and Moravia and the Northern Limestone Alps were declared as the type research areas for speleology.

Due to the fact that deeper shafts were inspected, teamwork gained more and more importance for cave exploration – however only a small part of the explorers earned most of the reputation. Back then the explorers found themselves in constant competition. Expeditions from the 18th and 19th century, which consisted of an employer, a guide and carriers, led to the development of new research groups. In accordance with the principle of division of labor ostensible equal members were working together in order to start with the survey and detailed documentation of caves.

This modification in the social structure of research groups resulted in an increased social disciplinary action and instruction of the members, who were typically organized in hierarchical groups. The travelers did no longer see themselves as passive visitors. They began to consider themselves as cave explorers and conquerors (see Figure 2). The speleological practice of naming and surveying underground places and new media for documentation played an important role for the ritual appropriation and conquest of subterranean worlds during the imperialism period (Mattes 2012a).

As a shared definition of a group, whose members have the same common interests, experiences, and solidarities, the term "cave explorer" became a widespread expression within the society of the 19th century. For the Sociologist Owen Whooley "the three major processes through which movements construct an identity are the establishment of boundaries, negotiation, and development of consciousness" (Whooley 1988, pp. 70). Similarly the construction of boundaries refers to collective norms, corresponding rituals and a special logic of exclusion from science.

Figure 2. The perception of cave explorers as "deep"-alpinists and conquerors of the underworld. Painting of Alexander von Mörk: Ice-Tower in the "Eisriesenwelt" (engl. "World of Ice Giants") in Werfen near Salzburg (Archive of the showcave Eisriesenwelt, 1913).

Speleologists like Adolph Schmidl (1802–1863) and Éduard-Alfred Martel (1850–1938) began to travel to the economically underdeveloped karst regions as tourists and named their explorations after a military expression "campaigns". For that purpose, underprivileged groups like woodcutters, shepherds, hunters and other locals were excluded from the "exclusivity of the first look" (Mattes 2012a). Although they still took part in the underground campaigns of their employers as guides and carriers, they were excluded from the right of naming, interpretation and ritual appropriation of the underground places, which was limited to the urban leaders of the expeditions. Since 1860 urban travelers started the (re)discovery of already known caves (Shaw 2008). In addition to that, famous caves were developed into showcaves and were opened for the public. This change in the self perception and social perception of cave explorers and speleologists is linked to an occurrence of a collective identification, which can be observed since the 1880s.

These three conditions apply to the caving clubs at the end of the 19th century. Through demarcation speleological organization created new group values and structures, which were published in just founded periodicals and club statutes. Especially Franz Kraus' "Höhlenkunde" (1894), Éduard-Alfred Martel's "Les Abîmes" (1894) and "La Spéléologie, ou science des cavernes" (1900) played an important role for the definition of the discipline's technical terms and aims.

Even the urban civic elite, fascinated by an imagined escape from civilization and longing for an original condition, entered caves searching for their lost immediate relationship to nature. The urban tourists did no longer feel as travelers, but began to regard themselves as explorers. The look of an admiring traveler changed to a competitive, demanding perception of the nature. In German this new self-consciousness led to a modification of the formerly common terms "durchforschen" (engl. "delve") and "durchmessen" (engl. "stride"). Focusing on the observer and no longer the nature as an object, now the explorers started to use the expression "erforschen" (engl. "explore") and "vermessen" (engl. "survey") (Mattes 2012b, pp. 123–124).

Furthermore, in day-to-day activities like expeditions and general meetings the collective identity of speleologists became manifest. In 1911 the First Speleological Congress of the Austro-Hungarian Empire took place in Hallstatt-Obertraun. There, not only expeditions were organized, but also the explorers discussed the social and scientific function of speleology and the limits to common cave visits. This historically based distinction, which is for the contemporaries anything else but clear, can be seen as a social construction. Before World War II collective identity in cave exploration was often linked to national concepts of identity. Especially during the Austro-Hungarian Empire cave exploration was a leisure activity of the German speaking social elite, mixed-speaking societies like the "Club Touristi Triestini" can be seen as an exception.

3. Historicization of speleology

Simultaneously with the institutionalization of speleology in private clubs and governmental organizations since the 1880s, the historiography of the discipline was initiated. The ambition was not only to construct a coherent and far back into the past reaching history of cave science, but also to legitimate the contemporary ambitions and to forecast a prosperous development of the field.

In particular with the creation of a persuasive prehistory early cavers tried to promote the acceptance of speleology as an independent scientific discipline and to legitimate contemporary research interests. On the other hand the historiographers also attempted to attribute themselves or their club an important personal role in the history of speleology.

During a period of around 1910, when caving clubs were founded, a second phase of increased discussion and debates on speleo-history can be noticed. With a steady and uninterrupted history of the own scientific field the communities were able to generate self-supporting identities, which let the explorers feel as successors of a long and successful tradition. Already Éduard-Alfred Martel unintentionally confirmed this circumstance in his book "Spéléologie ou Science des Cavernes" (1900):

"You would need a lot of pages and a whole enumeration of dates, famous names and titles of oeuvres to draw a complete tableau of all the activities, which were undertaken in caves during the last 125 years." (Martel 1900, pp. 8)

Finally, Éduard-Alfred Martel did not choose without reason the end of the 18th century as the birth date of speleology. He could have also defined the first known exploration of the "Breitenwinner Höhle" or the "Baumannshöhle" (Germany), Strein's and Gassner's penetration in the "Geldloch" (Lower Austria), Nointel's visit of a cave in Antiparos (Greece) or Kircher's and Valvasor's theoretical and practical examination of the underground (Italy, Slovenia) as the initial point of speleology. But of course the end of the 18th century – the Age of Enlightenment –, to whom many disciplines refer their history, ensured higher legitimation and reputation within the scientific community.

Figure 3. Photo of the Speleological Exhibition "Salzburger Höhlenschau" (Archive of the Speleological Club of Salzburg, 1913).

This increased interest in the history of cave exploration at the beginning of the 20th century can also be observed at a local level. After the foundation of the Upper-Austrian Section of the Austrian Caving Association, the secretary Ludwig Benesch delved into 30 volumes of the newspaper "Linzer Tagespost" in order to publish three articles on the "heimatliche Höhlenkunde" (engl. local cave research) in the feuilleton (Benesch 1911).

4. Locating memory

4.1. Musealization

During the second phase of increased discussion and debates on the history of speleology since 1910, the musealization of the discipline was initiated by the explorers themselves.

According to Anja Laukötter, the process of musealization can be divided in the three steps "remove, recreate, reintegrate" (Laukötter 2010, pp. 120–122). First the objects were removed from their original historical context, then their semantic meanings were changed by integration in the museum's rules and classification system, and finally the objects were re-integrated in exhibitions and the visitors' view gave them an exclusive aura and the significance of museum's objects. For Theodor W. Adorno the object's lost historical and cultural context, caused by the process of musealization, attempts to fix and reify memory as moments of greatness for subsequent generations (Adorno 1997). Thus museums became the location of memorialization and the construction of identities.

Only one year after the establishment of the "Alpenverein-Museum" (engl. "Museum of the German and Austrian Alpine Club") 1911 in Munich, the "First Speleological Museum of Austria" was opened to the public in Linz (Upper-Austria). It counts also as the first speleological museum world-wide. The exhibition, housed in the fortification tower on the "Pöstlingberg" near Linz, consisted of several showrooms where models of caves, special equipment like a folding boot to cruise subterraneous rivers and an aquarium with several specimens of the olm "*Proteus anguinus*" were presented. The exposition was designed as an artificial grotto and should create a cavern-like atmosphere (N. N. 1912). Due to moisture the museum had to move to the museum "Francisco-Carolinum" in 1915 and was integrated in a new exhibition in 1917 (Shaw 2010, pp. 146–149; N. N. 1913, pp. 6). The author of this paper was able to localize the exhibits of the speleological museum, which are today in the property of the "Oberösterreichisches Landes-museum".

Temporary expositions on speleology took place in 1908 and 1911 in Graz and in 1913 under the name "Salzburger Höhlenschau" in the castle "Mariabell" in Salzburg (see Figure 3). In 1922 the "Salzburger Höhlenschau" was re-opened in extended and adapted form as a museum in the Castle "Hellbrunn", also located in Salzburg. Regarding the content, Erwin Angermayer's draft for founding a "Central Speleological Museum of Austria" in the year 1922 tried to create an illusion of completeness and integrity, focused on the history of speleology:

"<u>Departement B:</u>

Applied speleology or the exploration and exploitation of caves

[…] V. Underdepartment. Clubs and Societies

History of cave exploration in Austria. Tables: historic events/explorations, statistics of the growth of speleology in Austria, strongbox with badges of clubs, index of speleological clubs. Images of famous cave explorers." (Angermayer 1923)

Also the decontextualized objects for the speleological museums, which the exhibitors got from different clubs and the Ministry of Agriculture, were re-integrated in a new context. During the opening of the Speleological Museum in Linz in 1912 the speakers mentioned the importance of this new institution for the development of the discipline:

"[Ing. Hermann Bock as President:] The intent of the club [Austrian Caving Club, Section Upper-Austria] was only to create the basis for the growth, further completion and propagation of speleology. [Rudolf Willner as functionary of the ministry of agriculture:] The Caving Club has set an everlasting memorial for itself in the history of speleology. Actually, the foundation of museum is a further page in the history of cave exploration." (N. N. 1912, pp. 3)

The new arrangement of the objects in the speleological museums not only had the function to instruct visitors, but also to convince them of the prosperous development and the social benefits for the local tourism and the exploitation of underground deposits. By focusing on the past with its "images of famous cave explorers" as a constitutive element of speleology, "lieux de mémoire" (engl. "places of remembrance"; Nora 1984–1992) like museums hold and legitimize the narration of speleology for the public and the explorers themselves.

4.2. Jubilees

Since the end of the 19th century jubilees of caving clubs, organizations and meaningful discoveries, became welcome occasions for presenting the history of speleology.

As a constitutive element of the bourgeois culture of remembrance, secular jubilees were celebrated since the French Revolution at the end of the 18th century. Around 1900 – at the zenith of the bourgeois era – a downright search for historic remembrance days began in order to present a social group publicly. In contrast to the dynastic culture of remembrance, which tried to affirm established traditions, values and norms during the jubilee, bourgeois remembrance attempted to connect to new traditions and values. These were generated during celebrations and ceremonies. In collective rituals, cults and myths like speeches, meetings, publications, and exhibitions, bourgeois and scientific clubs generated the consciousness of unity, created a corporate identity and history. The content, which should be commemorated, was always controlled and instrumentalized to legalize future purposes.

Since the beginning of the discipline until today, collective memory and normative views of history were activated and updated during speleological events and congresses. One of the first jubilees celebrated by caving societies was the 20th anniversary of the section "Küstenland" of the Austrian and German Alpine Club (Triest) in 1893. Peter August Pazze, chairman of the club, wrote in a historical chronic publicized on the occasion of the event:

"Everything, what the secretaries of the section <Küstenland> have narrated during the last 20 years of the glorious existence of the club, is presented in this book. It is ingeniously dedicated to all the companions as a remembrance for the long-standing harmonious solidarity and modest, unselfish and successful activity of the club." (Pazze 1892, pp. 1)

These processes of remembrance are often linked to competing national memories or "mythologies". Until the end of the 1950s speleology and cave exploration was part of competing concepts of national greatness and remembrance. In the Austro-Hungarian Empire cave exploration was propagated as a leisure activity of the

German-speaking social elite. This concept often implicates also the exclusion of the Czech, Slovak, Slovene, Italian and Jewish population, who founded own monolingual clubs.

When we celebrate anniversaries and jubilees of caving clubs and discoveries, we should pay attention to the mechanism of this problematic process of historicization. Behind the belief in a continuous development of the field, an inconsiderate belief in progress is frequently hiding. The present becomes a logical conclusion of events from the past and the history of speleology is reduced to a history of the achievements of the discipline.

4.3. Modeling heroes of cave science

At the beginning of 20th century the focus of speleology did not only lie on the caves and the subterranean discoveries, but especially on the explorers themselves. In biographical texts and obituaries speleologists like Éduard-Alfred Martel or Leopoldine Fuhrich (1898–1926) were often described as heroes of cave science, persons with supernatural strength. In most cases the intention for the posthumous glorification didn't come from the affected explorers. The instrumentalization of the commemoration often served as a self-affirmation for subsequent explorers and as a legitimation for their future aims. Because of this construction of an own history with timeless geniuses, each individual can feel like a lawful successor of a heroic explorer and give meaning to his activity (Mattes 2013). Bringing nationalism and scientific demand together, Hermann Bock described Fuhrich as a victim for her home country, as a fallen soldier in combat:

"Poldi Fuhrich was the most faithful companion and the earnest friend. Like the soldiers at war she died on the field of honor. She was in battle for the progress of science and for the glory and welfare of the fatherland and nation." (Bock 1926, pp. 70) Also in expedition diaries and protocols of caving clubs the speleologists not seldomly depicted their researches and discoveries as underground campaigns, obstinate battles against nature. The male-dominated caving societies often brought speleology and alpinism together and pursued right-wing politics. Each penetration in the subterranean world is connected closely with heroic acts of naming, interpretation and ritual appropriation of the underground places, which can be seen in the context of naming and "owning" of colonial territories during the imperialism period. Meter by meter of the mountain must be gained as a virgin territory. Special results like the length, total depth and vertical rage of a discovered cave were used as a scale for the heroic achievements of each explorer and his personal importance.

The medium of photography and the improved caving equipment led to an increased social disciplinary action within the research group. The strict division of labor between the cave explorers corresponded to the social prestige of each explorer. Due to the fact that speleologists began to separate themselves from ordinary cave visitors and tourists, carbide lights, rope ladders or distinctive instruments for cave mapping became emblems for speleology.

Similarly, the usage of photography as a suitable method for documentation had an effect on the self-perception of the cave explorers and the perception by others: During the romanticism period the painters were focused on the individual perception of the subterranean landscape, where humans just played a subsequent role as staffage figures. Because of the demanding lightning conditions, the photographers shifted the explorers to the centre of their artistic compositions. The most popular motif was no longer the predominance and greatness of the nature, but the explorer, who penetrated nature as a conqueror (see Figures 4, 5).

Figures 4, 5. The usage of photography had an effect on the self-perception of the cave explorers and the perception by others. The most popular motif was no longer the predominance and greatness of the nature, but especially the explorer. Left: Picture in Jules Vernes "A Journey to the Center of the Earth" (Paris, 1864). Right: Research group in the "Gassel-Tropfsteinhöhle" near Ebensee, Austria (Archive of the Speleological Club of Ebensee, 1919).

5. Summary

When we are studying the history of speleology we should contextualize the biographies and the scientific knowledge, which is often influenced by cultural components like hierarchical structures.

Nowadays, when we are reading (auto)biographies, laudations, official speeches, obituaries or popular articles on speleology, it seems that the history of speleology has in large parts still an apologetic function. For today's scientists, it is absolutely necessary to realize this problematic division of labor between speleological sciences and the history of science.

However, this predominance of historical thinking implicates also a clear purpose for the present. Because of the construction of an own, coherent history with its timeless geniuses, each individual explorer claims a place in history. As a result, former and future personal action is historically legitimated, gets higher meaning and importance and becomes comprehensible for the explorer himself. So the faith in the past is exceptionally frequently linked with a naive belief in progress.

For a very long time the connection between the popular imagery of progress, reminder service, memory and justification function shown here reduced the history of speleology to an assistant of the subject discipline. This excluded also an independent point of view. Not without reason Michael Hagner remarks in his book "Ansichten der Wissenschaftsgeschichte": "This historiography of scientific knowledge is anything other than established and is still regarded as a – welcome or unwelcome – novelty". (Hagner 2001, pp. 30)

Until today the benefit of the history of speleology and cave exploration is valuated as a memory of the speleological discipline, which is especially utilized for special occasions. This practice excludes the possibility of an independent profiling and professionalization. Historicizing the history of speleology would be a good start.

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THE DISCOVERY OF CAVES IN KHAMMOUANE, LAOS (1991–2013)

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No less than 26 campaigns of cave exploration, mapping and studies have brought a deep insight into the previously almost unknown karst of Khammouane. This 290 × 40 km wide area of highly diagenetized permo-carboniferous carbonate area in Laos has revealed no less than 90 caves to our team, totalling some 170 km of development. The most extensive cave in Khammouane is so far 29 km long and we reached a +467 m relative elevation in another cave. Perhaps the largest cave opening in the world (215 m wide), a dozen of large chambers, giant passages and world-class through rivers were also studied. Scientific work encompasses geology, karst organization and characteristics, hydrogeology, biology, ethnospeleology, ecotourism and other topics. This overview of this lifetime work on karst (23 years) is presented within its historical framework. Human aspects are taken into account and recommendations, including contract writing, are given.

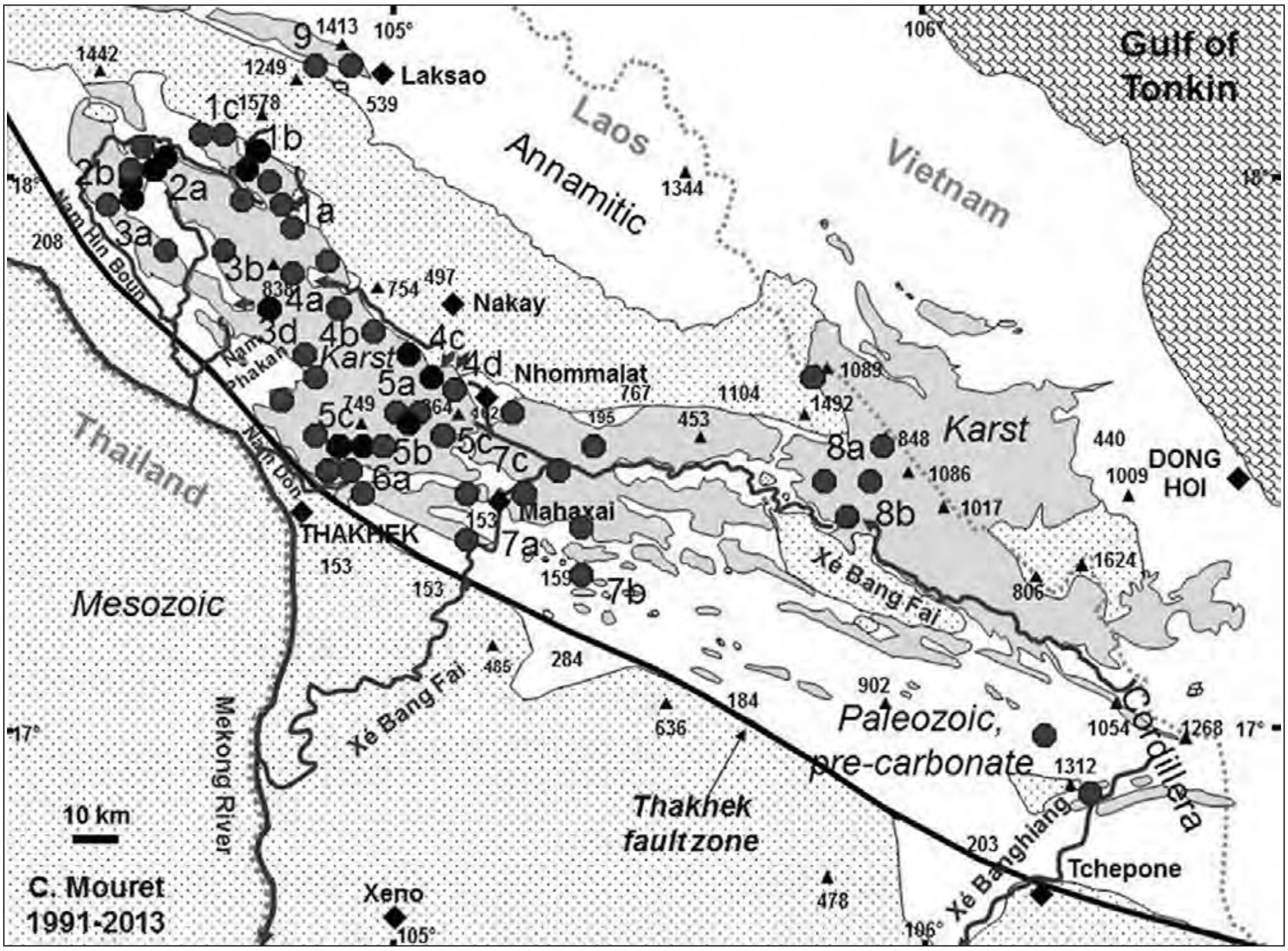

Figure 1. Simplified map of the karst of Khammouane in Laos and its continuation in neighbouring Vietnam. Dots represent the main areas that we investigated. Numbering of dot areas refers to text: a number may correspond to several nearby caves.

1. Introduction

As from 1991, systematic explorations and geological studies of the Khammouane karst area were initiated by the first author. In 1992, the first detailed cave mapping work was performed by the two authors (Mouret et al. 1993). Since, both of them have continuously cooperated until today, over no less than 26 exploration campaigns.

The team had a variable size, from two to 15 persons. Altogether, no less than 40 persons came with us, from France, Germany, America, Romania and Laos, of course.

We warmly welcomed all cavers willing to participate in the explorations and a number of scientific speleologists joined us. However, the system proved to reach a critical point when a few of the invited persons behaved as challengers, then left without sharing their results (e.g., surveys) acquired with the team, despite their promises.

Since the end-2009, we have been remapping those parts of caves which were diverted from the results of our team. Despite it is very time- and money-consuming, this work helps us in better understanding scientific aspects of the karst of Khammouane. We also continue mapping newly discovered passages.

This paper stresses the key periods of the 1991 to 2013 explorations, a view of the results achieved and some of the overwhelming difficulties we had to overcome.

2. A global approach to the karst

Since the beginning, our approach to the karst has always been global, as our goal consists of understanding the large tropical karst of Khammouane (290 × 40 km) in its natural and human setting (Mouret 2001, 2004). This large scale approach has been prepared by a previous similar approach to other karst areas and by a long experience of cave studies and geology in many areas throughout the world.

The global approach that we set up requires an adequate sampling and selection of caves to be explored and a careful recognition of karst phenomena and characteristics which can be original, never-described, nor interpreted. In addition, concentrating the mind on global karst organisation is of paramount importance, rather than focusing on unrepresentative or marginal details. A major breakthrough has been made on the karst hydrology, including the mapping of underground flows and the correction of more than once erroneous flow directions on the topographic maps (Mouret et al. 2003). We have been able to reconstruct the karst hydrogeological organisation of a substantial part of the large Khammouane karst.

The global approach had to permanently adapt to a variety of constraints and pressures, including human aspects.

It is worth also mentioning that speleology in Laos requires compulsory official specific authorizations.

3. A thorough search for caves and characteristic karst features

As our goal was a global approach to the karst, we first had to identify the most significant areas after a selection work based on scarce old speleological literature, more than 60 years old geological studies and modern investigations by the first author and other geologists, satellite imagery (Landsat at the time), morpho-geology (morphology and geology tied by their common logic), hydrogeology and other features of interest.

Search for caves in the field was systematically performed, mainly by the two authors. Together, more than 1,000 km of walk under variably difficult conditions were used to look for caves and another 2,000 km of walk for access to prospection areas. Most of the search was made along cliffs, as the karst surface is in many areas extremely rugged and very hardly accessible, with sheer cliffs, tsingy morphology and fengcong landscape.

The first author (team leader) often arrived in advance and was the last to leave, in order to look for more new caves and passages. The rule he applied was: **never finish an exploration campaign without knowing what the team would have to explore during the next campaign.**

Altogether, 460 days were spent in Laos by CM and 340 by JFV, i.e. far more than any other team member.

Cave mapping is only a part of our work, but it illustrates the gradual and almost regular progress globally made at every new campaign (see Fig. 3). Cave drawing was performed by several persons. The first author has been by far the main mapper and the second has highly participated in most of the surveys made by the team. Their cave maps on gridded paper have been shown to the team at every campaign. From the extremely difficult conditions in 1991 to the present day far easier explorations in Laos, we followed a long path, permanently improving the things, including the logistics, based on Mr Vannivong's deep experience and CM's years-long experience of field work in difficult remote areas elsewhere in Southeast Asia.

Figure 2. A surface view of Khammouane showing rugged morphology with tsingy, as seen from one of the upper outlets of Tham Phiseua. At the location, vegetation is nil to scarce and xerophytic. Photo by C. Mouret.

4. Main caves discovered and mapped

Altogether, 90 caves were explored and mapped. Out of them, 26 exceed a 1 km length, ten exceed 5 km, six are over 10 km, and three over 15 km and one is above 25 km. **All these caves are still under study by us**.

Here below, references such as 1b or 5a refer to Figure 1.

Tham Nam Non: 1b. Major temporary flowing resurgence. Giant passages. Two large chambers. Discovery by the first author (CM) on Landsat imagery, then confirmed on old geological maps. Investigations in: 1994 (the two authors and B. Collignon), 1997, 1999 (21 km), 2004, 2005 (25 km), 2010, 2011–2. The 55 m long final sump was dived in 2010 by others (what we learned afterwards), just after our publication on the cave: it is connecting Tham Nam Non with Tham Song Dang, both already mapped by us (Mouret et al. 2009). Total known length is **over 29 km**.

Tham Koun Dôn – Tham Houay Sai (the downstream part of what we called the **Nam Dôn System**, which includes sinking points several kilometres away). 5c.

Koun Nam Dôn is the karst spring (resurgence) of the Nam Dôn. The two main cave outlets flow during flood periods. Discovered in 1997 at the initiative of CM, after his geological investigations that followed the discovery of Tham Houai Sai (a different cave which is a temporary sinking point – see further down, 5b) and the discovery of Tham Kagnung by the two authors and J. Lordon in 1996 (Tham Kagnung is a subperennial sinking river cave, 5a).

1997 (0.5 km), 1998 (6.5 km), 2000 (7 km), 2004, 2005 (11 km), 2006, 2010, 2011 a, b, c, 2012 (**17 km**). Three large chambers.

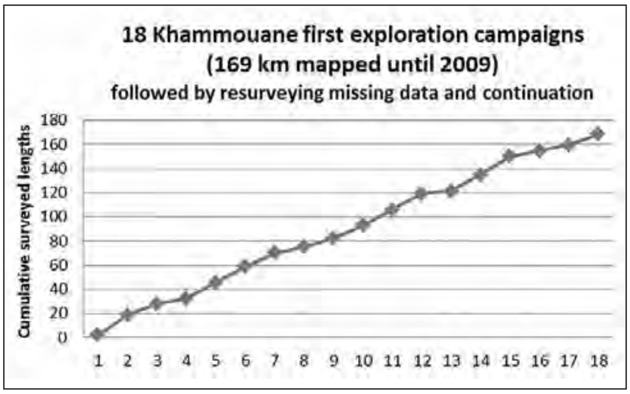

Figure 3. Progress of cave mapping during the 18 first campaigns, until Year 2009 included (n°18). After that, persons-related problems forced us to remap a part of the caves. Campaign 13 in 2004 was devoted mainly to archaeology and related surveyed length is short.

Tham Xé Bang Fai: 8b. Through cave with one of the largest underground rivers in the world (6.3 km long through-river). One large chamber.

First investigations by local fishermen, at least during the very early 20th Century (probably even before) then full crossing by Macey's team on a bamboo raft in 1904. 1995 (the authors, B. Collignon and C. Lagarde, in the difficult context of an ordnance-rich area due to previous wars) (9.1 km); 1996: car failure creating impossibility to reach the cave, then area closed to foreigners for nearly a decade; 2007: 1.5 km added; 2008: another 1 km; 2009 (the two authors alone for remapping). New length: **15.1 km** (Mouret et al. 2010).

Tham Nam Hin Boun, now largely called **Tham Konglor**: 1a. Through-cave with a large river (7.5 km through) used by villagers since the 19th Century at least. First western crossing by P. Cupet and H. Counillon in 1892. Sketch map by Macey (1908). Resurvey by the two authors and B. Collignon in 1994 (11 km). Additional investigations out of the river in 1997, 1999, 2004, 2005, 2006, 2011 (**13 km**). Giant galleries. Two large chambers.

Tham Phiseua: 5c. Discovered in 1996 by A. Gregory's team (1 km). Kind written authorization to continue exploration obtained from him by CM. 1998: reconnaissance inside by CM. 2000: Mapping starting at the entrance (J.M. Ostermann and CM) (1.3 km); 2002 (5 km, +315 m), 2003, 2004 (+376 m), 2005 (8 km, +465 m), 2006 (11 km), 2010, 2011, 2012 (**+467 m**, see below).

Sloping maze cave (Mouret et al. 2001) along dipping strata. Hollow stalagmites discovered by CM for the first time in Khammouane.

Tham Houai Sai (in the polje of Ban Vieng): 5b. Sinking temporary flowing river belonging to the Nam Dôn watershed. One large chamber. Discovery by Jean-François Vacquié (JFV) and C. Ferron in 1996. 1996 mapping mainly by the authors (2.5 km); 2000, 2001 (with X. Noguès) (9.9 km), 2011 (**10.1 km**).

Tham Lô: 5a. Two-level fossil cave in a cliff in the polje of Ban Vieng. Giant passages. One large chamber. Cave learnt in 2001 from Ban Vieng villagers at CM initiative. 2001 mapping by CM, X. Noguès, J. Lordon and C. Noiriel (1.5 km), 2002 (3 km), 2004, 2005, 2006 (**8 km**).

Tham Thon: 2a. Temporary flowing sinking streams leading to resurgence in the Nam Hin Boun valley. Information gathered in 1991 by CM. 1997: CM initiative to go there and mapping together with F. Brouquisse (2 km). 1998, continuation by the same mappers and L. Deharveng (**8 km**). The cave was subsequently explored by a team led by FB without us and connected in 2001 to a cave already explored by captain Jouan's team in 2000. The new investigations covered the central part of the system only (total length: ca. 15 km).

Tham Song Dang: 1b. Multiple sinking points of Nam Non, followed by giant passages. First mapped by the authors and Y. Dreybrodt in 2003 (4.5+ km). Additional mapping in 2004. Total length: **over 5 km**.

Tham Boumlou: 4a. Sinking point of upper Nam Pakan at the end of a narrow, 12 km long, blind valley. First reached in 2002 with JFV (see below). 2004 (**ca 5 km**).

Tham Kwan Ha: 1c. Temporary flowing sinking river. Discovered in 2009 by the two authors, and mapped. 2010, 2011, 2012 (**4 km+, work in progress**).

16 caves currently have a measured length between 5 and 1 km including: **Tham Kwan Ha** (CM, JFV, 2009); Grotte Sans Nom, i.e. **Nameless Cave**, **3 km** (1b. Discovery CM, JMO in 2004); **Tham En** in Phon Thiou area (**2.7 km**) (discovery CM in 1991, 3a); **Grotte Marie Cassan** (4d. Cassan, 1948; CM, 1991, 2003; 2004); **Tham Phu** (4a. discovery CM, 2004); **Tham** Ene near Tham Xé Bang Fai (8b. Discovery CG in 2007); **Tham Heup** (2b. Macey, 1908; CM-FB-JFV, 1998), **Tham Koun Houay Feuang** (CM, FB, 1997; topo 2002, 2006. 5a); **Tham Lom**, **Tham Thê** (CM, JL, LD, AB 1998. 2b); **Tham En** near Thakhek, (6a. CM and JFV, 1992, **1.98 km, giant entrance)**; **Tham Deua** (CM-CG-JFV, 2003. 4d); **Tham Khamouk** (CM-CG, 2003. 4d); **Tham Kagnung** (CM, JFV, JL, 1996. 5a), **1.5 km**, head of Nam Dôn System), **Tham Lom** (CM, JR, 2005.5c. Mapping by JMO in 2006); **Tham Phuhung** (CM-FB, 1997.1a);

Other caves of specific interest: Tham Nam Thieng, Tham Nong Ka, Tham Pa Fa, Tham Phanoi.

5. Main discoveries and results on karst

Geology: thickness of the Permo-Carboniferous carbonate, petrography, palaeontology, stratigraphy, sedimentology and depositional environments, petrophysical properties, tectonics, geohistory (palaeoburials and erosion depths, using a variety of methods), mineral seams crossed through by cave passages, phosphate and guano deposits.

Palaeokarst: discovery and interpretation of buried palaeokarst morphologies below Liassic red beds deposited under continental environments.

Cave maps: more than 170 km surveyed.

Karst systems: main types of cave systems, including subhorizontal active and fossil networks, sloping mazes (up to + 487 m), sunken passages, global organization.

Giant underground volumes: discovery of more than a dozen of giant chambers, of wide-sized passages (up to 120 m wide).
Cave sediments: studies of a number of fossil and present day sediments, with importance for the interpretation of cave genesis.
Hydrology: identification of the main, binary and unary, karst watersheds in Khammouane, identification of the sinking points, springs and many of their mutual relations, study of floods and of low waters, characteristics of flooding effects at surface.
Water chemistry: studies of chemical and physical characteristics of karst waters.
Cave meteorology: repeated measurements in a number of caves at different seasons.
Earthquake effects: the March 2011 Fukushima major earthquake was felt in a gallery located at the end of a funnel-shaped large chamber in the Nam Dôn System. Exceptional sonic phenomena were observed there.
Speleothems: among others, discovery of hollow stalagmites, pseudowallmites, rims, giant cave pisoliths, shields, circles of calcite, black circles, phosphate crusts, gypsum and moonmilk, giant speleothems such as pillars, rimstone pools, etc.
Cave mineralogy: sequential discrete sampling (a few tens of grams) in relation with cave organisation and geology, X-ray analyses, interpretation of thin sections, speleothem fabric.
Archaeology: study of two caves with respectively 229 (Mouret et al. 2005) and more than 100 Buddha statues and other artefacts. Cave wall drawings and paintings (Ostermann et al. 2003).
Biospeleology: study of cave macrofauna (buffaloes, wild boars, wild goats, snakes, rats, birds, bats, fishes, worms, crabs, the largest spider in the world and other arthropods) and microfauna. New species and genera.
Palaeontology: discovery of rhinoceros bones (now extinct in the area) and of wild goats.
Ethnospeleology: burial caves, hidden "treasures" related to Buddhism, cave use during Vietnam war, Buddhist caves, modern cliff and cave wall drawings, hunting and fishing in caves, caves as a link between villages, "cave is money" aspects.
Cave and karst protection: respect for caves, selection of permanent paths for progression, recommendations, guidelines for protecting caves open to visitors, assistance to Tourism Authority of Khammouane and to provincial Governement. Active participation in UNESCO meeting for selecting new World Heritage areas in Asia and setting guidelines and recommendations for this.
Photography and videography: comprehensive sets of photographs realized. Movies, shown at German TV.
Promotion of ecotourism: promotion of selected caves for tourism. Tham Konglor, mapped by us in 1994 and after, is now one of the world landmarks for tourists. This has contributed to the large economic development of the valley. Guidelines for officials on caves and karst value.

6. Publications

Despite not everything has been published yet, we have produced more than 60 papers on our explorations (Mouret 2001) and results. A comprehensive work is in progress. A significant number of papers was published in proceedings of previous International Speleological Congresses and in Spelunca, among others. Publications have been made despite not all parts of the surveys of our team were made available to us and despite heavy pressure put on our persons. We obviously had also to care of our time-consuming professional work and heavy responsibilities and activity in national and international speleological federations. Co-autorship has been given to team members who put their surveys "in the pot".

50 km of cave maps have been published with detail and another 28 km has been published as simplified maps. In the final work, full data (maps, longitudinal sections and cross-sections) will be given.

Figure 4. A fossil passage formed horizontally alongstrike of dipping carbonate beds, in Tham Phiseua. The slightly incised passage floor is covered with moonmilk and gypsum crust. For purpose of protection and respect, we walked only on the rocky shelf. Photo by J.-F. Vacquié.

7. Welcoming new team members

We welcomed all persons who expressed their interest in exploring caves of Khammouane with us. The conditions were co-signing publications and complementarity in everybody's speciality. Logically, no duplication of somebody else's work was permitted. Newcomers had to respect previous work and to bring something new and useful to the team: techniques, knowledge or – at least – participation to the team effort and friendship.

Every year, the team leader (the first author) proposed the caves and passages to be explored. In the field, he did not hesitate to give briefings on the current knowledge, to show the maps already drafted on gridded paper and to explain the objectives of the exploration.

Newcomers were taught of caves newly discovered (see Chapter 3). They were made aware of unexplored passages in caves under study and even guided, when necessary, by the authors up to the starting point of the survey of virgin galleries. Often, they were helped in such virgin passages by JFV, even for mapping. This was a major real proof of our deep consideration for them, by providing them with easy-to make discoveries.

The knowledge of unexplored galleries given to newcomers was largely the result of previous intense cave mapping work (see Chapter 3), as parts of passages under survey were left for the next campaigns.

Figure 5. A fossil passage in Tham Nam Non, with multistory rimstone dams. Photo by J.-F. Vacquié.

The purpose of this was to maintain motivation in the team. In addition, this allowed us better exploring and studying a cave, thanks to knowledge gained in others. We will see that this way of doing is not satisfactory because it generated unwelcomed consequences. For instance, a minor one is that a couple of persons lacked politeness by complaining that the virgin passages were "not good enough for them". They refused admitting that the discoveries offered to them could easily have been kept by us for our own use. A major one is that they subsequently did not communicate any of their surveys.

We feel that a few persons brought heavy disturbance and tried to "kill" our explorations and take them over, based on what they learnt from our knowledge. Recently among them, one or two never came with us in speleology.

8. Six periods of exploration

8.1. First period: pioneering (1991 to 1995)

In 1991, CM started studying the geology of Palaeozoic and Mesozoic strata in Khammouane. A good number of cave entrances were located in the field or learnt of, e.g., Tham En in Phon Thiou area, Tham Thon, Grotte Marie Cassan, also the characteristic polje of Ban Vieng. Roads were rare, narrow and unsurfaced, so access to sites was extremely difficult. Ongoing guerrilla rendered body guards compulsory. No foreigner can imagine today what Laos was at the time, as so much good progress has been made since.

In 1992, the first author managed to set up a first exploration campaign, under difficult conditions. Perhaps the widest cave entrance known in the world (215 m across) was discovered. 1993 was a period of political instability and no exploration was allowed – except two reconnaissance campaigns by CM. In early 1994, the authorization to explore caves was obtained again.

Immediately in 1994, then in 1995, we re-explored, after precursors a century ago, and accurately mapped with detail two major world-class river caves, Tham Konglor and Tham Xé Bang Fai through-caves (see above). We started exploring the gigantic Tham Nam Non and clearly established its large potential (it is currently the longest in Laos – over 29 km). 30 km of passages had already been surveyed in Khammouane by us as per 1995.

8.2. Second period: normal explorations (1996 to 1998)

The team was enlarged. In 1996, the Nam Ngo springs area near the Vietnam border proved disappointing and the Xé Bang Fai could not be accessed because of vehicle failure. J.F. Vacquié discovered the Tham Houai Sai dry sinking stream. With CM, he discovered and started exploring Tham Kagnung, the only perennial sink in the polje of Ban Vieng. CM geological studies then indicated two spots to be checked in a large karst valley on the opposite side (SW) of the massif: they might be the resurgence(s) of Tham Kagnung and possibly Tham Houai Sai streams. This was the beginning of the knowledge of the Nam Dôn System.

In 1997, Tham Nam Non was continued. The resurgences deduced from the study of Tham Kagnung were effectively discovered, including the spring of the major Nam Dôn, not shown on the then available 1:100,000 topographic map. CM surveyed the beginning of these three caves. Based on 1991 data, Tham Thon was spotted by CM and FB and mapped for over 2.5 km (FB drawer).

In 1998, the area of Ban Nakhok was investigated (Tham Heup, Tham Thê, Tham Nam Thieng…). Tham Thon was mapped up to 8 km length. The Nam Dôn caves (Tham Houay Sai and Tham Koun Dôn) were mapped to over 7 km and CM wrote that their system would be no less than 25 km long.

8.3. Third period: so many worries (1999 to 2004)

FB refused to join the team in 1999, despite our repeated invitations. He claimed he wanted to write papers with no co-author. Our focus was placed on Tham Nam Non, bringing the cave survey to over 21 km. After the 1999 campaign, we had already surveyed 60 km in the karst.

In 2000, a newcomer (JMO) was invited by CM. Mapping Tham Houai Sai (in the polje of Ban Vieng) and Tham Houay Sai (in the Nam Dôn valley) was significantly pushed further and Tham Phiseua was mapped from the entrance over more than 1.3 km. Tham Nong Kha showed at the ceiling the painting of a man.

In 2001, Tham Houai Sai was pushed to 10 km. The fossil Tham Lô was discovered after CM questioned villagers, and mapped with three other colleagues. Tham Koun Houay Feuang (1997 CM-FB discovery) was surveyed.

In 2002, Tham Phiseua, Tham Lô and the Nam Pakan valley (Tham Boumlou was first reached by JFV and three other colleagues) were studied. More wall drawings, including further human representations were discovered and studied. The karst of Lak Sao was investigated for the second time after 1991. More than 90 km had already been mapped in Khammouane by our team as per 2002.

During the period, we suffered a number of problems: FB, then a national speleological body official, continued Tham Thon, with a team he set up on purpose, and joined it with another cave mapped in 2000 by captain Jouan's team. In this way, a part of our work was diverted, as for two other caves discovered by CM. In 2001, FB mapped a passage in Tham Phiseua which branches from our 2000 discoveries without him. In 2002, he explored the resurgence of Nam Pakan that we had officially declared to a national speleological body as one of our objectives.

In 2003, partly with a newcomer invited by JFV: CG, CM resurveyed (after Cassan 1948) "Grotte Marie Cassan" up to the final sump. We mapped other caves in the same area (Tham Khamouk, Tham Deua…). With Y. Dreybrodt, the two authors accessed the sinking point of Nam Non and mapped Tham Song Dang over some 4.5+ km, this just after further mapping in Tham Phiseua. We were then at 105 km all together surveyed in the karst.

In 2004, we went to Tham Phiseua; then we continued Tham Boumlou, while a team led by a national speleological body official was trying to push up from the resurgence. A sump prevented them "invading" the upstream part of the cave that we were exploring. We mapped Tham Phu discovered by CM; then we continued Tham Lô.

Figure 6. The entrance to fossil Tham Lô (tree for scale). Photo by C. Mouret (2006).

8.4. Fourth period: apparent peacefulness or the wolf in sheep's clothing (2004 to 2005)

Again in 2004, after the discovery of Tham Pa Fa by a villager, CM was invited by the Tourism Authority of Khammouane to study the cave and he asked CG to join. In 2005, we focused on Tham Nam Non, Tham Phiseua and especially the Nam Dôn System. Many results remained unavailable to us despite repeated promises.

8.5. Fifth period: new big worries (2006 to 2009)

2006 was a good year for exploration and a bad one for human relations in the team. A group of four persons that we, JFV or CM, had invited to join our team, one in 2000, one in 2003 and two in 2004 were especially aggressive. CM had invited for 2006 a team of divers abandoned by their leader, who was with us in 2005 upon invitation by CM. The Nam Dôn System was further mapped, as was Tham Phiseua and Tham Lô. A dozen of kilometres were surveyed, but many of them are not available to us.

In 2007, focus was placed by CM on the Xé Bang Fai, which was newly accessible again. In 2008, two of the aggressive team members tried to take over the leadership using a number of disputable ways. The Xé Bang Fai area was on focus again and, upon CM's proposal, further work in the Grotte Marie Cassan area. Later on, we realised that, as in 2006, we were not told all the truth.

For 2009, CM put on the program further work in the Nam Non area. As so many surveyed kilometres were concealed by a few team members, it was decided that the latter would map separate caves, in order that our own work be not jeopardized. The two authors both discovered Tham Kwan Ha after a long prospection and operated a large part of the mapping work. They were unduly overtaken in the cave by two other team members while doing so. This latter behavior resulted, together with the long-concealed surveys, in a serious explanation.

A few months later, the team split, due to said unwillingness to work together. Subsequently, "the other team" used all diverted results as a capital to attract new and many people around them.

8.6. Sixth period: remapping missing parts (2009 to 2013)

The two authors understood that they would never receive the missing parts of the surveys that they asked for so many times during six years: 49 km altogether, probably a world record, this from a few persons only! Therefore, our publications were blocked and a part of our own surveys had become useless, due to lack of link with more proximal parts of caves. So, we decided to resurvey the missing parts, in order to publish.

At the end of 2009, the two authors resurveyed and checked enough data of the Xé Bang Fai to produce a paper in Spelunca Bulletin. In 2010, together with Terry Bolger, they further explored Tham Nam Non and Tham Koun Dôn – Houay Sai in the Nam Dôn System, making a very good mapping breakthrough in a giant maze area. Meanwhile, "the other team" went partly to caves already under advanced mapping by us, partly to caves started by them in 2009 and largely to a major cave about which they told us in 2008 that there was no continuation, after we taught them the entrance.

In 2011, the authors and Jacques Rolin resurveyed missing passages mainly in Tham Nam Non, Nameless Cave, Tham Kwan Ha, Tham Phu and in the Nam Dôn System. CM wrote that the length of the latter was likely to be over 50 km long. During that campaign, the authors made the bitter experience to find out that "the other team" had also been mapping the Nam Dôn System, after the publication of our report on 2010 work. At the next 2011 peak dry season, the two authors further explored and mapped the System, as well as Tham Phiseua, Tham Houai Sai (>10 km), studied Tham Phanoi and made further studies in Tham Heup and Tham Nam Thieng. They went again into the karst at the end of Year 2011, pushing the Nam Dôn System, Tham Phiseua and the Tham Nam Non mapping.

In 2012, "the other team" returned to the Nam Dôn System in February, our usual period of exploration. Therefore, the authors and J. Rolin could go there at the end of the dry season only. The previous elevation of Tham Phiseua (+465 m, a figure based on GPS control by CG in 2005 and checked by us with GPS and Google Earth in 2012) was revised by us to a lower value, but we gained another +24 m and now accept a +467 m value.

Our mentor and excellent friend in Laos, Mr. Vannivong

Soumpholphakdy, passed away no long after this 25th campaign, after having organised for us the Laotian part of the logistics since 1994, in close co-operation. At the end of 2012, we payed respects to our friend's ashes, then we continued the Nam Dôn System, Tham Kwan Ha and other caves, as he liked, until the first days of 2013. We continue our work in Khammouane in his honour. Early 2013, more caves we are exploring are being investigated by "the other team".

9. Relations with other teams

On our own, our wish was (and still is, despite adversity) to maintain good relations with people. We had no special problem with teams from other countries and a few teams from our country.

However, we have to face the paramount problems arisen from persons that we kindly invited and trusted. They came with us, learnt about the caves we discovered and explored, collected scientific knowledge and contacts from us, including the way how going through in the country and a good picture of our ideas and program. Now they use our elective time period during the dry season and all our usual facilities. They continue, on their own and with a very large team, the exploration of caves which were started mapping by our team and regularly continued by us until today, rather than to look for unexplored caves, still so numerous in such a large karst.

In this way, we are dispossessed from a large part of our investment in time, money, effort and knowledge**,** and of our results by persons that we welcomed and soon **did not respect the rules of the team**. Among the so many persons who came with us, many have been very correct.

10. Conclusion: protecting our work and proposal for written contracts

Despite clear mention to newcomers of the way how the team works, a few (though too many!) persons did not respect the rules and cheated the rest of the team, with 49 km of diverted mapped passages.

No less than eight caves that we discovered, mapped and studied (black dots on Figure 1) have been continued to be explored by "others" without our approval, despite our many publications and clear statements that they were under study. 1.5 month after the printing of our paper on Tham Nam Non, others dived inside without informing us. We continued and continue exploring all caves we discovered during our 26 campaigns over a time span of 23 years already, a lifetime investment which, we feel, has been deliberately jeopardized by invited persons.

Our experience may happen to other speleologists, especially when good results are achieved.

So, requesting any team member, especially newcomers, **signing a full written contract is nowadays a must and our deep recommendation**, with all aspects duly documented. Changing world and mentalities have largely moved traditional respect, friendship, trustfulness and verbal agreements into the abysses of a past lost for ever. It is preferable facing the future with a re-adjusted behavior designed to better fit today's reality.

Acknowledgments

Our exploration campaigns have been possible thanks to the help of Mr. Claude Vincent, then of Mr. Vannivong Soumpholphakdy. We cherish their memory and continue our explorations in their honour.

Nothing would have been possible without our many friends and our families.

Definitely, we have loved Laos since our first contact and we do appreciate the wonderful people and magnificent nature. Seeing the country changing permanently toward a good and fascinating future is a great pleasure.

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SIGNIFICANT "ERRORS" OF SOME THESSALONICA'S GEOLOGISTS AND ARCHAEOLOGISTS REGARDING PETRALONA CAVE

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For more than half a century Petralona cave is known mainly due to the discovery during 1960 of a human fossil skull. Its morphology revealed primitive europeoid traits, corresponding to approximately 700,000 years ago. In this concept Petralona man represents the eldest ancestor of the Europeans that used a particular pre-Acheulian Palaeolithic culture, accompanied by the first known traces of fire. The above conclusions entered into excessively strong debates for several decades, mainly by various scholars of N. Greece. According to the author's point of view these debates are due to (and/or led to) significant "errors", concerning even damages to the Petralona human skull, to other findings, and to the cave chambers. The lack of research and excavating permissions over the last 30 years to several scientists all over the world intensified the related problems, preventing a closer approach within an open and sincere scientific dialog.

1. Introductory history

Petralona Cave was incidentally discovered in May 1959, on the Chalkidiki Peninsula (Macedonia, N. Greece). It is located at an elevation of ~300 m above sea level on the western slopes of the Kalavros (Katsika) Mountain. In September 1960 an almost intact human skull was discovered in a small chamber.

Initially the fossil material was considered unstratified (mixed by running water) and of Upper Pleistocene age (~50,000–70,000 years old). In accordance with this chronology the human skull was therefore considered to be that of a Neanderthal woman, with a similar morphology to African skulls (cf. Kokkoros and Kanellis 1960; Breitinger 1964; Sickenberg 1964: Marinos et al. 1965).

"*Macedonia*" – the newspaper of Thessalonica – was the first on 18th September 1960 to report about the discovery of "Petralona man", publishing photography of the skull.

Aris Poulianos (father of the author) was working in the same year on his PhD thesis "*The Origin of Greeks*" (its main conclusion being that there is an uninterrupted presence of the same population in the Helladic area, as well as most of the Balkans since prehistoric times) under the guidance of Academician G. F. Debetz in Moscow. Therefore and because Petralona man was indirectly connected to his thesis, A. Poulianos (1961) sent a first short note to "*Vopross i Antropologhii*", based on the picture published in the above-referred newspaper. Also, the Petralona discovery triggered A. Poulianos return to Greece at the earliest possible time and, within the context of a huge effort to re-initiate anthropology to its motherland, he started exploringnd the Petralona Cave in 1965 (cf. A. Poulianos 1967, 1971). Soon he came to the conclusion that Petralona man was: (1) a male and not a female, (2) europeoid and not africanoid, (3) and belonged to the Lower to Middle Pleistocene (~700,000 years old) and not to the Upper Pleistocene, and that he therefore was (4) a prae-neanderthalian *Archanthropus* (i.e. an archaic *Homo sapiens*, also referred to as a late *Homo erectus* or even a *Homo heidelbergensis*) and not a classical Neanderthal. It is therefore the first europeoid, that practiced his own Palaeolithic culture and important for our general understanding of the hominisation process.

The Lower to Middle Pleistocene age is based on the detailed analysis of the cave stratigraphy (34 geological layers have been excavated until today). It is also based on the study of the Palaeolithic tools, as well as the exact diagnosis of the Palaeofauna that was discovered in almost all layers. Among the fossils of extinct species such as lions, hyenas, bears, panthers, elephants, rhinos, megacerines, bisons, various species of dear and equids were found, as well as 25 species of birds, 16 species of rodents and 17 species of bats. A considerable factor that helped in reconfirming the age of Petralona man contributed methods of advanced by nuclear physics. The materials used for such a purpose were bones, clay, stalagmites and ashes, the earliest traces of fire that have been lightened by human hands on Earth.

The systematic excavations of the site proceeded mainly during 1974–1983 under the auspices of the Anthropological Association of Greece (AAG – founded in 1971 by Dr. A. Poulianos), a large scientific group with 52 prominent specialists from twelve countries that was formed to support the studies. Researchers as B. Kourten (Finland), M. Kretzoi (Hungary), M. Ikeya (Japan), P. Bosak and I. Horacek (Czech Republic), G. Belluomini (Italy), A. Moigne (France), R. Murrill (U.S.A.), are among the most known authorities engaged in the studies, applying also many innovative scientific methods. The Lower to Middle Pleistocene chronological considerations were also reconfirmed by the author, while correlating Petralona with Razdolje, Stranska Skala, Mosbach, Isernia and other Lower to Middle Pleistocene sites (cf. N. Poulianos 1989).

During this same period A. Poulianos advanced his excavations, publishing dozens of articles and in 1981 he built the Anthropological Museum of the AAG next to the cave at his own expenses.

In 1989 and 1998 the author defended his two PhD theses, the first at the Florence Anthropological Institute of the State University in Italy and the second at the Prague Geological Institute of the Academy of Science.

In 1997 new catalogs of the fossils were compiled, this time in a digital form. This process was unfortunately advanced with no state support and under tremendously adverse conditions. As a consequence N. Poulianos in 2008 wrote: *"…to this digitalization purpose the most scientific effort of the Anthropological Association of Greece is directed"*.

The new data were presented for the first time at the UIS Congress at Sheffield by N. Poulianos (1977), who already participated as a high school student in the Olomouc UIS Congress in 1973 (cf. Sifneos and Poulianos 1974). New data were also presented at the UIS congresses at Kentucky, Barcelona, Brasilia, Kalamos (Attica, Greece) and more recently at Kerrville, 2009 by the author (cf. also detailed bibliography at http://www.aee.gr/hellenic/6petrlona/bibliography/bibliography.html). On the other hand almost 1,000 articles, radio and TV reports concerning the AAG contribution to Petralona cave studies have being brought to the public in Greek and other languages (cf. in www.aee.gr).

Today Petralona Cave – bejewelled with stalagmites and stalactites – is a touristic destination and at the same time constitutes an excavating site of considerable importance for many aspects regarding the passage from the end of the Lower to the beginning of the Middle Pleistocene. Prehistory, stratigraphy, palaeontology, archaeometry, palaeoecology, biostratigraphy and palaeoanthropolgy are the main topics under continuous investigation. These topics attracted a broad international interest and stimulated extensive studies of the site, leading to manifold discussions especially regarding the chronology of the cave.

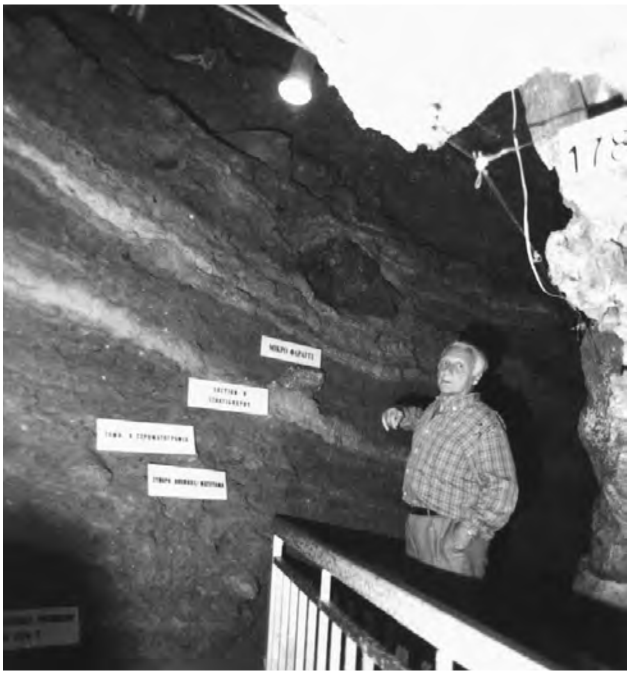

Figure 1. Dr. Aris Poulianos explaining the significance of the Petralona cave stratigraphy.

However, several scholars were reluctant to accept the above-referred revisions and others have never accepted them. As a result, the opponents of Dr. A. Poulianos managed to cause the interruption of the research three times. The first interruption was effected under the military junta (1967–1974). The second was caused more recently (1983–1997), i.e. in "democratic" times. The third interruption occurred on 4th April 2011, when AAG was again expelled from Petralona cave by an illegal (according to the appeals of the attorney Nicolas Triples) court decision. During all of the interruptions many excavating data disappeared (findings, diaries, catalogues etc.), indicating that medieval mentality still survives within "scientific" circles even in the 21st century.

In order to challenge the chronologies of Dr. A. Poulianos, some Thessaloniki-based geologists tried to date directly the skull by the method of amino acid racemisation. This method could not then surpass 200,000 years, but the amount of bone used caused severe damages to the skull. Since 1979 Dr A. Poulianos and especially other non-Greek anthropologists (Murril 1980 from USA; Hennig et al. 1982; Protsch 1983 from Germany; and Stringer 1983 from England) had published their concerns – addressed by AAG also to the Greek Government – about the catastrophic interventions made on the human skull by cutting off bone pieces. However, this matter was never investigated. A committee of Thessaloniki geologists and archeologists ignored the above-mentioned palaeoanthropological data, declaring that they observed no damages.

To my understanding unless an international committee is formed with the participation of at least one AAG member, the matter will not be solved soon. Since the Petralona human skull belongs to the international prehistoric heritage, its protection should become of first priority today.

2. Last decade status

Besides never investigating the mentioned damages on the Petralona skull and never discussing the new evidence for the Petralona chronology, the Greek Archaeological Service also failed to address concerns on other important issues:

I. Due to the long established Czech-Hellenic collaboration and the high scientific standards of Czech Geologists and Speleologists, AAG invited Dr. Pavel Bosak (and today our Brno UIS President) along with Dr. Ivan Horacek to visit Petralona Cave end of 2005 in order to formulate a program for further research with new techniques on speleogennesis and archaeometry. Along with the official and detailed proposals towards the Archaeological Service, the financial support of approximately a quarter million Euros was offered by the Czech Academy including also EU funds. Until now and despite the huge economic crisis during the last years, a response was not provided.

At Kerrville in 2009 Dr. Pavel Bosak renewed his proposals, but again there was not any reply, demonstrating that in Greece the "official" apparatus did not function properly. Specifically in Bosak's 2009 letter is written: *On behalf of the Czech Academy and in continuation of the 2005 proposal at investigating the speleogenesis, as well as the chronology of stalagmitic materials from Petralona Cave, I would like to renew the possibility of proceeding with such a program. Herewith, it is also noted that only for the next year (2010) there will be still the possibility of covering all lab and transportation expenses by the Czech part, and that the co respective results may be presented in the next (16th) International Congress of Speleology, which will be held in Brno during 2013.*

Kerrville, Texas, USA, July 21st 2009, Pavel Bosak, Vice-President of the International Union of Speleology

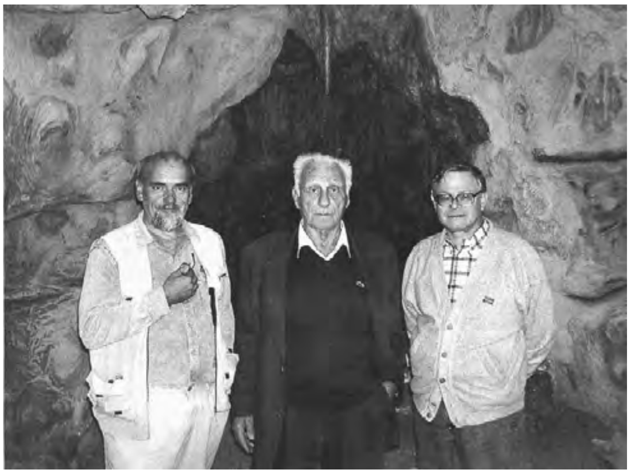

Figure 2. Ivan Horacek, Aris Poulianos and Pavel Bosak in the Anthropological Museum of Petralona Cave 24 Oct. 2005 (from newspaper "Chaos").

II. In 2007 Professors of Geology & Palaeontology at Thessalonica University published a bilingual book (in Greek and English) regarding Petralona Cave (Koufos and Tsoukala 2007). In this book many "mistakes" are reported (some also supported by state archaeologists), but the most evident concern are: A) The authors deny the existence of a stratigraphy in Petralona Cave, in order to question the correlation that exists between the chamber where the Petralona skull was found and the cave's stratigraphic sequence (cf. Fig. 1). B) Another distortion regarded the place and cave chamber that Petralona man was found as doubtful, in order to even more confuse the entire picture. Here it is worth of mentioning that the same issue was in details discussed at the Budapest UIS Congress, and further published on many occasions (p. ex. in both of N. Poulianos PhD theses). However, these bibliographical data were again totally ignored.

III. During the aforementioned "illegal" abolishment of 4th April 2011, AAG officially asked several times to produce commonly accepted catalogues of the findings together with the state employees. The "authorities" denied even this simple and absolutely necessary action, for a number of the about 100,000 findings deposited in the Anthropological Museum. By the end of November 2012 it became also known that the Archaeological Services started to rename and/or renumber findings that have been already published before, an action that surely will lead to great confusion in the future and violates common scientific rules as well as the rights of the first publishers.

IV. After the "illegal" abolishment of AAG in 4th April 2011, the Central Archaeological Council (CAC) decided that all of the drawings reproduced by one of the most important Greek folk painters, the late Christos Kagaras (resistance fighter against the Nazi occupation of Greece), must be covered and hidden as not adherent with the findings of Petralona Cave. This is unfortunately not correct, since these paintings (today displayed only on the AAG affiliated website) are referred to the prehistoric inhabitants of the Petralona region. Others of his drawings represent also the evolution of life, inspired from another great painter, the Czech Augusta Burian. It is worth mentioning that the former President of France, Valery Giscard d'Estaing, during his visit to Petralona exalted Kagaras' paintings, calling them "*magnifique*". CAC also decided to remove many sculptures made by Agella Korovessi who was the silver (2nd) winner at Beijing 2008 Olympic Art Games. Protests of AAG as well as of the main Greek artistic organization never reached the state's ears.

Figure 3. A picture of Ch. Kagaras, indicating prehistoric inhabitants of Petralona cave hunting a rhino.

Also, the sculpture of a Miocene giraffe, 3 m high, being the biggest tourist attraction, did not escape (in September 2012) from today's "barbarism". It is estonishing that during our current economic crisis state funding was not only available to destroy artistic representations but also – among other similar irrational actions – to replace the existing perfectly functional central gate with a very expensive one October 2012.

Figure 4. The giraffe referred to in the text as it was until October 2012.

V. On several occasions to both Poulianos even a simple lecture to schoolchildren or to a tourist group in front of the Petralona Cave was forbidden upon absurd excuses (claiming that the excavators are not granted to such rights).

Figure 5. The giraffe referred in the text, as it is destroyed and lying on the ground today (18th November 2012) 150 m away from the entrance of Petralona cave.

VI. The marble keystone of the Petralona Anthropological Museum was removed at the end of 2011. On this keystone it was carved that the Greek state inaugurated the building in 1978 on the initiatives of Dr Aris N. Poulianos.

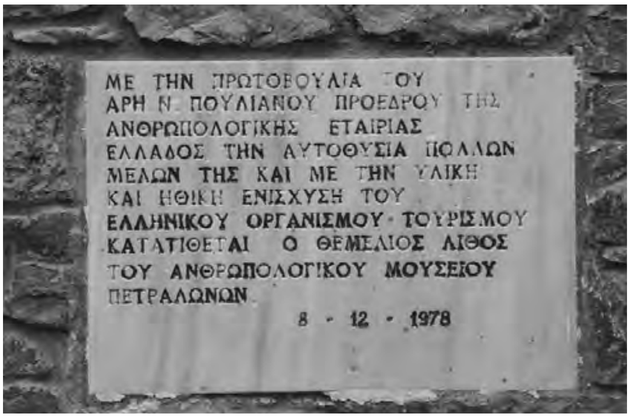

Figure 6. The keystone as it was until 2011.

Figure 7. The empty space on the Anthropological Museum's wall, indicating where the keystone was until 2011.

VII. On 8th March 2012 a masked man tresspassed the house of Aris Poulianos and his wife Daphne (200 m near the cave) attacking them with a rifle. The 88 years old anthropologist struggled with the gunman in order to stall him and give his wife the time to escape to the woods. As a result he got injured and received seven stitches at the local hospital. The gunman stole money he found and managed to get away. The most interesting issue is that as the state faces economic hardship no budget was allocated to post guards after 2011, and it was done so without informing the Poulianos family.

VIII. During summer 2011 CAC services provided unreal data to the Greek Parliament concerning the financial aspects of the cave. Until now no formal investigation started on the topic.

IX. For one and a half year and for thee consecutive times the CAC services refused to the author (as well as to Dr. E. Kambouroglou and Dr V. Giannopoulos – members of ISCA scientific committees) the study of the material deposited in the Anthropological Museum, while at the same time from its' exhibition hall many findings are missing, as for example a fossil leaf covered by stalagmitic material. The photo of this leave is published in the Greek version of the journal "*Economist – Intelligent Life*" in November 2012. Again, no answer was ever given to what happened to this fossil leaf.

Figure 8. The fossil leaf referred to in the text.

X. Since almost two years 13 employees of the AAG, all from Petralona village, are sent to unemployment for no apparent reason, augmenting this tremendous phenomenon of the Greek society.

The President of the European Anthropological Association, Professor C. G. Nicholas Mascie-Taylor, in 5th September 2012, summarized most of the above points, in a distress letter towards to the Greek Archaeological Service (where it was given the general protocol number 992999 on 28-9-2012):

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To the Greek Ministry of Education, Religions, Culture and Sports, Bouboulinas 20-22, Athens 106 82, Greece

5 September 2012

Dear Sir,

I am writing on behalf of the European Anthropological Association, which is the umbrella professional and academic association linking all of the national European biological anthropology and human biology societies, to express our concerns about the conservation of the Petralona Cave and Skull, the misinformation of the dating of the skull, as well as the treatment of personnel associated with the conservation of the Cave.

The bases of our concerns are that the skull has been damaged through many scratches and the crown of a tooth (1st right molar) *cut off. As requested by Anthropological Association of Greece what is required is a detailed description of the present status of the skull, so that no one in future can arbitrarily damage it further. There is also the problem of dating which has been scientifically dated at about 700,000 years ago not 300,000 as is given at the* *information desk* (today in front of the cave). *There is a very detailed record of the excavations and findings which need to receive further public presentation but which have never been catalogued so as to prevent specimens going missing.*

It is very unfortunate that the Greek Archaeological Department stopped Dr. Aris Poulianos from further work in the Cave without any explanation. It is also very worrying that Dr. Poulianos and his wife were physically attacked and injured in their home earlier this year and the culprits have not been found. He was also verbally abused when attempting to give an invited presentation to teachers and school children.

Senior anthropologists and geologists have also been denied access to the Cave and the specimens for further study on a number of occasions without substantive reasons. Earlier this year there has also been misinformation given to the Greek Parliament concerning financial aspects of the Cave.

I look forward to receiving answers to these questions. Yours faithfully

Professor C G N Mascie-Taylor MA, PhD, ScD (all Cambridge), FSB, FNAS (Hungary)

3. Instead of an epilogue

According to Dr. A. Poulianos all of the above questionable and rather suspicious events are due to the attempt of some state employees to receive EU funds for a project that already exists, presenting it as their own. Hopefully, the AAG along with the support of the International Scientific Community will not allow this to happen, especially because of the duty to protect Petralona's international and cultural heritage. It is also an expectation that the Archaeological Service will start to change the way it functions and will awaken especially with regards to public interest.

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THE RIO CAMUY CAVE SYSTEM, PUERTO RICO, AFTER 55 YEARS OF SPELEOLOGY

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Speleology began in Puerto Rico in 1958. Russell Gurnee led the expeditions that explored the Río Camuy Cave System and was the person who proposed that it be protected by the government. The Parque Nacional de las Cavernas de Río Camuy opened in 1986. Gurnee was also a founding member of several speleological organizations on the island. Most speleological publications about Puerto Rico have been written in English by non-Puerto Ricans. In the field, Speleology in Puerto Rico has always been carried out in both Spanish and English. Ideas developed in the caves and karst of Puerto Rico have been applied to other areas like Guam and China. Five caves in the Río Camuy Cave System have all been managed differently. Cueva Clara de Empalme is a successful show cave. It is difficult for scientists to obtain permission to visit Tres Pueblos which is the river level of the system. Cueva Angeles is used for extreme ecotourism and is too expensive for most locals to visit. Cueva Humo has no management and Cueva Ensueño is a failed show cave. The composition of the floating material in the cave system has changed over the last 55 years. Originally it was logs and leaves and now includes manmade garbage like tires and plastic bottles. The air temperature of the cave system ranges from 21.2 °C in February to 24.3 °C in August. The water temperature is near 22.6 °C and the relative humidity is around 90.6 percent.

1. Introduction

Speleology began in Puerto Rico in February 1958. The previous month Russell Gurnee had almost died in a snowstorm outside of Gage Caverns in New York, USA. One of the cavers in the group was José Limeres, a Puerto Rican doctor who practiced in Newark, New Jersey, USA. They decided that their next caving trip would be in a warmer place like Puerto Rico. After visiting a number of caves in the southwestern part of the island, on their last day in the field they went to northwest Puerto Rico where the geologic maps said that there was limestone. In 1958 very little was known about the geology of Puerto Rico. While driving alongside the Río Camuy they stopped and talked to the local residents who took them to Cueva Humo and Cueva Clara de Empalme. It would be ten years before they knew that these two caves were part of the same system, the Río Camuy Cave System. The Río Camuy Cave System is in the municipios of Camuy, Hatillo, Lares, and Utuado. Municipios are inclusive and are the equivalent of counties in the United States. Later that year Gurnee presented a paper about Puerto Rico at the Second International Congress of Speleology in Bari, Italy (Gurnee and Gurnee 1974) which is about 800 km south of Brno, Czech Republic.

A trend began in 1958 that has continued to today. Speleology in Puerto Rico is carried out both by Puerto Ricans and people from the United States. Most of the speleologists from the United States who have worked in Puerto Rico have been members of the National Speleological Society (NSS). At one point, Gurnee was the president of the NSS. In the field Spanish is crucial to obtain information from the people who live near the caves. The 1958 trip did not discover anything new because they were lead to the cave entrances and into the caves by the local residents and no cave exploration could have taken place without the language skills of Limeres. Most of what has been published about the caves of Puerto Rico has been published in English by people from the United States whose first language is English. Some of the speleologists publishing about Puerto Rico have been people like Russell and Jeanne Gurnee or Joan and John Mylroie (Mylroie and Mylroie 2007) who have never lived on the island but have made many trips and know the island well. Others have been people from the English speaking countries who have lived on the island for many years. This list would include Joseph Troester (Troester and White 1986), Tom Miller (Winter et al. 2011), and this author (Richards et al. 1998). A similar situation exists in other fields of environmental science in Puerto Rico. Most of what has been published about birds and water resources has been published in English by non-Puerto Ricans.

Speleology is the scientific study and documentation of caves. Publishing is crucial to Speleology. Before 1958 caves in Puerto Rico were part of the resource base and were used in many different ways but were not seen as subjects of study and documentation. As humans we are driven to make art and the oldest known art is in caves in France and Spain. Caves in Puerto Rico have been used for artwork both by the Tainos who were on the island when Christopher Columbus arrived in 1493 and by the Christians who make up the majority of the population today. For many decades people have gone in caves in Puerto Rico to mine guano, obtain water, and search for crabs and shrimp to eat. In the 1960s when Russell and Jeanne Gurnee were exploring the cave system, bananas were grown in the Tres Pueblos sinkhole at the entrances to the cave system and carried out over 100 m vertically on the backs of men. Isla de Mona is an uninhabited island that is 70 km offshore and has been politically part of Puerto Rico since the 16th century. Between 1887 and 1927, 150 Gg of guano were removed from the island (Frank 1998). Guano is rich in phosphorus and is used as fertilizer. In 1950 the Nationalist Party organized an armed insurrection against the United States and its colonial dominance over Puerto Rico. For years the author has heard rumors that Cueva

Aguas Buenas in Aguas Buenas was used by the Nationalist Party to store rifles and I have spoken to a life-long member of the party who said that he has spoken to the person who removed the rifles.

Russell Gurnee was an advocate of "Conservation through Development" where part of the cave would be commercialized and turned into a show cave. The revenues from the visitors would provide the funds to protect the cave as a whole. Gurnee produced development plans for a number of caves in Puerto Rico. His designs often included expensive items like elevators and cable cars. No cave in Puerto Rico has ever been developed according to the plans developed by Gurnee. For the Río Camuy, Gurnee proposed an elevator to enter the cave, a trail with bridges that would take the visitors along the Río Camuy above Tres Pueblos but high enough to be above most floods, and a cable car to lift the people out of the Tres Pueblos sink. Instead of the Gurnee plan, the government of Puerto Rico adopted a cheaper and shorter plan that has the tourists visiting only the higher and drier Cueva Clara de Empalme.

This study will give an overview of the status of Speleology in Puerto Rico and will look at how five caves that are in the Río Camuy Cave System or its drainage area are currently managed. The five caves that will be discussed in this paper are Cueva Clara de Empalme, Tres Pueblos, Angeles, Humo, and Ensueño. The five caves have five different management statuses. One is a show cave, one is protected and seldom visited, one is used for extreme ecotourism, one has no protection, and one is a failed show cave.

2. Speleology in Puerto Rico in the 21st century

Speleology includes exploration, documentation, scientific research about caves, publication, education, protection, and organizing support activities like search and rescue. These objectives are generally organized by speleological organizations. Organized Speleology in Puerto Rico has undergone several forms. In the 1970s the Gurnees and cavers resident in Puerto Rico organized a grotto of National Speleological Society (NSS). This was the first grotto of the NSS outside of the United States. Later some of the Puerto Rican members felt that Puerto Rico should have a national speleological organization in the same way that the island has a team at the Olympics separate from the United States. In 1976, the Sociedad Espeleológica de Puerto Rico Inc (SEPRI) was organized with the Sociedad Espeleológica de Cuba as its inspiration. Russell and Jeanne Gurnee were founding members of SEPRI. There have been divisions over the years and today the organization that represents Speleology in Puerto Rico on the international level is the Federación de Espeleológia de Puerto Rico (FEPUR). Today in Puerto Rico there are four speleological organizations in FEPUR. The four groups have varying levels of activity. Two of the organizations have monthly public meetings and organize regular field work.

In Puerto Rico, over the last 20 years, exploration and mapping has shifted from the main island to Isla de Mona. In 1992, Joseph Troester was working for the United States Geological Survey (USGS) and he organized a series of field trips to Isla de Mona which included both resident and off-island scientists. John Mylroie had developed his ideas on flank margin caves in the smaller caves of the Bahamas and he was invited to visit Isla de Mona because it is a place where his ideas would be tested on a larger scale. The Earth has an estimated 40,000 islands of which 30,000 are tropical. Good science on one oceanic tropical island should be applicable to other oceanic tropical islands. Today Mylroie is using his flank margin cave model to study the geologically more complex Mariana Islands in the Pacific (Stafford et al. 2005). The two largest of the Mariana Islands are Guam and Saipan. The Mariana Islands are next to the Mariana Trench, the deepest point in the oceans of our planet. Puerto Rico is next to the Puerto Rico Trench, the deepest point in any ocean outside of the Pacific.

Ideas developed in the karst of Puerto Rico can also be applied to continental settings. With a diameter of 305 m, the Arecibo Telescope is the largest radio telescope in the world and is essential in tracking asteroids that might at some point in the future collide with the Earth. The genius of the telescope is the idea that because the karst processes naturally form the bottom of a sinkhole into the shape of a telescope mirror, the telescope will be less expensive than if you tried to carve the rocks into that shape. Today there is a discussion of using multiple sinkholes in China to build a larger radio telescope. The project is known as "Super Arecibo" (Baoyan and Jingli 2008).

Today not all aspects of Speleology in Puerto Rico are at the same level. Unfortunately, on the main island of Puerto Rico there has been very little publication of cave maps in the last 20 years. At the same time decades of educational work has left large segments of the general population with the idea that caves should be protected. It is common to find caves that have been used as garbage dumps but in many cases it is clear that the dumping took place decades ago. Leaders of speleological organizations are available to give public talks or to present at public hearings organized by government agencies. Government agencies have solicited the opinions of speleological groups on projects that will affect caves and karst. Puerto Rico has hosted regular cave rescue classes including the "national" event for the United States. In Puerto Rico the word "national" is used in two ways. The nation being referred to can either be Puerto Rico or the United States depending on context. The National Park referred to in this article is national for Puerto Rico and not the United States. The volunteer instructors at the cave rescue classes are from both the island and the United States. The Puerto Rican instructors have translated the course materials into Spanish and people like Efrain Mercado are working to help organize cave rescue classes in a number of countries in Latin America.

A number of caves in Puerto Rico are now protected. The Parque Nacional de las Cavernas de Río Camuy has 1.08 km^2 (108 hectares) of land and controls 8 of the 9 entrances in the main part of the Río Camuy Cave System. The park operates Cueva Clara de Empalme as a show cave. The National Park opened in 1986, 24 years after if had been proposed by Gurnee. A number of other caves are in state forests or natural reserves. The most important nature reserve with caves is Isla de Mona. The Puerto Rico Land Conservation Trust owns the land around a number of the entrances to the Río Encantado Cave System in Florida, Ciales, and Manatí and Cueva Convento in Guayanilla. The

National Science Foundation has paid for the establishment of a field station at Cueva Culebrones in Arecibo that is operated by the Bayamon campus of the Universidad Interamericana. Cueva Culebrones is one of a number of caves where the Puerto Rican boa (*Epicrates inornatus*) gathers at the cave mouths to eat bats. The director of the field station is Armando Rodríguez-Durán, the foremost expert on the bats of Puerto Rico. Of the 13 species of bats on the island, 10 roost in caves. Rodríguez-Durán has published a number of publications on how bats use the caves (Gannon et al. 2005).

All caves in Puerto Rico are protected by law but for most caves this protection is a piece of paper in a law library. Important caves that have no protection include Cueva Humo of the Río Camuy Cave system, Cueva Cucaracha, Aguadilla, which has 700,000 bats, the largest known bat colony (Rodríguez-Durán and Lewis 1987), and the dozen or so caves in the Aguas Buenas Cave system. The private property system has collapsed in many parts of the karst of Puerto Rico. The area around the caves has become uninhabited as people have abandoned agriculture and moved closer to highways to have better access to jobs, schools, hospitals, and shopping. Property descriptions may include trees and rocks that no longer exist. In many cases the land is owned by collection of grandchildren and other family members of the last person who actually lived on the land. As of the 2010 census there are more Puerto Ricans in the United States than in Puerto Rico and this family collection is usually spread out between Puerto Rico and the United States. Many lands in karst areas could be claimed by the government for non-payment of property taxes. What this means is that most caves in Puerto Rico can be entered if you know where they are. In many cases the local residents do not know who owns the land near the cave. What is protecting the caves is a lack of interest. There is declining visitation in many caves of Puerto Rico. In the 1968 when an NSS expedition explored and mapped Cueva Aguas Buenas there were groups of school children in the cave every weekend (Gurnee 1968). Today in 30 visits to this area it is extremely rare to see another group in the cave. In many areas local residents do no know where the cave is and the trails leading to the cave are overgrown with vegetation.

One change since the explorations of the 1960s is the collapse of small-scale agriculture on the surface above the Río Camuy Cave system. In the 1960s the land above the cave system was used to grow coffee, sugar cane, milk cattle, tobacco, squash, bananas, and other fruits. Today the land is more forested than it was 50 years ago. At that time most houses were wooden and had neither running water nor electricity. During one expedition to explore the Río Camuy Cave system water for the team members was transported from 6 km away (Gurnee and Gurnee 1974). The new highway 129 which provides visitors' access to the National Park also allows the residents to drive to their jobs in Arecibo and other cities. The vast majority of the houses in the area around the National Park are concrete and virtually all have running water and electricity. As in all of Puerto Rico, cell phone towers are common near the National Park.

The USGS operates a gage at the Río Camuy near Bayaney (50014800). Between 1984 and 2010 the median daily discharge at this station was 2.1 cubic meters per second (USGS 2012). The Río Camuy has several resurgences (Gurnee and Gurnee 1974) and the station is downstream from all of them. The combined discharge of the several mouths of the Resurgence of the Río Camuy is the largest spring in Puerto Rico and is a second magnitude spring. First magnitude springs have a median discharge of over 2.8 cubic meters per second (Copeland 2003).

3. Cueva Clara de Empalme

In Puerto Rico, a Cueva Clara is a cave where you can see the light from the entrance. Cueva Clara de Empalme is a show cave operated by the government as a national park. Visitors pay to park and an entrance fee of around 12 dollars. They travel from a visitor's center to the cave in tram. Most of the tour takes place in one large room and except for one section the entrances are always visible. One section overlooks a bat colony. The bats that live in caves in Puerto Rico reduce insect levels and increase the biodiversity of the forest by spreading seeds and pollen. The cave has electric lights, concrete walkways, handrails, and tour guides. Tours are in either Spanish or English. In 2008, Socorro Elaine Smith (Fox News 2008), a visitor from Los Angeles, California, USA was killed by a falling rock as she waited for the tram to take her back to the visitor's center. The cave was closed for a year while a bunker was built to protect the visitors. The visitors can see the Río Camuy in the distance at a lower level but have no contact with the river. The Parque Nacional de las Cavernas de Río Camuy is one of the most important tourist attractions on the island.

In 1967 Stewart Peck collected over 100 blind depigmented amphipods from a 180 mm deep pool in Cueva Clara de Empalme. At the time of collection the pool contained hundreds more of the species. These animals were later described as a new genus and species *Alloweckelia gurneei*. The species was named to honor Russell Gurnee (Holsinger and Peck 1968). The pool where this species was collected still exists and is next to the concrete trail used by thousands of tourists. The amphipod no longer lives in the pool and its status is unknown.

4. Tres Pueblos

The entrance to this section of the cave is the Tres Pueblos sinkhole. This is the river level of the cave system. The entrance is controlled by the National Park and is restricted. Some people visit this section by rappelling into the Ventosa entrance and exiting via Tres Pueblos. All river levels of this cave system are dangerous and prone to flash floods. In 1968 Hector Bueso died while trying to exit during a flash flood. He was swept through the sinkhole and into the cave on the other side (Gurnee and Gurnee 1974). Several times the National Park has permitted this section to be used for mock rescues on Good Friday when the park is closed to the public. After a year of negotiations, the author was able to enter this section to measure the air temperature and relative humidity for the first time in 49 years. The air and water temperature and relative humidity data collected in the Río Camuy Cave System are shown in Table 1. The annual range of air temperature in the Río Camuy Cave system is 3.1 °C. The water temperature is around 22.6 °C and the relative humidity is 90.6 percent.

The early explorers noted the amount of wood and other floating debris in the river. The biggest change in the cave between 1962 and 2011 is that the naturally occurring wood and leaves now includes floating garbage. The source of the garbage is not cavers but rather garbage placed in the river upstream of the cave system. The cave has floating garbage such as tires, aluminum beverage containers, and plastic bottles. Puerto Rico as a whole and the upstream communities in particular produce far more garbage than they did 50 years ago. The river is transporting the garbage through the cave system as part of its natural function to move sediments and floating materials to the ocean.

5. Cueva Angeles

The Angeles sinkhole is a smaller version of the Tres Pueblos sinkhole. Tres Pueblos is 120 m deep while Angeles is 110 m. The Angeles sinkhole is also not as wide as Tres Pueblos, The Río Angeles flows on the bottom of the sinkhole. In both sink holes the river flows out a cave on one side and into a cave on the other side. The Angeles sinkhole is upstream of Tres Pueblos and the river is a tributary of the Río Camuy. At both locations the roof may be 30 m or more above the river. The Angeles sinkhole is about 2 km southwest of the Tres Pueblos sinkhole and 3 km north of Cueva Humo. The general direction of the flow in the Río Camuy Cave System is from south to north. In 1972, while still an undergraduate, Emily Davis led the expedition that connected Cueva Angeles with Cueva Humo (Gurnee and Gurnee 1974). After her marriage, she became Emily Davis Mobley.

Under Puerto Rican law caves are owned by government. Private land owners can control access across their land and can block access to caves. The land around the Angeles sink hole is owned by Rossano Boscarino who owns Aventuras Tierra Adentro a company that provides guides services for customers who want an adventure. Boscarino is an experienced rock climber and in 1991 participated in the rescue of Emily Davis Mobley in Cueva Lechugilla, New Mexico, USA. With a price of 175 dollars, the visitors are picked up in hotel district of San Juan and transported to Cueva Angeles. The trip to the cave includes four ziplines over the sinkhole, a 40 m rappel to enter, and a 60 m Via Ferrata to exit. Via Ferrata is an Italian word that means “Iron Way” and is a system of ladders that are climbed with protection. In the Alps the Via Ferratas are recognized tourist attractions. Except for the Angeles sinkhole, the author is unaware of any Via Ferratas in Puerto Rico. Both Cueva Clara de Empalme and Cueva Angeles are examples of how caves can be used to generate employment in Puerto Rico but with different business models. Many residents of the island, including organized school groups, have visited the National Park. Salaries are lower in Puerto Rico than in the United States and the price of the Cueva Angeles trip means that the vast majority of the people who have seen this cave live in the United States.

The author has biological notes from more than 50 caves in Puerto Rico. In November 2012, in Cueva Angeles the author observed 5 live scorpions which are more than in any other cave visited by the author. In most caves whip spiders are more common than scorpions but this is reversed in Cueva Angeles

6. Cueva Humo

In 1958 there were homes near Cueva Humo that could not be reached by car. Today there are no such homes. The roads have been extended or the remote houses were abandoned. The inside of the cave is much as it would have appeared in 1958. There is some but not a lot of graffiti. There has never been an attempt to commercialize the cave. The status of Cueva Humo is like that of most caves in Puerto Rico, if you know where it is there are no barriers to visit the cave. The number of people living near the cave has declined and levels of visitation are probably down. In 2012 the cave has bats, gnats, and water-deposited debris just as it did in 1958. Like most caves in Puerto Rico the bat population has never been counted. In much of the Río Camuy Cave System the height of the roof and the size of the entrances are obstacles to counting the bats. The only published bat census data from Puerto Rico are caves with a single constricted entrance that makes the counting process.

7. Cueva Ensueño

Cueva Ensueño is a small cave that is higher and dryer than the other caves discussed in this paper. Cueva Ensueño has pools but no flowing water. The cave is a failed show cave. Jeanne Gurnee wrote a proposal to commercialize the cave (Gurnee 1968). What was attempted was on a much smaller scale. For years the cave had a non-functional power cable with light bulbs at regular intervals strung out in the cave. The cable was recently removed by members of SEPRI. The cave has some pretty formations. There are at least two other caves nearby that have failed at commercial operations. La Cueva de Camuy was a private facility that operated for many years and at times had a bar and restaurant in the cave. More recently it was a recreational area that besides visiting the cave included a swimming pool and pony rides. A nearby cave also has the ruins of wooden ladders and wires that were nailed to the wall. In November 2012 La Cueva de Camuy was in ruins with all the buildings missing roofs. The cave was so open that an off road vehicle could drive into the cave. In November 2012 the author observed two live and two dead scorpions in Cueva Ensueño. This is the cave with the second largest number of observed scorpions. Cueva Ensueño is 2 km southeast from Cueva Angeles.

8. Conclusion

In Puerto Rico as in the United States, most attempts to commercialize caves fail and in bankruptcy the cave is left damaged and unprotected. Russell Gurnee and his idea of “Conservation through Development” overestimated the market for show caves in Puerto Rico. If all the projects proposed by Gurnee in Puerto Rico had been built then most would have failed and a much larger sum of money would have been lost. The challenge before the people of Puerto Rico is to develop Speleology among Puerto Ricans and not exclusively outsiders. The more cave science that is done by Puerto Ricans resident in Puerto Rico, the easier it will be to integrate the speleologists into activities to protect the caves. It is also a challenge to protect caves even if the market will not support "Conservation through Development". The bats that live in unprotected caves in Puerto Rico reduce insect populations and increase biodiversity in the forest by spreading seeds and pollen. The Río Camuy Cave System has an annual range in air temperatures of 3.1 °C. The five caves in the cave system are all managed differently. One has electric lights, concrete walkways, and bunkers to protect the tourists from falling rocks. One has administrative obstacles that make legitimate scientific access difficult. One is used for extreme ecotourism. One is an abandoned show cave and one has no protection. In the Río Camuy Cave System the composition of the floating material has changed from exclusively natural to now including manmade garbage which is deposited near the river near upstream communities.

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Table 1. Air and water temperature and relative humidity data from various locations in the Río Camuy Cave System, Puerto Rico. Data were collected by the author with the exception of the 1962 data which are from Gurnee and Gurnee (1974).

Location	Month	Year	Elev. m	Temperature Air C	Water C	Relative Humidity %
Tres Pueblos	Feb	1962	158	20	20	100
Tres Pueblos	Feb	2011	158	21.2		89.4
Tres Pueblos	Aug	2011	158	24.3		91.7
Angeles	Nov	2012	210	23.4	22.7	
Humo	Sep	2012	250	23.8	22.4	
Ensueño	Nov	2012	280	22.5		

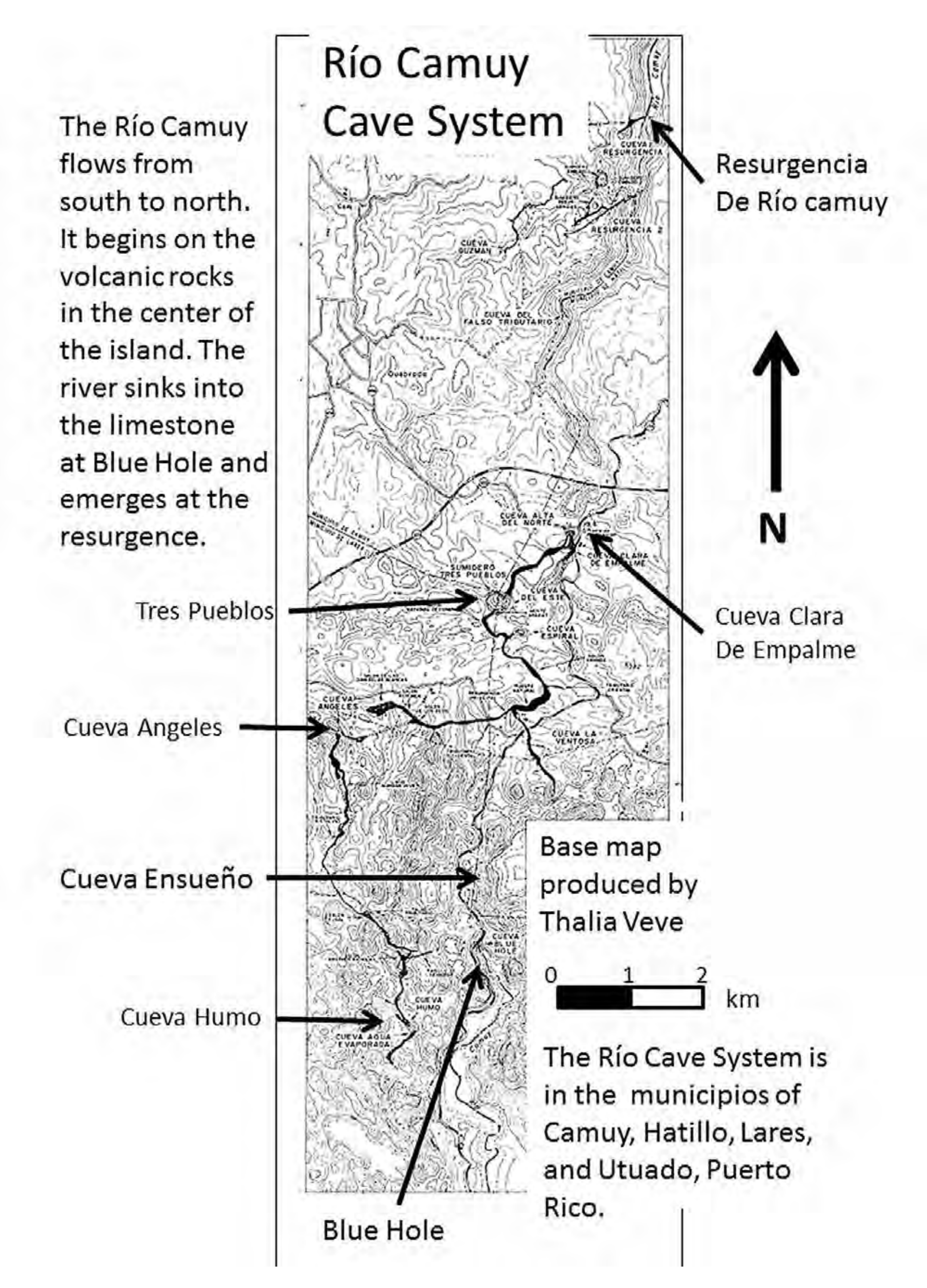

Figure 1. Map of the Río Camuy Cave System in the municipios of Camuy, Hatillo, Lares, and Utuado, Puerto Rico. Base map produced by Thalia Vev.

CERIGO SPELEOLOGICAL PROJECT IOANNIS PETROCHEILOS AND SPELEOLOGICAL RESEARCH IN KYTHERA ISLAND, GREECE, FROM 1930 TO 1960

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This paper aims at presenting Ioannis Petrocheilos' "works and days" and the speleological research on the island of Kythera, Greece, from 1930 to 1960. Ioannis Petrocheilos was born on Kythera and conducted the first speleological research in the area in the early 30's. Within 20 years Petrocheilos explored and studied more than 20 caves on the island with a specific and precise methodology. All his notes and data from that period survived in the archives of the Hellenic Speleological Society. Within the framework of the Cerigo Speleological Project we studied the history and the chronicles of that period in order to shed light on the beginning of Greek Speleology.

1. Introduction

As part of the Cerigo Speleological Project from the Local Department of Northern Greece of the Hellenic Speleological Society (H.S.S.), the historical background of the speleological research conducted on the island of Kythera between 1930 and 2008 was studied.

According to the historical evidence, the first speleological research in Kythera was conducted by Ioannis Petrocheilos, the founder of the H.S.S., from the early 1930s to 1960.The H.S.S. Department of Northern Greece continued the research on the island within a new framework until 2008. The speleological project of Kythera (Cerigo Speleological Project) was launched, in which scientists and speleologists from the Hellenic Speleological Society, the Aristotle University of Thessaloniki and the University of Crete participate. Research conducted between 1930 and 1960 is of great importance not only for the island but for entire Greece as well, because during this period the principles for both the creation of the H.S.S. and the general exploration and research of caves in Greece were established. Furthermore, Ioannis Petrocheilos was the first Greek speleologist who also originated from Kythera.

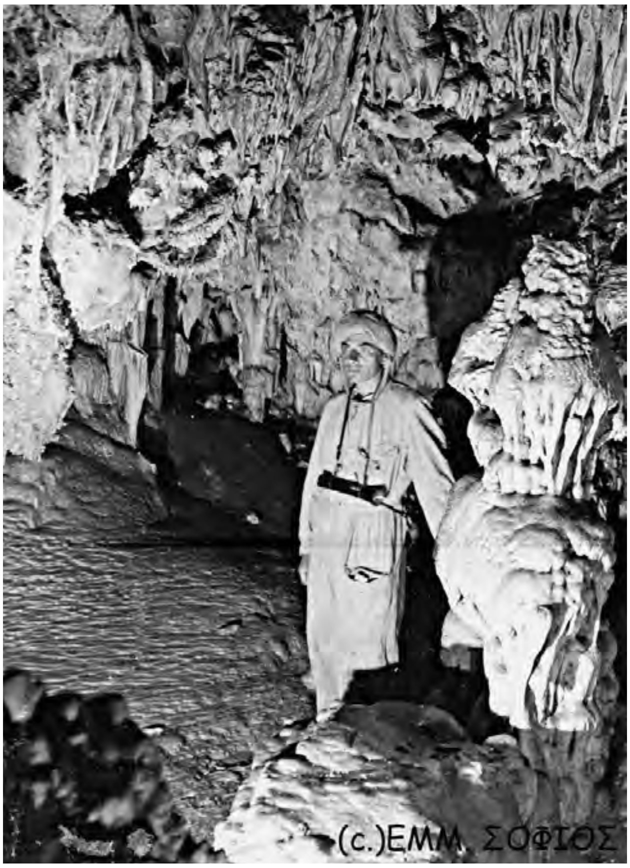

Figure 1. Ioannis Petrocheilos in Ag. Sophias Cave, Kythera, 1936. Photo M. Sophios.

2. Ioannis Petrocheilos[1]

Ioannis Petrocheilos was born in Smyrni (Izmir), Minor Asia, in 1900. His parents were natives from the island of Kythera. Petrocheilos' dream was to be a composer and therefore he studied music. In 1917, he started climbing, painting and drawing landscapes. He enrolled at the Faculty of Mathematical and Physical Sciences of the University of Athens in 1918 and graduated in 1921. Between 1922 and1926 he worked as a chemistry teacher in public schools.

In 1930, he moved back to Kythera with his wife Anna Minardou, originally from the island of Tinos, to work as a teacher at the school of Potamos village. He stayed on the island for two years. During this period, he explored two caves on the island and familiarized himself with speleology. This new activity enchanted him and he was awarded a scholarship from the Ministry of Education for a special course at the Sorbonne, Paris, in physical geology and anthropological geography (1932–1936).

Petrocheilos then returned to Kythera and continued teaching at the same school as before that, by that time, had become a secondary school. He started working in the field of applied speleology, scouting the island. In the two following years he explored four further caves in a more systematic way this time. In 1937, he published his first paper, bearing the title "Geotectonics". Furthermore, he

[1]Biographical information about Ioannis Petrocheilos was gathered from the following published works: Grafios Nidas 1961, Ioannou 2000, as well as from documents in the archive of the Hellenic Speleological Society.

drew the geological map of the island, published posthumously by the Institute of Geology and Mineral Exploration (1935). He also discovered a fossil skeleton of *Elephas antiquus* in Kythera, a discovery that was even announced at the French Speleological Society. In 1937 he was transferred to the secondary school of Andros, where he taught until1943.

In that year, during the World War II, the Germansbombed the island, and his residence was burnt to ashes. All his household effects and his scientific archive, his library, his scientific instrument collection as well as the manuscripts he had drafted during his 13-year speleological and geological research were lost. In 1943 he was therefore transferred to Athens where he worked as a teacher at the Evangelical School of Nea Smyrni. In 1948, he published a book on inorganic and organic chemistry which was republished in 1950.

In 1949, he participated with his wife Anna Petrocheilou in the 1st International Speleological Congress in Valance, France. In 1950, he was invited to participate in the 4th Speleological Congress in Bari, Italy. In the same year, he, his wife and a few other intellectuals founded the Hellenic Speleological Society which he served as its president until his death on February 11th, 1960. In 1951, he was appointed geologist at the Ministry of Industry and, later, at the Institute of Geology and Subsurface Research (which later became the Institute of Geology and Mineral Exploration).

In 1954, Petrocheilos returned to Kythera. Together with G. Grafios Nidas, his wife and the photographer Manolis Sophios, he explored 14 caves on the island.

Figure 2. Kuriakoulou cave, Kalamos, 1936. Photo M. Sophios.

In 1957, he participated in the 5th International Congress I.N.Q.U.A. held jointly in Madrid and Barcelona, Spain where he announced the first discovery of an *Ursus spelaeus* canine in Greece (Perama Cave, Ioannina). At the same congress, Gasparis Mistardis, member of the Hellenic Speleological Society, made another announcement regarding the traces of old glaciers in Greece.

Petrocheilos was elected member of the International Committee studying the Quaternary in the Mediterranean. Healso participated in marine research using the oceanographic boat *Alcyone*, in order to study the coasts of Southern Peloponnese and Northern Crete. He also completed a series of studies at the prehistoric cave of Alepotrypa in Diros, Mani.

In 1959, he and his wife explored the cave of Agios Andreas in Kastania (Voion municipality).

At the request of the Institute of Geology and Subsurface Research, he explored and excavated the Kokkines Petres cave in Petralona, Chalkidiki where he discovered traces (bones and teeth) of cave bear, wolf, deer and other animals and he anticipated the discovery of traces of prehistoric man. His hunch proved to be correct when subsequent researchers discovered a human skull, shortly after his death (in 1960).

Between 1950 and 1960, Petrocheilos conducted a series of extensive scientific research which included hydrological research on the water system of 50 communities and the town of Thebes, landslides and settlement displacement; while at the same time he was examining in collaboration with some colleagues the possibility to create a subsurface dam at the bed of river Evinos. Additionally, he conducted drills in Athens (Patision Street, Nea Ionia, Larissis station) in order to examine the subsoil in the Greek capital in view of the construction of the metropolitan railway, known as the Athens Metro, part of which was inaugurated in 2000.

Beginning in 1951 he also published descriptions and studies conducted in caves in the Bulletin of the Hellenic Speleological Society. Alongside with his research since 1925, he published a number of articles in scientific and nature magazines. In 1980, instead of holding a commemoration ceremony, Anna Petrocheilou published a volume with his poems, which she discovered in his archive after his death – to her surprise, since she was not aware of his poetic talent until then. The volume bears the title *Odoiporontas* (foot-walking).

3. Speleological research in Kythera, 1930–1950

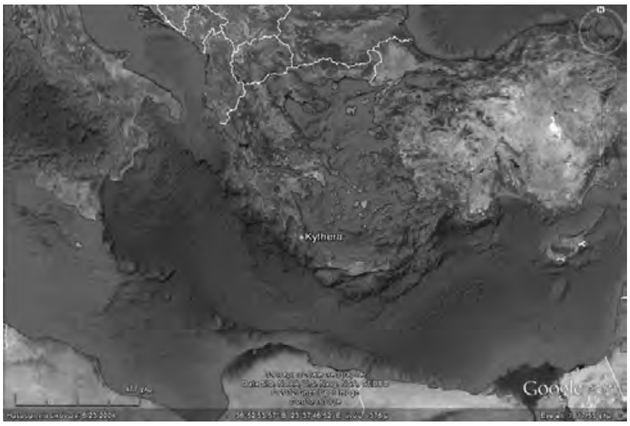

Figure 3. The position of the Island of Kythera in the eastern Mediterranean.

Information on the research conducted in Kythera during this 20-year period of Petrocheilos' studies was gathered from source documents of the Hellenic Speleological Society's archive. The archive maintains a file for each cave, including the cave's registry number as well as all relevant information. We examined 19 files[2] including

[2]These are the files (caves) registry numbers present in the archive: 2858, 2859, 2861,466, 2862, 2863, 2864, 2865, 2866, 495, 496, 509, 501, 558, 559, 698, 313, 4146, 314.

50 documents in total. Some files only contained a single document with information on the respective cave (e.g., 2866:Tourkos Cave). Nevertheless, most files included three to five documents. All documents but one had the signature of Ioannis Petrocheilos, while the names of those people who accompanied Petrocheilos in his explorations were not mentioned. The notes were taken in Demotic Greek and used multi-accented (or polytonic) spelling. Spelling rules were not always followed while there was a significant number of abbreviations and end-off-line broken words. The hand-writing was illegible even though some letters were written respecting the principles of calligraphy. In general terms, the hand-writing indicates that the notes were taken hastily, though no significant corrections appear. The paper used is not specific. Notepad sheets with horizontal blue lines and white A5 notepad sheets were mostly used. However, in some cases the writer used rice paper sheets, and in one case he even used the packaging from a pack of cigarettes.

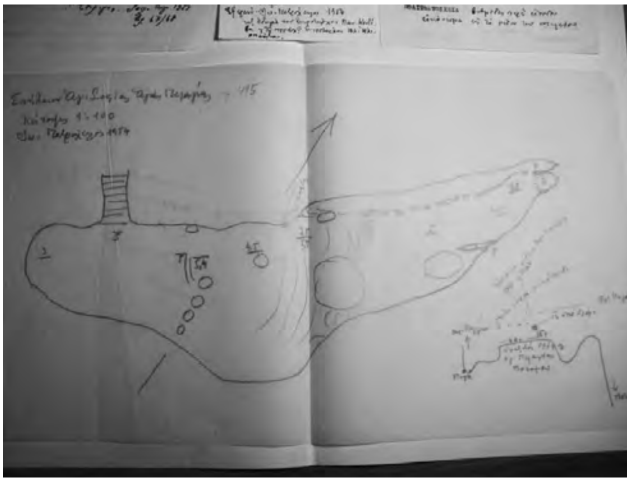

Figure 4. Plan by Io. Petrocheilos of Ag. Sophias Cave Ag. Pelagia, Kythera, 1954. Archive of M. Sophios.

These 19 caves were basically explored between 1930 and 1931 and during 1936, 1952, 1954, and 1955. Most caves were examined during 1954 (14 caves) while in 1930, 1931, 1952, and 1955 only one cave was examined per year. The first cave to be explored was the cave at Cape Moudari, in the north of the island. At first, the cave expeditions were more like excursions and nature trips. Later on, after Petrocheilos returned from France, the cave tracing was done more systematically while at the same time the team started examining the caves geologically.

In 1954, the research was more organized. The caves explored at the time were recorded alongside with a basic sketch of the area, while geological, biological, archaeological, historical, and other observations were also included. Furthermore, numerous pictures from the entrance and the interior of the caves visited during that expedition are present. To summarize, it appears that the 1954 research represented the first organized large field speleological expedition in Greece. Similar expeditions did not occur until the 1980s, when the first organized expeditions in areas such as the plateau of Astraka in Epirus, Kymi in Euboea, and Crete took place.

The notes do not bring to light any specific methodology that might have been followed during the research. They include information regarding the observations of the research team as well as more specific geological observations made by Petrocheilos himself. At the beginning of each document information about the cave's location is given, its accessibility and the interior dimensions. Then, details on the geology of the cave rock follow. Finally, each report concludes with any further details available regarding the cave. Seven out of 19 cave reports were complemented by a basic sketch of the cave.

Table 1. Caves of Kythera and their data.

No of the cave	Name of cave and nearest village	Year of explor.
2858	Ag. Aikaterinis, Kapsali	1954
2859	Theologou, Pitsinades	1954
2861	Klefti, Kalamos	
466	Kuriakoulou, Kalamos	1931
2864	Paliochora, Paliochora	1954
2866	Tourkou, Mulopotamos	1952
495	Ag. Sophia, Ag. Pelagia	1954
496	Panagia Orfani, Mulopotamos	1936/1954
509	Sparagariou, Kapsali	1954
501	Ag. Eleftheriou, Logothetianika	1954
558	Fournoi, Fournoi	1955
559	Spilaio Moudariou	1954
698	Vigla, Drumonas	1954
313	Ag. Ioannis, Kapsali	1936
314	Ag. Pavlos, Kapsali	1936/1954
315	Ag. Pelagia, Felwtis	1954
	Ag. Sophia, Kalamos	1936/1954
	Ag. Sophia, Mylopotamos	1936/1954

4. Summary

Speleology of Greek in Greece was not conducted until the second quarter of the 20th century with the research of Markovitz and Petrocheilos (Merdenisianos 2007). Petrocheilos continued his research until his death in 1960 and can been seen as the founder of scientific and exploratory speleology in Greece. He left behind important speleological publications and data collections and the country's first speleology society as his legacy. The speleological culture of Petrocheilos and his research methods were born and shaped in Kythera during the 1930s. A Kytherian and his small island were determined by fate to give birth to Greek speleology. As a small homage to this great teacher, the Cerigo Speleological Project aims at highlighting his activity and speleological legacy.

Acknowledgments

The research for this paper was supported by the Nicholas Anthony Aroney Trust. We warmly thank them. We would like also to acknowledge Mrs Eleni Charou- Koronaiou for the archive work and Ms Emily Varnava and Ms Konstantina Kalogirou for the tireless assistance in the English editing of this article.

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Documents and photos from the archive of Manolis Sophios.

CONTRIBUTION OF HERMENGILD AND KAREL ŠKORPIL TO THE BULGARIAN SPELEOLOGY

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The article presents some biographical aspects of the Czech nationals Hermengild and Karel Škorpil and their contribution to karst and cave studies in Bulgaria and in developing Bulgarian speleology.

1. Introduction

As a result of the Russian-Turkish War and according to the Treaty of Berlin, in 1878, two states were established in the Bulgarian lands: Principality of Bulgaria and the autonomic self-governing province East Rumelia, which was dependent on the Ottoman empire. In autumn 1885, both states united into one – the Principality of Bulgaria. In this period a considerable number of new secondary schools were opened in the Bulgarian cultural sphere. These needed well educated teachers of different disciplines. Because of that the Bulgarian government invited many foreigners to work as teachers. Most of them came from Slavic countries. In the first two decades after the Liberation of Bulgaria, more than 300 foreign teachers from 22 nationalities were employed (Penev and Petrov 1988). More than 100 of these teachers were Czechs. This was a result of the interest and sympathy of Czech people towards the destiny of Bulgarians. At the same time, many Czech intellectuals aspired to help with the educational and cultural development of Bulgarians in practice. They saw Bulgaria not only as a country where they could express themselves as pedagogues, but were also keen to help in the research of Bulgarian flora, fauna, mineral resources, archaeological sites, etc.

2. Why Hermengild and Karel Škorpil went to Bulgaria

The brothers Hermengild and Karel Škorpil settled in Bulgaria as a part of a large group of Czechs, whose aim was to assist the newly established Bulgarian state. The Škorpils family had close relation with the family of Prof. Dr. Constantin Josef Jireček. The father of the Škorpil brothers was a nephew of Jireček's father. Constantin Jireček was a Czech historian, diplomat and slavist. He entered the Bulgarian service in 1879 and in 1881 became a minister of education in Sofia. The bulk of Constantin's writings dealt with the history of the South Slavs and their literature, including: History of the Bulgarians, The Principality of Bulgaria, Travels in Bulgaria, etc. The close relationship between the two families played a very important role in increasing Hermengild's and Karel's interest towards Bulgaria, which caused them to go there and to devote themselves to the cultural prosperity of the country.

3. Brief biography of the Škorpil brothers

3.1. Václav Hermengild (Hermin) Škorpil (Fig. 1) was born on February 8th, 1858 in the city of Vysoke Myto (now part of Usti nad Orlici District, Pardubice, Czechia).

Figure 1. Hermengild Škorpil.

Figure 2. Karel Škorpil.

He finished high school in Chrudim and Pardubice and graduated at the Technical University in Prague and in natural sciences at the University of Leipzig. After he finished his education, he was invited by the East Rumelian government and in 1880 he was appointed as a teacher in Plovdiv's mens high school. Since 1906 he was teacher in various Bulgarian cities: Sofia, Sliven, Ruse and Varna, where he helped in the schooling of natural history, geography, zoology, botany, arithmetic and German. H. Škorpil published the first summary of mineral treasures in Bulgaria including a geologic map – a pioneering research that served as the basis for scientific mineralogy studies in Bulgaria. Very valuable were also his studies on the geography of Bulgaria. Among them, together with his brother, he studied the basic karst areas of Bulgaria including about 90 caves. Hermin Škorpil began the study of the natural resources in the surroundings of the town of Sliven and described them in his book "Izkopaemi bogatstva iznamereni do sega v tzelokupna Bulgaria" (Fossil Treasures Found up to Date in Bulgaria) (Škorpil 1882). In this book Hermin Škorpil described Morova dupka (Morovitza) near Teteven, the cave of Demir Baba near village Svestari, the Sokolska Cave at Sokol's monastery near Gabrovo and also Zmeevi Doupki Cave (Dragon Cave) near Sliven. In the same work H. Škorpil made a detailed description of the cave Zmeevi dupki, and concluded: "It is important for us to be aware of the alluvium on the bottom of this cave. It is possible to find fossils of prehistoric man and such of prehistoric animals of that era there."

The next book of Hermin was "Prirodni bogatstva v celokupna Bulgaria" (Natural Resources of the Entire

Bulgaria), issued in 1884 (H. Škorpil 1884), in which he located and described more caves than in his first book. Later he published the book "The Prehistoric People in Bulgaria" (Škorpil 1886). In it, the author described in details the cave-rock dwellings (most of them artificial) in Dobrudja, Dobrudga's Black Sea shore, the region of Provadia, Shumen and the in the river valley of Russenski Lom – northern Bulgaria. Hermin Škorpil also founded a museum in Sliven, as well as a museum of natural sciences in Ruse in 1902. From 1906 until his death he was the curator of the Varna Archaeological Museum. For decades he was the main motivator there fostering the interest and studies in the history of Varna, Varna Region, and northeast Bulgaria. Hermengild Škorpil died on June 25th, 1923, and was buried near Varna.

3.2. Karel Václav Škorpil (Fig. 2) was born also in Vysoke Myto on May 15th, 1859. He had finished high school in Pardubice before graduating at the Charles University and the Technical University in Prague. In 1881, he went to East Rumelia.

Here he worked as a high-school teacher in the Bulgarian cities of Plovdiv (1882–1886), Sliven (1886–1888), Varna (1888–1890, 1894–1915) and Veliko Tarnovo (1890–1894). In 1894 Karel Škorpil settled in Varna on the Bulgarian Black Sea Coast. There he founded the Varna Archaeological Society and later the Varna Archaeo-logical Museum. Since 1915 until his death he served as director of this museum. He was also a teacher and lecturer at the Naval Academy and the Trade School. Karel and Herman started to work as teachers in natural science and mathematics, devoting their free time to the research and description not only of antiquities but of Bulgarian karst and caves. In his career of more than 50 years, Karel published around 142 works, whether as the sole author or in collaboration with his brother, including 30 in German, Russian and Czech, primarily devoted to Bulgaria. He discovered and headed the excavations of the mediaeval Bulgarian cities at Pliska, Preslav and Madara. Karel was member of the Bulgarian Academy of Sciences and the Bulgarian Archaeological Institute. He was among the first researchers of the karst terrains and its archaeological remains. Meanwhile, in 1877, when Karel served as teacher in Sliven, he made a trip around North Bulgaria during which he visited and mapped the Emenska Cave near Emen village, Tarnovo region (Fig. 3). This is the first map of a Bulgarian cave known up to date (Škorpil 1887).

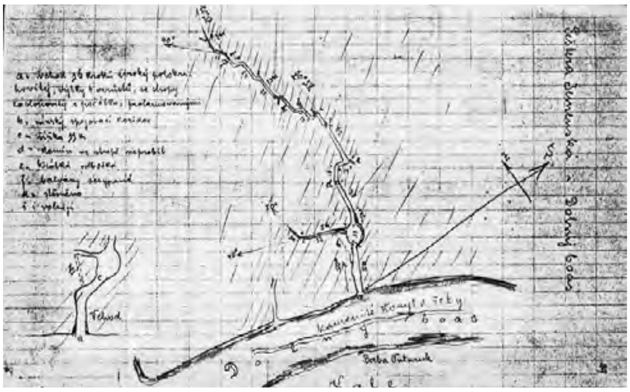

Figure 3. The map of Emenska Cave – 1887.

In 1915 Karel Škorpil went in pension and became a director of Archaeological Museum of Varna. He acted in this duty till his death on March 9th, 1944, and was buried among the ruins of the first Bulgarian capital Pliska.

4. The basic contribution of the Škorpils for the study of Bulgarian karst and caves

The most significant contribution of the brothers' Škorpil to the study of Bulgarian karst was in the field of physical geography. Their most important speleological books were: "Krašskýh zjevecu v Bulgarsku", "Sources et pertes d'eau en Bulgarie" (Fig. 4) and "Krazhski phenomena in Bulgaria" (Fig. 5).

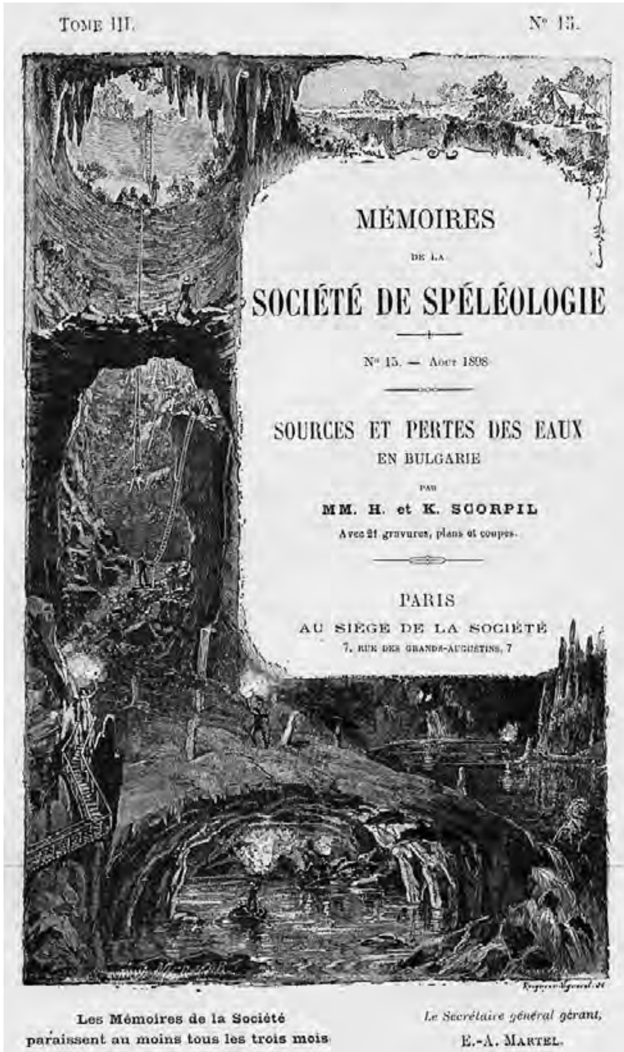

Figure 4. Cover of the book" Sources et pertes des eaux en Bulgarie".

In 1895, in Praha H. and K. Škorpil reported for the first time about the karst phenomena in Bulgaria (Škorpil 1895) internationally. In this work they described the conditions of karst and cave development and also the location and general information on 55 Bulgarian caves.

More complete and detailed was their later book, published in France: "Sources et pertes des eaux en Bulgarie" (Springs and Sinkholes in Bulgaria) (Škorpil and Škorpil 1898). In it they gave results of specific terrain explorations, described over 100 karst phenomena (uvalas, caves, springs) and published additional information of 18 new

Figure 5. Cover of the book "Krazhki yavlenia".

caves. The book included 21 figures that clearly illustrate the hydrogeological connection between sinkholes and karst sources in the explored regions.

The following book, published in Plovdiv in 1900, was "Krazhki yavlenia" (Underground Rivers, Caves and Springs) (H and K Škorpil 1900), that summarized the results from the brothers' continued speleological research in Bulgaria.

Besides publishing data about the phenomena of the superficial karst, its caves and karst springs, this book was also theoretical, including characteristics and mechanisms of the formation of karst phenomena. In the book eleven new caves are described. The book deals also with many cave research related aspects – palaeontology, archaeology, zoology, climatology, hydrology etc. It is illustrated with 30 drawings, maps and photos. In these three books a total of 87 natural caves are described. The information from these books became the starting point for the conducting of the next more profound researches of the karst and caves in Bulgaria.

During their studies in Bulgaria the brothers Škorpil encountered dozens of artificial or semi artificial cave monasteries and in the end of the XIX century the term "rock monastic cloisters" was introduced into scientific terminology (Škorpil 1914). This is also the most significant contribution to archaeological research of these objects in karst areas. K. Škorpil scientifically documented and described over 100 rock-cave churches and monasteries along the Lom Rivers (surveyed in 1887, 1892 and 1912 by the Archaeological Commission for identification and preservation of antiquities in Bulgaria at the National Museum in Sofia). He explored also the rock monasteries and hermitages in South Dobrudja (concentrated along the Black Sea coast and the Suha River) (Fig. 6). Meanwhile Škorpil explored also the cave hermits and churches in the periphery of the Shumen Plateau and surveyed and described more than ten natural and tens of artificial objects (K Škorpil 1905; K Škorpil 1932). The books contain also the maps of all explored cave churches and monasteries. Škorpils' explorations and publications mark the beginning of further studies of the natural and rock cut caves under archaeological and religious aspects.

Figure 6. Map of Cherven Rock Cut Monastery.

5. Conclusions

Finally, who were these two scholars? Karel Škorpil – the engineer and organizer, the fundraiser and researcher of international scale, who helped to establish many scientific associations at their early phase in Bulgaria; and Hermin Škorpil – the naturalist and traveler, who helped continuously in the studies of his brother as a teacher and educator in Bulgaria, the explorer and writer of the first books in natural history, geology, geography, speleology in Bulgarian language.

The researches of the Škorpil brothers were often self-funded and all unearthed monuments were preserved in Bulgaria. As a sign of appreciation of their activity for the development of Bulgarian education, science and culture, many Bulgarian places (streets in Varna, Sliven, Plovdiv, Sofia, Kavarna), schools, a village – seaside resort, were named after the brothers. Škorpil Glacier on Graham Land, Antarctica, was also named after Karel Škorpil. In honour of the Škorpil brothers three Bugarian plants were named: Shkorpilova vedrica (*Fritillaria graeca*) – Fam. Liliaceae, Shkorpilova mashterka (*Thymus euximius*) – Fam. Lamiaceae (Dimitrov 2006) and Argostelimia Skorpilii Vel. (Stanev 2001).

Even today, 100 years after the publication of the first important works of the Škorpil brothers about Bulgarian karst and caves, these books are favorite and important readings of Bulgarian speleologists and cavers. Without any doubt Hermengild and Karel Škorpils must be listed among the founders of Bulgarian speleology and caving.

Finally we have to ask, what Karel and Hermann Škorpil left during the period of their stay in Bulgaria – from 1880 to 1944? In spite of the fact that the known original sources of Škorpils' have been studied many times, there are still little personal data about the brothers' activity. Apparently the names of K. and H. Škorpil as karst and caves explorers are not well known in their native country – the Czech Republic. More information probably could be found in the archives at their birthplace Vysoke Myto, like their birth certificates or any other early sources.

Figure 7. Karel and Hermengild Škorpil – 1905, Varna.

Figure 8. The monument of Karel and Hermengild Škorpil in front ofn the Historical Museum in Varna.

Acknowledgments

We would like to express gratitude to our friend Marcel Meyssonnier and to Dr. Pavel Bosak for sending some very important works of the Škorpil brothers.

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JENOLAN SHOW CAVES; ORIGIN OF CAVE AND FEATURE NAMES

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The Jenolan Caves Historical and Preservation Society researchers and surveyors worked together to place names on maps being produced by the Jenolan Caves Survey Project. Their sources for the cave and feature names were guidebooks, newspaper articles, tourist publications, postcards, and photographs. Valuable contributions also came from the oral history supplied by past and current guiding staff. From 1838 to the present day, guides have striven to acquaint visitors with the "exotic" cave environment, resulting in a tradition of giving features familiar names. To the informed, names of caves and formations can take on a hieroglyphic character that can guide you through the history of the caves. Being aware of the feature names can give a glimpse of the discoverers, prompt interest in the adventures of early visitors and even recognise the work involved in making the caves accessible. The result is that over a thousand names have been found that links historically and culturally to the discoverers, management and visitors.

1. Introduction

In 2005, as part of the Jenolan Caves Survey Project, the authors started to work on names for the maps. The Jenolan Show Caves are made up of "caves", sections of a system that have been given specific names to facilitate them as cave tours (Figure 1). The naming project immediately expanded as some cave and feature names provided an historical and cultural record of the Jenolan Show Caves. The result is an important record of the tradition of naming at Jenolan from the discovery of the caves to the present day.

2. Discussion

2.1. The early years

The first recorded descriptive names, commenced with the discovery of the arches in 1838 (Ralston 1989). Samuel Cook (1889) suggested that an arch known as the Devils Coach House was so named for reasons that had led to similar names for numerous Devils Pinches and Peaks for surface features around the world. Captain Cook had given the name Devils Basin to a harbour because of its gloomy appearance, being surrounded by savage rocks. For a brief period, the Devils Coach House was renamed Easter Cave, although the name never became popular.

The cave system has been known by various names: McKeon's Caves (1856), Binda Caves (1867), Fish River Caves (1879), and finally on 19th August 1884 the name Jenolan Caves was approved (Havard 1933).

By the 1860's names had been established for the New Cave (Ralston 1989). Visitors began their tour to this cave by hiking through the bush to Wallaby Hole, entering the cave through the Sole of the Boot to reach the Cathedral. They had to negotiate The Slide by sitting on a bag and descending further into the cave. In the Exhibition Cave they climbed over rocks, lunched on Picnic Rock and drank water from the Hidden River. In Lurline Cave those familiar with William Wallace's opera Lurline, first performed in 1860, could see "…the coral bowers and cells to which Rudolph was transported" (Cook 1889). In an area of the Bone Cave called the Irish Corner there was an interesting formation known as the Potato Patch, and further along Bone Cave were Snowball Cave and Crystal Fountain. Returning to Irish Corner, visitors were astonished to find they had to ascend a wire ladder to return to Cathedral and thence the cave entrance. Although this route is not used today, many of these names are still in use on the Lucas tours.

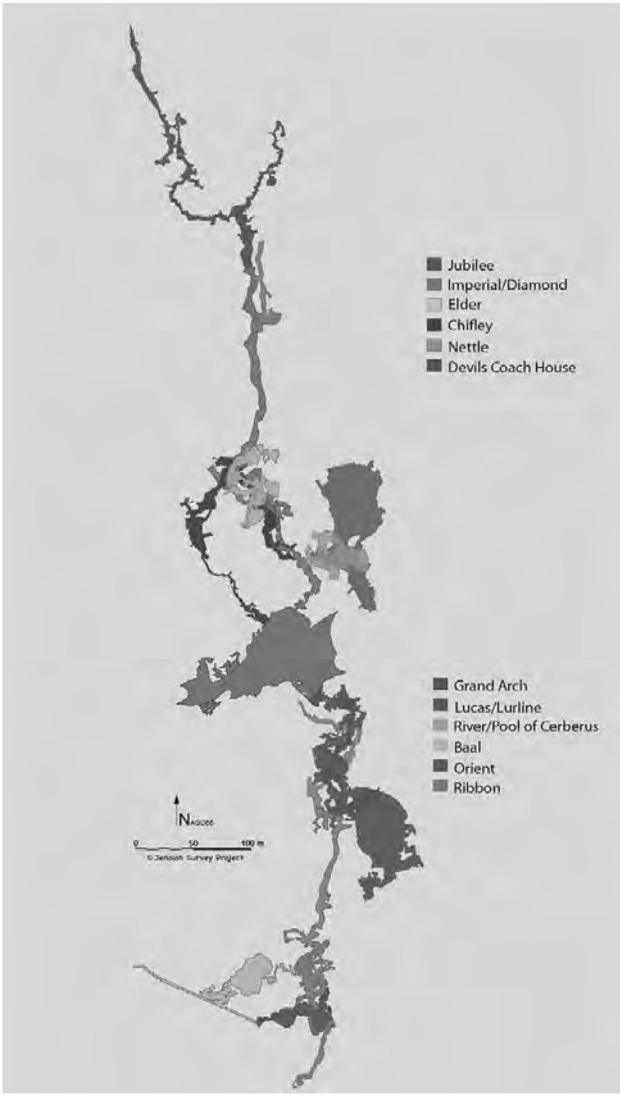

Figure 1. Jenolan Show Caves.

Figure 2. The Old Curiosity Shop.

Some names became enshrined with the advent of guidebooks; "English visitors see in this stalagmite the features of Lord Salisbury" (Trickett 1905). According to the 1924 Orient guidebook, visitors *"…one and all will recognise uncanny imitations…" and decorations seem "…veiled in a film of suggestion where more is meant than meets the eye and depends to a certain extent upon the imagination"* (Havard 1924). Figure 2 shows the Old Curiosity Shop where such a process has resulted 13 named features amongst a mass of helictites. The names for the features in this figure can be found in Figure 3.

At present the Orient (Figure 3) contains 134 named features, by far the most of any cave at Jenolan. Many of the features have been renamed over time, with some features like the Dome of St Pauls renamed as many as 5 times (so far), to give a total of 206 names for the Orient alone. There are only 119 of the 206 names on figure 3; it was not possible to fit any more on!

2.2. Names and Name changes

The reasons for names and name changes for caves, parts of caves and features are multitude, and the following paragraphs outline just a few examples. The shapes that prompt a person to choose names are usually explained by culture, history and, sometimes, even profession. The chambers in the Orient (Figure 3) have names from that part of the world which now known as the subcontinent.

The imagination of guides and tourists – From the very beginning, cave guides and tourists used names to describe formations, in part to make the strange more familiar. It is a tradition that has evolved and has continued even at the present as new cave is discovered. For example, renamed by young visitors, the Unicorn's Horn has become ET's Finger and The Minaret has become The Ice Cream Cone. The cave divers have named a stalagmite as the Upside Down Ice Cream Cone. A medical person was probably responsible for describing the helictites in the Dragon's Throat in Baal as Diphtheria Symptoms.

The beautiful and small – There are many sparkling calcite crystal decorations at Jenolan, such as stalactites, stalagmites, flowstones and helictites, that have been named but some of the most intriguing formations are obscure. Old publications and photographs have enabled identification of these treasures. Among one mass of tangled helictites, named The Battlefield, is the minute Leaping Stag. The Diminutive Horse Head is one of the smallest examples of named features at Jenolan (Figure 4).

The ambience of the environment – George Rawson (1883) wrote of a visit to Fish River Caves that *"…one is bought into a silent and reverent attitude…"* hence it is no surprise that many names of religious significance were used. There is an Organ Loft and Pulpit in the Grand Archway, a Sanctuary in Nettle, a Cathedral and Bishop in Lucas, Twelve Apostles in Orient (Figure 5), with Imperial and Chifley both having a Vestry. Biblical names include Elijah's Retreat, Tower of Babel and Lots Wife.

Historical events – have also played a part, particularly in renaming features. The Terraces in Exhibition Chamber became the Pink and White Terraces in remembrance of those in New Zealand destroyed by the 1886 eruption of Mount Tarawera (Cook 1889). Mafeking was besieged during the Boer War for 217 days, from October 1899 to

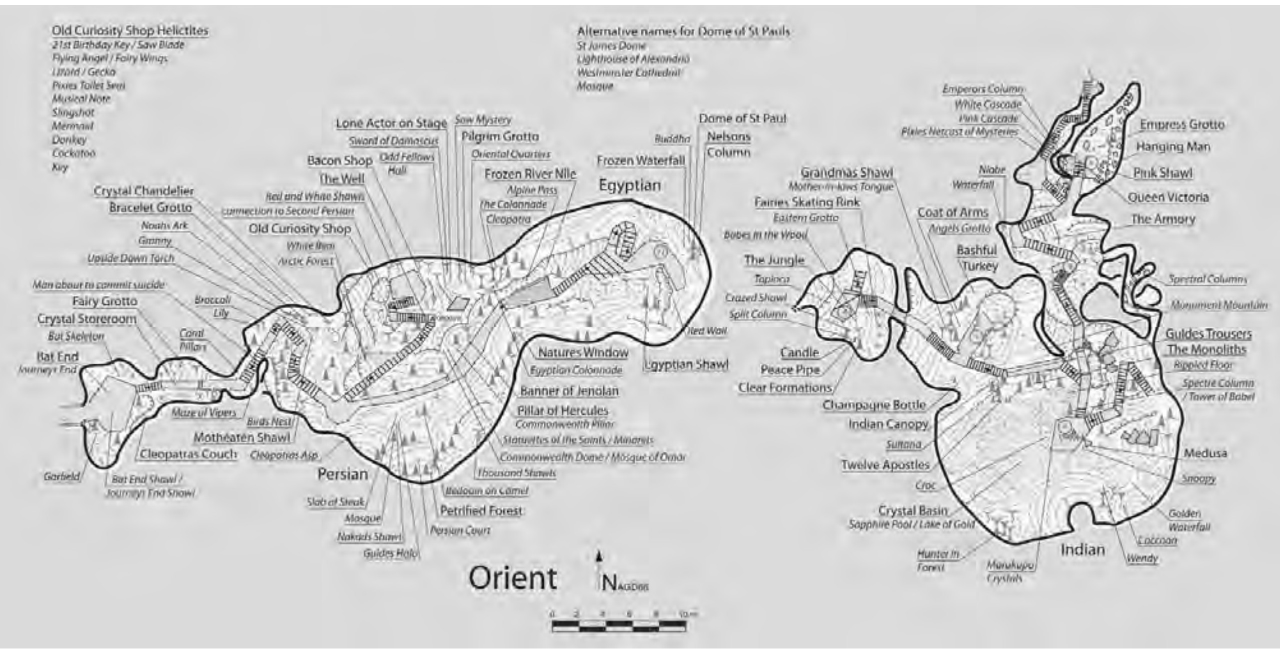

Figure 3. The Orient Map.

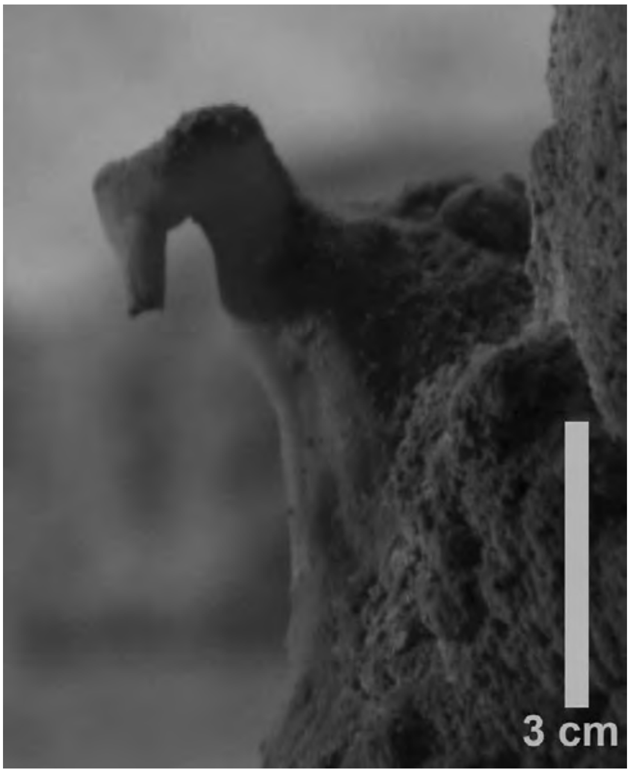

Figure 4. Diminutive Horse Head.

Figure 5. The Twelve Apostles.

May 1900. The relief of Mafeking by the British from the Boer coincided with the discovery of a high level passage in the Exhibition Chamber, hence its name and the names of some features in it (Figure 6).

Figure 6. Map of Mafeking.

Currently, there is a proposal to commemorate the Queen Elizabeth II Jubilee with a named dome and arch in Jubilee and Imperial respectively.

Honouring Australian dignitaries – In 1878 the New Cave was named Lucas after John Lucas, M.L.A; *"In consequence of the great interest I displayed, and by the publication of my paper, which first drew the attention of the public to them, the Surveyor-General and other high officials made an official visit, and named the largest cavern The Lucas Cave"* (Rawlinson 1976). One formation was named Judge Windeyer's Couch *"…because it is said that the learned judge sat on it when he visited the caves"* (Cook 1889). In 1952, the Left Branch of Imperial was renamed Chifley Cave in honour of J.B. (Ben) Chifley, who represented in the Federal Parliament the region that included Jenolan. The name change attracted some criticism; *"The gesture, however well intentioned, will not give much pleasure to Mr Chifley's admirers, for the sake of the memory of a highly regarded man, I hope some more tactful Chief Secretary changes the ludicrous name of Chifley Cave back to what it was before"* (Sunday Herald 1952).

Cave incidents – Jeremiah Wilson, exploring Jubilee in 1893, described the dreadful experience of having his candle go out and believing he had no matches. Fortunately he found some in his pocket, but he ensured the event was not forgotten by naming the place where he was at the time Wilson's Despair. In Imperial, Ridley's Short Cut was named after *"…a visitor who stepped back to allow a lady to pass and fell through (to a cave below)…"* (Leeder 1994). The guides describe the incident as a *"…rambling visitor who strayed from the fold, put a foot in the wrong place, and descended fifty five feet without the benefit of the rope. He landed on a coil of netting and bounced off"* (Ralston 1989).

The influence of lighting – Different lighting can influence what can be recognised in the caves. Scenes lit by flickering candles, and at times augmented by magnesium lamps, delighted early visitors. However, the Stooping Lady could "…be seen only by candle light, the magnesium flare being too penetrating for this particular effect" (Foster 1890). Harry Potter's Scar was visible in the Exhibition Chamber until the lighting system was recently upgraded. The new lighting did however result in a perfect representation of a Terracotta Warrior appearing in shadow on the wall over the River Styx in Lucas.

After Ladies – In Lucas, Queen Victoria is unmistakable as she looks out over the Royal Chamber in the Lucas (Figure 7).

Other ladies are also featured throughout Jenolan, with Lady Cecilia Carrington, Queen Esther and Margarita Cracknell having chambers, as do Selina and Lucinda. Katie and Edie have their bowers and Matilda has a retreat, while Josephine, Nellie, Ethel and Minnie only merited grottos (Figure 8).

Figure 7. Queen Victoria.

3. Conclusion

In this discussion the evolution of names in the Jenolan Show Caves has been illustrated with selected examples; the Excel spread sheets for the Survey now contain more than a thousand names. The Jenolan Show Caves can be thought of as the “*Caves of a Thousand Names*”.

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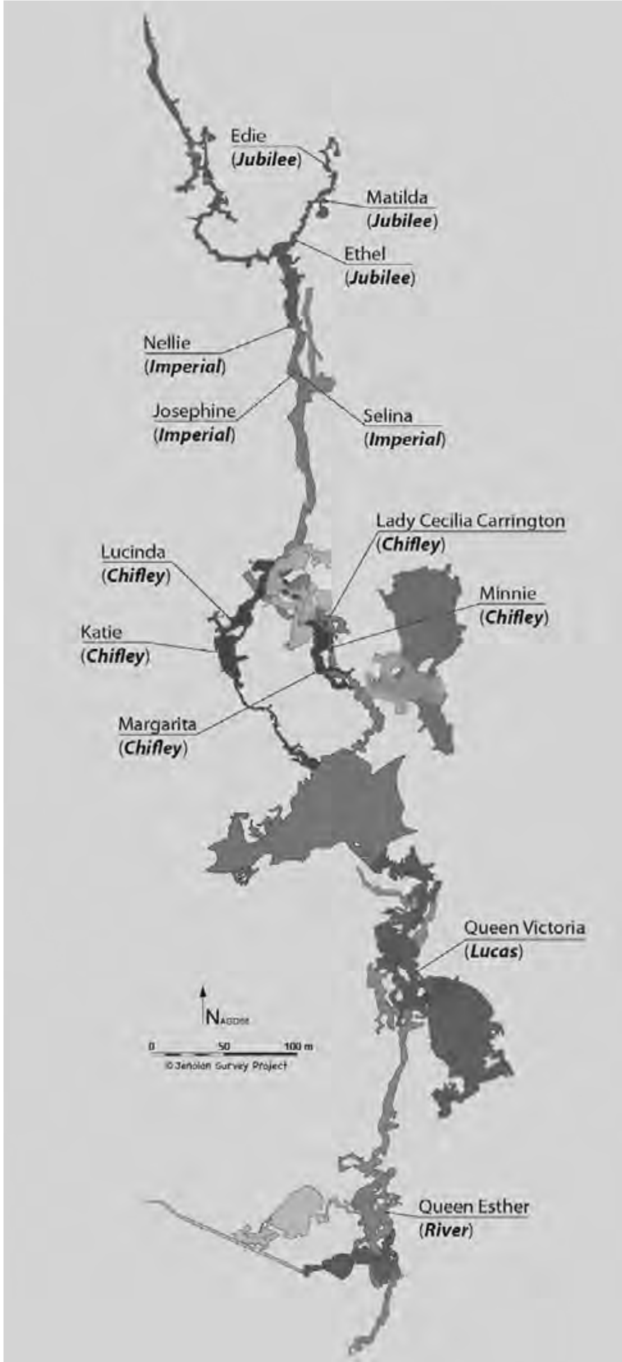

Figure 8. Location of features named for ladies.

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THE SLOVENE KARST PORTRAITED IN THE "UNIVERSAL GEOGRAPHY" OF CONRAD MALTE-BRUN AND ELISÉE RECLUS

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The karst landscape and the caves can be perceived by several people in an equally varied way. From the layman to the scientist, especially caves, assume different meanings according to historical and cultural conditions of a particular society. Therefore, one can say that the human relationship with caves is not really new in the history of mankind. It is also not less new the motivation for their use as shelters, safe houses and sacred places. Thus, caves and karst are important historical and geographical records of specific regions. In this context, the importance of the Slovene karst to Geography is confirmed by the Universal Geography of Conrad Malte-Brun and Elisée Reclus, two important classical geographers. By the analysis of their works ("Universal Geography") it was possible to identify how some important aspects of the karst landscape were portraited.

1. Introduction

The karst landscape and its caves may be perceived by different people in many different ways. From the layman to the scientist, especially caves have different meanings according to the historical and cultural evolution of a society.

Regions developed in carbonates such as limestone, make up about 10 to 15 % of the Earth's surface (Ford and Williams 2007). Williams (2008) states that karst is found mainly in soluble rocks such as limestone, marble and dolomite. However, it also can be developed in evaporites (e.g., gypsum and halite). The carbonate outcrops comprise about 15,000,000 km^2 of the non-frozen Earth's continental area (11 % of area). But percentage the subsuperficial carbonates involved in the movement of subsurface groundwater are considerably higher, perhaps about 14 % of the world.

A new proposition of these percentages, especially regarding rocky outcrops, was made by Williams and Fong (2008). The new proposal shows that about 12.5 % of global land surface outcrops have carbonates. The authors emphasize that they have tried to differentiate the areas where the carbonate rocks are relatively pure and continuous from those with relatively impure and discontinuous deposits. More recently, Hartmann and Moosdorf (2012), based on a new global lithological map, proposed that the continents are covered by 64 % sediments, a third of which are carbonates.

In almost all karst regions, archaeologists find evidence of human settlements. Around the world one can see that whole populations are supplied by karst water and, in many cultures, caves are still used as places for religious practice, as cultural manifestations, or for any other purpose (Travassos 2007). Such forms of use also comprise tourism in all its aspects, such as Cultural Tourism and Geotourism.

The study of this peculiar type of relief could be already seen in the works of Greek and Roman philosophers as highlighted by various authors (e.g., Travassos 2007). Brief descriptions of the Classical Karst (Region of the Kras Plateau, Slovenia) have already appeared in works of the 4th century BC, as well as in the works of Strabo, Pliny the Elder, Polybius, among others. In a clear description of a sink and a resurgence, Posidonius of Apameia (135–50 BC) stated that the river Timavus disappeared between the mountains, flowing into an abyss, only to reappear at a distance of 130 stadiums, toward the sea (Kranjc 1997; Kranjc 2006; Travassos et al. 2006). The Roman geographer Strabo (63 BC–21 AD) was probably the first to mention Lake Cerknica (Kranjc 2006).

In the Late Antiquity, the *Tabula Peutingeriana* (Peutinger Table, Peutinger Map) already showed signs of human settlements on karst areas. Cultural tourism in the *Kras* region (even in its primitive form) dates back to at least 280 AD in Sveta jama (Holy Cave), and at the Landarska jama (Cave of Landar) around 888 AD. Countless travelers were also attracted by the natural beauty of Postojnska jama (Adelsberger Grotte, Cave of Postojna) since at least the 16th century and the jama Vilenica (Vilenica Cave) since at least 1663 (Travassos et al. 2006; Travassos 2011).

According to Kranjc (1997), Travassos et al. (2006), and Travassos (2011), the region of the Kras Plateau became popular by the description of geographers, topographer, scholars, and travelers at the end of the 17th century and beginning of the 18th century. This popularity was also due to the fact that Trieste (Italy) became a free trade port in 1719 (Fig. 1).

Figure 1. Partial view of Trieste, probably from the Kras Plateau or, il Carso (Reclus 1876–1894b, 58).

The authors continued to demonstrate the importance of the region to karstology when affirming that many researchers were pioneers devotinge further studies to the region of Kras. Kranjc (1997), Travassos et al. (2006) and Travassos (2011) mention the books of J.V. Valvasor (1689), J.A. Nagel (1748), B. Hacquet (1778–1789), and F.J.H. Hohenwart (1830) and Kempe (2008) notes that the German word "Karst" evolved in parallel to the word "kras" and is documented on older maps such as those issued by Ortelius, Mercator, and Blaeu and in the text of Sebastian Münster (1628).

Geographers and geologists of the 19th century started to use more frequently the term "karst" and the work of Jovan Cvijić (Das Karstphänomen, 1893) provided the scientific basis of the study Classical Karst, followed by F. Kraus (1894) and E.A. Martel (1894), among others (see Kranjc 1997; Kranjc 2006; Travassos et al. 2006; Travassos 2011).

Based on the original works of Malte-Brun and Elisée Reclus, this paper intends to show how these two classical geographers made significant contributions to the study of karst, specialy in Slovenia.

2. The Universal Geography of Conrad Malte-Brun (1755–1826)

The first major work of "*encyclopedic inspiration in the domain of European geography was the Universal Geography ("Geographie Universelle") of Conrad Malte-Brun, Danish that was forced to exile in France due to his ideas, considered too liberal for the time.*" (Amorim Filho 1988, 19). The worked intended to provide a kind of renewal in geographical ideas that he thought to be crucial at that time (Amorim Filho 1988).

Conrad Malte-Brun was born at Thisted, Denmark, 1775, and is believed to be the founder of the first modern geographical society. Exiled from Denmark in 1800 for his verses and pamphlets in support of the French Revolution, Malte-Brun established himself as a journalist and geographic writer in Paris (Britannica 2010).

In his work karst and caves were integrating physical and human studies. Numerous references to the geology and the type of limestone from various regions of the world were made. Caves used as dwellings places and temples were also identified. Descriptions of cavities filled with fossils and concretions are also common in the eight existing volumes.

In his preface to Volume 1, Malte-Brun (1827) says that the idea of the work is to group – in a series of historical speeches – both the Ancient World and the Modern Geography in a way that could provide to the reader a vivid picture of the whole world, with all the different countries, their memorable places and their societies. He recognized that "*it appears an immense undertaking, when we consider how many varied details require to be combined in a work of moderate size.*" (Malte-Brun 1827, iii).

Malte-Brun continues stating that, in studying the physical aspects of the world, "*we shall take a view of the leading features of nature; the mountains (…), the seas (…), and the rivers and the valleys by which it is intersected. We shall seek our way downward, through caverns and through mines.*" (Malte-Brun 1827, iv). "*Cavities and fissures of the Globe*", grottos, caves, underground water, bones and even volcanic caverns are described (Malte-Brun 1827, 84–91).

In other parts of the work he affirmed that he will "*point out and occasionally describe at length the most remarkable caverns and grottos of our globe; but we must here confine ourselves to general views (…). Among the numerous caverns of Carniola, that of Adelsberg is said to afford a subterranean walk of two leagues; but this computation of rather too enthusiastic writer requires to be confirmed.*" (Malte-Brun 1827, 86).

Still regarding the region of Slovenia, he stated that many caves "*contain deep pits of water, or wells, sometimes so extensive as to acquire the name of subterraneous lakes*" (Malte-Brun 1827, 86). Malte-Brun registered the presence of other cavities issuing rivers from underground. Such examples are the "*innumerable cavities of the Julian Alps, in Carniola and Croatia*" that possibly affect the seasonal regime of the "*Lake of Cirknitz*" (Malte-Brun 1827, 86). It is important to mention that historically the region of Carniola was in Austria known as the Duchy of Carniola (until 1918), with the capital of Laibach (Ljubljana).

The mountainous region which stretches to Illyria (the area in the western part of today's Balkan Peninsula) are, to a great extent, composed of "*calcareous rocks which geologists have called Secondary, and which, from their tendency to give way, so as to form numerous cavities, might well be termed cavernous. It seems, indeed, as if all these heights were hollow; at least it cannot be denied that almost as many rivers flow below as above the ground. The stranger who follows their course, observes them entering and returning at different distances from the depths of the earth. Others become wholly dry at certain seasons of the year, and afterwards reappear.*" (Malte-Brun 1832, 212).

He further affirmed that is possible to enumerate "*more than a thousand caverns in the chain that traverses Illyria from north-west to south-east; but none can be compared in point of extent with the one at Adelsberg, which is situated in a small valley at no great distance from that burgh. Some writers consider it equal in length to five miles. It is by no means easy to trace the rapid declivities in the labyrinth, or the narrow and tortuous passages which lead to immense halls. All agree that it surpasses most places of the kind; the soil is encrusted with fossil bones; a torrent rushes through the cavities with a frightful noise, which is repeated by many echoes; stalactites adorn the halls, and appear in some places like the ruins of old palaces, in others like magnificent columns.*" (Malte-Brun 1832, 212).

Not too far away from the Grotto of Adelsberg, Malte-Brun (1832, 212) described the "*Cave of Magdalene, although not nearly so large as the last, is fully as deep, and perhaps as remarkable on account of its stalactites (…). Their calcareous concretions exhibit the most varied forms.*" (Today called Črna jama, part of the Postojnska jama system). Regarding the field of biospeleology, the aquatic species "*known by the name of Proteus anguinus abounds in a small marsh at the extremity of the cave*" (Malte-Brun 1832, 212).

Malte-Brun stated about the Lake of Cerknica that it has been more "*frequently examined by naturalists than any other (…). Calcareous mountains bound it on every side; Mount Jovornick commands it on the south, and the Sliviza on the north. It may be about four or five leagues in circumference in dry seasons and in wet about seven or eight. The waters of eight streams flow into it, and four or five islands rise in the middle of the lake; the village of Vorneck has been built on the largest of these islands. The lake disappears at irregular periods, and flows through forty clefts or apertures in its channels. The inhabitants then collect the fish that have not been carried away by the water, and shoot the aquatic fowl that seek in vain for their haunts. The husbandman deposits the seed in the fertile ooze, trusting that his labors may be crowned by an abundant harvest; but his labor, his outlay, and his hopes, are often vain. By the same issues, which served to drain the lake, the waters rise suddenly with a tremendous noise resembling a thunder; the fish reappear, the teal and water birds find their wanted asylum, and man complains of his improvidence.*" (Malte-Brun 1832, 212).

The main credit of Malte-Brun's work is due to the fact that it helped to increase the prestige of geography, being sovereign for aproximatly 60 years until the emergence of Elisée Reclus' Universal Geography (Amorim Filho 1988, 21). Even though one cannot consider him as a karstologist, it is possible to recognize his precise descriptions of the karst landscape and its phenomena.

3. The Universal Geography of Elisée Reclus (1830–1905)

Elisée Reclus is mostly known because of his Géographie Universelle (1876–1894), the largest opus on regional geography ever written by one person, among other publications. "*Even though criticized by some French geographers and sometimes thought as superficial in some issues (geological basis of Geography, for example), the work of Reclus may be described as magnificent.*" (Amorim Filho 1988, 24). All the 19 volumes of the Universal Geography approach the thematic of caves, ponors, springs, and the use of karst by different cultures.

The books are divided as follows: Volume 1 – Southern Europe (Greece, Turkey in Europe, Rumania, Serbia, Italy, Spain and Portugal); Volume 2 – France and Switzerland; Volume 3 – Austria-Hungary, Germany, Belgium, and the Netherlands; Volume 4 – The British Isles; Volume 5 – The northeast Atlantic. Islands of the North Atlantic, Scandinavia, European islands of the Arctic ocean, Russia in Europe; Volume 6 – Asiatic Russia; Volume 7 – East Asia; Volume 8 – India and Indo-China; Volume 9 – South-Western Asia; Volume 10 – North-East Africa; Volume 11 – North-West Africa; Volume 12 – West Africa; Volume 13 – South and East Africa; Volume 14 – Australasia; Volume 15 – North America; Volume 16 – The United States; Volume 17 – Mexico, Central America, West Indies; Volume 18 – South America (the Andes regions); and Volume 19 – Amazonia and La Plata.

Like Malte-Brun, the karst phenomena which most called Reclus' attention were caverns, dolines, ponors and springs. He often related legends associated with these places. For the present paper, special attention was paid to Volumes 1 and 3.

Althougth Reclus talked about other regions than Slovenia in Volume 1, it is important to state that he mentioned the same karst phenomena as common in Slovenia. Under this perspective, in Volume 1, he discussed and compared the limestone mountains of Bosnia with those of the Jura, being very similar due to the existence of grottoes, sinkholes, and subterranean rivers. "*Sinkholes from 60 to 100 feet in diameter, and shaped like funnels, are met with in many localities. Several rivers appear suddenly at the foot of a hill, and, after flowing on for a few miles, disappear again beneath some portal in the rocks. The land of the Herzegovina especially abounds in phenomena of this kind. The ground there is pierced by "sinks", or ponors, which swallow up the water derived from precipitation. "Blind valleys" and "troughs" present everywhere the traces of currents of water and of temporary lakes, and after heavy rains the subterranean basins sometimes rise to the surface, and a river then flows for a time along the valley. As a rule, however, the inhabitants are compelled to collect the water they require in cisterns, or to fetch it from long distances. Elsewhere the hydrography of the country is subject to annual changes. Lakes which still figure upon our maps are drained through subterranean passages only recently opened; other lakes are formed in consequence of some passage, which formerly carried off the surface water, having become choked with alluvium. No more curious river probably exists in the world than the Trebinishtitza in the (…) Herzegovina.*" (Reclus 1876–1894a, 127–128). (This river may be the Trebinica (=Trebišnjica) river, in the south of Bosnia-Herzegovina).

In Volume 3, possibly the most important book regarding this paper, Reclus discussed the Kras Plateau, or, as he would call it "*the Carso, with its piled-up stones and grotesquely shaped rocks, presents a unique appearance*." (Reclus 1876–1894b, 40).

He also refered to the abundance of dolines of all shapes and dimensions: "*some of them presenting the appearance of amphitheatres surrounded by rows of seats. These sinks swallow up all the rain that falls, when they are converted into temporary lakes, unless the water immediately disappears in the bowels of the earth.*" (Reclus 1876–1894b, 40). For the bottom of such karst features, the author noted that "*these hidden spots are carefully cultivated by the inhabitants, for upon the open plateau, owing to high winds and arid soil, cultivation is not practicable*." (Reclus 1876–1894b, 40). Still talking about the Kras Plateau, he affirmed that it "*forms a good natural boundary, for it presents great difficulties to a traveler, not so much because of its height, but owing to its formidable precipices*." (Reclus 1876–1894b, 43).

Obviously, Reclus also made important references to the "*Dinaric Alps*" and registered countless seasonal lakes and karst springs and paid attention to the behavior of these lakes and karst-rivers present in the region as "*a strong strategic barrier, not only because of their height, but also because of the want of water*." (Reclus 1876–1894b, 43). "*The limestone of which they are composed quickly sucks up the rain, and no other country in Europe abounds so* *largely in underground rivers. These rivers have their waterfalls, their freshets, and other phenomena, like rivers flowing on the surface. M. Schmidt*[1] *and others, by descending into the sinks and embarking in small boats upon mysterious watercourses, have succeeded in mapping several of these subterranean river systems. Of all these rivers the Rieka, or Recca, near Trieste, is the most famous. Rising upon the Snowy Mountain, it flows for some distance through a narrow canyon, until it disappears beneath the rock, surmounted by the picturesque village St. Canzian. Still lower down it flows over the bottom of a sink, then forms some cataracts, and disappears once more, only to appear again after an underground course of 22 miles."* (Reclus 1876–1894b, 43–44) (Fig. 2).

Reclus also mentioned that a large portion of Carniola and Dalmatia would show sinking rivers in the limestone. When encountering layers of impermeable rocks, occasionally the underground rivers re-appear on the surface. When those rivers are not visible on the surface, many towns have to use cisterns for their water supply "*although voluminous rivers flow through inaccessible caverns beneath them*." (Reclus 1876–1894b, 66).

About the Pivka River he reported that it "*is swallowed up by the caverns of Postojna, or Adelsberg (…),* (it) *is perhaps quite as remarkable a river as the Timavo. After an underground course of about six miles the Pivka once more reaches the surface, a calm and powerful river. Soon after its junction with the Unz, it is again swallowed up, and only reappears a short distance above Laibach*." (Reclus 1876–1894b, 66–67).

Figure 2. Drawing showing a map of the region surrounding Postojna and Planina. Scale 1:120,000 and one can see also the rivers Pivka and Unz, as well as the Planinško polje (Reclus 1876–1894b, 66).

As it is commonly observed in the reports of travelers and scholars, the imaginary of karst areas almost always presents some points in common. In this case, Reclus said that "*on a map these rivers, which hide themselves from time to time in underground channels, resemble a serpent cut into pieces.*"(Reclus 1876–1894b, 45–46).

Regarding the human relationship with karst, Reclus stated that "*one of the most difficult tasks of the people dwelling around the Carso consists in protecting themselves against the sudden floods caused by these subterranean rivers. The water, not being able to spread laterally, rises vertically, fills up the sinks, and even overflows them. The Rieka has been observed to rise 350 feet above its ordinary level in the sink of Trebic. The villages are thus perpetually threatened by inundations. The inhabitants take many precautions to avert the danger. They place gratings over the openings of the sinks, to prevent their becoming choked up; they occasionally clean cut the underground channels; and sometimes even resort to blasting in order to open more commodious passages for the surplus waters. Permanent or temporary lakes are formed in many places, in spite of these precautions.*" (Reclus 1876–1894b, 46).

Even with all the precautions, perennial or temporary lakes (Fig. 3) form in various places, but none can be compared "*with the Zirknitz which lies on the northern slope of the Carso.*" (Reclus 1876–1894b, 47). "*In the dry season its water is drained off through the numerous fissures and caverns which perforate its bed. After rains it rises to the surface, sometimes very suddenly, and occasionally the lake spreads over a surface of 30 square miles. Drainage works have to some extent regulated the ebb and flow of the lake. In former times, however, the whole of the plain was occasionally converted into a lake, and the villagers alternately gained a livelihood by fishing and by tilling the land when it emerged."* (Reclus 1876–1894b, 67).

Figure 3. Drawing showing a map of the area of Lake Cerknica or Cerkniško jezero. Scale 1:115,000 (Reclus 1876–1894b, 67).

[1] This may be a misprinting for Adolf Schmidl.

Kranjc (2006) remarked on the antiquity of the first citation of the Lake Cerknica: The Roman geographer Strabo (63 BC – 21 AD) was probably the first to mention it and G. Leonberger (1537) was the first to publish it. According to the Kranjc (2006), the early authors from the 16th and 17th centuries often just admired it but in the 18th century many dedicated themselves to discuss its seasonal behavior scientifically, and for the first time proposals emerged to change its regime (e.g., drying up the lake).

Many projects have been suggested; a lot of research and even some practical works were conducted until the middle of the 20th century. No project was fully implemented because of fear of flooding the capital, Ljubljana. After World War II, the situation changed. Instead of draining the lake, it was proposed to make the lake permanent. The first experiments were not successful and in the 1980s attitudes towards the lake changed. Environmental movements prevailed and many projects began to protect the ephemeral lake as a natural phenomenon (Kranjc 2006) (Figs. 4–6).

Figure 4. Partial view of Lake Cerknica or Cerkniško jezero. (Photo: L.E.P. Travassos.)

Figure 5. View of Lake Cerknica from the Mount Slivnica in the winter. (Photo: L.E.P. Travassos.)

Figure 6. View of Lake Cerknica from the Mount Slivnica in the summer. (Photo: L.E.P. Travassos).

4. Conclusions

This study was intended to demonstrate how the Slovene karst was portraited by two important “Classical Geographers”, who both published a “Universal Geography”.

One can say that most of the descriptions of the Slovene karst are mostly correct with the exception of the surface of the Lake Cerknica made by Elisée Reclus. He claimed that the lake has an area of 30 square miles or more than 75 km^2, while in reality the lake surface changes from 20 to 25 km^2 (Dolinar et al. 2010). These authors state that during an average flood, water covers an area of 20 km^2. If one think about the surface of the plain, one can see that the polje is a relatively flat enclosed karst depression, with a floor area of 70 km^2, and a catchment area of over 475 km^2 (Žibrik et al. 1976; cited by Kovačič 2010), thus Lake Cerknica has an extensive karst watershed (Kranjc 2003; cited by Dolinar et al. 2010).

Possibly Reclus was mentioning the area of the polje, not the water surface. Further measurements of the karst water behavior was not given by the authors, so one must understand that such behavior were identified only by personal observation and indigenous information.

The work of Malte-Brun (with approximately 4,200 pages divided in eight volumes) lacks in cartographic representations, but some artistic illustrations are included. Unfortunately the karst region of Slovenia or the Dinaric Karst is not pictured, just discussed.

The magnificence of the Slovene karst took the geographers’ attention presenting interesting descriptions of the territory. In the work of Reclus, regional maps were made with the intention to better explain the texts. The author showed the inundation zone of the Sava, the caverns of Postojna (Adelsberg), the Lake of Zirknitz and the Plain of Laibach.

It is desirable to expand this work towards the study of other fields of geography such as general geomorphology, for example.

Only with an in-depth study of the two authors, one can assure that they have an important role in the development of Karstology. Regarding Elisée Reclus, perhaps one of the reasons for this was the fact that he had spent most of his life in exile, away from France, due to his political ideas (Anarchism). Amorim Filho (1988) reminded that Reclus participated in the resistence movement against Napoleon III, end of 1852, and in the Paris Commune in 1870/71. The exile didn’t give him the stability demanded for a productive academic life.

Finally, one can say that the reading of classical geographers is considered to be a good opportunity for interdisciplinary academic work, helping future researchers to better understand the present by knowing the past.

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IN MEMORIAM OF ERATO AGGELOPOULOU WOLF: THE FIRST GREEK FEMALE CAVER

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In the spring of 2012 Erato Angelopoulos Wolff died, aged 102 years. Erato was the woman who left her mark on Greek caving in the late 1920's and early 1930's. During that period, some active members of the Greek Mountaineering Club of Athens (EOS Athens) were caving in Attica, Euboea South and North-eastern Peloponnese. Caves like Koutouki in Peania, Attica, Ermis in Ziria, Corinth and Ag. Triada Karystos Euboea, were explored for the first time by this group. Erato was the only woman who participated in these explorations. She also published these explorations in articles that she signed them herself in the "Ekdromika chronika" magazine of EOS Athens.

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OLDEST DOCUMENTED CAVES OF THE WORLD: BIRKLEYN CAVES

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The Birkleyn Caves are located near Lice, 25 km north of Diyarbakır, south-eastern Turkey. Three of the four caves are close to each other and dry, but the forth is the longest and the most important of them. It is known as “Iskender-i Birkleyn” among locals, and is traversed by a branch of the Tigris River flowing through it. These caves are probably among the most interesting caves historically and speleologically because they contain 3,000 years old Assyrian inscriptions and reliefs engraved on the walls. When the former stream bed of the Birkleyn River, which the caves are named after, was blocked by subsidence in prehistoric times, the river opened a new bed to itself by physical erosion inside a nummulitic Tertiary limestone south of its former bed.

The Birkleyn Caves were first examined by Taylor in 1862. Later Lehmann-Haupt made a short study of the caves in 1899. After a long interval, Anthony C. Waltham visited the region in 1974 and in 1977 members of Speleo Club de Paris mapped three of these caves. In 2007, Andreas Schachner from German Archaeological Institute began to study the Birkleyn caves in detail. The best known one of those caves, “Iskender-i Birkleyn” has a total length of 870 meters and was thought to be the spring of Tigris because of its interesting geographical position. This was probably the reason why Assyrian kings Tiglath-Pileser I and Shalmaneser III had reliefs and inscriptions made there. Likewise, the same cave was depicted as the “Tigris Source” in the bronze ornaments at the gates of Balawat City, which is now in Iraq, forced under Shalmaneser III. Those bronze reliefs, which date back to 850 BC, are displayed in the British Museum today and it is most probably the oldest picture in the world that depicts a cave.

In this poster session these caves will be reviewed geologically and the translations of the Assyrian inscriptions on the cave walls are presented in detail.

1. Introduction

Performative engagements with specific, culturally significant places were among the primary means of configuring landscapes in the ancient world. Ancient states often appropriated symbolic or ritual landscapes through commemorative ceremonies and building operations. These commemorative sites became event-places where state spectacles encountered and merged with local cult practices. The Early Iron Age inscriptions and reliefs carved on the cave walls of Birkleyn Caves in Eastern Turkey (Fig. 1), known as the “Source of Tigris” in monuments, present a compelling paradigm for such spatial practices. Assyrian kings Tiglath-Pileser I (1114–1076 BC) and Shalmaneser III (858–824 BC) carved “images of kingship” and accompanying royal inscriptions at this impressive but remote site. This important commemorative event was also represented in detail on Shalmaneser III’s bronze bands at Tell Balawat (Fig. 2), as well as in his annalistic texts, rearticulating the performance of the place on public monuments in Assyrian urban contexts. These bronze ornaments from the gates of Balawat – Iraq, dated 850 BC, are on display at the British Museum today and most probably are the oldest pictures in the world that depict a cave.

It is clear that the “Tigris Source” must have ranked high as a sanctuary not just in local but also in international esteem. Shalmaneser III deemed a visit to this cave so important that in 852 BC he had his army take a detour on its march back from inner Anatolia to Assyria; he and his predecessor Tiglath-Pileser I performed sacrifices at the “Tigris Source” and both left inscriptions and reliefs at the site. Moreover, as a holy precinct in open nature, with unlimited water and shelter from the powers of nature offered by three caves in addition to the river grotto itself, the “Tigris Source” would seem uniquely qualified to serve as a refuge sanctuary.

Figure 1. Location of Birkleyn Caves.

Figure 2. Balawat door bands, showing sacrifices and Birkleyn Cave at upper band, right corner. (Source: Wikipedia).

2. Caves of Birkleyn in general

2.1. Cave no. 1

This is the most important one of the four known caves in the region, also called "Tigris Tunnel". It is located underneath of the southern bluff that forms the westward expansion of Mount Kohra and has a northeast-southwest direction (Fig. 3). The cave has a total length of 870 meters and is 20–25 meters high on average. At the entrance of the cave, 4–5 meters above the floor there are three cuneiform inscriptions. The westernmost one is the inscription and relief of Tiglath-Pileser. 1.5 meters away is the Shalmaneser III's inscription and relief, and another inscription of the same king 10 meters further on. In the following the translations by Russel (1986) are cited.

The inscription of Tiglath-Pileser I (1114–1076 BC):

With the supports of my lords, the great gods Ashur, Samas (and) Adad, I, Tukultī-apil-Ešarra (Tiglath-Pileser I), the son of Ashur-resh-ishi, the king of Assyria who is the son of Mutakkil-Nusku, the king of Assyria, the conqueror of the great sea of Amurru Land (=Mediterranean Sea) and the great sea of Nairi Land (=Lake Van), have been to the Nairi Land three times.

The inscription of Shalmaneser III (858–824 BC):

Šulmānu-ašarēdu (Shalmaneser III), great king, strong king, the king of four realms, the king of Assyria, the king of all humanity, with the support of his guides, the great gods Samas and Adad, the mighty one (king) proceeds with power. They (the gods) gave him (the king) the mountains from the place the sun rises to the place the sun sets.

A king that never stops to follow his enemies and like the hills that flood devastated, strides the impassable rivers and mountains, a brave, merciless king. Son of Aššur-nāir-apli (=Ashurnasirpal II) who is the son of Tukulti-Ninurta II, the king of Assyria, the conqueror ruler from the sea of the land of Nairi (=Lake Van) to the great sea where the sun sets (=Mediterranean Sea).

I have taken the land of Hatti and all their borders, the land of Melindu, the land of Daianu, the land of Suhmu, the city of Arsaskun, the crown city of Urartus, Aramu, the land of Gilzanu, the land of Hubuskia-(the region) from the spring of Tigris to the spring of Euphrates, (the region) from the sea within the borders of Mazamua (=Caspian Sea) to the sea of the land of Kaldu (=Persian Gulf) under my feet. I went to Babylon and made a sacrifice. I went to the land of Kaldu, took their cities under my rule and accepted their tributes and gifts.

Adda-idri of Damascus and Irhulenu of Hamat revolted with fifteen cities. I fought with them four times.

The second inscription of Shalmaneser III (858–824 BC) reads:

The great gods Ashur, Bel, Sin, Samas, Adad, Ishtar who like my kingdom and elevate my name.

Šulmānu-ašarēdu (Shalmaneser III), son of Aššur-nāir-apli (=Ashurnasirpal II) who is the son of Tukulti-Ninurta II, the king of Assyria, the conqueror ruler from the sea of the land of Nairi (=Lake Van) to the great sea where the sun sets (=Mediterranean Sea). I have conquered the land of Hatti completely. I entered the Enzu Crossing. I conquered the lands of Suhmu, Daianu (and) Urartu completely. I went to the land of Gilzanu. I accepted the tributes of the people of Gilzanu. I went to the land of Nairi for three times. I wrote my name to the spring of Tigris.

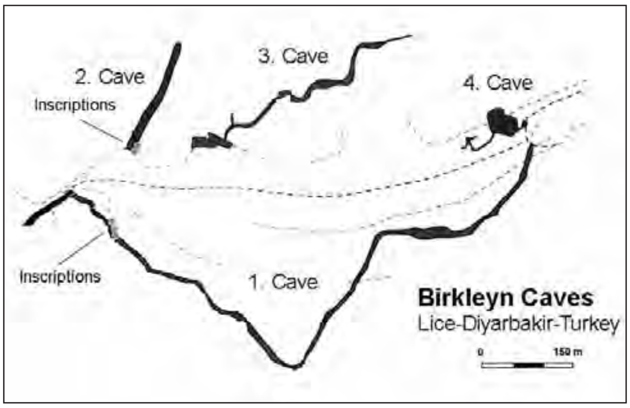

Figure 3. Map of Birkleyn Caves (after Schachner 2004).

2.2. Cave no. 2

This cave lies in the northern outcrop and has a NE-SW direction like the others. It has a length of 150 meters, an average width of 25 meters and a height of 20 meters. It has been used from prehistoric to medieval times. Sadly, inside and outside of the cave many traces of illegal excavations are found.

In front of the cave, there is a rock mass resembling a huge platform. On the eastern side of this natural agglomeration, where the cave wall intersects the outside wall, there are two more inscriptions and another relief that belongs to Shalmaneser III. The content of this inscription, which dates back to 858–824 BC, is almost the same as the inscriptions of the same king in the entrance of Cave no. 1.

2.3. Cave no. 3

With a total length of 600 meters, this cave is located 200 meters east of Cave no. 2 and has two parts. After a large entrance and two large spaces between small clearances and bluffs that expand to the canyon, the visitors enter the interior of the cave with a narrow corridor. The whole cave is covered with stalactites and stalagmites. The ceramics, that are found everywhere in the cave, suggest that the cave was used intensively in the past.

2.4. Cave no. 4

Located above the entrance of the Cave no. 1, at the northern bluffs, this cave consists of two successive spaces. The majority of the ceiling of the main chamber, which is larger compared to the entrance, has collapsed. The original size of the cave is therefore difficult to estimate. In the light of the discoveries of archaeologists, it is seen that these two spaces were used over ages intensively by humans. On the floor of this cave, several terracotta fragments were found mostly from the Iron Age.

Figure 4. Entrance of Cave no 1 (Tigris Tunnel). (Foto by author).

3. Conclusion

Though it has been a politically problematic region of Turkey for a long time; we believe that culture, history and natural beauties are the assets of all mankind. In the light of all the information above, it is evident that Birkleyn Caves have a great natural and historical importance and those lonely natural values in a troubled land have to be taken under protection without wasting any more time.

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Session:

Archeology and Paleontology in Caves

NAHAL ASA'EL CAVE: A UNIQUE 6,000 YEAR OLD WOODEN INSTALLATION AND THE LATE CHALCOLITHIC PRESENCE IN HARDLY ACCESSIBLE CAVES IN THE JUDEAN DESERT, ISRAEL

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Human occupation of caves located within high sheer cliffs in the remote arid region of the Judean Desert forms a distinct regional phenomenon of the Ghassulian cultural sphere during the Late Chalcolithic period of the Southern Levant. Over the last sixty years scholars have debated the nature of this phenomenon, suggesting that the caves were used either for habitation, as seasonal herders' shelters or storage facilities, for mortuary or ritual functions, or as temporary refuge places. Recently, in order to test the various interpretations, the spatial and material traits of 70 caves with reported Chalcolithic remains from the Judean Desert were analyzed. One such cave is located in Nahal Asa'el (Asa'el valley), ca. 10 km north of Masada and 5 km west of the Dead Sea shore. This small cave features one of the most difficult approaches among the studied caves, demanding a vertical abseiling of ca. 30 m. The cave was first visited in 1960, and a rare wooden construction, a platform made of unworked logs, was discovered in its innermost passage. The discovery prompted the late archaeologist P. Bar-Adon to launch an expedition to the cave in 1974. However, neither the initial discovery nor the results of the 1974 expedition were ever published, and even the exact location of the cave was forgotten over the years. As part of the renewed research we collected unpublished documents related to this cave, and re-located the cave in the field. This was followed by systematic survey and mapping of the cave, detailed examination of its environmental properties, and sampling of the wooden installation for taxonomic identification and radiocarbon dating. The results show that the platform, which was constructed of local trees, is dated to the early fourth millennium BC, and is thus the earliest of its kind in the entire Levant. The highly difficult access to the cave, the location of the platform within its deepest section, its careless construction, and the scarcity of other material remains, all seem to support the notion that the cave, as other neighboring caves, served as an ephemeral refuge during the Late Chalcolithic period.

1. Introduction

During the Late Chalcolithic period (ca. 4500–3800 BC), a new culture emerged in the Mediterranean, semi-arid regions of the Southern Levant (present-day Israel, Palestine and Jordan). This culture, termed the Ghassulian culture after the type-site of Teleilat Ghassul (e.g., Mallon et al. 1934), is characterized by rural communities settled in various environmental zones while practicing mixed farming subsistence economies (Levy 1986a; Gilead 1988a; Rowan and Golden 2009). Debates concerning the level of social complexity, existence of hierarchical institutions and degree of economic specialization characterize the scholarly discourse on the Ghassulian (Levy 1986b, 1995, 2006; Gilead 1988b, 2002). One of the hallmarks of this cultural phase, which marks a distinct change from the preceding periods, is the wide-scale exploitation of the subterranean sphere. Caves, both natural and artificial, served for various purposes in and around the settlements, such as habitation, storage and burial (e.g., Perrot and Ladiray 1980; Perrot 1984; Gilead 1987; Gopher and Tsuk 1996; van den Brink 1998; Scheftelowitz and Oren 2004). These caves were easily accessible from the sub-aerial sphere, and their forms were chosen (or fitted) to suite their intended functions.

The Judean Desert, a small local desert in the rain shadow of the Judean Highlands (Fig. 1), shows a somewhat different pattern. While no permanent settlements are known in this region during the Late Chalcolithic period, numerous natural caves, opened in the cliffs of the Dead Sea Escarpment and the deep canyons draining into the lake, contain material remains from this period. The first caves with Ghassulian materials were discovered in 1952 (in Wadi Muraba'at; de-Vaux 1961), and during the last sixty years ca. 100 caves with similar remains were found in the entire region (e.g., Aharoni 1961a, b; Avigad 1961, 1962; de Vaux 1962; Yadin 1962, 1963; Allegro 1964; Bar-Adon 1989). The most renowned is the "Cave of the Treasure", located in Nahal Mishmar (Mishmar valley), where a hoard of more than 400 copper objects was hidden, wrapped in a reed mat, in a niche inside the cave (Bar-Adon 1961, 1962, 1980).

Over the years, several interpretations for the Late Chalcolithic presence in the precipitous caves of the Judean Desert were suggested. Most scholars view the caves as either herders' shelters or storage installations in relation to seasonal movements of semi-nomadic pastoral groups (e.g., de Vaux 1970; Mazar 1990; Gates 1992). Another prominent suggestion is that the caves served as temporary refuge places for groups of people fleeing from the sedentary areas in turbulent times (e.g., Avigad 1962; Haas and Nathan 1973; Ussishkin 1980). Other hypotheses include permanent habitations (de Vaux 1961), semi-sedentary traders' stations (Tadmor 1989), mortuary preferences (Ilan and Rowan 2007) or a cultic incentive of an unclear nature (Bar-Adon 1980; Goran 1995). All explanations remained rather speculative, however, as no comprehensive examination of the environmental, spatial and material characteristics of the caves under discussion was conducted.

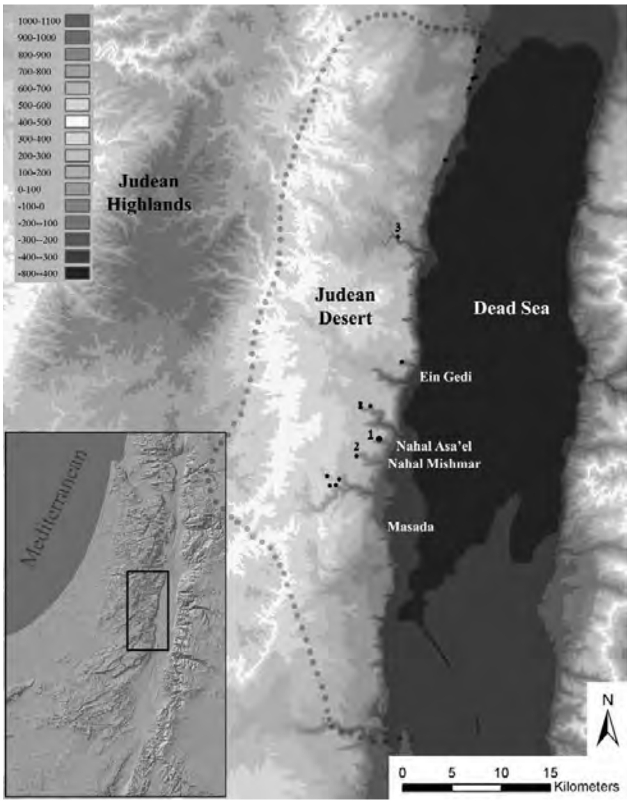

Figure 1. Study area of the Judean Desert with place names mentioned in the text. Small black dots mark caves with Late Chalcolithic remains. 1) Nahal Asa'el Cave; 2) Cave of the Treasure; 3) Wadi Muraba'at Caves.

In order to test the aforementioned interpretations, we recently compiled all available data from 70 caves in the region (Davidovich 2008), ca. 20 of which were discovered by us during an intensive cave survey conducted between 2001 and 2005 (Eshel and Porat 2009). Our analysis of the spatial and structural properties of the caves seems to support the refuge model, at least with regard to the majority of caves (Davidovich forthcoming). The most fundamental issue is that of accessibility. Most of the caves are located within high precipitous cliffs, and demand walking on steep slopes above sheer cliffs, and in half of the cases also the use of ropes and rope ladders. No attempts to improve the access ways were noted, and there are no signs indicating that access was essentially different during the Late Chalcolithic. Regarding structure, all caves were used entirely in their natural form, in many cases involving the use of dark, narrow, low, and unventilated spaces. Only rare examples of man-made modifications for prolonged occupation were observed. In addition, the material remains found in the caves are essentially different from contemporary settlement sites, primarily in the low frequency of several mundane artifact categories, such as small ceramic vessels and various flint tools. These features stand in striking contrast with the patterns observed in the subterranean spaces used within the settled provinces of the Ghassulian culture (above). They also differ from historic and modern cave use patterns of both settled agriculturalists and semi-nomadic pastoralists living in and near the Judean Desert (Davidovich 2008).

Here we wish to demonstrate the characteristics of the Late Chalcolithic presence in the Judean Desert caves using one case-study, that of Nahal Asa'el Cave (henceforth NAC). This cave, located only two km northeast of the famous Cave of the Treasure (Fig. 1), contains a unique wooden installation, discovered already in 1960 but never studied in detail, even though the cave was extensively excavated in 1974. Neither the initial discovery nor the results of the excavation were ever published, and the very existence of the cave was forgotten over the years. In what follows, we discuss the results of our renewed research of the cave, which included a study of the unpublished materials relating to the previous explorations of the cave, and recent fieldwork concentrating on environmental and spatial aspects, as well as on the wooden installation. At the end of the paper we consider the contribution of NAC to the discussion over the role of the Judean Desert caves within the Ghassulian cultural sphere.

2. Methods

Unpublished documents, including a field notebook of the 1974 expedition to NAC written by Pesach Bar-Adon, the cave's excavator, as well as a prosaic summary written by an expedition member, S. Heiman, an Israeli Defense Force order, and a few photographs, were located in the house of P. Bar-Adon's son, Doron, in 2006, and formed the starting point for the present research. Following conversations with D. Bar-Adon, Y. Tsafrir and Y. Govrin, all participants in past explorations of the cave, the latter was re-located in the field in spring 2007. Consequently, a systematic survey and mapping of the cave was undertaken. Mapping was conducted using basic equipment (Leica Disto D3 laser inclinometer and Silva Ranger 3 prismatic compass), and mapping grade was 5B.

The focus of the renewed research was the wooden installation found in the innermost passage of the cave. Samples from four different logs were taken for wood identification. Cross and longitudinal, tangential as well as radial sections were made by hand with a sharp razor-blade. The identification of the wood to species level, based on the three-dimensional structure of the wood, was made microscopically from these sections. Comparison was made with reference sections prepared from living identified tree specimens and with anatomical atlases.

Two of the aforementioned samples were submitted for Radiocarbon dating. Both samples were pretreated in order to extract the cellulose and to remove any contamination. The purity of the extracted cellulose before dating was checked using Fourier Transform Infrared Analysis. The cellulose was oxidized to CO_2 and then transformed to graphite for the Accelerator Mass Spectrometry measurement (see detailed procedures in Yizhaq et al. 2005). Calculated ^{14}C ages have been corrected for fractionation, referring to the standard $\delta^{13}C$ value of -25‰ (wood). Calibrated ages in calendar years have been obtained from the calibration curve Intcal04 (Reimer et al. 2004) by means of the 2005 version of OxCal v. 3.10 software (Bronk-Ramsey 1995; 2001).

3. Environment and Cave Structure

Nahal Asa'el (Arabic: Wadi an-Nidah) is a short ephemeral ravine draining ca. 10 km^2 of the central part of the Judean Desert into the Dead Sea. It flows along its upper course in a shallow channel, but ca. 1 km west of the Dead Sea Western Fault Escarpment it enters a deep box-shaped canyon, entrenched in Late Cretaceous carbonate rocks of the Judea Group. A major dry waterfall divides the upper part from the lower, 300–400 m deep canyon, which ends in the Dead Sea Fault Escarpment. Further east, Nahal Asa'el flows in the Quaternary fill of the Dead Sea depression. The latter has developed as a pull-apart basin within the Dead Sea transform since the late Miocene (Garfunkel 1997). The major dry waterfall appears to be a nickpoint associated with the Plio-Pleistocene downcutting of the lower canyon, responding to the deepening Dead Sea depression. The waterfall retreats in a rate reflecting the rare flash-flood events (occurring no more than few times a year) which perform the major geomorphic work. Annual precipitation in the Nahal Asa'el catchment is ca. 70 mm.

NAC is located ca. 300 m east of the major waterfall (grid reference 233200/590110, New Israel Grid), approximately 100 m below the top of the northern bank of the canyon, within the Turonian limestone of Shivta Formation (Raz 1986; Fig. 2). The approach to the cave involves a walk on steep slopes of Nezer Formation, leading to the top of the vertical cliff ca. 30 m above the cave's opening. From this point, the only way to get to the cave is by abseiling down the cliff face, which drops ca. 50 m further down below the cave towards the canyon bed.

Figure 2. View of NAC in the northern bank of Nahal Asa'el, as seen from the opposite bank.

NAC, as most other Judean Desert caves (Frumkin 2001; Lisker et al. 2010), developed as an isolated chamber karst cave below watertable during the mid to late Cenozoic (Frumkin and Fischhendler 2005). It was drained empty when base level and associated watertable dropped during the development of the Dead Sea morphostructural depression. Sometime during the Pliocene-Early Pleistocene, the cave was truncated by the entrenching canyon. The most dominant process which shaped the present structure of the cave is roof collapse, possibly of tectonic origins.

The cave is comprised of outer and inner sections (Fig. 3). The outer space is a 9 m long, 12 m wide and 7 m high chamber, and its floor is entirely strewn with collapsed boulders. Shallow pockets of sediments are found between the boulders, containing concentrations of small branches, probably bird-nesting materials. From the northeastern part of the chamber one can descend ca. 2 m, through two narrow shafts-like opening between collapsed blocks, to the inner, lower part of the cave, which consists of a few intersecting narrow and low passages, forming a maze-like structure. This area of the cave is completely dark and requires crawling. Only little sedimentation is found in the passages, mostly the result of local erosion together with minor biogenic contribution (mainly bat guano). Box-work is abundant on the ceiling of the passages, due to selective weathering of bedrock between paleokarstic veins of calcite. The innermost passage is slightly higher compare with the rest of the system (over 2 m), and has a trapezoidal cross-section with elevated "shoulders"; it contains almost no sediment. The total length of the inner section reaches 30 m.

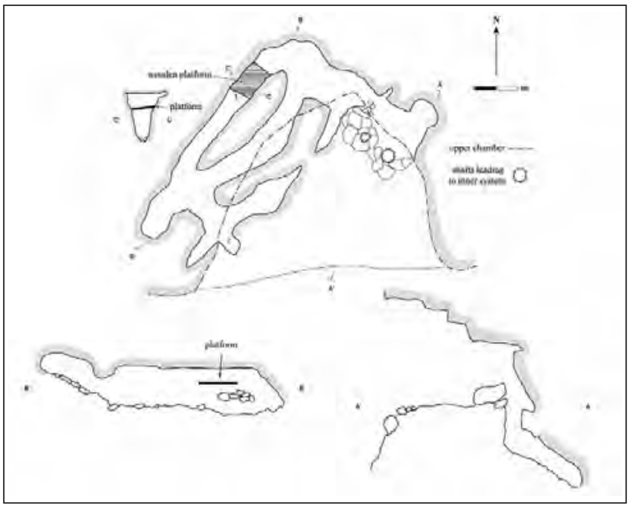

Figure 3. Plan and sections of NAC.

4. Past Explorations

NAC was first discovered in 1960 by a survey team of "Camp C" headed by P. Bar-Adon, one of four camps that formed part of the "Judean Desert Operation", a large-scale expedition to the caves located between Ein-Gedi and Masada, on the Israeli side of the Judean Desert (Bar-Adon 1961). One young volunteer (and a future professor of archaeology), Yoram Tsafrir, managed, with great difficulty, to abseil down to the cave, where he found peculiar concentration of wooden logs that were clearly brought by humans. While the evidence for anthropogenic activity inside a very hard-to-access cave was intriguing, the expedition later focused on other caves in the region, mainly the Cave of the Treasure (Bar-Adon 1980).

It took another 14 years before Bar-Adon decided to go back to NAC. In August 1974, in the heat of the summer, he arranged an expedition devoted exclusively to the exploration of this cave. Administration and manpower were provided by the Israel Defence Force, under an order entitled "Bar-Adon Operation". According to the unpublished field documentation, the actual excavation in the cave totaled five days. The work included survey, mapping, and minor excavations in the inner passages and around the shafts connecting the inner and outer parts of the cave. It turned out that the few anthropogenic elements found in the cave were all observed already during the preliminary survey, while the excavations yielded nothing but a small unindicative flint flake. The survey finds included the wooden platform (to be described in detail below), few more logs scattered in the southernmost part of the inner passages (probably the ones seen by Tsafrir in 1960), as well as few pieces of ropes and a small ceramic bowl collected from the innermost passage, southwest of the platform. The bowl, which was dated by Bar-Adon based on typological grounds to the Chalcolithic period, was in fact the only typo-chronological element found inside the cave. Both the bowl and the ropes were lost after the excavations, and their re-assessment is therefore impossible. Thus, the dating of the anthropogenic activity in the cave in general, and of the wooden platform in particular, remained somewhat obscured following Bar-Adon's expedition.

5. The Wooden Installation

As already mentioned, the main find from NAC is the wooden installation, constructed in the northeastern portion of the innermost passage. This is a kind of platform (which may also by termed shelf or board) made of unworked wooden logs, which was built ca. 1.4 m above the passage floor, and ca. 0.7 m below its ceiling, leaning on the elevated shoulders of the passage (Fig. 4). Two logs (0.9 and 1.2 m long) were placed across the passage, while the other logs (1.3–1.6 m long) were laid perpendicularly on top of the former, spaced 10–20 cm apart, in a disorderly fashion. The logs are 5–15 cm thick, and their weight is estimated in 2–5 kg each. Few twigs were placed on top of the construction, but it is unclear whether it was entirely covered with twigs in origin. All the wood was preserved in a dry state, as most organic materials found in the Judean Desert caves.

Figure 4. The wooden platform of NAC, looking NE. The location of radiocarbon samples MA1 and MA4 is indicated.

The dendroarchaeological inspections have shown that the wooden platform was made of local trees, growing in the Dead Sea basin and the eastern part of the Judean Desert. Four different logs were sampled, three from the main construction and the fourth from the twigs resting on top. The state of preservation of the xylem was excellent in the three logs, while the xylem of the small twig was found deformed. Two samples were identified as made of *Acacia raddiana Savi* (Acacia), while a third specimen (the twigs) was attributed to the same genus, but could not be identified to the species level. The fourth log was made of *Ziziphus spina-christi (L.) desf.* (Christ thorn; Jujube). Both tree species can still be found today in distances of up to 1 km from the cave.

Two of the Acacia specimens, a thick log (MA1) and the small twigs (MA4), were dated by radiocarbon. The stable isotope ratio $\delta^{13}C$ and the radiocarbon results are reported in Table 1. Both samples gave $\delta^{13}C$ values close to -25‰, in accordance with their identification as deriving from a C3 plant. The calibrated ^{14}C ages show that one sample (MA1) most probably dates to the 45th–44th centuries BC, while the second sample is dated to the 40th–39th centuries BC. Both ages fall within the accepted range for the Late Chalcolithic period, though the second age may be considered rather late in the period, on the verge of the transition to the Early Bronze Age I (Gilead 1994; Bar and Winter 2010; Davidovich forthcoming).

Table 1. Stable isotope ratio $\delta^{13}C$ *and radiocarbon results for two samples from NAC wooden platform.*

Sample #	Lab #	$\delta^{13}C$ ‰ (PDB)	^{14}C age $\pm 1\sigma$ (years BP)	Calibrated age $\pm 1\sigma$ 68.2% prob. (years BC)	Calibrated age $\pm 2\sigma$ 95.4% prob. (years BC)
MA1	RTT 5894	-25.2	5590 ± 65	4490–4350	4560–4320
MA4	RTT 5895	-23.45	5110 ± 60	3970–3800	4050–3760

6. Discussion

The wooden platform of NAC constitutes a unique item from the Late Chalcolithic period in the Southern Levant, and the earliest well-preserved wooden construction known from the entire region. The dry conditions prevailing in the Judean Desert, as well as the hardly-accessible location of the cave, contributed to the preservation of this rare element. While other caves in the region yielded occasional wooden logs, including modified ones (e.g., the Cave of the Treasure: Bar-Adon 1980; Wadi Muraba'at Cave #2: de-Vaux 1961), only in one case was a relatively large wooden log radiometrically dated to the Late Chalcolithic (in Zruia Cave; Davidovich forthcoming). The only other wooden platform known from the Judean Desert, found in Nahal Mishmar Cave #5, ca. 300 m west of the Cave of the Treasure (Bar-Adon 1980), had never been dated, and there are circumstantial arguments in favor of a much later date for this element.

The incentive for the construction of the platform in NAC and its exact use remain somewhat vague. While carrying the logs into the cave and inserting them into its innermost section were very demanding tasks, the actual construction appears to be rather carelessly built. No effort was invested in modifying the logs or in constructing a solid installation (as the logs were not tied together). The platform probably served to carry something on top which would have been better off the ground, but there are no indications as to what this might have been. Options include daily artifacts such as beddings and utensils, food supplies, or even prestigious objects, though the flimsy construction may not accord with the latter option.

The radiocarbon dates place the wooden platform within the time-frame of the Late Chalcolithic period, and are paralleled by few dozens of dates from other Judean Desert caves (Davidovich 2008: 131–135). Although the two dates obtained from the platform are a few centuries apart, it is more likely that both belong to a single constructional phase rather than to two chronologically-separated phases. It seems that the later of the two dates, in the very early fourth millennium, would be the better estimation for the time of construction of the platform (and of the occupation of the cave in general), as it derives from small twigs. The existence of an earlier date might be the result of an "old wood effect" related to the relatively thick log from which this date derives. Another possibility is that the occupants of the cave used old dry trunks for the construction of the platform. It should be noted that the radiocarbon dates accord well with the Chalcolithic date ascribed by Bar-Adon to the ceramic bowl based on typological grounds (above).

The radiometric dating of the platform showed beyond doubt that NAC is indeed part of the phenomenon of Late Chalcolithic presence in hardly-accessible caves in the Judean Desert cliffs. Actually, it is one of the caves with the most difficult and dangerous approach in the region, involving both walking over steep terrain and the use of long ropes to reach the cave's mouth. Even more astounding is the fact that such an effort was invested in a cave with very little space for occupation. In fact, the only potentially convenient part of the cave is the outer chamber, but the latter's floor is piled up with boulders, and no attempts to evacuate them and to create a more suitable space were noted. The inner passages are even less suited for a long stay, as they are dark, dusty, unventilated and tedious to move through.

It seems that the Late Chalcolithic occupation of NAC was rather ephemeral, as attested by the meager material remains found in the cave, even though it was meticulously surveyed and excavated. The erection of the wooden platform possibly indicates that some preparations for an extended stay were made, but the poor execution and the scarcity of related artifacts suggest that eventually the occupation was brief. This should come as no surprise, since the topographic setting and the cave's structure are not favorable for prolonged habitation.

Considering the question posed in the beginning of the article, regarding the nature of the Late Chalcolithic presence in the Judean Desert caves, it appears that NAC fits well within the temporary refuge model. The highly difficult approach to the cave, its inhospitable structure, the lack of man-made modifications intended to create more convenient spaces, and the scarcity of material remains, all seem to support the notion that the cave served as an ephemeral hideout for a small group of people, occupying the cave for a short duration. Other interpretations raised in the past regarding the discussed phenomenon do not seem valid in the case of NAC; it is highly unlikely that the cave served as a temporary shelter for shepherds or other passers-by, and there are no indications for mortuary or ritual practices conducted in the cave. Yet, it should be stressed that the high degree of difficulty in accessing the cave coupled with the almost complete absence of artifacts makes NAC a somewhat unusual manifestation of the refuge phenomenon. In addition, the exact function of the wooden platform within the refuge model is unclear (could it be that it once carried important objects for the people taking refuge in the cave, which were removed when they decided to leave the cave for good?). It may be hypothesized that the cave had a specific function within the system of refuge caves in the Judean Desert, a function which remains, for the time being, a mystery.

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SEDIMENTS AND FAUNAL REMAINS OF THE KURTUN-1 CAVE AT BAIKAL LAKE

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Rich Upper Pleistocene fauna was studied in the Kurtun-1 Cave. The cave is located in Rhiphean limestone in the South West vicinity of Baikal Lake. Entire collection of faunal remains comprises of 23 species of large mammals, 20 species of micromammals, 29 species of birds, 13 species of terrestrial and aquatic molluscs, and 1 species of fish. Kurtun-1 is the only site at Baikal where terrestrial fauna of Kargin Interglacial (MIS 3) is known.

1. Introduction

The cave Kurtun-1 (Fig. 1) is located in Rhiphean limestone on the Primorski Mountain Ridge, South West of the vicinity of Baikal Lake (Fig. 2), on the left bank of the Kurtun River at the height of 133 m above thalweg of the river valley. The site was studied by researchers from the East Siberian Scientific Research Institute of Geology, Geophysics and Mineral Resources (Irkutsk), Archaeological Laboratory of the Irkutsk State University and Geological Institute of the Siberian Branch of the Russian Academy of Sciences.

Figure 1. Entrance of Kurtun-1 Cave.

2. Methods

Cave sediments were tested in five pits and a trench (Fig. 3). Test intervals ranged from 5 to 20 cm depending on saturation of sediments by limestone rubble and the size of clasts. Sediments were sieved in dry condition through 5 mm round aperture screen and bones were picked up from this coarse fraction. Then size fraction -5 mm was washed and wet screened using 1 mm mesh sieves. Size fraction +1 mm was being dried up and faunal remains were extracted.

3. Cave sediments

Cave deposits from the entrance grotto were studied in the test pit #2 (Fig. 4), from the top to bottom:

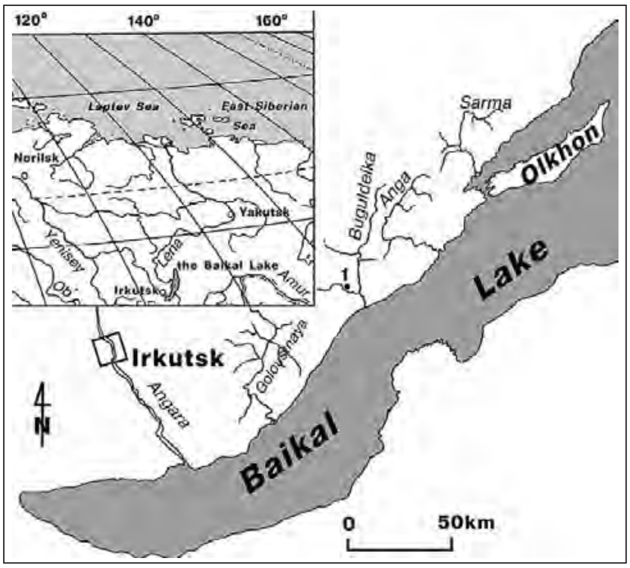

Figure 2. Location of Kurtun-1 Cave.

Thickness, m

Unit 1. Limestone rubble of granule to pebble size, with common slabs of boulder size, abundant plant detritus, excrement from pikas and rodents, and molluscs shells. 0.1–0.15

Unit 2. Unconsolidated breccia consisting of clasts from pebble to cobble size, some irregular lenses of clasts from granule to pebble size, with soft light brown silty clayey moderately calcareous cement, occasional wood debris and pieces of tree branches. Rock fragments are represented by limestone and firm orange brown claystone with manganese films on clast faces. Breccia fills a vertical hole up to 1.8 m deep along the west wall. Contact with unit 3 is gradual. 1.0

Unit 3. Multicolored clayey breccia consisting of angular firm claystone clasts up to 80–90 %. Cement is soft orange brown sandy silty clay with yellow mottles and convoluted lenses. Occasional highly weathered siliceous schist fragments. Sharp subhorizontal contact with unit 4. 0.9

Unit 4. Greenish brown silty clay with fine mica and indistinct inclined parallel lamination. 0.3

Unit 5. Clay breccia with granule sized clasts. 0.1

Unit 6. Greyish yellow and lemon-yellow clayey silt with indistinct lenticular structure. >0.2

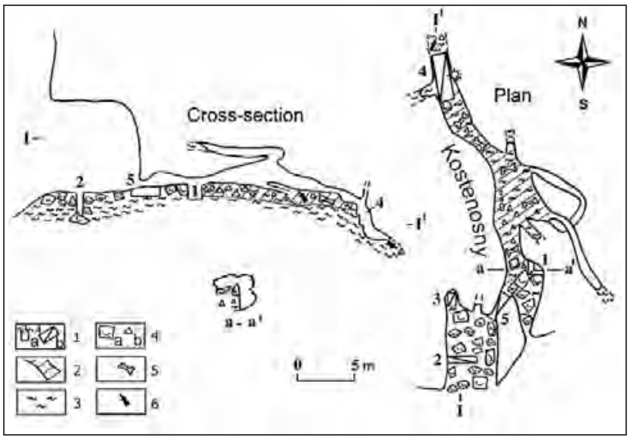

Figure 3. Map of Kurtun-1 Cave. 1 – test pit: a – on cross-section, b – on plan; 2 – trench; 3 – loam; 4 – rock fragments: a – of cobble to boulder size, b – of pebble size; 5 – large mammal bones; 6 – fragments of stalactites and flowstone cores.

Observed thickness: 2.3

Grain-size analysis of the 2-d unit showed, that sediments consist of silt (11.7 %), sand (20.1 %) and clay (46.7 %). Fine and medium sand grains prevail in sand fraction (11.7 % and 5.6 % respectively).

Light minerals consist of quartz (82.0 %) and potassium feldspar (11.4 %) with minor quantities of muscovite (3.6 %), biotite (0.3 %) and plagioclase (2.7 %).

Main components of heavy minerals are epidote (26.8 %) and hornblende (22.8 %), minor pyrite (8.4 %), unidentified Ti minerals (11.8 %), goethite (7.3 %), ilmenite and magnetite (7.1 %), leucoxene (2.6 %), zircon (2.6 %) and garnet (2.0 %).

Illite and chlorite compose the clay fraction of unit 2.

Cement and filling of the clay breccia of the unit 3 consist of silt (18.4 %) and clay (63.5 %) with insignificant admixture of fine and medium sand. Bulk content of carbonates, both in the form of sandy and silty grains, and also in a form of cement, comprises 15.5 %.

Light minerals of sediments of the unit 3 consist of quartz (86.2 %), muscovite (9.8 %) and insignificant admixture of plagioclase (2.3 %) and biotite (0.6 %).

Heavy minerals consist of epidote (31.6 %), ilmenite (22 %), hornblende (14.1 %), unidentified Ti minerals (8.8 %) and goethite (6.8 %), with very minor zircon (3.8 %), tourmaline (2.7 %), sphene (2.4 %), rutile (1.5 %), leucoxene (1.7 %), pyrite (1.5 %) and garnets (1.2 %).

Grain-size analysis of sediments of the unit 4 showed dominancy of the clay fraction (81.7 %) and presence of silt particles (11.2 %). Fine and medium sand content was insignificant (0.9 % and 0.1 % respectively).

Light minerals of the unit 4 consist of quartz (66.6 %) and muscovite (33.3 %) with admixture of potassium feldspar (0.3 %).

Heavy minerals consist of unidentified Ti minerals (33.1 %), limonite (18.9 %), pyrite (12.1 %), ilmenite (10.3 %) with minor amount of hornblende (9.8 %), zircon (6.3 %) and tourmaline (7.0 %).

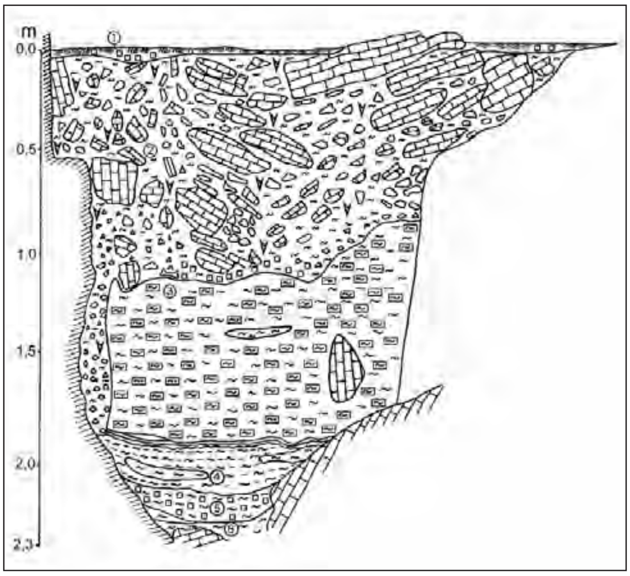

Figure 4. Cross-section of cave deposits from the entrance grotto: northern wall of the pit #2. See legend at Fig. 5.

According to grain-size analysis, unit 6 consists of silty (36.9 %) clays (48.7 %) with admixture of fine (2.3 %) and medium (0.3 %) sand.

Quartz prevails among the light minerals (84.5 %), while muscovite plays a secondary role (12.1 %). Quantities of potassium feldspar and plagioclase are insignificant (2.8 % and 0.6 % respectively).

Heavy minerals predominately consist of unidentified Ti minerals (44.6 %), minor quantities of zircon (11 %), tourmaline (11.8 %), pyrite (8.6 %), leucoxene (8.1 %) and epidote (4.8 %) with admixture of ilmenite (3.2 %), goethite (1.6 %), garnets, sphene, hornblende, anatase, disthen, and tremolite (0.5–0.7 % each).

Cave sediments in the Kostenosny Passage were studied in the test pit #1 (Fig. 5), from top to bottom:

Thickness, m

Unit 1. Sandy loam, brownish grey, containing limestone clasts up to 0.4 × 1.2 m, stalactite and flowstone fragments up to 0.7 × 0.5 × 0.4 m, abundant mammal bones, fish scales and plant detritus. The layer was highly disturbed by pika burrows and saturated with their excrements. 0.5–0.9

Unit 2. Silty clay, brown, with abundant fine limestone and grey siliceous slate fragments, bones of large mammals and micromammals. Quantity of rock fragments vary in wide limits. 0.4–0.6

Unit 3. Sandy silty clay, brownish-grey. 0.1–0.2

Unit 4. Silty clay, reddish-brown, highly calcareous, containing abundant fragments of firm claystone. 0.15

Observed thickness: 1.7

The #1 pit exposed limestone at bottom only near the wall. Central parts of the passage have much thicker sediments; full thickness of cave deposits was intersected nowhere.

The upper rubble layer of unit 1 in the Kostenosny Passage was formed from the Kargin Interglacial (MIS 3) to Holocene. This conclusion is supported by ^{14}C data 33,500±1,000 (GIN-5823) of brown bear bone extracted from the depth 0.4–0.6 m. The unit 1 is not stratified and contained the remains of fossil Pleistocene and subfossil Holocene fauna.

Brown silty clays of the underlying unit 2 in the Kostenosny Passage were accumulated during Kargin Interglacial (MIS 3) on the basis of ^{14}C data >40 K (SOAN-2902) obtained from charcoal. Also the shell of a relatively thermophilic terrestrial mollusc *Gastrocopta theeli* (West.) (Popova et al. 2002) was found there.

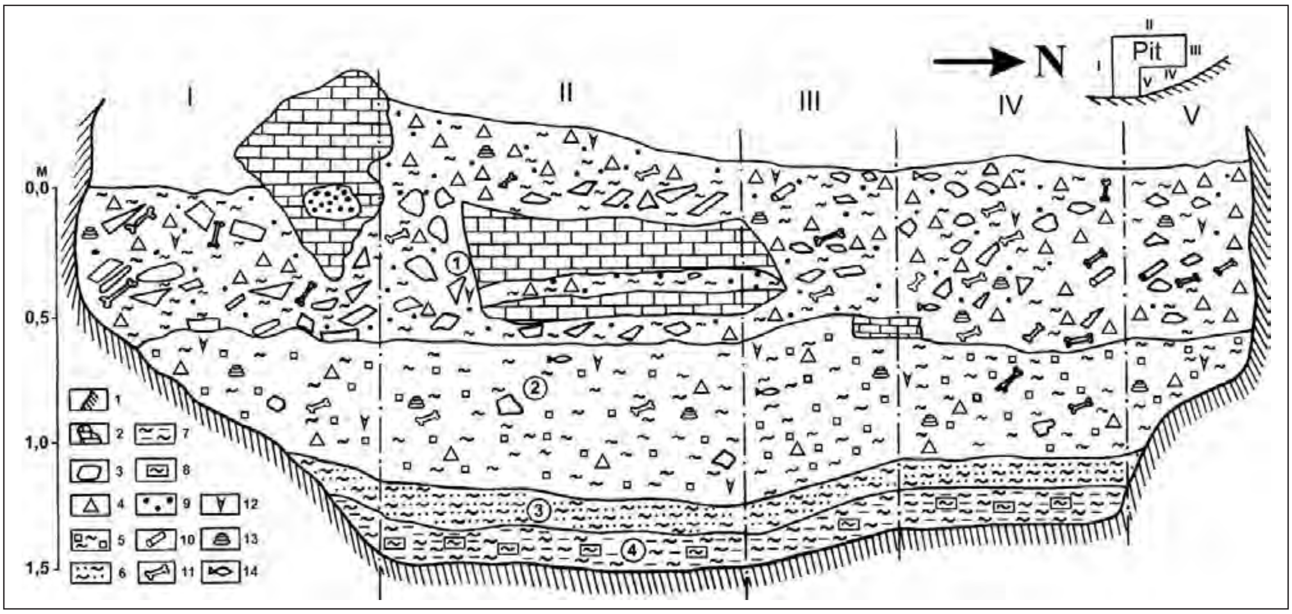

Figure 5. Cross-section of cave sediments in the pit #1, Kostenosny Passage. 1 – host rocks; 2–4 – limestone fragments: 2 – of boulder and bigger size, 3 – of cobble size, 4 – of pebble size; 5 – clastic silty clay; 6 – sandy silty clay; 7 – silty clay; 8 – claystone clasts; 9 – pika's excrements; 10 – wooden debris; 11 – large mammal bones; 12 – micromammalia bones; 13 – mollusc shells; 14 – fish remains.

No paleontological remains were found in the underlying units 3 and 4.

4. Faunal remains

Bone saturation of sediments varies significantly in different parts of the cave. Bone remains are rare in the entrance grotto, whereas they were abundant in the Kostenosny Passage. The latter can probably be explained by the likelihood of usage of distant parts of the passage as dens by carnivores. Relics of recent bear's lair and fox's den were clearly visible before excavations began. Extensive physical weathering of walls and ceiling triggered collapse of blocks, slabs and smaller rubble, and also contributed to impoverishment of the paleontological remains in the entrance grotto.

Overall, 602 identified bones of 23 species of large mammals and small carnivores were extracted from the cave sediments; one taxon was identified to genus. Total number of micromammalian bones is not available because plentiful bone remains obtained from unit 1 in the Kostenosny Passage were not counted. Micromammalian remains belong to 20 species and 12 taxa identified to genus. Collections of avifauna remains consist of 194 bones of 29 species; 4 taxa identified to genus. Along with the above, numerous Arctic grayling remains, isolated snake spondyls, and shells of 13 species of terrestrial and aquatic molluscs were found.

Amongst the bones of large mammals, 11 % of which belong to the extinct species of the Upper Palaeolithic faunal complex, namely woolly rhinoceros, Baikalian yak, cave hyena and cave lion. At the present time, the Siberian goat, red wolf and arctic lemming locally extinct on the Primorski Ridge (Nekipelov et al. 1965), while their bones are part of the cave taphocoenosis.

The most abundant remains among the large mammal bones belong to roe deer (19.0 %), red deer (10.0 %), musk deer (9.5 %) and brown bear (9.0 %). The bones of the extinct woolly rhinoceros, cave hyena and bison make up 4 %, 3.5 % and 2 % respectively.

Faunal remains extracted from the layers, which had been formed during Kargin Interglacial (MIS 3), have especial significance amidst obtained collection because terrestrial fauna of this time interval was not yet studied at Lake Baikal. Total number of large mammal bones comprises of 301 specimens. Remains of roe deer, red deer and sable prevail (18 %, 12 % and 10 % respectively), and the bones of other mammals are less common: wooly rhinoceros, cave hyena and badger (all by 6 %), fox (5 %), brown bear and reindeer (by 4 %), wolf and bison (by 3 %).

The collection of micromammalian bones extracted from the Kargin sediments consists of 3,510 specimens. The largest part of it belongs to the remains identified only to Arvicolidae family, which comprises 42.7 % of whole collection. Remains of other rodents and lagomorphs are far less abundant: *Ochotona hyperborea* (18.8 %), *Lepus timidus* (2.8 %). *Clethrionomys rufocanus* (12.5 %), *C. rutilus* (5.1 %), *C.* sp. (2.3 %), *Microtus gregalis* (4.0 %), *M.* sp. (3.4 %), *Alticola cf. argentatus* (3.4 %).

Abundance of pika remains in taphocoenosis of the cave is attributed to the wide spread nature on rocky screes and cliffs in the surrounding area.

The list of the Kargin fauna is populated with fish (1 species), snakes, birds (20 species and 4 taxa identified to genus), terrestrial (7 species) and aquatic (1 species and 2 taxa identified to genus) molluscs.

A list of fauna of the Kargin Interglacial from the cave Kurtun-1: Mammalia: Insectivora: *Sorex sp*.; Chiroptera: *Murina hilgendorfi* Peters; Lagomorpha: *Lepus timidus* L., *Lepus* sp., *Ochotona hyperborea* Pall.; Rodentia: *Pteromys volans* L., *Sciurus (Sciurus) vulgaris* L., *Tamias (Eutamias) sibiricus* Laxm., *Spermophilus (Urocitellus) undulatus* Pall., *Spermophilus (Urocitellus)* sp., *Marmota* sp., *Apodemus* sp., *Micromys* cf. *minutus* Pall., *Cricetulus* sp., *Alticola* cf. *argentatus* Severtzov, *Clethrionomys rufocanus* Sundev., *C. rutilus* Pall., *Clethrionomys* sp., *Lagurus* cf. *lagurus* Pall., *Myopus* sp., *Arvicola* cf. *terrestris* L., *Microtus (Stenocranius) gregalis* Pall., *M.* aff. *fortis* Büchn., *M. (Microtus) oeconomus* Pall., *M.* cf. *arvalis* Pall., *Microtus* sp.; Carnivora: *Canis lupus* L., *Vulpes vulpes* L., *Cuon alpinus* Pall., *Ursus (Ursus) arctos* L., *Martes (Martes) zibellina* L., *Mustela (Kolonocus) sibirica* Pall., *M. (Putorius) eversmanni* Lesson, *Meles meles* L., *Crocuta (Crocuta) spelaea* Gold., *Panthera (Leo) spelaea* Gold., *Felis (Lynx) lynx* L.; Proboscidea: *Mammuthus primigenius* Blum.; Perissodactyla: *Equus* sp., *Coelodonta antiquitatis* Blum.; Artiodactyla: *Sus scrofa* L., *Moschus moschiferus* L., *Cervus (Cervus) elaphus* L., *Capreolus capreolus* L., *Rangifer tarandus* L., *Bison (Bison) priscus* Boj., *Capra (Ibex) sibirica* Pall., *Ovis (Ovis) ammon* L. Pisces: Salmaniformes: *Thymallus arcticus* Pall., *Thymallus* sp., Reptilia: Squamata: Serpentes. Aves: Anseriformes: *Anas clypeata* L., *A. platyrhynchos* L., *A. acuta* L., *A. guerguedula* L., *Bucephala clangula* (L.), *Mergus serrator* L.; Falconiformes: *Accipiter gentilis* (L.), *Falco peregrines* Tunstall, *F. tinunculus* L.; Galliformes: *Bonasa bonasia* L., *Tetrao tetrix* (L.), *T. urogallus* L., *Lagopus* sp., *Perdix dauricae* Pall.; Strigiformes: *Strix* sp., *Otus scops* (L.), *Surnia ulula* (L.); Apodiformes: *Apus pacificus* (Latham); Piciformes: *Picus* sp.; Passeriformes: *Turdus* sp., *Monticola saxatilis* (L.), *Pyrrhula pyrrhula* (L.), *Coccothraustes coccothraustes* (L.), *Nucifraga caryocatactes* (L.), *Pyrrhocorax pyrrhocorax* L. Mollusca: Gastropoda: *Succinea* ex gr. *oblonga* (Drap.), *S. putris* L., *Bradybaena schrencki* (Midd.), *Vallonia tenuilabris* (Al. Brawn), *V.* ex gr. *pulchella* (O.F.Müller), *Gastrocopta theeli* (West.), *Pupilla muscorum* (L.), *Lymnaea* sp., *Anisus (Gyraulus) acronicus* (Fér.), Bivalvia: *Euglesa* sp.

5. Archaeological findings

Isolated bone artefacts were found in the upper layer 0.6–0.8 m in the Kostenosny Passage (Goryunova et al. 1996). They are represented by the harpoon, needle case and the fishhook of unknown age. Most likely the cave was used occasionally as a temporary dwelling by human beings.

A fire-pit was discovered in the layer of brown loam with limestone rubble at the depth of 0.9–1.0 m. ^{14}C data >40K (SOAN-2902) was obtained from the charcoal. The charcoal location was in the entrance part of the manhole into the Kostenosny Passage. The passage was used by brown bears, foxes, cave hyenas and cave lions as a den and a lair. This suggests that the fire was started with the purpose of hunting for carnivores.

6. Conclusions

The Upper Pleistocene site Kurtun-1 is characterized by vast diversity of discovered species of mammals and birds, and novelty of number of finds:

1) the richest site of the Kargin mammal and avian fauna by the number of species in Eastern Siberia;
2) the only site of Upper Pleistocene avifauna at Baikal lake;
3) first locality at Baikal where bones of the cave hyena, the steppe polecat and the red wolf were found;
4) second locality at Baikal containing remains of *Panthera (Leo) spelaea* Gold. (the first find was made in the vicinity of the Sagan-Zaba bay (Ovodov 2009);
5) first site at Baikal where relatively thermophilic terrestrial mollusc *Gastrocopta theeli* (West.) was found in the Upper Pleistocene sediments;
6) the presence of fire-pit and charcoal older than 40 thousand years in cave sediments, advantageous location of the entrance grotto for temporary shelter, overnight stop and hunting for carnivores allows to consider the cave Kurtun-1 as the most promising place for the search of Palaeolithic human remains at Baikal at the present day.

The cave carries a great potential for additional characteristics of the fauna of Kargin Interglacial.

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BAROVÁ (SOBOLOVA) CAVE, MORAVIAN KARST (CZECH REPUBLIC) UPPER PLEISTOCENE FOSILIFEROUS IN-CAVE SEDIMENTS INSTRUCTIVE PALEONTOLOGICAL EXCAVATIONS

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Since the discovery of Barová Cave in 1947, three periods of excavations in the inner part of the cave had been done until present, in context with both caving activities connecting distand parts of the cave and archeological/paleontological research projects proceeded within the cave entrance. Fossil bone remains of typical Upper Pleistocene fauna (Weischelian glaciation) were excavated, exspecially bone remains of the cave bear (*Ursus* ex gr. *spelaeus*). These activities followed by intensive speleological work led to the filling up all the entrance parts with huge slag deposits. Then the locality became unclear and taken as paleontologically completely excavated. As the consequence of the underlying sediments slide succesion in the northwest part of the "Shaft II", new layers of bone rich sediments were opened in the basis of the old excavation sites and their surroundings. Subsequently, new restoration of old excavation sites was done, the terrain had been cleaned, newly topographically measured and used as the entrance to more distand parts of the cave. New instructive profiles have been opened in front of the fossiliferous debris tongue. Fossil bone remains excavated during these works belong to these taxa: *Ursus* ex gr. *spelaeus*, *Panthera spelaea*, *Crocuta spelaea*, *Canis lupus*, *Vulpes* sp., *Rangifer tarandus*, *Cervus* sp., *Capra ibex*, *Lepus* sp., *Aves* gen. sp. Most of the samples still wait for identification, which will proceed next season. No remains of Pleistocene small mammal fauna were found yet, the washing result is still negative (rodent bones found in there are recent), as well as the palynologic analysis. One of the valuable founds is almost complete skull of the subadult cave lion (*Panthera spelaea*) female with part of her postcranial skeleton. Researches, excavations and recovery works still run in the cave, the goal is to create educative site of the Pleistocene paleonthology for the next student or speleologist generation didactical use.

1. Introduction

Paleontological researches inside the caves of Moravian Karst have their rich tradition. Many of the caves here became the "classic" localities of Quaternary paleontology, used since the start of 19th century and, naturally, exploated by bone collectors and for some magic purpose since almost ancient times. Some of them were hugely devastated and destroyed, when only a small part of paleontological founds is now kept in some european museums, some classic localities are now used as open-for-public sights and very recent excavations were going on mostly as salvage activities, when turistical use had priority. The finds of these localities were scientifically processed and now are kept in public collections in museums and other institutions. Keeping at least a part of the original sediments, bone layers of Pleistocene fauna, stone beds, artefacts or local finding situation is presented in case of very important archeological or paleoantropological sites in entrance part of caves like Kůlna Cave. In-cave sediments left in shape of the instructive cross-section, profile, or intact layer sequence, these are much rarer. Mostly they had been built in caves not allowed for public visitors, ones of the most important are those in Holštejnská – Nezaměstnaných Cave and Malý lesík Cave. Here in the caves of active speleological work the goal is to discover a new part of the cave or connect it with another underground place. Profiles and cross-sections are one of more consequences only. Most of the Pleistocene "bear caves" with bone rich sediments of the Upper Pleistocene has been already exploated, processed and used for another purpose, they are already empty. Intending to visit some in-cave fossiliferous Upper Pleistocene sediments (once so typical for many Moravian Karst caves), at least partially preserved, one must look after elsewhere. It's worth to look at the cave where works began later, i.e. the cave was discovered later, and the terrain, cave shape, inaccesibility, or inatractivity (of course, the in-cave facie does not offer such rich variety of results and discoveries, there are no rich stratigraphically important fossils, above all small mammals and molluscs) caused saving the cave off the very interest. However, even there are some complications here.

Figure 1. Second Shaft in Barová Cave, shape in 2007, V. Káňa.

Barová (Sobolova) Cave, situated in the central part od Moravian Karst on the right side of Josefovské údolí Valley, had been discovered in 1947 by Dr. A. Sobol and hid companions, digging through the debris at the entrance under the wall of "Krkavčí skála" limestone rock cliff. Now the entrance lays in 346 m above sea level. The cave is complicated polygenetic system of vertical and horizontal corridors and shafts. The active Jedovnický potok Creek

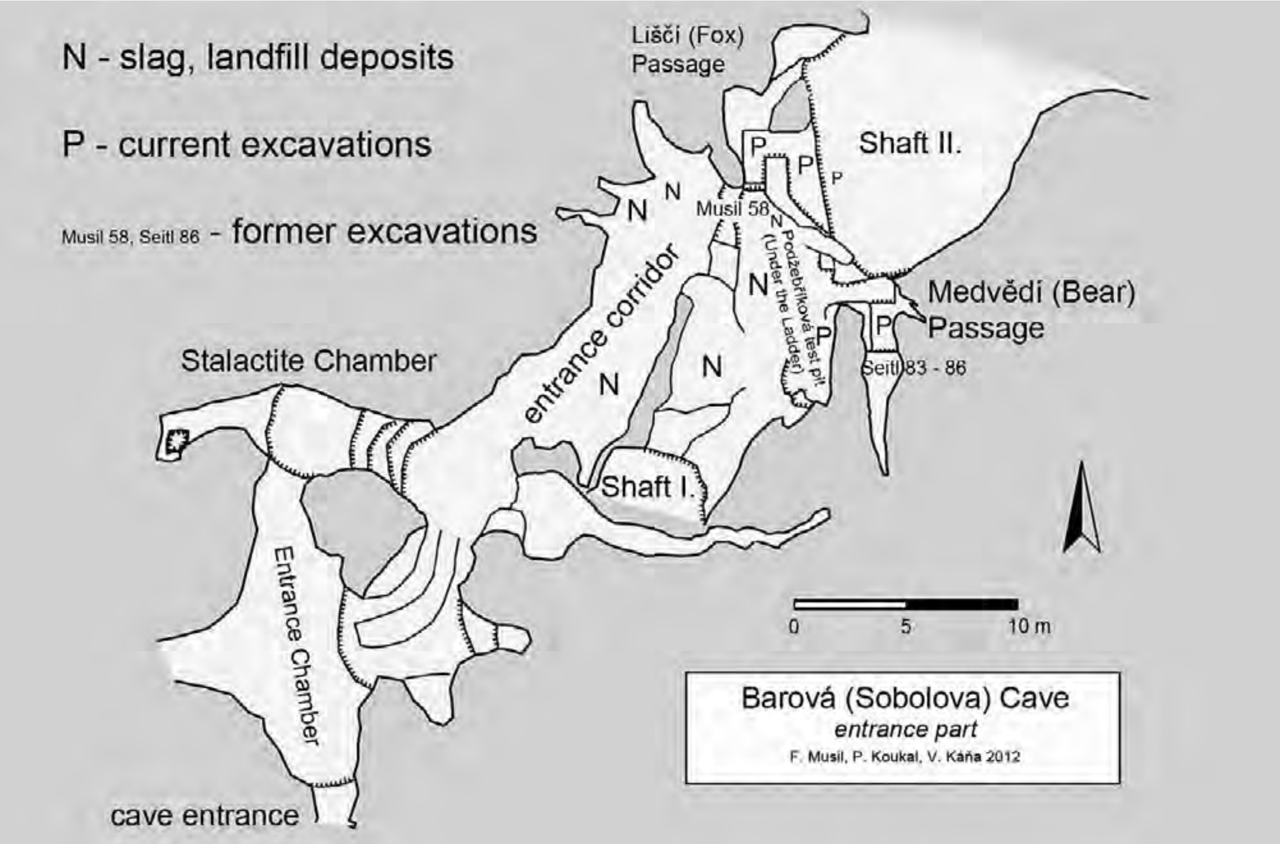

Figure 2. Entrance part of Barová Cave, measured by F. Musil and P. Koukal 2012.

flows through the underneath level. It is the part of Býčí skála – Rudické propadání cave system, the second longest in the Czech Republic. Total denivelation of the Barová Cave reaches 60 meters, the length is app. 900 m. There are three levels of the cave, each has the different shape and formation. The upper level is mostly vertical, chimneys are or filled with sediment (Jurassic and cretaceous origin) or already emptied. The entrance corridor is such an emptied chimney, filled at the base with fossiliferous Pleistocene sediments. The middle level in shape of six shaftlike domes is created by sedimental fallings and slides filling otherwise unbroken underground corridor, approximately 100 m long (see Fig.1). The names of these shafts correspondent with the time of discovery in 1947 (First, Second, Third…, in following we use I., II.). The underneath level is, in fact, the system of siphons and corridors on the flow of Jedovnický potok Creek. Two of shafts protrude to the creek (I. and II.). There were lots of actions and speleological works done at the underneath level of the cave from 2006 to 2012, including water pumping and hydro-mining, digging and new discoveries.

2. Previous paleontological excavations and researches

The first paleontological excavations were done by A. Sobol and his companions in 1947–1956, some bones of Pleistocene mammals were taken from the ground in the entrance corridor, from some small excavations and connective passages dug between the entrance and the Shaft II (see Fig. 2). Some paleontological material had been found directly on the surface of the entrance corridor and small cavities near Shaft II. From the collection of A. Sobol (now in Moravian Museum Brno) is to list long bones and jaws of cave bear cubs (*Ursus* ex gr. *spelaeus*), numerous bones of the woolf *(Canis lupus)*, and the cave lion *(Panthera spelaea)*. Sadly, all space on the ground of the cave between the entrance and the Shaft II. had been covered by very thick layer of slag deposits.

In 1958, R. Musil opened the test pit at the beginning of the passage between entrance corridor and the Shaft II. He sketched basic stratigraphy of the sediments as the debris cone, excavated Upper Pleistocene large mammals bone remains and, based on these excavations, characterized the cave as the typical cave bear den (Musil 1959, 1960). From these excavation finds the brain case of the cave hyena (*Crocuta spelaea*), the part of ibex *(Capra ibex)* skull and two hemimandibulae of the cave lion *(Panthera spelaea)* are worth to be reminded here. These finds show that the cave served to cave hyenas as a den, too. There were clearly cave hyenas transporting their prey body parts to the cave as they still do with their prey and den in Africa. Sadly here again, lots of debris, slag, huge quantity of sandy and clay material had been deposited within the cave, too.

The next phase followed between 1983 and 1986, when in terms of the research project, L. Seitl managed comparatively extended excavations within the cave. Most of excavations were concentrated in the entrance parts, archeology and sedimental cone in front of the cave. Some in-cave sediments were excavated at the branch called Medvědí (Bear Branch). Three layers were distinguished, upper loess-like, middle bone sediments and underlying reddish clay, all covered by calcite sinter plate. Bone remains belonged mostly to cave bear and cave hyena, very interesting was pelvis fragment of the wooly rhinoceros *(Coelodonta antiquitatis)*, chewed by hyenas. Most sediment was taken away from the cave, washed and purely controlled, in case of the in-cave sediments with negative result.

Other speleological works (digging, excavations, washing, measuring) were then concentrated in the distand parts of the cave, fossiliferous sediments yet unexploated

Figure 3. Excavations in the probe "Pod žebříkem" in November 2012, photo by M. Maláč.

dissapeared under the slag deposits, the corridor nearby was used only to pass to the next parts of the cave, excavation sites were abandoned, only some small test pits made by cavers appeared and disappeared. Only important natural proces inside the cave was continual falling of the underlying sediments in the northwestern part of the Shaft II. The shaft had changed many times, continuous slides of the complexed sands, clay, and gravel sediment of uncertain age formed the shape of the shaft (Hypr and Koudelka 1995). The strongest slides took place from 2008 to 2011, when the space of the Shaft II increased by one third. The new cross-section through fossiliferous sediments emerged nearby both older excavation sites Musil 1958 and Seitl 1986. Then, immediately, the reconstruction of all former excavation sites started, the new passage between entrance corridor and the other parts of the cave was made and after that, new test pit through the debris cone at the centre of the fossiliferous sedimental tongue was started to dig and explore. The place has been named Podžebříková sonda (Testpit Under the Ladder, see Fig. 3). The branch of the sedimental tongue near former Musil 1958 pit, on the northwestern border of the Shaft II, has been named Liščí chodba (Fox Passage). These three test pits (Liščí – Fox, Medvědí – Bear, Podžebříková – Under the Ladder) are the places, where we process current excavations and research.

3. Material, methodology and osteological analysis

The excavated area is the front of large sedimental tongue spreading from northwest, ending on the border of the Shaft II. It's topography follows the ceiling relief almost without difference. The parts cropped by pendants have thickness to 2.5 m, the main part is a lot thinner, about 30–40 cm. Only some parts are covered by the sinter plate, most parts are buried under slag and debris or sandy deposit.

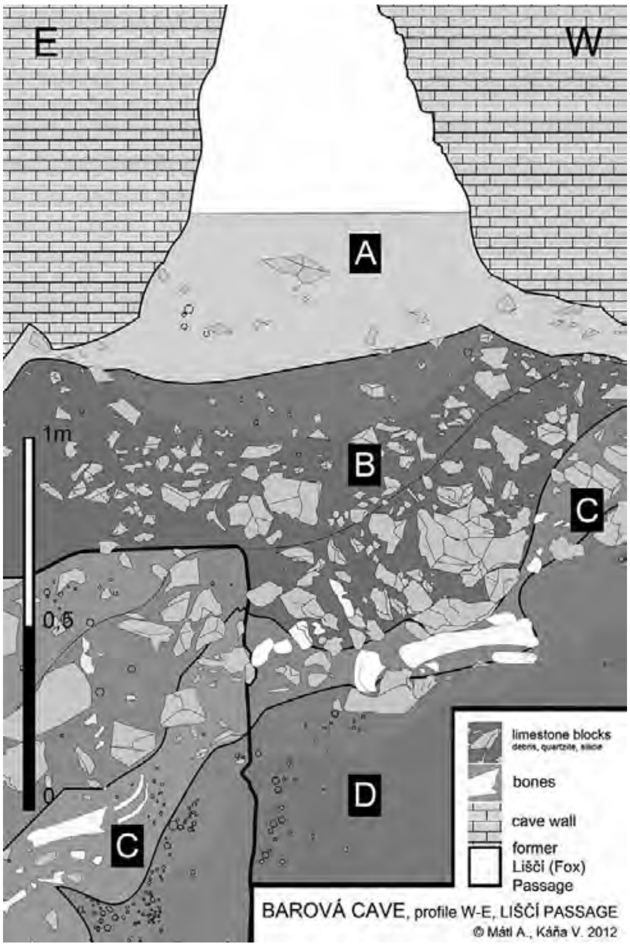

Figure 4. Liščí (Fox) Passage test pit profile, shape of December 2012, A. Mátl, V. Káňa.

The fossiliferous sediments appear in all test pits consisting of three layers. Layer A is overlaying, consisting of sands, clay and loess-like sediments and rarely contains Pleistocene bones, the remains of recent rodents *(Apodemus, Microtus)* are present. It reaches thickness up to 60 cm in terminal parts of the tongue, where originally the calcite plate covered it (Seitl 1988). Layer B is constituted by limestone blocks, debris, sinter and calcite fragments, quartzite, silicite stones, sand, clay and disarticulated Pleistocene bones in mass from 10 cm to 1.2 m. Layer C is incontinual base of the layer B, consisting of red clay, corroded limestone blocks, sinter plates and the clusters of crashed and compressed Pleistocene bones (see Fig. 4). It is from 5 cm to 80 cm thick. The sediments of the layers B and C were washed, the result was negative yet, palynological analysis was made from the sample of the layer C in Liščí (Fox) test pit, it is negative, too (Doláková in verb. 2012).

Numerous osteological materials are found in both Liščí (Fox) Passage pit and Medvědí (Bear) pit, and so in currently excavated test pit Podžebříková (Under the Ladder). Bones are not in situ, they were transported vertically and horizontaly as a part of rocky sediments of the debris cone. Consequently, bones are not in anatomical position, their affiliation with skeletons is unrecognizable. Larger bones like skulls, pelves, long bones, are often badly fragmented, although it is possible to reconstruct most of them.

Bone determination of paleontological finds is processed using comparative collection of Anthropos Institute, MM and osteological handbooks, atlasses and monographies (Hue 1907, Lavocat 1966, Pales and Lambert 1971, Schmid 1972). Ontogenetical age of the bone remains is reckoned by Habermehl (1985). Minimal number of individuals (MNI) is to reckon using methodics of Chaplin (1971), cave lion dentical measurment by Driesch (1976).

All osteological, taphonomical and paleontological analyses is just beginning, the research is still running, all results are to be taken as preliminary. Dominant species within all finds is the cave bear from the group of *Ursus spelaeus*, what corresponds to the situation published by Musil (1959, 1960) and Seitl (1988). Until now, these taxa were validated from our current excavations within all three test pits:

Ursus ex gr. *spelaeus* Rosenmüller, 1794

Panthera spelaea (Goldfuss, 1810)

Canis lupus Linnaeus, 1758

Crocuta crocuta spelaea (Goldfuss, 1823)

Capra ibex Linnaeus, 1758

Rangifer tarandus (Linnaeus, 1758)

Cervus sp. Linnaeus, 1758

Vulpes sp. Frisch, 1775

Lepus sp. Linnaeus, 1758

In comparation with frequency of remains of the cave bear, other taxa, lions, hyenas and wolves exceptional, bone remains of ibex, reindeer, deer, hare and foxes are very rare, but present.

Only a part of the osteological finds from current ecavations in Barová Cave could be analysed until today. The first analysed sample is from Liščí chodba excavations. As is visible from results, 95.3 % of determined bones come from cave bear (*Ursus* ex gr. *spelaeus*), both wolves and cave lions are 2.3 %. No other taxa were found in the sample. Following samples are to be analysed and the taxa ratio can be different.

The cave bear bones processed until now (December 2012) belong to at least 4 individuals, (MNI = 4), the bone remains of wolf and lion both belong to just one individual (MNI = 1). In case of the cave bear, all parts of skeleton are present here, presumably no alimentar transport (at least out of the cave) or only slight manipulation with carcasses took place. Basing on the teeth development and wearing, epiphysal merging and cranial suture shape it shows, that most present remains of the cave bear belong to young adult individuals, bear cubs or senile individuals are present more rarely. Both sexes are present in case of the cave bear. Bone remains of the cave lion and wolf from Liščí chodba test pit belong to adult individuals.

Figure 5. Situation in the time of the cave lion (Panthera spelaea) skull excavation in October 2012, photo by I. Harna.

Very important find comes from newly excavated test pit Podžebříková (Under the Ladder). Here almost complete skull of the cave lion *(Panthera spelaea)* subadult female has been found, including complete mandible, and a part of postcranial skeleton (see Fig. 5). Basing on the age, size, bone shape and situation, these bones appear to belong to the skull: axis, atlas, three cervical vertebrae, one thoracal vertebra, two lumbar and seven caudal, five sternal segments, ulna, two metacarpals, two tibiae, patella, calcaneus, all metatarsals of the left hindlimb, and several individual carpals, tasals and phalanges. In spite of fact, that the excavation is still at the beginning, the number of bone remains belonging to this individual can increase in the future.

Most of the cranial sutures are still open, the individual is young, about two to thre years old, until the discovery of this skull supposed as a female. Dental measurment of lower praemolares p4 and molares m1 were accomplished in comparation with data of the works of F. G. Baryshnikov (2011). In the article, there the data of the length and width p4 and m1 from many European localities are present (Baryshnikov 2011, pp. 205–206, tab. 3). The data from the individual of Barová Cave correspond with female shape (see Tab. 1 and Fig. 6, Fig. 7). The individual is a young, not fully grown female with already permanent teeth, unique in the region of Moravian Karst and this part of the central Europe by its well-preserved state.

4. Discussion

Individual fossiliferous sediment layers in Barová Cave are presumably not a consequence of more in-cave landsliding events, the base (layer C) is the result of relatively slow sedimentation gravitationally transported bones and other components to shallow waters or muddy pits on the surface of underlying sediments, where the bones were crashed and fragmented by stones overlaying consequently. Faunal structure in individual parts show slight difference (no hyenas present in Liščí test pit, at least some hyenas in others), taphonomical state is slightly different too, it suggests that different parts of sedimental tongue have different origin, e.g., places of source. The shape of sediments in the entrance corridor shows the possibility, that the animals during Upper Pleistocene time used this part of the cave, which was more complex, large sized underground dome, as a den, the transport of bone remains

Table 1. Length (L) and width (W) of cave lion (Panthera spelaea) lower molars m1 from European localities, according to Baryshnikov (2011). Molars m1 from Barová Cave (bold print) fall into the range of females.

Males			Females		
Locality	**L**	**W**	**Locality**	**L**	**W**
Kent's Cavern, England	30,0	14,7	Kent's Cavern, England	26,7	12,5
Kent's Cavern, England	29,8	15,7	Kent's Cavern, England	28,0	14,8
Kent's Cavern, England	30,8	15,3	Jaurens, France	27,9	14,2
Jaurens, France	29,9	15,1	Jaurens, France	28,0	14,1
l'Herm, France	31,3	15,3	Circeo, Italy	25,9	13,8
Widkirchli, Switzerland	31,2	16,5	Zoolithen Cave, Germany	28,1	14,4
Wierzchowska Górna, Poland	31,1	17,0	Wierzchowska Górna, Poland	27,8	13,5
Wierzchowska Górna, Poland	30,9	16,2	Wierzchowska Górna, Poland	27,1	12,8
Schusteriucke, Austria	30,3	16,0	Předmostí, Czech Republic	26,7	12,8
Lautscher, Austria	29,7	16,9	Předmostí, Czech Republic	27,9	12,6
Předmostí, Czech Republic	30,2	14,1	Švédův Stůl, Czech Republic	25,8	13,4
Kodak, Ukraine	29,9	15,5	**Barová Cave, Czech Republic**	**27,3**	**14,1**
Krasnyi Yar, Russia	32,0	16,7	**Barová Cave, Czech Republic**	**27,4**	**13,9**
Sukhoi Log, Russia	28,9	14,1	Starye Duruitory, Moldova	25,9	12,4
Kurtak, Russia	30,1	14,9	Krishtaleva, Crimea, Ukraine	25,9	12,4
			Krasnyi Yar, Russia	27,0	13,3
			Shubnoe, Russia	27,5	13,5
			Medvezhiya Cave, Russia	26,2	13,6

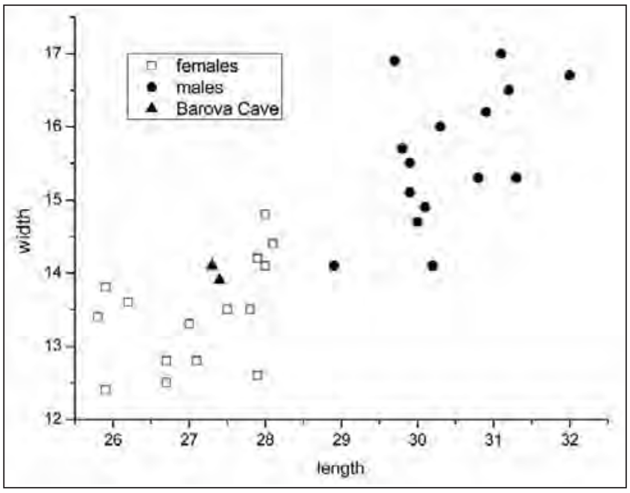

Figure 6. Ratio of length to width of cave lion molars m1 from European localities (see Tab. 1, according to Baryshnikov 2011). Molars of males and females are clearly divided on the basis of size. Molars from Barová cave fall into the range of females decidedly.

could not be for a long horizontal and even vertical distance (Complete skull of young lioness could not "survive such transport"). So the entrances had to be different and maybe numerous, being now buried (along with most of the entrance corridor) under meters of Holocene sediments, debris and man-made deposits.

Most of the cave entrance part served as wintering habitat for cave bears, while (probably in periods, when bears were not present) some parts could be a hyena den or a shelter for cave lions. Although the most finds are remains of the cave bears, increasing number of other taxa promises that, in following seasons, the locality can bring some more important finds opening the view at the paleoecological state of the Upper Pleistocene in the central part of Moravian Karst.

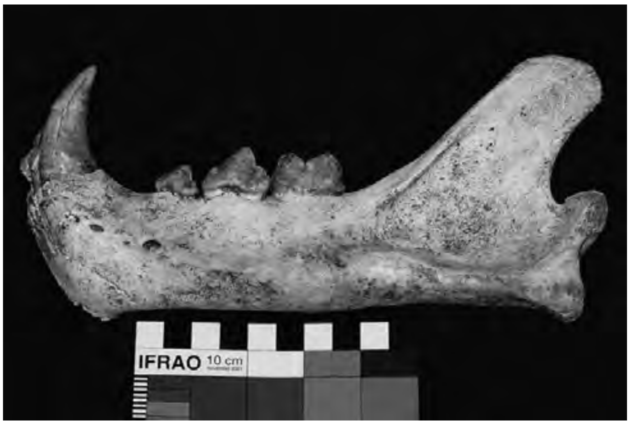

Figure 7. Young cave lioness left lower jaw, excavation "Pod žebříkem" in Barová cave.

5. Conclusion

Although the fauna is not much varied, the place still seems to be an ideal training site for Pleistocene paleontology. The goal is not what we remove from the cave, it is about something different. The most important is, what remains in the cave as an instructive educational locality shaped for in situ teaching. We will form the locality in Barová Cave to the didactic tool for university students of paleontology, geology, karsology etc., cavers, speleologists, instructed visitors. It is presumable, that the rest of our test pit in Podžebříková will grant more various fauna than any others in Barová and as such can be ideal cross-section profile for the next studies. As well as the teachers and specialized public get unique place to see rests of intact Pleistocene bone sediments. The excavation in Liščí chodba test pit now already serves as such teaching profile. The restoration of other parts of the cave continues.

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MARESHA – A SUBTERRANEAN CITY FROM THE HELLENISTIC PERIOD IN THE JUDEAN FOOTHILLS, ISRAEL

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The ancient city of Maresha is identified with Tell Sandahannah, situated in the Judean Foothills, about 40 km southwest of Jerusalem. The city was founded in the Iron Age and continued in existence until the late Hellenistic period. During the Hellenistic period Maresha flourished and became the central city of a region known as Idumaea. The archaeological site consists of an Upper City (= UC), a Lower City (LC) and a large number of artificial subterranean complexes comprising caves, columbaria, water cisterns, store rooms, oil presses etc, designated as the Subterranean City (= SC). This Hellenistic period' subterranean infrastructure is the focus of this paper. In this paper we present and discuss the typology and functions of the caves of Maresha. We suggest to identify ten basic types of rock-cut (artificial) caves: 1. Columbarium (pl. Columbaria) – Subterranean dovecotes; 2. Olive presses (or, olive-oil plants); 3. Baths (and "filter chambers"); 4. Underground quarries; 5. Cisterns; 6. Stables; 7. Ritual caves; 8. Storage chambers; 9. Burial caves; 10. Hiding complexes

1. Introduction

The ancient city of Maresha is identified with Tell Sandahannah, situated in the Judean Foothills, about 40 km southwest of Jerusalem. The archaeological site consists of an Upper City (= UC), a Lower City (LC) and a large number of artificial subterranean complexes, comprising caves, columbaria, water cisterns, storage rooms, oil presses etc. These complexes, rock-cut underneath the LC, are designated as the Subterranean City (= SC). This subterranean infrastructure is the focus of this paper.

2. History of Maresha

The city of Maresha was founded in the Iron Age and continued in existence until the late Hellenistic period. During the Hellenistic period Maresha flourished and became the central city of a region known as Idumaea.

According to 1 Macc. 5:66, Maresha was used by the Seleucids as a base from which to instigate attacks on Judea and therefore became subject to reprisals from the Maccabees (2 Macc. 12:35). During the reign of the Hasmonean ruler John Hyrcanus I (137–104 BCE), Maresha, along with the rest of Idumaea, was conquered. Well dated finds attest to the abandonement of the upper and lower city in 112/111 BCE or slightly later.

Maresha was briefly (and only partly) inhabited during three additional, later periods: the Bar Kokhba Revolt (132–136 CE); the Byzantine period; the early Islamic period.

3. Archaeological Exploration and the Lower City (Fig. 1)

Archaeological excavations were conducted in the UC in the summer of 1900 by F. J. Bliss and R.A.S. Macalister on behalf of the Palestine Exploration Fund (= PEF). These and the renewed excavations revealed the ancient layers of a Tell (mound) dating to the Iron Age II and the Persian periods, with two Hellenistic phases (Ptolemaic and Seleucid); (Bliss and Macalister 1902; Kloner 2003). The Seleucid city, established on the top of the mound, dating from the 2nd century BCE, is referred hereafter as the Upper City. The UC in its last phase was fortified, almost square in plan and measured about 6 acres (24 dunams; Avi-Yonah and Kloner 1993).

At the foot of the upper city there was a vast surrounding lower city, covering c. 80 acres (320 dunams). Excavations on behalf of the Israel Antiquities Authority (= IAA) have been directed by the author in the LC and in the SC from 1972 to 1999 (Kloner 1996; Kloner 2003).

The LC – at least in its general layout – was almost certainly planned in advance. The street grid and adjacent buildings were obviously pre-planned and public buildings were also provided for. In excavation Areas 53, 61, and 930 in the LC, large dwelling houses were uncovered, with ground level areas extending between 150 to 400 square metres. Walls and parts of buildings were discovered in all of the excavation areas of the LC. The densely built-up buildings appear to have served as residences, commercial stores, and workshops.

Most of the construction work at Maresha employed roughly rectangular blocks of local chalky limestone (regarding the characteristics of the local stone, see below). Most of this building stone was extracted from subterranean quarries that were left disused following the stone-extraction process. Other sources of stone were quarried in subterranean spaces that were primarily, and in a few cases only subsequently, adapted for use as workshops, columbaria, and water cisterns.

A fortification wall surrounded the LC. The general course of this wall is marked on the map (Fig. 1), that also includes the location of the UC uncovered in the 1900 excavations, and the subterranean complexes that were surveyed, measured, and drawn during our work.

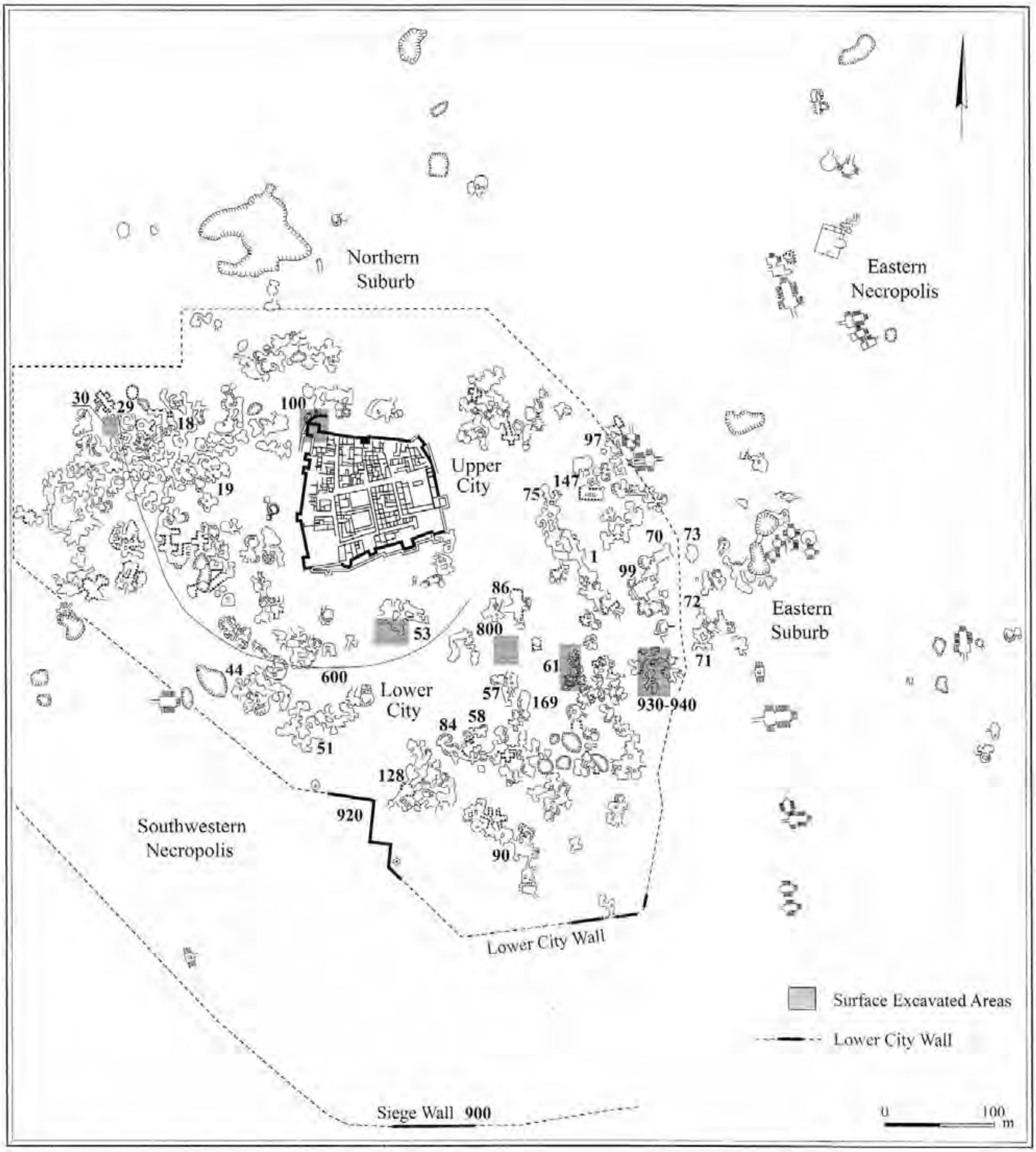

Figure 1. Maresha: General plan, showing the UC, the LC, surrounded by a wall, and location of 160 subterranean complexes in the SC. (Kloner and IAA expedition).

4. The Subterranean City

The SC is unique in terms of its overall size and number of spaces, by comparison to all other known complexes in other regions and from other periods. Artificial, man-made caves were found beneath all excavated residential houses and in all of the excavation areas. The number of subterranean rooms and spaces accessed through one opening from the ground surface varied from one to four.

The most common layout of a subterranean unit, consisted of a descent by way of a dromos-like staircase (Fig. 2), which gave access to spaces on the right and left, and to a third space whose opening was opposite the lower end of the dromos. Only in few cases were there more than four subterranean spaces per house. Where there were more than four subterranean spaces, these apparently served specialized functions. The cave interiors were sometimes joined up at a later time by the cutting of openings through the contiguous walls. New chambers were also later hewn and added to the complex. The hewing of the caves at Maresha apparently started in the eighth century BCE and reached its peak in the 2nd century BCE.

Bliss and Macalister numbered the subterranean complexes they found below the LC from 1 to 63 and published a map of their locations. They pointed out that many of these complexes were not surveyed. More than 100 additional complexes have been identified and documented since (Fig. 1). The subterranean complex no. 61 at Maresha, for example, which is defined as one cave, comprises of about

Figure 2. Stepped corridor (dromos) leading into subterranean complex in area 53 (B. Zissu).

50 different chambers and spaces connected to each other in the underground (Fig. 3). The soft chalk that was systematically removed from the caves was used for building, and this process links between the quarrying of the subterranean chambers, subsequently used for specific functions, and the construction of buildings on the surface of the site.

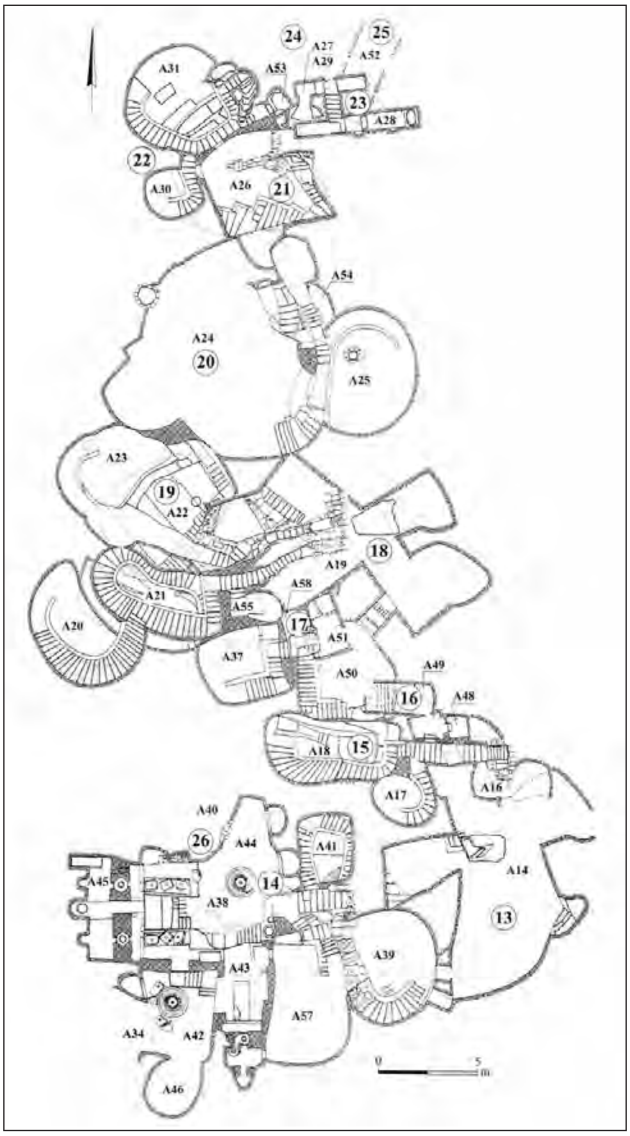

Figure 3. Plan of Subterranean Complex 61 (Kloner and IAA Expedition).

5. The Geology of Maresha and the Surrounding Region

The area of the Judean Foothills is characterized by formations of soft, chalky limestone from the Eocene. Maresha is situated on rocks of the Zor'a formation, the Maresha member. The thickness of Maresha member varies between 30 m and 100 m. Above the chalky limestone, known locally as kirton, a harder nari crust formed, 1 to 3 m thick.

The residents of the region in antiquity were familiar with the geological conditions. Due to the relative ease of quarrying and accessibility, thousands of subterranean chambers were hewn in the region, for various purposes (Bliss and Macalister 1902:204–270; Kloner 2003:4).

6. A Typology of Caves

The entrance and basic layout: The most common arrangement of the caves in Hellenistic Maresha consisted of a descent by way of a dromos-like rectangular staircase, which gave access to spaces on the right and left, and to a third space whose opening was opposite the lower end of the dromos-like staircase.

In this paper we present and discuss the typology and functions of various types of caves, typical to Maresha. We suggest to identify ten basic types of rock-cut (artificial) caves:

1. Columbarium (pl. Columbaria) – Subterranean dovecotes
2. Olive presses (or, olive-oil plants)
3. Baths (and "filter chambers")
4. Underground quarries
5. Cisterns
6. Stables
7. Ritual caves
8. Storage chambers
9. Burial caves
10. Hiding complexes

6.1. Columbarium (pl. Columbaria) – Subterranean Dovecotes

Hundreds of columbaria hewn in caves have been found in Israel, mainly in the Judean Foothills. This large number may be due to the ease of hewing the soft limestone and the structures' durability even when subjected to secondary use in later periods. A great deal of research has been devoted to ascertaining the purpose of the niche-bearing structures, and numerous explanations have been offered (Tepper 1986). Today, most researchers tend to agree that the structures in question were used to raise pigeons (Tepper 1986; Kloner 2000; Zissu 1995).

The term columbarium refers to structures used for the raising of doves or pigeons. (The term also applies to subterranean structures containing niches for cremated ashes. But it should be stressed that these burial installations are common in Italy – in Rome, Ostia, Pompeii and elsewhere, but entirely absent from the archaeological record in Israel, where cremation was a rare custom, practiced mostly by Romans). Pigeons' raising was a source of economic income; pigeons were raised for three purposes: their meat was a fine source of food; their droppings were used as an excellent fertilizer; the doves were used for cultic purposes as sacrifice in pagan temples. In order to maintain this active economic endeavor there was the need of quarrying caves with small niches (about 0.25×0.25 m each), arranged in rows along the walls.

Pigeon-raising in Israel, particularly in the area of the Judean Foothills, evidently dates back as far as the third century BCE; it flourished during the Hellenistic and Early Roman periods. The number and technological sophistication of underground dovecotes reached their peak in the Judean foothills, particularly at Maresha and its surroundings.

At Maresha's LC, 85 columbaria installations were found in caves, dating from the third and the second centuries BCE. The number of niches per cave varies from 200 to 4,000. These columbaria were carved underneath the dwellings of the lower city, and were accessed by staircases from their courtyards. The pigeons would fly in and out of the subterranean chambers through vertical shafts opening at the courtyard level of dwellings.

The Columbarium cave situated in the western part of the LC (Subterranean Complex 30), was quarried in the shape of a double cross and contains about 2,000 niches (originally it contained about 2,600). This cave, locally known as es-Suk, is one of the largest and best designed – by its size, by its shape and by its quarrying quality (Fig. 4).

Figure 4. Main columbarium in Complex 30 (B. Zissu).

6.2. Olive Presses (Olive-Oil Plants)

Twenty-seven subterranean olive presses (or olive-oil plants), all of them hewn in the chalky bedrock, were found at Maresha. The presses are located beneath the dwellings of the LC and accessed by rock-cut steps from courtyards or from streets. The presses are dated to the Hellenistic period, from the third-second centuries BCE. With the exception of perishable, organic components that were of made of wood, rope, leather, etc., the presses have entirely survived.

All of them were planned in advance as olive-oil plants and were built and operated according to an identical method: Each contained a crushing basin and two or three pressing installations of the "lever and weights" type (Kloner and Sagiv 1993).

The crushing basin had a concave crushing surface and a convex or lens-shaped crushing stone cut in order to fit them. There was only one crushing stone to each crushing basin. The lens-shaped crushing stones (of a somewhat different method) are known from other Mediterranean sites, as Olinthos and Pompeii (Kloner and Sagiv 1993).

The pressing installation: The beam (varied in length – 4.5–7.5 m) was anchored in a niche cut in the wall. A rock cut wall about 1.5m high divided the area at the back where the beam niche was found from the main chamber of the press. The collecting vat was at the bottom of a cylindrical aperture that was cut into this wall and that was open both to the back and the front. The crushed olives were piled up over the opening of the collecting vat and held in place in the cylindrical aperture, the sections of wall on either side acting as press piers. The beam was raised and lowered in the openings in the cylindrical aperture pressing down on the crushed olives; the extracted liquid seeped straight down into the vat. In front of the collecting vat there was often an elongated shallow rock cut basin in which the jars for the oil, water and residue probably stood. Each press in which traces of the weights can be found, was equipped with three weights of the type with a bore in the form of a reversed T.

There was usually an entrance in the dividing wall, cut with the purpose to enable passage between the back room and the main press room. The presses often came in pairs and then the approach to both back rooms was through one entrance in the wall that was usually between the two presses. In some cases a third press was added, probably because the two presses were insufficient to handle the amounts of crushed olives in given point of time. An unusual feature in the Maresha press rooms was a cultic niches – a small rock-cut altar located in a niche in the wall, often above the entrance in the dividing wall, between two presses (Kloner 2003: 51–72).

Figure 5. Olive press in Complex 61 (B. Zissu).

6.3. Caves used as baths (and "filter chambers")

Baths were unearthed in some of the subterranean complexes at Maresha. More than twenty rock-hewn facilities have been discovered, which served as baths mainly in the third and second centuries BCE. The plans of a the bathing installation at Maresha are similar to each other; a typical bath contained a staircase leading from the surface to a roomlet, a feeding channel and funnels, through which hot or lukewarm water were flown to the roomlet, and a low seat that was carved on the roomlet's floor, enabling the bather to seat inside the half-meter deep water.

It is worthy of mentioning the Bath Cave in subterranean complex no. 82. It had two small chambers containing seats for the convenience of the bathers (seating-bath), who showered in sprays of water emerging from jets in the bedrock wall. The bather was concealed from the slave pouring the water, and thus his modesty was preserved. One other cave with a bath, which is located in subterranean complex no. 61, under one of the dwellings, was probably the private bath of the house owner.

Some scholars postulated that the baths and the practice of washing the body were involved with some cultic purifying rites. As early as the third and second centuries BCE, the Idumean population of Maresha used also another type of baths – similar in layout to the mikwaot or Jewish ritual immersion baths. These stepped and plastered water installations, were hewn underneath homes in the UC as well as in the LC (Kloner 2003:15–16; Kloner and Arbel 1998:162). Since the mikwaot at Maresha apparently predate the conquest and conversion of the Idumeans to Judaism by John Hyrcanus I by the end of the second century BCE they probably testify to similar ritual purification practices among Jews and Idumeans. We cannot rule out entirely the possibility that the baths belonged to Jews living in the city prior to the Hasmonean conquest.

Another kind of installation involved with water, was designated as "filter chamber" by Macalister. There were at least 15 filter chambers, or filtration rooms at the site, which were small rooms usually hewn directly above the cisterns to collect rainwater that was drained into them. The runoff water was flowed from these small rooms to the cisterns through a small opening spilling into the cistern itself. The cisterns were huge in size in proportion to these small rooms. The writers assume that the filter chambers had the same function as the baths.

A total of about 60 bathing installations were documented so far at Maresha.

6.4. Quarries

Some 2,500 chambers and spaces of various dimensions and designs have been discovered beneath the lower city of Maresha and its surroundings. These spaces are arranged in 160 clusters, designated by us as "subterranean complexes". These complexes sometimes contain as many as 70 spaces per complex. Bliss and Macalister (1902) determined that any connection between underground spaces and chambers, even if reached by climbing or crawling, associated them with the same complex. We still follow this method (Kloner 2003: 18–21).

Among the types of caves originally cut to quarry blocks of chalk, used to build the houses of the city, the underground quarries are particularly prominent. It is obvious that the purpose of the quarrying was to extract blocks of kirton for construction and then to use the resulting large, underground spaces for various purposes, as storage, the housing of animals, and so on.

6.5. Cisterns

The water supply of Maresha was almost entirely based on runoff diverting and collection in water cisterns.

Most of the bell-shaped subterranean caves at the LC that were accessed by spiral curving staircases with well carved parapets and comprised a hewn channel along the stairs for runoff drainage – are water cisterns (Fig. 6).

These are wide as well as relatively deep bell-shaped cavities, usually circular in plan (about 10 m high and 6 m across; few are oval or square in shape). Given that the local kirton is water impervious, merely a part of the subterranean cisterns are plastered, usually along fissures in the rock, for allowing the collection and storage of rain water. A typical cistern has a spiraling staircase with parapets, leading down for the drawing of water and the cleaning of silt that accumulated over time. The cisterns could have held up to 300–400 cu ms. each, and they were usually cut in the rock in pairs or threes.

About 320 subterranean cisterns were identified underneath the houses of the LC, dating mainly from the third century BCE to the first century CE.

Cisterns of this type, with aesthetically designed parapets are found only in few other sites in the Judean Foothills.

Figure 6. Typical cistern in Complex 61 (B. Zissu).

6.6. Stables

Seven subterranean stables for horses, mules and donkeys and probably also cattle, were found in the LC. They were identified as such by the discovery of hewn feeding troughs placed between pillars supporting the roof, and by the stone floor that was sloped to facilitate the collection of urine, which was an important component in the tanning industry in antiquity. There are also places to tether the animals in these chambers.

6.7. Ritual Caves

Another type of cave-use is as artificially cut installations for ritual and cultic purposes. Such caves are found in Subterranean Complex 51 and at some other Hellenistic period' subterranean complexes. This assumption is based upon discovery of decorative cultic niches in some of the areas as well as schematic anthropomorphic reliefs carved into some of the walls. It is possible the reliefs are representations of the Idumaean god Kos. The exact purpose of these chambers awaits further discussion.

6.8. Storage Caves

There is little doubt that many of the subterranean areas at Maresha were also used for the basic function of storage. The presence of ties in the walls, storage niches, and remains of silo-shaped chambers are clear indications of this.

6.9. Burial caves ("Necropoleis")

Three cemeteries (= necropoleis) are known in the vicinity of the LC, and outside the perimeter of the walls. The necropoleis contain a total of 40 burial caves, all of a similar design: a rectangular chamber into whose walls *loculi* (burial niches) were cut, featuring typical gabled openings. All the burial caves were initially cut in the Hellenistic period. Two of these caves, discovered in 1902, had outstanding decorations and wall paintings (Peters and Thiersch 1905) dating from the third century BCE.

The Hellenistic period burial caves of Maresha were long-term family tombs – made for the burial of families of the city residents. The tombs continued to serve this purpose throughout the 3rd and 2nd centuries BCE. (Peters and Thiersch 1905; Oren and Rappaport 1984; Kloner 2003).

Inscriptions and other epigraphic remains from Maresha's necropoleis reflect the multi-ethnic makeup of the city; Idumaeans, Phoenicians, Greeks, some Egyptians and possibly a few Judeans were part of the population, producing the special ethnic and social fabric of this Hellenistic city.

6.10. Hiding Complexes

Hiding complexes are a particular type of subterranean complex linked to the second Jewish Revolt against the Romans (the Bar Kokhba Revolt, 132–136 CE) and to the period of preparation prior to the outbreak of that revolt. The Judean Foothills, where about 110 sites (out of total 140 in Judea) with about 380 (out of a total of c. 450 in Judea) hiding complexes have been found, has been revealed as a major focus for the activity of this revolt (Kloner and Zissu 2009). At Maresha five hiding complexes were located on the western slope of the LC.

7. Conclusions

Almost all Maresha subterranean spaces were hewn to serve existential and economic needs. The underlying assumption is that the residential houses of Maresha, and the subterranean chambers and means of production hewn underneath, served the local population over generations.

Economic activities were conducted below the surface of the ground out of engineering considerations, due to the durability of the rock walls and ceilings. The cost of quarrying and providing suitable spaces for workshops and installations in the underground was far cheaper and more convenient than constructing these above ground where the cost of building and maintenance of structures was much higher.

Descent into the subterranean spaces was from the houses above, from courtyards and inner spaces, from rooms and corridors to baths, from passages between houses, and in some cases from passages to the street adjacent to the house through separate entrances.

Manufacturing and processing installations and other types were found in caves throughout the LC. Olive-oil presses and columbaria were very common, albeit in smaller concentrations in the northern sector compared with most of the areas of the city. As indicated above, these installations were closely connected with the large residential units. Even where the entrances to the installation were not in the house itself, the caves extended directly beneath the rooms of the house. Water for use in the home or for sale was drawn from rock-cut cisterns, sometimes being used jointly by neighbouring households. Thus, two such adjoining installations – even if they had been hewn in the rock during one operation – each had its own entrance and functioned independently.

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NEW PROFILE OF CIEMNA CAVE SEDIMENTS (POLISH JURA) – PROBLEM OF CORRELATION WITH FORMER INVESTIGATIONS

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Ciemna Cave is a famous Polish palaeolithic site, the eponymic site for Prondnikian culture of Neanderthal man. Archaeological investigations have been conducted since the beginning of 20th century and engaged many researchers. However the reliable scheme of chronostratigraphy of sediments was not established. It was a reason for providing new excavation in 2007–2012 that yielded a 5 meters long profile of sediments. The sequence was divided into 24 layers, grouped in six lithostratigraphical series. They are: I – the oldest one, yellowish and reddish clays and silty loams; II – brown and grayish brown loams and silty loams with limestone rubble, dated to marine oxygen isotope stage OIS 5 and probably also OIS 6 and OIS 7; III – brown and grayish brown debris of limestone rubble, dated to OIS 4; IV – brown and grayish brown loams, silty loams and loess with limestone rubble, dated to OIS 3; V – yellowish brown redeposited loess, dated to OIS 2; VI – dark humus sediments, dated to OIS 1. The upper part of profile may be easily correlated with analogous or similar sediments excavated during former investigations. However correlation of lower part with older data is difficult and may be only roughly made on the basis of current knowledge. Further researches are necessary to explain the detail stratigraphical position of sediments from the Ciemna Cave system.

1. Introduction

Ciemna Cave is known as palaeolithic site and was explored from the beginning of 20th century (Czarnowski 1924; Krukowski 1924, 1939–48; Kowalski 1967, 2006). Among other Middle Palaeolithic chert tools, S. Krukowski has found there a characteristic asymmetrical knives and named them "prondniks" after "Prądnik", the name of stream flowing beneath the cave. Basing on the chert artifacts from this cave and from the Wylotne Rockshelter, so called "Micoquo-Prondnikian" assemblages were defined by Chmielewski (1969). Published information about the lithological composition of sediments was very poor. New excavation has been provided since 2007 by Institute of Archaeology, Jagiellonian University (P. Valde-Nowak, K. Sobczyk, B. Ginter), Archaeological Museum in Kraków (M. Zając, D. Stefański) and Institute of Systematics and Evolution of Animals, Pol. Acad. Sci (P. Wojtal, B. Miękina) with participation of Institute of Geological Sciences, Pol. Acad. Sci., representing by the authors.

2. Geomorphological setting

Ciemna Cave is one of the biggest caves in southern part of the Polish Jura Chain (Kraków-Częstochowa Upland, southern Poland). It is situated near the top of the Prądnik Stream karstic valley, at altitude of 62 m above the valley bottom, 372 m a.s.l., and is connected with the middle horizon of caves in the region (see Madeyska 1977). It is developed in Upper Jurassic rocky limestone (Gradziński et al. 2007). Besides the main chamber and channels the cave system consists of several parts, fragmentally destroyed by erosion and situated outside the cave: tunnel-like form *Oborzysko Wielkie*, passing into small cave called *W Leszczynie Cave*, and unroofed area called *Ogrojec* – an open terrace, a part of former cave (Fig. 1). The recent excavations are situated in the main chamber, while the former ones at the entrance area and in the *Ogrojec*.

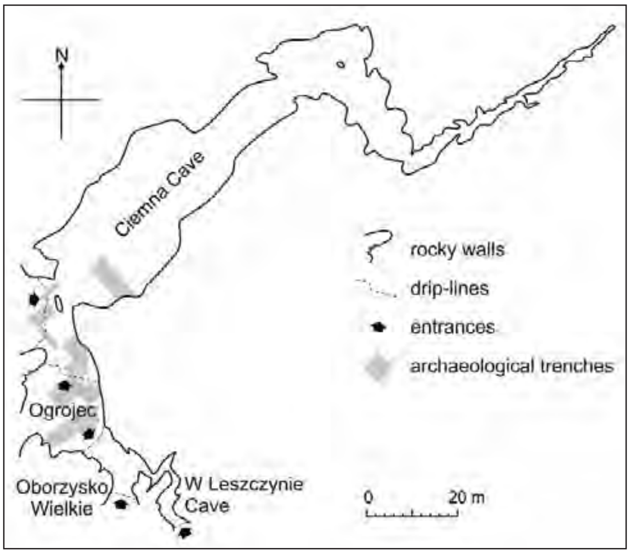

Figure 1. Plan of the Ciemna Cave system; location of older trenches after Kowalski (2006).

3. Description of the profile

24 lithologically different layers were distinguished during the excavations in 2007–2012 (Fig. 2). They are grouped into 6 series:

Series I – layers 19-17 – they form the oldest series. They are reddish and yellowish clays and silty loams.

Series II – layers 16-9 – a series with greatest thickness, built mainly of loams and silty loams with abundant limestone rubble. These layers are usually colored brown or grayish brown. Sedimentary structures do not occur, except of rubble impact structures, what indicates relatively low energy of sedimentary environment and low sedimentation rate. As the contrary, postsedimentary structures are numerous and formed as subsidence bending and cryoturbation. These disturbances were caused by climate-controlled secondary processes. Macroscopic differences between layers are weakly marked and boundaries are unclear. Main differences are caused by color and rubble quantity. Detail analyses indicate important differences in weathering parameters, however in lower part these differences are also poorly marked.

Series III – layers 8-6 are limestone debris with brown and grayish brown sandy-silt matrix. The rubble is sharp-edged, mechanically weathered.

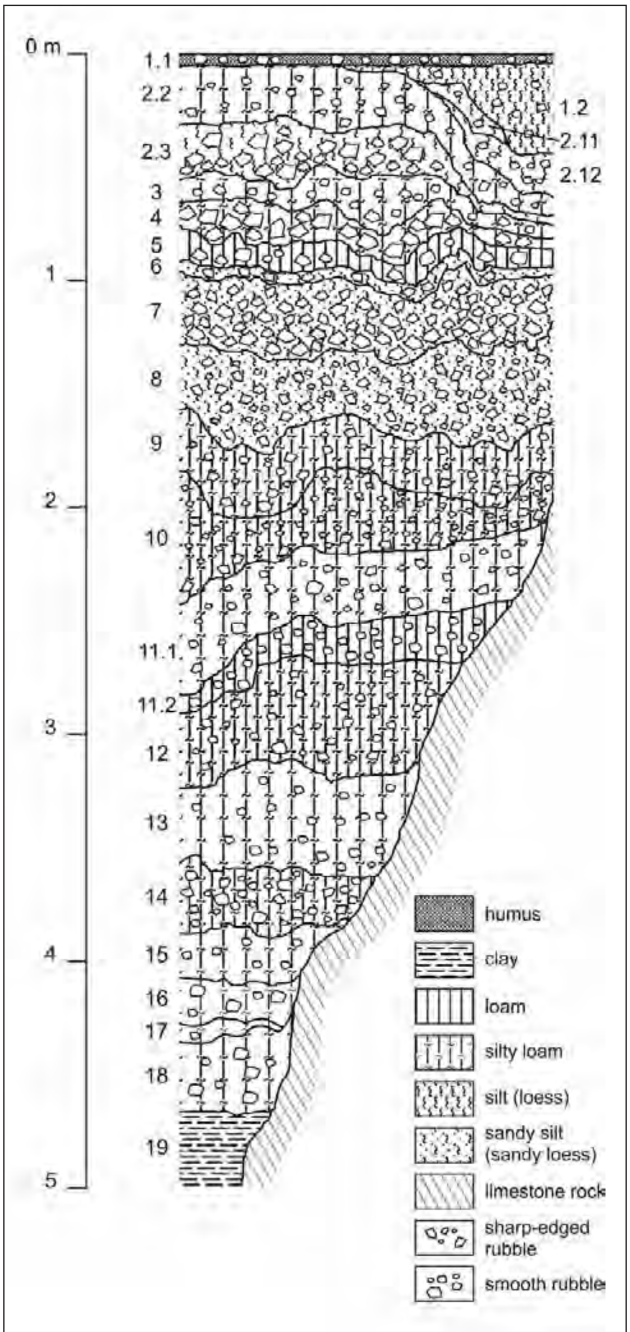

Figure 2. Profile of sediments in Ciemna Cave excavated during 2007–2012.

Series IV – layers 5-2.2 – brown and grayish brown loams, silty loams and loess with limestone rubble. Clasts are smoothed what indicates mild climate during sedimentation of the series.

Series V – layers 2.12-2.11 should be distinguished as a separate series, although the most weakly developed. Layers occur in south part of chamber only, near the cave wall. These sediments are yellowish brown loess with sparse limestone rubble. Some sedimentary structures were noticed and they have a form of poorly preserved trough stratification. It indicates that sediments were washed into the cave by water flow or by mud slides.

Series VI – layers 1.2-1.1 – the youngest dark colored humus sediments. Two layers are relatively different. The upper one 1.1 is a modern cave pavement built of condensed trodden sediments. The lower one 1.2 is the remnant of natural layer. The primary uppermost part of profile including the greater part of the Holocene sediments has not survived. It is proved by erosional character of 1.2/1.1 border as well as traces of sediment removing, preserved on the walls.

4. Discussion

Series I – layers 19-17. Age of these sediments was not established, however it should be noted that similar red loams or clays lying in similar stratigraphic position are known from other caves of Polish Jura (for example from Biśnik Cave, Nietoperzowa Cave, Cave in Dziadowa Skała, Koziarnia Cave). Their age was estimated to Neogene or Lower Pleistocene (Madeyska 1981; Mirosław-Grabowska 2002). Layer 17 is lithologically similar to layer 19 and its lense-like shape suggests that it is a fragment of layer 19, redeposited by slope processes. Analogical situation was observed in Biśnik Cave and connected with OIS 8 / OIS 7 boundary (Krajcarz and Cyrek 2011). Similar sediments were also noticed from outside parts of Ciemna Cave system– from *Ogrojec* (Madeyska 1981) and from entrance to the Ciemna Cave (Krukowski 1939–48). In *Ogrojec* the sediments lie in the same position – in the bottom part of Quaternary profile, directly on the rock surface (Fig. 3). At the entrance to Ciemna Cave situation is different – red loam is situated between loess series (Fig. 3). Here the loam layer is thin and mixed with Pleistocene bones (Krukowski 1939–48) what indicates that sediment is not preserved *in situ*, but it was redeposited from the cave interior by slope processes. It may not be excluded that the loam was redeposited during the same event which resulted in deposition of layer 17 inside the cave. However the fresh character of lowermost loess at the entrance to the cave and good preservation state of frost-weathered rocky bottom in this place (Krukowski 1939–48) suggest that the redeposition event was relatively young and should be correlated with Vistulian Glaciation (OIS 5d-2). Further investigation is needed to explain that situation.

Series II – layers 16-9. Layers 15-16 and 11.2 exhibit the highest stage of limestone rubble smoothing in the whole sequence of this set, what probably indicates interglacial (or warm interstadial) age of mentioned layers. They can be correlated either with OIS 7 and OIS 5e, or with OIS 5e and OIS 5c isotopic stages, respectively. Further researches are necessary to choose one of these stratigraphical models. Layers younger than 11.2 present distinctly lower weathering stage of limestone rubble, what indicates that climatic conditions had moved toward more cold and dry conditions of Early Vistulian. The age of whole series II is OIS 5, and lowermost parts probably may be correlated with OIS 6 and OIS 7. Analogical sediments are not known from the entrance to the cave, however they were found in *Ogrojec* (Madeyska 1981; Kowalski 2006). Poor Middle Palaeolithic levels are known from these sediments, both from the Ciemna Cave interior (Sobczyk 2011) and from *Ogrojec* (Kowalski 2006), what additionally allows to correlate these sediments.

Series III – layers 8-6. The limestone rubble is strongly mechanically weathered, with sharp edges, what indicates that these sediments are related to cold Pleniglacial period of OIS 4 stage. These layers should be stratigraphically correlated with loess sediments of the same age (Fig. 3) that occur at the entrance to the cave and in *Ogrojec* (Krukowski 1939–48; Madeyska 1981; Kowalski 2006). It seems probable that redeposition of sediments at the entrance to the cave (mentioned above) and deposition of the thickest loess series at the same place are related to the same period of Early Pleniglacial.

Series IV – layers 5-2.2. Limestone ruble is weathered and smoothed what indicates the climate milding during deposition of these layers. Weathering parameters as well as radiocarbon dates (unpublished data – B. Alex, P. Wojtal), Middle Palaeolithic levels in lower part and Jerzmanowician-like artifacts in its upper part (Sobczyk 2011) allow to correlate this series with Middle Pleniglacial, isotopic stage OIS 3. Similar loams with rich Middle Palaeolithic (Micoquian) level were described from *Ogrojec* (Krukowski 1939–48; Madeyska 1981). At the border of *Ogrojec* and *Oborzysko Wielkie* the loams disappear, however Micoquian cultural layer is still present between two loess packets (Krukowski 1939–48).

Series V – layers 2.12-2.11. Probably these loess-like redeposited sediments constitute the only trace of Upper Pleniglacial, i.e. OIS 2, inside the Ciemna Cave. On the contrary, well preserved loess deposits occur outside the cave (Fig. 3) and were found in each archaeological trench, at the entrance to the cave, in *Oborzysko Wielkie* and in *Ogrojec* (Krukowski 1939–48; Madeyska 1981; Kowalski 2006).

Series VI – layers 1.2-1.1. These sediments were undoubtedly accumulated during Holocene, OIS 1. Layer 1.2 is a natural deposit, partially destroyed by erosional event, most probably due to anthropogenic activity in modern times. It is possible that modification of cave interior was connected with preparation of cave for the visit of Polish king Stanisław August Poniatowski in 18th century. These layers may be correlated with humus sediments from outside parts (Fig. 3), described from all trenches and excavated during the earliest archaeological works in 19th century by Czarnowski (1924). Holocene sediments are the best developed in *Ogrojec* and *Oborzysko Wielkie*, where they are stratified and contain numerous Holocene artifacts (Czarnowski 1924; Kowalski 1967). Similar black humuous sediments are known from almost every cave of Polish Jura (Madeyska 1981).

5. Conclusions

Upper parts of newly excavated profile of sediments from Ciemna Cave may be easily correlated with sediments from outside parts of the cave system (at the entrance to the cave, in *Ogrojec* and *Oborzysko Wielkie*). More problematic is lower part of new profile. Several models of chronostratigraphy of this part may be presented on the basis of current data. In addition, former investigations had not provided reliable stratigraphy of sediments from other archaeological trenches. Further detail studies are needed to explain the stratigraphy and age of sediments from Ciemna Cave system.

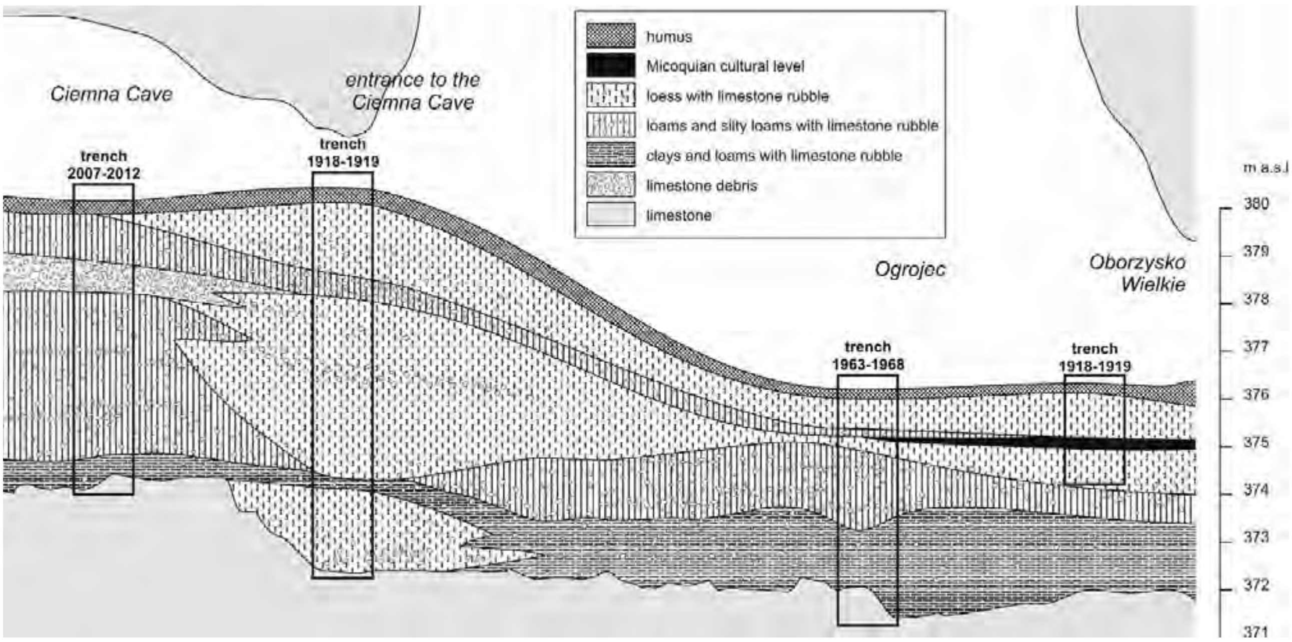

Figure 3. An attempt of correlation of sediments excavated in different archaeological trenches (from 1918–1919 according to Krukowski 1924, 1939–48; from 1963–1968 according to Madeyska 1981, Kowalski 2006; from 2007–2012 – new data) and possible geological cross-section from the Ciemna Cave interior across Ogrojec to Oborzysko Wielkie.

Acknowledgments

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CAVE ARCHAEOLOGY IN HUNGARY – SYNOPSIS AND NEW PERSPECTIVES

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Caves are not only the parts of our natural, but our cultural heritage as well. A significant number of caves contain particular archaeological remains, from the Paleolithic to the Middle Ages. In the Ph.D. thesis we are trying to reconstruct the role of the caves in different younger prehistoric eras (from the Neolithic to the Iron Age), by examining the archaeological finds, relationships between the settlement types and involving new scientific methods. It is very important to reinterpret the find material from "old excavations" in the light of the new results as well. Our first attempt of reinterpretation was the Baradla Cave, which resulted in several unanswered questions.

1. Cave protection

The first legislations of Hungarian cave protection came from the beginning of the 20th century, in 1935 the law only involved the protection of the caves with "scientific value". Since 1961, caves have been *ex lege* protected. In 1998, the conditions of cave exploration, research, visit, and the obligations of the researchers were strictly codified.

In the late 19th century, the archaeological data were mostly discussed by researchers interested in the Paleolithic period. In later eras – because of the rich open air settlements, cemeteries, etc. – cave sites were not, or only marginally mentioned in the prehistoric investigation.

2. Research history, cave sites

In cave exploration, the first written document is known from 1549, and only mentioned the stalagmites (Wernher 1549). From the 18th and 19th century, our most common source of research are *itineraria*; systematic research and excavations only began with Baron Jenő Nyáry's work at Hungary's largest natural cave, the Baradla Cave at Aggtelek (Nyáry 1881). At the beginning of the 20th century, remarkable and large-scale excavations began at Hungary's greatest archaeological cave sites, like Szeleta Cave, Istállós-kő Cave (work of Lajos Bella, Jenő Hillebrand, Ottokár Kadić, Tivadar Kormos, Andor Saád, Géza Megay, Andor Leszih, etc. – their work highly exceeded the century's excavation standard.) After World War II, the research's opportunities suddenly declined, only a few tried to continue – mostly in the Paleolithic period – the cave research.

Within the framework of younger prehistoric (Neolithic, Copper Age, Bronze Age, Iron Age) several attempts were made to collect and organize the cave sites of each archaeological culture: József Korek and Pál Patay in 1958 the Neolithic Bükk Culture (Korek, Patay 1958), Tibor Kemenczei in 1970 (Kemenczei 1970) and 1984 (Kemenczei 1984) the Bronze Age Kyjatice Culture, Zsuzsanna M. Virág between 1995 (Virág 1995) and 2002 (Virág 2002) the Copper Age Ludanice Culture, and György László in 2009 Copper Age Baden Culture (György 2009).

Also sereval attempts were made to collect all the Hungarian archaeological cave sites, last time Kinga Székely tried to summarize archaeological records of the National Cave Registry (http://www.termeszetvedelem.hu/). The Registry does not contain earlier archaeological literature, thus the latest list considered to be incomplete. Despite of the several attempts, no one could valuate the significance of this settlement type from the Neolithic period to the Iron Age.

3. Baradla Cave

The Baradla Cave is the longest natural cave in Hungary, with the lenght of 20,500 m, and part of the Baradla-Domica Cave System (25,000 m total length). The Slovakian Domica Cave – like the Hungarian Baradla Cave – is also a Middle Neolithic cave site.

This outstanding cave system has been on the UNESCO World Heritage List since 1995, with altogether 712 caves from the Aggtelek Karst (Hungary) and Slovak Karst. The cave system has 10 known entrances, 3 opens from Slovakia and 7 from Hungary (http://whc.unesco.org/en/list/725).

Strikingly large number of educational and scientific literature is known about the Baradla Cave, but there is hardly any work in which the author is striving for completeness. Despite the continuing interest, long-winded summaries of archaeological work are rarely born. Most of the literature does not use their results and observations but uses fragments from existing reports, or information based on verbal communication. This makes it more difficult to create a proper scientific assessment; meanwhile completely contradictory information can be revealed in the literature.

Previous archaeological finds from the Baradla Cave were taken to different collections across the country, more archaeological remains (human bones, botanical specimens) whereabouts were an open question at the time of documentation. The Baradla Cave finds are officially stored in two museums: the Herman Ottó Museum at Miskolc and the Hungarian National Museum, however it is likely that large amount of artefacts are in private collections. The situation is complicated by the fact that the data in the inventory books of the Hungarian National Museum does not always match the stored material.

The recent earthworks, visitor activities and the natural water drips steadily disturb the intact archaeological layers. Despite of the hundreds of years of illicit excavations, illegal collecting, archaeological excavations and earthworks still a significant amount of artefacts can be found in the cave. The last intensive field survey in 2001/2002 – without any excavation – resulted more than 8,000 archaeological finds (Fig. 1).

After several years of excavations and research it is clear that there was no Paleolithic occupation in the Baradla Cave, the first inhabitants were the people of the Middle Neolithic Bükk Culture (The Bükk Culture is a part of a large, Middle Neolithic culture complex in the Carpathian Basin, the Alföld Linear Pottery Culture, i.e. ALPC, which is parallel with the European Middle Neolithic culture complex, the Transdanubian Linear Pottery Culture or simply Linear Pottery Culture, i.e. TLPC or LPC). After the Neolithic period, the cave was only inhabited in the Late Bronze Age by the people of Kyjatice Culture.

The publication of the finds is based on – in the absence of stratigraphy – the artificially created geographic information system (GIS), which contains a total of 246 units, following the natural units of the cave. The field survey and the mapping was started at the main entrance, the separation of the spatial units is based on the natural demarcation of the cave branches.

According to the archaeological finds (mostly ceramic styles and burial rites), the areas closer to the cave's natural entrance were mostly inhabited during the Bronze Age, the more distant areas were inhabited during the Neolithic period (Holl 2007). Both household and fine ceramics had been found at the whole occupied territory, as well as chipped and polished stone tools, bone tools and animal bones (Raczky et al. 2007).

Despite the accurate field work, elaborate GIS, the great number of literature, systematic processing of ceramics, there is still very little known about the concrete usage of the Baradla Cave. This problem gave us the idea to investigate all the archaeological cave sites in the country, also publishing the material finds, and examining the relations with the other type of settlements. Hopefully this work can finally reveal the exact functions of the cave sites through the ages.

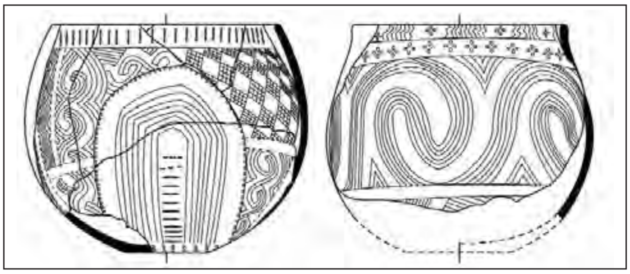

Figure 1. Incised three-quarted spherical Bükk Culture fine bowls fom the Baradla Cave, stray finds. (O. Laczi, "The Neolithic archaeological finds of Baradla Cave at Aggtelek" [Az aggteleki Baradla-barlang neolitikus emlékanyaga], MA Thesis, 2011, unpublished. Table XLVIII. 2–3).

4. The archaeological use of cave sites

One of the greatest questions is the purpose of inhabiting various caves during the different phases of prehistory. In several caves, artefacts from the Paleolithic to the Middle Ages can be found. The reason probably lies within the various usage in different ages.

Not all the caves were used for animal husbandry or housing purposes, mostly the suitable sized and easily accessible caves were occupied. Often the fear of a supernatural being withheld the people of the use of the cave, but the "supernatural" was often the rhythmic drip of the stalactites, or the clattering of cave bats and owls.

In archaeological terms, we can distinguish secular and ritual usage.

4.1. Secular use

Water access: One of the most obvious secular usages of the caves was obtaining water. In prehistoric cultures, water played a very critical role in the life of the community. Settlements were mostly established nearby natural water sources, like ponds, rivers or caves. Water had a special role in the life of the community, for example in the end of the Middle-European Neolithic, lack of water and its deterioration often led to ritual acts (Holl 2007; Laczi 2011). In the Baradla Cave, more than a kilometre away from the natural entrance a Bükk Culture pottery was placed under a stalactite, probably during a drier weather period. The hemispherical, well burned, incised and incrusted fine pottery is the last occurrence of any archaeological artefact in the cave branch, which can indicate both secular and ritual function. The lack of artefacts also encumbers the interpretation of the bowl, no other remains are known from that part of the cave (Kiss 1997).

Husbandry: Not only archaeological remains refer to animal husbandry in the caves, but the name of the caves, rock shelters as well. The Istallós-kő Cave's name refers to the livestock function, it means "stone stable". According to written sources, more than one thousand swine could been herded in (Paládi, Kovács 1965), and it was also the nocturnal and winter shed of the local landowner's flock of sheep in the 19th century (Hála 1995). Other cave names, like Kecskés (Goat) Cave, Kis-Lócsűr (Small Horse Barn) Cave also refers to animal husbandry (Gunda 1962). One of the oldest linguistic evidence is the Greek word "strunga", which means milking pen. The Romanian strungā, Albanian štrungɛ, Ukrainian strunka, Hungarian esztrenga words can be traced back to the "cave" word (Laczi 2011). Besides the nomenclature, the most important source of lifestocking in caves is animal bones and fire rings. However, we should be careful with both phenomena, because animal bones – especially if fragmented and cut marks can be found on them – rather indicate the meat's ingestion in the cave. Also the fireplaces can be more recent than we first suspect.

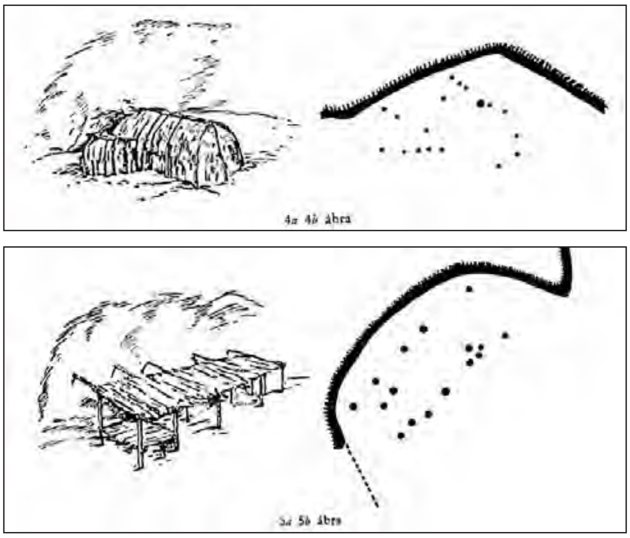

Figure 2. Reconstructions of the stake hole structures in Kőlyuk Cave. (J. Korek, "Bükk Culture settlement in the Hillebrand Cave" [A bükki kultúra települése a Hillebrand barlangban], Folia Archaeologica X, 1958, p. 23, figure 4a–4b, 5a–5b).

Habitation: The most important, and also the most divisive role of the archaeological caves is the habitation function. In the early and middle 20th century, archaeologists discovered different stake- and post hole structures with fireplaces in caves, which were interpreted as houses. Two of these asymmetrical structures were excavated in the Baradla Cave in 1937 by Sándor Gallus (Korek 1958; Fig. 3), and two in the Kőlyuk Cave in 1958 (György 2009), by József Korek (Fig. 2). Both of the authors agree that the stake hole structures were houses, and their main function was the protection of fireplaces from the dripping water. The irregular arrangement, the dry cave climate and the great number of the stake holes contradict this theory. Balázs Holl, cave researcher drew my attention that these holes are likely to be imprints of the torches people used to light with through the ages until the late 19th century. However, the clear archaeological evidences of habitation are the large amount of household pottery, grinding stones, animal bones, fireplaces from sterile layers, etc.

Other: We have no archaeological evidences for other secular uses, but defensive, storage, high-stand, mining (clay, limestone, guano), medical treatment functions could also have been important.

4.2. Ritual use

Cultural anthropologists agree that whenever a crisis threatens the community, the people can respond by increasing ritual activity to propitiate the divine being, presumably a similar case had happened in the caves as well.

Burial: The first and very important ritual cave use is the burial function. The most common rite in cave burial is the inhumation. One of the most frequent skeleton burials in Hungary can be connected to the Bükk Culture. However, few burials can be found in caves, the exact rites can be precisely studied. Middle Neolithic burials are contracted, lying mostly on the left side, with only a few grave goods (like pottery, *spondylus* beads and/or bracelets, lithic tools and sometimes red ocher). Artefacts associated with the burials are slightly, or not differentiated by gender.

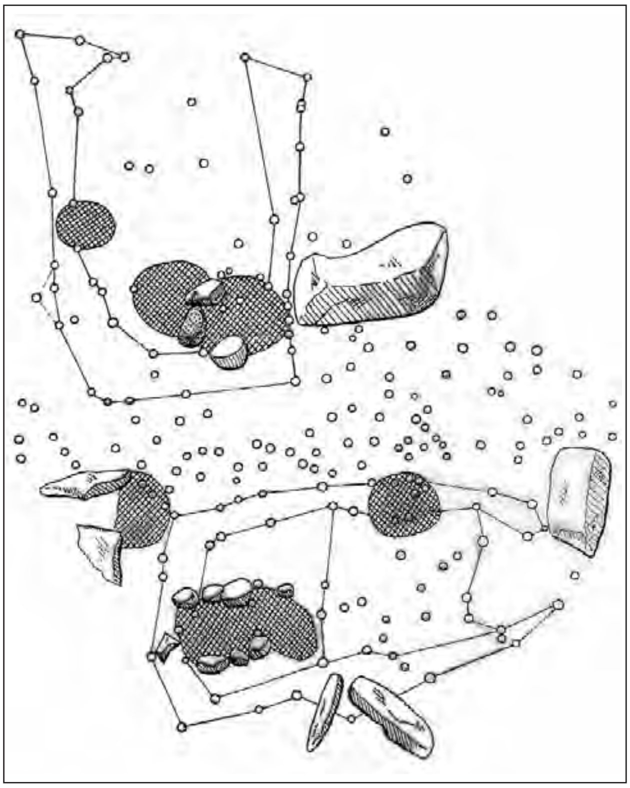

Figure 3. Reconstructions of the stake hole structures in the Baradla Cave (unpublished after Sándor Gallus, Hungarian National Museum – Archaeological Repository).

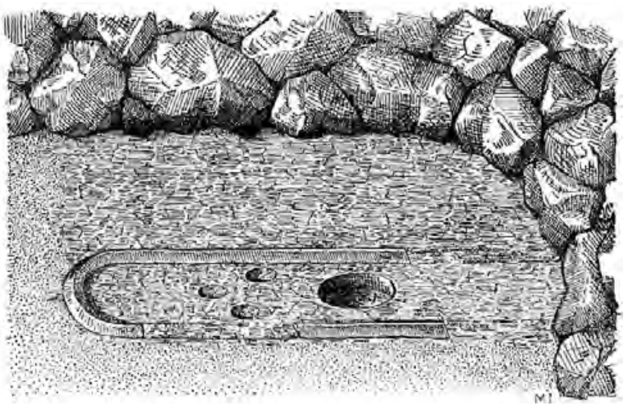

Figure 4. The so-called furnace from Baradla Cave (F. Tompa, "25 Jahre Urgeschichtforschung in Ungarn 1912–36", Bericht der Römisch-Germanischen Kommission 24–25, 1934–1935, 39).

The Late Copper Age Baden Culture's cave sites also include burials. In the recently excavated Ősi Cave, cavers and archaeologists collected the human bones from the disturbed graves. The bones were identified and they belonged to at least three people (a young woman, a child and an infant.) Unfortunately the burial rite couldn't be studied because of the heavy disturbance (Kemenczei 1984, 42–43). In the Late Bronze Age Kyjatice Culture the most characteristic burial type – similar to the other Late Bronze Age Cultures – is the cremation. The only exception is the cave sites of the culture, where graves with inhumation rite are documented. The relatively small number of inhumational cave burials may refer that the people had a special role in the whole community (Tompa 1934–1935). Despite of the archaeological investigations and collections in the Baradla Cave, one can still find human bones scattered on the surface, sometimes under 2–3 cm thick dripstone layer.

Special objects: One of the most controversial objects in the Hungarian cave archaeology is also from the Baradla Cave. Ferenc Tompa excavated in 1929 the so-called furnace 200 meters away from the entrance. The elongated, rounded-end furnace was surrounded by a higher rim, it was also found in a sterile Neolithic layer, and it was lying directly on the rock, at the depth of about 130 cm. Closer to the rounded edge (from approx. 30–35 cm distance) three, each of 10 cm diameter holes were placed in an isosceles triangle shape. Next to the three smaller holes, there was a 25 cm diameter small pit, which was interpreted as a fire ring. The author interprets the whole structure as a "place of worship" (Fig. 4). Unfortunately we have no opportunity to reinterpret the furnace from primary source, because it has been destroyed during the excavation process (Raczky – Anders 2003).

Face-pots: The so-called face-pot fragments – excavated in several caves – may refer to special use as well. This pottery type played a special role in the Central European Middle Neolithic: according to the newest results, they were "external manifestations of templates, maps of existence coded into clay", corresponding to comprehensive "views of the world" (Tompa 1937; Fig. 5).

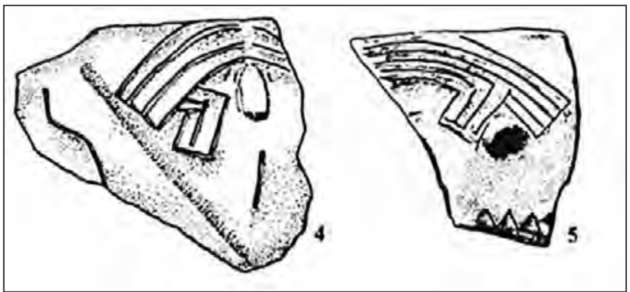

Figure 5. Face-pot fragments from the Baradla Cave. (J. Kalicz and J. Koós, "Neolithic anhtopomorf vessels from the North-Eastern part of the Carpathian Basin" (Újkőkori arcos edények a Kárpát-medence északkeleti részéből), a miskolci Herman Ottó Múzeum Évkönyve, 2000, Picture 11, after J. Korek and P. Patay, "The spread of Bükk Culture in Hungary" (A bükki kultúra elterjedése Magyarországon), Régészeti Füzetek II/2, 1958).

Depots: The large amount of Bükk Culture fine ceramics in the Baradla Cave raises the possibility of a Middle Neolithic "storehouse" in the cave branches. Unfortunately, due to lack of archaeometrical research we are unable to give further information about this possibility.

In 1929, a Late Bronze Age special assemblage of artefacts had been excavated by Ferenc Tompa in the Baradla Cave as well. The treasure-hoard included 28 pieces of gold items, including bracelets, spirals, and small gold fragments. The findings are still unpublished (Tompa 1937).

5. The problems with Hungarian cave research

One of the most important problems with the Hungarian cave research is the limited amount of archaeological literature. Most of the literature comes from the early 20th century, and based on the Paleolithic research. We are also lack of greater, summary works, we have only smaller publications with an archaeological culture's cave site register or a summary of a specific site (like Szeleta Cave). The inadequate documentation of previous excavations and field surveys is also a great problem, at some sites it is extremely hard to examine the exact places of the earlier excavation trenches. Sometimes there is a strip of land left unexcavated, and we are also able to reconstruct the section walls, but most of the previously excavated caves are completely disinterred with no possibility of control excavations.

The unprocessed archaeological finds from rescue excavations encumber the appropriate research, the museum inventory system also makes it difficult to do our job.

There is only minimum or no communication between the different research areas, like hydrology, geology, biology and archaeology, the cave exploration also drifted towards the sport caving. "Too much" attention from hiking people and excessive cave pollution is also a great problem.

Most of the cave archaeological finds are unfortunately stray finds, not even the contemporaneous documentation transmits the exact findspot.

6. New perspectives and methods

Like in any other archaeological sector, cave archaeology has undergone a paradigm shift as well. After the long-term historical approach, within the framework of processual and postprocessual archaeology researchers started to involve the "neglected" sciences like geology, radiocarbon dating, two- and three dimensional modelling, etc. Field survey, mapping of archaeological sites, the relationship between open-air settlements, cemeteries and cave sites have become a quite popular new research area.

One of the most significant research advances is the accelerator mass spectrometry (AMS) method for dating small amounts of organic substances. Based on the radiocarbon dating, AMS method is able to determine even the age of the pigments of Upper Paleolithic cave paintings (Valladas et al. 2001). One of the most recent results of the Slovakian cave research is the dating of an organic-rich dripstone stratum – between two white, sterile dripstone layers – filled with charcoal particles. These radiocarbon results from the Domica Cave perfectly fit in the chronology of the Middle Neolithic Bükk Culture (Gradziński et. al. 2003). Like in the Domica Cave, the Baradla Cave is rich in charcoal dripstone layers as well: one of the fragmented stalactite formations includes two charcoal layers, separated with sterile white dripstone strata. The two charcoal layers could probably cover the two main archaeological periods (Middle Neolithic and Late Bronze Age) in the cave.

Relatively new method in the archaeological research is the electron paramagnetic resonance (EPR) method, which is mostly used in biology and chemistry, measuring the light-absorbing features of the material. The technique is suitable for dating calcite (stalactites, bones and microorganisms), aragonite (corals and molluscs) (Ikeya, Ohmura 1981), hydroxyapatite (fossil teeth and bones) (Ramya and Velraj 2012) and quartz (volcanic and sedimentary rocks, bones and aquatic organisms). Attemps have been made for dating zirconium, rock salt, gypsum, feldspar, archaeological ceramics and peat. The disadvantage of the technology that at least 4,000 years old remains can be dated (Wencka, Krzyminiewski 2004).

The dripstone formations are also suitable for climate studies: scientists examined the thorium/uranim (Th/U) ratio of the dripstone samples in the North American McFail Cave. The measurements showed that the period between 7600 and 7000 BP was warmer and wetter, and between 7000 and 3000 BP a slower transition towards the cooler weather have been observed (Van Beynen et al. 2004). The method was also used at the Helderberg Plateau for dating the caves without archaeological remains (Lauritzen and Mylroie 2000).

The fairly decentralized nature of the cave science facilitated the formation of very different types of research methods. The different national research traditions considerably complicated the analysis of the gathered information. Because of the presence of geographic information systems the comparison of caves became somewhat easier. The storage, display and comparison of the large amount of collected cave data is essential for the appropriate research.

However the three-dimensional recording of the archaeological finds is sufficiently widespread, the research of three-dimensional cave modelling is in relatively early stage. The Arizona State University's South African coast studies shed additional light on the paleoclimate, paleoenvironment and paleoanthropology (Fisher et al. 2005).

7. Conclusions

The use of different scientific methods (e.g., radiocarbon dating, Th/O ratio measurement, EPR, GIS) is essential of the up-to-date processing of the previously excavated and newly discovered cave sites. The special status of caves – disturbance, polluttion, finds in secondary context and their protection by law – constantly requires to involve more and more research areas and methods over time.

Every successful response to a question leads to a couple of new question: what is the relationship between the cave sites and the open-air settlements? What were the natural features of the cave during the different archaeological ages? What led the people to inhabit these dark, dangerous subterranean formations?

The upcoming Ph.D. dissertation about the Hungarian cave archaeology can be a source of a versatile, searchable database and a tool for starting-point of the newer cave research. In this work, it is extremely important to revise the old excavations finds, and (re)interpret in the light of new research. We are also planning to collect the problematic, unregistered archaeological sites' field survey, excavation, sampling and analyzes for science.

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NEOLITHIC DRAWINGS FROM BESTAŽOVCA CAVE, WESTERN SLOVENIA

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Bestažovca is the remnant of an old horizontal cave system which was reshaped by sediment fill, karst denudation and collapsing. The present entrance to the cave is a 25 m shaft. Red ochre drawings are preserved on the walls in the main passage of the cave, along with black dots on the passage ceiling. Dating of the dots and charcoal with ^{14}C suggest that the drawings are about 7,000 years old, dating from the Neolithic period. The ochre drawings are most likely of the same age, but they may also be older. Some drawings have been damaged by dripping water or condensation or are covered with fine white calcite crystals. The drawings are preserved because sediment creep closed the main former entrance to the cave. This stabilised the climate in the cave and made the cave climate favourable for preservation. The drawings from Bestažovca currently represent the only known Neolithic cave art in the wider area of the Dinaric Mountains and the neighbouring Alps.

1. Introduction

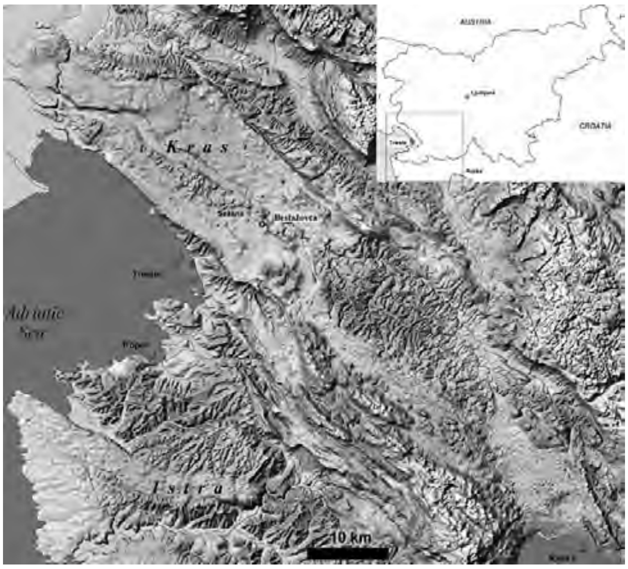

Figure 1. Kras plateau above the Gulf of Trieste and position of Bestažovca cave E of Sežana.

Bestažovca is 250 m long and 45 m deep. The cave is located at the top of a small hill on the Karst plateau about 10 km from the coast of the Gulf of Trieste at a height of 480 m (45°41’34.92”N, 13°53’30.22”E).

A small opening with a 25 m shaft is located at the top of a large entrance chamber. The floor of the chamber is covered by rocks that have been thrown into the cave over the past two millennia by farmers clearing rocks from the karst surface. From this chamber a narrow passage and 15 m shafts lead to the main part of the cave. This consists of a nearly horizontal passage about 150 m long, 10 m wide and up to 15 m high. Phreatic features on the walls and allogenic fluvial deposits, clays and silts show that the passage is a relic of an old epiphreatic cave (Mihevc 2001). The passage, known as Glavni Rov (Main Passage), was until recently connected with a collapse doline. The connection between the cave and the doline was later closed as a result of sediment creep, separating Bestažovca from one of the entrances, which is now just a large rock shelter or abri called Perkova Pečina.

Present climatic conditions in the main passage are stable, mean annual temperature is about 9 °C, and fluctuations of temperature and humidity are small.

Figure 2. The vertical entrance to the cave.

Figure 3. Perkova Pečina – the former main entrance – is today separated from Bestažovca by sediment fill.

Bestažovca was first entered in 1913 but the cave was not explored and surveyed until 1979. Cavers noticed pieces of prehistoric pottery, charcoal and some bones scattered on the cave floor and reported this to the local museum. Archaeologists visited the cave but because of the difficult access no further exploration was done (Saksida and Turk

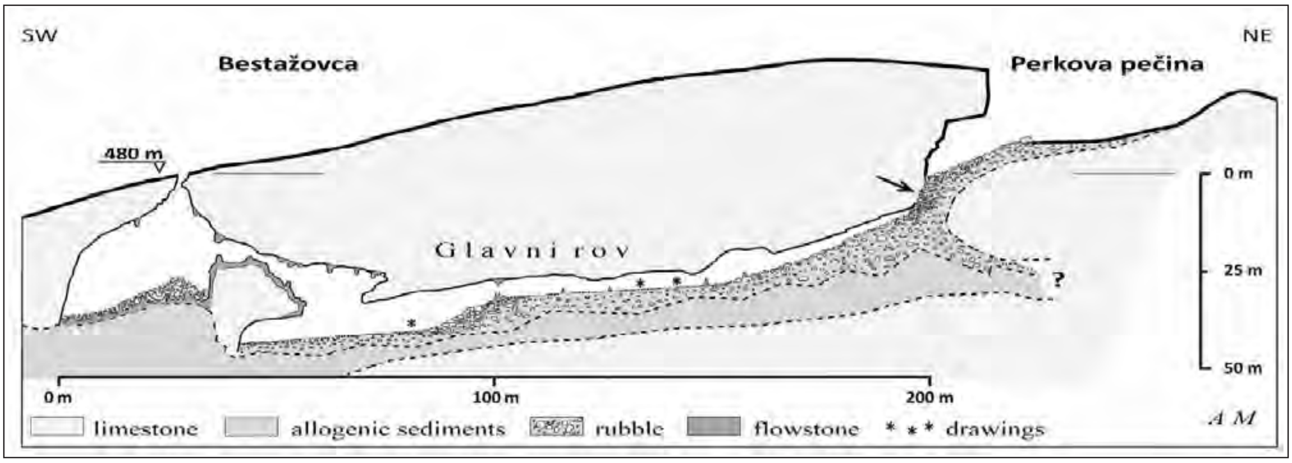

Figure 4. Schematic cross section of the two caves. The arrow indicates the narrow part of the passage that was blocked after the drawings were made and separated the caves.

1988). The pottery was defined as Neolithic.

More attention was devoted to the cave when Mihevc (2001) used archaeological remains in the cave as a time tracer to evaluate the intensity of sediment creep, which he attributed to the fact that the cave had two entrances in the past and was exposed to severe seasonal freezing. Sediment creep narrowed the entrance from the collapse doline and eventually completely filled it.

The entrance was already narrow when Neolithic people began using Bestažovca, but the cave was still quite exposed to the elements and cold in the winter. When the passage filled completely, the cave climate became stable, enabling the formation of straw stalactites on the ceiling and the growth of stick stalagmites on the formerly unstable floor (Mihevc 2009). Close study of the evidence for these events led to the discovery of red ochre drawings on the cave walls and black dots on the ceiling.

The discovery was kept secret until a stainless steel gate had been installed to protect the cave against further damage. Work in the cave is still in progress (Mihevc and Veluščček 2012) and the results presented here are only preliminary results.

Figure 5. The main panel with drawings and white coating of calcite crystals.

2. Drawings

The drawings are symbols made with red ochre on the walls and black dots on the passage ceiling. There are 32 red lines or dots preserved in three different places.

Some of them are only remnants and their original shape cannot be discerned. They have been washed away by dripping water or condensation or covered with fine white calcite crystals. The drawings only cover a very small proportion of the cave walls.

Figure 6. The largest group of drawings.

The largest group of drawings consists of 23 dots and lines. Straight vertical lines prevail. These were probably made by fingers soaked in red dye. The longest line (31 cm) splits into two branches in its lower part. Some of the lines are double width and also split in the lower part. It is most likely that these were made by two fingers. A smaller number of drawings appear on two other panels, although

Figure 7. A V-shaped symbol (top left) and three similar symbols in the lower central part of the image.

only four of them are fully preserved. In a more distant part of passage there is a drawing of one V-shaped symbol and a group of three identical V-shaped symbols tilted to the left at an angle of about 45°.

Near the largest panel on the ceiling of the passage are 35 scattered, rather irregular black dots. These were made by torches or burned sticks at least 1.5 m long. Radiocarbon dating of one of the black dots, of a piece of charcoal from a fireplace and a piece of charcoal from a torch show a narrow time span of about 500 years, dating to between 6730–7289 BP, which matches the age determined for the pottery.

In addition to the drawings, in three places there are remnants of grass or some other plant that were deliberately positioned where dripping water deposited on them a thin layer of calcite, thus preserving their shape.

After the drawings were made the entrance closed completely and created conditions that preserved the drawings.

3. Conclusions

The discovery of cave art in Bestažovca is very important for several reasons. The drawings currently represent the only known Neolithic cave art in the wider area of the Dinaric mountains and the neighbouring Alps.

They help us to understand the conditions in which cave art might be preserved. In the entrance sections of comparable caves in the area, seasonal air movements cause condensation on the walls in summer and desiccation in winter. Condensation can wash away the drawings, while evaporation of the water can cover them with white calcite crystals. Cave art is probably therefore preserved deeper inside the caves, in a zone with a more stable climate.

The find is also important because it tells us that there are still many things to be found even in well-known caves or karst areas such as the Karst plateau.

Figure 8. Grass or some other plant was covered by a thin film of calcite.

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Figure 9. Main passage (Glavni Rov): a caver is standing in front of the main panel with the drawings. Black dots can be seen on the ceiling. The floor was levelled due to cryoturbation and sediment creep from Perkova Pečina. After the connection was closed, sediment stabilised and tall stick-like stalagmites began to grow.

CAVES IN THE NEOLITHIC AND EARLY AENEOLITHIC PERIODS FROM THE NEAR EAST TO CENTRAL EUROPE

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Interpretive models of the function and significance of caves in prehistoric society are closely related to developments in the field of archaeology and changes in thinking during the 19th and early 20th centuries, which in Central and Southeast Europe continues to have a strong influence on these models to this day. Looking at the period from the Neolithic to the Early Aeneolithic, the paper tests the relationship between archaeological finds, caves' characteristics, and basic functional models of their use (habitation, pastoralism, cult practices). The most important archaeological sites are associated primarily with dark or semi-dark caves, and for the most part show evidence of cult activities. At the same time, the main phases of cave habitation correspond to periods of significant climatic changes with periods of drought. It would appear that cult activities during these periods of climatic disruption occurred only in traditional societies, whereas caves were not used by cultures that were more advanced from a civilisational viewpoint. From a general cosmological viewpoint, the underworld is part of the nonhuman realm and, like the heavens, is reserved for the gods. As a natural archetype in human society, caves were a space for communicating with the gods and, along with archaeological sites from hilltops, may express a knowledge of the mythological *axis mundi* as early as during the Neolithic and Aeneolithic.

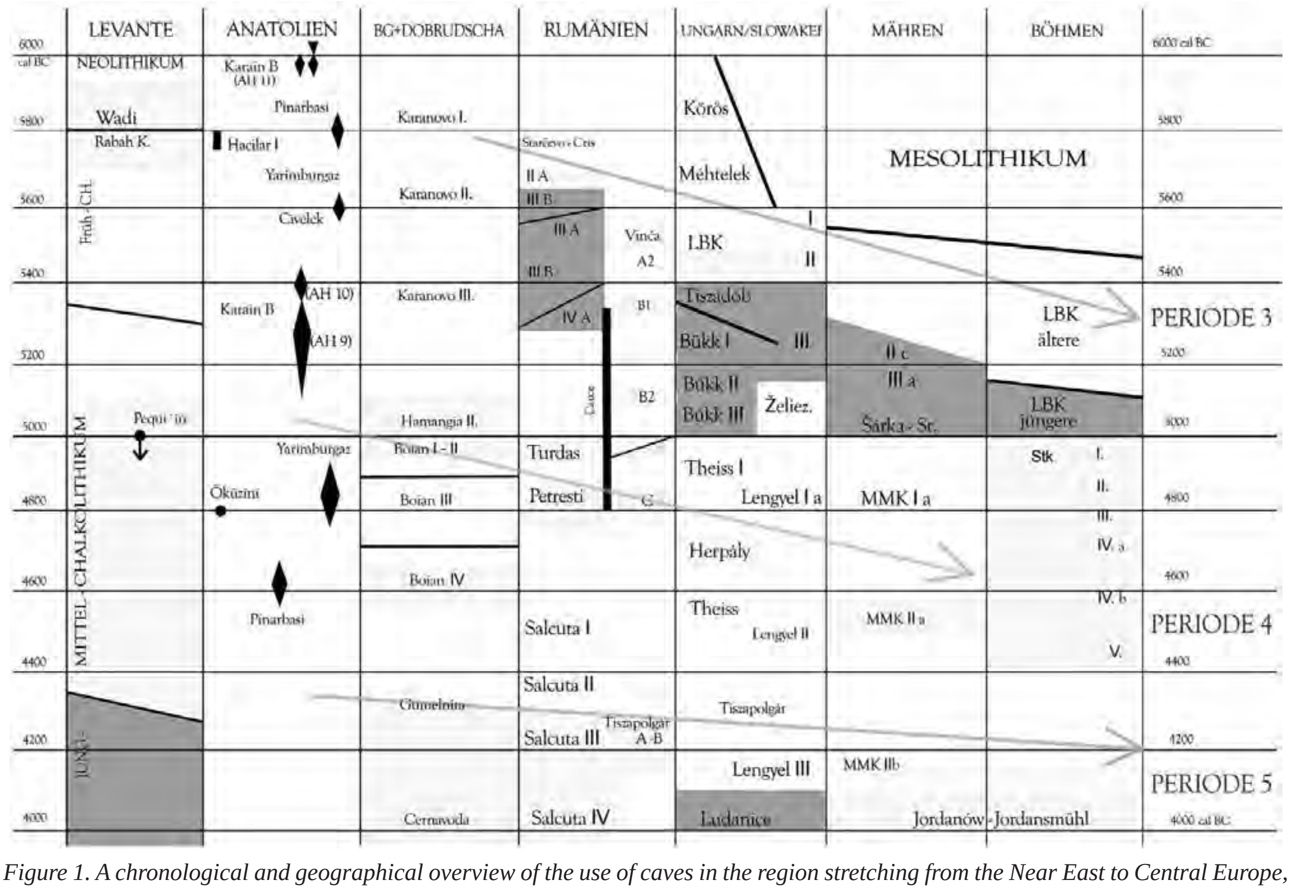

Figure 1. A chronological and geographical overview of the use of caves in the region stretching from the Near East to Central Europe, showing the hypothetical waves of the spread of the cave phenomenon (arrows). Cultures with an especially strong relationship to caves are marked in red (Peša 2011).

1. An interpretation of caves as a socio-cultural phenomenon

From the beginning of archaeological excavations in the 19th century up to the present day, caves as archaeological sites have most often been interpreted as longer- or shorter-term settlements, refuges or shelters for herdsmen; other possible interpretations for caves include cult functions and shelters for social outcasts. I see the beginnings of these notions of the universal functions of caves in two contexts. Until the second half of the 20th century there was a predominant interest throughout most of Europe in Palaeolithic history, and an interpretive model of Palaeolithic cave settlement was subsequently applied to post-Mesolithic find situations that were often less distinct or even different. Secondly, at the close of the 19th century society in general (including archaeology) viewed caves mainly as a refuge from war or as providing shelter from inclement weather while engaged in agricultural or pastoral activities away from one's main settlement. Speculations as to the greater importance of cult activities and the symbolism of caves does not appear with greater regularity in the literature until the 1980s, but the image of caves as a place of habitation persists. Using the Neolithic period as an example, the present paper attempts to describe the phenomenon of cave use within the broader chronological context while also providing a functional interpretation of the archaeological evidence in connection with the natural character of caves (Peša 2011).

2. Testing the functional models of caves

2.1. The Levant and Anatolia

The Near East is an important region for the study of caves in many different aspects. At the end of the hunter-gatherer period of the Late Palaeolithic, caves served as more or less seasonal sites that were also used for certain ritual activities. The gradual sedentarization of the people of the Natufian culture added residential objects to cave entrances, with the more important sites probably inhabited for the greater part of the year (Hayonim, Nahal Oren, i.e. Bar-Yosef and Valla eds 1991). In terms of morphology, the preference was clearly for bright, spacious and dry caves (Kebara, Shuqba, Erq el Ahmar, Hilazon Tachtit etc.) or the entrance areas of larger, wetter, and darker karst caves or the terraces in front of them (e.g., Raqefet). A similar trend continues in the Pre-Pottery Neolithic (PPN), for which there is clear evidence of more central settlements of long-term use as well as seasonal (summer) sites. The blossoming of Neolithic culture in the Near East during the PPNB and the emergence of large settlement agglomerations is accompanied by the first evidence of a cave cult (Nahal Hemar, Bar-Yosef and Alon 1988).

The Pottery Neolithic can be called a period of transformation of man's relationship to caves. Following the cultural collapse in the southern Levant and the region's partial depopulation at the close of the PPNB, but in Anatolia's Neolithic settlement centres this relationship apparently moved towards the ritualization of the underground world, one possible example of which are the anthropomorphic cave speleothems from the shrine in Çatal Hüyük. In the Late Neolithic, interest in dark and wet caves not well disposed for habitation spread to the southern Levant as well, but archaeologically more significant contexts associated with cult activities are not found in this region until during the Chalcolithic. If we accept the frequently proposed connection between climatic events (indicating, at least in local situations, the desiccation of the landscape) and the profound changes in Neolithic civilisation at the end of the PPNB, then the possibility that agricultural society would turn its attention to karst caves with a permanent circulation of underground water that was essentially independent from external fluctuations seems the logical result of the new threat to society and culture. Cave burials can be seen as early as during the Natufian Culture, when we find not only occasional burials in inhabited caves but also the first smaller burial sites separated from the inhabited area. All known burials are pit burials, and were apparently marked on the surface. There is no safe evidence of cave burials during the subsequent Pre-Pottery and Pottery Neolithic, nor is there any mention of other human remains. The situation changed during the Middle Chalcolithic at the latest, when the first caves were transformed into graves – i.e. into spaces assigned exclusively for the dead and with the associated cults, with the bodies placed on the surface of caves, either into ossuaries inside underground spaces (Peša 2011, 2011a, with bibliography).

2.2. The Balkans and SE central Europe

A similar picture of the transformation in the choice of caves is offered by the central Balkans and the Carpathian Basin from the Late Mesolithic to Early Neolithic. With the emergence of the Starčevo-Criş II B culture outside of the Mesolithic region near the Iron Gates on the Danube River, the Neolithic population focused its attention on various types of caves (Petrescu 2010), many of which are not well suited or downright unsuitable for inhabitation. A similar trend can be seen throughout the region during subsequent periods all the way to the Middle Aeneolithic. In addition to a highly variable morphology of cave interiors, we also frequently encounter skewed find sets that, with a few exceptions, lack any evidence of chipped or ground tools being processed on site, or in which food remnants are seriously underrepresented. Only two localities show evidence of features that may be considered residential (Devetashkata, Aggtelek – in front of Baradla Cave; Mikov and Dchambazov 1960, Korek 1970). The find contexts and the actual finds indicate that these sites were used intermittently for a long time (at Aggtelek, the Tiszadob group through the Bükk I culture); in my opinion, the evidence points towards a conscious and/or final placement of artefacts, and not towards discarded waste material left behind after the cave was abandoned (Peša 2011).

Figure 2. Cave in the mountain, or mountain in the cave? Children's drawing from an art contest held by the Cave Administration of the Czech Republic (2010). In prehistoric central Europe, we encounter the connection between the underworld (cave) and sky (mountain) during periods of climatic unrest, as demonstrated by archaeological finds from both borderline worlds.

2.3. Pastoralism

Pastoralism has been frequently associated with the use of central European caves since the 19th century, but this connection is only rarely based on more specific evidence. By comparison, the caves of the Near East offer abundant materials for study. The oldest known sites (rockshelters) are found in the Pottery Neolithic of the southern Levant (Rosen et al. 2005). In the landscapes of the Near East, rock overhangs and bright caves containing only a limited range of finds related to a mobile way of life and typical layers of ash left over from the burning of dung are to this day associated with a nomadic way of life (e.g., Kuijt and Russell 1993).

We find almost no cave localities in Central and Southeast Europe with characteristics similar to those of the Levant. Although we do encounter caves with thick cultural layers and a large amount of pottery in the potential pastoralist landscape of the Romanian Dobruja (Harţuche 1976), there is no further evidence except in the microregion surrounding La Adam Cave – not to mention the fact that several caves (e.g., Baba, Limanu) are not suitable for providing refuge to livestock. Another presumed pastoralist region in the Neolithic is the karst of Hungary and southern Slovakia, for which – based on the study of the region's most important caves, Domica, Baradla and Ardovo – there exists a hypothesis (Lichardus 1974) regarding winter cave habitation with stabling for livestock. We might counter that the set of animal bones from Domica and Ardovo Caves consists primarily of game (70–80 %), meaning that domesticated species including the most common (sheep/goats) strike us as merely supplementary. What is more, none of the many comprehensively explored caves throughout the region yielded layers of ash containing animal dung, which would have indicated the long-term stabling of animals. Also, the model of winter cave habitation and summer pastures in the surrounding countryside does not correspond to the system of transhumance as described for the Near East and Balkans, which by all indications never included dark and wet karst caves.

2.4. Cult and ritual activities

In all regions, the aforementioned change in the significance of caves associated with the emergence of the agricultural civilisation of the Pottery Neolithic was expressed primarily in the choice of new types of caves that had not been sought out previously and that were less suitable or entirely unsuited for habitation. It would seem that these sites may have been visited for their specific natural features – for instance, cave formations featuring various sinterous formations that often were of an anthropomorphic or zoomorphic nature, underground sources water, or the overall character of dark spaces without any sensory stimuli and thus suitable for meditation or for bringing about altered states of consciousness. Whereas the Neolithic find contexts in Balkan caves are generally nothing special, with the onset of the Aeneolithic they become more distinctive, and there is an increase in the thickness of cultural layers and the number of finds, especially pottery (e.g., Devetashkata, Hoţilor, Româneşti). In archaeological terms, the apparently most significant function of caves is as a place of final – probably votive – placement of various items, with vessels (empty or not) later clearly predominating (e.g., Kjuljuk in Bulgaria, Meziad in Romania) (Peša 2011 with bibliography). In the karst regions of the western Carpathians, the intensive use of caves spread at the beginning of the Middle Neolithic. The archaeologically significant Domica, Baradla, and Ardovo Caves are part of an active karst system interlaced by underground streams and contain Neolithic finds exclusively in dark portions of the cave far from the entrance. The specific importance of these caves or of the activities performed therein is evidenced by archaeological finds containing a high incidence of anthropomorphic decorations of vessels, as well as the more frequent incidence of decorated ceramic tableware as compared to open air settlements (Kalicz and Makkay 1977, Šiška 1989, Soják 2003). In the smaller Bükk Mts. caves, the cultural layers contain human bones related both to occasional burials (Büdöspest) as well as to potential ritual activities (Istállóskö). In the Moravian Karst, dark caves or caves with decorative cave formations would appear to have been popular for cult activities as well (Koňská jáma, Výpustek).

3. Caves as an archetype of nature in human culture?

Based on archaeological sources, I can say that for the studied area of the Near East, the Balkans, and the SE part of Central Europe there is clearly more information on various forms of cult activities starting in the Neolithic than the mostly unclear evidence of a habitational, economic, or pastoralist character. Settlement activities or shelters outside of permanent settlement structures are related to the economic and social development of society (i.e. archaeological culture) and can be highly variable on the level of individual human lifetimes. If we take into account the period of the past 400 years, practically every generation has experienced some war or period of unrest, but archaeologically speaking these events have left only very imperceptible traces in caves (Peša 2013). A similar situation can be found in Central Europe and further to the east in relation to modern pastoralism, which has left very different and less conspicuous traces than the majority of important Neolithic cave sites.

The conspicuous alternation of periods of intensive use of caves with periods containing no archaeologically documented interest has been repeatedly discussed by researchers (e.g., Matoušek 1996), albeit with uncertain or pessimistic conclusions. The alternation of several centuries of hiatus with another several centuries of more or less continuous usage (Fig. 1) tends to indicate global causes that go beyond the specific local problems of society. Should the majority of important Neolithic caves yield evidence of cult or ritual use, then this would mean that periods of interest in caves are related to the religious topics of the era and the long-term needs of communicating with the spiritual realm. Human culture can be threatened by extensive military conflicts or global changes in climate. Both causes have been felt in the past and continue to have a catastrophic impact primarily on a society's economic and agricultural potential. As compared to conflicts, climatic changes are reflected either indirectly through changes in settlement structure and topography, or are increasingly documented and thrown into a clearer light by palaeoclimatological research. The strong correlation between unstable climatic fluctuations of the Sub-Boreal period (i.e. Ložek 1998) and an increase in cult practices (not just in caves but also at other natural features) serves to corroborate events from the Late and Final Bronze Age and may offer an explanation for the situation in the Neolithic and Aeneolithic as well (cf. fluctuations between 5200 and 5000 cal BC – Gál, Juhász and Sümegi 2005, Gronenborn 2012).

Figure 3. The cave as a living being in a mixed-media drawing from an art contest held by the Cave Administration of the Czech Republic (2010). Among the peoples of Mesoamerica or Siberia, the cave's personification with the intangible forces of nature is a part of the cultural consciousness to this day, and fragments of this worldview have been preserved in central Europe as well.

In response to the question, "If all the cultures from this period were under the same environmental pressures, why didn't they all use caves during this same period?" I offer the following hypothesis: Cultural societies express their identity via cultural norms, through which they define their relationship to extra-cultural phenomena – which, according culturological definitions, include all that is biological and natural. The stronger a society's socio-cultural sensibilities and the deeper its faith in its mechanisms of cultural development, the lower its need to turn to culturally indefinable and incomprehensible nature and its forces. As is clearly visible from an overview of the cave phenomenon from the Neolithic to the Early Aeneolithic (Peša 2011), the most civilised societies in terms of the most advanced expressions of material culture and social (power) hierarchies – i.e. the inhabitants of large settlements, tells or agglomerations – show only an imperceptible or often no interest in caves – as compared to the agricultural populations of less fertile regions with a lower social and power hierarchy. For these traditional societies, caves may have represented an unchanging archetype of the natural forces that were more than tangible during times of environmental change.

Global climate changes with periods of drought affected first and foremost landscapes with a sensitive ecosystem – of which karst regions and their caves are a perfect example. As the landscape's economic potential declined, the region's underground with its wet spaces (and, in rare instances, underground streams of water) must have appeared all the more promising. Theories as to the practical importance of such caves as mere sources of water are off target, not to mention the fact that despite their wet character most caves could scarcely suffice as an equivalent source of water. According to the general cosmological division of the world into three planes (the sky and the underworld as the seat of the gods and the earth's surface as the realm of people), caves are part of the non-human realm. This is confirmed among other things by cultural anthropologists' observations from various parts of the world (e.g., Eliade 1971, Brady and Prufer eds. 2005). The underground, with its typical attributes of permanent darkness and the absence of stimuli, differs significantly from man's natural environment and in the mythologies of non-European nations is inhabited solely by gods or demigods that rule the forces of nature associated in particular with rainfall and harvests. In mythology, the main significance of the underworld is as the potential source of all rivers and streams that spring from the ground, as well as all plants that grow out of it. Similarly, on the basis of ethnoarchaeological analogies, caves contain a multitude of meanings as sacral symbols or as diverse parts of comprehensive ideological systems, and when associated with the vagina or the womb of the earth and fertility, they may represent places of transition between different states of existence (Brady and Prufer eds. 2005, Lewis-Williams 2002). What is more, caves' frequent location on mountains or hillsides forms a figurative Cosmic Axis – *Axis Mundi* – connecting the underworld with the heavenly realm (Satari 1981, Matoušek 1999). This connection may in fact be why caves are ascribed the ability to influence the weather and why people have sought the source of winds in the underground, i.e. in the draughts coming from cave (for Mesoamerica, Brady and Prufer eds. 2005, 21fl; for Central Europe, Peša 2013). Even in the recent past, this vertical view of the world was still a natural, universally valid and respected part of the human awareness of existence (e.g., Eliade 1971). In fact, the concurrent existence of cult activities in caves as well as on hilltops and mountain peaks may represent an archaeologically tangible testament to this Cosmic Axis.

4. Conclusion

It strikes me as likely that because they were accessible natural objects from the underground realm of the universal cosmological model of the world, caves represented primarily a place for man to communicate with the relevant deities that according to the various cultures' mythologies ruled over the natural elements. Thus, during times of climatic pressure, not only actual sources of underground water but perhaps also most other caves in general became places of worship and cult rituals. Of course, this return to natural values as the result of global events could take place in those cultures and societies that retained at least a partial awareness of man being a part of nature. According to our picture of caves, in most cases this therefore did not include highly developed societies with significant social hierarchies and advanced levels of organization – at least not in the studied territory from the Neolithic to the Early Aeneolithic. Also, despite the presumed universality of this interpretation, this does not mean that all caves were necessarily and unconditionally used merely as places of cult activity or sacrifice. In many cases, specific regional or societal customs or cultural traditions surely played a role as well.

Caves as important cult or religious sites fall within the concept of the sacral landscape, whose universality is documented by geographically remoted analogies (Brady and Prufer eds. 2005). Such a concept of the landscape is closer to the traditional view of the Central European landscape of the Middle Ages and the modern era, and was only recently forgotten by modern society.

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THE CULTURE OF ANTHROPOGENIC CAVES WITH STONE DOORS IN ANCIENT ARMENIA

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There are lot of underground constructions in the Armenian Highland, which has not natural tunnel gates, have stone made doors, and in the holes there are from 500 to 3,000 liter capacity pitchers for grain and some vine and oil products in just rock-cut and cave monuments. Those anthropogenic caves are called the caves with stone doors. Almost 100 of them could be found in the foot of mount Aragats. Those caves are considered to be Midvale period constructions, but depend on our observations we could justify that there appeared in 6 thousand years ago.

1. Introduction

Based on the large amount of collected scientific material about rock-carved dwellings and anthropogenic caves in Asia Minor and in the Armenian Highland, we can boldly speak about the “cave culture”. I think we can use the term “cave culture” since, starting from architectural and engineering specificities up to the daily life and relationships of the cave dwellers have made a unique thinking and culture.

The surroundings of Mount Aragats have been repeatedly investigated by archaeologists, architects and naturalists, and since 1982 – also by speleologists. The speleological expedition of the Geographic Society of the Armenian SSR Academy of Science in 1982–85, 1989–90 and the expedition of the Armenian Speleological Center, since 2002–03, have implemented voluminous works in this site discovering, studying and classifying rock-cut and cave monuments. Simultaneously, local geological surveys were carried out to provide the geological assessment of the location of the cave structure. Overall, more than 160 rock-cut structures and improved and used-by-man caves were discovered in the area from Talin to Ashtarak and then Mount Ara – Aragats area. The caves with stone doors are rare rock-cut structures. This type of cave structures have compactly survived only in this area.

2. Stone doors and tunnels

The maximum size of the stone doors of caves in Aragatsotn region is 160 cm × 130 cm × 42 cm, weighing more than 3 metric tons; the minimum size is 60 cm × 40 cm × 16 cm. The stone doors are placed both lengthwise and crosswise, depending on the composition of and structure of the rocks in the installation place. Stone doors are placed in frames and work like regular doors.

The frame is a plate with comparatively large cutting and made of a partially polished basalt, andesite and in rare cases hard tuff. In one corner of the plate, usually near the already installed stone doors, in the left side (where the entrance is), a funnel-shaped pit was dug up to 50 cm deep and up to 50 cm diameter of edges. In both sides of the stone door there are hewed lugs adjusted to the funnels carved in the stone frame and firmly but still suitably enough to keep the mobility of the well settled door.

Figure 1. Image of tunnel from inside the cave.

Figure 2. Stone door (“secret” door) between the two rooms of the cave.

Figure 3. Large stone door: the entrance.

Figure 4. The lug of the axis of the stone door enters into the round pit on the plate over the arch.

The technology of installation of stone doors prompts that these anthropogenic caves were built based on a plan of general architectural setting. This is evidenced by the sequence of construction process.

3. Methods

First, the tunnel was dug, and then the stone doors and separate polished pieces constituting the frame were taken in. Inside the cave, while in horizontal state, the plates with funnel-shaped pits were fitted on the lower and upper sections of the door and then placed vertically in the tunnel: Then the side plates of the door frame box were installed, one from each side. Then the door was reinforced with rock pieces, in rare cases using also mortar. In the last phase, the tunnel was laid, and small and large pieces of volcanic-fragmented rocks were disorderly filled over the surface section, thus covering up the structure.

The lower and the upper sections of the frame of the stone door is polished, smoothed in the size of the segment of the door's movement and ends by a low lug crossing the stone plate in its entire length and limiting that surface, which restricts the door's movement and does not allow to open outwards. The rotation axis is put under slope to the direction of the stone door lugs, which makes the work of the door easier. Even a child can easily shut the door weighing hundreds of kilograms: My son Aren was only 8 when he could open and shut average size stone doors.

Inside, the stone doors are locked either by entering edge under the door or by a lock. All doors we have come across or studied are opened only towards the cave so it is impossible to lock from outside.

There is a unique example of engineering solution of a lock in Seven-Door Cave, to the north of Kosh village, in the vicinity of medieval St. Stapanos Church. Right on the left section of the frame of the entrance door (looking from inside the cave), three 12–13 cm deep, 4.5–5 cm wide and 36 cm long parallel furrows are carved on the basalt plate in 5 cm distance from each other. From the flank of the frame, in the middle of the plate's cutting, a vertical penetrating hole is opened that crosses these furrows through the entire width of the plate. There is a 6–8 cm deep, 5 cm to 7 cm wide and 13 cm long pit carved towards the hole. After locking the door from inside the cave, a pole made of a hard material (metal, stone, at least hard wood) is inserted into the penetrating hole so that it thrusts into the door pit. The parallel carved furrows play a role of windows, whence the watcher can see and make sure the shutter is well placed. This was how the doors were locked in past times.

On most of the stone doors, special pits were made on one or both sides to fix the door handle.

Figure 5. Flooded cave.

As we already mentioned, the funnel-shaped pits carved on the upper and lower plates towards the rotation axis are not necessarily carved only on the plates. We have come across several "foundation stones" that look square, similar to stone for chopping up grains, which are still used in mountainous villages. Such mortar-like component of the frame with pits intended for the stone door lugs was used only for the lower section of the door; the surface of the upper section plate is smooth. In rare cases one can encounter doors with lugs smoothed only in the lower part. Stone doors processed this way have, as a rule, smaller than average size.

These carefully smoothed square or rectangular 18–20 cm thick basalt doors are disseminated mainly on the slopes and at the foot of Mount Aragats, as well as in quaternary lavas erupted from the volcanic mountains in Lake Sevan basin or in the area of caves located in the contact of consecutive layers.

Figure 6. The stone doors are locked from inside with a lock. The lock can be made of a stone or wooden beam which passes through the rigid stone and enters deep into the pit over the door.

Figure 7. The lock and the pit over the door into which the catch of the lock enters.

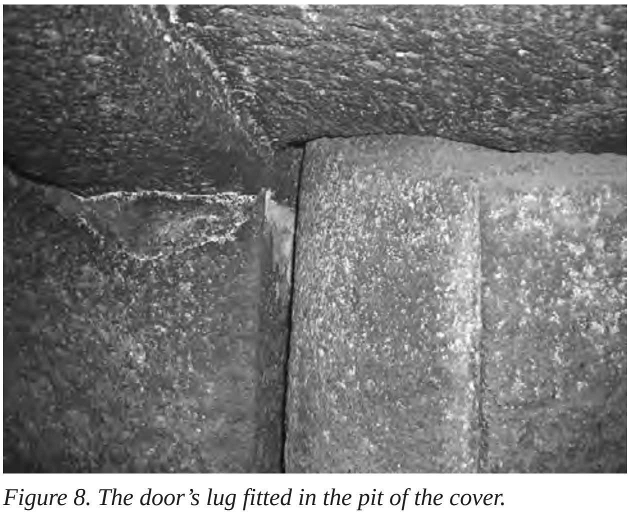

Figure 8. The door's lug fitted in the pit of the cover.

A large number of caves with stone door, about 60, have survived in the areas of Kosh-Avan and Sasunik-Ujan; there are another two, still used, caves with large doors in Talin region and a few doors and ten door frames on the volcanic mountain slopes in the south and south-east of Gegharqunik marz. All these have been processed by the same principle and mainly for the same purpose – to lock the tunnel and cave entrances.

We came across the remains of the only ignimbrite tuff-made smoothed door in the vicinity of Karmrashen; however, I don't think this can be a pattern. The caves with

Figure 9. Probably wooden handle was fitted into the pit made on the outside surface of the door.

stone doors are built in a way that the doors can be locked only from inside; i.e. when there is nobody inside the cave, it is easy to enter the cave in case when the main stocks of food for the survival of a large group of people were stored there. On the other hand, the possibility of locking the stone doors only from inside directly points out that a person or a large group of people had the opportunity to get isolate themselves from the world for some ritual reasons. And there is not a single structure for defense or any construction detail that would indicate the necessity of confronting the enemy; hence the hypothesis that theft, robbery, fraud and war were alien to the times of stone-door caves. Probably this thinking was characteristic to the natives of the Armenian Highland in 1^{st}–2^{nd} millennia B.C. and then it became a custom and was preserved until mid 20^{th} century.

Here are descriptions of a few caves.

4. Results and discussion

Seven-Door Zagha (the cadastre number 172-9).

Located to the north of Kosh village, 0.1 km north of St. Stepanos Church, in the right cliff wall of Vanadzor, approximately 30 m high from the bottom of the ravine. The narrow corridor covered with basalt pieces leads to the hall. You can pass through the tunnel-corridor only if you bent or creep. The tunnel is laid with whole rectangular basalt plates with removed sharp lugs on the surface. Along both sides of the corridor, the vertical 10–12 cm thick basalt plates laid without mortar are arched by similar plates that provide the ceiling of the tunnel. The engineering concept of the tunnel resembles a megalithic structure. Although the local people call this cave a Seven-Door Zagha, it has only two doors, one directly at the entrance and the other at the hall entrance. The doors is likely working, however the dust, soil and sand accumulated during many years covered the door's foundation with a 20–25 cm layer thus making the door nonoperational. The door was still working at least in 1987 when we were studying and measuring the cave. The frame of the stone door of the hall has three lengthwise hollows with another transverse hollow crossing these three. The transverse hollow is made on the surface that longwise fits in the door frame. Most likely, transverse hollow has been made to run the shutter, while the longwise crack-hollows played the role of "windows" to see how the shutter moved. The doors, like in all other caves, open inward.

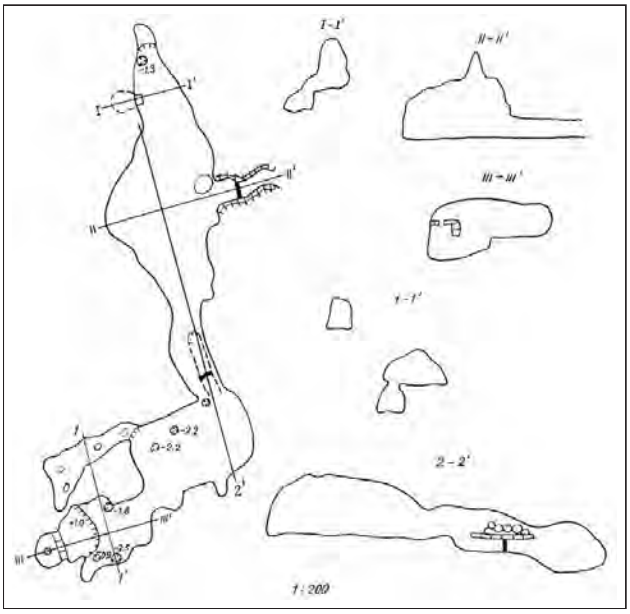

Figure 10. Plan and section of cave; cadastre # 172-6.

On the north-east wall of the cave, a clay canal opens 2.5–3 m above the ground. The diameter of the mouth of the pipe is 23 cm. How the canal conveyed water to the cave through the thick basalt layer with 15 m cutting – is something still to be find out. The assumption could be that the pipe way was a natural hydrodynamic tunnel, and the ancient builders, after laying the clay pipe through the tunnel, have skilfully veiled the tunnel with some constructional trick still unknown to us.

The walls of the cave are laid with large pieces of basalt reinforced by lime mortar. In the southern and south-western part of the cave, under the wall, there are casks on two platforms for keeping fluid (probably vegetable oil or wine) and for dry food (grains). The first platform is 15–20 cm above the bottom of the cave; and 4 cask mouths open here, while in the second platform, 120 cm higher than the first one, 6 cask mouths open. The small cavity located at 6m depth from the tunnel entrance was perhaps another storage place.

The cave is one of the favorite places for the village children; they are frequent guests here. They often make fire, however the smoke immediately flows out through the cracks in the basalt cover.

Bkoyi Gegh Seven-Door Cave (the cadastre number 172-9). This cave is located in the right cliff wall of the Bkoi Dzor

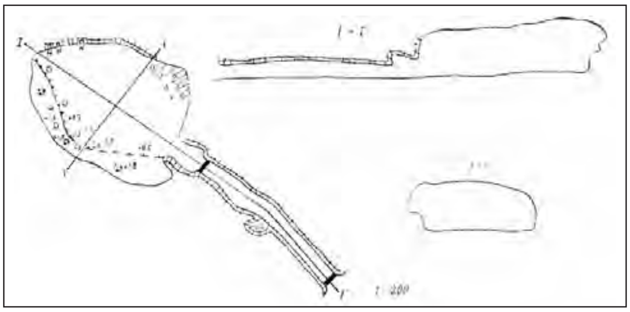

Figure 11. Plan and section of cave; cadastre # 172-9.

ravine, 20 meters above the ravine's bed, 1 km to the north-west of Ujan village, 100 meters to the north of cave.

It is possible that the cave has received its name due to the number of its doors in the past.

The tunnel-passage leading to the cave is hardly passable; two nearly equal size doors are placed here, both can be easily opened and shut. Here, like in all caves with stone doors, the doors are locked from inside. The artificially laid part of the tunnel is totally collapsed, and most likely the remaining 5 doors were left under the landfall, as the local folklore says. The entrance of the tunnel is narrow and hardly passable. The narrow passage leads to the first door; opening this door you move on to the second door either creeping or half-sitting. Opening the second door, you appear in the cave hall. The distance from the entrance to the 1st door is 3 meters, and from the 1st door to the 2nd door – 2.5 meters. The hall is misshapen, the bottom is flat, and the ceiling is 2.4 meters high. There are cask-like pits in the corners of the cave, which are intended only for storage of grain food. There are no fired clay casks. There is an opinion that the cave was of ritual importance.

Figure 12. Pit for liquid foods.

Acknowledgments

The stone-door caves are rare architectural, engineering and cultural monuments of the past that are now exposed to the danger of demolition. These caves are part of not only Armenian culture but also part of the culture of the Indo-European peoples in general. With the loss of these caves we will lose yet another possibility of seeing the past alive. Saving these caves must be the point of concern for all of us.

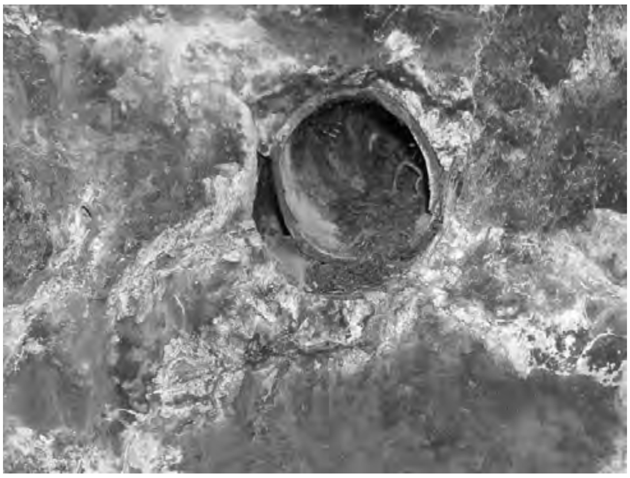

Figure 13. Clay pipe of canal opening in the cave.

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LEVANTINE CAVE DWELLERS: GEOGRAPHIC AND ENVIRONMENTAL ASPECTS OF EARLY HUMANS USE OF CAVES, CASE STUDY FROM WADI AMUD, NORTHERN ISRAEL

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The human use of caves has its origins as far back as million years ago, when early humans began to use them as seasonal camp sites. At about 500,000 Ka the use of caves by these small groups of hunter-gatherers became a widespread phenomenon in Africa and Eurasia. In Israel alone (at an area of 8,800 km^2) there are about 40 prehistoric caves, dated between 500,000 and 50,000 Ka. Because the number of caves on the landscape is much higher than the number of caves used by our ancestors, we assume that the preference of particular caves within a group's geographic territory involved a system of decision-making based on selection criteria. We attempted to identify these criteria in the Amud catchment, where four well-known Paleolithic caves are located. The study included a systematic pedestrian survey of the canyon, detailed documentation of the physical properties and locational characteristics of the caves, and analysis for pattern recognition with GIS and statistical methods (at an area of 2.6 km^2). One hundred and twenty caves and rock shelters were located, studied and mapped. By comparing the characteristics of caves that were uninhabited with those of the four known Paleolithic sites we constructed a model of the "preferable cave". Paleolithic hominins selected large caves, consisting of one large central hall, with large entrance that allowed good ventilation and natural day light. Preferable caves were rather hidden and protected in the lower part of the canyon and could be approached easily from the streambed or lower slopes. Finally, prehistoric caves in the Amud canyon are located next to the stream outlet (rather than at the center of the hilly region), where a large number of habitats could be reached on a daily basis.

1. Introduction

At the dawn of mankind, different types of hominins (early humans) evolved at the African savanna. A set of preconditions have led at least one of them to develop culture and technology. The earliest stone tools are dated 2.6 Ma years ago, at Gona, East Africa (Semaw et al. 2003). The earliest firm evidence to controlled use of fire is 780,000 ka years old, at Gesher Benot Ya'aqov site, Israel (Alperson-Afil and Goren-Inbar 2010). Technological and cultural innovations accumulated, allowing early humans to occupy a growing variety of ecological habitats and resulted in the geographic expansion of Homo erectus outside Africa. The strategy of using caves as temporal shelters might be considered as one of these innovations. The advantages of cave occupation may have played a significant role in colonizing of cooler climate zones out of Africa.

The prehistoric site at Wonderwerk Cave (South Africa), with an arguable date of 1.58 Ma (Chazan et al. 2012), may be the earliest recorded cave occupation, but it is followed by a long gap in cave habitation by hominins. Other, more firmly dated cave site is Sima del Elefante (Spain) ~1.3 Ma (Martinón-Torres et al. 2011). Then, from about ~600,000 Ka and through the Late Lower Paleolithic (LP) and the whole Middle Paleolithic (MP), occupation of caves by humans became a widespread phenomenon with hundreds of cave sites at Africa and Eurasia (Neuville 1951; Lubin 1997; Rink et al. 2003; McNabb and Sinclair 2009; Lombard 2012).

Prehistoric research in Israel began during the 1920's with the work of pioneer archaeologists Turville-Petre (excavation in Zuttiyeh Cave, 1925), Garrod (excavation at Shukbah Cave, 1928), Neuville (excavation at the Judean desert and Qafzeh Caves, 1928–1932) and others (See summary in Hovers 2009). Currently, the PL and MP record of Israel and the southern Levant is relatively rich in excavated cave sites. Some 30 of them are known from the Mediterranean climatic zone, especially from Mt. Carmel and Wadi Amud. Additional 10 are known from the western fringes of the Judean Desert, mainly in Wadi Haritun and at Upper Wadi Arugot (Neuville 1951) (Fig. 1). Some caves have a long sequence of layers (e.g., Tabun Cave in Wadi Me'arot and Ha'Yonim Cave in the Western Galilee, with finds from the LP through the MP [Garrod and Bate 1937; Jelinek 1982; Stiner 2005]). Other caves have a shorter occupation sequence (e.g., Amud Cave, dated to late MP ~70,000–50,000 Ka [Hovers et al. 2011; Valladas et al. 1999]). In some cases, occupied caves are clustered geographically (e.g., Wadi Me'arot, Wadi Amud, and Wadi Haritun). Yet, not *all* the caves in these cave-rich areas were occupied. Moreover, some catchments with large caves in them seem to be devoid of prehistoric cave occupations. The repeated occupation of specific caves over thousands to tens of thousands of years therefore points to underlying processes of selection from an existing inventory of available caves and rock shelters, based on a combination of decision criteria.

The "pull" and "push" of hominin groups to specific places depends on physical traits of the landscape as well as social considerations (e.g., Jochim 1976). The type of study reported here is informative about the former type of decision criteria, as it stands to reveals regularities in cave locations relative to landscape features. But it can also point to some social considerations. Our purpose in this study was to create a model of early human's decision-making system regarding the selection of caves for occupation by hominin groups. Towards this end, we collected geological and speleological data regarding caves and their nearby landscapes. Characterizing both “Paleolithic caves” and “empty caves” at a selected research area, in this case Wadi Amud enabled us to discerning some features that are shared by “Paleolithic caves” which likely played a role in early humans decision-making process.

The use of a cave as a seasonal occupation site offered several advantages, such as protection from the elements: rain, wind, direct sun light, some isolation from cold temperatures, as well as a confined space easier to protect from predators. The typical archaeological finds in cave sites dated to the LP and MP consist of the remains of stone knapping and stone use and faunal remains. Plant remains are less common. From the late LP (ca. 400 Ka), combustion materials and remains of fireplaces become typical feature of cave occupations. Hearths were used among other possible purposes for food processing and probably for heating and lightning, and perhaps also for protection from predators. Such finds, and their massive accumulation in many of the prehistoric caves, indicate that the localities were used repeatedly as habitation sites by groups of prehistoric hunter-gatherers. Combined with non-anthropogenic sediment accumulation, this has led in some instances to the accumulation of deep stratigraphic sequences reaching several meters.

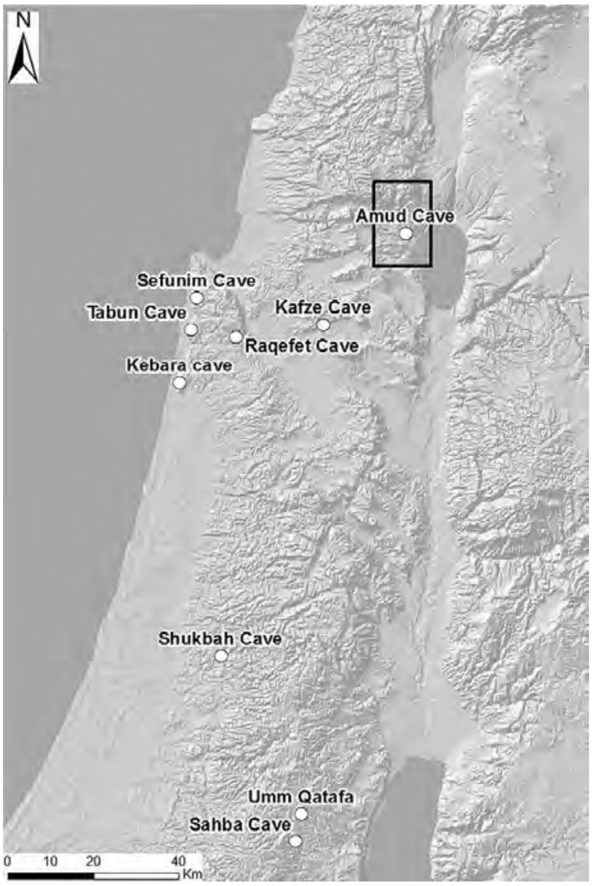

Figure 1. Map of Israel with important LP and MP cave sites. The research area is marked with black frame.

2. Geography and geology

The majority of caves in Israel (among them the caves that contain prehistoric occupations) are karstic chamber caves that formed up to tens of millions years ago in calcareous lithology (limestone or dolomite) as phreatic hypogenic voids. Incision of streams, associated with tectonic uplift of the central mountain range of Israel, as part of a regional uplift truncated and exposed those karstic caves (Frumkin and Fischhendler 2005). As a result they became accessible to hominins inhabiting the landscape.

Wadi Amud drains an area of 124 km^2 of the Upper Galilee. The channel drops some 1,400 m from an elevation of 1,200 m above msl at its origins at Mt. Meron, to 200 m below msl at its outlet, at the Sea of Galilee, over an aerial distance of 15 km. The climate at lower Wadi Amud is Mediterranean semi-arid, with 450 mm annual rainfall (Hovers 2004). The direction of the flow and the configuration of the channel are a phenomenon of the last ~2 myr, and were formed as a result of channel capture due to tectonic activity in the Rift Valley (Kafri and Heimann 1994). The geographical structure of the middle and lower part of the stream consists of two geological formations (Timrat and Bar-Kokhba Fms.) of Eocene limestone (Bogoch and Sneh 2008). The Bar-Kokhba Fm. forms cliffs and canyon morphology, while the underlying Timrat Fm. appears as moderate slopes. The meteoric water draining eastward over the steep gradient incised a deep canyon through the hard limestone, exposing a large number of karstic voids (Fig. 2).

Our project focuses on this section of Wadi Amud (Fig. 1), where four prehistoric cave sites are located (see below). From an elevation of 20 m above msl, to the stream base level at the Sea of Galilee 200 m below m.s.l.

Figure 2. General view of Wadi Amud canyon (looking south).

3. Methods

In order to explore the use patterns of caves by prehistoric people at Wadi Amud we first had to gain detailed data about the number, morphology, location and contents of the caves and rock shelters in the study area. Filed work was conducted as follows:

a) <u>Defining the survey areas:</u> Wadi Amud drainage system was selected because it has four known Paleolithic cave sites located at the same canyon, less than 2 km from one another (from north to south: Shovakh, Amud, Zuttiyeh and Emireh caves).

b) <u>Survey of both walls of the wadi, using topographic maps (1:50,000) and panoramic photographs:</u> Every cave larger that 2 × 2 m, and every rock shelter that could provide some protection from the elements, were mapped. The panoramic photographs facilitated locating cave entrances, which sometimes were hardly observed by foot. A systematic field survey of the slopes at different elevations allowed us to locate hidden cave openings as well as remains of eroded caves.

c) Description of the characteristics of each cave or rock-shelter, including: 1) Determining its location by 12 digit GPS coordinates (ITM coordinate system); 2) Morphological description with planar and vertical standard cave mapping (Grade 5B), (Dasher 1994); measurements were done by Leica Disto D3 laser meter-inclinometer and Silva Ranger 3 prismatic compass; 3) Determination of prehistoric human presence by archaeological observation; 4) Documentation of a variety of traits/features such as evidence of roof collapse, speleothems, breccias, etc.

d) Creating a computerized database: Data was processed in an ACCESS data base, to enable sorting and comparing the different parameters.

e) Spatial and statistical analysis of the data.

4. Results

In total, an area of 2.6 km^2 was surveyed along ~6 km of Wadi Amud canyon. One hundred and twenty caves and rock shelters were located and mapped (Fig. 3). Most are phreatic voids that developed along tectonic fissures. Ninety percent of the caves and rock shelters are within the massive limestone cliffs of Bar Kokhba Fm, while less than ten percent are within the well-bedded limestone slopes of Timrat Fm. The latter caves are also much smaller.

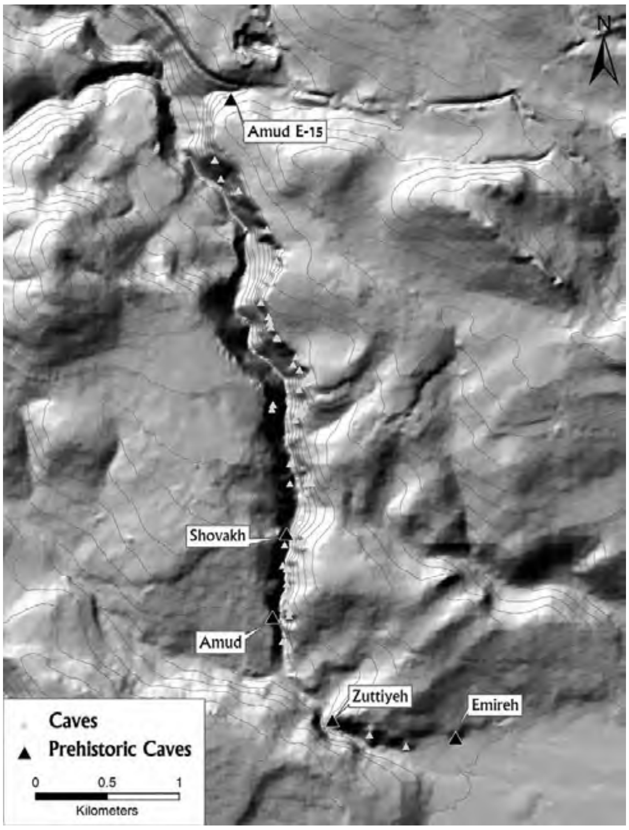

Figure 3. Caves, rock shelters and prehistoric caves at Wadi Amud (N =120).

4.1. Prehistoric sites

Four Paleolithic cave sites had been known in Wadi Amud prior to the current study (Turville-petre 1927, Binford 1966, Gisis and Bar-Yosef 1974, Valladas 1999, Hovers et al. 2011) (see Table 1). An additional cave (AmE-15) was found during the survey. This cave contains anthropogenic *breccia*, inclusive of flint artifacts, bones and what appears to be charcoal. Similar breccias are described at many Paleolithic cave sites in the Levant (e.g., Zuttiyeh, Tabun, Qafzeh caves) and we therefore deduced that the artifacts in the *breccia* of AmE-15 reflect Paleolithic human activity in the cave. Some other caves yielded considerable amount of flint artifacts and bones of large mammals, but with the absent of any "*fossil directeur*" we could not determine the time of the human activity there.

4.2. Cave types

We distinguish between caves and rock shelters: The shape and dimensions of a cave forms a confined void, in which the conditions differ from those of the surrounding environment. The morphology of a rock shelter offers only some protection from the elements, and is considerably more exposed than a cave. We sorted both types according to their dimensions (Tab. 2). The size category refers to the main hall of the cave/rock shelter. Beside those, other three types of caves were found at the research area during the survey: Phreatic passages (narrow and long passages with phreatic morphology, such as oval cross section); Maze caves (having a network of chambers and passages along tectonic fissures); "Tectonic fissures" (have elongated shape and straight parallel walls along fractures or tectonic faults, but did not develop to wide passages) (Tab. 2).

4.3. Cave approach

The approach difficulty level was assessed on the basis of two parameters: 1. Slope inclination (minor/moderate/steep/nearly vertical). 2. Time required to approach the cave from the nearest topographically comfortable area (e.g., streambed or the plateau above stream) while carrying 10 kg load. A short time approach is considered as a walk of up to 5 minutes. Medium time approach takes 5 to 15 minutes and long approach is of more than 15 minutes walk. An easy approach is when the slope is minor or moderate and walk takes up to 5 minutes. A medium approach is when the slope is moderate and walking time is medium. A difficult approach is when slope is moderate and walking time is long or when slope is steep and no matter how long the walk is; dangerous approach is when the slope is almost vertical or vertical in a manner that requires the aid of belay equipment or rock-climbing skills. Table 3 shows the distribution of assessed approach difficulty regarding to each cave type.

5. Discussion

5.1. Cave dimensions

The first notable characteristic of the prehistoric caves at Wadi Amud is their relatively large dimensions. Shovakh,

Table 1. Periods of prehistoric occupations at Wadi Amud caves.

	Shovakh Cave	Amud Cave	Zuttiyeh Cave	Emireh Complex
UP				
Transition MP-UP	+			+
Late MP	+	+		
Middle MP				
Early MP			+	
Late LP			+	

LP = Lower Paleolithic 1.4 Ma–300/250 Ka, MP = Middle Paleolithic 300/250–50/47 Ka, UP = Upper Paleolithic 50/47–23 Ka (Levant chronology).

Table 2. Distribution of caves and rock shelters according to their dimensions and type.

Cave type	Length (m.)	Width (m.)	N	%
Large chamber caves	X ≥ 15	X ≥ 15	7	5.8
Medium chamber caves	8 ≤X <15	8 ≤ X < 15	12	10
Small chamber caves	2 ≤X <8	2 ≤ X < 8	37	30.8
Large rock shelters	2 ≤ X	X ≥ 15	9	7.5
Medium rock shelters	2 ≤ X	8 ≤ X < 15	12	10
Small rock shelters	2 ≤ X	2 ≤ X < 8	35	29.2
Phreatic passages			3	2.5
Tectonic fissures			3	2.5
Maze caves			2	1.7
Total			120	100%

Table 3. Distribution of estimated approach difficulty according to cave types.

	Easy	Medium	Difficult	Dangerous
Large chamber caves	3	3	1	0
Medium chamber caves	4	5	3	0
Small chamber caves	11	21	2	3
Large rock shelters	0	5	3	1
Medium rock shelters	4	6	2	0
Small rock shelters	9	21	4	1
Phreatic passages	0	3	0	0
Tectonic fissures	1	1	1	0
Maze caves	1	1	0	0

Amud and Zuttiyeh are among the largest caves in the research area (Fig. 4). AmE-15 is a medium sized cave. The “Emireh complex” consists of a small cave, a small rock shelter and a medium size rock shelter. However, in this site the bulk of prehistoric sediments was found at the foot of the cave and rock shelters and was not restricted to the confined space, unlike the other prehistoric caves. Therefore it is possible that when early humans choose to use Emireh complex their main consideration wasn’t derived by a need for a very efficient shelter, and the site was chosen for other reasons (see below). The selection of large caves might indicate that they were occupied by a band of few tens of individuals, rather than by nuclear families of ~3 or ~4 individuals (for suggested band sizes see Layton et al. 2012).

5.2. Cave morphology

The mutual characteristics for caves with Paleolithic presence in Wadi Amud are that they have a large spacious main hall and that this hall is well ventilated and illuminated or semi illuminated by natural day-light, having wide and tall entrances. Some other caves in the research area are few tens of meters long, with some medium size halls, but have narrow entrances, and the halls are dark. These caves show no presence of Paleolithic finds, although they are very often rich with proto-historical and historical archaeology.

5.3. Cave approach

All the prehistoric cave sites at Wadi Amud are much easier to approach from the gorge below, then from the plateau above. All approaches require some walk up hill but it is a rather short and moderate climb (Tab. 4). Taking into account that 50,000 Ka the bed of Amud Canyon was some 6–8 m higher than it is today (Inbar and Hovers 1999) the approach to Emireh, Zuttiyeh, Shovakh and AmE-15 caves was even easier than it is today. Actually, in Wadi Amud, all *large* caves that are *easy* to approach were occupied at Paleolithic times. Amud Cave is different: it is not located very high (only 35 m up the slope), but requires some scrambling up an almost vertical rock face. Climb is not dangerous but it is a bit physically demanding. Inbar and Hovers (1999) have suggested that during the MP occupation of Amud Cave, the approach was even harder than it is today, as the soft sediments of the cave floor extended 10–15 m to the east and created a slope steeper than today (Inbar and Hovers 1999). Therefore Amud Cave stands out, as none of the other LP or MP cave in Israel is difficult or dangerous to access. The relatively easy approach to the LP/MP caves is consistent with the assumption that those caves used for habitation, and were populated by human groups assembled of men, women, infants and elderly. The other relatively large caves at Wadi Amud (AmE-8, AmE-10, AmE-11) are located much higher in the slope and seem to be devoid of Paleolithic presence.

Table 4. Cave's accessibility.

Cave	Vertical distance from streambed (m)	Estimated approach difficulty	Paleolithic presence
Emireh	10	Easy	Yes
Shovakh	15	Easy	Yes
Zuttiyeh	20	Easy	Yes
AmE-15	30	Easy	Possibly yes
Amud	35	Difficult	Yes
AmE-8	120	Medium	Was not observed during survey
AmE-10	100	Medium	Was not observed during survey
AmE-11	100	Medium	Was not observed during survey

They are not so difficult to access, but the climb is more time consuming (Tab. 4). It is possible that the long climb required have ruled them out for a Paleolithic use. Regarding Amud Cave, we can suggest two possibilities: firs, it is possible that the steep but short climb to the cave offered an excellent protection from predators and invasion of other unwanted animals. It was pointed out that the cave is remarkably poor with evidence of presence of hyenas (Inbar and Hovers 1999). Second, the cave may have been chosen due to "cultural" reasons: few meters to the north of its entrance there is an impressive natural stone pillar, about 20 m Tall. This pillar stands out dramatically at the view, and gave the wadi its modern name (The Wadi of the pillar = Wadi Amud, Hebrew).

5.4. Cave location and landscape control

It has been suggested that site location of hunter-gatherers in the landscape takes into account a strategic viewpoint, which gives an advantage regarding the visibility of food resources (Jochim 1976). The view from Shovakh, Amud, Zuttiyeh and AmE-15 Caves is quite limited and offers no major control of the landscape. The view observed is that of the opposite canyon wall, with hardly any view of the stream bed and no sight of the plateaus and hills above the canyon. Emireh complex is located differently, at the margin of the Ginosar Valley, and has a wide view of the valley, the surrounding hills and lake. We suggest that the selection of Emireh as a habitation site potentially has more to do with control and accessibility to food resources than with providing shelter.

5.5. Cave location and variety of habitats

All prehistoric cave sites in Wadi Amud are within the distance of 5 km walk from the fertile Ginosar valley. Although this research focuses on the middle and lower sections of Wadi Amud, it is known (at least until now) that there are no Paleolithic cave sites in the mountainous

Upper Galilee. It is possible that hominins looked for caves that were located at the openings of Wadis, since this localities are ecotones, where both hilly/mountainous and valley habitats can be approached on a daily basis. The same notion applies to all of the Paleolithic cave sites of the Carmel Mountain.

6. Conclusions

The Wadi Amud project is just the first step in a comprehensive research that will relate to the phenomena of cave habitation during the end of the Lower Paleolithic and the Middle Paleolithic in the Levant. At this stage we can suggest the following as significant characteristics of the Paleolithic caves sites, and what we assume represents the preferences of early humans regarding to cave-site selection:

1) Large-medium caves (but not rock shelters).
2) A cave with morphology of one main hall, which has a large entrance. That hall is well ventilated and well illuminated.
3) A cave that is relatively easy to approach.
4) Approach to the cave is based on movement through the streambed or lower slopes.
5) The cave is located within a distance of daily walk from a large valley and large body of water.

The use of large caves which are relatively easy to access, along with the typical archaeological finds in those caves, support the hypothesis that each cave was used by a band of several tens of hominins. The cave selection was with preference for proximity to divers habitats, from where a verity of food resources and raw materials were brought to the cave and there they were processed and consumed.

Our future research will aim at characterizing all LP and MP cave sites in the Mediterranean climate zone of Israel, in order to get a better understanding of Paleolithic human decision-making patterns regarding cave selection and cave use.

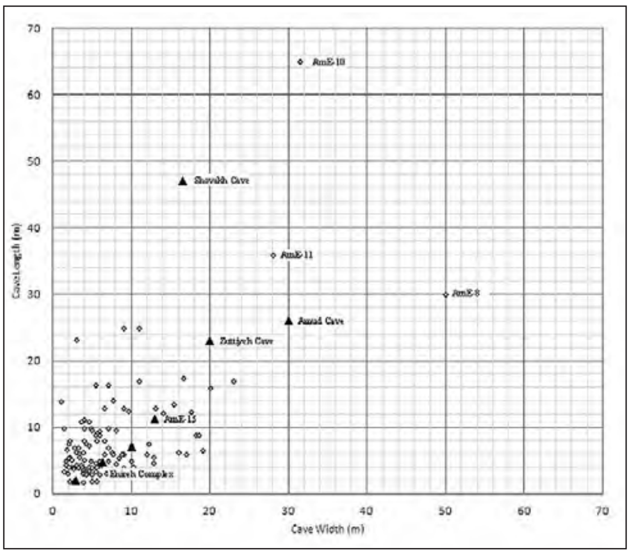

Figure 4. Width and length dimensions of caves and rorck shelters at Wadi Amud (N=120).

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RECONSTRUCTION OF THE CHATYRDAG PLATEAU (CRIMEAN PENINSULA) ENVIRONMENT DURING THE LAST 40,000 YEARS BASED ON STABLE ISOTOPIC ANALYSIS OF RED DEER BONE COLLAGEN

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The Crimean Peninsula is an extraordinary region located on the border, between Europe and Asia. Because its location, the region was important refuge for migratory animals during entire Pleistocene. One of the most important species of great herbivores in the Crimean region is red deer (*Cervus elaphus*). Its remains are represented in great number from several cave sites, including Emine-Bair-Khosar Cave (Ridush et al. 2012). Recent genetic studies on samples from that cave suggested presence of two group – Western (European) and Eastern (Asian) red deer in different periods of the Pleistocene (Stankovic et al. 2011). However, the reasons of domination of Western or Eastern red deer is still not know.The answer might be the changes in climate and environment conditions during the last 40,000 years. For recognize these changes we studied isotopic composition of carbon and nitrogen of collagen from red deer bones deposited in Emine-Bair-Khosar trap cave. Some of remains were dated with radiocarbon and Uranium-Thorium dating methods for time control in the sediment sequence. On the beginning of our record, we found high values of $\delta^{15}N_{coll}$, suggesting relatively high soil activity and indirectly high temperature. The high ^{15}N concentrations were correlated with high $\delta^{13}C_{coll}$ values. Hence, we think that this part of sequence was deposited during relatively warm and dry period (OIS 3) and that steppe was dominant vegetation type at that time. After that, $\delta^{15}N_{coll}$ value decreased significantly and $\delta^{13}C_{coll}$ remain on similar level than before. This strong decrease in soil activity suggests climate deterioration and tundra development during Last Glacial Maximum. After LGM, $\delta^{13}C_{coll}$ decline to the minimum value -17.5‰ and $\delta^{15}N_{coll}$ significantly increased reflecting mild climate condition and extend of forest nearby the cave.

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A GALLERY OF LATE MEDIEVAL AND MODERN PAINTINGS AND INSCRIPTIONS IN NA ŠPIČÁKU CAVE, SILESIA, CZECH REPUBLIC

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Na Špičáku Cave, located in the Jeseník Karst, is the only publicly accessible cave in the Czech Republic to contain a unique gallery of ca. 4,000 historical inscriptions and symbols from the Middle Ages to the middle of the 20th century. The cave's first written mention is from the 15th century. This period also coincides at least partially with the oldest horizon of features in the cave – petroglyphs of a globus cruciger or a jousting shield with a stylized tableau apparently depicting Adam and Eve beneath the Tree of Knowledge (1519), paintings of the sun and a crescent moon (15th- and 16th-century) and the Adoration of the Cross with Jesus Christ and the portraits of patrons representing secular and churchly power (most probably the 1530s–50s). An analysis of red pigments from the 16th- and 17th-century features shows the use of special pigments. The historical context offers a connection, over the course of the 16th century, between the cave and intensive mining on the surrounding noble or bishop's estates. The cave's surroundings were apparently an important site of mining, and the mine's ownership (i.e. an indication of who held mining rights) may have been legitimized using wall paintings that were comprehensible to anyone. The prospecting horizon ends with the onset of the Thirty Years' War, as reflected in a significant decline in the number of dated inscriptions and archaeological finds. The cave was practically forgotten until the early 19th century. The greatest number of inscriptions comes from the time after the cave opened to the public in the 1880s.

1. Introduction

Na Špičáku Cave is a karst system situated in Devonian crystalline limestone (marble) formed by surface water at an elevation of around 439 m. The passages' unusual shapes are the result of an underground lake from the waters of a continental glacier that extended to the northern borders of the Czech Republic during the next-to-last ice age (Zajíček et al., 2005). The cave's air temperature is 7–10 °C and the relative humidity ranges from 90 to 98 %. The cave is located in the Jeseník Karst on the northern slopes of the Hrubý Jeseník range, within the municipality of Supíkovice, Jeseník County, Olomouc Region. A report mentioning this cave from sometime before the mid-15th century is the oldest description of a cave in the Czech Republic and one of the first in all of Central Europe. The cave's interior contains the largest set of epigraphic relics ever found in the Czech Republic, numbering around 4,000 inscriptions and illustrations made using various techniques. The central painting of Christ on the cross with figures standing in adoration has no equal in any other Central European cave.

2. An overview of historical reports

The oldest written record of the cave is in "Wegweiser zu den Bergwerken in der Oberlausitz und in Schlesien" by Antonius Wale, a merchant from Florence who was active in mining in the Silesian town of Wroclaw between 1410 and 1443. Compared to other mining localities, the cave is mentioned only briefly, and classified more as an interesting place than an important prospecting or mining locality (CDS XX, 198). The text, which is usually dated to 1430 or 1436, contains a brief description of the cave's passageways leading into the interior of Špičák Hill (Spitczenstein, 516 m), second-hand information on the site, and an obligatory report as to the discovery of treasures typical for this type of locality and for "Italian" literature. The text also includes two symbols (a "crescent moon" and "sun"), which the editors of the CDS interpret as silver and gold – i.e. the alchemist symbols that (according to the text) can be "found" in the cave. These symbols truly exist on the cave walls, and according to our research they belong to the oldest demonstrable horizon of epigraphic relics; based on the layering of inscriptions, they are older than 1583 (Fig. 2).

Later brief mentions (1689, 1806, 1836) offer an indirect link between the cave's existence and mining activities on Špičák Hill. Drechsler (1951) also states that the entrance to the cave was allegedly walled up for safety reasons and remained closed until work was undertaken to make it accessible to the public. That the site was all but forgotten can be seen from historical maps: maps from the 1760s indicate the now-nameless creek previously known as "Gold Wasser" and the local place name "Kalch Ofen", but maps from the mid-19th century lack any information whatsoever. The first detailed reports about Na Špičáku Cave come from when it was made publicly accessible in 1883–1885. During this time, the village of Supíkovice (Saubsdorf in German) was known as the "Silesian Carrara" because of the local marble mines. Another description of the cave by Luňáček and Ryšavý in 1949 formed the foundation for the cave's extensive tourist-related works in 1954–1955, which gave the cave its contemporary look.

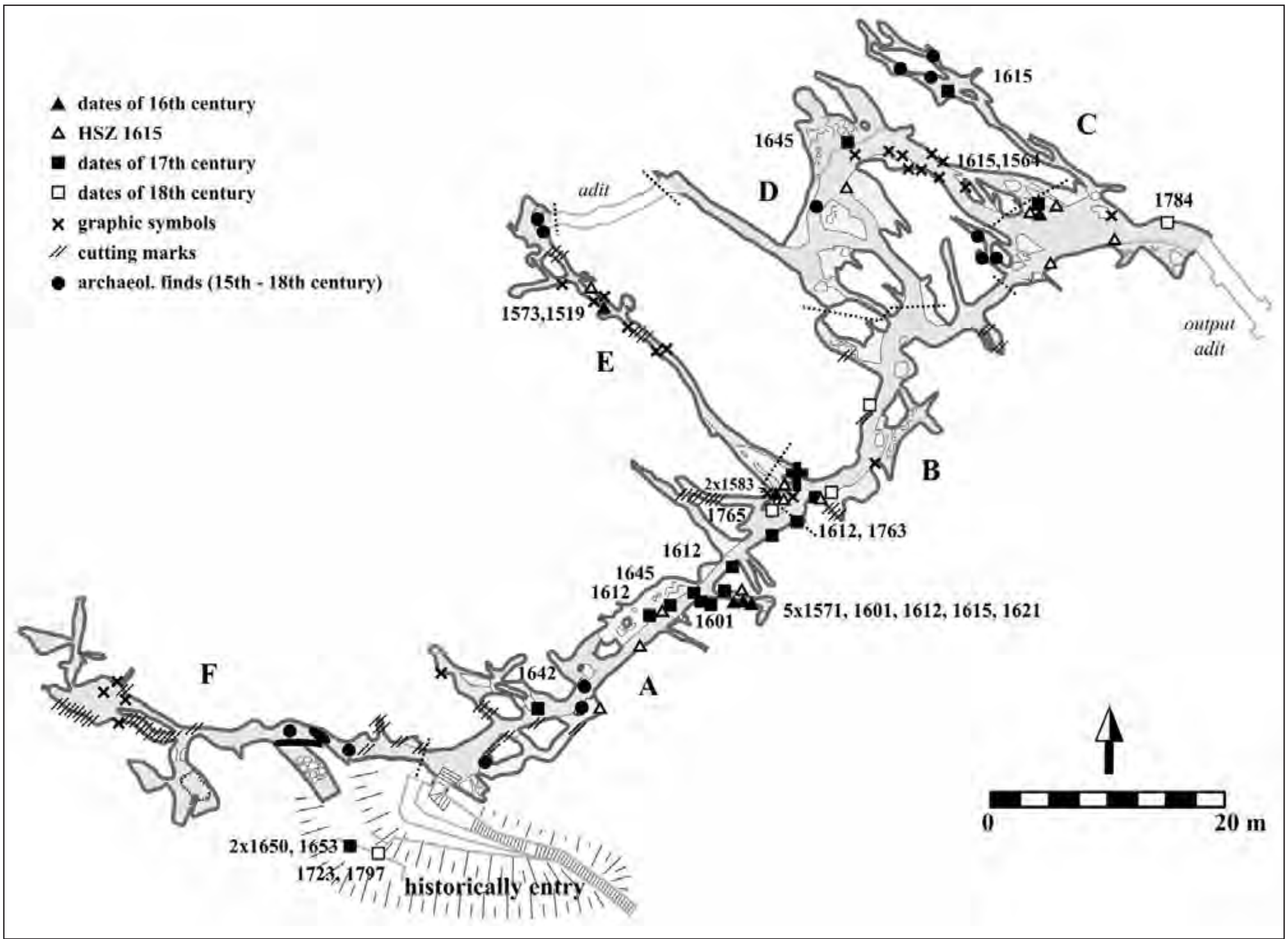

Figure 1. Map of the cave as per V. Ouhrabka, amended and supplemented. White segments with light gray borders quarried away in 1954–55.

3. The original layout of the cave

Before it was made accessible to the public, the cave opened up into a funnel-shaped chasm created by ancient mining activities. According to A. Makowsky (1886), from the bottom of this chasm one entered the cave's first section consisting of the Main Corridor (sections A and B; Fig. 1) measuring 54 m in length, 2–3 m in width, and with a predominant height of 1,5–2 m. Short branches lead off to both sides. The third left-hand branch (Double-Heart Chamber [E]) was 33 m long, 1m wide and 1,6–2 m high, and terminated in a 7 m-deep chasm with sporadic water at the bottom. All these spaces were covered with various types of partially damaged deposits and, except for a few places, were blackened from torches. The rear part of the cave was called "Labyrinth" after three interconnected chambers whose connecting corridors are often passable only by crawling or sliding along the ground. The interiors were around 2 m high and the sinter deposits were equally damaged and blackened from smoke. From the central Great Dome (D), one passed through a 18 m-long corridor measuring 2 m in width and 1–2 m in height to reach the final Dome of Hope (C); length 15 m, width 3–7 m, height 3 m. Leading off from this chamber is a crevice passage (C2) rediscovered in 1885 and 25 m long, up to 1m wide and 1,8 m high, with whitish speleothems and sinter formations. The overall measured length in 1886 was thus 111 m, or 232 m if we include all branches. It is not entirely clear why today's corridor (F) leading off from the entrance into the crawlspaces with abysses was not mapped at the time.

4. Archaeological finds from the cave

J. Skutil (1953) described the cave's sediments as archaeologically sterile. When the cave was made publicly accessible in 1954–55, no archaeological finds were observed, which was more the result of inattentiveness and lack of interest during construction work, since the volume of material removed from the cave in 1954–55 was enormous. The first finds were made in 2007–08 by employees of the Na Špičáku Cave Administration in various parts of the cave during the renovation of walkways and while cleaning chasms. Other surface finds followed during epigraphic documentation, primarily in corridor F in 2008–09 and 2012.

The fragments of pottery and iron objects found in various parts of the cave represent a chronologically roughly uniform set of unglazed pottery as well as glazed ware. Due to the absence of more significant fragments, the finds can be dated only roughly as being from the advanced High Middle Ages (14th–15th century) and the early modern era. The most significant horizon is from the conclusion of the High Middle Ages (late 15th to first half of the 16th century). This period corresponds at least partially with the oldest horizon of historical engravings and paintings. The most significant grouping of finds in the front part of corridor F points towards a secondary deposit from the area around the funnel-like entryway. In these locations, mining activities opened up the corridor onto the floor of the entry-chasm, as documented by the situation in a filled-in depression next to today's stairway from around 1884.

5. Documentation and restoration of paintings and inscriptions

In the late 19th century, reports of the extraordinary wealth of epigraphic relics on the walls and ceiling throughout the cave garnered only little attention. Their significance was first emphasized in the mid-20th century by J. Skutil (1953), who provided an "overview of at least the most important, leaving out a large number of scrawlings and scratchings dating for the most part from the nineties" of the 19th century. Especially interesting is his description of the central painting of the adoration of the crucifix (improperly called Calvary; Fig. 2), which was later erroneously associated with the cave's use as a shelter from religious persecution. In 1989–90 student M. Korejtková engaged in a preliminary unpublished inventory, and in 1993 P. Zajíček and K. Gregor (Moravian Karst Cave Administration) made black-and-white photographs of selected epigraphic features. These unsystematic attempts at recording the state of the inscriptions are important for a comparison with today's state and show the increasing tendency towards the features' degradation caused by the high humidity and the formation of sinters.

In 2003–10, the Archaeology and Speleo-Anthropology Office of the Regional Museum and Gallery in Česká Lípa systematically documented all surviving inscriptions, paintings, and engravings in the cave (Jenč and Peša 2009). The cave was divided into sectors and each epigraphic feature was given a number, surveyed and mapped (Fig. 1). The researchers took detailed photographs including close-up details, and selected features were also sketched. A total ca. 4,000 features were recorded (more than 4,900 images) in 796 main locations (Jenč and Peša 2011; on methodology see Jenč, Peša, Pátková eds. 2001, Roháček 2007). Since 2011, a supplementary research project has focused on a historical assessment of the acquired information, and a restoration project has been working to save the most important paintings degraded by moisture and sinter growth. Long-term microclimatic measurements are being performed at the site of selected features, and the use of pigments is being analyzed as well (Ing. Martin Dvořák and Ing. Ivana Kopecká, Prague). These findings will be used to engage in the stabilization and restoration of the oldest features.

The analyzed paintings are found at the intersection of the Main Corridor and the Double-Heart Corridor, at the border between sections A, B and E. The paintings did not use standard techniques; they were painted onto a chipped ceiling without a base coat or organic binding agent. The main feature (the Adoration of the Cross; Fig. 2) is preserved only in fragments; at the upper part of the picture, there are only traces of the color layer, best visible when lit from the side. The nearby paintings of the sun, cross, and moon are preserved in an easily recognizable form. The base underneath the painting is non-uniform, and consists of smaller sinter formations with depressions. The color layer is slowly being washed off the protruding sections by the dripping water, and so is preserved only in the depressions. This layer is also being reduced by the growth of sinter or the formation of small speleothems. Samples of the pigments were microscopically analyzed under incident light using a Leica DML optic microscope. An external analysis of organic materials (varnish and binding agents) was performed via FTIR spectrometry (diamond ATR technique) on a Nicolet FTIR spectrometer. The determined spectrum was compared with the standard spectrums from various industrial databases. The samples were analyzed in a solid state from both sides and within the limited possibilities of the measuring equipment. The determined spectrums are not from pure substances, but mixtures. In some cases, the analysis could not determine a specific substance, but only the chemical group to which it belongs (e.g., waxes, polysaccharides).

By the end of 2012, a total of 11 samples were taken for analysis. The stratigraphy of layers is clear, the individual paintings are monochrome and painted directly on the limestone wall without a standard base coast. One important piece of information is the nature of the pigments used: minium (red lead, Pb_3O_4), burnt umber, and vermilion – i.e. painting materials, not randomly used local sources. The paintings were made with a particular intent and with a knowledge of painting techniques. The binding agent was probably soft cave sinter (moonmilk), whose consistency corresponds to normally used binding agents (oil, resin, etc.), or it may have been limewater. The paintings were never restored and are preserved in their original form. The technique resembles *al fresco* – paintings made on a wet foundation (plaster or lime paints) by wiping paint diluted with (lime)water. It is hypothetically possible that the artists took the cave's particular environment into account when choosing a suitable technique for their inscriptions.

6. The oldest paintings and inscriptions

The oldest dated feature is located in the rear part of the Heart Corridor (E) and was not identified until 2003. It is a chiseled image in the form of a jousting shield. The scene inside is probably a stylized tableau of Adam and Eve beneath the Tree of Knowledge, "a(nn)o" with the year "1519" and the letters "hb" (Fig. 4). Nearby is a solitary petroglyph of a globus cruciger (a symbol of secular power, the sovereign ruler; Fig. 3) and an etching resembling the Rod of Asclepius. Another set of painted features is located at the intersection of the Main Corridor with the Double-Heart Corridor (A/B/E) near the cave's central painting, the Adoration of the Cross (Fig. 2). It is a painting of a cross with the crucified Jesus Christ and a figure standing on each side in adoration. The red initials HSZ covering the older cross are of chronostratigraphic significance; based on their placement elsewhere in the cave, these came from 1615. Like the neighboring paintings of the sun and crescent moon, the scene of the adoration is done using a dark red pigment (made using vermilion), which differs from pigments from the 17th and 18th centuries. It is quite possible that the sun and crescent moon – which were previously mentioned in connection with the oldest description of the cave – date from as early as the 15th century; in any case, they predate the year 1583. Using iconographic analogies, the Adoration most probably dates to the 1530s to 1550s. Especially in Silesia, this subject is quite common in Renaissance art after the middle of the 16th century, and so the figures bowing to the Holy Cross in the painting in Na Špičáku Cave may very well be a patron/nobleman (on Christ's right) and a high church official (on his left).

Figure 2. Central feature of the Adoration of the Cross from the 16th century with the mouth of the Double-Heart Corridor (B/E); at the lower left is the painting of the son and moon with the black cross. Photo P. Jenč.

The oldest horizon is associated with inscriptions (including the year) dated to the 16th and early 17th centuries. This includes the oldest name in the cave, "Sam(uel) Baksor", which is dated by the inscription "1571". An interesting inscription is the red "HSZ 1615" made using minium, which can be found in practically all parts of the cave and has survived in 11 locations. In our view, another feature associated with the period of increased interest in the cave from the Late Middle Ages to the Thirty Years' War are the inconspicuous cuts made here and there by tools (chisel/pick), which document the expansion of impassable corridors at a time long before the cave was made accessible to the public. In most cases, they are covered by fossil moonmilk. It is quite likely that this horizon of cave visitations is associated with at least some of the graphic symbols made using charcoal or red clay (diamonds, lines, human faces, crossed "sabers" and more). Based on the distribution of features, the most frequently visited area would seem to have been the section from the entrance to the scene of the Adoration and from there the crevice passage of Double-Heart Corridor. By comparison, there are almost no features in the largest area (the Great Dome [D]); instead, they are accumulated at its rear margins, where they seem to point the way to the cave's end in the Dome of Hope (C).

Figure 3. Engraving of globus cruciger, Double-Heart Corridor (E). Photo P. Jenč.

7. An attempt at a historical interpretation

Based on the available information, the cave was discovered either while digging a mineshaft or quarrying limestone. According to historical sources, gold was mined intensively in nearby Zlaté Hory at least since the first half of the 15th century, with a peak after 1467, when the bishopric in Wroclaw added the mining district to its properties. In 1510, the Fuggers – an influential merchant family allied with Wroclaw's Bishop Johannes V. Thurzo, acquired the Jeseník (Freiwaldau) estate, where they were successful in mining.

Both towns received mining freedom in quick succession – Zlaté Hory in 1524 and Jeseník in 1529. The region's greatest mining boom was in 1550–1560 under Bishop Balthasar of Promnitz. Starting in the mid-16th century, high-quality limestone was mined in the region as well (Zuber 1966, 85–86).

Figure 4. The oldest feature in the cave, dated with the year "1519", Double-Heart Corridor (E). Photo P. Jenč.

The alchemist symbols in the cave are of the sort we know from precious-metal prospecting sites; combined with the choice of pigments (minium/red lead, burnt umber, vermilion) and painting techniques, they point towards higher social classes of religious or secular power. Bishop Johannes V. Thurzo (1506–1520) had close ties to mining, thanks to which he acquired extensive wealth. In 1510, he published his own mining rules. His brother Stanislaus, 1496–1540 Bishop of Olomouc, also promoted mining within his bishopric (for instance on the Osoblaha estate), where the Fuggers were active as well (Baletka 2004, 154–155; Janál 1959, 179–187). In fact, we date the central image of the Adoration of the Cross, with its symbolic depictions of secular and spiritual power, as having being created in the 1530s to 1550s. We thus assume that the cave's surroundings were a region of significant mining activities whose ownership may have been legitimized in the form of wall paintings that were comprehensible to anyone, with references to the bishop and the Fuggers. The paintings also acted as a reminder that, without the owner's permission, it was forbidden to mine around the peak of Špičák Hill – including hidden underground. The Christian symbolism also fulfilled a generally protective function, especially in the dangerous underground environment. Another painting besides the Adoration of the Cross that supports this theory is the globus cruciger, which – as a symbol of royal power and in its isolated placement in the cave – may represent a (to us unknown) royal act related to the cave. Mining activities involving precious metals were always subject to royal inspection, although the king could temporarily pass it on to the nobility. The globus cruciger in Na Špičáku Cave may thus represent the return of mining rights back under royal control.

Written dates from the 17th century are predominantly from that century's first quarter, and probably reflect the waning prospecting tradition of the 16th century. The onset of the Thirty Years' War only had a marginal impact on the region, but the inscriptions "GA 1642" and "GATLOF 1645" in the Main Corridor (A) may be connected with the Swedish invasion to Moravia during those years (Kolektiv 2009). The prospecting tradition was no longer relevant after the Thirty Years' War; based on inscriptions, the cave was visited only rarely, and general awareness of its existence slowly faded. A minor revival of interest took place in the early 19th century, but a more significant increase in visitors came only after it was first made publicly accessible after 1883, when most of the walls and ceilings were covered in thousands of signatures and dates, most commonly graphite or ink and charcoal.

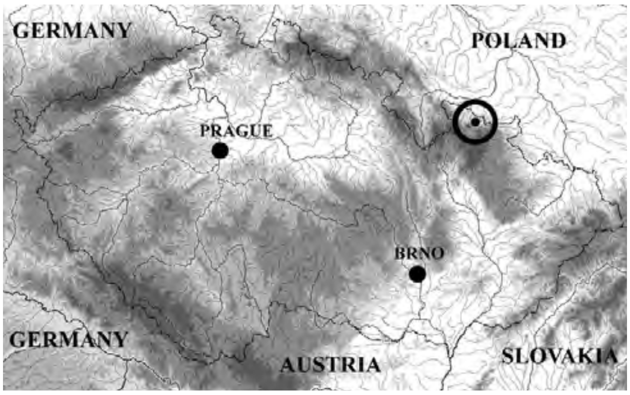

Figure 5. Location of Na Špičáku Cave.

Acknowledgments

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RESULTS OF STUDYING THE PALEOLITHIC KAPOVA CAVE (SHULGAN-TASH) IMAGES

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Kapova Cave (Shulgan-Tash) is located in the Southern Urals, Russia. In 1959, A. Ryumin discovered Paleolithic paintings in it. Current research of a team from VSEGEI and RGS resulted in the discovery and classification of more than 140 new images. There is an assumption of long process of creating the images and informative value of abstract symbols. A conclusion was made that in the Southern Urals, a center of ancient human culture rather similar to the Western European one had existed during the Paleolithic.

1. Introduction

Kapova Cave (Shulgan-Tash; Fig. 1) is located in Bashkortostan, the Southern Urals, in the “Shulgan-Tash” reserve. In 1959, A. Ryumin discovered Paleolithic drawings in it (Ryumin 1960). Later, they were studied by O. Bader (1965) and V. Scelinskij (Scelinskij, Sirokov 1999). Our team from VSEGEI and RGS has been engaged in studying and fixation of Kapova Cave paintings for more than 10 years under a contract with the Ministry of Culture of Bashkortostan. During this time, more than 140 new images were discovered. Totally, 195 images are known, which are very diverse. They can be divided into zoomorphic (anthropomorphic) realistic drawings, abstract geometrical symbols and obscure spots – relics of the images. A very important characteristic of the image is the colour. Previously it was thought that this is almost monochromatic red ocher with some variations, but now it is clear that a variety of dyes from scarlet to brown and black was specially created.

Based on image morphology, style, colour and location in the cave, it is possible to develop a classification that will take into consideration all peculiarities of the images and allow conclusions about ancient “artists” ideas, epochs of image creation and the intended purpose. The Kapova Cave drawings form several groups depending on a set of features and image location in specific parts of the cave; they show different stylistic features, reflect different traditions and concepts of world perception and possibly were created in different epochs. Image classification is required for the historic and art review of the “painting.”

The problem of image conservation is very serious. As for their state, only 14 % of the images can be assessed as satisfactory, 15 % are of intermediate state, and the majority (71 %) are in poor condition, i.e. the degree of degradation is so high that it threatens their total loss.

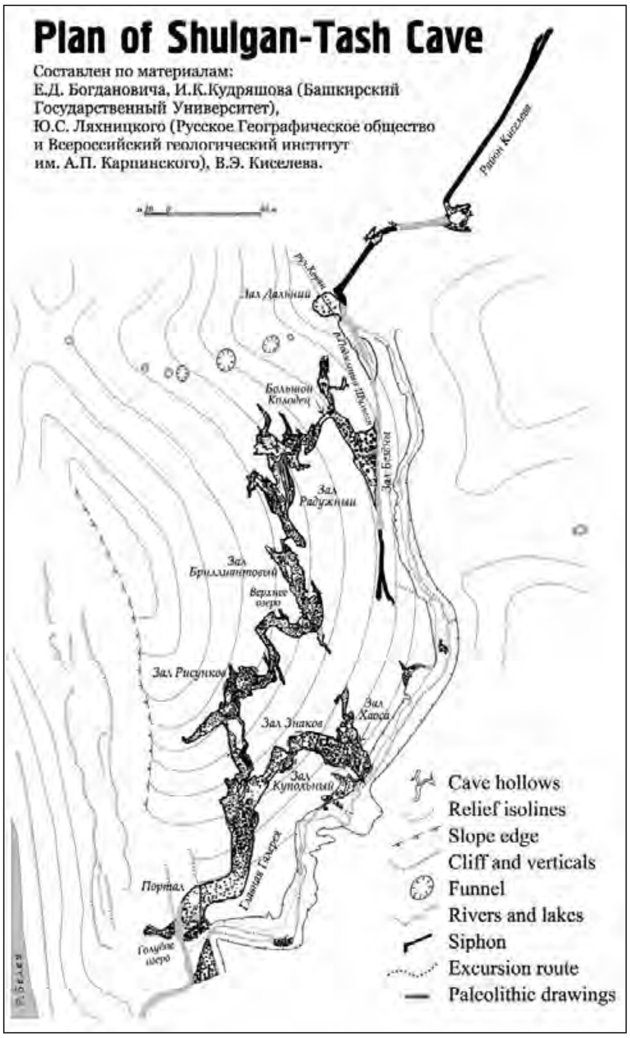


Figure 1. Plan of the Shulgan-Tash Cave.

2. Survey groups of drawings

Red realistic outline drawings in the Drawings Hall of the first floor (Going Mammoth, Big Horse, etc.) are best known and best preserved. These zoomorphic drawings are rather realistic, resemble in their style the Magdalenian paintings of Western Europe. They are contour; some of them show zones of contour line widening and shading of details, parts of figures (Big Horse and Rhino). Only the Red Mammoth is a silhouette figure dyed almost completely, but the intensity of the dye varies. Drawings of this type are dominated by mammoths (7); there are woolly rhinoceros (2) and a bull. The colour of these images is red; the intensity of the dye is medium and low. Almost all of them are made in the same style, as if following a certain canon. Besides, two anthropomorphic images occur in different compositions. There is only one geometric symbol in the hall – a large trapezium with twelve edges at the bottom right corner of the first composition. This is a single formational group that resembles most of all the West

European Madeleine. According to the classification of Leroi-Gourhan, the images belong to the transitional group between the third and the fourth. The painting is dated from the age of the coal from the O. Bader's prospecting shaft in the Drawings Hall (Tatiana Shcherbakova material); according to VSEGEI laboratory data, their age is 16,000–17,000 years. This is undoubtedly the Upper Paleolithic.

Drawings of the ground floor with distinct styling elements accompanied at least by two geometric symbols (trapezia) can be assigned to the second group of realistic red images (apparently originally polychrome). Horses from the Chaos Hall and the Bison from the Symbols Hall are assigned to this group. There are already no mammoths among the animals. Drawing stylization is expressed in further elongation of horses' neb, contour distortion of the upper horse silhouette, unnatural sharp bend of the tail, exaggerated mane luxuriance. Near the animals, there are characteristic "trapezia" found only in the Kapova Cave. They widen upward, have internal near-vertical edges and "earlets" hanging from the upper corners; the right one is short and left one is long. Sometimes the "earlets" are bifurcated. The trapezia are geometrically correct, have a different number of edges and peculiar internal features of the structure. A new figure appears – one-sided bent staircase above the Upper Horse. The drawings in the ancient time were covered with thick sinter calcite crust owing to which they are well preserved. They were multi-colour (from red to black and brown). These compositions are situated on the ground floor of the cave: at the entrance to the Symbols Hall and the Chaos Hall. This is the continuation of the ancient tradition with the observance and development of its rules. They belong to the fourth group of Leroi-Gourhan's classification. The age of the drawings of this group is probably the most recent stage of the Paleolithic.

The third group of drawings in the Symbols and Dome halls is characterized by small, scarce zoomorphic stylized and formalized "simplified" drawings of abundant abstract symbols. Instead of the traditional trapezia, various new symbols appear: U-shaped, radial, circular, various derivatives of trapezia, etc. In this case, there is no distinct relation between zoomorphic drawings and symbols. Probably they were drawn at different times on the same site. They are characterized by poor preservation, the lack of details, static figures of animals. New Mammoth and Red Horse are among typical zoomorphic images of this group. The image of a mountain goat from the Dome Hall probably also belongs to this group. This group includes numerous and variable images of the northern wall in the Symbols Hall and small spot symbols – indicators. In addition to the trapezia, there are also triangles. The best expressed Double Triangle is situated on the northern wall of the Symbols Hall. Another variety of symbols is a trident. These figures are derivatives of trapezia. They differ in the fact that they contain only one internal edge, side faces are parallel and the top face is almost invisible. The typical Trident is situated in the northeastern corner of the Symbols Hall. There are symbols, derivatives of a trapezium, with internal, sometimes complicated structure, usually parallel side faces and double short earlets. They can be exemplified by the Complex Trapezium in the Chaos Hall. U-shaped structures are rather abundant. Several of such symbols are drawn on the northern wall of the Symbols Hall. There is an interesting variety of characters – Y-shaped sticks that remind an asymmetric "shanghai" (branch fragment with a spike) accompanied by a number of straight line segments, small triangles. Two of these symbols are in the Chaos Hall. Central-type structures consisting of segments of circles, arcs or spirals with a bright isometric spot in the center are distinctive. Such symbols are drawn on the northern wall of the Symbols Hall. There are also straight and slightly curved lines located, as a rule, in groups, vertically, e.g., oblique lines in the Chaos Hall. Three complex structures that resemble trapezium derivatives with elements of radial structure that remind cast of a huge hand are described. They are exemplified by the Radial Structure on the northern wall of the Symbols Hall.

In this group, symbols located in isolated flattened cavity under the eastern wall of the Chaos Hall are of interest. These are singular, specific, usually complex, composite symbols consisting of several elements. The most representative of them is "Tower" symbol consisting of two red rectangular structures with short horizontal black lines in between partly accentuated with red ocher. It is elongated vertically. There are also such symbols as Complex Trapezium and Tuning Fork, which are distant derivatives of traditional trapezia. Such symbols have not been described elsewhere.

Images of the ground floor are usually poorly preserved. This may be due to the loss of a methodology or unfavourable conditions, large water inflow, impact of condensate. Perhaps they were created during interglacial periods or in postglacial time, when hydrological and meteorological conditions in the cave deteriorated. In general, the group mainly consists of abstract symbols; they were created based on an entirely new concept, although some rare details came from old symbols of previous groups. For example, double earlets of some complex symbols. Apparently, this group of images was created already in post-Paleolithic time.

Next, very complicated and heterogeneous type of images is spots that usually look like unstructured irregular-shaped images. These are relics of very poorly preserved drawings, dye stains of destroyed images, and sometimes, perhaps, natural formations. Interpretation of the spots is a challenge. Computer image processing techniques allow in some cases the identification of the primary structure of the drawings or symbols, but often such an interpretation is ambiguous. In this case, the suggested interpretation is probabilistic, and the conclusion of the authenticity of the received version of the image depends on the skills and qualification of the operator. The spots are common in the halls of the ground floor of the cave.

The fourth group is "points". In fact, they are small spots. These small images consist of "points – indicators", small symbols, fragments of image relics, and natural mineral formations. Despite their small size, they sometimes show a distinctive geometric structure, small tails and other features. Their identification is even more difficult than that of the spots. A typical indicator is Acoustic Point in the Crossway Hall or triangular Secret Symbol in the Chaos Hall.

Most of the Kapova Cave images are red and painted with ocher. But the ocher differed in composition. This was specially prepared red dye of different tints, which consisted of iron hydroxide, natural red (and other) clay ocher made of weathering crust and various mineral admixtures. The ocher composition was specific in different regions depending on the availability of natural components. There is a small brown ironstone occurrence not far from the Kapova Cave. In the immediate vicinity of the drawings in the Split of the Chaos Hall, there are nests of limonite, goethite and other varieties of brown ironstone. The choice of primary mineral components was very wide. Sampling of brown ironstone microadmixtures and ocher samples showed their high similarity and rather diverse composition of both. We managed to find an ancient "palette" – a plate with the ocher prepared by an ancient artist. We studied its composition. It turned out that the basis of the dye consisted of burnt brown ironstone and clay ocher. We carried out an experiment on the preparation of the dye. In order to get cherry-red hematite from the brown ironstone, it is necessary to anneal it intensively in the fire. The resulting hematite grains were grinded with clay and then mineral admixtures were added to this mixture to obtain necessary colour tint. Then, in order to give the adhesion properties to this mixture, the resultant powder was rubbed up with "animal glue" – a mixture of fat, blood and lymph. The resultant mixture could be brought to the consistency of oil and then rubbed into the rock.

Images (usually symbols) differing in tint from the typical "scarlet" colour are repeatedly found the cave. Darker, tinged with violet, dark red colour residing in some images is distinctive visually. An example is a bright line on the right side of Hash symbol on the eastern wall of the Dome Hall. One of the initial components for this paint was purple clay, which is found in the cave vicinity.

Monochrome drawings and symbols prevail in the cave; however there are many shades of scarlet with different saturation. Perhaps, they acquired such appearance under the influence of negative hypergenesis factors, which have destroyed the dye for thousands of years. The only composition that relatively quickly after its creation was preserved by thick calcite crusts (Horses from the Chaos Hall) was almost polychrome after opening. It is characterized by bright red and dark red lines of the main outline, red with brownish tint zones of acute neb, crest, and tail of horses, thin, black-brown lines of the external outline, pink, light red interior zones of paintings. Kapova Cave paintings were originally polychrome or had a richer palette than now, and that makes them more similar to the West European analogs. The question on the authenticity of black images is fundamental. Archaeologists have not considered black figures as a subject of study, but for one symbol of the ground floor. However, the presence of several black images requires a solution. Using of coal for black images is most probable, but perhaps this is pyrolusite (MnO_2), which is found in the cave in the form of crusts and films of cavern filling.

The fifth group of images is distinguished conditionally, as paintings authenticity has not yet been proved. These are black archaic drawings with primitivism features, present only in the Paintings Hall on the first floor. They can be exemplified by Black Mammoth, Black Fox, and Black Horse. According to Leroi-Gourhan, this is the first or the second group. It can be assumed with very great care that the age of these paintings may be close to the Middle Paleolithic.

It seems that the Kapova Cave drawings considerably differ from the West European samples, and the very concept of drawing pictures from the Kapova Cave and many paintings and symbols are quite specific and have the right to be considered original within the overall global cultural Paleolithic field.

The first composition on the eastern wall of the Drawings Hall is a solemn procession of animals, representing the totem of some groups of people. All of them are disposed regularly, compositionally bound together. All but one animal are on the hall perimeter from the right to the left. Lone Going Mammoth ahead, other animals in a large V formation move at some distance behind. One has the impression of a solemn procession. This is an esoteric painting drawn on a certain canon.

The second composition on the western wall of the hall is noted for the absence of solemnity and conventionality. It is more likely a sketch of an everyday scene, subordinate to the compositional unity, using the same stylistic devices. The wall is sufficiently large to accommodate many figures, however only 4 animals are drawn.

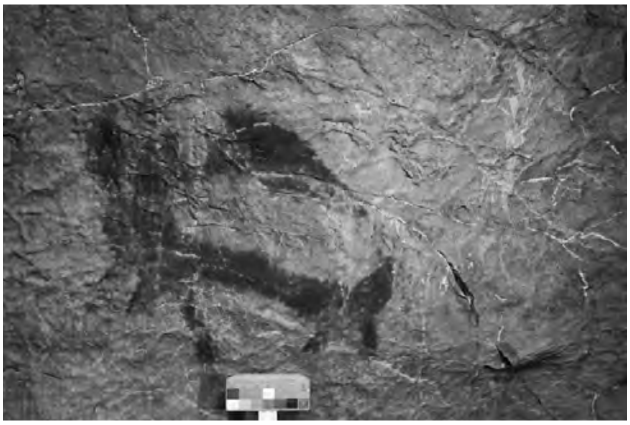
3. Conclusions

If we compare these compositions with the masterpieces from Western Europe caves, for the first time it seems that they are much more primitive, but thoughtful profound reading of the paintings shows that they are just different in conception. The difference between the Western drawn up in detail, multi-figured masterpieces of art and compositions from the Kapova Cave is about the same as between the splendor of Catholic churches decoration and imagery of Russian icons. Artist of the Kapova Cave sought not to reflect the external beauty of animals, but to create their images, to convey the inner solemnity of meeting people with the world of their totems, with higher forces in which they believed. This is sort of Paleolithic altar, not an art gallery. Hence the observation of certain canons, conditionality in paintings.

This classification is, in fact, genetic; of course, it is based on the general regularities and has a hypothetic character. Nevertheless, the actual material enables such grouping, beyond the timeframe. Perhaps the difference in the pictures character is to some extent due to the functional specifics of various areas of the cave sanctuary; however this is less likely for the Kapova Cave.

Thus, images from the Kapova Cave are quite diverse morphologically. This is one of its features, and it confronts future researchers with complex and difficult questions on understanding the collected material, which of course does not fit into the concept of "art" and represents a complex system of cultic, conventional symbols, abstract and perhaps information signs. Morphologically homogeneous trapezia always found next to pictures of totem animals are some "identifiers" providing additional information about them. As they have a different number of internal edges, it is logical to assume, as a hypothesis, that these are a kind of numerical symbols characterizing a group of people worshipping these animals – totems.

Variety of symbols in the Kapova Cave is much greater than in the West. This can be explained by the fact that it apparently remained the largest regional sanctuary for a long time, and drawings and symbols of different traditions, at least of two epochs were telescoped in it. Thus, the described properties and features of the Kapova Cave images provide strong evidence of the originality of this interesting monument, which proves the existence in the Southern Urals during the Paleolithic of an independent source of the original ancient culture that has evolved for a long time, probably even after the end of the Paleolithic.



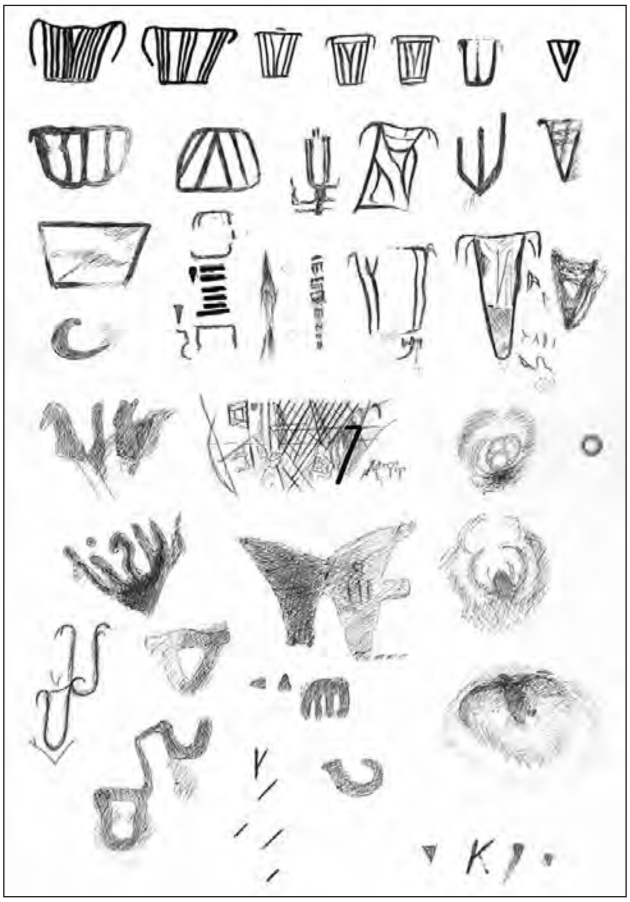


Figure 2–6. Zoomorphic (anthropomorphic) realistic drawings, abstract geometrical symbols and obscure spots – relics of the images. (Shulgan-Tash) Kapova Cave.

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THE CAVE ŽEDNA PEĆINA (THIRSTY CAVE), SERBIA

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The SEC Rock & Ice has been doing new speleological research of the karst massif of Lazar's Canyon and the Zlot river basins for 12 years now. During this period 245 speleological objects have been located and Lazar's Cave, whose length of mapped channels was 1,720 m, today is the longest cave of Serbia with 10,870 m of mapped channels. On the day of May 2nd 2012, a team: Milan Stojadinović, Mladen Milošević, Dejan Mirosavljević located the cave which not only offers a key to understanding of the huge cave system but also is significant because of the paleontological finding of an ibex (*Capra ibex*). It has been estimated that the ibex fossil remains are between 780,000 and 120,000 years old and that they belong to the middle Pleistocene period. According to the estimate made by the paleontologists of the Natural History Museum in Belgrade, this discovery is of greatest importance for Serbia as well as for Europe.

1. Introduction

Fossil remains of Capra ibex has been found in Zlot cave complex, near Bor town in eastern Serbia. This discovery is very important, estimated by paleontologist of Museum of Natural History in Belgrade. Remains of ungulates in caves are present but often rare, but they are in very good conditions because of specials terms in caves. They may be introduced by carnivores as their pray and after-wards the bones were scavenged by carnivores. It is assumed that remains of Capra ibex in Zlot cave complex maybe introduced by river, since the cave in which they found remains, are the oldest found abyss of the main river. It has been estimated that the ibex fossil remains are between 780,000 and 120,000 years old and that they belong to the middle Pleistocene period. Basis on preliminary results this is the oldest fossil remains of *Capra ibex* in the Balkan penisula and maybe in Europe.

2. Method

Precise identification and age estimate will be made after excavated of remains using uran-234/thorium-230 method, which use when the age range of the sample comes out carbon-14 (more than 40,000 years).

3. Results

Left parts of the skull were found with preserved impressive horn size. After excavated of remains we will have some results like precisely size of the scull, age of remains etc.

4. Conclusion

Also, fossil remains of *Capra ibex* were found in Austria and Eastern Alpine caves, and in Slovenia, but it is considered that fossil remains of Capra ibex from Serbia are much older, because this species extinct from this area.

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ARCHAEOLOGY AND THE WINTER SOLSTICE IN THE CAVES OF THE BOHEMIAN KARST, CZECH REPUBLIC

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After the Moravian Karst, the Bohemian Karst is the most important region of speleo-archaeological interest in the Czech Republic. The region's caves are primarily smaller in size, but around 80 known sites with archaeological finds document interest in them throughout prehistory. During the agricultural prehistoric era, use of the caves peaked in the Middle to Later Neolithic and the Late Bronze to Early Iron Age. When contemplating their function, the most clearly visible aspects tend to be those related to cult activities. During the Bronze Age, vertical caves and dark caves were used as well. In the Neolithic, abundant finds are often concentrated in caves that for various reasons were not suitable for regular habitation. The example of Nová Cave shows a possible connection between the cave's unusual Neolithic find context and lighting impressions inside the dark cave during sunrise around the winter solstice, which allows us to assume the possibility of cult rituals associated with this important date in the surrounding caves with an entrance oriented to the southeast.

1. Introduction

The roughly 130 km^2 Bohemian Karst is the largest karst region in Bohemia and the only karst region with a demonstrated incidence of prehistoric cave localities in Bohemia. It consists of islands of Silurian and Devonian limestone, separated from one another by non-karst rock, fault lines or valleys at an elevation of 200–499 meters above sea level. The region's cave systems tend to be smaller in size (as compared, for instance, to the largest karst region in the Czech Republic, the Moravian Karst), which is caused in part by the region's lack of water – and this despite the fact that the its axis between Prague and Beroun is made up of the Berounka River. The climate of the Bohemian Karst is moderately warm to warm, with mild winters, an average annual temperature of 8–9 °C, and average annual rainfall of 530 mm.

2. Summary of the caves' use

There are around 80 speleo-archaeological cave localities registered in the Bohemian Karst from practically all periods of the prehistoric and historic eras. The high level of interest in caves is related to the region's location within the ancient settlement area of the Bohemian Basin, which has been continuously settled since at least the early Neolithic. The distribution of caves with evidence of human presence significantly corresponds to the natural concentration of karst phenomena resulting from geological developments, and is concentrated in three more or less separate regions: a central region delineated by the municipalities of Karlštejn, Tetín, Srbsko and Svatý Jan pod Skalou; the southeastern region of Koněprusy; and a northeastern region on the outskirts of Prague. The main archaeological interest in the caves of the Bohemian Karst was in the 1920s to 1940s, when many of today's known localities were explored, for the most part comprehensively. Other individual explorations followed in the 1950s (F. Prošek) and the 1980s and '90s (V. Matoušek). The findings of these explorations have been published (Fridrich and Sklenář 1976, Sklenář and Matoušek 1994, Svoboda et al 2004).

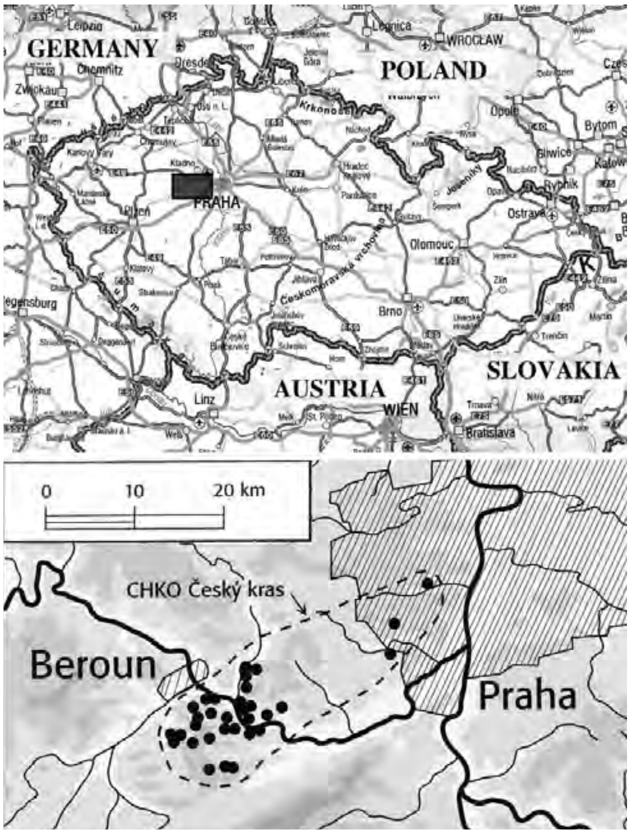

Figure 1. Location of the Bohemian Karst and sites of caves from the Bronze Age/Hallstatt Period.

The caves of the Bohemian Karst were already known to the populations of the Middle Palaeolithic, but more localities are not recorded until during the Upper Palaeolithic. Human skeletal remains and artefacts in the tourist complex of the Koněprusy Caves are dated around 30000 BP. Several smaller caves (e.g., Děravá Cave with a ibex carved on a shale tablet) were settled during the Magdalenian period, and a larger open settlement was located on the promontory near the village Hostim. Occasional finds document a human presence in caves in the Late Palaeolithic and Mesolithic as well (Fridrich and Sklenář 1976, Vencl 1995, Svoboda 2000). By the Early Mesolithic, the highest peak in the Bohemian Karst, Bacín (499 m), was probably a shrine, as documented by the lowest horizon of human remains in vertical fissure I (Matoušek 2001). A significant increase in archaeological cave finds is associated with the Middle and Late Neolithic (see section 3). During the Aeneolithic, interest in caves apparently fluctuated depending on the various archaeological cultures (e.g., Koda and Tří Volů caves, and the Bacín II fissure). Sporadic interest in caves continued in the Early and Middle Bronze Age (Sklenář and Matoušek 1994, Matoušek 2001).

A second significant find horizon from the caves of the Bohemian Karst corresponds with the period from the Late Bronze Age (Bz D / Ha A, ca. 1200 BC) to the Early Iron Age (Ha D, ca. 380 BC) – a total of 37 sites. All types of caves were used: vertical (pit) caves, horizontal clefts, cave passages, and halls. Less commonly found non-ceramic finds (in particular bronze rings, bone awls and human bones) come from vertical caves, horizontal caves with shafts, narrow clefts, and caverns whose height does not exceed 160 cm – i.e. not from spacious and bright caves. According to a pottery analysis, sets consisting primarily of decorated vessels and graphite-painted ceramic tableware are associated with caves that have narrow or overwhelmingly dark interiors (Barrandova, Turské Maštale/Poslední Síň, Ve Stráni) and are found alongside other find categories (human bones, zoomorphic vessel, strainers/incense burners, or items made of bronze, stone and bone). The relationship between the spectrum of finds and the choice of caves leads the author to consider the possibility that these caves held a special status, for instance associated with ritual activities. This is because a profane use of these localities can be imagined only under the most extreme conditions. During this period, the caves were located in a relatively densely settled area, so they were no farther than 2 km from the settlements of the time (Matoušek and Peša 1998, Peša 2006).

In terms of archaeology, during the Late Iron Age (the Celtic era), the time of the Roman empire, the Migration Period, and the Early Middle Ages caves appear only as isolated localities or finds (Sklenář and Matoušek 1994). The onset of the Middle Ages (and the general spread of Christianity) probably led to a transformation of the importance of caves. Exceptional places with a prehistoric tradition and a spirit of a place (*genius loci*) were Christianised (Svatý Jan pod Skalou, Tetín, Prokopská Cave), while the most common use for other caves was as shelters or refuges – later mostly during wars. An important locality in this regard are the tourist-accessible Koněprusy Caves, whose public tour route includes a money-forging workshop from the 1460s to 1470s. During the 16th and early 17th century, the Bohemian Karst (like other regions) was probably sought out by prospectors, as possibly indicated by passages dug into the clayey sediments and roughly dated using archaeological finds (Koněprusy Caves, Krápníková), as well as by the proximity to Prague, which under Emperor Rudolf II had become a European centre of alchemy. This era also saw an increased interest in speleothems, which the monks mined in the no longer extant caves near Svatý Jan pod Skalou, then processed, and sold as medication (Peša 2013).

3. Caves during the Neolithic (5100 – 4300 BC)

There are Neolithic finds from around 30 caves in the Bohemian Karst. In terms of inhabitability, only the largest of these (Koda, Nad Kačákem, Sloupová) offer room for 2–3 nuclear families – i.e. hardly enough for the inhabitants of a Neolithic long house. The other caves could be used at most by a few individuals – in the case of crevice passages with a width of up to 2 m only in the most extreme circumstances, while others are entirely unsuited for settlement purposes either because of their small size or their (for instance, vertical) shape (Peša 2011).

Caves were used during the Middle Neolithic (Late Linear Pottery) and during the Late Neolithic with an overlap into the Early Aeneolithic (Stroke-ornamented ware culture, Lengyel horizon), but only in the central area and the NE Prague area. The finds and find context offer evidence of cultural strata with numerous preserved and scattered fireplaces and occasional preserved structures (Na Průchodě Cave). The dominant finds are fragments of vessels, but there are also larger pieces or even some vessels preserved in their entirety (Malá and Hlohová caves). It is highly probable that these last two caves involved the final placement of vessels in connection with cult activities. Generally associated with sacral purposes are the finds of dislocated human bones in the Late Neolithic cultural layers in Galerie and Nová Caves and, in Prague, possibly in Prokopská Cave as well. The significance of the extraordinary archaeological context in the rear portion of Nová Cave is further enhanced by an astronomical observation of the unusual conditions at sunrise around the winter solstice, which offers the possibility that this cave (and possibly, though with a less spectacular effect, the neighbouring Patrová and Úzká caves as well, and perhaps even Galerie Cave) was associated with cult rituals marking the start of the astronomical year (Peša 2011).

4. Astronomical phenomenon and archaeology

Nová Cave (municipality Srbsko, Beroun county) and another 12 archaeologically significant caves are located in a distinctive rock formation above the Berounka River. The cave's entrance, which opens towards the southeast, is located 45 m above the surface of the river in the upper part of a side ravine. The entryway narrows into a low passageway that opens up into a vestibule that today measures ca. 190 cm in height. From here, two impassable crawlspaces lead off into the rock massif. In both summer and winter, the lighting conditions inside the cave can be called twilit or semi-dark, which reflects the enclosed shape of the cavern.

On 21 December 1996 (i.e. on the winter solstice), the author and A. Majer recorded unexpected lighting conditions in the cave. At 9.30 in the morning, the sun rose above the opposite slope of the ravine, and the sun's rays illuminated the rock above the cave's entrance. As the sun rose in the sky, the rays entered the cave and projected a brilliant orange disk onto the cave's rear-most part 12 m

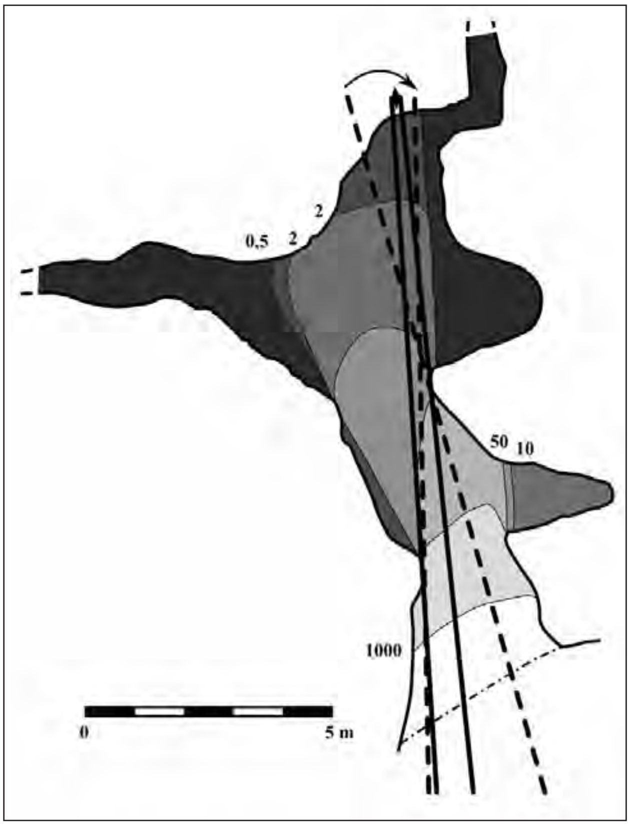

Figure 2. Nová Cave – illumination map (isolines in lux) showing the penetration of sunrays from 9.30 to 10 a.m. (dashed lines) with diamond-shaped climax (full line).

from the entrance, in front of the low right-hand passageway; the disk quickly grew in size, climaxing at 9.45 a.m. as a diamond measuring about 40 cm in height. This final shape was the result of the row of rocky protuberances in the cave's entryway, which allowed only some of the sun's light to enter. The sunrays reflecting back from the illuminated location coloured the cave's twilight in a dim orange glow. The entire event lasted half an hour, with the constantly shrinking sun's disk disappearing completely at 10 a.m. and the vestibule again falling into a half-darkness (Peša and Majer 2003). The author observed the entire event again during later years, and documented it photographically on December 24, 2000 and January 4, 2001. During the second measurement 13 days later, the astronomical phenomenon was the same, except that the changing angle of the sun's rays gradually deformed the diamond shape. Although it was not possible to precisely define the phenomenon's period of existence, it is probably observable at most for a period of 2–3 weeks before and after the solstice, but the shape is purely vertical only for a period of several days around December 21, 2000.

In Nová Cave, this unusual natural phenomenon is further accentuated by the extraordinary archaeological find context. The original surface in the Neolithic was a mere 30 cm higher than today, and the cave thus had similar lighting conditions. In the Middle Neolithic, there was a fireplace at the beginning of the right-hand passageway, and deeper inside, near where the sun's rays hit the cave wall, there was a layer of ash and an overturned bowl. Another fireplace located in the just 80 cm-high left-hand passageway contained chipped stone tools and a ground stone hatchet. A similar find context is repeated for the Late Neolithic, with a fireplace again located in front of the right-hand passageway, an ash heap in the left-hand crawlspace, and the vestibule yielding among other things splintered human bones (Sklenář and Matoušek 1994). Both fireplaces in a space just ca. 1 m high call into doubt the practical use of fire, not to mention that, at least today, the cave's microclimate is static and the crawlspaces do not act as natural chimneys. The lighting conditions inside the cave were thus very similar during the Neolithic, and we may assume that the rising sun shone into the cave in a similar manner as it does today. The exceptionally impressive spectacle – in which the reflection of the rising sun is briefly transformed into a shape resembling a woman's womb – makes Nová Cave a holy site that was home to rituals associated with the winter solstice and perhaps also Mother Earth. The site's special status is also confirmed by the unusual find context, which differs from profane activities. To date, the author has been unable to find any analogous phenomenon for a speleo-archaeological locality in the literature.

5. Conclusion

As much as the caves of the Bohemian Karst with their overwhelmingly bright interiors enabled occasional profane usage, more specific evidence relates primarily to cult activities. However, this claim may be made only for the Neolithic and Late Bronze to Hallstatt Period, when the caves were visited more frequently and for which we have corresponding archaeological findings. For the Neolithic, the group of caves around Nová Cave in the central Bohemian Karst offers a possible connection with cult activities and the winter solstice – i.e. the start of the agricultural year. It is certainly no coincidence that these caves with their presumed function as sites of cult activities are among the localities with the thickest cultural layers, unusual find contexts, and the largest number of archaeological finds. Similar contexts are found in other karst regions in central and southeast Europe during periods of intense interest in karst caves (Peša 2006, 2011).

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Figure 3. Srbsko – Rock face with caves, seen from the south. All photos V. Peša.

Figure 4. Srbsko – Rock face with Úzká and Patrová Caves; Nová Cave is outside of the picture on the right.

Figure 5. Srbsko – Nová Cave, entrance.

Figure 6. Nová Cave. Sunrays entering the cave.

Figure 7. Nová Cave. Sunrays being projected onto the cave wall around the winter solstice (4 January 2001).

Figure 8. Nová Cave. Sunrays being projected onto the cave wall near the right-hand crawlspace (24 December 2000).

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FOSSIL ASSEMBLAGES FROM NEANDERTHAL SITES OF SLOVAKIA – PRELIMINARY RESULTS

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The environment of Neanderthals was distinctly changed during the Late Pleistocene in the whole area of their occurrence because of severe climatic changes. Differences found in the composition of fossil assemblages reflect that in the terrestrial envitronment. Based on the definition of the taxonomical diversity of extinct organisms, the palaeoenvironmental reconstruction, and the exact age determination of the fossil record, a definition of individual events is possible from the evolutionary-phylogenetic and the climatic-environmental viewpoints. The fossil record also represents an evidence of multiple immigrations, including also migration of Neanderthal hunting groups. The most important Neanderthal sites in Slovakia with the large quantity of fossil remains are as follows: Bojnice, Čertová pec, Gánovce, and Bešeňová.

1. Introduction

The Neanderthal Man (*Homo neanderthalensis*) is an object of the intensive worldwide research since the time of his discovery in 1856 in the Neanderthal Valley near Düsseldorf. This extinct human kind, occupying Europe and Near East almost over 200,000 years, left proofs enough of his presence, such as skeleton remains, stone tools, or game remains in caves or in open-air settlements. At present, the research of Neanderthals is focused not only on the study of their population history, living requirements, technology and social organization, but mainly on their phylogenetic position from the palaeogenetic viewpoint as well as on their environment, including also the study of their adaptive ability on climatic changes at the time of their existence (Koenigswald et al. 2006). From this viewpoint, the palaeontological remains of organisms from the Neanderthal sites have the greatest information value because many of them responded very sensitively to environmental changes and form an important source of proxy-data about palaeoenvironmental conditions (Wiśniewski et al. 2009).

The presence of Neanderthal Man in the territory of Slovakia is documented minimally at 31 sites from the Middle Palaeolithic Period (Kaminská 2005). Except for 2 sites with finds of Neanderthal anatomical remains (Gánovce and Šaľa), the rest of sites is mainly known by a record of stone industry connected with the Neanderthal population (Taubachian, Mousterian, and Micoquian). Only exceptionally, some sites represent a more continual settlement with the large palaeontological, or archaeozoological record respectively. The best-known sites are as follows: Bojnice, Čertova pec, Bešeňová, Hôrka-Ondrej, and Gánovce (Fig. 1). Apart from Hôrka-Ondrej (Kaminská (ed.) 2000), the fossil remains from the sites are only partly interpreted (Čertova pec, Gánovce) or they were so far not totally evaluated (Bojnice, Bešeňová). Fill "this niche", a new scientific project started in 2012, focused mainly on the definition of the taxonomical diversity and the palaeoenvironmental conditions in the territory of Slovakia during the Neanderthal period.

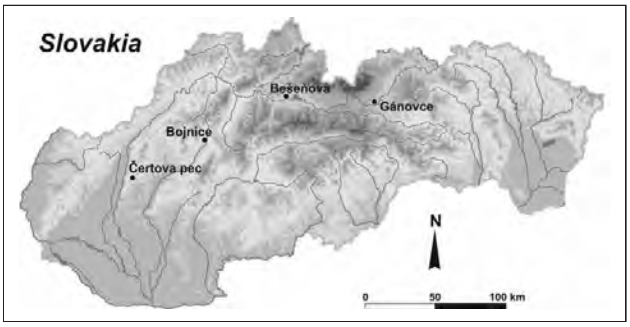

Figure 1. Location of Slovak Neanderthal sites under study.

2. Studied sites

The Neanderthal settlement from the **Bojnice** area (48°46' N 18°34' E) near Prievidza is well documented mainly in two locations – the Prepoštská Cave (Bojnice I) and the Hradná priekopa (Bojnice III). The Prepoštská Cave, representing an abri with 8 metres long cave space within the travertine heap, is known since 1926 (Medvecký 1927). The researches of Prošek (1952) and Bárta (1966) here demonstrated one of the most important Neanderthal settlements in Slovakia with Early Mousterian culture. The last dating by ^{14}C method places this settlement to the period before 40000 BP, corresponding with Moravian Micoquian sites of Kůlna (layer 7a) and Šípka (Kaminská and Neruda 2010). The location Hradná priekopa has been identified in 1964 close to entrance gate of the Bojnice castle. The subsequent research in 1966 to 1969 shows the presence of 11 cultural layers with Taubachian stone tools, disrupted fireplaces, animal bones and gastropods from the end of the Eemian to the beginning of the Weichselian (Bárta 1972). In spite of the discovery of large quantity of fossil remains of malacofauna (Prošek and Ložek 1951) as well as of vertebrates (Hokr 1951, Prošek 1952, Fejfar ex Bárta 1972), indicating an organized hunting of relatively small Neanderthal group (Bárta 1972), the whole fossil record has so far been not studied in details from the taxonomical, taphonomical, palaeoecological, and biostratigraphical viewpoints.

The **Čertova pec** site is situated in the Považský Inovec Mts. near Radošina village (48°33’ N 17°54’ E). It is 27 metres long cave with two opens. The first excavation at the site has been realized by L. Zotz in 1937, later by F. Prošek in 1950 (Hokr 1951, Musil 1996). During the last research of the cave in 1958–1961, headed by J. Bárta, three Palaeolithic layers with stone industry of Gravettian, Szeletian, and Mousterian have been found. A find of fireplace within the layer 4 with Szeletian stone tools yielded a datum 38320 ±2480 BP (Bárta, *unpubl. manuscript*), whereas ^{14}C dating of found cave hyena remains yielded the age older than 50000 BP (Nagel, *pers. comm.*). Although Musil (1996) partly evaluated a fossil record from the cave, a part of found fossils from the time of Bárta’s research, recently housed at the Department of Geology and Palaeontology, Faculty of Natural Sciences, Comenius University in Bratislava, was so far not studied yet.

The best known and the the most important of mentioned Neanderthal sites in Slovakia is the travertine mound of **Gánovce-Hrádok** (49°01’ N 20°19’ E) with the sedimentary record from the Saalian termination up to the Holocene. A scientific research at the site was realized since 1880s, but the complex systematic research was realized only during 1955–1960, conditioned by the famous record of Neanderthal braincase in 1926. The research results have been published in the final report (Vlček et al. 1958) and within a monograph (Vlček 1969). The basic analysis of palaeontological findings of mammals was realized by Fejfar (in Vlček et al. 1958), who divided them into 6–7 groups, providing together with fossil molluscs (V. Ložek) and plants (V. Kneblová) a basic picture on both the climate and the palaeoenvironment in the vicinity of Gánovce during the formation of the travertine mound. Apart from remains of mammals, birds (Petrbok 1937, 1939), and reptiles (Štěpánek 1934), the most important record at the site is represented by fossils of Neanderthal Man. The age of the place, where Neanderthal fossils have been found, was determined as 105000 BP (Jäger 1989). Recently, the datum is, however, called into question (Rabeder, *pers. comm.*). Also, the whole palaeontological record from the site, unlike the palaeoanthropological (Vlček 1969) and archaeological one (Bánesz 1990), was so far also not evaluated in details, including so far not studied fossils housed in the Podtatranské Museum in Poprad (Bekessová 2007, Bekessová and Mlynárčiková 2009).

Travertine heaps near **Bešeňová** (49°06’ N 19°26’ E) are next promising site, where no archaeological and also no systematic palaeontological research was realized up to now, although J. Kovanda found a flint artefact in the location of “Skalie” in 1960 (Kaminská 2005). Also, remains of the Pleistocene fauna from the location of “Báňa” are known since the period of travertine exploitation before the Second World War. In spite of reference to gastropod fauna and isolated finds of small mammals (Vaškovský and Ložek 1972), the substantial part of faunal record from the site (except of fossil remains of lions; Sabol 2011) is not evaluated yet.

3. Preliminary results

3.1. Bojnice I – Prepoštská Cave

So far (October 2012), the detailed morphometric analysis of vertebrate fossils (more than 350 remains) from the site (Bárta’s pit III) shows relatively large animal diversity. The whole up to the moment studied assemblage consists of frogs (Anura indet.), birds (cf. *Anas querquedula*, cf. *Falco* sp., Aves indet.), hares (*Lepus* sp.), rodents (*Arvicola terrestris*, *Microtus* cf. *agrestis-arvalis*, Rodentia indet.), canids (*Canis lupus*, *Vulpes* sp., *V*. cf. *lagopus*), ursids (*Ursus* sp., *U*. ex gr. *spelaeus*), mustelids (cf. *Martes* sp.), cave hyena (*Crocuta crocuta spelaea*), cave lion (*Panthera spelaea*), woolly rhino (*Coelodonta antiquitatis*), horse (*Equus* cf. *germanicus*), cervids (*Rangifer tarandus*, Cervidae indet.), bovids (*Bos primigenius – Bison priscus*, Bovidae indet.), and woolly mammoth (*Mammuthus primigenius*) (Figs. 2 and 3).

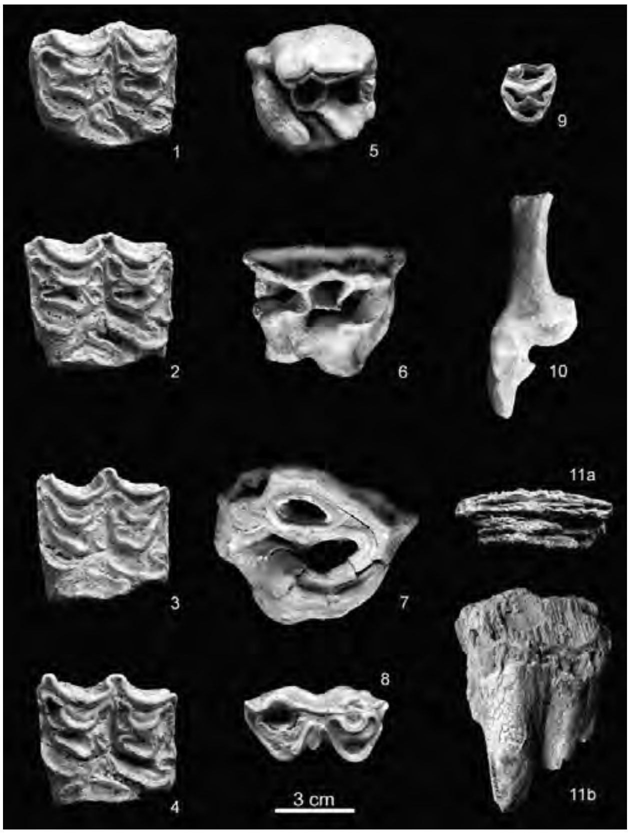

Figure 2. Fossils of mammals from the Prepoštská Cave. 1–4: Equus ferus cf. germanicus (1 – P3 sin., 2 – P4 sin., 3 – M1 sin.,4 – M2 sin.), 5–7: Coelodonta antiquitatis (5 – P2 sin., 6 – M1 dext.,7 – M3 dext.), 8: Bovidae indet., m2 sin., 9–10: Rangifer tarandus (9 – P2 sin., 10 – calcaneus dext.), 11: Mammuthus primigenius (molar fragment).

Based the taxonomical determination and the sedimentary record, found taxa represents an assemblages that lived probably in open Late Pleistocene environment with the presence of a water area or source (a travertine lake – hot travertine spring[-s]) in the near vicinity.

Figure 3. Fossils of mammals from the Prepoštská Cave. 1: Panthera spelaea, m1 sin., 2–3: Crocuta c. spelaea (2 – p4 sin., 3 – C sin.), 4: Canis lupus, ulna sin., 5–6: Vulpes sp. (5 – C dext., 6 – Mt III sin.), 7: Lepus sp., humerus dext., 8: Arvicola terrestris, mandible dext., 9: Aves sp. I, tarsometatarsus dext., 10: Aves sp. II, tarsometatarsus dext. Scale A (1–6), scale B (7–10).

From the viewpoint of the quantification of studied mammalian fossils, remains of carnivores (42 %) and perissodactyls (26 %) dominate, althought the largest quantity of fossils (228 bone remains) is undeterminabled (Mammalia indet.) because of their fragmentation. Many of these fragments, however, display marks of biotic agents, such as hyena (bitting, gnawing, and chewing marks) or ancient man (cutting marks and fragmentation due to marrow). Some bone fragments were also attacked by fire with the temperature moving in the range from 300 °C to 550 °C (based on the colour of bone fragments).

The preliminary results allow to characterize the site mainly as a hyena den that was occasionally used by small groups of Neanderthals during their migrations, probably in a warmer period (interstadial) of the Last Glacial.

3.2. Bešeňova travertine quarry

Fossil record from fissures of the Bešeňova travertine quarry consists mainly of remains of large mammals that have been found during the exploitation in 1920s and 1930s. The largest portion of fossils comes from rhinos (Rhinocerotidae indet., probably *Coelodonta antiquitatis*) (36 %), showing also gnawing marks at some bones. Originator of these taphonomic characters could be hyenas (absent in the fossil record) or a lion-like felid (*Panthera* sp. – *Panthera* cf. *leo*), although fossils of ursid (*Ursus* sp.) are also known from the sedimenetary fillings of the travertine fissures. The rest of the found mammalian remains belongs to caballoid horses (*Equus* sp.), cervids (*Cervus elaphus*, *Megaloceros giganteus*, Cervidae indet.), and bovids (*Bos primigenius* and/or *Bison priscus*, Bovidae indet.).

So far, the exact age of Bešeňova fossil assemblage(-s) is unknown. Although the mid-Pleistocene (Holsteinian?) age of the Bešeňova-Báňa travertine is assumed (Gradziński et al. 2008), vertebrate fossil record found in the "rusty karst loam" from travertine fissures is younger. Its preliminary analysis indicates a possible existence of minimally two temporal different faunal assemblages – the former one probably from the Last Interglacial period and the latter one from the Last Glacial period (maybe from an Interstadial?). The thanatocoenosis of the lower red loam corresponds to a warm humid climate, which was a little colder than at present. Fossils of *Clethrionomys* and *Apodemus* (Fejfar in Vaškovský and Ložek 1972) indicate a development of mixed forest. From this viewpoint as well as on the basis of found flint artefact, the Bešeňová is assumed to be a potential (Middle) Palaeolithic site with the presence of ancient (Neanderthal) man. It could be supported also by a record of partly polished cervid antler with possible cutting marks(?) (Fig. 4).

Figure 4. Detailed view on the cervid antler part with possible cutting marks produced by an ancient man(?).

3.3. Čertova pec and Gánovce

As abovementioned, the fossil record from the both sites have been previously evaluated either only in the form of basic palaeontological analysis (Fejfar in Vlček et al. 1958) or only as a part of the whole collection (Musil 1996).

From this viewpoint, a repeated complex evaluation of the fossil record from both these sites is required, using modern taxonomic, taphonomic, isotopic, and dating methods. It will be opened in 2013. On the other hand, a new field research of the Čertova pec Cave could yield more exact data on the faunal composition, environment, and climate in the time of existence of the last Neanderthal communities in the Central Europe.

4. Conclusions

The state of the art of Neanderthal palaeoenvironment during the Late Pleistocene in the territory of Slovakia is more or less limited only on basic data from archaeological researches, realized mainly in 1950s to 1970s. Based on new scientific approaches and achieved knowledge in connection with data from other scientific fields as well as research methods (taphonomy, forensic (palaeo-anthropology, isotopic analyses, and radiometric dating), the solution of some unanswered questions will be important (e. g. What did species live in Slovak territory at the time of the presence of Neanderthals? Which of them did form a forage and material basement of Neanderthals? What was a relationship between Neanderthals and large predators (such as lions, bears, or hyenas; see also Rosendhal and Darga 2004)? How did single phases of the Late Pleistocene in the Slovak Carpathians differ from the viewpoint of climate, palaeotemperature, or composition of faunal assemblages? What were migration paths of fauna and ancient people? etc.). From this viewpoint, the main objectives of the new project are focused on (1) the specification of the Late Pleistocene biodiversity at selected sites, (2) the determination of biotic and abiotic taphonomic agents at selected sites, (3) the reconstruction of climatic-environmental conditions at the Slovak territory during the Late Pleistocene, (4) the specification of the stratigraphical position of Neanderthal sites selected in the Slovak Carpathians, and (5) the definition of geophysical characteristics of the sedimentary environment and its changes caused by human activity. It can also stimulate a new interdisciplinary field research of prospective localities, such as Čertova pec or Bešeňová.

Acknowledgments

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PRE-HISTORIC REMAINS AT THE CÓRREGO DO CAVALO FARM, PIUMHÍ, MINAS GERAIS, BRAZIL

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The distribution of human occupation in Brazil is not a new subject. Neither is the fact that in the country, remains of past occupation are very common in carbonate karst areas. For this reason, during the field studies for the geomorphological mapping of a future natural reserve, remains of prehistoric occupation where found. The region of the Córrego do Cavalo farm, which is mainly drained by the Barreado creek, is located at the west portion of the Speleological Karst Region of Arcos-Pains-Doresópolis and is famous for its archaeological potential. The municipality, known for increasing mining activites, urges for the identification of such sites in order to preserve them as much as possible. In this work, the authors identified a total of 51 caves in the research area and 7 of them contain significant archaeological remains. Considering the archaeological remains identified in the study area, and their spatial distribution, one can infer that the region was occupied by prehistoric communities due to the fact that these traces are distributed along the 2,913 km^2 of the study area. These traces should be treated as important documents that should lead to the understanding of the ecological and cultural relations of these prehistoric group and/or goups.

1. Introduction

The idea of an Environmental History began to emerge in the 1970s, succeeding the first global conference on environment, and also the growing environmental movements in various countries. Its main goal was to deepen the understanding of how humans were, over time, affected by their natural environment and, conversely, how they can affect the environment. In very simple terms the Environmental History deals with the role and place of nature in human life (Worster 1991).

Therefore, according to Oliveira (2007) in order to understand the processes that promote landscape transformation, Environmental History rest on two pillars which constitute the landscape: *culture* and *territory*.

Canedo (2009) afirms that one can understand culture through three fundamental concepts. First, on a wider sense, where all individuals are producers of culture being nothing more than a set of meanings and values of human groups. Second, as the intellectual and artistic activities with a focus on production, distribution and consumption of goods and services that makes up the system of the cultural industry. And the third concept states that culture can be perceived as a tool for political and social development.

The term *territory* has important associations with the term *power*, since territories are formed primarily from relations of power. Territoriality remains associated with the relations of power and presents itself as an attempt to establish a territory (not always concrete) through well-defined borders (Lisboa 2007).

For Worster (1991), besides the above described, Environmental History must also consider the concepts of the natural sciences. This is due to the fact that this type of analysis must always start with the reconstruction of past landscapes, seeing how they were and how they worked before being modified by human groups. Thus, the environmental historian must relate the development of various civilizations with some concepts of the natural sciences such as ecology, geology, geomorphology, pedology and climatology, for example. The authors of this paper also think that Kasrtology and Speleolgy can play an important role in this analysis.

Understanding the dynamics of ecosystems also requires an understanding of how social and ecological factors interact, and how these interactions are continuously modified (Fraga and Oliveira 2011). As Prof. Yuan Daoxian, a renowed kasrtologist from China would say, comprehending karst dynamics is also very important to better understand the complexities of human use of karst.

Worster (2011) says that scientists tell us that a natural ecosystem has a role, so everything influences the functioning of the whole. Inversely, all things are affected by being in an ecosystem. In this line of thought appears the term "techno-environment" (or the application of technology to the environment) as the core of any culture. This is the most important influence on how people live with each other and think their world.

According to Oliveira (2007), the changes that occur in this process concern the landscape transformation. Within this interdisciplinary vision, the integrated study of Environmental History can bring valuable benefits to understanding of landscapes transformation, particularly on very current issues such as global climate change, biodiversity losses and landscape fragmentation.

Therefore, over time, the succession of these uses leave marks, spatializes itself and overlaps as paleoterritories – a concept proposed here as a part of the process of succession and defined as the spatial distribution of the ecosystems used by past populations in search of their conditions of existence. Hence, the paleoterritory is an anthropogenic variable of abiotic and biotic processes that influence the development of forests regeneration, for exemple. In this case, traditional cultures play a decisive role (Oliveira 2007).

Similar to the concept of *paleoterritory* one can suggest the term *palimpsest* (concept used to describe a papyrus in which the original text was scraped to make way for a new one) to characterize the constant search of geomorphology, karstologyu and speleology for "scars", "tracks" or "secrets" hidden in the landscape.

The historic features of the landscape constitute a significant factor in its evolution, which reflect how human relationships influence their occupation (Fraga and Oliveira 2011), the same way that the control of the landscape is made by interactions of terrestrial geosystems (Press et al. 2006).

For all these reasons, this paper is intended to demonstrate that a not well known prehistoric group and/or goups used a specific karst region in the south portion of Minas Gerais State, Brazil.

2. Study area

The study area, (aprox. 2,913 km^2) is located at the Córrego do Cavalo Farm, between the municipalities of Doresópolis, Pains, Pimenta and Piumhí (Fig. 1), cities at the west portion of Minas Gerais State (IBGE 2010).

With a tropical climate subjected to dry winters, the average annual temperature registered is 20.7 ºC. July is considered to be the coldest month with an average temperature of 16.3 ºC, and January the warmest one with an average of 23.3 ºC. The local annual average rainfall is arround 1,344 mm (Meganesse et al. 2011).

The vegetation cover in the study area is transitional, with fragments of Atlantic Rain Forest and Cerrado, knonw as the *Brazilian Savannah*. The main typology observed associated with limestone is the Seasonal Decidous Forest (Barbosa 1961).

The vegetation displayed on the study are is also called "Dry Forest", mainly associated with the karst relief, composed by typical features such as dolines, ponors, outcrops, and karren (Fig. 2), for example (Timo et al. 2012).

Regarding the study area hydrography, the Córrego do Cavalo Farm is located in the portion of the Upper São Francisco river portion. The surface drainage area is controlled by the Patos Creek, a tributary of the São Francisco river.

The Patos creek has its flow from south to north, with its source near the city of Pimenta. It flows reaching the São Francisco river near the city of Iguatama. The main tributaries of the left bank of Patos Creek are the Cavalo Creek and the Barreado Creek.

The Cavalo creek, which delimits the cities of Piumhí and Pimenta, flows to the Patos Creek in the study area. The most representative watercourse in the study area is the Barreado creek which has much of its flow in the underground. For this reason are frequent many sequences of sinks and resurgences, "carved" in calcarenite lenses. The gradual lowering of the local base level provides today, access to these conduits that are actually a series of caves arranged in the path of this watercourse. Localy they are known as the Barreado System. Therefore, resurgences and sinks are the most significant features of exokarst, occurring abundantly in the region (Campelo and Pizarro 2004).

A system of karst lakes or ponds is also connected to the Barreado Creek. These are located in solution dolines. Collapse dolines can also be seen in the study area, and its upper edges are between altimetric elevations that rage from 700 to 720 m.

The region of the Barreado creek basin is located in the western portion of the Speleological Karst Region of Arcos-Pains-Doresópolis (SKRAPD), placed in the Block of Patos creek (*Bloco do ribeirão dos Patos*) as the main geomorphological compartiment of this province.

The most important karst features of the Barreado creek are the large massive limestone outcrops (heavily oriented in NW–SE direction), plus a set of caves with conduits structured along axial planes in hinge zones of asymmetric folds with preferential direction to NE.

In this system, 51 caves were found and explored, with slopes greater than 10 m and horizontal developments up to 1,000 m. These numbers are important considering the average size of caves in the SKRAPD.

The high hydraulic gradient in place has a significant importance to local speleogenesis, with the predominance of ancient caves interconnected due to the drop of groundwater level. Caves like the *Loca dos Pescadores*, *Loca da Mureta* and the *Gruta dos Óculos* are examples of caves related to the current water level.

It is also noteworthy in the region, the vast potential of archaeological findings. According to Timo et al. (2012), 7 caves out of the 51 found had prehistoric archaeological remains characterized by lithic hatchet remains, pottery and pottery shards.

3. Prehistoric occupation at the Córrego of Cavalo Farm

According to Toledo and Molina (2007), cited by Fraga and Oliveira (2011) the environment in which human societies produce (or reproduce) the material conditions for their existence are to be considered as a kind of social metabolism. These authors proposed the study of social metabolism based on five processes: 1) appropriation, 2) transformation, 3) distribution, 4) consummation and, 5) excretion.

From the perspective of the landscape, one can consider that archeology is dedicated to the study of human societies, by the remaining set of materials. In other words, the material culture, its arrangement, and especially, its location in the landscape in which established historical and environmental relations (Orejas, 1998).

Accordding Orejas (2008), the material culture is understood as the group of physical evidence resulting from human activity such as its artifacts and remains of its manufacturing, housing structures, urban centers, manifestations of art, food waste, and the modified environment, among others.

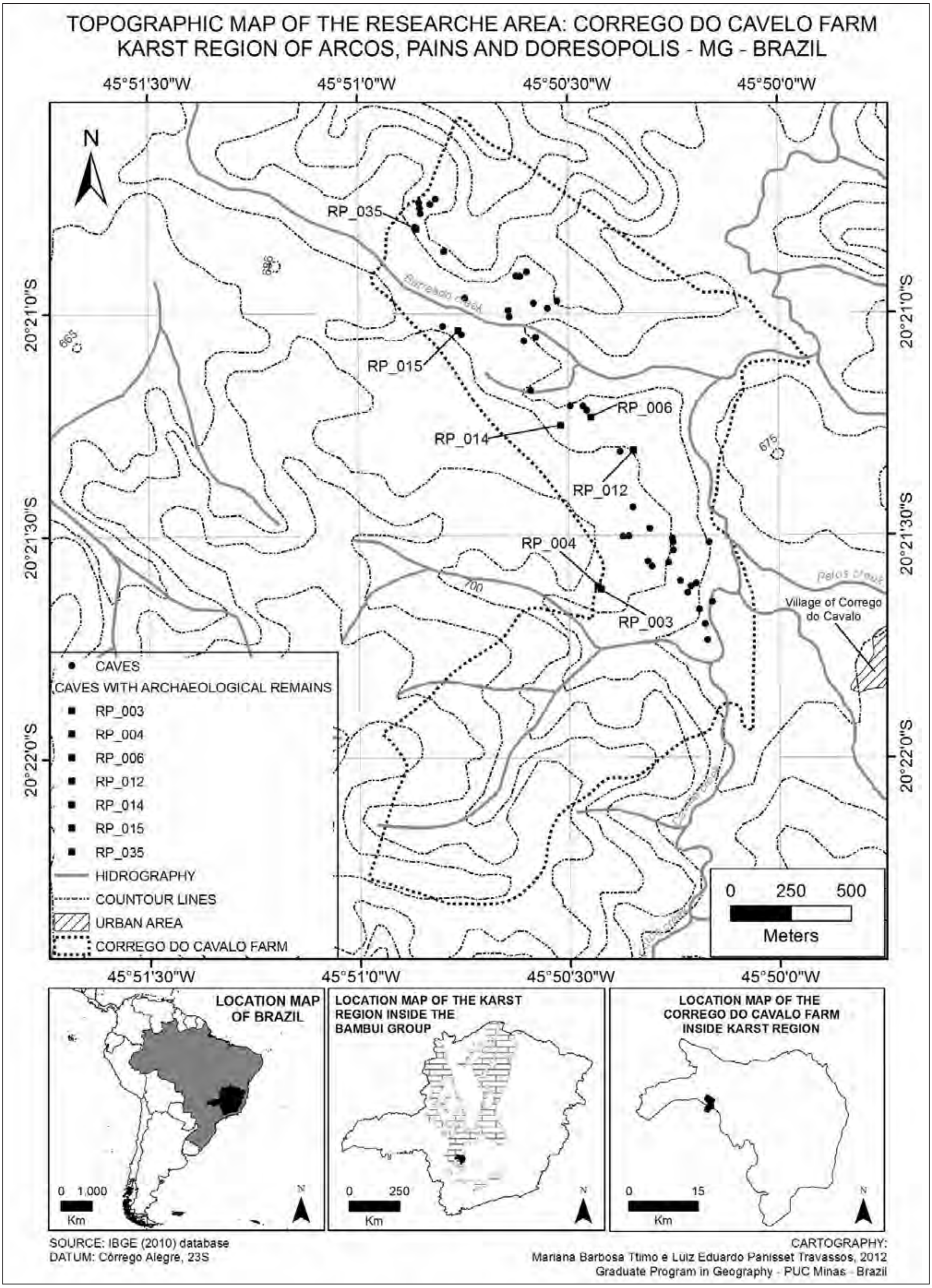

Figure 1. Topographic map of the research area: Córrego of Cavalo Farm, karst region of Arcos, Pains and Dorésópolis, Minas Gerais, Brazil.

These traces should be treated as documents, vectors of information that leads to the understanding of the ecological and cultural relations of prehistoric peoples. In this perspective, all structures or material remais, as well as its articulation with the natural and modified environment, or the landscape itself, are potentially significant for the reconstitution of cultural processes from the past.

Regarding the suty area, one can say that the richness of the archaeological remains identified in it is enormous. Its natural caves function as true "time capsules" (Prous, 1992), which preserves these remains allowing the establishment of occupation sequences of prehistoric groups who inhabited the region

The number of identified archaeological remains in the region suggests that it was occupied by a prehistoric group (or groups). According to the proposal of social metabolism, this community has used the region and its available resources in order to survive in the karst.

The availability of water resources in the area is an important factor for the establishment of this particular group (or groups). The entire area is drained by perennial and seasonal streams which probably was the same setting in the past.

In the site one can also found raw material for the production of pottery bowls that were used in ceremonial burials, as well as for storing food and water.

Furthermore, most of the caves have large euphotic zones where light are present during the all day. This characteristic would be very important for human occupation in cave entrances since in Brazil it is not commom to find remais of deep cave usage by prehistoric peoples. Nevertheless it is noteworthy the existence o cave art in dark zone in the caverna das mãos, in the state of Pará, Brazilian Amazon. This occurrence was registered by Travassos, Rodrigues and Motta (2012).

Finally, for the group or groups of the Córrego do Cavalo Farm, caves provided also a privileged view of the region. This strategic position in the territory could facilitate some kind of control in this area.

Currently, the vegetation of the area is very modified, mainly by human activities such as deforestation for the expansion of grazing areas for cattle. "Dry Forests" only can be observerd on carbonate outcrops, possibly spared (a priori) by its position in the rocky escarpments and over its tops, inappropriate and incompatible with livestock activity.

Figure 2. General aspect of the karst area. Flooded doline with limestone outcrop in the back (Photo: Marco Tulio Magalhães).

Figure 3. Archaelogical remains at the Loca dos Pescadores. The GPS serves as a scale with 15 cm near pottery fragments (Photo: Mariana Timo).

Figure 4. Surgency at the Barreado creek, near to the Loca dos Pescadores (Photo: Mariana Timo).

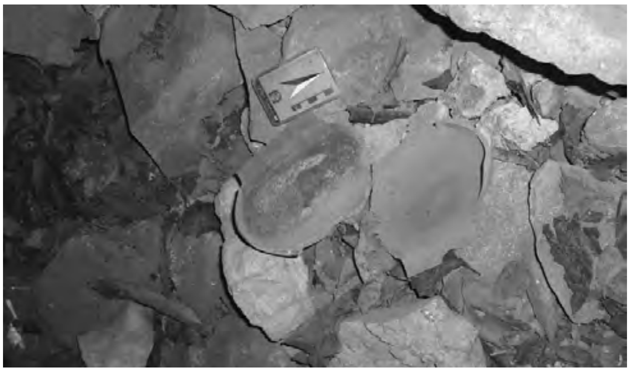

Figure 5. Archaelogical remains at the Gruta da Lamparina. The scale has 7 cm and is near a broken bowl (Photo: Mariana Timo).

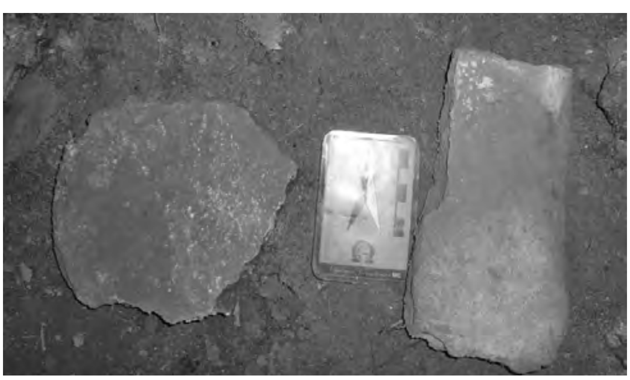

Figure 6. Archaelogical remains at the Gruta da Lamparina. The scale has 7 cm (Photo: Mariana Timo).

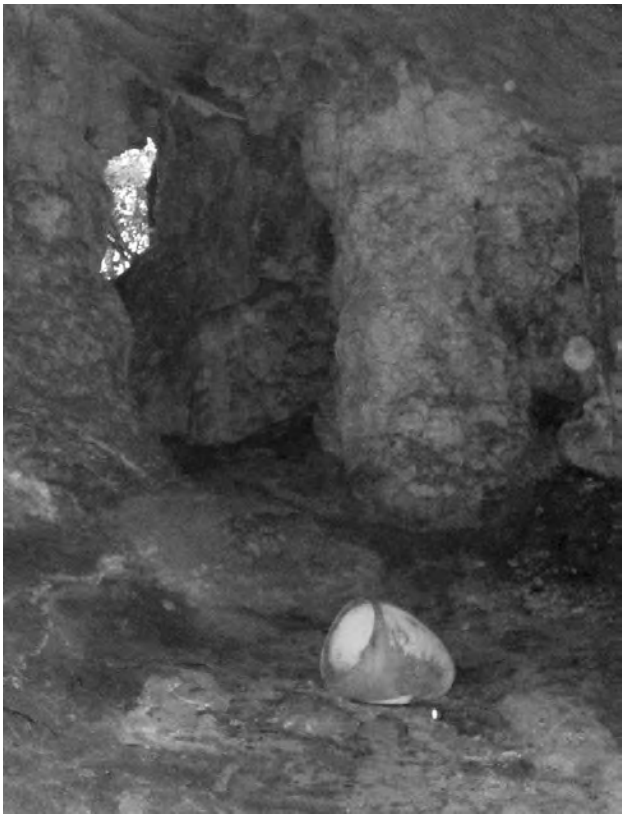

Figure 7. Intact pottery at the Gruta dos Óculos. One can see some incrustations over the artifact, giving some idea of its old age (Photo: Mariana Timo).

Figure 8. Detailed image of the pottery from figure 5 at Gruta dos Óculos. The artifact was removed from the cave by an Archaeologist from the municipality of Pains. As scale, the flashlight on the right of the image has 30cm. (Photo: Mariana Timo).

6. Conclusion

According to the abundance of archaeological remains, the region of the Córrego do Cavalo Farm can be analyzed by the concepts of Environmental History. It seems that this karst area offered ideal conditions for the survival of a prehistoric group (or groups), demonstrated by the amount of material found and its spatial distribution along its 2,913 km^2.

It is important to emphasize that this work is a preliminary approached which inteded to show the importance of the region, and not all pictures of the artifacts were inserted due to size limitations.

The remains were found during the studies for the development of a geomorphological map of the area and, therefore, one can say that it is necessary further and in depth studies performed by professional and academic archaeologists in order to better understand these evidences.

Acknowledgments

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ANATOLIAN CAVES IN STRABO'S GEOGRAPHICA

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Only a small part of the written works of Ancient Greece, Rome and Byzantium which could reach today is about geography. The works of Pliny, Pausanias and Strabo are the most important ones among them. In the works of these authors, some caves that they happened to see or hear are mentioned. Yet, these sources need to be approached carefully because many superstitious, myth and hearsays are available in such ancient geography books as in various other books written in ancient history. Among all these books, the most comprehensive work about the Anatolian geography is the "Geographica" written during 7–18 AD by Strabo who was born in Turkey, ancient Amaseia. This is a general book of geography consisted of 17 books; and its 12nd, 13th and 14th volumes are completely about Anatolia. Strabo, in these three books, mentions 7 caves that he sees or hears. Today, some of the 7 caves which is mentioned in Strabo's book is still unknown but, some others are among the most important ones of Turkey. Those 7 caves mentioned in "Geographica", written by Strabo, will be analysed in this poster presentation and the transformation of them within 2,000 years will be shared.

1. Introduction

Some of the written works beginning from Ancient Greece and Rome to Byzantium and Middle Ages which could reach today is about geography, and these books give us invaluable information about the nature of that region. In a way, we can regard them as the priceless sources of nature history written hundreds of years ago provided that we search them carefully. We say "on condition that we search carefully" because many superstitious, myth and hearsays are available in such geography books as in various other books written in ancient history.

There are a few different books telling Anatolian geography. On the other hand, Geographica by Strabo is one of the primary resources and the one which lays the largest place to Anatolian geography. This is a general book of earth geography consisted of 17 books; and its 12nd, 13th and 14th volumes are completely about Anatolia. Although there are some pieces of papyrus available dated to 100–300 AD, most of the the manuscripts, which are about 30 today, are all the copies from Middle Ages.

Strabo was born to an affluent family from Amaseia in Pontus (modern Amasya of Turkey) at 64 BC. His life was characterized by extensive travels. He journeyed to Egypt and as far south as Ethiopia in addition to his travels in Asia Minor and time spent in Rome. Travels throughout the Mediterranean and Near East, especially for scholarly purposes, was popular during this era and was facilitated by the relative peace enjoyed throughout the reign of Augustus (27 BC – AD 14). Strabo moved to Rome in 44 BC, and stayed there, studying and writing, until at least 31 BC. It's been known that around 25 BC, he sailed up the Nile, reaching Philae.

It is not known precisely when Strabo's Geographica was written, though comments within the work itself place the finished version within the reign of Emperor Tiberius. Some authorities place its first drafts around 7 AD, others around 18 AD.

In addition to Strabo, in the works of Pliny, Pausanias and some other classical authors, there are various information about Anatolian caves. Analysing all those ancient resources and travel books of the people wandering around that land hundreds years ago in terms of speleology will open new horizons to us for the future.

2. Anatolian Caves in Strabo's "Geographica"

Strabo mentioned 7 different caves in his three books about Anatolia. Interestingly, though he had travelled most regions of Anatolia, he had mentioned only 7 caves and 6 of them are on the south of Maeander River, the area with nearly no limestone and the 7. Cave is on the Mediterranean shore.

The caves of Anatolia from Strabo's "Geographica" are:

Book 12. Chapter 8. Section 16. *"Above the city lies Mt. Cadmus, whence the Lycus flows, as does also another river of the same name as the mountain. But the Lycus flows under ground for the most part, and then, after emerging to the surface, unites with the other rivers, thus indicating that the country is full of holes and subject to earthquakes"*.

The abovementioned Mt. Cadmus is Mount Honaz, in the South east of Denizli. Lycus River, namely Çürüksu today, on the other hand, flows from the west and unites with Menderes River near Sarayköy in the west. Yet, this river flows in the narrow canyons in the most parts; even in a small canyon in front of the Colossae ruins near Honaz town, which gives its name to the mountain. However, as far as we know, it has no underground course. We say "as far as we know" because there is no underground course in the Honaz part of the river but the parts before arriving Honaz Town of the river have not been researched in detail.

Book 13. Chapter 4. Section 14. "*…while the Plutonium, below a small brow of the mountainous country that lies above it, is an opening of only moderate size, large enough to admit a man, but it reaches a considerable depth, and it is enclosed by a quadrilateral handrail, about half a plethrum in circumference, and this space is full of a vapour so misty and dense that one can scarcely see the ground. Now to those who approach the handrail anywhere round the enclosure the air is harmless, since the outside is free from that vapor in calm weather, for the vapor then stays inside the enclosure, but any animal that passes inside meets instant death"*.

Figure 1. Location map of 6 caves of Strabo's Geographica: 1) Mount Honaz, 2) Pamukkale, 3) Bafa Lake, 4) Avsar Village, 5) Salavatlı Village, 6) Karahayıt Village.

The cave that Strabo is mentioning is namely Hierapolis Plutonium today which is in Denizli/Pamukkale, and in the South of Hierapolis Theatre. Later on, Apollon Temple was built on the structure. According to the report of Italian School of Archaeology, Apollon was joining Kybele who is the most important goddess of the region before Helen. The cave, closed with the collapse of the temple, was excavated and found again in 1964. Today, after the restoration, it can be seen almost as Strabo mentioned. On the entrance of the cave, there is a marble niche dated to Roman period. In spite of the fact that the poisionous vapor that Strabo mentioned now has become fairly less compared to the past, the entrance was still closed with a handrail.

Book 14. Chapter 1. Section 8. *"This mountain lies above Heracleia, and at a high elevation. At a slight distance away from it, after one has crossed a little river near Latmus, there is to be seen the sepulchre of Endymion, in a cave."*

Today, we definitely know the cave which we suppose that Strabo mentioned. There is a mansion which is remoured to be Endymion's on a point near lake, under the ruins of Temple of Athena in Kapıkırı Village on the shore of Bafa Lake. On the other side, it is quite surprising that Strabo did not mention several important caves which were discovered by Anneliese Peschlow in the area and only mentioned one cave that he thought to be the sepulchre of Endymion within.

Book 14. Chapter 1. Section 11. *"Thence, within four stadia, one comes to a village, the Carian Thymbria, near which is Aornum, a sacred cave, which is called Charonium, since it emits deadly vapours."*

Unfortunately, we do not know the exact location of this antique town. However, in the light of the data from the other narrations of Strabo, we can say that this settlement is between Avsar Village and Söke, near Büyük Menderes River. In Anatolia, there are many different caves called "Charonium" dedicated to Charon who carries the deads to Hades with his boat in the underground river Styx, mentioned in Greek Mythology.

Book 14. Chapter 1. Section 44. *"On the road between the Tralleis and Nysa is a village of the Nysaeans, not far from the city Acharaca, where is the Plutonium, with a costly sacred precinct and a shrine of Pluto and Core, and also the Charonium, a cave that lies above the sacred precinct, by nature wonderful; for they say that those who are diseased and give heed to the cures prescribed by these gods resort thither and live in the village near the cave among experienced priests, who on their behalf sleep in the cave and through dreams prescribe the cures."*

The place of Acharaca is not precisely known. In the excavations carried years ago in Salavatlı Village near Aydın, Sultanhisar, the sacred precinct, Pluto and Core shrines were also discovered. Yet, other Charonium which he mentioned to be just on the upper part of the mentioned temple is unavailable. George Bean, in his work "Turkey Beyond Maeander", talks about a sulfureous river called Sarısu in a deep and steep valley in the west, and states that the dejective foldings on the rocky slopes of the valley may be the places used instead of a natural cave. Numerous dedications to this cave in the ancient resources show the place as a significant religious point.

Book 14. Chapter 1. Section 45. *"Thirty stadia from Nysa, after one crosses over Mt. Tmolus and the mountain called Mesogis, towards the region to the south of the Mesogis, there is a place called Leimon, whither the Nysaeans and all the people about go to celebrate their festivals. And not far from Leimon is an entrance into the earth sacred to the same gods, which is said to extend down as far as Acharaca."*

What is surprising is that no cave could be found in this area despite the detailed description whereas the place of Leimon is – even if roughly – known. The city is estimated to be in the South of Aydın, Sultanhisar, near Karahayıt Village today. What is more, the land is smooth aluvial soil which is not available for the formation of any caves.

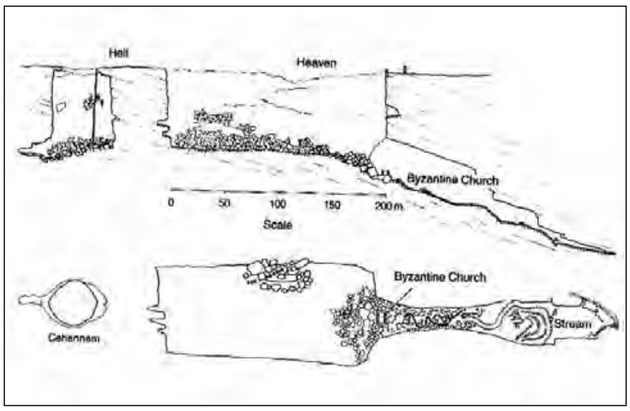

Figure 2. Hell and Heaven caves (after Aygen T 1984).

Book 14. Chapter 5. Section 5. "…*and to Crambusa, an island, and to Corycus, a promontory, above which, at a distance of twenty stadia, is the Corycian cave, in which the best crocus grows. It is a great circular hollow, with a rocky brow situated all round it that is everywhere quite high. Going down into it, one comes to a floor that is uneven and mostly rocky, but full of trees of the shrub kind, both the* *evergreen and those that are cultivated. And among these trees are dispersed also the plots of ground which produce the crocus. There is also a cave here, with a great spring, which sends forth a river of pure and transparent water; the river forthwith empties beneath the earth, and then, alter running invisible underground, issues forth into the sea. It is called Picrum Hydor."*

This is namely Heaven Cave today, near Silifke. There is an underground river reaching Mediterranean Sea after flowing a few more kilometers from the deepest point of doline, which is 70 m depth and 200 m width. In this cave, the only change within hundreds of years from the narrations of Strabo to-day is that there is no more a crocus in the cave and a church built during the Byzantium period. It is also very surprising that Strabo, who mentioned Heaven Cave in such a detail, did never mention other doline, Hell Cave, which has nearly the same depth as the Heaven Cave and only 50 metres far from this doline, but however he had mentioned "Picrum Hydor", namely Dilek Cave today, which is nearly two kilometers far from these two dolins.

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Session:

Protection and Management of Karst, Education

EXPLORATION, PROTECTION AND MANAGEMENT OF KARST CAVES: GOOD AND BAD PRACTICES

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Power Point presentation (75 diapositives with 85 photographs) illustrating good and bad practices in protection of cave exploration and discovery management.

1. Introduction

All natural areas deserve protection; the karst ecosystem and the caves in particular, because of their sensitivity and fragility, need more.

The caves with their sparkling and thousand-year-old landscapes and the karstic underground environment in general, can for various reasons be rapidly and irreparably devastated.

The thoughtless exploration of recently discovered cavities or the wild but not managed visits of superbly sintered networks in a considered way can be one of the causes. It will form the gist of this lecture.

This is astonishing because "discoverers" and "plunderers" are nevertheless all cavers!

Figure 1. Drawing realized by Franquin for the Commission de Protecction des Sites Spéléologiques (Belgium).

2. Pictorial demonstration

No wishful thinking, but specific and realistic proposals. No nonsense, all reports and all suggestions are illustrated by photographs that are sometimes astonishing or comical.

No long speeches, the pictures even speak for themselves; the sad truth of the "before and after" photographs.

The topics and subjects taken on in the 85 pictures deal with graffiti, staining and breaking of concretions following the cavers passing through, wanton destruction, carbide, bivouacs, leaving behind of waste and pollution which they generate, and looting and sale of concretions.

The problem of the closings and the doors caves should not be looked at as such because they are there for a reason and are not there to annoy cavers.

Advices, tricks, easy ways and alternatives are often suggested to avoid, heal or overcome the problems encountered during the explorations.

Take care, because to foresee is better than to repair; this takes much time and a lot of patience.

This is not a reason to feel guilty, depressed.

Despite all these negative aspects, caving remains a wonderful experience and the ultimate integration of nature, adventure, sport and science.

3. Conclusion

Without cavers, there would be no caves! Their discoverers are their best protectors.

Cavers, they who discover the jewels of the underground world, must remain the attentive protectors of this fragile and irreplaceable collective inheritance. As such, they must always be regarded as essential and impossible to circumvent partners in the management and the protection of the karstic environment.

Generations of young cavers are now educated continuously for caves and karst are respected. Together now trying to remove the stigma left over the years by their predecessors unconscious.

Copyright and acknowledgements

Paul De Bie of the Spéléo Club Avalon – Belgium, initiator of this reflexion.

To the cavers all over the world who replied to my search for pictures.

To the Commission Wallonne d'Étude et de Protection des Sites Souterrains. To Karen Sobol for her immeasurable linguistic support.

Figure 2. Sensitization poster at the Postojna cave entrance (SLO).

Figure 3. High-Tech cleaning. Grotte du Père Noël (BE) Photo: Paul De Bie.

PROPOSAL TO ESTABLISH GEOTURISTIC TRAILS AT THE MONUMENTO NATURAL ESTADUAL GRUTA REI DO MATO, MINAS GERAIS, BRAZIL

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In recent decades humanity has experienced various changes in its relations with the environment. Since the 70s, several environmental movements have emerged around the world, highlighting the importance of preserving natural resources. In this context, more recently, the terms "geodiversity," "geoconservation" and "geotourism" have been adopted to help conserve the geological heritage of our planet. Thus, the creation of Conservation Units, such as parks and natural monuments such as the Monumento Natural Estadual Gruta Rei do Mato (Natural State Monument Rei do Mato Cave) have emerged as an attempt to preserve an important karst area. Its regional context appears as a landscape with caves and limestone outcrops that host traces of South American prehistoric man. This paper aims to propose the creation of geological and educational trails in this monument, in order to help increase karstological knowledge. Field missions have been carried out, and four geosites identified and proposed, each with its specific points of geomorphological interest. Such points of interest have been linked in each geosite to form trails of different difficulty degrees for access and natural heritage interpretation. Finally, the idea is the proposal of a type of "field school" to help teachers and students better understand karst and cave dynamics.

1. Introduction

Throughout the second half of the 20th century and the first decade of this century, concern about environmental issues has been raised, with natural resources being more valued. Several movements promoted by civil society, members of universities and political authorities throughout the world have, thus, encouraged and fought for environmental preservation, sometimes at the expense of economic development and sometimes combined with the idea of sustainable development.

In the fields of geography and geology, studies about environmental issues have recently proposed the terms *geodiversity*, *geotourism* and *geoconservation* (see Brilha 2005; Gray 2004; Hose 1995, 1996, 1997, 2000; Sharples 1993, 1995, 2002). These terms have been "created" to demonstrate the importance of various physical aspects of the environment, the need to preserve them, and also, the desire to spread information about their importance.

In this context, this study aims to propose geological and educational trails with the use of interpretive resources for different target audiences at one Brazilian Conservation Unit (UC) called Monumento Natural Estadual Gruta Rei do Mato (MNGRM) or, in English, the Natural State Monument of Rei do Mato Cave. Such trails would provide what are referred to in this work as a "field school" that will help teachers and students better understand karst and cave dynamics.

Consequently, it has been necessary to undertake research, to identify geosites and places of geomorphological interest, in order to identify areas likely to become trails which could link different sites and also enhance the knowledge of tourists or students on geological, geomorphological, archaeological and cultural aspects of each identified place.

Located in the northern portion of the metropolitan region of Belo Horizonte, capital city of the State of Minas Gerais, the MNGRM remains susceptible to uncontrolled human activities that can be detrimental for the natural environment. The present mining activities in the vicinity of the highway BR-040 and the urban occupation of Sete Lagoas city can endanger the preservation of the Natural Monument.

It is believed that the work would help planners better use the area by promoting environmental awareness among the people visiting the site. Such awareness should not only make visitors care about the Monument, but also about other similar karst areas. In addition, visitors will be able to spread ideas and strengthen the case for conservation by causing authorities to increase supervision and enforce environmental legislation.

2. Study Area

The Natural State Monument Rei do Mato Cave is located in Sete Lagoas, Minas Gerais (Fig. 1). Bordered by two main roads, the conservation unit is about 60 km from the state capital, Belo Horizonte.

The region's climate is tropical semi-humid with rainy summers and dry winters. Average high temperatures of 29.2 °C can be registered with the minimum annual average being 22.1 °C. The annual rainfall ranges from 1,200 to 1,500 mm (CPRM 2010).

The hydrographic network of the region is part of the São Francisco river and Paraopeba river sub-basins. Being located over limestone rocks, the site presents sinks and underground systems which support groundwater storage and movement.

The city of Sete Lagoas, as well as the Natural State Monument, is located in the geological macrostructure called São Francisco craton, a geotectonic province corresponding to the western part of the Congo/São Francisco craton, which occupies the center of Western Gondwana and was originally split into two by the opening of the South Atlantic (Almeida 1977). One can find carbonate rocks of the Bambuí Group, Sete Lagoas Formation, there. Also lateritic and alluvial deposits can be seen (CPRM 2010).

The Monument is near the convergence of two geological units of the Bambui Group: the Serra de Santa Helena Formation (northern portion) and the Sete Lagoas Formation (the southern portion). The first is marked by the presence of mudstones and siltstones. The second has limestone rocks, medium gray to dark gray in color and rich in organic matter (CPRM 2010). The terrain is characterized by typical karst features with ponors, sinks, dolines, blind valleys, karren and caves.

The predominant vegetation in the area is "dry forest," otherwise known as Deciduous Seasonal Forests, associated with large areas covered by carbonate rocks. The Cerrado vegetation or "Brazilian Savannah" can also be found in the northern part of the Monument in the areas covered by the Serra de Santa Helena Formation.

The touristic structure of the State Monument is composed of an auditorium with capacity for 120 persons, exhibition areas, a small cafeteria, office and administrative area, restrooms, locker rooms and an exclusive parking area for approximately 200 vehicles. The Rei do Mato cave, the main attraction, is a show cave currently lighted by LED technology.

The area of the monument is noted as an important archaeological and paleontological site on the register of rock paintings and ceramic artifacts. Prehistoric burial can also be located in the vicinity (MINAS 1984 *apud* Soares 2007).

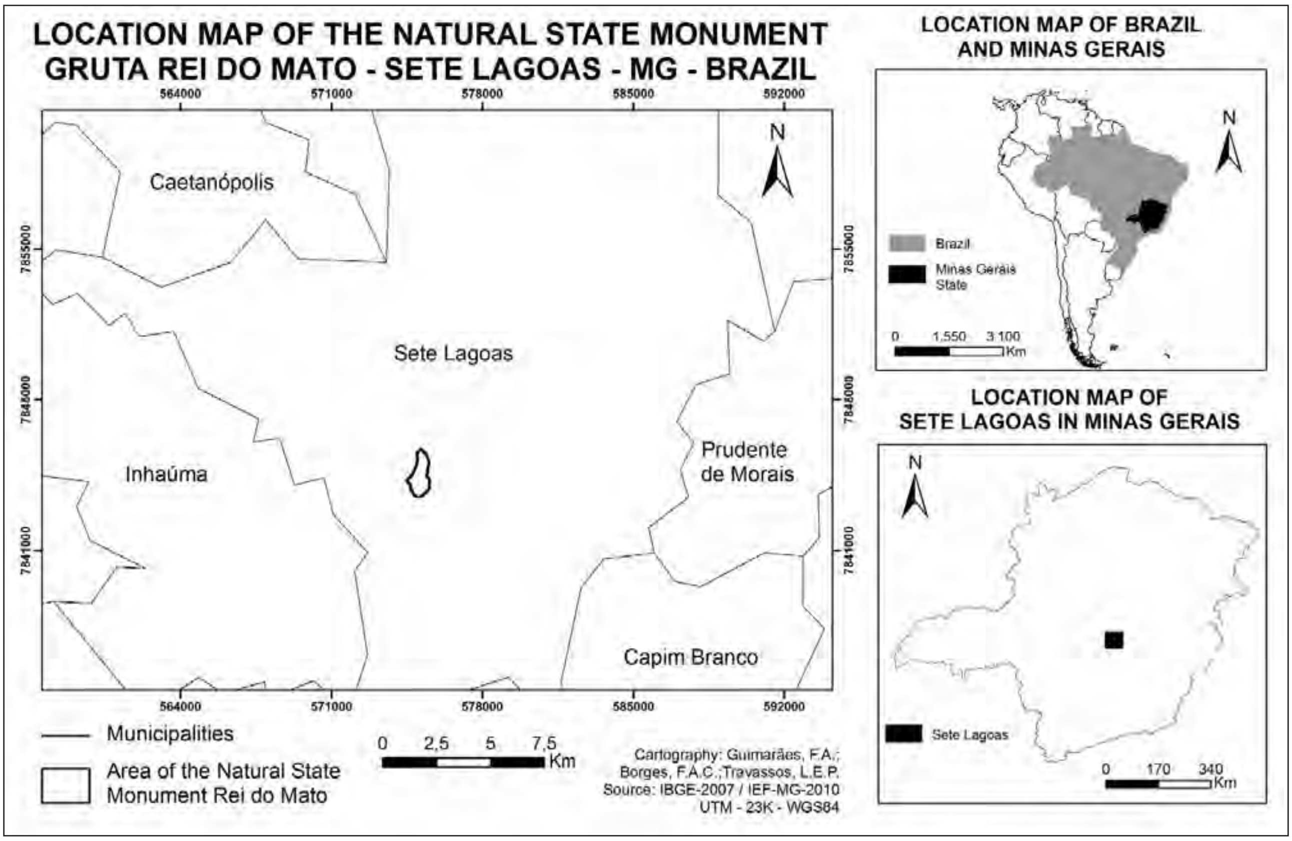

Figure 1. Location map of Minas Gerais, Sete Lagoas, and the Natural State Monument of Gruta Rei do Mato.

3. Methods

The methodological procedures adopted to achieve the proposed objectives can be best understood by splitting them into three stages: the first refers to the period prior to the completion of field missions; the second refers to field missions; and the third corresponds to the post-field missions.

3.1. Pre-field Missions

During this step the authors conducted a bibliographical review to better explore the concepts and principles of *geodiversity*, *geotourism* and *geoconservation*. The authors also reviewed papers regarding different techniques to be used in making pedagogical and/or geological trails and how to promote the physiographic characteristics of the study area.

Satellite images were used and provided by Google Earth (free version). A mosaic of 1:5,000 images was made, in order to better orientate the field missions.

3.2. Field Missions

The authors considered the field missions as the most important and crucial stage of the research. Four field missions took place, and the researchers used GPS (Garmin eTrex Vista HCx), the mosaic of GoogleEarth images of the study area (scale of 1:5,000), digital cameras, helmets, lights and field notebooks.

The first mission was exploratory and intended to identify main places of geomorphological interest, and also points of archaeological, cultural and historical significance. These points were registered, photographed and marked in the GPS. The routes tracked by the GPS were also saved. The other field missions aimed to identify other possible routes for the trails and were also saved for future analysis. The expected time for each probable trail was also recorded.

3.3. Post-field Missions

In this step, the first action was to organize a database with the information collected in the field including the name, geographic location, elevation, description, time spent and photographic records of each trail and point identified.

The identified paths and the points stored in GPS were introduced in the software in TrackMaker 7.13, which allowed the conversion from *.gtm extension to *.shp to be used in ArcGIS 10 licensed for academic use at PUC Minas University.

After calculating the length of each trail, maps were produced. According to the time spent, length, and difficulty of each trail, the authors decided to differentiate the level of access and complexity of the interpretative resources to be developed.

To elaborate the interpretative resources of the identified sites, various proposals were made to be printed as signs (2 m × 1.2 m). In these prototypes various types of information regarding coordinates, location map with satellite image, altitude, geological and geomorphological information are recorded. Due to their size and numbers, these have not been included here, although one example is shown in Fig. 2.

Figure 2. Example of one of the panels explaining the process of doline formation. Source: Research data.

4. Results and Discussions

Based on the conducted field missions, the authors have proposed different trails with different places of geomorphological interest (Table 1). *Geosites* have been

Table 1. Geosites, Trails and Points of Geomorphological Interest. Source: Research data.

GEOSITE	TRAIL NAME	POINTS OF GEOMORPHOLOGICAL INTEREST
Rei do Mato Cave/Gruta do Rei do Mato	Gruta Rei do Mato Trail	Grutinha – small cave
		Gruta Rei do Mato – Rei do Mato cave
Limestone Towers/Clover cave/Torres Calcárias e Gruta do Trevo	Gruta do Trevo Trail	Torre Cárstica I – Karst tower I
		Torre Cárstica II – Karst tower II
		Torre Cárstica III – Karst tower III
		Gruta do Trevo – Clover Cave
Stonebreaker Massif/Maciço do Britador	Stonebreaker Trail/Climbing Trail	Maciço explorado por mineração – massif exploited by mining activity
		Dolinas de Abatimento – Collapse dolines
Climbing Massif/Maciço das Escaladas		Processo de dissolução do calcário – Solution process of limestone
		Sumidouro, área de recarga do Carste – Ponors
		Expressões Culturais: Bob Marley e Nossa Senhora – Cultural expressions: Bob Marley and Our Lady
		Abrigo da Macumba – Macumba shelter

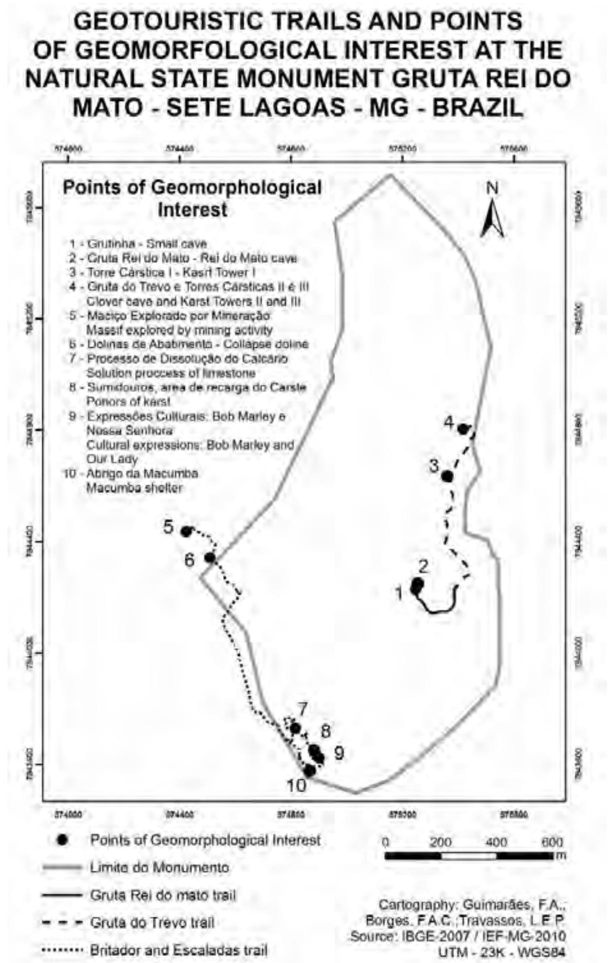

Figure 3. Proposed trails and points of geomorphological interest. Source: Research data.

proposed for all four trails (Fig. 3). Three trails of different difficulty levels of access and educational interpretation have been identified (Rei do Mato Cave, Limestone Towers/Clover cave, Stonebreaker Massif and, Climbing Massif). Twelve places of geomorphological interest have been selected and seven interpretation panels were developed as prototypes.

4.1. Gruta Rei do Mato Trail

The Rei do Mato cave trail is the only one that already exists and is in regular operation. However, the route of this trail is lacking any interpretative resource, which has caused the authors to propose a panel containing information about the attractions of this trail: The *Grutinha* (small cave), which is an important archaeological site, and the Gruta Rei do Mato, a karst cave with rare types of speleothems (Fig. 4 and Fig. 5). This trail crosses the geosite named Gruta Rei do Mato.

Figure 4. Entrance of Gruta Rei do Mato – the small poles at the entrance measure approximately 1m and can be used as scale reference. (Photo: Felipe Borges.)

Figure 5. "Twin columns" at the end of the tourist path of Gruta Rei do Mato. (Photo: Luiz Eduardo Panisset Travassos.)

The trail is paved with stones and, according to data obtained by GPS, has an approximate length of 291 meters. The cave can be reached leaving the tourist installations of the Natural Monument, passing by the Grutinha (small cave) after 248 m, at which point the panel relevant to this trail should be installed. The altitude along the path varies from 858 to 885 meters and the average time spent by the tourists is 50 minutes, including a visit to the Rei do Mato cave. The return is made by taking the same path.

Due to its short length, structure and the fact that it has the largest and most famous geomorphological landmark, the trail is most often visited by people with no knowledge of Earth Sciences. For this reason, the authors have decided to develop an interpretative resource that does not require specific knowledge of karst geomorphology or geology.

This trail can be used by any kind of audience, including elementary school students. Moreover, the access conditions favor its classification as "easy level."

4.2. Gruta do Trevo Trail

This trail is the second proposed by the authors. It leaves the tourist center and has its end in the Clover Cave (Gruta do Trevo), near the highway BR-040. Besides the existing clearings along its route, there is no formal touristic structure. On the trail, normally used in educational or promotional events of the Natural Monument, are four places of geomorphological interest: Torre Cárstica I – Karst tower I, Gruta do Trevo – Clover Cave (with some rock paintings – Fig. 6), and two other limestone towers in the back of the Clover Cave called Torre Cárstica II – Karst tower II and Torre Cárstica III – Karst tower III.

Figure 6. Rock Art: representation of a deer in Gruta do Trevo. (Photo: Felipe Borges.)

The proposed trail is 777 meters in length from the parking area to the Clover Cave and the second and third karst towers. The first karst tower is located about 520 meters away from the parking area and the altitude of the trail varies from 848 to 865 meters. The average time spent is one hour and a half. As with the first trail, the return takes the same route back.

Due to the longer length of the trail, the absence of touristic structures and a certain degree of knowledge and abstraction for the interpretation of how karst towers are formed, this trail has been classified as intermediate-level.

Those exploring this trail should possess some prior knowledge of Earth Sciences (high school students and others interested in the subject). Two features panels have been developed, one to be located near the first karst tower and the second near the Gruta do Trevo (Clover Cave).

4.3. Stonebreaker Trail / Climbing Trail

The third trail is considered the longest and most complex. The hike can be started from the tourist center, but it is recommended it start in another location, outside the limits of the Natural Monument.

The trail can be divided into two sections. One starts in an old disabled limestone quarry (locally known as "stonebreaker" or "britador") near the State Highway MG-238. The second section, which can also be considered another trail, is linked to the first one as a single route, due to complex geological, geomorphological and structural features.

When starting the Stonebreaker Trail/Climbing Trail, it is recommended to follow two directions. The first, towards the west, takes the group to two places of geomorphological interest: the Maciço explorado por mineração (massif exploited by mining activity) and the Dolinas de Abatimento (Collapse dolines) (Fig. 7), located in the geosite Stonebreaker Massif/Maciço do Britador.

Figure 7. Collapse boulders inside the collapse doline. It is believed that the collapses occurred due to quarrying activities. (Photo: Lucas Zenha.)

After studying this geosite, the group should return to the beginning and move towards the east, starting the trails at the Climbing Massif/Maciço das Escaladas geosite. This path contains four places of geomorphological interest: 1) Processo de dissolução do calcário – solution process of limestone, 2) Sumidouro, área de recarga do Carste – Ponors of karst, 3) Expressões Culturais: Bob Marley e Nossa Senhora – cultural expressions: Bob Marley and Our Lady; and 4) Abrigo da Macumba – Macumba shelter.

The Stonebreaker Trail/Climbing Trail extends 1,969 meters from the "Collapse dolines" to its end. The altitude varies from 800 to 835 meters and the average time to complete its path is approximately two and a half hours. The distance between each place of geomorphological interest relative to the starting point of this trail is outlined in Table 2. Much of the trail occurs in areas very close to the massif and is covered with dense vegetation.

Table 2. Distance between each place of geomorphological interest relative to the starting point of this trail. Source: Research data.

POINTS OF GEOMORPHOLOGICAL INTEREST	DISTANCE FROM THE TRAIL STARTING POINT (METERS)
Maciço explorado por mineração – massif exploited by mining activity	173
Dolinas de Abatimento – Collapse dolines	390
Processo de dissolução do calcário – limestone solution process	1,012
Sumidouro, área de recarga do Carste – Ponors of karst	1,037
Expressões Culturais: Bob Marley e Nossa Senhora – cultural expressions: Bob Marley and Our Lady	1,019
Abrigo da Macumba – Macumba shelter	1,422

To better inform visitors about the complex phenomena of the area, four interpretative panels have been created. The first one refers to the "Maciço explorado por mineração – massif exploited by mining activity" and should be installed in front of this outcrop. It contains information about the formation of karst massifs, mining activity and its impacts on karst.

The second panel refers to the point called "Dolinas de Abatimento – Collapse dolines", and should be installed in front of the dolines. For the places of geomorphological interest called "Processo de dissolução do calcário – Limestone solution process" and "Sumidouro, área de recarga do Carste – Ponors of karst" one panel has been made taking into account the physical constraints found in the area. A similar factor occurs with the places of geomorphological interest called "Expressões Culturais: Bob Marley e Nossa Senhora – Cultural expressions: Bob Marley and Our Lady" and "Abrigo da Macumba – Macumba shelter". Due to space limitations and the possibility of damaging some places, it was decided to make a single panel for the two to be installed in the area in front of "Abrigo da Macumba – Macumba shelter". Another factor that encouraged the authors to merge these two places into a single panel was their cultural aspect: sacredness.

Although the interpretative resources help the tourist and/or students understand the importance of each place, given the level of knowledge required on this trail, it would be necessary to have an expert on karst to guide the group.

Considering the length, difficult access, high level of knowledge needed to understand the karst phenomena developed in such places of geomorphological interest, this trail has been classified as “high difficulty”. Earth Science knowledge is needed to better understand the site. It is recommended for undergraduate and graduate students of disciplines related to Environmental Sciences and Earth Sciences, such as geography, geology, biology.

5. Conclusions

This study has aimed to propose a “field school” activity in Natural State Monument Gruta Rei do Mato to help disseminate the knowledge of Earth Sciences, in general, and karst geomorphology, in particular.

The authors have also tried to highlight some geological and geomorphological attributes of the Natural Monument, in order to help with the conservation of its geological heritage.

Four geosites, which are the main objects of three educational trails, have been proposed. For each trail the authors have identified places of geomorphological interest totaling twelve points.

The tracks have been characterized in terms of their location, extent and average time spent. The level of knowledge required for the interpretation of each place of geomorphological interest has also been identified.

For the interpretation of these places, the authors have proposed information panels containing the main features of local interest regarding the geological, geomorphological, speleological, archaeological and cultural aspects of the region.

It is the authors’ desire to implement this project in conjunction with the staff of the Natural Monument, in order to disseminate knowledge of karst using the principles of geodiversity, geotourism and geoconservation.

Organizing such actions could be also a way to enhance the social and economic development of the region through well-planned geotourism.

The tools and techniques of primary data acquisition and GIS have proven quite useful for making the tourist trails and educational proposals.

It is important to mention that a second phase of this study must be carried out in order to study the possible environmental impacts of the proposed trails. Since this is a preliminary work of an issue still under development in Brazilian karst areas, the identification of carrying capacity of each trail has not yet been made.

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THE DEVELOPMENT OF SHOW CAVES: NEW MATERIALS AND METHODS

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The fundemental criteria presently adopted are the protection of the cave environment, the safety of the visitors and a correct profit from the cave management. Recent years have seen a veritable plethora of innovations and concepts relating to the best cave management, which are here pointed out. New criteria for the application of new materials and an up-to-date methodology for the best development of show caves are reported.

1. Introduction

The development of a wild cave in order to obtain an easier way started many ten thousands of years ago when our ancestors decided to use the caves for their ceremonies. Obviously at that time the main scope was to obtain a reliable result with the simplest intervention. Probably some steps carved into a steep soil are one of the earliest examples (Fig. 1). If the consequence to the environment was negligible the step life was acceptable only if their use was limited to a small number of people.

Figure 1. The prehistoric (6000–4000 years b.C.) staircase in the Grotta dei Cervi di Porto Badisco, Italy (Photo Cigna).

Similar interventions continued for a long time, but only more recently the interventions on wild caves became more relevant when the aim was the development of a cave into a show cave to be visited by a large number of persons. Excavations, demolition of some formations, construction of pathways became widespread and the advantage for the visitors prevailed to the protection of the environment. Only in the last tens of years the protection of the environment was taken into due account to make a choice among different solutions.

This paper has the scope to describe the up-to-date solutions provided by the most advanced technology.

2. The development of a show cave

The fundemental criteria presently adopted are the protection of the cave environment, the safety of the visitors and a correct profit from the cave management. All such criteria must be taken into account otherwise the development would have very negative effects.

As David Summers (2012) stated, the worst fate that can befall a cave is for it to be developed as a show cave, then for it to fail as a business entity, and be closed. The cave becomes very vulnerable to misuse. Therefore the show cave nust not be profitable for the short term, but perpetually.

The view that a show cave is a golden goose laying golden eggs implies that the goose must be properly fed and protected. This means that is necessary to having all of the knowledge and awareness regarding the physical needs of the cave to ensure that its environment is preserved and conserved.

Recent years have seen a veritable plethora of innovations and concepts relating to the best cave management, which are here pointed out.

3. Materials

3.1. Conventional materials

3.1.1. Surface infrastructures

Buildings, with the ticket office, direction, guides, souvenirs, etc., were built as close as possible to the cave entrance. The same criteria were followed for the car and bus parking, which were asphalted. Often these areas were close to the cave and, in particular, above the cave itself, with the consequence of avoiding the rainwater percolation.

3.1.2. Pathways

The first developments of show caves had a minor impact on the environment because in general the pathways were obtained by carving some steps into the rock in order to decrease to a minimum the displacement of material into or out the cave. Also formations, mainly flowstone, were excavated to allow an easy transit of visitors.

A further improvement was obtained with concrete (reinforced when necessary) for steps and floor. This material has no adverse effects on the cave environment because from a chemical point of view has the same composition of limestone. The iron or steel used to reinforce the cement could sometimes cause breaks when got rusty.

The handrails in stainless steel were also a convenient solution, particularly when they were also used as pipes to provide water in different parts of the cave to wash out the pathways. The higher cost of stainless steel was justified by a lack of any maintenance also after many years of operation Cigna et al. 2000).

Sometimes zinc plated iron structures solved the problem of providing pathways in difficult situations as overcoming cave passages at a level higher than the lower floor or negotiating upwards or downwards a pothole or a big hall (Fig. 2). It must be stressed that zinc is toxic for cave fauna and therefore it is acceptable only in caves with an important water flow that assures a good dilution of any zinc release.

Figure 2. Zinc plated iron parhways in the Su Mannau Cave, Sardinia, Italy (Photo Cigna).

Occasionally only, wood was used for bridges and staircases because of its decay in a wet environment (Fig. 3). Its use in ice caves was frequently adopted because it is less slippery and the organic decay is absent in this special environment. In temperate temperature caves wood becomes an important food source altering the cave biota.

3.1.3. Lighting

The lighting candles, torches and oil lamp were successfully substituted by electric lamps in the XXth Century. Unfortunately the overall luminous efficiency of incandescent lamps is no higher than 5% the rest of the energy being released as heat. This fact implies an unwanted release of energy to the environment and a higher cost of the power supply.

Figure 3. Wooden staircase in Grotta di Trebiciano, Trieste, Italy, These staircases have been initially installed in 1894 during the investigation for providing water for Trieste. The platforms (top in the photo) were installed one century ago in pitchpine treated with copper sulfate and carbonileo (Photo Maizan/SAS).

3.2. Modern materials

3.2.1. Surface infrastructures

The siting of the above ground facilities must be well planned by avoiding that these features be built over the cave itself, or relevant parts of it. In particular any intervention such as the watertight surface of a parking area must be avoided. Any change in the rainwater seepage into a cave as well any change to the land above the cave may have a negative influence on the cave and the growth of its formations.

3.2.2. Pathways

In the last tens years new material were developed with incredible advantages with respect to the past. In particular the pathways can be built entirely with plastics. The material used for the pathways, including the railing and kickplate, are manufactured by a pultrusion process. It is is a continuous molding process whereby reinforcing fibres are saturated with a liquid polymer resin and then carefully formed and pulled through a heated die to form a part.

Pultrusion results in straight constant cross section parts of virtually any shippable length.where continuous fibreglass roving and mat is covered by resin. The resin used for handrails is, e.g., isophtalic polyester and the resin used for other components is vinil ester. Both have a low flame spread rating of 25 or less. These materials are delivered in various colours, avoiding, e.g., the brightness of the stainless steel that is not aesthetically agreeable.

These components have abot one-third the weight of steel allowing easy installation using standard circular or sabre saws. Stainless steel bolts connect the different parts. Such pathways may be easily repaired or modified to adapt to new layout if necessary.

Since the mechanical properties of this materials are very close to steel's properties it is evident the advantage because also long sections can be easily transported inside a cave, while the different parts can be easily woked out with simple instruments.

3.2.3. Lighting

Nowadays very efficient light sources have been developed. The most useful in caves are the LEDs and the cold cathode lamps (CCL). Both are characterized by a very long life of 50,000 hours and longer. The LEDs cost from 20% to 100% more than CCLs for the same results.

Table 1. Indicative comparison of the overall luminous efficiency per input power for different lamps (lm/W).

Lamp	lm/W
Incandescent (IL)	15
Light emitting diodes (LED)	45
Light emitting diodes (LED)	67

In Table 1 a comparison among the overall luminous efficiency (as lumen/watt) per input power for incandescent lamps (ILs), LEDs and CCLs.

The advantage of the new light sources is evident both for the cost of lighting and the long life of the lamps. But these new sources have specific qualities of their own. LEDs are point sources while CCLs are linear. LEDs may be choosen with different temperature colour, i.e. warm (with a red component) or cold (more white). CCLs may be produced with a negligible contribution of their emission spectrum in the regions (around 430–490 nm and 640–900 nm), which mostly contribute to the chlorophyllian process. In this way the proliferation of lampeflora is reduced.

The emergency lighting can be obtained at a very low cost with the "rope light" i.e. a flexible plastic polymer rope with lights in inside that can be cut at a convenient length and placed along the pathways (Fig. 4). In particular such emergency lights can be divided into two sections distributed alternatively and connected to two different power lines in order that, in case of a failure of one section, there will always be another one in operation.

Such a kind of lighting can also supply enough light to the pathways in normal conditions, and special features only must have additional light sources.

3.2.4. Environmental monitoring

In the past a complete network to supply environmental data to a central computer was considered a best solution data to a central computer was considered a best solution to be achieved. But it was experienced that such a network might be convenient for larger caves only. The main problems being a relatively high cost (installation and maintenance) and the danger of damages due to lightning, which may discharge high tension peaks on the line connecting the sensors with the main computer.

Figure 4. The emergency lights placed along the edge of the pathway in the Grutas de Bustamante, Mexico (Photo Cigna).

A less expensive solution, which is also more robust, is obtained with a sumber of stations whose data are download, e.g., once a month, and the elaboration is carried out in a computer outside the cave without any harware connection.

In addition to the usual parameters (temperature, relative humidity, etc.) radon became a relevant issue due to the regulation in some countries requiring a monitoring of its concentration in air on a yearly basis. The scope is the evaluation of the yearly average dose to cave guides to be kept below a given value, otherways this personnel woub be classified as professionally exposed and implying a number of constraints for the cave managers (Cigna 2005).

The most suitable detector is the etched track detector because it is unaffected by humidity, may be kept to record the average concentration up to one year and their cost is very low. Other detectors do not comply with such characteristics and, in general, should be avoided.

4. Methods

4.1. Conventional methods

4.1.1. Pathways

In the past the layout of the passages was simply obtained on the spot according a procedure quite similar to that adopted for the staircase of Fig. 1. Later, the use of concrete and the escavation into the rock of formations required a more detailed preparation.

4.1.2. Lighting

The layout of the lighting network was often left to local electricians, resulting in a bundle of cables close to the passages, with the lamp sometimes attached to cave walls or formations.

4.2. Modern methods

4.2.1. Pathways

The design of fibreglass pathways needs a detailed survey of the strip where the pathway its self will be installed, because each element can be prepared in advance according the design. During the assembly of the pathway the legs require only small adjustment that can be easily obtained with sliding feet.

4.2.2. Lighting

The power supply must comply with both the country rules, which at present are in general rather severe and the aesthetic requirements. The plastic pathways may host below the platform and along the legs, pipes with the cables of the power supply. The cable network may be somewhat more complex than in the past because in general only the parts of the cave occupied by visitors should be switched on. The power supply of the emergency light should be splitted into at least two independent sections as reported above.

4.2.3. Other networks

In case of a complete network to supply environmental data to a central computer, as well as the telephone, cables run into other pipes. To improve visitors' safety, a special network enabling a guide to talk with the outside office from any point of the cave would be strongly advisable.

4.2.4. Visitors carrying capacity

As it is well known, caves may be classified caves into widely different energetic categories. Heaton (1986) proposed three categories: high-energy, moderate-energy, and low-energy levels. In order to avoid any permanent change in the environmentl equilibrium it is necessary to avoid the introduction of energy beyond the intrinsic cave capacity. Such a constraint implies a limitation of both electric power supply for the cave lighting and the visitors' flow, i.e. the visitors carrying capacity.

This limit may be evaluated according different methods and specialists only are entrusted to carry out the whole procedure according the best choice to be applied to each local situation (e.g.: Mangin et d'Hults 1996; Lobo et al. 2013).

5. Conclusions

The UIS Management Guidelines for Show Caves are very useful recommendations, if not a list of the least requirements, for a good development and management of a show cave. But such guidelines do not include the principle that it is imperative to keep oneself always up-to-date with the advancement of technology. But it is also important to have an open mind and not to stick to old solutions when something new and more reliable becomes available.

Since technology is evolving so fast, it is often impossible to suggest or recommend the best solutions because in the meantime an important improvement has already occurred.

In addition to the new materials and methods reported above, any data collection might be of little or no use at all in the absence of persons who have the capacity to take advantage of the data themselves. Probably a good Scientific Committee abreast of the management is the most important tool to assure a good development of a show cave. In any case the members of such a committee must obviously have a deep competence in their specific fields of interest but also a good knowledge of the cave environment is instrumental.

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QUALITY ASSESSMENT OF SHOW CAVES: THE MANAGEMENT EVALUATION INDEX (MEI)

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Show caves management should meet two basic criteria: the protection of the environment and the profit. The protection of the cave environment has been the prerogative of many initiatives, which have been reported in many examples. A first editing of the show cave management guidelines already started at once with the foundation of the International Show Caves Association (ISCA) in November 1989, and the most updated version is presently headed by the Union International de Spéléologie (UIS). The purpose of this paper is to propose a methodology for a quantitative assessment of a show cave management level. The Management Evaluation Index (MEI) calculation procedure based on the definition of indicator scores is here described. Some application examples referring to show caves from all over the world are reported.

1. Introduction

Show caves management should comply with at least two basic principles: the protection of the environment and the profit. These two principles shall apply simultaneously with no conflict. In the view of ensuring and improving standards of financial income, both the best environmental preservation and the high-quality management represent at once the main goals of show cave managers. In other words, a show cave represents the chicken with golden eggs that needs regular "feeding".

Sometimes, however, the immediate profit prevails mainly due to the shortsighted attitude of undervaluating further possible dangers for the cave. Around middle of the last Century, several attempts were made in supplying management recommendations for preventing cave spoiling risks, however common. During the 3rd International Congress of Speleology in Vienna (Austria) in 1961, Gordon T. Warwick presented a paper on cave protection. At that time, the main threats to caves were represented by large engineering workings, as roads, railways, tunnels and quarries. The regulations of the "Cave Preservation Society" of Great Britain, founded on September 1953, were attached to the paper. These rules, still fully applicable, include two subjects about the outside cave environment, and 18 focused on the inside.

Later, during the 4th International Congress of Speleology in Postojna in Slovenia, a Symposium on show caves was organised. Two paper contributions (Gurnee 1971 and Petrochilos, 1971) included some information on good management rules for both correct visitor behaviour and criteria of development of a show cave.

During the same Congress, the opportunity to establish a Commission for Show Caves was discussed within the newborn Union Internationale de Spéléologie. During the following 5th International Congress of Speleology, held in Stuttgart in 1969, the Commission was indeed established and became operative during the successive International Congresses.

In the meantime, an International Congress on the Scientific, Technical and Economical Aspects of Show Caves was organised in Borgio Verezzi, Italy. The UIS Commission for Show Caves guidelines for the correct development of show caves was included in the proceedings (AA., 1982; page 352–353).

As a matter of fact, it was the contribution by show caves all over the world to be instrumental to many scientific researches, against the widespread belief that a show cave is a lost cave for science. Such contributions give a great support to science, although the relatively small amount of funds available as compared as the whole budget of the cave management.

2. The guidelines evolution

When the International Show Caves Association (ISCA) was founded in November 1989, the opportunity of supplying show cave managers with a document listing what should be done and what should be avoided, particularly for the protection of the cave environment was again taken into account.

Meanwhile, a similar initiative was jointly developed by the International Union for Conservation of Nature and Natural Resources (IUCN) and the Union Internationale de Spéléologie (UIS) and presented at the 11th Int. Congress of Speleology in Beijing, China, in 1993 (Watson and James 1993).

Under the coordination of ISCA, a draft of the Management Guidelines for Show Caves was submitted to the attention of stakeholders and presented at the 14th International Congress of Speleology of Kalamos, Greece in 2005. After relevant contributions by the members of the Scientific and Technical Committee of ISCA, the document was then shared with the Union Internationale de Spéléologie (UIS) and the International Union for Conservation of Nature and natural Resources (IUCN-WCPA). This release was presented at the 15th International Congress of Speleology of Kerrville, Texas, USA in 2009 (Cigna 2009).

Due to several objections and economical reasons, during the 6th ISCA International Congress of Liptovský Mikuláš, Slovakia, in October 2010, the General Assembly of ISCA did not formally approve the final release of the document. Since the prevalence of economic interests on widely acclaimed scientific principles, adding risks for the cave environment, is not an acceptable policy, the UIS Karst and Cave Protection Department took on further Guidelines updates, by the contribution of its Scientific Committee and allowing their dissemination within the show caves domain.

These Guidelines must be assumed as recommendations to the show caves managers. Consequently it should be admitted that some show caves, presently operated, require some time for the implementation. Therefore the full adoption of the Guidelines should be considered as a goal to be achieved together by both the protection of the environment and the socio-economical constraints.

3. Quatitative evaluation

As reported above, in terms of cave management, the environmental sustainability emphasises the interrelated nature of economic, social and environmental factors, and the need for an integrated approach that recognises their interconnection and interdependency. Central to environmental sustainability is the notion of ecological thresholds, where human-induced changes can push a natural system beyond the point of recovery.

Van Beynen and Townsend (2005) proposed a procedure for reducing the outdoor cave system to elements easy to be studied by the evaluator, so that the human-induced effects on caves can be measured. They proposed a Karst Disturbance Index (KDI) based on a framework encompassing physical, biological, and social aspects, and the evaluation of a number of indicators for each category. Each category should encompass detailed attributes: geomorphology, atmosphere that deals with air quality; hydrology that includes surface practices influencing water, mineralogy/ore and ore deposits Subsequently a sustainability index for Karst environments was also described (Van Beynen et al. 2012).

Table 1. Indicators matrix for show cave management index.

Category	Attribute	Indicator	0	1	2	3
Previous study	Suitability	Access to the cave	Difficult	Poor	Fair	Perfect
	Synergy	Close-by attractions	None	Little	Some	High value
	Conflict	Local facilities	Very important	Relevant	Little	None
	Funding	Partners	No interest	Indifference	Some interest	High interest
Acces and pathways	Entrance	Access	Artificial, no air locks	Artificial, poor air locks	Artificial, fair air locks	Artificial, good air locks
	Cave structures and deposits	Formations	Wide destruction	Some damage	Little damage	No damage
	Materials	Pathways and other facilities	Wood	Some wood	Concrete	Sainless steel or plastics
	Lighting	Light sources	Incandescent lamps	Halogen lamps	High efficiency	LEDs
		Lamp position	Close to walls and direct light	Close to walls and no direct light	No close to walls and some direct light	No close to walls and no direct light
		Light spectrum	No limitations	Some limitation	Fair limitation	No emission for chlorophilian process
		Lampenflora	Widespread	Some cleaning	Frequent cleaning	Absent
		Power supply	No emergency	One emergency power supply	More emergency power supply	More emergency power supply and many sections
	Lighting network	Sections	Single network	Some portions not automatic switching	Many portions and not automatic swithing	Many portions and automatic switching
Visitors	Flow	Capacity	No limitations	To and from trail	Round trail	Compilance with capacity
		Adventure tourism	Free	With one guide	With two or more guides	With guides and strict trails
Surface	Ecosystem	Disturbance	Totally modified	Many interventions	Few interventions	Pristine
Cave environment	Cleaning	Frequency	Never	Some time	Some time and water disposal	Frequent and water disposal
	Monitoring	Climate parameters	No monitoring	Few stations	Many stations	Many stations and scientific committee
	Fauna	Protection	None	Food in cave allowed	Only for bats	Any species protected
	Management	Cave managers	Not competent	Some competent	Fairly competent	Fully competent
		Guides	No school	Some education	Some education and foreign languages	Good educations and foreign languages

A similar approach was recently adopted to evaluate the indoor cave environment with particular emphasis to mine caves (Pani and Cigna 2012). Since the implementation of the Management Guidelines for Show Caves requires different time intervals depending on the local situations, a system to obtain a quantitative evaluation is here described.

A Management Evaluation Index (MEI) for show caves can be determined by applying the indicator scores composing the matrix, as reported in Table 1. This indicator matrix was built according to the UIS Management Guidelines for Show Caves (Cigna 2009).

The index is obtained by tallying all of the indicator scores ($\Sigma\ I_n$) and dividing this sum by the highest possible score (=3), multiplied for the number (N) of applicable indicators considered. The resulting value ranges between 0 and 100:

$$MEI = \frac{\Sigma\ I_n * 100}{N*3} \qquad (1)$$

A mean score, as e.g., 2.5, typically applies as intermediate value, for instance when concrete and stainless steel are used at the same time for pathways and other facilities.

A higher value of MEI indicates a good management assessment. Values below 40, therefore, suggest a rather poor compliance with an acceptable management level, values up to 60 correspond to a management that can be conveniently improved, while values starting from 60 to 100 confirm a good management.

Table 2. Management Evaluation Index for: Frasassi C. (IT); Kartchner C.(USA); Cango C. (SA), Aven Armand C. (FR).

Category	Attribute	Indicator	Frasassi Cave (IT)	Kartchner Cave (USA	Cango Cave (SA)	Aven Armand (FR)
Previous study	Suitability	Access to the cave	2	3	2	3
	Synergy	Close-by attractions	1	2	1	3
	Conflict	Local facilities	2	3	3	3
	Funding	Partners	1	3	1	3
Access and pathways	Entrance	Access	1	3	-*	3
	Cave structures and deposits	Formations	2	3	0	3
	Materials	Pathways and other facilities	2.5	2,5	2.5	2.5
	Lighting	Light sources	0	2.5	1,5	2
		Lamp position	1	2	0,5	2
		Light spectrum	0	2	1	1
		Lampenflora	1	2	0.5	1
		Power supply	1	3	2	1
	Lighting network	Sections	1	3	0	2
Visitors	Flow	Capacity	0	3	3	2
		Adventure tourism	1	3	3	3
Surface	Ecosystem	Disturbance	3	3	3	3
Cave environment	Cleaning	Frequency	1	3	1	1
	Monitoring	Climate parameters	0	3	2	0
	Fauna	Protection	0	3	3	3
	Management	Cave managers	0	3	3	3
		Guides	1	3		3
MEI =			**34**	**94**	**60**	**71**

* Cango Caves has a natural access without any tunnel

4. Examples

The method here described aims to provide an objective evaluation of a show cave management quality after its development. It is well known that, during its life, the management of a cave may change both in positive and in negative way, and monitoring this evolution might be useful.

Following, the application of the assessment matrix to four show caves located in different parts of the world and with different levels of management is reported as an example. These are: the Frasassi Cave (Italy), the Kartchner Caverns (Arizona, USA), the Cango Cave (South Africa), and the Aven Armand (France). The results are reported in Table 2.

While starting the development of the Kartchner Caverns in the Arizona National Park, the Frasassi Cave was designated as the best example of a show cave management, therefore visited and analysed in detail. Cango Cave is one of the oldest show cave in the world, where also protection criteria were applied.

The rather low value obtained by the Frasassi Cave, which is the most important show cave in Italy, confirm the decay of its management in the last tens of years. This downside aspect unfortunately was already clear to anyone familiar with the cave.

Kartchner Caverns has been developed following very strict plans during both the engineering works inside the cave, and successively the opening to visitors. This cave has kept its top position in the show caves management list.

Cango Cave started to be visited in the XIX Century and, therefore, it suffered some lack of knowledge about the environmental protection criteria. In particular, the lampenflora spread out in some part of the cave to the point that it is not possible to further clean out the walls. The socio-economical situation of the Country, unfortunately, led to some decrease of routine management.

The Aven Armand is one of the most important French show cave. Its development started in 1927 and was successively improved according to the best protection criteria.

The Management Evaluation Index as applied to the four mentioned caves (Table 2) is, respectively:

Frasassi Cave (Italy)	34
Kartchner Caverns (Arizona, USA)	94
Cango Cave (South Africa)	60
Aven Armand (France)	71

Score 34 for Frasassi Cave merely means that significant changes of management are required for a positive assessment; a MEI equal 60 for Cango Cave means the need of few actions for rising to a proper level that the most important show cave of the country should hold. Scores 71 and 94 for Aven Armand and Kartchner Caverns respectively highlights a quite good cave management, the latter being just at the top of the classification.

5. Conclusions

It is often assumed that the development of a cave into a show cave does not mean at all that the cave itself is lost for science: this is not always true. Show cave managers, conversely, have provided an instrumental support for the achievement of important scientific investigations.

The development of a show cave implies many actions, which could negatively affect the cave environment. The management guidelines quoted above give a general indication for a suitable protection of the cave environment and the visitors' safety; their level of implementations must be, however, evaluated. It must be also emphasised that a continuous effort to keep up to date the management to avoid the risk of serious mistakes, is required.

The Management Evaluation Index (MEI) here described can be considered as a useful tool to supplying quantitative and objective data. This procedure might be applied by the organisations interested in the cave environment protection to evaluate the level attained by any show cave.

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"CAVE LIGHTING" PROJECT: THEORY AND PRACTICE OF THE DEVELOPMENT AND MAINTENANCE OF MODERN SUBTERRANEAN TOURIST ATTRACTIONS – A SPELEOLOGIST'S POINT OF VIEW

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This presentation tells about eight year experience of GermTec GmbH & Co in equipping (development and maintenance) modern subterranean tourist attractions. Here are just a few tourist attractions we equipped: Herbstlabyrinth Cave (Germany), Fundata Cave (Romania), Postojnska Jama (Slovenia), Grotte de Clamouse (France), Prometeus Cave, Georgia, Höllgrotten Cave (CH), Wendelstein Cave (Germany). We are going to talk about problems arising when operating a cave for a long time on a daily basis, as well as strategies and tactics in their solution. We are presenting tried-and-true modern technologies and equipment, which allow minimizing the harm caused by anthropic interference when operating a cave. The objective of this presentation is to attract attention of speleological society towards the problems in running speleological tourist attractions. We would also like to present technical and technological innovations which can help to preserve show caves.

1. Introduction

Today, there are more than three thousand operating subterranean tourist attractions, located all around the world. On average, three to five new ones open to the public every year.

Due to the high demand of quality service, in modern society, show caves are very popular tourist attractions. There are plenty of people who would like to discover the wonders of an underground world. Running a show cave can be cost effective, if it is well organized, has proper infrastructure and marketing.

Subterranean tourist attractions have not been accurately classified yet. Our classification is not accurate either; this is just a relative systematization. This classification is based on the point of view of speleologists developing show caves. In our humble opinion, the human component an criterion which must be taken into consideration and which is essential for the proper planning/concept of a show cave business attraction.

The major criterion is the specific attraction

- Natural subterranean cavities, such as caves, ravines, canyons, funnels and craters, etc.
- Man-made attractions such as tunnels, mines, excavations, religious objects, drainage systems, etc.

As a rule, natural vs. man-made attractions attract a different type of tourist.

As far as man-made attractions are concerned, information is of major importance. The point is to show and tell the history of the object and the role of human activity within it.

Natural subterranean attractions are aimed at presenting the underground world with its mysteries and wonders, beauty and fragility. A strong emotional impact of a show is of more importance than information provided.

The approach to equipping natural and man-made attractions differs as well. Properly functioning technical lighting is a major focus when equipping a man-made attraction. As for natural attractions, the artistic perspective is more important, because it presents the beauty of the inside surroundings to the public. Equipping and running a natural tourist attraction is a more sensitive business, which requires caution and high professionalism. Visitors must be provided with the highest comfort possible, with minimum interference of the cave ecosystem.

Today, there are more than 300 show caves in Europe alone. But, for some reason, only few of them make the public want to return again.

Let's see what affects the contradictory perception of tourist attractions?

- low quality lighting (a cave is seen as a poorly lit basement),
- general condition of a cave (lamp flora, mold on the walls, litter),
- technical condition of show routes and lighting equipment (rusty, slippery paths, broken steps, outdated lighting fixtures, cables along walk ways, etc.),
- low quality of shows (boring and uninteresting tours),

Figure 1. "Cave Lighting" Project logotypes.

- poor maintenance and care of caves. Owners are out to make maximum profit. They overcrowd caves and do not care about natural ecology. This is especially sad and unpleasant to cave lovers, including speleologists.

Idea of "Cave Lighting" was born when visiting one of those caves mentioned above…

Figure 2. "Cave Lighting" Team, 2006.

Eight years ago (in 2005) two speleologists visited some show caves in Germany. The unbelievably poor maintenance/condition of one of those caves unbelievably disappointed and upset the cave professionals. They both decided that, since show caves are extremely popular among crowds of tourists (not just speleologists), the aim should be to preserve the caves as much as possible. Visitors must have a chance to enjoy and experience the mysteries of the underground world, while experiencing maximum positive emotions and unforgettable memories without harming cave ecosystem.

2. Methods of "Cave Lighting" Project

"Cave Lighting" Development is eight years old now.

Project "Cave Lighting" has been constantly developing:

- We formed a team of speleologist associates and specialists in different adjacent fields (design engineers, constructing engineers, planners, lighting designers, assemblers, IT specialists, etc.);
- We developed special equipment purposely designed for caves. (LED lighting systems, music systems, control systems, etc.);

Figure 3. "Cave Lighting" Manufacture.

- We selected and tested modern ecofriendly materials and technologies;
- We gained precious experience in the planning and running of subterranean tourist attractions.

3. Results

- Project "Cave Lighting" today is:
- philosophy of light,
- conceptual and individual approach to every task,
- exclusive equipment
  - purposely designed for caves,
  - manufactured by us;
- modern materials for subterranean show;
- international team of speleologists;
- registered trade name;
- successful business project.

Figure 4. "Cave Lighting" LED Lamp.

Figure 5. "Cave Lighting" FPR.

Project "Cave Lighting" is:

- a consulting business:
  - we have hundreds of presentations of our equipment and offer consulting for owners/managers of subterranean tourist attractions worldwide.
- about 40 equipped tourist attractions, including:
  - brand new unique show caves, which didn't suffer from human activity/damage. Namely we performed all-inclusive work in the Herbstlabyrinth Cave in Germany – from developing a business concept and a show cave concept, to overall equipment installation (controlled LED lighting system, FRP route paths, monitoring system).

- Restored attractions. Namely we restored the Fundata Cave in Romania. Tours to this cave hadn't been properly organized before; therefore it was in a poor condition. In 2011 Romanian speleologists, together with "Cave Lighting" cleaned and restored the Fundata cave and turned it into a successful subterranean tourist attraction. It was all-inclusive work from planning to ready to operate cave.

We partially or completely upgraded/replaced outdated electrical equipment and redesigned lighting systems in the part of oldest show caves in Europe, Postojnska Jama (Slovenia) and Grotte de Clamouse (France).

In some caves we designed and installed electrical power supply systems, lighting systems, music and light systems (DMX-show) and monitoring systems. These systems were developed according to customers' requirements (Prometeus Cave, Georgia).

Figure 6. Project by "Cave Lighting". Dechenhöhle, Germany, 2012.

Besides modern lighting and music systems, our project specialists developed unique software which integrates all of these systems into one network and allows remote controlling and if necessary, correct operation of all (something similar to a "smart home" system). Höllgrotten Cave (CH), Wendelstein Cave (DE).

"Cave Lighting" project is constantly developing. We observe modern scientific achievements and cooperate with leading speleological organizations and associations (ISCA, Karst Institute (Postojna), speleological clubs in different countries, etc.).

We continue to perfect our equipment and promote our specialists' self-development.

In the near future, we plan on reconstructing that cave in Germany which made such an unforgettable negative impression on the "Cave Lighting" development creators eight years ago.

4. Conclusions

The objective of this presentation was to attract attention of speleological society towards the problems in running speleological tourist attractions. Speleologists and show cave owners must work hand in hand, use all discoveries in modern science and up-to-date technologies if they want to find solutions.

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Figure 7. Project by "Cave Lighting". Herbstlabiynth, Germany, 2012.

ENVIRONMENTAL MONITORING AND RADIATION PROTECTION IN SKOCJAN CAVES, SLOVENIA

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Škocjan Caves were listed as UNESCO World Heritage Sites in 1986, due to their exceptional significance for cultural and natural heritage. Park Škocjan Caves is located in South Eastern part of Slovenia. It was established with aim of conserving and protecting exceptional geomorphological, geological and hydrological outstanding features, rare and endangered plant and animal species, paleontological and archaeological sites, ethnological and architectural characteristics and cultural landscape and for the purpose of ensuring opportunities for suitable development, by the National Assembly of the Republic of Slovenia in 1996. Park Škocjan Caves established monitoring that includes caves microclimate parameters: humidity, CO_2, wind flow and radon concentration and daughter products. The approach in managing the working place with natural background radiation is complex. Monitoring of Radon has been functioning for more than ten years now. Presentation will show the dynamic observed in the different parts of the caves, related to radon daughter products and other microclimatic data. Relation of background radiation to carrying capacity will be explained. Implementing the Slovene legislation in the field of radiation protection, we are obligated to perform special measurements in the caves and also having our guides and workers in the caves regularly examined according to established procedure. The medical exams are performed at Institution of Occupational Safety, Ljubljana in order to monitor the influence of Radon to the workers in the cave. The equivalent dose for each employed person is also established on regular basis and it is part of medical survey of workers in the caves. A system of education of the staff working in the caves in the field of radiation protection will be presented as well.

1. Introduction

Škocjan Caves were listed in UNESCO World Heritage List in 1986. The Caves system of 6,5 km consists of extraordinary underground halls, chambers and canyon of the Reka River. Its underground course was recognised as wetland of international importance according to Ramsar convention. The Park Škocjan Caves is also a Man and Biosphere Reserve Site, known as The Karst Biosphere Reserve. Monitoring of caves microclimate consists of radon and microclimatic parameters survey. We have been performing the monitoring of the radon for almost two decades now. The continuous monitoring of temperature, CO_2, relative humidity and wind flow on defined spots started four years ago. Radon ^{222}Rn enters the underground spaces of the caves by diffusion from the rock surface of the walls, floor, depths, where it is produced as decay product of ^{226}Ra. Rn is radioactive gas with decay half-time 3,83 days and results in short-lived decay products polonium ^{218}Po, lead ^{214}Pb, bismuth ^{214}Bi and polonium ^{210}Po. All these are heavy metals that are retained in the air as free floating particles or as attached to the molecules of water and aerosols in the air. During respiration they are laid on surface of respiratory ways from the nose and pulmonary alveoli, where they decay with emitting particles alfa, beta or gamma. The most dangerous are both isotopes of polonium, which emit alfa particles that can cause damages in the cells of epithelium of bronchial walls of lung.

2. Monitoring

According to Slovene legislation in the field of radiation protection we are obligated to have regular monitoring of radon, education and medical exams for tourist guides that are exposed to radiation in majority of their working time (The Rules on Radiation Activities Performer's Commitments 2004, The Rules on conditions and methodology for dose estimation in radiation protection of workers and inhabitants 1994, The Ionizing Radiation Protection and Nuclear Safety Act 2003). Environmental monitoring in the caves was designed in a way to assess the anthropogenic impact on delicate caves environments and consequently the carrying capacity of the site. The latest is defined by the highest number admissible that does not cause irreversible damage to the site and still enables the visitor to enjoy in quality visit of the site. Several aspects should be included in order to propose a range of lower and upper limits. Among most important are of course physical features of the site, social and economical aspects of the site. In the caves the number of guided visits is also limited by the advised time spent in the cave that does not cause rise in effective dose of Rn. Observation of anthropogenic impact is done by survey of dynamics of temperature, humidity, CO_2, which are supposed to rise after the visit (Decree by Slovenian Radiation Protection Administration 1999, The Ionizing Radiation Protection and Nuclear Safety Act 2003). Monitoring of caves microclimate reveals interesting dynamics of parameters that are on general believed to be constant. The influence of outer air is observed in certain part of caves.

3. Methods

In Škocjan Caves we have designated six measuring places in the caves for Rn concentration among them three for constant monitoring of temperature, CO_2, humidity and wind flow.The monitoring programme is performed by Institute of Occupational Safety, Ljubljana and Park Škocjan Caves, Slovenia.We continuously measure Rn concentration and quarterly also Rn daughter products using these instruments: RGA-40 (Scintrex, Canada) EQF-3020, RTM-2010 (Sarad, Germany), for Rn daughter: WLM-30 (Scinterx, Canada), EQF-3020 (Sarad, Geramany) and Rn – integrated method: track each. The effective dose for employees is calculated by the model ICRP32. Some other parameters of caves microclimate are measured by instruments Ahlborn ALMEMO, Germany, temperature is measured by thermocuples, humidity by stationary Psychrometer FP A836-3, CO_2 by Almemo sensor FYA600CO2. Last year we adopted measurements of temperature and humidity also by Hanwell instruments HT330.

During summer and winter period of 2011 a monitoring of concentration of particles was performed by low volume sampler Sven Leckel SEQ47/50 with gravimetric method. In December 2011, PM10 and gases NO, NO_2, NOx, CO, where analysed with Airpointer, optic method.

4. Results and discussion

The first part of the cave Silent Cave is quite closed and therefore the circulation of the air is modest. On the contrary the second part of the cave Murmuring Cave is more opened towards outside and the influence of the outer air are observed. The highest Rn concentration was measured in summer period in Silent Cave system: Kalvary, Tent, Great Hall entrance and Great Hall. The lowest value of Rn concentration was measured in Murmuring Cave and Limestone pools. This is true for entire period of monitoring with fluctuations that depends on outside temperature and exchange of air.

The average values of Rn daughter products were measured in first part of the caves, from April to October when there is a highest difference between temperature in the cave and outside. Factor of balance is high through the year due to modest ventilation of the first part of the cave.

Several measurement sites in the caves, revealed constant temperature in first part of the caves 11.9 °C and rising up to 13 °C in Murmuring Cave. There is slight increase in temperature and CO_2 levels after the visits of tourist in more closed spaces, though no permanent rise in value is observed (Figure 3). The same is true for CO_2, with night and day dynamics. Since the air flow is modest in first part of the cave, there is constant influence of outer air in Murmuring Cave. The air in the cave is very clean as resulted from data of PM10 and gases (Figure 5) (Cigna 1993, Cigna 2000, Comparative dosimetry of radon in homes and mines. 1991, Debevec 2002).

With comparison of average monthly data from meteorological station in the surface, we can observe rise in temperature at the measuring point Bridge during the summer (Figure 4). There is air flow towards the inside of the caves, due to difference of air temperature which is not so high during the winter. This can explain also the high values of Rn concentration in the first part of the cave, due to poor air exchange (Figure 1). The environmental monitoring is planned and performed in order to establish the upper limit of carrying capacity (CC) for caves area. Physical carrying capacity is mainly related to the geomorphological features, but in real carrying capacity values, we can determinate also other parameters that are found to be altered by the presence of tourist or the visit itself is altered due to accessibility, weather conditions or other phenomena. We have measured the values of microclimatic parameters in order to observe the irreversible change in value due to the number of visitors. For now no such changes were found. Though we can say that one of the limiting factor for visits is also radon concentration from the point of view of occupational safety, since tourist guides can not have extended time of tours due to the low annual effective dose. For easier implementation of adoptive management it could be useful to introduce an indicator that could describe the balance between man and caves environment. Cave Use Index should accomplish the data of CC and present the possible limits of anthropogenic impact on biotic and abiotic component of the ecosystem.

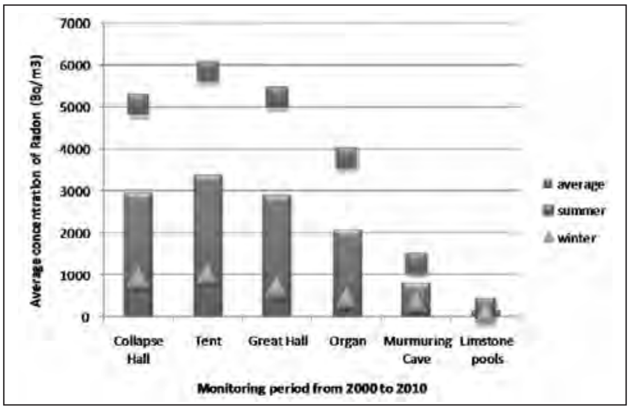

Figure 1. Average concentration of Rn at different locations in Škocjan Caves.

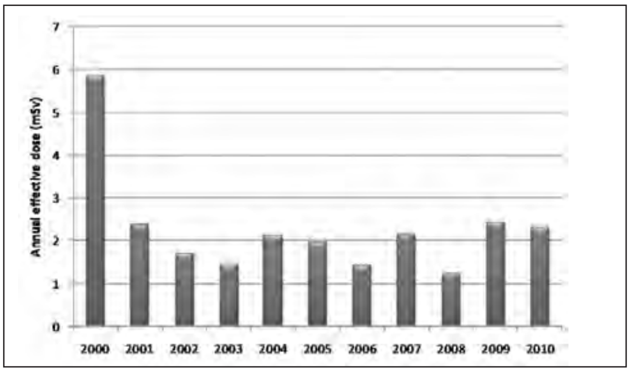

Figure 2. Average annual effective doses in ten years period of monitoring.

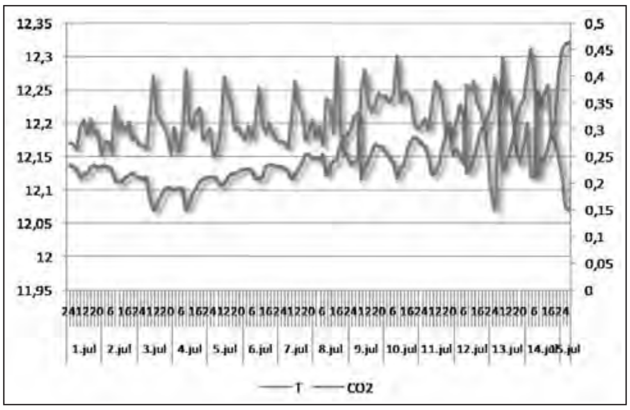

Figure 3. Increase of temperature and CO_2 values after the visits of the caves.

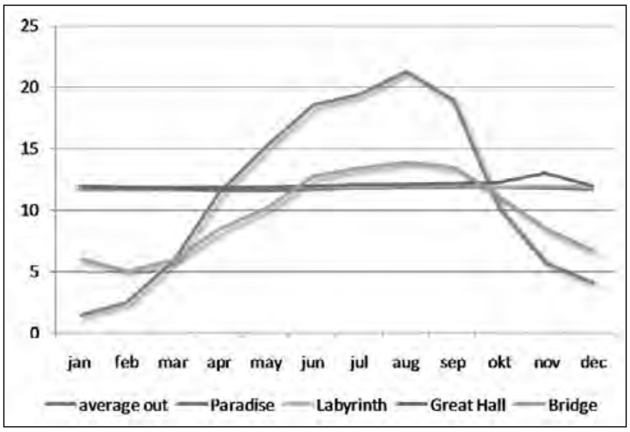

Figure 4. The influence of outer air.

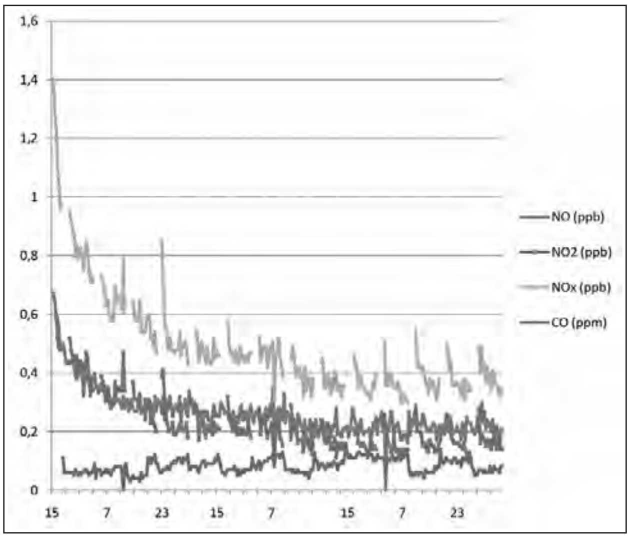

Figure 5. Measurement of different gases in the caves air.

Where we can define: *CUI = Ecc/Hhf*

Ecc – Environment factors related to carrying capacity,

Hhf– Human health factor

One of the most important aspects of radiation protection is also education and medical exams. The rise in awareness resulted in lower annual effective doses in ten years period of monitoring (Figure 2).

5. Conclusions

The concentration of Rn and daughter products is higher during summer and lower during winter period. During summer the night – day dynamics is observed; during the night the concentration of Rn rises, and descend during the night, since then the difference between temperature between outer and inner air is lower and results in modest air exchange.

There is a need for and continuous measuring of ions, dust particles, aerosols besides other parameters of caves microclimate in order to find the limit of carrying capacity of the cave. The estimation of the latest should have also take in to account the effective dose due to radiation. It should be well established in order to provide the workers in such special environment with proper occupational safety.

6. Summary

Monitoring of caves microclimate in Škocjan Caves was established in order to define and monitor carrying capacity of the World Heritage Site. Due to the dinamyc of air exchange variations in parameters are observed. High levels of radon concentration are present in first part of the Škocjan Caves due to poor ventilation. Continuous monitoring is a useful tool for adaptive management and study of microclimate in the caves.

Acknowledgments

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CAVE AND KARST AT THE CINEMA: CULTURAL SPELEOLOGY AND THE GEOGRAPHICITY OF SYMBOLIC LANDSCAPES

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Abstract. The aim of this paper is to analyze of technical and scientific and also symbolic aspects in-circuit cinema films, produced between 1927 and 2012. We start from study of the geographicity of symbolic landscapes. We used 150 films related to the theme cave, cavern and karst, which were identified between 2007 and 2012. The material was registered in their own spreadsheets and analyzed by its symbolic and technical-scientific contents. The data were obtained on video stores, sites specializing in film and others (IMDb, Allmovies, Adoro Cinema, Wikipédia and others) and in film analysis texts and their relation to studies about natural and symbolic landscapes. The oldest examined film was ***Metrópolis***, a classic science fiction movie directed by Fritz Lang in 1927, which shows a conflict of classes, being a group of rulling elite and another of oppressed and enslaved working class who lives in an underworld. It was observed that there is a negative imaginary world around the idea of the cave, this fact has been reinforced and seeing erroneously appropriate by film production. It was also observed that most of the movies that have the cave as a background landscape are the horror or suspense categories. In the selected movies for film analysis about caves it is observed that they are always accompanied by excitement of the unknown and the discovery, interlaced by the adventure, the hideout, while feelings of fear are most evident in ***Batman Begins*** film, because of the protagonist's relationship with the bat, even as a determinant of the genesis of the hero. In the ***Dead Poets Society*** film the cave appears as pleasant place and a sense of freedom, fraternization, but the aura of being something hidden. It is hoped that studies such like promote actions through the films more suitable for environmental education and speleological training more appropriate to spread the environmental and cultural role of the caves, allowing the development of activities that promote the protection of the speleological world heritage.

Resumen. Cuevas y karst en el cine: espeleología cultural y la geograficidad de los paisajes simbólicos

El objetivo del presente trabajo fue analizar los aspectos técnicos, científicos y simbólicos presentes en las películas de circuito de cine producidos entre los años de 1927 y 2012. El punto de partida fue la perspectiva de estudios relacionados con la geograficidad de los paisajes simbolicos. Fueran identificados 150 películas acerca del tema cuevas, cavernas y karst, identificados entre 2007 y 2012. El material recogido fue catastrado en formulario própio y analizado por su contenido simbólico y técnico-científico. Los datos fueran obtenidos en tiendas de vídeos, sites especializados en el cine o afines (IMDb, Allmovies, Adoro Cinema, Wikipédia, entre otros) y en artículos y textos sobre analisis fílmica y su relación con estudios del paisaje natural y simbolico. La película más antigua analizada fue ***Metrópolis***, un clásico de la ciencia-ficción dirigido por Fritz Lang en 1927, en el cual se relata acerca de los conflictos entre clases sociales, siendo una elite gobernante y otro compuesto por la clase trabajadora que viven oprimidos y esclavizados en un mundo subterráneo. Se observó que existe un universo imaginário negativo alrededor de la idea de cuevas, y este hecho ha sido apropiado y reforzado por la producción de las películas. Se observó también que la mayoría de las películas que tienen la cueva como paisaje de fondo son las de la categoría de terror o suspense. En las obras seleccionadas para analisis fílmica la cueva viene siempre acompañada por la excitación del desconocido y del descubrimiento entrelazado por la aventura, el escondrijo, al mismo tiempo se producen sensaciones de miedo que parecen más evidentes en la película de ***Batman Begins***, derivado de la relación del protagonista con el murciélago, incluso como factor determinante de la génesis del héroe. Por otro lado en la película ***Dead Poet Society*** la cueva aparece como lugar agradable y la sensación de libertad, de fraternidad, sino también por el aura de hacer algo oculto. Se espera que estos estudios puedan promover acciones a través del cine para la educación ambiental y la formación espeleológica de manera más adecuada para el papel de protección ambiental y cultural de las cuevas, permitiendo realizar actividades que pueden ayudar a proteger el patrimonio espeleológico mundial.

1. Introduction

The caves have values connected with dreams, stimulation to the imagination oppressed, loves hidden, place of mysteries, discoveries, secret chamber, or even housing. Bachelard (1990, 2000) helped us to identify this task resulting from reveries of underground images. In film production that symbolism is potentiated and it is offered to the viewer in a more definitive form or not, according to the vision of the author/screenwriter, director, suffering sometimes also influences of producers, sponsors and spectators.

From the analytical point of view the essay conducted by Travassos (2007), yielded evidence for a deepening in the psyche and cave symbolism present in film productions. In this study, the author reflects on the role of the karst in works of fiction, checking the imaginary in literature, film and media, where many times the word cave is associated with negative feelings, as well as claustrophobic shadowy world where demons live (Travassos 2007, p. 62).

This research reinforced that representations of caves appear both in film and in literature, because it often movies are readings of literary works, such as Chronicles of Narnia, Harry Potter and The Lord of the Rings. The author also identifies diverse landscapes of fear as analyzed by Tuan (2006); these movies are fantastic adventures, science fiction or action. But this negative imaginary of the caves is a favorite of horror movies, such as recent: The Descent and The Cave. The locations and natural sceneries favorite when it comes to karst landscapes are Romania, Slovenia, Mexico, New Zealand, Scotland and England; in rare cases also depict regions of Brazil, as the Chapada Diamantina in the movie Tourists, by having a typical karst (Travassos 2007, p. 66–67).

In their final discussion, the author emphasizes that the works analyzed were identified as the most classic and could be divided into two different "worlds", a fictional and one real landscape. He believes that these issues are fundamental to understand the values of karst landscape and ways to seek their preservation (Travassos 2007, p. 69).

The purpose of this study, connected to Anthropospeleology Committee of the Section of History of Speleology and Section of Environmental Education (SBE), was to conduct an analysis of the technical, scientific and symbolic aspects in films of the cinematographic circuit, produced between 1927 and 2012. Preliminary versions of this study were presented in Figueiredo (2001, 2010a, b), Figueiredo, Travassos and Silva (2009) and Figueiredo and Travassos (2010). Following this path, we intended to make a critical reading of the imaginary cave in these movies, checking which are symbolic images embedded in movie productions, in addition to descriptions and depictions of underground landscapes.

The theoretical basis of the research focused on cultural geography (Rosendahl and Corrêa 2001a, b; Claval 2007) and humanistic geography (Tuan 1980, 2006; Gratão 2006). The search for geographicity of symbolic landscapes, based on film production reinserts the question of the lived world and the perceived world and allows approximations of possible educational and phenomenological dimensions involved with this theme. Were also used texts about film analysis (Vanoye and Goliot-Lété 1994; Pereira 2000; Vadico 2001; Melani 2006; Ito and Nogueira 2007) and the relation between cinema and landscape studies (Steward 2004; Peckham 2004).

2. Methods

Data were obtained on video rentals or video stores, movie in Theaters, DVD, or specialized sites like (IMDb, Allmovies, Adorocinema, YouTube, Wikipedia, and others). The search was conducted by the terms cave, grotto, natural cavity, karst, karst landscape, speleology among others keywords associated.

We identified 150 films title, between the years 2007–2012, which possessed content related to the topic cave and karst landscape. The material was registered in own worksheets and analyzed by its own symbolic and technical-scientific contents according to the used references. Two movies were selected for more detail analyses (Batman Begins and Dead Poets Society).

3. Results and discussion

3.1. General analyses of the filmography

Among the older films analyzed, we emphasize four films, whose predominant category was fiction and horror, but one also addresses aspects of drama, romance and the War. The oldest of all is the film ***Metropolis*** (1927), a classic science fiction film directed by Fritz Lang, who portrays a population divided into a class of the ruling elite and another class of workers who live in an underground world, totally enslaved.

Figure 1. Poster of Fritz Lang's Metropolís (1927).

The Mole People (1956, re-released in 1964) cover an archaeological survey of ancient Sumerian people who possibly would live in caves. The other film was ***Beast from Haunted Cave*** (1959), indicating an emphasis on horror and thriller, with the presence of frightful monster in the cave. Another old movie registered as ***Sette contro la Morte*** (1964), an Italian-Germany production, distributed in the U.S. in 1965 with the title ***The Cavern***, by virtue of portraying the lives of a group that takes refuge in a cave and gets stuck during the Second World War, has a strong sensual appeal to the standards of that time.

Of all the cinematographic works analyzed, over 60 % of them were distributed in Brazil since 2000. Predominant adventure genre films, action, fantasy or science fiction, and followed by horror and suspense, noting that some of the previous category may also be present doses of suspense or horror related. Only 13 of analyzed films treat animation, though Beowulf is also an animated film.

The films that deal with cave as the main focus of the plot are the horror and suspense genre, which indicates excessive use of negative or pejorative imaginary for the cave in film production, prevailing views about monstrosities, deformation or brutalization. On the other hand, in the other films the cave presents aspects of adventure, discovery and learning.

3.2. Symbolic aspects of the caves

Regarding the symbolic aspects were chosen 64 keywords used as indices of the films, which were subjected to these words and ranked, based on the preliminary study of Figueiredo (2001) and doctoral thesis (Figueiredo 2010b). Figure 2 shows the distribution of simple indices and the interrelationship between the words most often cited.

The results highlighted that the image of the cave in the film sample contains aspects of conflict and confrontation, creating difficulties, exposing limits. In many movies were portrayed situations of struggle or battle and the issues of power and domination. Reinforcing also the danger, traps and obstacles almost insurmountable, generating injury or death. The study identified that appear caves as shelters, residence, hiding place, refuge, with emphasis on hostile environment. However, appear moments of challenges overcome, search and demand, where there are aspects of interpersonal relationships involving friendship, discovery, skills and heroism.

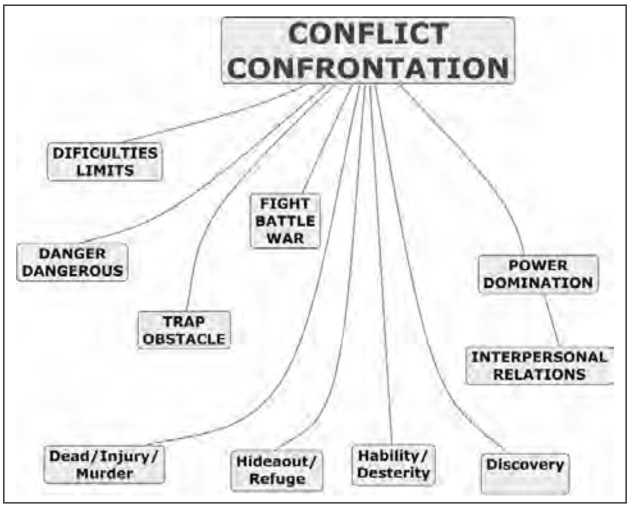

Figure 2. Diagram of indices representing the symbolic aspects of the cave in the analyzed movies.

3.3. Technical and scientific aspects of the caves

From the point of view of the technical and scientific aspects, the images depict the karst landscape worked as a physical medium, even artificial (scenarios). It is observed in Figure 3 is a predominance of words that represent aspects of the typology of caves, prevailing images of endokarst, internal features, especially the inner halls and the formats of the ducts and galleries, especially in large environments frameworks shooting, but also the strictures and labyrinthine networks. Walk-entry is also portrayed in the film as well as the presence of walls and cliffs.

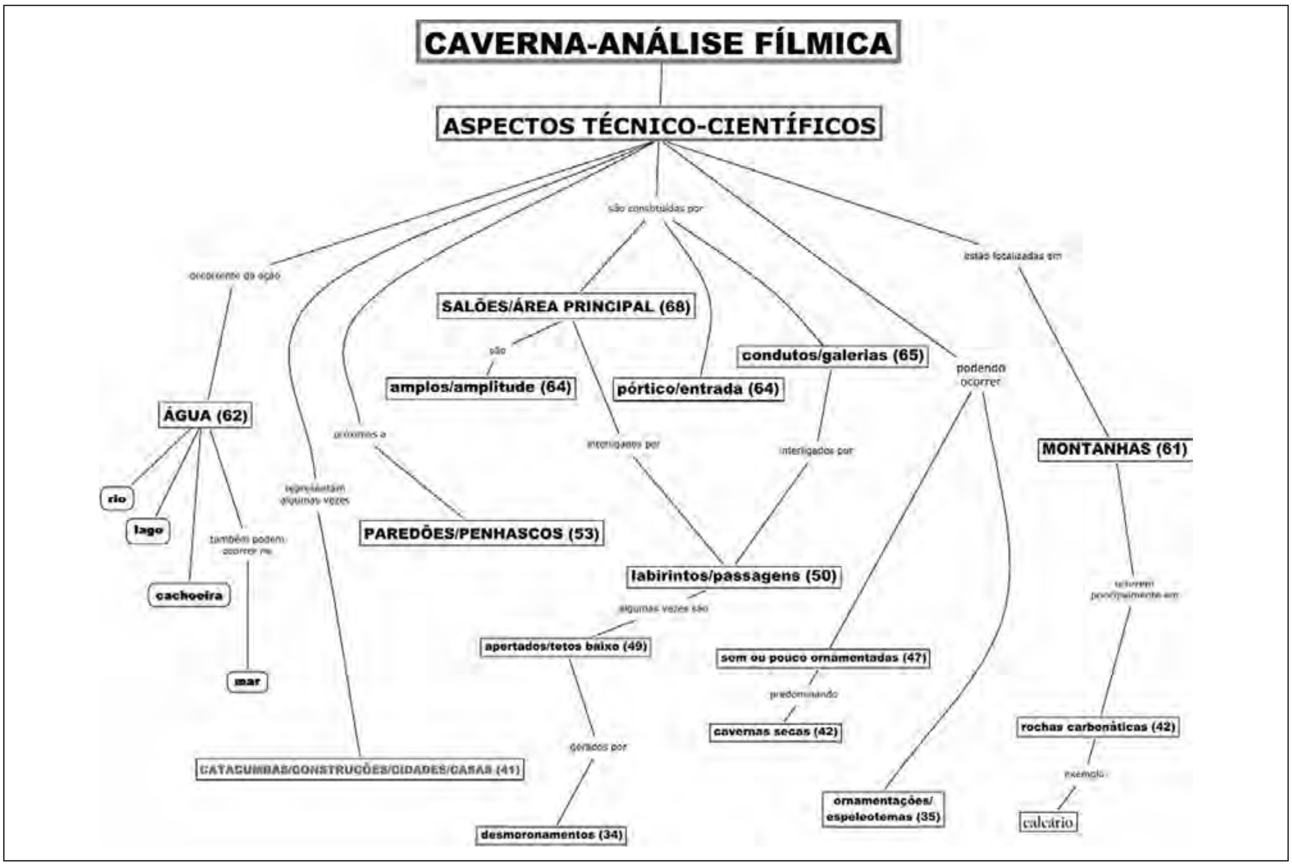

Figure 3. Model for conceptual map-cave and the technical and scientific aspects.

The caves are often associated with the presence of water, such as rivers, underground lakes, waterfalls, and are sometimes related to the sea or coastal regions. This is due to the vision of water as forming agent and shaper of cavities and caves that usually appears real world.

The last highlight comes on account of exokarst, external images and the karst landscape, ruiniform features with bridges, Karren, pinnacles and karstic cones (cockpits).

One issue to be emphasized is the lack of cave fauna in the cinematographic caves, even bats, which are regular inhabitants. When bats appear that are associated with negative content and horrifying, like vampires who attack mercilessly, and then why filmographic emphasis, however, they often end up being replaced by something more terrifying as giant spiders and insects, monsters, dragons and orcs.

3.4. Description of selected movies

The selected films allow a dip in the cave symbolism, with several specific tones, while also presenting some similarities. The selection was: ***Dead Poets Society*** and ***Batman Begins***, so we managed to cover two major filmic categories: drama and action (HQ), but it was possible to make a general presentation of images on posters and promotional material from several movies.

The movie ***Dead Poets Society*** is based on the novel and adaptations made by Tom Schulman, who won the Oscar for best original screenplay, with director Peter Weir and actor Robin Williams as a protagonist, like the controversial and provocative literature teacher, John Keating. The plot is built around the discovery by some young school freshmen, a strict boarding school, about the existence of a secret society where students took refuge in a cave near a river that crossed the forest to freely read the classics of literature, especially those prohibited by the school, like a Henry David Thoreau.

The scene of the way to the cave at night is remarkable; flashlight beams of lights running and dancing in the woods, and everything goes as if the boys were in a back in time, back in history, back to secret societies, there is an excitement in the air, what will be awaiting them.

Figure 4. Poster and scenographic cave of DPS.

The cave used in the movie was mounted in a studio setting, because the locations in the field were not enough for filming and there was the problem of light. To solve this was prepared a hole in the artificial cave, which made the function of skylight, was created a perfect environment with speleothems, drip and everything. The director says that the history of cinema is littered with caves badly made, he even would like to make a book about it, so the film crew went to great pains to do something that was very close to reality and could handle the filmography needs.

In the case of ***Batman Begins***, the focus, of course, was the adventure, superhero, and again reveal the chthonic heroes, neomyths. The protagonist is a young millionaire and living with their fears and regrets. The cave is represented by these fears, being used as a symbol of the bat to the genesis of the hero. The story could be divided into four major parts in which the fear provides the plot for the film. First, would be nightmare: fear terrifying, the the second step would be, Penance and training: fear that attacks and its control, the third time would be the pregnancy of superhero: fear that approaching, and the last moment was action, fear shared with enemies.

Figure 5. Movie Poster of Batman Begins.

This cave, filmed in Batman Begins, oddly enough, such perfection, was also produced in the studio. It is of huge proportions, with several galleries, a wide river with a tributary, and a waterfall as well as a large main portico entrance. Spent up millions of reinforced concrete and a shed for this gigantic undertaking, which were made even more action scenes during the recording.

3.5. Movie posters, scenes and visual narratives

Several other films portray caves as a place of mystery, conflict and fear, the monsters, or even the adventure of treasure, discovery and friendship, other recent films are more realistic. The images of Figures 6 to 13 show some promotional materials, movie posters, scenographic caves and scenes of their films, emphasizing the cave in cinema.

Figure 6. Movie Poster of The Cavern homonyms.

Figure 7. Two old movies about horror and caves.

Figure 8. Movie poster and choking scene of Turists.

Figure 9. Movie poster and horrible scenes of The Descent.

Figure 10. Two adventure movies about caves.

Figure 11. Movie poster and suspense scene of The Cave.

Figure 12. Movie poster and adventure scene of Sanctum.

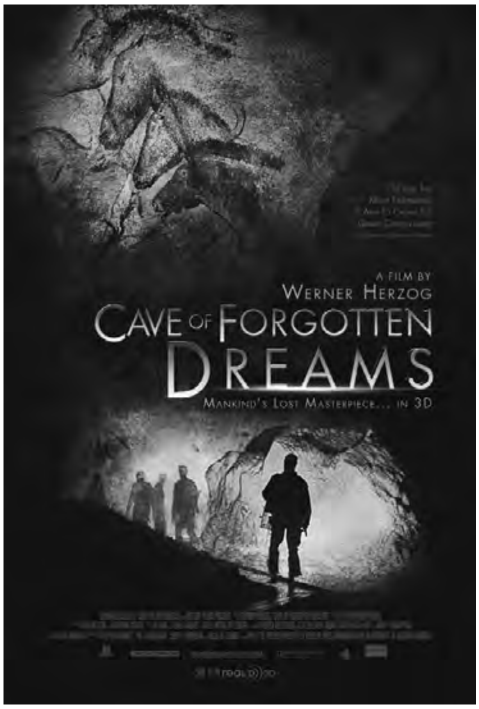

Figure 13. Movie poster of Cave of Forgotten Dreams.

4. Conclusions

It is observed at the end of this film analysis that there is a negative imaginary universe prowling the idea of cave and has been appropriated by film production, exploring and strengthening archetypes. In the selected works the cave always came accompanied by the excitement of the unknown and discovery, punctuated by adventure, the hideout, while feelings of fear appear more evident in Batman Begins, arising from the relationship of the protagonist with the bat, even as a determinant of the genesis of the hero, while in the cave appears as DPS nice place and the feeling of freedom, brotherhood, but also by the aura of doing something hidden.

Recent movies such as Sanctum and Cave of Forgotten Dreams have a more focused approach in speleological activities and in the cave as it really is. (Figs. 12 and 13). Despite not appearing monsters or excessive mysteries, still present a sense of adventure or a more poetic language, as highlighted by Herzog film.

The investigation is still in progress, due to its scope and research possibilities, with various developments, now reaching more than one hundred films registered. Moreover, it is expected that such studies favoring environmental education and training speleological most appropriate dissemination of environmental and cultural role of the caves, allowing activities protected speleological world.

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VENEZUELA'S GUACHARO CAVE: THE GUIDES' PERSPECTIVE

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Abstract. The Alexander Humboldt Natural Monument, better known as Guácharo Cave, is located in northern Monagas State, in eastern Venezuela. This is the most famous cavern in the country and also its third longest (10.2 km) (SVE 1968). It counts with approximately sixty thousand (60,000) visitors a year. The members of the Ramón Salazar Cooperative 928 rl, who have a contract with the National Institute of Parks, provide the guiding services to these visitors. The present work is the group's first initiative to capture, from the guides' own perspective, the impact that the cave has had on their lives.

Resumen. El Monumento Natural Alejandro de Humboldt, mejor conocido como La Cueva del Guácharo, se encuentra ubicado al norte del estado Monagas, en el oriente de Venezuela. La misma es la caverna más famosa del país y la tercera más larga (con 10.2 kilómetros) (SVE 1968). Recibe un aproximado de sesenta mil (60.000) visitantes al año, contando para la atención de dichos visitantes con un sistema de visitas guiadas las cuales son realizadas por autorización y tutela del Instituto Nacional de Parques por el grupo de guías agrupados bajo la figura jurídica de la Cooperativa Ramón Salazar 928 rl. El presente trabajo representa la primera iniciativa propia de miembros de dicha Cooperativa en relatar el impacto que la cueva ha tenido en sus vidas.

1. Introduction

Based on archaeological artifacts found and dated at the Alexander Humboldt Natural Monument, there is evidence that American indigenous peoples have visited Guácharo Cave since at least 3,500 years ago (Perera 1976). It was not until the XVII century that we have definite evidence that Spanish missionaries also visited the cavern, and eventually developed it as a site of guácharo or oilbird (*steatornis caripensis*) oil production (Urbani 1999). With this Guácharo Cave begins to gain its international fame, thus attracting both regional and foreign visitors. Among the most famous was Alexander Humboldt, who together with Aimée Bonpland, local missionaries and indigenous guides, entered 422 meters into the cave on the 18th of September 1799 (Urbani 1975). This, in very broad strokes, begins the tradition of guiding visitors to Guácharo Cave. While there have been some efforts to analyze and document the history of guides at the cave (Pérez and Galindo 2009), this is the first time that they do so in their own voice, and at their own initiative.

2. Guiding at the Cave

Historically, or at least since the XXth century, a trek within Guácharo Cave was an adventure. As visitors of yesteryear note, there was no stone path as there is today. "Uno salía bañao de charco" (One would come out bathed in mud), is one of the more common commentaries referring to the experience. More recently, the focus on the Guácharo Cave experience is more educational, while at the same time maintaining some of the traditions of interpreting the symbolism of the formations and their shadows, such as the Palm, Moses, the Nazarene, the Cow's Tongue, and the imposing Tower. There is special emphasis made on the photosensitivity of the nocturnal oilbird (for this reason there is no electric lighting in the cavern, the importance of the ecosystem, and specially on addressing the popular but erroneous myth that the cave reaches Brazil.

Figure 1. Tourists at the entrance of Guácharo Cave (Pérez 2008).

The service that the guides currently provide has many faults. However, it is virtually impossible to meet a visitor that does not enjoy the experience. It is very rare to get negative feedback from tourists. More likely is that visitors' expectations are dramatically exceeded, especially if those expectations were that the guides would only point out stone figures throughout the 1,200 meters of cave tour. Still, tour experiences do vary, depending on the group and the guide. They vary between an hour and a half to three hours in length, all of it marked with characteristic Venezuelan humor (particularly the eastern Venezuelan kind). It is worth noting that the round trip can easily be done in less than an hour because of the stone path.

The guides make up a diverse group with their personalities and aptitudes. Some have university degrees such as educators with Masters degrees. Others only count with a basic elementary school education. However, all of them have been marked by the experience of being guides of Guácharo Cave. To take on this responsibility, which involves dealing with such diverse public, one has to be dedicated with love to the job. Its biggest reward is to be part of a symbolic place of national and international importance.

Figure 2. Juan Antonio Tronchoni (member of the Speleology Section of the Venezuelan Society of Natural Sciences, later Venezuelan Speleological Society) with Ramón Salazar, mid 1960s. Salazar was known as the caretaker of the cave years prior to the formalization of the park rangers and guides at the site. He, among other local guides, offered key support to the speleologists from Caracas who finally explored, surveyed, and published the map of the cavern in 1968 (Pérez and Galindo 2009; SVE 1968). The Guides Cooperative is named in his honour (SVE Archives).

Being a guide at Guácharo Cave is an opportunity to learn and teach, things that happen daily, based on the anecdotes of the guides. It could not be any other way, considering that the guide that has been working in that capacity the least has been doing so for 15 years.

3. Conclusion

Recognition of the historical and cultural importance of Guácharo Cave would not be complete without accounting for the role of guides that have defined the experience of thousands of visitors. For the first time, and by their own initiative, these guides share what the experience means to them, in their own words. It is hoped that this effort will help produce a more complete and human history of this natural monument.

Figure 3. First author Galindo holding a fresh water crab in one hand and the guide's preferred mode of lighting (a Coleman lamp) in the other, during a trip into the non-touristic sector of the cave, November 2012 (Pérez 2012).

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GROUNDWATER PROTECTION AND MANAGEMENT IN A COVERED KARST WATER SYSTEM

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Southwestern China covers a karst area of 540,000 km^2, and supports a population of approximately 100 million people. This groundwater can easily regress or become highly polluted without effective management. Sound management of karst areas requires the conscientious participation of citizens including homeowners, planners, government officials, farmers and other land-use decision makers. A covered karst water system in Southwestern China was expatiated as a pilot study. Hydrogeology condition and geo-environmental problems were investigated in detail. An auto monitoring station for hydrology and water chemistry was built to detect the change of water resources. A series of educational materials were developed and delivered to the local government, residents, and students. An artificial tracer test and a groundwater polluted accident were tracked to increase understanding of the vulnerability of the area's karst aquifer. More than 200 people attended the communication and training course on groundwater protection and environmental justice law. By which, several efforts have appeared as a result, such as a proposal for Lingshui water resources protection that was put forward.

1. Introduction

China is currently undergoing rapid growth with economic development, especially in the west of China, which has changed greatly since the policy of Western Development in 1999. Rapid economic growth in southwestern China is also bringing fundamental changes to traditional land use and human activities. Some of the activities that have the greatest impact on the environment include intensified agriculture, mining, and infrastructure development (Yuan 2003). Coupled with a growing industrial base and urban expansion, these activities have caused varying degrees of contamination to the karst aquifers throughout the region (Guo et al. 2010).

Typical tools for managing groundwater in karst are (Kacaroglu 1999; Escolero et al. 2002): land use zonation; pollution risk assessment and management; groundwater monitoring; increased public awareness of the value and vulnerability of the aquifer. Due to the wide distribution of karst areas in Southwestern China and the limit of scientific and technologically-trained professionals, managing the area's resources without the support of local people is difficult. For example, karst groundwater pollution readily occurs because of a lack of implemented and enforced karst regulations and a lack of knowledge regarding the unique character of karst areas. Education is an important part of any natural resource protection plan because it can often be difficult for people to protect something they do not understand (Zokaites 2006). This is especially true for karst protection, because karst is an unfamiliar topic to most people. Students, citizens, farmers and agency personnel in karst areas need education to gain the necessary knowledge to help protect this valuable and unique resource.

This paper reviews actual and potential measures of karst groundwater protection and management in selected karst springs in Southwestern China. The paper does not present a comprehensive study of science in karst areas, but more a pilot study of how to manage karst groundwater resources in potential contamination. The purpose of this paper is to explain how important public education on karst is and how to apply the scientific study results to protect groundwater resources. More karst area should be tried to protect water resources through science and education in order to provide basic measures for future groundwater management.

2. Geography and hydrogeology

2.1. Study area

Lingshui Spring is located in Wuming County, Guangxi Zhuang Autonomous Region. Lingshui Spring, the former training base for the Chinese National Swimming Team, is a highly scenic spot that produces excellent drinking water for more than 100,000 people. With the establishment of the Nanning Association of Southeast Asian Nations economical garden, more than 200,000 consumers will rely on the spring by 2025. However, water quality was gradually deteriorated and water level declined following by the agricultural and industrial activities in the spring catchment increasing. For example, NO_3^- which is related to agriculture activities has increased over the past 30 years, while water consumption has also gradually increased, resulting in discharge that has decreased by nearly 50% compared to that in the dry seasons of 1977 and 1978. From summer in 2008, submerged plant-tape grass was found to be gradually degraded or die, which destroy the original sight and ecosystem. It is still the perennial problem of how it happens and how to control. The local government and residents are appropriately worried about these problems.

2.2. Climatic and Hydrogeologic setting

Wuming basin belongs to south subtropical monsoon climate region. Annual average precipitation is 1,247 mm. Precipitation rates show large long-term seasonality, with maximum values in May to August of 63% of the total rainfall in a year. November to March is dry seasons, with only 16.5% of total rainfall in a year. The average evaporation is 1,300 mm. The relative humidity is 78% in a year. The annual average temperature is about 21.9 °C. The temperature ranges from 13 to 35 °C. July and August is the hottest month with temperatures frequently exceeding 35 °C. Minimum temperature records in January with average of 13 °C.

The basin belongs to covered karst type. Varied kinds of stratum from Tertiary to Cambrian are outcrop, in which carbonate in carboniferous and Devonian extends large. Rainfall is the only supplement for groundwater. Karst depression, sinkhole and foot cave are absent in the basin, so dispersed recharge is the main pattern. Alluvial fan from mountains could probably be the zone of surface water recharging to ground water, but rarely concentrated recharge of river to groundwater happens in the basin. Wuming River is the drainage datum base of surface water and ground water. Karst groundwater discharges to rivers usually with short length and small drainage area. There are 19 springs or underground rivers in the basin, among which Lingshui Spring is the biggest one. Deposited of siliceous rock with a thickness of 20 m between Paleozoic and Mesozoic and mudstone in low Triassic can not be good aquitard due to small thickness. The boundary of spring is difficult to determine. But some geological structures are an advantage for karst water collecting and formation of karst conduit. Water depth in the middle of catchment is less than 10 m, while in the east and west-north can be ranged from 10 to 30 m.

3. Methods and Methodology

Hydrogeological and environmental geological survey at a scale of 1:50,000 was done from 2010 to 2012. The hydrogeology conditions and relative environmental geological problems were detected in detail by multi methods, including surface investigation, geophysical prospecting, hydrogeology drilling, and tracer test and so on. Water discharge in important springs and other types of water were measured in rainy and dried seasons in order to calculate water resources quantity and evaluate the change of water flow. Water was sampled in large range and in more frequency. Previous data of 1976, 1977, and 1978 were collected in order to compare the change of water resources. An auto-monitoring station of hydrology and hydrochemistry was built in the outlet of Lingshui Spring. pH, Spec, water temperature and water level was recorded by data-logger.

A training and communication course was held in Wuming County in order to show the latest research results to the local government and people, and give them some suggestions on how to protect and manage the karst water resources.

4. Results and discussion

4.1 Interpreting source of Lingshui spring by hydrogeological, chemical and isotopic methods

Hydrogeological and environmental geological survey at a scale of 1: 50,000 was done from 2010 to 2012. The hydrogeology condition and relative environmental geological problems were detected in detail. Surface investigation found out the status of karst development, water point outcrop and their basic information. Environmental geological problems, such as drought, water pollution and so on were also surveyed. Geophysical prospecting found out five relative large scaled low apparent resistivity anomaly zones, which indicate the location of water concentrated runoff zone. Hydrogeology drilling exposed the underground karst development. Tracer test determined the relationship of water interaction and water flow rate. In a word, hydrogeological background and relative socioeconomic and geo-environmental problems were clear by the survey. These were the premise of water protection and management in the basin.

In order to study the relationship between groundwater, rainwater and surface water in the basin, $\delta^{18}O$ and δH was analyzed in different seasons. The relationship between them is showed in Figure 1. Variation of $\delta^{18}O$ and δD value in the basin has a characteristic of seasonal change and elevation effect. The isotope analyses showed groundwater is all recharged by precipitation in the basin.

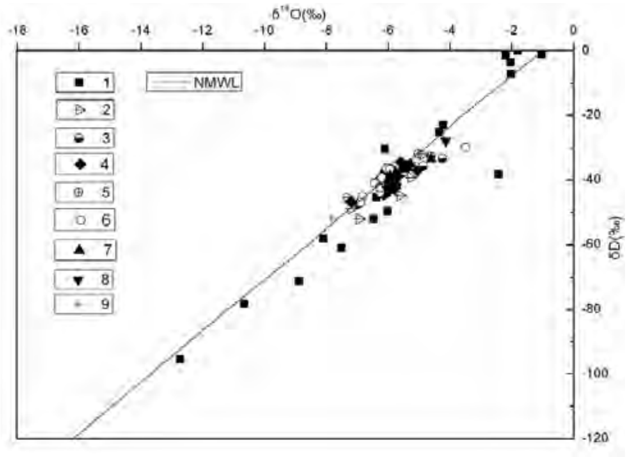

Figure 1. Relation of $\delta^{18}O$ and δH value in the basin.

1. rainfall; 2. river; 3. reservoir; 4. karst spring; 5. epikarst spring; 6. underground river, karst window, sinkhole; 7. well; 8. borehole; 9. spring in non-karst area

Change of water resources including water quantity and quality. Beside the biggest spring – Lingshui Spring in the basin as mentioned in the background, water discharge of 28 springs and underground rivers in the catchment were measured in order to compare the change of water flow with 1976. The results shows only two springs showing increased flow, 25 springs obviously decreased. The reduced percentage ranges from 3% to 97%. Only one spring has no change. Water resources assessment showed the total discharge has greatly decreased in the basin. The reasons for water discharge decrease were contributed to change of land use and land cover, different annual precipitation and much stronger groundwater exploitation.

Water samples were collected from 71 points including rivers, reservoirs, springs and wells in different seasons for water chemistry analysis. Variation of water chemistry in Lingshui Spring show NO_3^- content has gradually risen at 2001, with a value of 3.90 mg/l, and NO_2^- can be detected. From 2008, the average value of NO_3^- was 6 mg/l, indicating the water quality had a trend of deterioration.

36 water samples were evaluated according to method of ground water quality assessment. 28 water samples in 36 were in very good quality, accounting for 78 % of the total. 5 water samples were in good status, 1 in relative bad and 2 in very bad level. So in general, groundwater was in good quality in the basin. Individual water was contaminated by industry, such as starch factory, agriculture activity and domestic waste water or solid stuff.

According to multiple methods including GIS-based hydrochemistry and environmental isotope, tracer test, surface investigation and geophysical exploration, the total area of Lingshui catchment is draw out as about 697 km^2. Based on this, the protection area of Lingshui Spring was determined.

4.2. Tracer test to show vulnerability of karst aquifer

Groundwater tracers can include both artificially introduced and naturally occurring substances (Todd 2003). Groundwater tracing with artificial tracers involves adding a label to the groundwater that can be identified, if that same water is sampled at a different location. Natural tracing involves the use of naturally occurring components of a water sample to determine information about the source and age of the sample. The most commonly used natural tracers are isotopes and chemical compounds that originate in the atmosphere and become incorporated in the rainfall that recharges an aquifer (Field et al. 1995; Field and Nash 1997; Käss 1998).

2 kg of fluorescein sodium was injected to a sinkhole in north of Lingshui Spring with about 3km long distance. A flow-through field fluorometer was installed in the outlet of Lingshui Spring to receipt the tracer. The result showed that the average flow velocity was 17–23 m/d in dried season. And it also showed between the injection and reception, the possibility of karst main conduit existence was small. Water usually flowed in network dissolution fissures.

As it is mentioned below, during the training course, a fieldtrip was lead to a spring in Tang village to illustrate the vulnerability of the local karst aquifer, how the pollutants are transported in the extremely vulnerable karst areas, and the serious consequences of pollution. Villagers suddenly discovered that their household tap water was covered by a strong smelling layer of black oily substance someday. On the next day, the Tang village water plant stopped water supply, leaving more than 4,000 people without drinking water for over a month. After the accident, the county government set up a working group to identify causes for deteriorating water quality. The group found the pollution source was sewage effluent from a starch factory, which is about 2 km far away from the sinkhole. A sewage ditch of treatment plant from the factory was under construction. And when it came to the sinkhole, which is about 800 m far away from the spring, some sewage effluent leaked into the aquifer, resulting in water pollution. This contamination accident indicated pollution can be easily happen, especially when waste was improper disposed in the upstream, even people can not find connection directly between water points by naked eyes (Beddows 2003; Gondwe et al. 2010).

4.3. Public education

In order to deliver information about the importance of karst groundwater, how groundwater flows, and how to protect karst groundwater supplies through regulations, brochures that serve as calendars were developed and distributed to Wuming government officials, members of Wuming county political consultative conference, local citizens, students, and others. A training and communication course was held in Wuming County with the title of “Training and Communication on Understanding Groundwater, Protecting Groundwater in Wuming County”. In order to learn about U.S. experiences, two American scientists with research interests focusing on national and international informal environmental education efforts related to anthropogenic karst disturbance, and water resources were invited to attend and present. Two presentations were given during the workshop. More than 200 people attended this training and communication workshop, including the vice head of county, director from Wuming county government, all members from the Wuming county political consultative conference, the Bureau of Water Resource, the Bureau of Environmental Protection, the Bureau of Forestry, the Bureau of Land and Resources, Bureau of Housing and Urban-Rural Development, Bureau of Tourism, Wuming Water Company, representatives from local citizens, and graduate students from University.

5. Conclusion

Karst aquifers, where fractures or cavities permit rapid flow, tend to be more vulnerable than those where water flows slowly through porous rock. Karst aquifers usually have complex systems. Once polluted, they generally make cleanup difficult, expensive, and in some cases impossible. Groundwater movement and risk of pollution have known exactly based on detailed surveys and monitoring in some important springs or underground rivers in South of China. But sometimes they still can not escape from pollution when only depend on the scientists. An important spring in South of China was selected for pilot study on how to manage karst groundwater. Detail scientific research was done to find out the problems and countermeasures. Public education through training course and related material deliver for local government, residents, and students have been successfully conducted. According to this way local people know about knowledge of karst water, and now they are more caution before undertake activities which may threat water quality. Tracer test and groundwater pollution accident were exhibited by scientists in order to show the vulnerability of karst aquifers. These can be new methods for karst groundwater management and should be spread. More measures should be tried to convey to local people after science study in order to protect karst groundwater self-conscious.

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ICAVERNS: PROMOTING CAVE AND KARST UNDERSTANDING AND STEWARDSHIP VIA SMART DEVICE APPLICATIONS

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Karst landscapes form when acidic groundwater dissolves carbonate rocks that are at or near the earth's surface. Karst landscape features develop both on and below the surface and are often described as looking "otherworldly" as well as "breathtaking". Karst landscapes make up an estimated 12 percent of the earth's surface with 20–25 percent of the global populace depending on karst groundwater resources. Yet few understand the importance or fragility of these resources. Karst environments and associated resources are fragile. Human interactions in karst areas make these resources highly susceptible to damage and environmental degradation.

Worldwide, there are hundreds of parks or park-like attractions focusing on cave, spring, or sinkhole resources. Visitors to cave and karst attractions have a built-in curiosity about these places. Engaging this audience in cave and karst interpretive programming could greatly increase their knowledge of these systems. Paradoxically, the same attractions can also be responsible for promulgating cave and karst misconceptions. However, digital media can be very effective tools for increasing awareness and stewardship of cave and karst resources, especially when the media is developed for coviewing or joint media engagement.

Smart device applications present several advantages over traditional interpretation media including, engaging audiences outside of the attraction's boundaries, and presenting interpretational messages to visitors in their native language, maintaining content integrity. However, video and photography methods in cave environments present many challenges. Filming crews and gear requirements can cause irreparable damage to caves. This paper discusses the development of the iCaverns application, which was developed utilizing new green filming techniques as an educational and travel guide for Carlsbad Caverns National Park.

The iCaverns application makes cave resources at Carlsbad Caverns National Park available, via 5 hours of video and more than 2,000 photographs, to more than 400 million people, in 155 countries. As well as providing users to engage in cave and karst educational and interpretive media in 38 languages.

1. Introduction

Karst landscapes are prevalent over most of the Earth's surface. Worldwide millions of people depend on karst aquifers for drinking water. In many situations, the people living on karst have never heard the word, or do not understand how karst works.

Figure 1. Rattlesnake Spring supplies potable water to Carlsbad Caverns National Park.

A lack of understanding of karst can increase the negative impacts on karst environments and its inhabitants. In fact sound management of kart areas require input and cooperation from land managers, planers, government officials, farmers, and local citizens (Guo 2011). Examples illustrating karst environmental concerns, issues, and impacts are broadly documented within the body of cave and karst science literature.

Furthermore, the notions of the general public's lack of knowledge and the need to decrease this gap are widely accepted throughout the cave and karst community. Land managers acknowledge the important role education plays as a part of any natural resource protection plan, because of the difficulty people have in protecting something they do not understand (Guo 2011). Yet, there are very few examples in the literature identifying the general state of cave and karst education, common misconceptions in cave and karst related topics, or effective instructional delivery methodologies. However, an extensive body of knowledge exists within the realm of environmental education and interpretation.

Utilizing effective interpretive methodologies, the iCaverns application (app) was developed as an educational travel guide for the cave and karst resources at Carlsbad Caverns National Park and World Heritage Site. The main educational goal for iCaverns is to inform users about the speleogenesis, unique environments, and impacts man has had on the cave and karst resources of Carlsbad Caverns National Park. The app gives access to these resources through photographic images. App users learn about the resources through interpretive tours led by a geologist. Users can also increase their knowledge through the educational portion of the app.

2. Cave and Karst Education Trends

Karst landscapes often have an exotic but beautiful appearance and thus, cave and karst features have become the feature attraction at many park-like locations around the globe. These park-like attractions draw in millions of visitors each year.

Figure 2. Underground landscape along the Lower Cave trail in Carlsbad Cavern.

The assumption is made that visitors to cave or karst-focused attractions have an interest in the resource. This built in interest primes the audience, making them more open and eager to learn about cave and karst resources. Therefore, cave and karst focused attractions are excellent venues to deliver cave and karst interpretation and education (North 2011).

Indeed many of the cave or karst focused attractions have interpretive programs. Unfortunately, some of these programs have been responsible for passing forward miss-information about cave or karst resources (Kastning and Kastning 1999; North 2011).

This same paradox exists when developing digital interpretive media. People purchasing cave or karst-centered media have an assumed interest in the subject. Because media products typically have a long shelf life, it is increasingly important to ensure the content be correct or in agreement with accepted scientific theories. Developing cave or karst focused for joint media engagement, like smart device apps would provide an effective interpretive experience for the whole family (Takeuchi and Stevens 2011).

There are several advantages smart device apps have in comparison to traditional interpretation. Smart device apps engage the younger "plugged-in" generation as well as older generations. Apps bridge the generation gap, because they give generations the opportunity to experience them together. Apps put the resource in the pockets and hands of those interested in it, whereas traditional interpretation requires an onsite visit. Lastly, app developers have a higher level of control over the content. Both developers and end-users easily update apps, which makes content maintenance somewhat effortless and seamless.

3. Conceptual Phase

The iCaverns project was born from the developer, Michael Hernandez, conceiving the notion to put Carlsbad Cavern into people's hand. The major conceptual theme for iCaverns is developing a comprehensive guide of Carlsbad Caverns National Park, which will entertain, and educate visitors. This app is intended to enhance visitor experience and provide virtual experiences for people that do not have the ability or means to visit the park.

Users will have multiple choices available to move through the app. There is information provided about the town of Carlsbad, New Mexico as well as general information about Carlsbad Cavern National Park, an educational area, various animations, and nine virtual "ranger" guided tours.

iCaverns is targeted for Apple's smart device market, which reaches more than 450 million people in 155 countries (Monaghan 2012) / 38 Languages. The app will also be developed for Android devices; however, the two users vary greatly in expectations.

The major themes driving the design and development for the iCaverns app are high quality, authentic, and engaging. All pieces for this application have been developed applying these qualities.

4. Development Phase

Quality, authentic, and engaging are the driving principles for each portion of the app's development.

4.1. User Interface

Hernandez developed the user interface focusing on the main principals of quality, elegance, and simplicity.

The resulting interface is engaging, beautiful, and yet simple to navigate. This was accomplished by keeping the interface design, uncluttered.

The users can navigate away from the main screen by dialing up the portion of the app they would like to visit. Each sub-interface also carries the simple and uncluttered look. The interface for the cave tours is a replica of cave maps, so users will know where they are in relation to the item being discussed.

4.2. Animations

There are multiple animations on the iCaverns app, including one for modeling speleothem development and another modeling a Mexican Free-tailed bat in flight.

Figure 3. Screenshot of Mexican Free-tailed bat animation.

The animations were developed using Pixar Studios. While the methods are proprietary, one of the designs did include input from bat specialists, as well as the use of video and photographs to build the bat within the app with a high level of authenticity and quality. Users can view every angle of the bat and observe muscle movement during flight.

4.3. Video Guided Tours

The "guided" tours section of the iCaverns app is patterned after the tours offered at Carlsbad Caverns National Park. Dianne Joop a cave education and interpretation specialist and Mark Joop, a geologist and cave interpretation specialist, co-developed each of the nine tours around a central theme. With nearly five hours of video, the virtual ranger, Mark Joop, guides users through topics including, the geologic setting, speleogenesis, cave biota, historic uses, human impacts, and various historical figures of the park.

Figure 4. Photo example for iCaverns photography tour of Spider Cave.

Capturing high quality video in low-light situations is challenging, yet does not compare to capturing video in no-light settings. The iCaverns' Director, Dianne Joop developed a green filmmaking technique for capturing video and stills underground with a minimal equipment and crew.

The iCaverns' photographer, Dianne Joop, worked within the boundaries of two photographic concepts, one taking photographs to support the video component and two capturing photographs to convey a story. Joop composed her shots to give users a sense of being in the caverns, traveling through passages, and making the discovery of the beauty that waits around the corner. Joop previewed photographs to small audiences to test the notion of people having the sense of being "there". In all instances audience members affirmed this feeling.

Lastly, both visual elements are implemented to allow for immediate updates, accommodating for new discoveries.

5. Summary

The iCaverns App is schedule to hit the market in March 2013. It is the most comprehensive travel guide/educational app currently available. The app will make cave resources at Carlsbad Caverns National Park available to more than 400 million people, in 155 countries. As well as providing users to engage in cave and karst educational and interpretive media in 38 languages.

Acknowledgments

We would like to express, the success in producing this project was greatly enhanced by the unwavering support of Carlsbad Caverns National Park; Chief of Interpretation and Education, Marie Marek, Fee Program Manager, Paul Cox, and Supervisory Park Ranger, Pam Cox. As well we would like to thank Rolf Siegenthaler for his generous equipment donation.

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PETITION FOR PROTECTION OF CAVE CONTENTS

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In 2010 a petition for a better protection of cave contents was addressed to the European Union by several speleological federations. The petition was supported by major nature protection NGOs and handed over to the EU Commissioner of Environment. Its aim was to stop the trade, import and export of cave contents. The European Union did not implement these demands but referred it to national legislation.

1. Introduction

Due to growing tourism in the wild caves of Europe, the need for cave protection is constantly growing. One of the problems arising following touristic impacts is the damage and loss of cave contents. Therefore, in 2008 a written declaration on the protection of caves as a cultural, natural and environmental heritage lapsed in the European Parliament.

To bring cave protection again into better effect, a petition to stop the trade of speleothems was born in 2010.

Verband der deutschen Höhlen- und Karstforscher e.V. (VdHK, German Speleological Federation) had the chance to accompany a group of German NGOs in a meeting with EU Commissioner of Environment Janez Potočnik. European Speleological Federation FSE supported the petition and emailed the first draft to its members. After an intensive discussion, the following petition was passed.

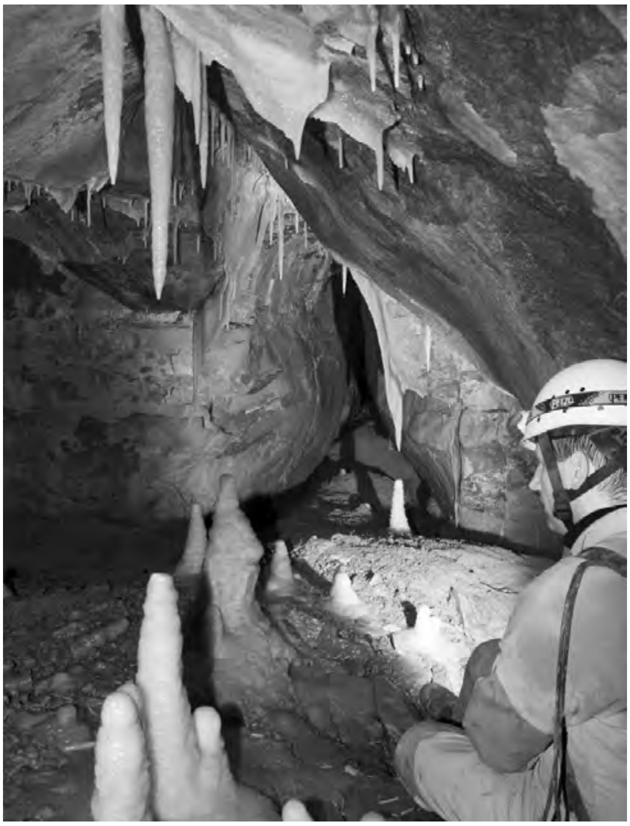

Figure 1. Speleothems in the Riesenberghöhle, Lower Saxony, Germany. Photo Stefan Meyer.

2. Petition Text

Petition to Stop Trade, Import and Export of Cave Contents

Regarding Article 3 (b) and (l) of the Treaty establishing the European Community and the UNESCO Convention (concerning the Protection of the World Cultural and Natural Heritage), we, the signatory organisations, petition to stop the trade, import and export of cave contents.

Analogous to the Convention on International Trade of Endangered Species of Wild Fauna and Flora, there is an urgent need for a convention on the nonliving heritage of the world. This includes, among others, cave contents.

Caves and karst areas are often transboundary regions, but the legal framework dealing with caves and cave protection varies greatly within the EU member states. The EU Habitats Directive mentions only bats but no other cave fauna. The EU Groundwater Directive does not take karst phenomena like high flow rates and low filtration capacity into account. With the ongoing climatic change and the expected water shortage in certain regions the importance of karst aquifers will increase even more. Up to now, there is still a profound lack of concern and protection for caves and karst in the European Community.

Caves belong to the most fragile ecosystems in the world. They are also archives of geological history, evolution, climate and culture. To be meaningful, the protection of caves has to include the protection of cave contents – otherwise it would only be the protection of the cover of a book without its pages.

Cave contents include speleothems, sediments, fossils and archaeological findings. Speleothems are defined as any natural mineral formation or deposit occurring in natural caves, including but not limited to stalactites, stalagmites, helictites, gypsum flowers, flowstones, crystals, draperies or rimstones.

Caves from which speleothems have been removed lose in value and beauty. This is seen in many showcaves and reduces the value of tourist regions of member states. Extracting and trading the unique formations of caves causes not only the loss of aesthetic and emotional value, but invaluable scientific information like palaeoclimatic data is lost as well.

Fossils and subfossils are often found in caves and their uncontrolled removal is not only a loss to scientific research but can also lead to significant damages of the cave and its content.

Generally, all member states have laws dealing with archaeological discoveries. However, archaeological sites inside caves are usually not readily visible. Experts are needed to detect and evaluate sites prior to their uncovering. Even minimal changes in sensitive sections of a cave can lead to the total destruction of unique archaeological sites.

Removal of speleothems, fossils, sediments and archaeological findings for scientific investigations must always be reduced to a minimum, in order to avoid an excessive depletion of the natural cave features. Decisions require careful considerations by specialist researchers and advice from experienced cave and karst experts. If research on a speleothem or fossil will likely result in the destruction of a sampling site, then the choice should be to abstain from the study.

To ensure the protection of cave contents, the following demands have to be implemented:

a) Speleothems or fragments of these (even if already broken), fossils, sediments or archaeological findings must not be extracted from caves, except for cases mentioned under c).

b) Trade, import and export of cave content has to be prohibited.

c) Scientific sampling has to be restricted to the absolutely necessary minimum. Scientific benefits have to be maximized through consultation with cave experts.

Figure 2. Human fossil bones, Bronze Age, Lichtensteinhöhle (Rotkamphöhle), Lower Saxony, Germany. Photo Landkreis Osterode am Harz.

3. Support

Every speleological federation of Europe was asked to be involved. Many cavers contributed and the final version was signed by 25 national and 6 international organisations.

Furthermore letters of support arrived from Paolo Forti, Full Professor of Geomorphology at the University of Bologna, Director of the Italian Institute of Speleology and Past President of the International Union of Speleology, and Dr. Jean Clottes Foix, President of the International Federation of Rock Art Organisations (IFRAO).

International speleological organisations signed the declaration: the Commission on Cave Protection and the Commission on Volcanic Caves of the International Union of Speleology (UIS) and the International Show Caves Association (ISCA). The International Symposium on Subterranean Biology has boosted the petition, 54 participants from all over the world signed it.

4. Outcome

As Slovenian EU Commissioner Janez Potocnik was already aware about cave protection we had a good start. But other topics like the Soil Directive were discussed at that time and minimised our political impact. We gained support also from the International Union for Conservation of Nature and inside the European Commission. Although the petition was rejected, it was important to launch the campaign and the resulting discussions were fruitful.

5. Perspective

In the United States of America the trade of speleothems is forbidden since 1988. Speleology should pay attention to current EU politics and intervene for cave topics. The Flora-Fauna-Habitats (FFH) directive/Natura 2000 as well as the Water Framework Directive are partly dealing with caves and karst. Therefore, also the EU Working Group C Groundwater could be used as a chance to set up cave protection in the process of legislation.

Acknowledgments

Many people helped a lot to set up the petition – we thank every caver who had remarks on the text and helped us. Special thanks go to Stefan Näff, Basel, for the website work; Ioana Meleg, European Cave Protection Commission of the FSE, for support; Olivier Vidal, General Secretary FSE, Jean-Pierre Bartholeyns, UIS Adjunct Secretary, President of Karst and Cave Protection Department, and Deutscher Naturschutzring DNR for giving us the chance of the meeting in Brussels.

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CAVE AND KARST RESOURCES AND MANAGEMENT IN THE UNITED STATES FOREST SERVICE

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The United States Department of Agriculture Forest Service (Forest Service) manages caves, karst systems, and associated resources on over 780,000 square kilometres of public land. The management of these resources is mandated by the Federal Cave Resources Protection Act (FCRPA) of 1988 and other federal acts, and is guided by the Code of Federal Regulations (CFR) as well as the Forest Service Manual (FSM). The FCRPA provides for the designation and protection of caves as significant per definition in the statute. Under this United States law, land management agencies designate caves as significant based on biology, cultural resources, geologic/ mineralogic/paleontologic resources, recreational value, or educational or scientific value, or location in a specially designated area. The FCRPA and its implementing regulations at 36 CFR Part 290 – Cave Resources Management provide the framework for management guidance in the FSM. Known caves and karst areas occur in over 100 National Forests and Grasslands, and over 2,200 significant caves have been identified to date, often with the assistance of partners such as the National Speleological Society and Cave Research Foundation.

The goal of the Forest Service National Cave and Karst Program is to protect and maintain the biological, geologic/mineralogical/paleontological, hydrological, cultural, educational, scientific and recreational values of caves and karst resources. Management actions such as timber harvest, mining, grazing, herbicide application, and development of infrastructure and recreation sites on National Forest System lands can impact cave and karst resources. Additionally, such actions in karst areas may exacerbate hazardous conditions related to karst. As per the National Environmental Policy Act of 1972, Environmental Assessments and Environmental Impact Statements may require a section on geology and specifically on cave and karst systems where these resources occur in project areas. Additionally, the Forest Service Office of International Programs provides assistance to land managers abroad in areas of cave and karst management. This paper will outline the current status of cave and karst management in the Forest Service through an overview of cave and karst resources on National Forest System lands and highlight current management issues on individual national forests and regions.

1. Introduction

The United States Department of Agriculture Forest Service (Forest Service) manages a wide variety of natural resources, including caves and karst, across 780,000 square kilometers of land in the 48 contiguous United States (U.S.), Alaska, and Puerto Rico. The Forest Service has a unique and separate mission from other U.S. land management agencies, one of multiple uses and conservation as opposed to preservation, and allows for activities such as timber harvest, mining, grazing, and recreation with the proper environmental considerations. When considering a management activity on National Forest System (NFS) lands, the agency must take into account the needs of many user groups, as well as the best available science in terms of environmental conservation. In cases of proposed environmental disturbance, this is accomplished through evaluation of projects and management strategies through the National Environmental Policy Act (NEPA) process.

The Federal Cave Resources Protection Act (FCRPA) of 1988 defines caves and mandates protection of caves designated as significant. The Code of Federal Regulations (CFR) guides management of caves on federal lands. The Forest Service Manual (FSM) guides cave management in sections relating to recreation, geology, and prohibitions. In addition, cave and karst resources are also protected through approximately 40 additional federal acts addressing items such as watershed, groundwater, and threatened and endangered species protection.

In order to base management decisions on sufficient data, inventory of cave and karst resources is conducted by Forest Service field personnel and qualified volunteers through partnerships and memorandums of understanding (MOUs) with the National Speleological Society (NSS) and associated groups, Cave Research Foundation (CRF), and Geological Society of America (GSA). Areas with potential for cave and karst development are identified through field geologic mapping as well as work with remote sensing datasets. Once located in the field, caves are mapped and inventoried, and significant cave nomination forms are populated and approved by the proper authority. Data storage of cave and karst resources is highly sensitive, and significant cave locations are not subject to requests filed under the U.S. Freedom of Information Act (FOIA) by the public, similar to federal archeological or “heritage” resources. These data are then utilized during the NEPA process to ensure consideration of land management action on cave and karst resources. Currently, cave and karst resource protection is carried out on a forest by forest and project by project basis depending on the type of project and the standards and guidelines incorporated into each forest plan. Future plans include standardization of cave and karst inventory and mapping, development of best practices and technical guides, unified national data storage, and increased cooperation with stakeholders. Finally, the Forest Service Office of International Programs offers assistance with cave and karst management in protected areas in other countries.

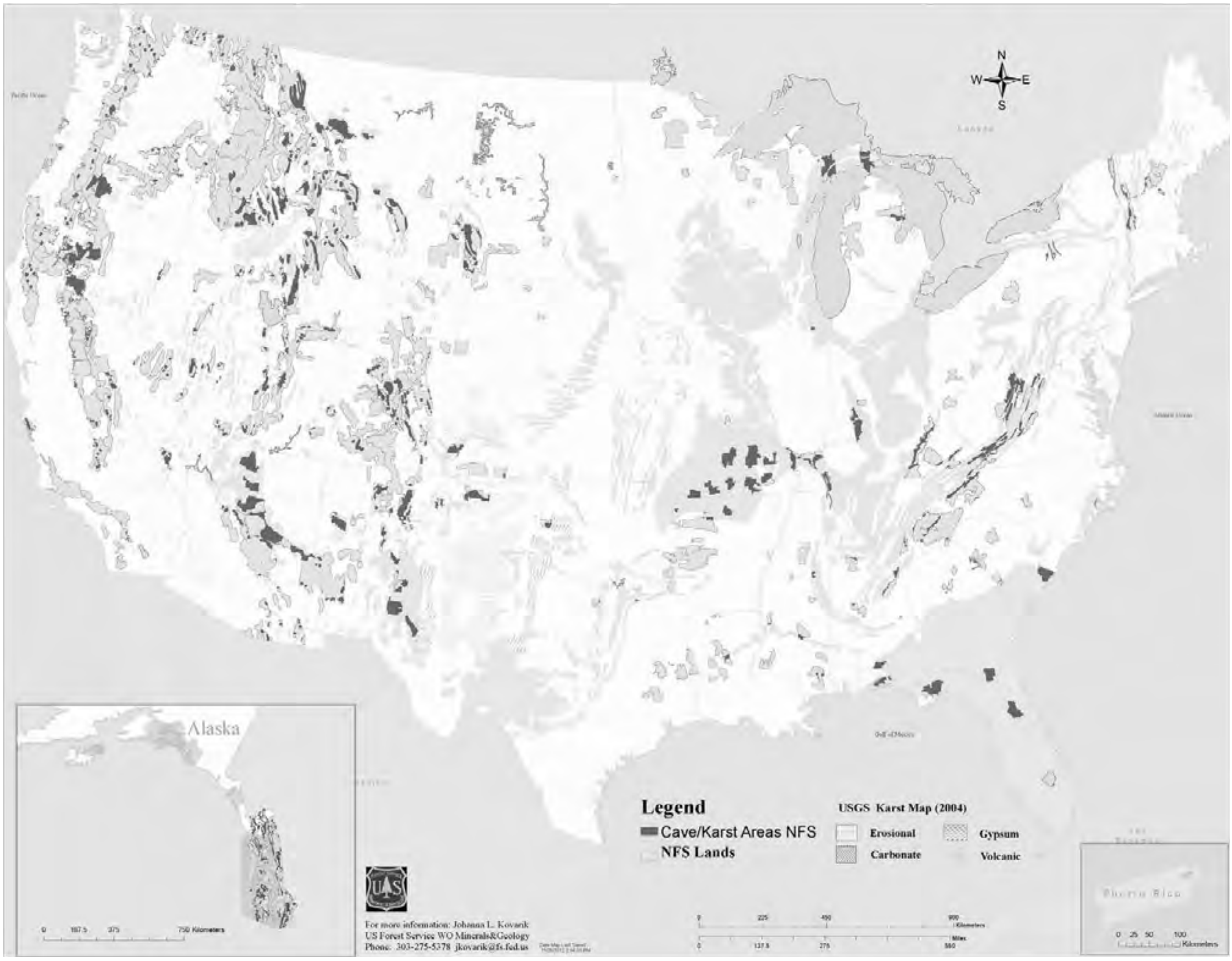

Figure 1. Forest Service caves and karst in the U.S.

2. Cave and Karst Resources in the Forest Service

NFS lands encompass a broad diversity of cave and karst resources across the 513,000 square kilometres (198,000 square miles) of potential cave and karst forming geologic units in the U.S. (Figure 1). Karst is formed by the dissolution of soluble carbonate bedrock such as limestone, dolostone, and marble. Caves are often classified by the parent material or speleogenic process, and are not only or always formed as a portion of the karst system. All types of caves such as volcanic, glacier, stream-cut, wave-cut, shelter, crevice, and framework, as well as solution, occur on NFS lands. Figure 1 reflects the different units and areas in which they may occur.

The Forest Service is organized into nine regions, and within each region are individual forests and grasslands. In the eastern U.S., solution caves and karst systems occur in carbonate rock from Green Mountain and Finger Lakes National Forests in the northeastern states down the Appalachian chain through the Monongahela National Forest to the relatively young limestone in the Ocala National Forest in Florida. The longest underwater cave system, and thirteenth longest cave overall in the U.S. is hydrologically connected to springs on the Apalachicola National Forest. The Mark Twain National Forest in Missouri is underlain almost entirely by carbonate rock and includes approximately 600 caves. In the western U.S., a broad diversity of cave resources include sea and glacier caves on the Tongass and Chugach National Forests in Alaska; ice caves on the Mt. Baker-Snoqualmie National Forest, Washington; lava tubes on Deschutes and Umpqua National Forests; and hypogene solution caves on the Lincoln National Forest in New Mexico as several examples. As the Forest Service is working to inventory and document historic and current cave data, it is anticipated that the list of significant caves and resources within their passages will grow exponentially. This section highlights a selection of the caves and cave resources currently known on NFS lands.

2.1. Long and deep caves

In the Southern Region, Omega Cave is currently the longest mapped cave known on NFS lands, the longest mapped cave in the state of Virginia, and the sixteenth longest cave in the U.S. at 47.07 kilometres (29.25 miles) (Gulden 2012). It is the tenth deepest cave in the U.S. with a vertical extent of 379 meters (1,243 feet), and the sixty-sixth longest cave in the world (Gulden 2012). Exploration began in 1996 and 1997 in a non-Forest Service entrance called Blowing Hole and a Forest Service entrance called "Lori Cori Canyon Cave". In November of 1998, exploration continued with the connection of these two entrances and pushing of further leads. This cave is located on the Washington and Jefferson National Forests in

Virginia. In the Eastern Region, Sloan's Valley Cave is currently the twentieth longest cave in the U.S. at 36.3 kilometres (22.56 miles) of passage (Gulden 2012). Many of the entrances are privately owned, however one entrance is on NFS land, and a portion of this total length underlies the Daniel Boone National Forest.

In the Northern Region, Virgil the Turtle's Great House Cave is located in the Bob Marshall Wilderness on the Flathead National Forest in Montana, and is the fifth deepest cave in the U.S. at 423 meters (1,586 feet) (Gulden 2012). Also in this area on NFS land is Tickle Me Turtle Cave, which is the twenty-first deepest cave in the U.S., at 271 meters (890 feet) (Gulden 2012). In the Rocky Mountain Region, Columbine Crawl is the sixth deepest cave in the U.S. at 472.7 meters (1,551 feet) deep and 3,703 meters (2.3 miles) long (Gulden 2012). It is located in the Teton National Forest in Wyoming. The Uinta-Wasatch-Cache National Forests in the Intermountain Region contain well-developed alpine karst areas which include Main Drain Cave, as well as Neff's Canyon Cave. Main Drain and Neff's Canyon are also on the deep caves list in the U.S., with Main Drain ranking eleventh at 374 meters (1,227 feet) and Neff's ranking thirteenth at 354.5 meters (1,163 feet) (Gulden 2012). An additional cave on NFS lands in this area is Nielsen's Well, the twenty-second deepest cave in the U.S. at 268 meters (880 feet) (Gulden 2012). Down in the Southwestern Region, Three Fingers and Virgin Caves are on-going cave survey projects on the Lincoln National Forest in New Mexico. Virgin Cave is the thirty-sixth deepest cave in the U.S., and Three Fingers is the sixty-third deepest cave in the U.S (Gulden 2012). Both of these hypogene caves were discovered in the 1960s and 70s, and are currently undergoing remapping projects.

In Pacific Northwest Region, Deadhorse Cave and Ape Cave, the two longest mapped lava tubes in North America are located on the Mt. St. Helens National Volcanic Monument in Washington State (Gulden 2012). Puffin Grotto is the ninth longest sea cave in the world at 287 meters (942 feet) in length, and is located in the Alaska Region on the Tongass National Forest (Gulden 2012). It is thought to have formed through mechanical wave action as well as dissolution of the Silurian-aged marble, and is uplifted to approximately 15 meters (50 feet) above current sea level.

2.2. Biology

Forest Service caves in the eastern and western U.S. provide habitat for a wide range of life from all three domains: bacteria, archaea, and eucaryota. This ranges from several species of troglophiles (eutroglophile), trogloxenes (subtroglophile), troglobites (troglobiont), and stygobites such as bats, salamanders, spiders, crayfish, and loaches to biofilms commonly described as speleothems such as moonmilk. Additionally, cave and karst systems on NFS lands play a critical role in the overall biological productivity of an area, including the geochemistry of waters emanating from karst systems impacting the productivity of fish; and the development of karst features impacting vegetation productivity on the surface (Aley et al. 1993, Harding and Ford 1993, Bryant and Swanston 1998).

Researchers have documented microbial communities in caves on NFS lands as part of a growing discovery of the role of bacteria and archaea in speleogenesis and speleothem formation. University researchers found microbial activity integral in pool finger precipitation in Hidden Cave, Lincoln National Forest, New Mexico as well as in development of subaqueous moonmilk in the form of "cottonballs" on the Tongass National Forest, Alaska (Curry et al. 2009, Melim et al. 2010).

Federally endangered bat species found utilizing Forest Service caves include the Gray bat (*Myotis grisescens*), Indiana Bat (*Myotis sodalis*), the Ozark big-eared bat (*Corynorhinus townsendii ingens*) and the Virgninia big-eared bat (*Corynorhinus townsendii virginianus*). Additional bat species found in Forest Service caves such as the Little brown bat (*Myotis lucifugus*), the Big brown bat (*Eptesicus fuscus*), and the Tricolored bat (*Perimyotis subflavus*) are not currently listed as threatened or endangered, but Forest Service caves provide important habitat as the population numbers of these bats are dropping due to White-nose Syndrome (WNS).

The largest diversity and richness of troglobitic and stygobitic species is currently documented primarily in the eastern U.S., which is covered by the Eastern and Southern Regions (Culver et al. 2001). In the Southern Region, Blanchard Springs Caverns on the Ozark-St. Francis NF is second only to Tumbling Creek Cave in Missouri for the Ozark Plateaus ecoregion in biological richness in Arkansas with 96 total and 9 obligate species (Graening et al. 2003).

In the Eastern Region, the Monongahela, Hoosier, Shawnee, and Mark Twain National Forests have designated many vertebrate and invertebrate cave species as Regional Forester Sensitive Species, such as the Marengo Cave ground beetle (*Pseudanophthalmus stricticollis*), the Carter Cave spider (*Nesticus carteri*), Eastern cave-loving funnel web spider (*Calymmaria cavicola*), Fountain cave springtail (*Pseudosinella fonsa*), and Dry Fork Valley cave pseudoscorpion (*Apochthonius pauscisinosus*). Many of these species are found only in a handful of caves in the eastern U.S., and some of these species are rare and ound only in a single particular cave on NFS land.

2.3. Paleontology

The Forest Service is working to collate information from the wide variety of paleontological studies conducted in caves on NFS lands. Researchers have conducted a great amount of work which is well documented in Forest Service caves across the western half of the country, from Alaska to California, through Nevada and into South Dakota.

Samwel Cave and Potter Creek Cave on the Shasta-Trinity National Forest in the Pacific Southwest Region are significant fossil repositories, with 52 species excavated in Potter Creek Cave, and 21 of those species extinct (Merriam 1906). These 52 species include the, "short-faced bear (*Arctotherium simum*), shrub ox (*Euceratherium collinum*), hores (*Equus*), mammoth, bison, and camelid" (Payen and Taylor 1976). Faunal deposits in Samwel Cave included 45 mammal species, a portion of which were a large variety of rodents, which were utilized in a recent study assessing the impact of global warming on mammal populations (Faranec et al. 2007, Blois et al. 2010).

In the Alaska Region, the Tongass National Forest's caves are repositories for a large quantity of paleontological resources. Work in eighteen caves in this region by Heaton (2002) documented species of mammals not previously found in southeast Alaska, such as red fox (*Vulpes vulpes*) and wolverine (*Gulo gulo*). Additionally Heaton found a 10,750 year old black bear skeleton (*Ursus americanus*) and 12,295 year old brown bear (*Ursus arctos*) bones on Prince of Wales Island where currently only black bears are found (Heaton 2002).

2.4. Archeology

Archeologists have conducted research in Forest Service caves for years, often with the initial discovery of artifacts occurring when volunteers from the NSS or CRF locate artifacts during cave surveys, such as the case of the 8,000-year-old man from Hourglass Cave in region two (Mosch and Watson 1997). Archeologists unearthed one of the most significant discoveries for Forest Service cave archaeology in On Your Knees Cave on Prince of Wales Island in southeast Alaska after discovery and survey of the cave by the Tongass Cave Project of the NSS. In 1992, the 10,300 year-old remains of young man called Shuká Kaa ("Man Ahead of Us" in the native Tlingit language) were excavated and studied along with paleontological artifacts in a ground-breaking cooperative effort with the native Alaskan groups in southeast Alaska as well as with several universities (Fifield 2008). Results from genetic studies on the individual's remains contained significant implications regarding the settlement of the North American continent (Kemp et al. 2007). This discovery and the studies based upon the artifacts excavated from On Your Knees Cave were given wide press attention, including articles in National Geographic Magazine and Smithsonian.

On the Ozark St Francis National Forests, 64 caves and 55 rock shelters were inventoried as prehistoric sites (Jurney and McCluskey 2012). Rock art panels were discovered in Gustafson/Wingard Cave, and are the, "only known Native American art work in cave dark zones in Arkansas" (Jurney 2009). The rock art panels included the only depiction of a bison currently known about in the state of Arkansas, as well as a centipede which is not common in the eastern U.S. (Jurney 2009). Archeologists also found artifacts in Gustafson/ Wingard Cave including Mississippian pottery shards and archaic dart points. In 1955, cavers discovered human remains in Blanchard Springs Caverns and later discoveries included torch remnants and other items which suggested that human use of the cave spanned 760 years, A.D. 225–985 (Wolfman 1974).

3. Policy

3.1. Federal Acts

There are approximately 40 federal laws directly and indirectly impacting the many facets of cave and karst resource management, including the FCRPA, NEPA, the Organic Administration Act, Endangered Species Act (ESA), Paleontological Resources Preservation Act (PRPA), Archeological Resources Preservation Act (ARPA), and the Watershed Protection and Flood Prevention Act (WPFPA). These laws relate directly to the management planning and responsibilities of geology, archaeology, wildlife biology, and recreation in cave and karst resource management.

3.1.1. Federal Cave Resources Protection Act

In 1988 the FCRPA was established in order to,

> "…secure, protect, and preserve significant caves on Federal lands for the perpetual use, enjoyment, and benefit of all people; and to foster increased cooperation and exchange of information between governmental authorities and those who utlize caves located on Federal lands for scientific, education, or recreational purposes."

In the FCRPA caves are defined as,

> "Any naturally occurring void, cavity, recess, or system of interconnected passages which occurs beneath the surface of the earth or within a cliff or ledge…and which is large enough to permit an individual to enter, whether or not the entrance is naturally formed or manmade." (1988).

The FCRPA defined seven criteria by which caves could be designated as significant, including biology, cultural resources, geologic/mineralogic/paleontologic resources, recreational value, or educational or scientific value, or location in a specially designated area. The federal agencies were tasked with designating significant caves based on the seven criteria immediately following the establishment of the FCRPA, and given three years to complete this initial designation working with cave and karst stakeholders. This Act also mandated that locations of significant caves are not available to the public through Freedom of Information Act requests unless a specific request is made via one of the federal agencies or an educational or research institution. A list of prohibited acts relating to federal caves, as well as punishment for violating those prohibitions, is included. Prohibited acts include destruction, disturbance, alteration, removal, or sale of federal caves and associated resources. Today, any federal agency employee or member of the public may nominate a significant cave for designation based on this Act, and periodic updating of the significant caves list and protection of caves while under consideration is mandated.

3.2. Code of Federal Regulations

In the Code of Federal Regulation (CFR) Title 36 – Parks, Forests, and Public Property, there are several sections which relate directly to Forest Service-specific cave resource management. CFR Part 290, Cave Resources Management, contains explicit direction for the Forest Service on cave resources including definitions, the nomination, evaluation, and designation of significant caves, confidentiality of cave information, and collection of information related to caves.

CFR Part 261, Prohibitions, contains prohibitions against such things as occupying, having domestic animals, lighting fires, and discharging firearms underground.

3.3 Forest Service Manual

The Forest Service Manual (FSM) contains program level guidance for cave and cave ecosystem management, and assigns roles for leadership and coordination. The sections relevant to cave and karst resources are chapters 2356 and 2880. Chapter 2356 outlines the cave management responsibilities of Recreation, Heritage, and Wilderness Resources, and Chapters 2880 describe the cave and cave ecosystem management responsibilities of Geologic Resources, Hazards, and Services.

In section 2356, the FSM outlines the roles and responsibilities of Recreation, Heritage, and Volunteer Resources, including controlling cave use, establishing use limits, developing cave management plans in coordination with other resources, acquiring cave inventory data in order to consider human cave use impacts, and coordinating and developing cave interpretive and educational materials and alerting the public to cave hazards.

In section 2880 of the FSM, the Forest Service manages geologic resources, and caves and karst resources are defined as geologic resources here. This section identifies the Director of Minerals and Geology as being responsible for sharing the lead responsibility for cave and cave ecosystem related management, specifically acting as the lead for all caves which are not designated for recreational use:

> "Coordinate lead responsibility for cave and cave ecosystem management on National Forest System lands with the Washington Office Director, Recreation, Heritage, and Wilderness Resources. Forest Service Manual 2356 provides the direction for significant caves and karst features developed for recreational use; FSM 2880 provides direction for protection and management of non-recreational significant caves and their associated ecosystems."

Forest Supervisors are tasked with making certain the caves under their jurisdiction are being evaluated for significance by a qualified geologist in accordance with the FCRPA of 1988, and CFR 36 290.

Under FSM 2880, the Forest Service is required to collect and evaluate material to rate the potential for presence of caves and cave ecosystems, and to assess the quantity, quality, and vulnerability of groundwater dependent ecosystems (karst aquifers). For caves and cave ecosystems, the Forest Service is tasked with collecting information on existing caves from the caving community and tribes utilizing spatial data in order to depict a regional description of known caves (locations confidential). In order to designate geologic factors affecting resource allocations and presence or absence of caves, reconnaissance mapping of bedrock and surface geology should occur. The addition of inventorying the extent of known caves is added, and finally field surveys including mapping caves and karst areas/ features, dye tracing, and air flow studies are required in order to evaluate the extent of resources and sensitivity to human disturbance. All cave-related documents should be secured to protect cave locations.

MGM According to FSM 2880, the Forest Service identifies management activities affecting caves, cave ecosystems, and karst environments and determines the effects of proposed activities on the hydrologic function and biological significance, safety, recreational opportunities, and cultural and paleontological resources of cave resources and ecosystems. The Forest Service additionally determine the need for protection of cave resources and ecosystems as critical wildlife or aquatic habitat. The Forest Service then then protect caves and cave ecosystems with the assistance of the scientific community and / or recreational caving groups in accordance with Federal law. The Forest Service protects and preserves significant caves by regulating or restricting use, as appropriate, and monitoring the condition of cave resources. Finally, the Forest Service also manages hazardous geologic conditions which includes the potential for flooding and sinkhole collapse in karst areas.

4. Land Management

As mentioned in FSM section 2880, the Forest Service is tasked with identifying management activities impacting caves, cave ecosystems, and groundwater dependent ecosystems such as karst ecosystems. Where active management occurs on NFS lands, standards and guidelines written in forest plans provide mitigation measures as guided by the policy described above to protect significant caves and karst resources where appropriate.

Examples exist in many national forest plans for standards and guidelines to manage the impact of timber harvest on cave resources. These examples include no-harvest buffers placed around significant caves and karst features and guidelines for building roads in karst areas. Studies on the Tongass National Forest in southeast Alaska established 30 meter (100 foot) buffers as the scientific standard for cave and karst resource protection; however the actual buffer diameter differs and on some forests in different ecosystems may be greater or less (Aley et al. 1993). If the appropriate official has designated caves found within planned mining areas to be significant, those caves are protected. However, caves not designated as significant cannot be protected as per the 1872 Mining Act once a U.S. citizen has placed a valid claim on an area where that cave is found. If caves are located during mining operation, they are documented; however the mining claimant has the right to continue operation including destruction of located caves.

Recreation is also a managed activity on NFS lands. During surveys, caves that lack sensitive resources and are deemed safe for visitation are identified as possible recreation sites. The Forest Service contains quite a few show or commercial caves including Wonderland, Blanchard Springs Caverns, Minnetonka, and El Capitan Caves. These caves are managed by cave management plans drafted to protect all cave resources found within those caves, but are often run by outside entities with Forest Service guidance. Visits to these caves for visitors with no caving experience are led by Forest Service guides or contractors. Self-guided cave and karst educational trails and boardwalks also exist on NFS lands including: Big Ice Cave on the Custer National Forest, Ape Cave Interpretive Trail on the Mt. St. Helens National Volcanic Monument, Ice Caves Trail on the Mt. Baker-Snoqualmie National Forest, Beaver Falls Karst Trail on the Tongass National Forest, and the Leon Sinks area on the Apalachicola National Forest. These include Forest Service-placed interpretive signs and structures, such as boardwalks, which educate visitors with information about cave and karst features and provide for the safety of visitors and protection of sensitive features. Finally, permitted recreation in cave systems is open to cavers of all skill levels on the Lincoln and Tonto National Forests. Current restrictions are in place such as decontamination due to White-nose Syndrome. Caves in the Eastern, Southern, and Rocky Mountain Regions are currently closed to recreational caving with exemptions for operating commercial caves.

The Forest Service is managing the impacts of White-nose Syndrome (WNS) in the U.S. through blanket closures in the eastern and southern regions and blanket and targeted closures with exemptions for science and exploration in some of the western regions. Established national decontamination protocols are in place for cave entry regardless of the area. Detailed NEPA procedures are ongoing in Forest Service units across the U.S. including Categorical Exclusions (CEs) and Environmental Assessments (EAs) in order to further evaluate the impact of cave and mine closures due to WNS.

5. Future Goals and Conclusion

The Forest Service is currently working to improve agency cave and karst management through targeting several specific management goals. Minerals and Geology Management (MGM) and Recreation, Lands, and Heritage are working together at the national level to identify roles and responsibilities for each respective department. The Forest Service has renewed MOUs with stakeholders such as the National Speleological Society (NSS) and the Cave Research Foundation (CRF). Tasks such as system-wide inventory of caves and identification and designation of significant caves, development of a corporate spatial database with protections for locational information, and establishment of best practices and technical field guides are identified as crucial.

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SOLVING KARST FLOODING IN LAS CRUCES, PETÉN, GUATEMALA

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Heavy rainfall in 2008 and 2010 resulted in severe flooding in the town of Las Cruces, Peten, Guatemala. Recent deforestation of the area draining into the town resulted in record high runoff. Previously, a cave in the middle of town had accepted all floodwaters but its capacity was exceeded causing the water to overflow into the community. Groundwater levels consequently rose causing additional flooding from overflowing wells. Flood levels averaged 1–3 m deep in the town.

In early 2011, the National Cave and Karst Research Institute collaborated with Engineers Without Borders to relieve the flooding by means of a drainage channel to divert most floodwaters around the town and away from the cave. The proposed route needed evaluation for potential underlying caves that might collapse the channel and still result in flooding. Geophysical methods were initially planned but the logistics were not feasible. Instead, a series of 4-m deep test pits were dug and the geology carefully interpreted to evaluate the stability of the proposed route. This survey revealed the route extends through an area of relatively deeper soils where no caves or karstic disturbance of the soils was evident. Though there is no assurance that leakage through the channel floor and subsequent collapse will not occur, it is at least outside of the town's boundaries and the best solution available given the community's limited resources. Reforestation of the watershed above the town, especially with sustainably harvestable plants, is the best long-term solution to their flooding problem.

1. Introduction

Las Cruces is one of the largest towns in the department of Petén in northern Guatemala (Figure 1). Heavy rainfall associated with a hurricane in 2008 and a tropical depression in 2010 caused severe flooding, resulting in displacement of 7,000 residents. An Engineers Without Borders (EWB) team began investigations of the area to evaluate the potential for constructing a drainage channel around the north and west side of town to mitigate future flood events. However, they recognized the possibility for intersecting caves along that route that might complicate or defeat their efforts and asked the National Cave and Karst Research Institute (NCKRI) to assist with this humanitarian effort by evaluating the potential for underlying caves. EWB (2010) provided the data specific to the Las Cruces area described below in this report.

2. Hydrogeologic setting

Petén is bounded to the north and northwest by Mexico and to the east by Belize. The geology of northern Guatemala is relatively simple compared to the southern part of the country, which includes a transform boundary between the North American and Caribbean plates, with associated volcanism, metamorphism, and extensive structural deformation. By contrast, most of Petén is underlain by relatively undeformed shallow marine carbonate bedrock of Cretaceous and Tertiary age. Thick limestone deposits and the humid tropical climate are responsible for the extensive karst topography of northern Guatemala. The Petén region has limited surface drainage relative to the rest of the country, typical of karst terrain.

In the general vicinity of Las Cruces, a layer of unconsolidated non-carbonate sediment of variable thickness (zero to several meters) overlies limestone bedrock. In the immediate vicinity of the village, the elevation decreases from east to west, reflecting the distribution of bedrock. Extensive outcrops of limestone are exposed on the east side of town, particularly in the northeast quadrant. Within the populated area of Las Cruces, isolated exposures of limestone near the center of town reflect the irregular character of the sediment-bedrock interface. The subdued topography on the west side of Las Cruces coincides with very limited limestone outcrops.

Figure 1. Map of Guatemala with location of Las Cruces.

There is abundant evidence for karstic conditions in the area. El Tragante, a small cave in the center of town, is formed in a limestone knoll with ~2 m of relief. The cave entrance is about 4 m in diameter, but the cave itself extends only about 8 m and narrows to a passage about 50 cm in diameter that is choked with trash. A smaller second entrance that does not receive significant natural drainage is present about 15 m west of the main entrance to the cave. Because of limited access, its connection to the main entrance is assumed but not known. In addition to El Tragante, a sinkhole approximately 25 m in diameter occurs on the north side of town. Las Cruces residents also report the existence of a second cave within the village limits that was filled recently to prevent access by children and animals.

Detailed hydrologic information for the village of Las Cruces and surrounding area is almost non-existent. At this stage of investigation, only a general conceptual model is possible based on observations of local outcrops, wells, and test pit results from this study.

The north half of Las Cruces has access to a municipal water supply, which pumps water from a 90 m deep well on the east side of town that is screened in limestone. In addition, many households either supplement their water supply with or rely exclusively on shallow domestic wells. Several homeowners reported that their wells sometimes went dry for part of the year. Most of the domestic wells observed were hand-dug, which may account for their concentration on the west side of town where bedrock is overlain by a blanket of sediment. Several of the test pits dug for this study on the west side of town encountered limited water flow (<5 liters/min) at 3–4 m below ground level. These observations are consistent with a conceptual model of a deeper limestone aquifer overlain by several meters of clay and silt. The clay/silt overburden contains perched aquifers of limited extent that provide water for small domestic wells. The municipal supply well draws water from the underlying limestone aquifer.

3. Karst flooding and groundwater contamination

El Tragante is located at the south end of a drainage ditch running from north to south through the center of town. The community of Las Cruces exploits its natural karstic drainage system to manage floodwater and stormwater runoff. Surface floodwater is conveyed via the ditch into the cave and transported downgradient through karstic conduits; it is assumed to discharge from El Oroyo, a spring located roughly 4 km to the south.

Since about 1980, the 89-km^2 drainage basin flowing into Las Cruces has changed from a lowland jungle to deforested cattle ranches, corn fields, and papaya plantations (Figure 2). From 1990 to 2009, the area has experienced an average annual rainfall of 1,640 mm and until recently all drainage has flowed through El Tragante.

However, progressive deforestation has increased the flood pulse into the cave and in 2008 and 2010 the cave overflowed during a hurricane and tropical depression, flooding much of the northern part of the town with up to 3 m of water. Also, trash clogging the passage at the back of the cave inhibits its ability to efficiently transmit floodwater. Groundwater mounding also caused water to rise up to 0.6 m above the surface from wells to flood much of the southern part of the town. An estimated 7,000 residents were displaced and much property was damaged and destroyed. Repeated flooding is expected unless the drainage area is reforested and/or some of the runoff is diverted away from Las Cruces.

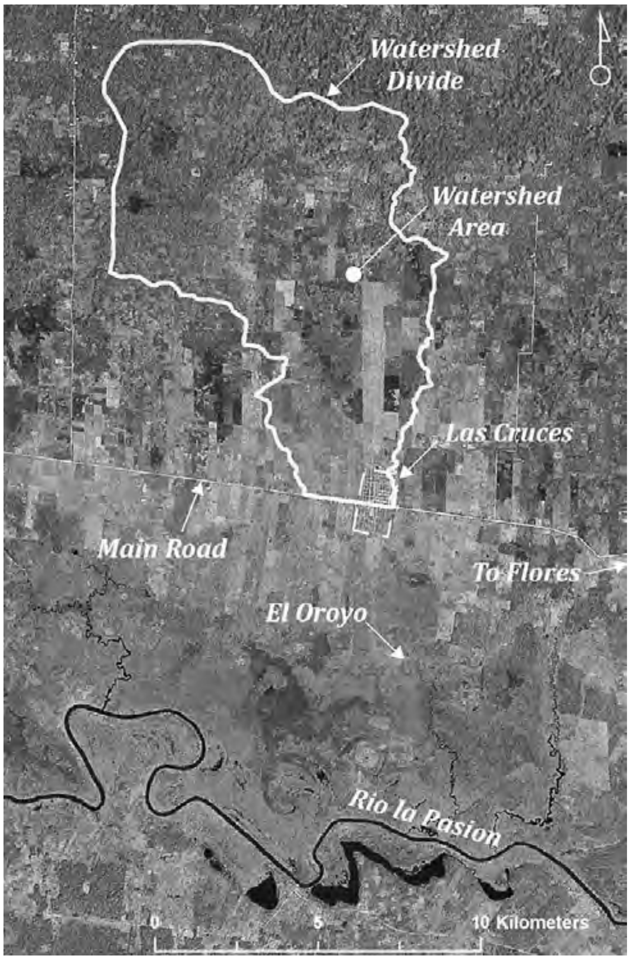

Figure 2. Drainage basin into Las Cruces (EWB, 2010).

The drainage ditch also receives much of the graywater drainage as well as unknown quantities of domestic sewage and animal waste from homes located along the canal. In addition, a sewage line has been inserted directly into El Tragante’s probable second entrance (Figure 3). Water


Figure 3. Sewage pipe into El Tragante; the cave entrance is 3 m deep.

samples collected from all wells in Las Cruces showed moderate to high levels of fecal coliform and *E. coli* bacteria, probably associated with the widespread use of pit latrines in the village as well as the discharge of graywater and sewage into the cave. Most residents rely on either bottled water or water from the municipal water distribution system. A sample collected from the municipal supply well had low levels of fecal coliform, in spite of the fact that raw sewage is being injected directly into the karstic aquifer beneath Las Cruces. The position of the municipal well upgradient from El Tragante may account for the relatively low level of contamination found in the well samples.

4. Flood remediation channel: evalution

Engineers from EWB proposed excavation of a 5.2 km long channel that would capture the majority of floodwaters as they enter the north side of Las Cruces, and divert them via the channel west and then south of town (Figure 4). The channel would be approximately 5 m wide by 3 m deep and prone to intersecting a cave during excavation. It could also collapse at a later time by water in the channel piping soil into underlying cavities, which could shift the location of flooding by surface overflows and continue flooding by groundwater mounding.

NCKRI geologists recommended conducting an electrical resistivity survey along the length of the proposed channel to identify any significant caves so EWB could reroute or design the channel accordingly. Logistical issues with transporting the resistivity equipment to Las Cruces prevented its use, so a second plan was developed to evaluate the stability of the channel route with the equipment that was available.

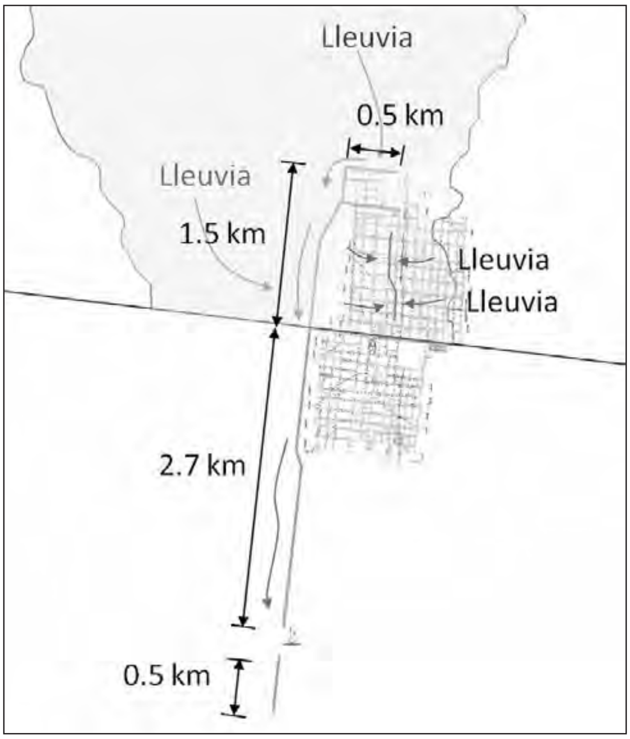

Figure 4. Proposed route of diversion channel around Las Cruces ("lleuvia" is Spanish for rain); the short channel in the north-central part of town flows into El Tragante at its south end and they gray area to the north is the watershed for the channel (EWB, 2010).

Using a backhoe, 25 tests pits were dug at 150–200 m intervals along the proposed channel's route to evaluate the near-surface geology and soil conditions. The pits had depths of 3.5 to 4 m (maximum depth dictated by the length of the backhoe arm), and assessments were made of sediment cover, depth to bedrock, and locations of soil piping, caves, and other karst features in the subsurface (Figure 5). Information from a recently-excavated cesspit was also included as part of the geologic investigation. A Garmin 76S handheld GPS receiver was used to collect location and elevation data at each station, accurate to within a few meters.

Twenty-two of the 25 pits encountered only soil and dense clay. These pits represent about 90 % of the total length of the survey. Two of the pits exposed weathered limestone bedrock 1.5 to 3.5 m below ground level, and one unearthed several large limestone boulders at ~3.5 m, suggesting proximity to bedrock. In addition, four pits in the southern portion of the survey encotered limited water flow.

5. Conclusions

Results of the test pit survey, coupled with observations of the local geology, indicate the presence of an irregular bedrock surface overlain by one to several meters of clay and silt on the north and west sides of Las Cruces. Test pit and borehole data have inherent limitations when evaluating depth to bedrock in karst terrain. That said, it appears that limestone bedrock is probably greater than 4 meters deep over ~90 % of the length of the proposed channel. Near-surface bedrock (< 4 m) or limestone boulders indicating proximity to bedrock were encountered in three pits over a

Figure 5. Backhoe excavating pit for geological examination.

distance of roughly 500 m, along which more difficult excavation conditions are anticipated.

Although no caves or soil pipes were encountered in the test pits, caves are obviously present in the vicinity of Las Cruces. It is thus possible that leakage from the drainage channel into underlying caves or karst conduits may initiate sinkhole collapses. Ideally, the ditch should be lined to prevent or minimize leakage, but budget constraints for the community may not permit this. For a more permanent solution, the people of Las Cruces are encouraged to reforest the town's drainage area with trees and other plants that will reduce runoff while yielding economically valuable harvests. Alternatively, or in combination, the example of the town's ancient Maya ancestors should be followed by terracing the landscape to reduce runoff and soil erosion, which is a well-recognized environmental and economic problem for the region.

While remediation of groundwater quality was not a part of this study, contamination of the karstic groundwater supply would be at least partially mitigated by removal of the sewage line into the second entrance into El Tragante. In addition, Las Cruces residents should stop discharging graywater and sewage into the existing canal, since that waste is transported directly into the limestone aquifer via El Tragante. Lastly, the installation of a debris rack, designed to keep trash from entering the cave and not restricting recharge, would reduce both flooding and groundwater contamination.

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KARST FROM SÃO DESIDÉRIO REGION (BAHIA – NORTHEASTHERN BRAZIL): PROTECTION AND MANAGEMENT PROPOSITION

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The region of São Desidério is located in one of the newest discovered frontiers in the Brazilian karst areas. The region draws attention for the amount and variety of surface and underground karst formations, as well as for the number of recorded caves. These characteristics called the attention of Brazilian environmental authority, who proposed an establishment of a Natural Protected Area (NPA). Hydrogeological, biological, landscape and social studies were performed aiming to evaluate the hydrologic connection between the João Rodrigues and Tamanduá river basins, both important in karst development of the region, hence in its conservation. Herein is proposed the creation of a mosaic of protected natural areas: a National Park (full protection) and an Environmental Protection Area (conservation and sustainable use of natural resources), encompassing Tamanduá and João Rodrigues river basins, as well as the areas contiguous to the second one.

1. Introduction

The karst system of the João Rodrigues river (KSJR) stands out in the Brazilian scenario for its geodiversity and biodiversity, beauty, and grandiosity of its caves and landscapes. Its main axis is formed by a series of caves of huge dimension, such as the "Buraco do Inferno da Lagoa do Cemitério" with 4.8 km in length. The KSJR is considered a threatened area, due to its proximity to urban areas, highway traffic and plantations. This situation called the attention of the environmental Brazilian authorities, represented by the *National Center for Cave Study and Management* (CECAV), which proposed the creation of a National Park.

From this, several multidisciplinary studies were carried out in the region over 14 months (from July 2011 to August 2012), aiming to propose the most appropriate limits to create a Natural Protected Area under federal jurisdiction, compatible with Brazilian laws, which restrict the human impact. The conducted studies were: hydrogeology, geology, geomorphology, speleology, speleobiology, microclimate, archeology, paleontology, anthropic vectors, and geological and speleotourism. In the present paper we provide: a) a summary of the main results; and b) recommendations for the conservation of the KSJR, including the proposition of two different Natural Protected Areas, which showed to be more appropriate for the regional context than a single one.

2. Characterization of the study area

The study area is located in the northeastern region of Brazil, west of Bahia state, and is inserted in the municipality of São Desidério, but it also encompasses the municipalities of Catolândia, Baianópolis and Crisópolis (Fig. 1).

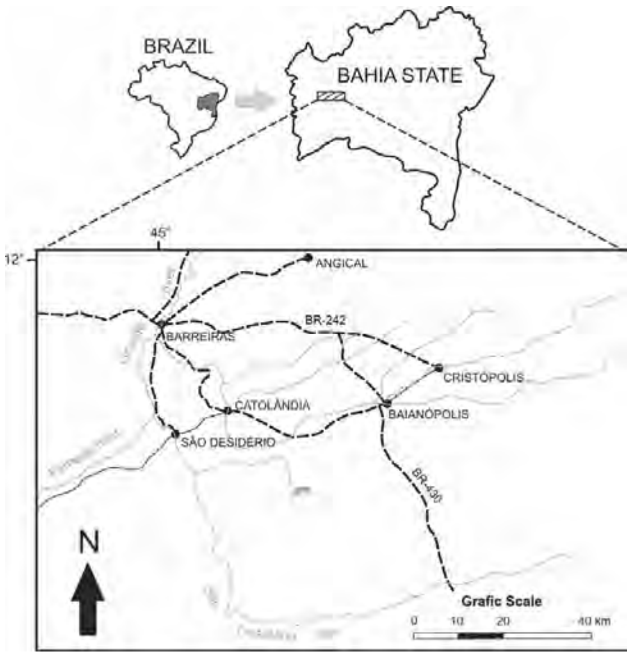

Figure 1. Study area location, highlighting the main roads and rivers.

The study area is located in the northwestern region of the São Francisco Craton, and comprises Phanerozoic sediments that belong to the Sanfranciscan Basin, represented by the Urucuia Group, and Neoproterozoic metasedimentary rocks of the Bambuí Group, represented by the São Desidério and Serra da Mamona formations (Egydio da Silva et al. 1989; Campos and Dardenne 1997a).

The Sanfranciscan Basin covers a large area from the north of Minas Gerais State to the south of Piauí State, in a total area of approximately 150,000 km^2, and it is considered to be a sag-type basin, which is characterized by a broad intracontinental basin with little subsidence and reduced presence of tafogenetic processes, whose deposition history starts in the Paleozoic and extends to the Cretaceous period (Campos and Dardenne 1997 a, b). It has an elongated format following a N–S direction, with thickness reaching roughly 500 m. The Sanfranciscan Basin is divided by the Paracatu High into two sub-basins: the Urucuia sub-basin, to the north, and the Abaeté sub-basin, to the south. The longitudinal limits of the basin are parallel to the Brasília Belt, to the west, and the Araçuaí Belt, to the east, and is bounded on the north by the São Francisco High, which separates its deposits from the Parnaíba Basin, and to the south it covers part of Paraná Basin's sediments (Campos and Dardenne 1997 a, b). The Sanfranciscan Basin is subdivided into five main units, which are, from the base to the top: Santa Fé Group (glaciogenic deposits), Areado Group (alluvial fan deposits and river, lake, and aeolian environments), Mata da Corda Group (alkaline volcanic rocks and river and alluvial fans), Urucuia Group (aeolian and river deposits), and Chapadão Formation (Cenozoic eluvial-coluvial deposits) (sensu Campos and Dardene 1997 b).

The Urucuia Group covers a large area and comprises the states of Minas Gerais, Goiás, Bahia, Tocantins and the southern part of Piauí, and is composed by siliciclastic rocks, mostly conglomerates, sandstones and siltstone, deposited in aeolian environment (Posses Formation, located at the base of the unit) and river environment (Serra das Araras Formation, located at the top) (Spigolon and Alvarenga 2002). The Urucuia Group directly overlaps the neoproterozoic metasediments of the Bambuí Group, but it also overlaps the Areado and Santa Fé groups, in addition to the granites and gnaisses of the basement (Campos and Dardenne 1997 b).

The Bambuí Group represents the Neoproterozoic sedimentary coverage rocks with the biggest expression in terms of area in the São Francisco Intracratonic Basin, whose deposition occurred between 750 to 600 Ma. (Iglesias and Uhlein 2009).

Four main geological units were recognized in the KSJR area, as follows: metasedimentary deformed rocks of the Bambuí Group, represented by the São Desidério and Serra da Mamona formations, Cretaceous sedimentary coverages of the Urucuia Group and talus deposits, which are probably Cenozoic (Fig. 2).

In the region, two marked seasons are identified: one dry and cold, from May to September, and the other rainy and warm, from October to April. Minimum and maximum temperatures range from 20 to 26 °C. Regional rainfall varies from east to west, from 900 to 1,100 mm per year, approximately.

According to Koppen classification, the climate type in the area is warm (Caw) and there is at least one month in which the rainfall is below 60 mm. The temperature in the coldest month is above 18 °C and the monthly average thermal range does not surpass 5 °C (Brasil 1982). The average relative humidity of the air is 70 %, ranging from 80 % in December to 50 % in August (Embrapa 2008).

From the local standpoint, the rainfall influence in the surveyed environment is remarkable, considering the structure of karst environment underlying a sandstone sedimentary package. This implies a specific condition of the hydrological regime, since the effective recharges that control most of the hydraulic gradient in the KSJR depend on the contribution of the rainfall on the sandstone hydrogeological units located around its distribution, mainly in the east and south portions.

In this context, the study carried out initially considered the fact that the karstification started from an allogenic recharge, and then changed to an autogenic recharge with the exposure of the carbonatic rocks. Once this process advanced, the capture of Tamanduá river basin started to occur, represented by the KSJR, as depicted in Figures 2 and 3.

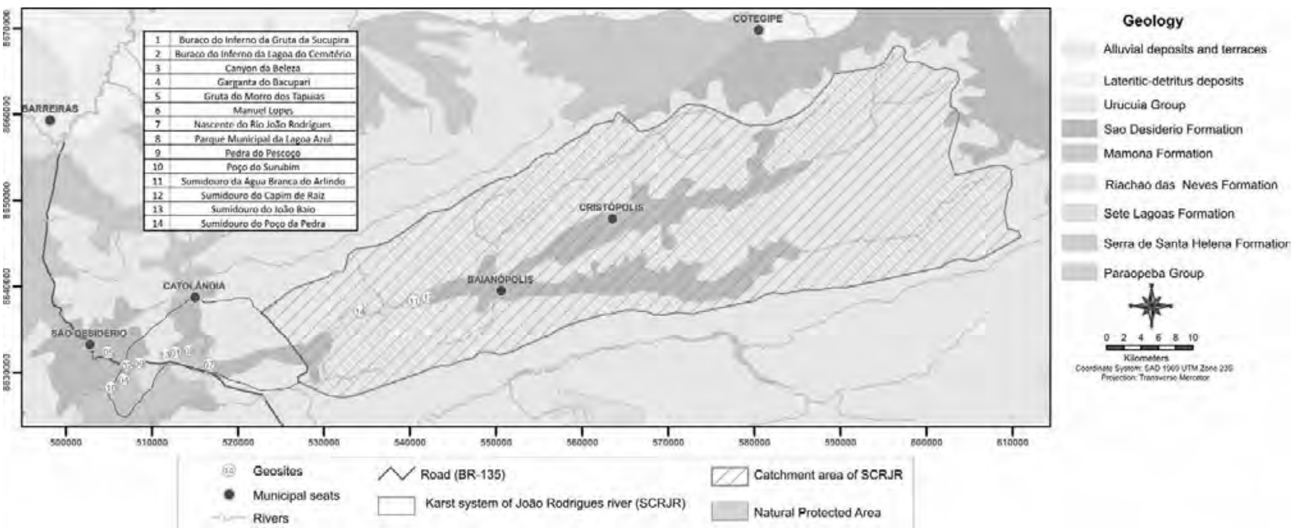

Figure 2. Geological map of the area representing hypothetical relationship between the KSJR (smaller polygon) and the Tamanduá river basin (larger polygon).

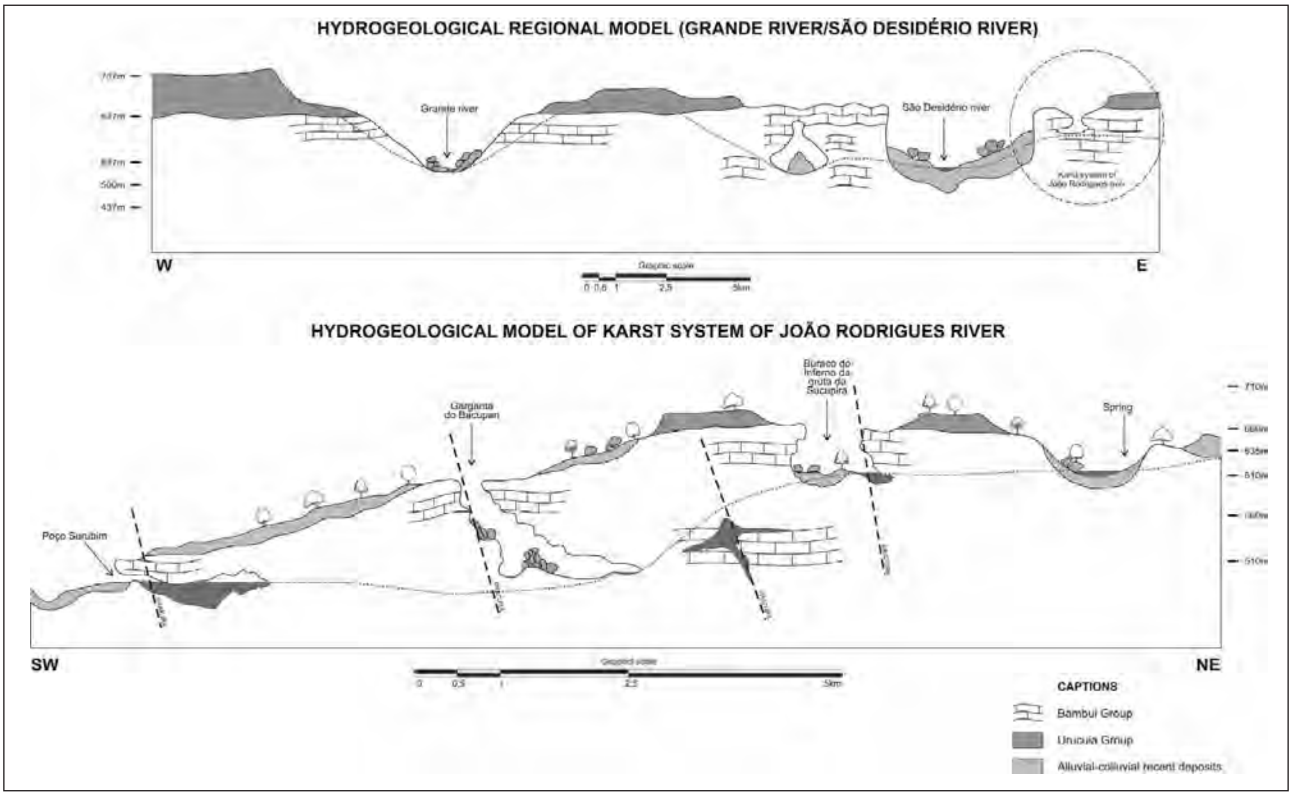

Figure 3. Hydrogeologic conceptual model of KSJR.

3. Methods

The caves are among the main karst landscape and have an important role in enabling the local authorities to propose the João Rodrigues river basin as a Natural Protected Area. Nevertheless, several studies conducted worldwide (e.g., Watson et al. 1997; Williams 2008) as well of national level (e.g., Trajano and Bichuette 2010) have been reasserting the need to understand caves as part of a complex system, especially for conservation purposes. In general, Karst system differs from the fluvial basins, in which the planning is performed satisfactorily, with the hydrographic basin as the territorial for conservation. In karst areas, hydrographic basins are outlined in the surface by the watershed, not always corresponding to the total water catchment domain (Ford and Williams 2007). Rock solubility – especially in carbonatic areas – and other environmental factors result in an extensive network of underground conduits enabling the intake of water from adjacent basins. Thus, karst terrains are special cases of territorial management for conservation purposes, once the totality of their areas can vary from dozens to hundreds of square kilometers, larger than the immediate perimeter of the projection on the surface of the reference hydrographic basin. Taking this into account, several multidisciplinary studies were carried out and the methodology of this work had to consider social and natural parameters to define the limits of the proposed Natural Protected Area.

The work was divided in two major stages: 1. data collection; 2. data comparison to obtain an integrated analysis of the KSJR. In summary, at the first stage, the following methodological procedures were performed:

- Hydrogeology: Identification of the main flow pathways with tracers and monitoring of the flow rates in strategic points of João Rodrigues river;
- Geomorphology: mapping and identifying the geomorphological compartimentation of the karst system;
- Speleobiology: biotic and abiotic surveys, monitoring the fauna in a representative part of the KSJR;
- Archeology and paleontology: prospection and logging of archeological and paleontological sites;
- Geological heritage: inventory and assessment of the most well known geosites;
- Speleology: complementary mapping of the main caves of the system and use of the existing databases to verify the amount of caves in the region;
- Human occupation: land use survey, to identify the situation of human occupation.

The integration of thematic studies to categorize the space can be carried out in different ways, including the processes of overlaping and wheighting of the thematic maps (e.g., Lobo et al. 2013) or by simple juxtaposition of the analyzed territories. Due to the environmental features of the karst terrains, it was decided to use a simple method of juxtaposition of the priority areas according to the various themes, independently of the spatial coincidence of these points, in order to ensure a broader territory, based on technical criteria. In the definition of the polygons proposed herein, the limits established were based on natural features identified at the karst terrain, which had to be visible at a working scale map, whenever possible. However, considering that the aim of this process was not only to outline the karst area, but also to categorize it for conservation, we also considered the possibility of exclusion of certain areas within a priority polygon. In the present study, as an exclusion criteria, we used the previous anthropization of the territory and the possible socio-economical impact generated by affecting productive and/or densely populated areas, for the definition of the final Natural Protected Area. In summary, the study was carried out following the stages below:

I. Identification of the recharge zone (autogenic and allogenic) of the karst system;

II. Analysis of the proposed geomorphological compartments;

III. Identification and juxtaposition of priority points for conservation, with emphasis on speleobiological, archeological, and paleontological matters as well as those of heritage value;

IV. Based on previous stages, identification of areas with different conservation priorities, by thematic juxtaposition and by the exclusion of areas that would cause socio-economical impact, by affecting productive and/or densely populated areas;

V. Proposal of a mosaic of Natural Protected Areas, being one of Full Protection (priority area, considered the most representative nucleus of the studied system) and another one of Sustainable Use (to add a territorial planning compatible with the needs of sustainable management of the water basin that feeds the system);

VI. Proposal of Natural Protected Area categories, based on the environmental and socio-economical features of the areas to be affected, as well on the Brazilian environmental legislation.

4. Results and discussion

Although it was not possible to confirm the hydraulic connection between the Tamanduá and João Rodrigues river basins through the use of tracers, the river capture was inferred from a comparative study on the flow rates and the catchment areas of these basins. The entire river network was analyzed based on geomorphological perspective by establishing topographic markers. Three major compartments were proposed for the karst system of the João Rodrigues river: the polygonal karst zone, the karst zone with springs associated to the fluvial network and the fluvial zone (Fig. 4).

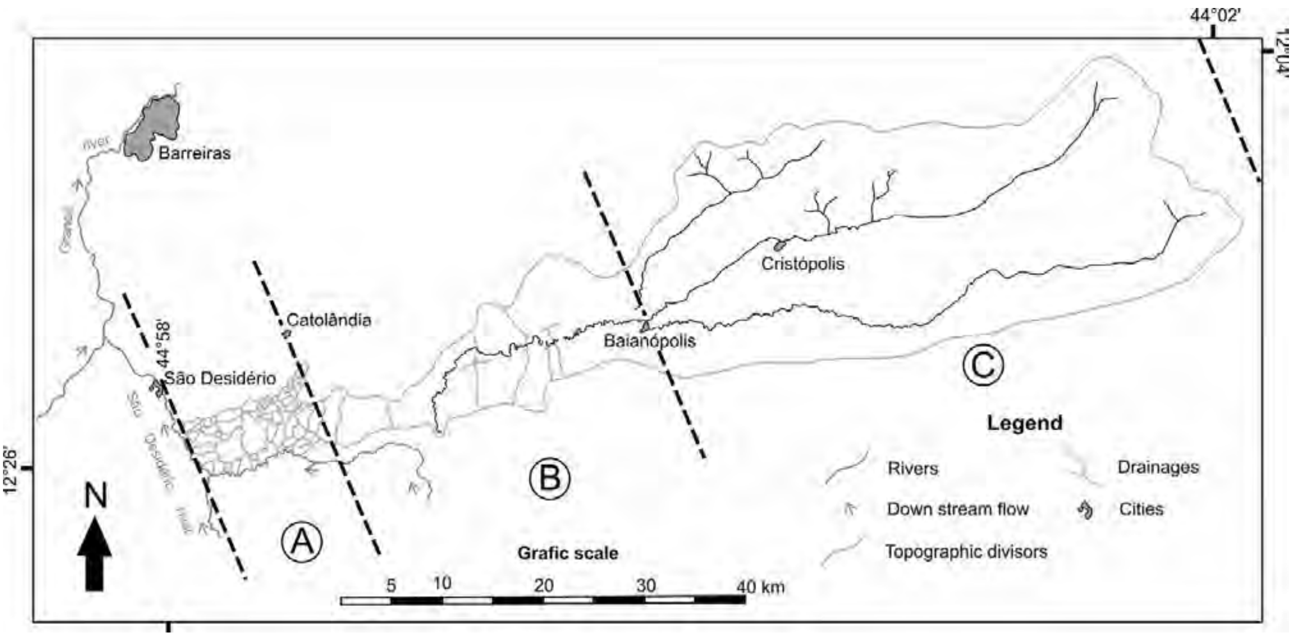

Figure 4. Geomorphological map."A", "B"and "C" represents the three major geomorphological zones of the karst system: "A" – polygonal karst zone, "B" – karst zone with springs associated to the fluvial network, and "C" – fluvial zone.

The first important aspect is the existence of two municipal settlements in the hypothetical catchment area of the KSJR, namely: Baianópolis and Crisópolis. Tab. 1 summarizes the description of these municipalities.

Table 1. Social and economic data from the municipalities of Baianópolis and Cristópolis.

Municipality	Population	Urban Population	Rural Population
Baianópolis	13,850	3,482	10,368
Crisópolis	20,046	8,612	11,434

Source: Ibge (2012) – data from the census of 2010.

As may be seen in Tab. 1, there is a numerous population living in the urban and rural area of the region and, for this reason, the creation of a Natural Protected Area would interfere in this population. The existence of municipal settlements and rural occupation in part of the karst system area makes impracticable the proposition of a Natural Protected Area, with total restriction to the human occupation, comprising the whole karst system. Doing that would cause conflicts without precedents, followed by the displacement of two entire municipalities, with all their citizens and economic activities. This scenario is not possible for two reasons: 1. lack of political support for such situation, 2. it could generate a rejection for the establishment of a future Natural Protected Area.

On the other hand, the field work carried out in this project, as well as in previous projects (e.g., Rubbioli 2004) and the current record of natural caves in Brazil, show that the region of the Tamanduá river have less karst features than the São Desidério river region. However, the former is an area with extensive changes caused by human occupation, most of the region being used as grazing areas. The polygonal karst zone, which corresponds to the entire autogenic recharge zone and part of the allogenic recharge zone of the KSJR, have an impressive number of karst features, such as caves, dolines, blind valleys and polygonal basins with centripetal drainage. Moreover, this area hosts vast areas of virgin forests and it should be the target area for conservation efforts.

The studies on speleobiology, paleontology and valuation of geological heritage also indicated the polygonal karst zone as the most relevant area, with endemic and rare species. Archeology studies demonstrated the existence of a series of archeological sites close to the São Desidério river and beyond the studied karst system. The human occupation studies indicated larger gaps of human occupation in the polygonal karst zone. Fig. 5 summarizes the main results of these studies.

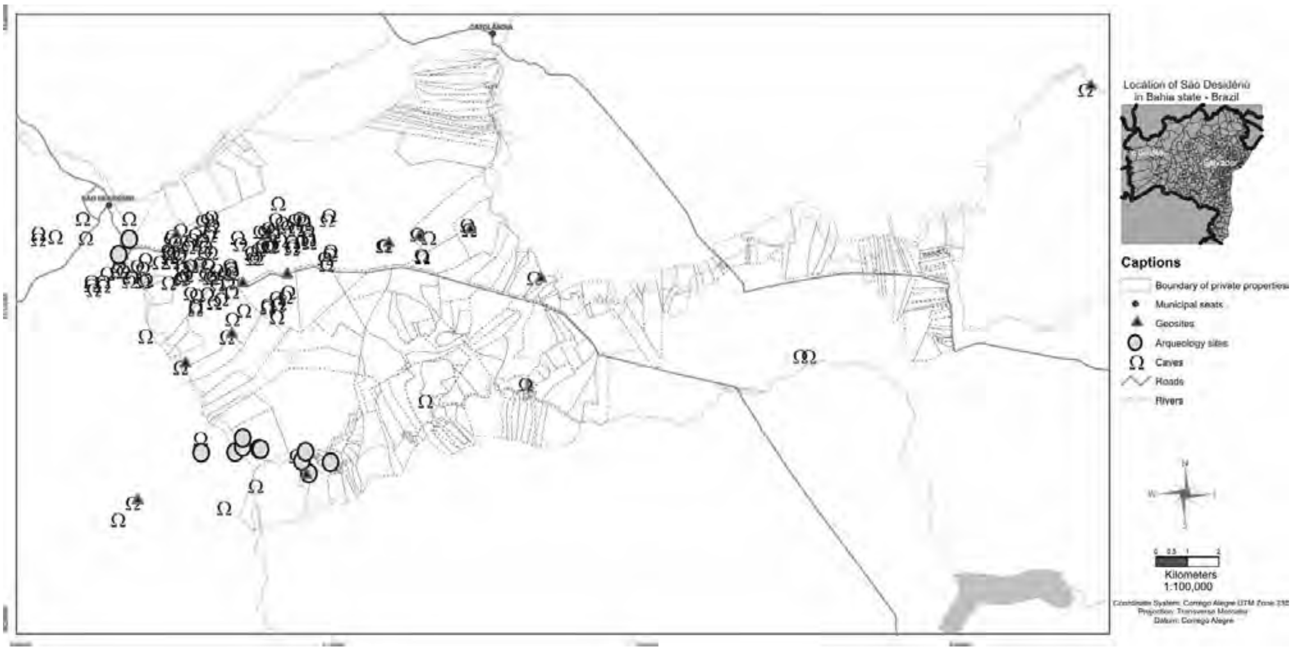

Figure 5. Results on archeological studies, geosites, presence of caves and the land situation of the polygonal karst zone.

6. Conclusions and final recommendations

Based on the studies which were conducted, some characteristics were considered for establishing general principles for the conservation of the KSJR:

- Although it was not possible to obtain confirmation by means of the study with tracers, a comparative analysis on the relationship between the flow and the catchment area of Tamanduá and João Rodrigues river basins allowed us to deduce that the recharge area of the KSJR reaches out up to the Tamanduá river basin, forming a partial river capture. As such, the waters of Tamanduá river basin are strategic for the conservation of the local karst system;
- The geomorphological zones denominated fluvial zone and karst zone with springs associated to the fluvial network do not reveal elements which make up the local geospeleological heritage, since they have few or none karst features, such as caves, dolines and polygonal basins, and presents dense populational occupations, encompassing the municipal seats of two municipalities (Baianópolis and Cristópolis);
- The polygonal karst zone has typical characteristics of a karst relief and constitutes the autogenic recharge zone of the system. On the other hand, the human occupation in this region is relatively less dense, with the exception of the riverside of São Desidério river;
- The caves located in the polygonal karst zone are more relevant for the conservation of representative species of hypogean ecosystems, were new and endemic troglobite species were identified. In addition, the hypogean ecosystem is an important shelter for the epigean fauna during the dry season. The most important archeological sites with considerable potential that were identified are located in the polygonal karst zone and its adjacent areas;
- The caves in the polygonal karst zone, as well as the dolines and the São Desidério river represent attractive landscapes comparable to other karst areas with tourist attraction in Brazil and other places all over the world.

Based on these facts and also on the current categories of the National System of Conservation Units (SNUC), already analysed for its appropriate applicability in karst areas by Pereira et al. (2008), we propose the further strategic actions to the conservation of the KSJR:

I) To consider the entire extension of João Rodrigues river and the largest part of the polygonal karst zone as a Full Protection natural preservation area, under the category of National Park. From this area, only the riversides of São Desidério river shall be excluded – with the exception of the area close to the João Rodrigues river mouth. This area of the polygonal karst zone, together with the archeological sites and the Sopradeira cave, shall be mandatorily included in the buffer area of the future National Park, then, sustainable management practices may be adopted in these places;

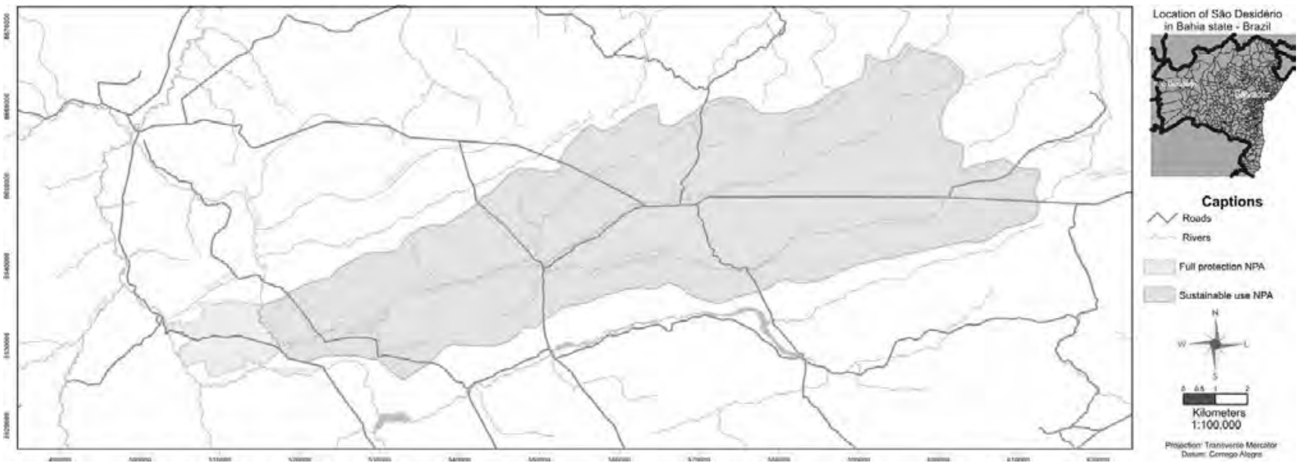

Figure 6. Mosaic of Natural Protected Areas with full protection and sustainable use for the region of São Desidério.

II) To propose the other karst zones related to the system, (bounded by the watersheds of the Tamanduá river basin) as a Federal Natural Protected Area, with Sustainable Use (in the category of Environmental Protection Area).

The proposal of the Natural Protected Area with Full Protection and Sustainable Use is shown in Fig 6.

By creating these areas, the conservation of an area with 189.04 hectares of karst terrains could be assured, and also 143 caves which are already known and recorded, in a Brazilian region with few attention for effective protection. Therefore, we recommended that this proposal should be considered for the planning and designing of the protection of São Desidério region natural heritage, taking into account both the mosaic of Sustainable Use Natural Protected Areas, and the Full Protection Natural Protected Area.

Acknowledgements

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UNDER YOUR FEET: DEVELOPING AND ASSESSING AVENUES FOR PROMOTING KARST GROUNDWATER AWARENESS AND SUSTAINABILITY THROUGH COMMUNITY-BASED INFORMAL EDUCATION

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The rapid transport of percolating water through karst and inability of carbonate bedrock to effectively filter pollution from water lends these terrains to extensive environmental degradation. It also makes groundwater in karst regions highly vulnerable to pollution. Moreoever, rapid industrial, agricultural, and/or urban growth in karst regions has raised concerns about future groundwater availability in these locations. In an effort to promote karst groundwater awareness and encourage its sustainable use, a multi-year groundwater awareness campaign was launched in the iconic karst landscape of south-central Kentucky and west-central Florida. In both of these locations, water availability and groundwater quality are becoming increasing concerns. Informal learning allows for both adults and children to be simultaneously educated about a particular topic, so this campaign centers on the use of multiple informal learning tools. These include, but are not limited to, interpretative signs, webpages, infographics, workshops, open community forums, social media, and multi-media productions. Since the launch of the campaign, more than 100 Facebook “likes” have been received, two workshops were hosted, a short teleprompter video has aired at a Western Kentucky University sports venue, and 3 infographics were developed and distributed. To date, knowledge surveys, pledges submitted by visitors to the Under Your Feet campaign webpage, and public support and requests for additional educational materials indicate these efforts have been successful at enhancing public understanding of karst groundwater issues and spurring behavioral and attitudinal changes in members of the general public. Research on combining the use of multiple informal education tools into a single karst and groundwater education initiative that changes affective domain and increases understanding about this topics are also being pursued as part of this campaign.

1. Introduction

Karst environments, which are characterized by springs, caves, sinkholes, and aquifers systems, which form from the dissolution of carbonate (limestone, dolomite) rock, are fragile ecosystems that provide substantial groundwater resources. These significant landscapes are susceptible to negative impacts from development, stormwater pollution, and agriculture, among other sources (van Beynen and Townsend 2005; North et al. 2009). Moreover, since these landscapes require a holistic perspective in determining the extent of possible environmental impacts, they are difficult to manage and thereby more susceptible to degradation than many other landscapes. Thus, despite the abundance of karst landscapes, their sensitivity to anthropogenic disturbance, and connection to fresh drinking water supplies, overall there is a severe lack of effective policies at most federal, state, regional, and local levels (Fleury 2009). Even when regulatory tools seem well-suited to karst management, budgetary and time constraints of municipalities frequently curtail enforcement.

Human impacts to karst regions are frequently unintentional and/or ignored due to public lack of effective and accessible environmental educational materials about the basic science of caves and karst environments or the importance of these landscapes to water resources (van Beynen and Townsend 2005; Fleury 2009; North et al. 20009; North 2011). Thus, instances of anthropogenic karst disturbance will likely continue until the general public is adequately educated about the vulnerability and interconnectedness of the terrains. Yet, because of their complexity, educating about karst landscapes and groundwater requires a holistic perspective and multi-faceted approach.

Even in iconic karst landscapes such as Bowling Green, Kentucky and west-central Florida, USA, which are among some of the most extensively studied karst landscapes in the world, there is a lack of effective karst regulation (Fleury 2009) and understanding about these landscapes by members of the general public. In short, there exists a need for general audiences to fill an educational gap about the uniqueness of the karst environments in which they live and the important role their individual actions play in groundwater quality. By filling these existing voids in public knowledge about karst through the development and quantification of the effectiveness of an *informal* educational campaign, it may be possible to mitigate the ever-increasing instances of karst and groundwater degradation despite shortcomings in regulation.

Although interpretative signs, brochures, and promotional materials are regularly used to inform about multiple environmental topics, few of these efforts also investigate the effectiveness of these signs and associated outreach materials to educate the public once implemented. Furthermore, in an ever-increasing technological world, it is important for educators to understand how more traditional and new-media techniques can be successfully combined to maximize learning and positive behavioral change. Thus, in an effort to ameliorate environmental degradation over time and provide a foundation for continuing to devise educational materials that achieves these goals, this project centered on assessing the success of a multi-faceted informal educational campaign. Assessment specifically focuses on the effectiveness of developed education materials to spur behavioral changes in a karst community, improve understanding of karst terrains and its role in groundwater supplies, and spark curiosity and ownership about karst groundwater issues by the general public. This work involves cooperation with state and local governments, educators, and students.

2. Methods

The city of Bowling Green, Kentucky and the Tampa Bay Metropolitan Area in Florida, USA, have both attempted the use of television commercials and brief radio spots to communicate messages about their groundwater supply in past years, but to date the effective use of these often expensive outreach techniques has not been justified for their cost. Furthermore, as more people switch to online bill payment, the expensive outreach strategy of inserting informational brochures in water bills is becoming obsolete. For this project we combined the use of multiple new outreach techniques and avenues (including social media) that reach a broader audience, with a focused website platform. This platform provided the ability to research the effectiveness of the selected informal educational strategies and allowed for the best means by which to strategically focus and improve upon the means to be ascertained.

This project used a participatory needs assessment approach, with the partnership of several community stakeholders to refine and develop the materials in Bowling Green, Kentucky and west-central Florida. Specifically, this study involved the following steps:

1) perform a participatory needs assessment in which the community partners, researchers, and interested stakeholders determined the primary goals of a karst education campaign, the best method of disseminating the information, expected outcomes, and the minimum standards to measure its success;

2) develop and implement informal learning tools, including, but not limited to, data- and concept-driven infographics, a series of 30-second videos, a print ad, and a interactive and user-friendly website equipped with an events calendar, community discussion forum, and karst and groundwater data;

3) equip each created educational tool with Quick Response (QR) codes so the interactive web component of the campaign is readily accessible;

4) establish a mechanism for displaying water quality and quantity data (determined by quarterly-tested water quality parameters and discharge measurements) from nearby karst features on the website; and

5) evaluate the applicability, usefulness, and success of the created educational materials through focus groups, opinion-based surveys, and pre-and post-assessments.

Website visitation tracking is used to establish how the site was accessed, peak visitation hours, and the location of web visitors. Since infographics are designed to be downloadable and printable by users, the number of times these materials are accessed is also quantified to estimate the campaign’s reach. Content analysis techniques are used to assess the outcomes of voluntary opinion-based surveys available on the website and at selected events. Discourse analysis methodologies are used to draw conclusions from the public webpage forum.

As the project continues, focus groups will be used to follow-up with website visitors who pledged behavioral changes to investigate the success of these pledged changes. Water bills of willing participants will also be evaluated to assess if changes in the quantity of water usage decreased since interacting with the educational materials. Lastly, groundwater quality and quantity data will later be studied to ascertain if improvements in these measures have occurred since the initiation of the educational initiative.

3. Preliminary Results and Discussion

Since the launch of the Under Your Feet campaign, more than 100 “likes” have been received on its Facebook page, nearly 100 participants were hosted at two groundwater workshops, two short teleprompter video aired at a Western Kentucky University sports venue, and 3 infographics were developed and distributed. To date, knowledge surveys, pledges submitted by visitors to the campaign webpage, and public support and requests for additional educational materials indicate these efforts have been successful at enhancing public understanding of karst groundwater issues and spurring behavioral and attitudinal changes in members of the general public. Specifically, visitors spend an average of 20 minutes on the developed website and demand for additional infographics continually increases with over 90 percent of survey respondents indicating the infographics (see Figure 1) are the most informative and useful component of the campaign. 66 percent (n = 67) of web visitors were unable to answer two or more questions on pre website surveys, while 87 percent correctly answered at least 11 out of 12 questions on post website surveys, thus highlighting a significant improvement in karst and groundwater understanding after exploring the series of created resources. Lastly, 97 percent of pledge respondents pledged to participate fully in each proposed activities and/or behaviors in 5 categories (conserve, prevent, maintain, protect, show). In August 2013, focus groups with website visitors will be held to establish if pledged activities and behaviors were pursued and factors influencing successes and failures in attempts to do so.

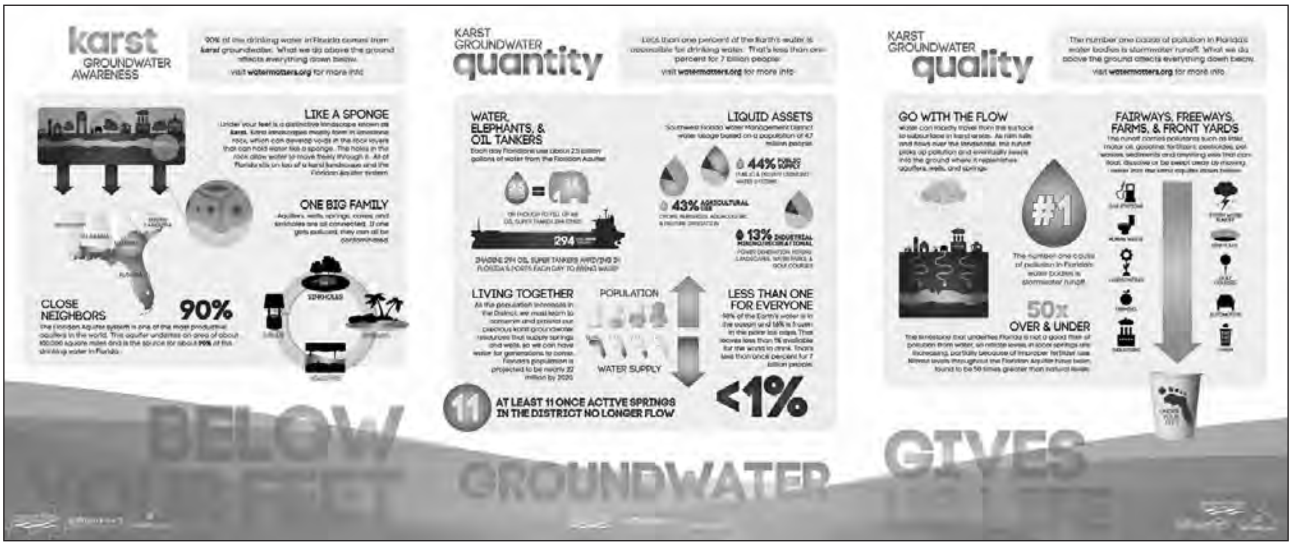

Figure 1. Three-panel, data-driven infographic created as part of the Under Your Feet Karst Groundwater Education Campaign. Infographic be viewed as a single unit, or each panel can be printed as a standalone item.

Due to the uniqueness of this project, both in terms of approach and content, few if any studies are available to use as a baseline for evaluating this study's preliminary results. Thus, the results of this research are significantly adding to the theoretical knowledge base of informal science education. New tools to effectively communicate about karst environments and valuable water resources in the study areas are also being directly advised by this research.

It is the hope of the researchers and public officials assisting in the project that conclusions from this study's emerging results will serve as a general framework for future community-based groundwater education efforts locally as well as internationally. Moreover, if this Campaign shows these techniques are effective and positively received, we hope to encourage the pursuit of personal "pledges" in all aspects of community outreach and environmental sustainability initiatives.

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THE STATUS OF CAVE WILDERNESS IN THE UNITED STATES OF AMERICA

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In 1872 the United States of America first began setting aside federal lands for the enjoyment of the American public. In 1964 the United States government passed landmark legislation creating a National Wilderness Preservation System to preserve and protect natural landscapes for primitive use only. Despite four attempts to create a Cave Wilderness designation, two by the Cave Research Foundation, one by the National Speleological Society and one by a unit within the National Park Service system, no Wilderness designation has been made to protect and preserve a specific cave, region within a cave or a karst region. The question remains: if and when will the US declare a cave or portion of a cave/cave system as Wilderness? Criteria used in defining of Cave Wilderness and values associated with a Cave Wilderness designation, is used to evaluate the 2009 federal legislation creating the Fort Stanton – Snow River Cave National Conservation Area as a potential step in the eventual creation of a designated Cave Wilderness.

1. Introduction

In 1872 the United States of America established Yellowstone National Park, creating the nation's (and the world's) first national park dedicated to conserve and protect the natural landscape for the enjoyment of the American public for generations to come. Since that time, public lands, under various special designations have been set aside for similar purposes. These public lands are managed primarily by the National Park Service (NPS), the US Forest Service (USFS) and the Bureau of Land Management (BLM). These three agencies have differing histories regarding the management of public lands for recreational use.

The NPS was established in 1916 expressly for the purpose of conserving public lands for the enjoyment of the American public and future generations. Of the three agencies mentioned, it is the only one that does not have a multi-use mandate.

The USFS was established in 1891 for the management of national forests. At that time the agency's primary focus was the management of forest resources for timber. In 1960, their mandate was expanded to include a sustainable multiple-use management concept, acknowledging the American public's increasing use of national forests for recreational purposes.

The BLM was created in 1946 from two federal agencies: the General Land Office (GLO) and the US Grazing Service. The GLO had been created in 1812 for the purpose of promoting and managing the settlement of the Western Territories of the United States. At that time the BLM managed its lands for grazing, mining and petroleum exploration and extraction. In 1976 the BLM's mandate was changed to include multiple-use management similar to that of the USFS, thus including the recreational values of the lands they managed. Despite wide-ranging recreational sites, most Americans continue to think of the BLM in terms of its original mandate.

Since the late 19th century the United States federal government has set aside lands for the enjoyment and recreational use of the American public. It would be another 150 years before there would be a designation that would preclude development of these lands beyond access and "primitive use"; and include the directive to preserve the lands in their wild state as wilderness. Supporters of the Wilderness Act sought to achieve such protection for public lands having extraordinary scenic value and which were untrammeled by the presence of man.

The 1964 Wilderness Act was eight years, eighteen public hearings and over 60 drafts in the making. Input was received from numerous organizations, agencies and private citizens via reports and testimonies. The National Speleological Society (NSS) and the Cave Research Foundation (CRF) submitted reports and testified during hearings advocating caves as Wilderness.

In 1962, the Outdoor Recreation Resources Review Commission (ORRRC) released *Wilderness and Recreation – A Report on Resources, Values, and Problems*. In this report the Commission addressed the idea of caves as potential wilderness sites. It failed to specifically support such a designation. The report did address the importance of caves as potential wilderness resources: *It is apparent that special study is needed to develop suitable definitions for these recreation resources, which can be applied in survey and management efforts* (ORRRC 1962, p. 4)

The ORRRC Report included as Appendix B a statement on cave resources authored by Raymond DeSaussure, a caver. DeSaussure represented neither the NSS nor the CRF. His commentary negated the value of caves as wilderness:

Once a wilderness area has been well explored and mapped, it is still useful as a wilderness area. But when a cave has been extensively explored by even a handful of people and the results published in journals and circulars of the field, the elements of discovery and exploration vanish. The cave becomes valuable as a recreational resource or, if its initial exploration has not been too damaging, as a scientific resource (DeSaussure, 1962, p. 323).

The final summation of Appendix B, while not supporting the idea of caves as Wilderness, did advocate for the development of management plans for caves on public lands. It is possible that this particular commentary was included as it may have reflected the Commission's lack of support for caves as Wilderness.

The 1964 Wilderness Act was landmark legislation, recognizing the need to preserve and protect wild lands of America. It created a land use designation called Wilderness. The legislation did not define which environments would or would not be considered as suitable for Wilderness designation; instead it used the all-encompassing terms of land and landscape. Neither caves, nor other ecosystems, were mentioned in the Act. Cave conservationists concluded that caves had not been excluded from potential Wilderness designation.

For the purpose of this paper: Cave Wilderness is defined as those caves and cave passages exhibiting exceptional scientific and cultural resources, and wilderness qualities. These sites display a high degree of wildness, in which the physical structure and ecological systems are largely unimpacted by humans and in which there is a sense of remoteness from the ordinary activities and works of humankind. Cave Wilderness is to mean those caves and cave passages in which stewardship shall protect the cave resources, its wilderness values, and future discoveries (Seiser 2003, Seiser and Schuett, 2006).

2. Attempts to Create Cave Wilderness

Efforts to gain Cave Wilderness status for Mammoth Cave, Mammoth Cave National Park, Kentucky occurred in 1967 and 1971 (Figure 1). An attempt was made in 1972 to create a Karst Wilderness of the Guadalupe Escarpment in New Mexico and Texas. This would have included caves located in both Carlsbad Caverns National Park, New Mexico and the region that would become Guadalupe Mountains National Park, Texas. All three attempts for Cave or Karst Wilderness designation failed (Seiser 2003).

Neither of the Mammoth Cave Wilderness attempts proposed Cave Wilderness beneath existing Wilderness designated lands. It was considered advantageous for Cave Wilderness to exist without an associated surface Wilderness, as there would be no conflict regarding management priorities between surface and subsurface resources (NSS 1967).

In 1974 the National Park Service (NPS) released the Draft Environmental Statement for the Master Plan and Wilderness Study for Mammoth Cave National

Park. The plan concluded that caves were not eligible for inclusion in the National Wilderness Preservation System precisely because the Wilderness Act did not address caves as potential Wilderness:

Much of the discussion about "underground wilderness" has focused on the Flint Ridge Cave System, which has been studied and mapped by scientists since 1947. The proponents of underground wilderness feel that the language of the Wilderness Act is broad enough to cover this concept except for the "semantic problems of subsurface acreage." Surely, caves are places where "man himself is a visitor who does not remain," and they provide truly "outstanding opportunities for solitude." On the other hand, the words "landscape," "area," and "land" all appear in the definition of wilderness in the Act and each refers specifically to the surface of the earth, according to the dictionary. Clearly, when considering passage of the Wilderness Act, Congress did not extend the concept of wilderness to caves or cave systems. In view of the fact that underground wilderness was not identified in the Wilderness Act, nor have underground wildernesses been established subsequently, the National Park Service neither endorses nor proposes underground wilderness for Mammoth Cave National Park (NPS, 1974, p. 48).

Figure 1. Main entrance to Mammoth Cave, Mammoth Cave National Park, KY. Photo by Patricia E. Seiser.

Following the release of the Draft Environmental Statement, the NSS submitted a legal brief showing that legally the term "land" encompassed both the surface and the subsurface. It also demonstrated that land could be divided by horizontal and vertical boundaries. In 1975, the Department of Interior sent a letter to the President noting: "there is no legal barrier to the designation of subterranean lands as wilderness" (Stitt 1993).

In 1988, Carlsbad Caverns National Park submitted a proposal for Lechuguilla Cave, a cave located beneath surface Wilderness, to be designated Cave Wilderness (Figure 2). Unfortunately, the National Park Service did not support the proposed designation. One consequence of the proposal was the establishment of official NPS policy that caves having all entrances within a Wilderness area will be managed as wilderness (Kerbo, 2002).

Lechuguilla Cave lies on the northern boundaries of Carlsbad Caverns National Park, adjacent to lands managed by the BLM. Currently there is no known passage that extends beyond the Park boundaries. However, geologic studies and mapping of known cave indicates a strong potential for Lechuguilla Cave to extend beyond this boundary. Concern for the protection of Lechuguilla Cave resulted in the passage of the Lechuguilla Cave Protection Act of 1993. The Act stated: Congress finds that Lechuguilla Cave and adjacent public lands have internationally significant scientific, environmental, and other values, and should be retained in public ownership and protected against adverse effects of mineral exploration and development and other activities presenting threats to the areas. BLM lands adjacent to Lechuguilla were withdrawn from all mineral and geothermal leasing and development. The Act protects unknown cave, then and

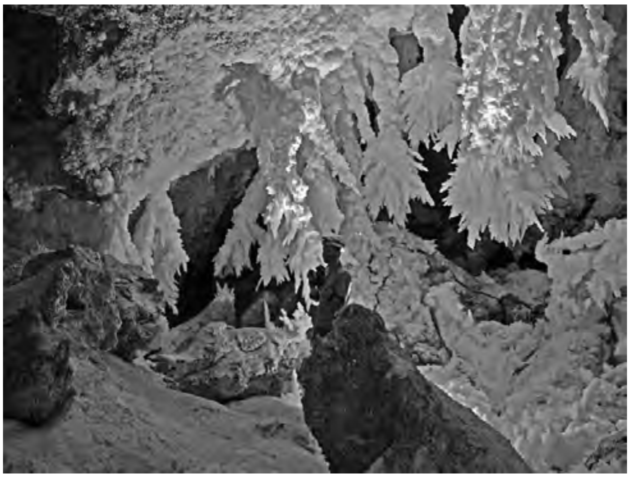

Figure 2. Max Wisshak in the Chandelier Ballroom in Lechuguilla Cave, Carlsbad Caverns National Park, NM. Photo by Patricia E. Seiser.

now. This was the first time that a cave or cave passages were given congressionally mandated protection without an associated special designation.

3. Fort Stanton Snowy River NCA

In 2000, the Bureau of Land Management took a major step forward in the preservation and conservation of public lands by creating the National Landscape Conservation System (NLCS). Individual sites would be known as an National Conservation Area (NCA). The mission of the NLCS is to "conserve, protect, and restore these nationally significant landscapes that have outstanding cultural, ecological, and scientific values for the benefit of current and future generations." The NCLS was created without Congressional authorization, existing at the pleasure of each president. As such, there was no guarantee that the System would be permanent. The National Landscape Conservation System received congressional approval as part of the 2009 Omnibus Public Land Management Act. The Act permanently unified BLM's NCAs as a public lands system. This marked the first new congressionally authorized public lands system in decades.

Fort Stanton Cave, located on BLM land near Capitan, New Mexico, has a long history of exploration beginning first with Native Americans. The earliest documented date is of soldiers from the nearby Fort Stanton in the mid-1800s. The cave is not only a significant recreational site, it is also an important site for science and exploration. In 1975 Fort Stanton Cave was named a National Natural Landmark.

In 2001 Fort Stanton Cave made caving headlines. After almost 30 years of work, following air through breakdown, cavers made a significant breakthrough. The discovery of Snowy River and its subsequent exploration has added, more than twelve miles to the known extent of the cave, bringing its current known length to approximately 20.5 miles, making it the third longest cave in New Mexico. Snowy River is named for a white calcite coating that spans almost the width of the passage, a dramatic contrast to the dark walls (Figure 3). The Snowy River passage alone is over ten miles in length and is considered the longest known cave passage in the world, as well as the largest cave formation. At the time of this writing, exploration continues and no end has been found to the passage.

In 2005, the Fort Stanton-Snowy River Cave National Conservation Area bill was first introduced to Congress. The bill was eventually folded into the 2009 Omnibus Act. The Fort Stanton – Snowy River Cave National Conservation Area (FSSRC NCA) was established to: "protect, conserve, and enhance the unique and nationally important historic, cultural, scientific, archaeological, natural, and educational subterranean cave resources of the Fort Stanton – Snowy River cave system" (BLM,2011).

In preparation for the NCA designation the BLM conducted a Wilderness inventory. It was determined that no portion of the proposed NCA had Wilderness characteristics. Due to the presence of multiple roads, no areas within the NCA qualified for management as wildlands (BLM, 2011). Although there would be neither Wilderness nor wildland management associated with the Fort Stanton – Snowy River Cave NCA the cave would be given priority in management planning, while allowing for appropriate surface usages.

4. Discussion

Fort Stanton Cave has had extensive of visitation. Much of the 8 miles of passage mapped prior to the Snowy River discovery does not lend itself to Cave Wilderness consideration. However, the extraordinary nature of the Snowy River Passage and its growing remoteness, both in time and distance, gives pause for consideration.

Figure 3. Donald Davis examining Snowy River in Fort Stanton Cave, Fort Stanton – Snowy River Cave NCA. Photo by Patricia E. Seiser.

Legislation creating the Fort Stanton – Snowy River Cave National Conservation Area is evaluated using the seven value related themes associated with a Cave Wilderness designation (Seiser, 2003; Seiser and Schuett 2006) and the eight criteria identified as important to defining the idea of cave wilderness (Seiser, 2003; Seiser and Schuett 2006). The intent of the evaluation of the FSSRC NCA legislation is not to suggest that a de facto Cave Wilderness has or has not resulted**,** rather, that it has set the ground work for the creation of a Cave Wilderness at some point in the future; whether at Fort Stanton Cave or elsewhere remains to be determined.

As noted earlier, the FSSRC NCA was established to: protect, conserve, and enhance the unique and nationally important historic, cultural, scientific, archaeological, natural, and educational subsurface resources. These closely align to values associated with cave wilderness designation (Table 1). The one significant value lacking is experiential; a value closely associated with any wilderness experience.

The FSSRC NCA addressed six of the eight criteria defining the idea of cave wilderness (Table 2). The legislation language lacked "visionary impact" and "experiential values." Although protection and conservation are addressed, the legislation did not specifically mention meeting future generation needs and values; a component critical in the definition of visionary impact.

The significance of the Fort Stanton – Snowy River Cave National Conservation Area lies in the establishment of a designation for the protection of scientifically notable caves, regardless of their wilderness values. It has created the management priority for cave resources while allowing appropriate (non-impacting to subsurface resources) surface usage; thus setting the scene for potential subsurface designation is another step toward the establishment of a Cave Wilderness designation.

Table 1. Protected Areas Values Typology.

Protected Areas Value Typologies	
Cave Wilderness	Fort Stanton Snowy River Cave
Designation Values[1]	National Conservation Area Values[2]
	To protect, conserve, enhance
	the historic, cultural, scientific
	archaeological, natural,
	and educational cave resources
Experiential	No
Research & Monitoring	Yes
Existence	Yes
Educational	Yes
Future	Yes
Resource Protection	Yes
Protecting Water Quality	Yes
Protecting Air Quality	Yes
Protecting Wildlife Habitat	Yes
Preserving Unique Wild	Yes
Plants & Animals	
Protecting Rare &	Yes
Endangered Species	
[1] Seiser 2003	
[2] Omni Bill 2009	

5. Conclusions

While there are currently no discussions for cave Wilderness on a federal level; a bill has been introduced in the United States Senate entitled "Oregon Caves Revitalization Act of 2013." The legislation includes a Scenic River designation for the subterranean River Styx that flows through Oregon Caves National Monument, located near Cave Junctions, Oregon.. This designation would be the first time the Wild and Scenic Rivers Act will have been applied to a waterway that flows through a cave.

The National Park Service has a long history of protecting and managing exceptional cave resources. Both Mammoth Cave and Carlsbad Caverns National Parks are World Heritage Sites. A Scenic River Designation for the River Styx provides increased protection for the cave resources. It supports the idea that caves are valuable and treasured ecosystems that deserve special protection. This is another step toward a potential Cave Wilderness designation for a cave within the National Park Service system.

It would be a reasonable to assume that the first designated Cave Wilderness would be found on NPS managed lands.

The Bureau of Land Management has had legislation recognizing that cave are of national interest. The first addressed the protection of unknown cave and the second recognized the significance of a specific region within a cave. While the BLM is commonly associated with grazing, mining and petroleum extraction it would not be unreasonable to wonder if they will manage the first federally designated Cave Wilderness.

The question appears to no longer be if there will be a Cave Wilderness designation; but of when.it will be established. It is also, which agency will be the first to have the honor of managing a federally designated Cave Wilderness.

Cave Wilderness is not an intuitive concept. Understanding the associated values is critical to understanding the idea of Cave Wilderness. So too is an understanding of the intentions of the designation. The objectives delineate Cave Wilderness stewardship goals without placing specific restrictions or requirements on how they are to be achieved, thus allowing each designated site to be managed as appropriate to protect the values and resources for which it was designated (Seiser and Schuett 2006).

Acknowledgments

I would like to thank those employees of the Bureau of Land Management having the insight and courage to defend that which is not readily visible nor understood by the average individual. My father would have been proud of your work.

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Table 2. Protected Areas Values Typology

Criteria Important in Defining the Idea of Cave Wilderness	
Intent	Is the designation for resource protection or recreation and knowledge? It is necessary to define what is being protected and from what activities or events. Cave Wilderness should not be established primarily for recreational purposes.
Visionary Impact	Designation must protect caves based on today's knowledge and values and preserve caves and cave resources for future generation's needs and values.
Scientific Values	Designation must provide protection of the cave's scientific values and resources, for study now and in the future, including preservation of future discovery opportunities.
Experiential Values	Designation must provide for the protection of individual's ability to have a wilderness experience that offers the perceptions of solitude, remoteness, and self-sufficiency.
Access	Access restrictions would occur for the protection of the cave resources, but should not result in permanent closure of the cave. Rationales for limiting access include the existence of other caves open for recreational purposes and the ability to provide alternative ways to experience the cave via the use of photographic and videographic imagery.
Resource Protection	Designation will need to provide protection for physical, biological, and other components of a cave, preservation of the cave's natural state, its original resources, and recognition of resource fragility. The designation will address surface as well as subsurface activities that may impact upon the cave resources. It will also need to provide protection for the human dimension aspect of a cave – protection of physical and social sciences' values, aesthetic values, wilderness values, and other values.
Education	Specially designated caves can serve as educational resources (with or without requiring physical visitation), generating public awareness of the significance of caves.
Management	Designation must recognize that each cave is different. It would be necessary to tailor management practices to meet specific cave needs. Specific management should evolve from cave resources (physical and social sciences) and skill requirements.
From: Seiser and Schuett, 2006	

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KARST AREAS AND THEIR PROTECTION IN THE CZECH REPUBLIC

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Karst areas of the Czech Republic are valuable natural and culturally-historical heritage. The most valuable localities are protected in natural reserves and natural landmarks and in several protected landscape areas. The nature and landscape protection act regulates the protection of both surface and subterranean karst phenomena. Caves not open to the public are also an object of the protection of the system Natura 2000 within the whole European Union.

1. Introduction

Karst areas in the Czech Republic are remarkable types of landscape which still hide various secrets. Are there in densely populated areas any places of which we can say that no human foot has yet entered them? If so, are such places free of human influence? The first question can be unhesitatingly answered in the positive: the second must be answered in the negative. Areas where this is fully true are karst areas, in particular the Moravian Karst.

Although karst areas are known mainly for their specific landscape hosting caves and other underground and surface karst phenomena, their natural and cultural heritage is no less particular and important.

The Czech Karst is located near Prague and is visited by high number of visitors. It's environment is distinguished by preserved areas of rock steppes, forest steppes and deciduous forests with rich flora and fauna, one example being the endemic *Sorbus eximia* (Rosaceae) (Ložek et al. 2005). A similar situation is in the Moravian Karst. Cortusa matthioli subsp. moravica (Primulaceae) belongs to the endemic species. It grows in the Macocha Abyss at its only locality in the Czech Republic (Štefka et al. 2007).

Figure 1. Cortusa matthioli subsp. Moravica.

18 out of 23 bat species hibernate in caves of the Moravian Karst; The cave fauna is diverse, many of the cave animals, such as springtails (*Arrhopalites ruseki* and *A.pygmaeus*), being described on the basis of discoveries in the caves of the Moravian Karst and some of them are considered to be endemics (Šťastná et al. 2003).

Karst areas are significantly important for geology and paleontology. Within the Czech Karst we can mention the global boundary stratotype between the Silurian and Devonian geological periods at Klonk near Suchomasty. The Moravian Karst is the largest and the most affected area in terms of karstification of the Czech Republic harboring the two longest cave systems of the Czech Republic and over 1,000 caves.

Figure 2. Amatérská Cave.

Cave sediments have preserved unique evidence of past life, including artefacts and remains related to the development of humankind. Prehistoric tools and animal bones from the cave at Stránská skála near Brno prove the existence of *Homo erectus* settlements. Many caves were inhabited by Neanderthal man; settlements of modern *Homo sapiens sapiens* people of the Aurignacian culture have been documented in the Mladeč caves in Litovelské Pomoraví; the sediments found in the Pekárna cave in the Moravian Karst provide evidence for people belonging to the Magdalenian culture; the discovery concerning the Hallstatt period made in the Býčí skála cave by Dr. Jindřich Wankel is nowadays being interpreted as a cultic place with sacrifices, including human sacrifices.

Karst areas deserve the protection for their both animated and inanimate nature. In the Czech Republic these areas are protected in several categories of protected areas. Even the cave protection is set down in the law. Examples of the karst phenomena protection are presented on the example of the Moravian Karst.

2. Protected karst areas in the Czech Republic

The first protected areas declared in the territory of the current Czech Republic also includee karst areas. The Pekárna cave (now a national natural monument) has been protected since 1933, the surroundings of the Macocha Abyss with Pustý and Suchý žleb (now a national nature reserve called Vývěr Punkvy) have been protected since 1930. Protection of the Moravian Karst as a large protected area dates back to 1956 and the Protected Landscape Area of the Czech Karst was declared in 1972. The strictest protection is applied to both surface and underground karst phenomenon from natural reserves and natural monuments. In the Moravian Karst there are four national nature reserves, two national natural monuments and ten nature reserves declared in order to protect the karst phenomenon. By implementing the EU standards into Czech legislation (in particular the Habitats Directive No. 92/43/EHS on the conservation of natural habitats and of wild fauna and flora) over 1000 caves not open to the public are protected in the Moravian Karst. The underground Punkva system with its coherent areas of swallow holes and springs has been included in the list of internationally important wetlands under the Ramsar Convention since 2004 as the only karst area in the Czech Republic protected as wetland.

Figure 3. "Kolíbky" in National natural monument Rudické propadání.

3. Cave protection within the Czech law

By adopting Act No. 114/92 Coll. on the protection of nature and landscape a special section on protection of caves has been stipulated in the Czech legislation.

§ 10 (extract)

Cave protection and utilization

(2) It is forbidden to destroy, damage or modify caves or otherwise change their preserved condition.

(3) For exploration or research in caves the permission of a nature protection authority is required.

(4) Natural surface phenomenon (such as karst sink holes, limestone pavements, swallow holes and springs of karst waters) enjoy the same protection as caves.

(5) In a case where a cave is found when exploiting mineral resources, the person authorized to exploit the resource is obliged to notify a nature protection authority of this fact immediately. The person is also obliged to interrupt, for a reasonable period of time, any exploitation work which might damage the respective cave, and to provide documentation of the cave at his or her own expenses.

§ 61 (extract)

State's right of first refusal and funding of land buy-out

(1) Owners of land in the vicinity of caves are obliged to offer such land to a nature protection authority preferentially in case of its intended sale.

(3) Caves are not part of the land and are not subject to ownership.

The offices charge with public administration and protection of nature and landscape in protected areas are the following: the Administrations of Protected Landscape Areas as regional offices of the Agency for Nature Conservation and Landscape Protection of the Czech Republic. Taking the Moravian Karst as an example, we can describe a few issues which such offices have to solve, to protect karst areas. Cave protection cannot be perceived only as protection of the cave ecosystem. For permanent preservation of this unique heritage the reasonable utilization of the adjacent surface is also essential.

4. Protection of show caves

In the turn of the 19th and 20th century the caves of the Moravian Karst were being open to the public. Often insensitive works for their accessing., the high number of visitors and insufficient protection of the unique underground world had a damaging and in some places devastating effect. In many places up to 50 % of the original dripstone decoration is missing and some important speleothems are replaced by artificial models. Intensive illumination gave rise to "lampenflora".

In accordance with the law, the Administration of the Protected Landscape Area of the Moravian Karst has set conditions of nature conservation for utilization of the caves as show caves. For example – limits for numbers of visitors, time limits for visits and time between visits, switch light off between visits and rule to have two guides in larger groups.

5. Speleological exploration

The history of speleological exploration in the Moravian Karst has a very long tradition. Besides the undoubtedly major and important findings that speleology has brought it has also involved significant interference with karst phenomenon. By blasting off the siphons the hydrology of the underground streams has been changed and the archeologically and paleontologically valuable sediments were dug through, often without any appropriate scientific assessment. The dripstone decoration has been destroyed in many places. Now there are neither swallow holes nor

Figure 4. Punkevní Caves.

Figure 5. and 6. Pustožlebská zazděná Cave in 1943 and in 2010.

springs without more or less intensive human interference in the Moravian Karst. Only a few larger sink holes have not been dug through with the aim of penetrating the underground.

Speleological exploration in the Moravian Karst is currently carried out by non-professional groups mostly under the auspices of the Czech Speleological Association. The Administration of the Protected Landscape Area permits speleological exploration and sets conditions to such groups, in particular for the reason of protection of wintering bats, sets the framework of cave enclosures, the scope of documentation, etc. In the most valuable caves we also set routes for visitors. On the other hand, we provide finances for example for repairs and reconstructions of cave enclosures or removal of remains after previous speleological exploration.

6. Species protection

The characteristic group are bats (*Chiroptera*). There have been 23 species found in the Moravian Karst. 18 species are known to hibernate in the caves. In the Moravian Karst active protection of bats is focused mainly on protection of the wintering localities. Three out of five caves open to the public, which are important wintering localities, are closed for a part of the year (December–February). At the beginning (November) and at the end (March–April) of wintering the number of tourist entries to the cave is limited and so are other activities such as music concerts, maintenance and other work. Speleological activities in the caves not open to the public but populated by bats for wintering are either completely forbidden or limited in those places where bats formed colonies.

Other problems which directly or indirectly relate to protection and utilization of the caves are briefly the following:

1) Motor vehicles are forbidden on the karst canyons of Pustý and Suchý žleb, also the parking places near the most-visited Punkva Caves.
2) Guidelines for agricultural land management above the Amateur cave system were established, in particular the grassing over the sinkhole surroundings and areas above the caves is forbidden.

Figure 7. Rhinolophus hipposideros.

3) Construction of wastewater treatment plants in municipalities in swallow hole areas with direct connection to the cave systems is forbidden.

7. Conclusion

Karst areas represent types of landscapes with extraordinary inanimate and animated nature and also with numerous sights of mankind development. In the Czech Republic the protection of many of them is guaranteed by their declaration of protected areas.

We must realize the quality and value of the area in all surface / underground connections when planning, assessing and realizing all activities in these areas. We must never forget that it is a sensitive ecosystem. Just as we can never replace a damaged work of art, we can never replace a broken fragile dripstone.

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THE CAVE ANIMAL OF THE YEAR – AN EASY WAY TO WIDE-SPREAD PUBLIC RESONANCE

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Since 2009 the Verband der deutschen Höhlen- und Karstforscher e.V. VdHK (German Speleological Federation) participates in the public campaign "Nature of the Year" of German nature conservation NGOs by proclaiming the "Cave Animal of the Year". Providing a homepage with detailed information material and pictures, which is linked to the official Nature of the Year pages, guarantees broad attention of the media and general public. As a result, cave animals are discussed in kids magazines, school calendars and print media from garden club journals to daily newspapers. The VdHK also supplies information folders which are distributed among show caves and other interested members. With a comparable small financial and technical budget, the Cave Animal of the Year is an easy way to reach cavers and the public.

1. Introduction

Two of Germany's major nature conservation societies, the Naturschutzbund Deutschland NABU and the Landesbund für Vogelschutz LBV, declared the first "Bird of the Year" in 1971. The election criteria were the endangerment of the species and its habitats by human activities. The campaign was so successful that it was copied soon by other countries. Nowadays, Birds of the Year are presented not only in Europe but from South Africa to New Zealand. In the 1980s other organizations joined the campaign with other fauna and flora.

Now over 40 different species and habitats are elected – Tree of the Year, Cactus, Poisonous Plant as well as Fish, Dragonfly and Mollusk of the Year. The concept was even extended to non-living things or more abstract units like the River Landscape, Alley and Rocks of the Year. One German authority also joined – the Federal Environment Agency is proclaiming the Type of Surface Waters of the Year to bring attention to the EU Water Framework Directive. At an international level NaturFreunde are responsible for the Landscape of the Year.

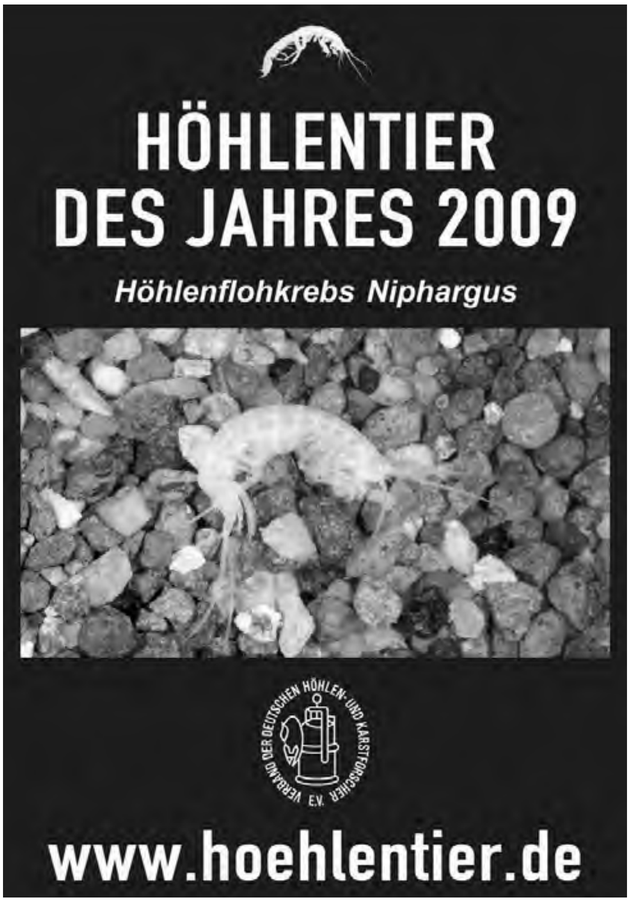

Figure 1. Poster with Niphargus.

Figure 2. Poster with Scoliopteryx libatrix.

2. Cave Animal of the Year

The first public campaign of VdHK was the Position Paper on Cave Tourism in Wild Caves, developed by the speleological federations of Switzerland, Austria and Germany in **1998**.

Since no strong network existed in Germany at that time, support was low and results were minimal. It was found to be very difficult to sensitize authorities for cave protection.

Due to the fact that environmental protection is mostly based on biology, the VdHK decided to declare a national "Cave Animal of the Year".

By publishing facts about the life history and habitat protection, wider public attention was sought with the ultimate goal to intensify the general discussion on cave protection.

In **2009**, the genus *Niphargus* was chosen as the first Cave Animal of the Year. As an eutroglobiont, a real cave animal, colorless and without eyes, an interesting type of movement and a photogenic appearance, it was chosen as the perfect animal to start with.

Figure 3. Poster with Myotis myotis.

In **2010** the Herald Moth *Scoliopteryx libatrix* was highlighted. This beautiful animal is easy to observe and thus has at least been seen by all cavers. It was chosen to arise interest in biospeleology within the caving community, but also to demonstrate that there are much more animals hibernating in caves (i.e. subtroglophil) besides the well-known bats. The project was supported by Musee national d'histoire naturelle du Luxembourg.

2011, being the international Year of Bats, *Myotis myotis* was elected in cooperation with EUROBATS, who supported the campaign and delivered the Cave Animal of the Year information material to their members.

2012, the Large Cave Spider *Meta menardi* was presented in cooperation with European Society of Arachnology as both: European Spider of the Year and German Cave Animal of the Year. Due to its size and prevalence it is one of the most conspicuous cave inhabitants.

Figure 4. Poster with Meta menardi.

2013, the fungus gnat *Speolepta leptogaster* is promoted to Cave Animal of the Year. Genetic studies on this species started in 2012.

3. Homepage and Handout

The website www.hoehlentier.de started with the first Cave Animal of the Year in 2009 and is linked to all national "Nature of the Year" pages.

For each presented animal, information on life history, ecology and geographical distribution is available. Subterranean ecosystems, cave protection and biospeleology are explained as well as a call for action.

A press release is submitted including photographs to ease public relations. Poster and flyer can be downloaded. Printed versions are offered to all German show caves and VdHK members. First requests by the media are usually received in October of the previous year, therefore the next Cave Animal of the Year is chosen in summer and the new campaign is organized that autumn.

Figure 5. Poster with Speolepta leptogaster.

4. Outcome

Over the years, the interest of the media in the Cave Animal of the Year has greatly increased, and there is a wide-spread coverage in the media. More than 70 newspapers and magazines annually report on it, furthermore there are publications in calendars, school materials, etc.

In 2012, the homepage of the Cave Animal of the Year received on average 250 hits per week. 9,000 flyers and 250 posters were distributed.

5. Perspective

In 2011, the first European Cave Animal of the Year was declared. If other speleological federations are developing interest in the campaign, a worldwide initiative should be conceivable.

It is not essential to declare a worldwide species, because of the wide geographical scale a family or order could be chosen. Federations of continents and each country could easily join and consider which species, family or order should be declared.

Within the European Union, the Flora-Fauna-Habitat Directive declares habitat type 8310 "Caves not open to the public" as a habitat which has to be protected. The organized speleology now has the obligation to contribute its knowledge.

The Cave Animal of the Year was the first widespread step of VdHK to sensitize its members towards biospeleology. Learning and training workshops for the determination of common cave species with a special focus on the EU Flora-Fauna-Habitats Directive are now following. But it is still a long way to a nationwide coverage of biospeleological research, as demanded by the EU.

Just as the animals themselves, their habitats are endangered. To enforce cave protection, wide-spread cooperation is necessary. Another easy way to create public awareness could be to declare an "Endangered Cave of the Month / Year" on national and international websites. Best practice and worst case examples could be published. Effective public relation work for the benefit of cave protection should be based on the slogan "Acting local, thinking global and cooperate over borders!".

Acknowledgments

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Web layout: Tobias Busch (Bad Hersfeld).

Flyer and poster layout, dispatch: Torsten Kohn (Berlin).

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VdHK Head of Department for Biospeleology: Dieter Weber (Hassloch).

A special thank goes to the European Speleological Federation FSE for spreading Cave Animal and European Spider of the Year 2012 information and materials to their members.

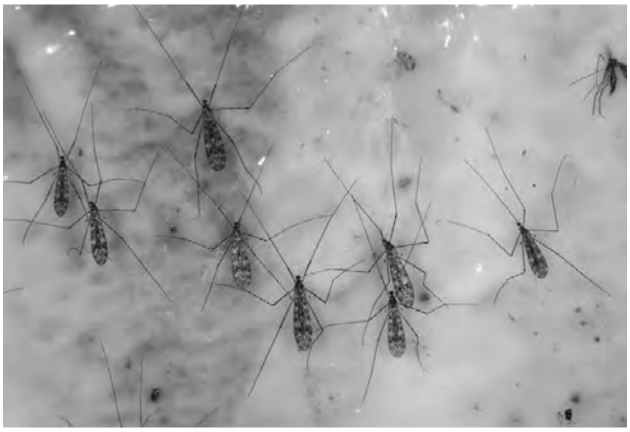

Figure 6. Limonia nubeculosa. Photo Klaus Bogon.

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THE BRANDS AND GEOTOURISM SUSTAINABLE DEVELOPMENT OF SHOW CAVES IN CHINA

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At the beginning of reform and opening-up in China in 1980s, there was a saying of "the exploitation of one cave can stimulate whole county's economic development", more than 300 caves were exploited, some of them are successful incredibly, but some not, even closed in the past 30 years. Cases research showed that the former had similar growth model: they carried on a sustainable development through establishment of brands such as geopark, natural heritage and national scenic area, the later not. The brands attracted more investment and good management, who explored more geosites and geotourism to achieve big changes from geotourism site to geotourism park, from low level management to modern management, from one county to a province, from independent to cooperation, from single business to multi-business, from bureaucratism to service government.

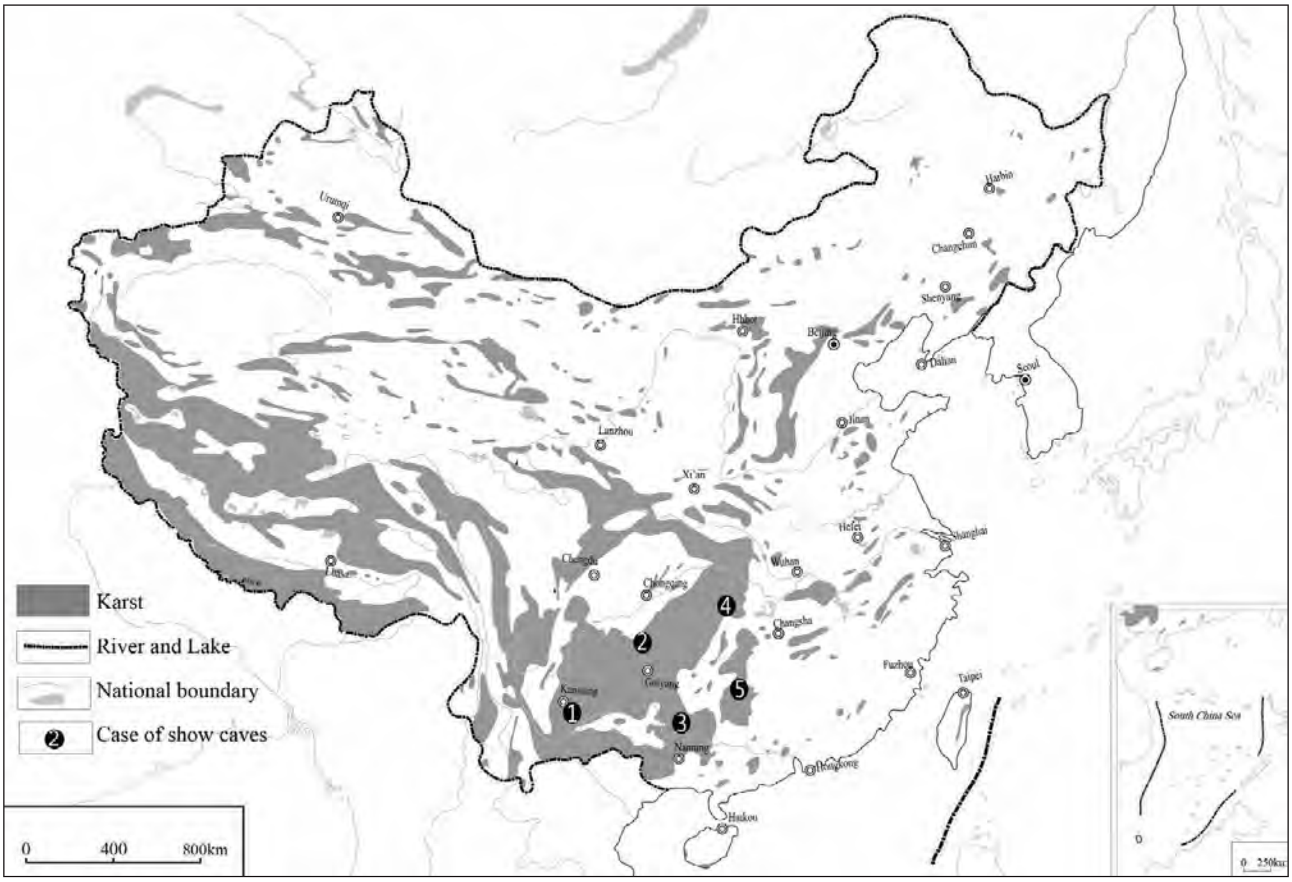

Figure 1. Distribution of limestone karst and cases of show caves in China. 1 – Alugu Dong, 2 – Furong Dong, 3 – Crystal Cave, 4 – Huanglong Dong, 5 – Wanhua Yan.

1. Introduction

Since the reform and opening-up in China in 1980s, all business came into market economy including tourism. It gave a good chance for farmer to find geosites to exploit and shared the profit with local government. The best way is a cave, because a cave is easier to find, easier to exploit, easier to invest, easier to construct, easier to manage and sell tickets, easier to make promotion and easier and more quickly to get profit than other geosites, in particularly China has a widespread of carbonate rocks of 910,000 square kilometers in outcrop (Fig. 1, Li and Luo 1983), thousands of caves are developed in these carbonate rocks, most caves are within an almost continuous carbonate outcrop of 500,000 square kilometers (Yuan 1991) that underlies the provinces of Guizhou and Guangxi and also extends into Yunnan, Sichuan, Chongqing, western Hunan, western Hubei and northern Guangdong.

According to statistics there are 3,319 discovered in China and 60 % of caves are developed in southern China (Zhang, 2010), about 10 % of them have been exploited to be show cave.

2. Cases

2.1. Alugu Dong

Alugu Dong is located to the southeast of Kunming city (Figures 1, 2) in Yunnan Province; it was discovered and exploited by a primary teacher in 1988, which was the first geotourism site in Luxi County. It received 71,000 tourists and got 3 million Yuan ($500,000) for 5 Yuan ticket each in 1989, where even the third national karst conference was invited to be held. “the exploitation of one cave can stimulate whole county’s economic development” was first proposed in the meeting. After that the local government controlled it and it received half million tourists and 6 million Yuan profit every year till 1998. The rise of the show cave not only stimulated other tourism industry development in the county, and led related industries’ fast development such as transportation, restaurant, hotels, etc., creating more than 6,000 jobs, but also the tourists brought tremendous information and material, and the old agricultural county town changed to be a modern town, with spacious straight concrete road, lined with hotels and rich people.

The Alugu Dong created more than 10 years splendid story of economic growth in Luxi County, but its development immobilized when entering new century, it withdraw from the show caves competition, it was defeated by itself.

Figure 2. The king Wei and his soldier chamber (Photo: Zhang Yuanhai).

2.2. Furong Dong

Furong Dong is a magic of show cave and it created a Wulong County developed mode.

Furong Dong is in the Wulong County of southeast of Chongqing city (Figures 1, 3). It was explored by the Sino-British cave expedition team in 1993. It was a beautiful cave and Wulong government invited Professor Zhu Xuewen, who was the president of committee on speleology of China, and his team to make design and planning. Zhu proposed the exploitation of Furong Dong, like Alugu Dong, would definitely bring about another “the exploitation of one cave can stimulate whole county’s economic development”. Wulong government accepted his suggestion and opened it up in May, 1994. It received 120,000 tourists by February next year. Then, the Furong hot spring, Sanqiao natural bridges and Xiannv Mt. were exploited gradually, it got lots of profit, but it did not stop promotion. After that Wulong government applied in time for national geopark in 2001 and listed in the world natural heritage in 2006.

Because of the good brands, Chongqing Municipality invest the road from Chongqing to Wulong, which changed from the second class road to the highway and the drive time from Chongqing to Wulong decreased from 8 hours to 3 hours. Wow! Lots of outside investment flooding flowed onto Wulong county, the tourists and income increased 30% annually, 3 four-star class and 2 five-star class hotels have been established in this small county town, it developed super-normally in Wulong.

Figure 3. Crystal towers in Furong Dong (Photo: Zhu Xuewen).

It created a Wulong mode: starting from a show cave, an old, small, side and poor county turned into a large tourism county, depending on the idea of creating opportunities and no wasting it, and daring in thinking and action.

2.3. Crystal Cave

Crystal is a catalyst for tourism development in Bama County in Guangxi Province (Figures 1, 4), which is in the southeast of Leye-Fengshan Global Geopark.

Before its discovery by the Sino-British cave expedition in 2005, Bama got the brand of the fifth longevity town in the world in 2001, but the county’s tourism was under developed without any outside investment and any geotourism.

In May, 2008, Crystal cave was opened to the public with the highest price of 180 Yuan in China and got 10 million Yuan in 8 months. The tourism began fermentation catalyzed by Crystal cave after its establishment of national scenic area, and in particularly the setting up of Leye-Fengshan Global Geopark in 2010. It received nearly 100 million tourists a year and increased 45% of tourism revenue. Similarly to Wulong County, Bama county was poured into many outside investment covering tourism, mining, green food, health, resort hotels and so on.

Figure 4. White formations in Crystal Cave (Photo: Zhang Yuanhai).

2.4. Huanglong Dong

Huanglong Dong is located in Zhangjiajie City of Western Hunan Province (Figures 1, 5); it is the richest show cave in China with 100 million Yuan profit each year.

It was exploited in 1983 and set up the brand of world natural heritage in 1992; it had a brilliant story before 1996. After that it immobilized being short of modern management and even closed.

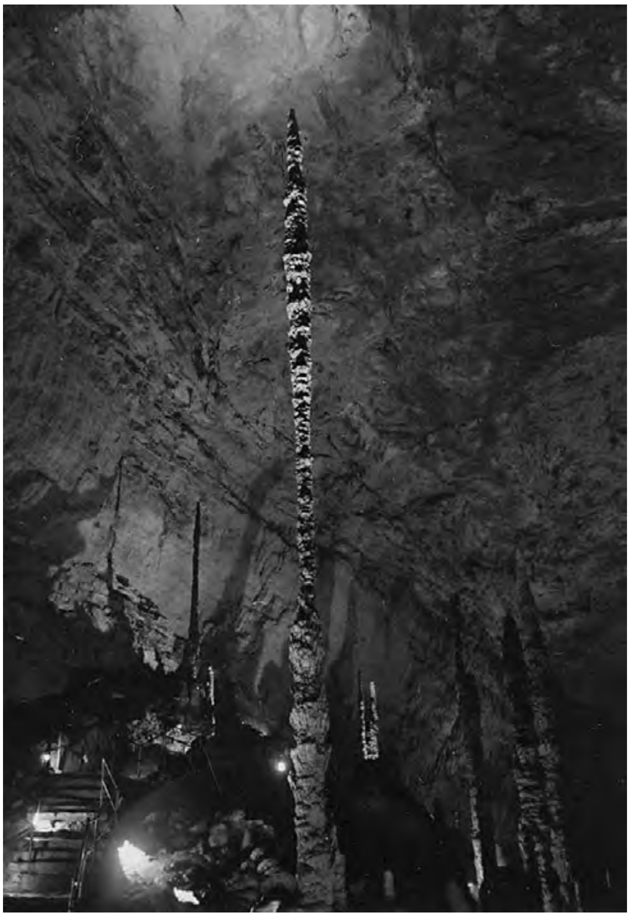

Figure 5. Magic needle in Huanglong Dong (Photo: Zhu Xuewen).

The local government had to rent it to a Beijing company for 45 years by 4.5 billion Yuan, the local government holds some shares. The Beijing company had it redesigned and reorganized recruiting staff. In 2004, it applied the global geopark successfully and got splendid future.

2.5. Wanhua Yan

Wanhua Yan is situated only 5km away to the west of Chenzhou city in Southern Hunan Province (Figures 1, 6).

Like the show caves mentioned above, Wanhua Yan had a wonderful story from 1985 to 1996, now it struggled along without any outside investment, although It has a very good situation of tourism.

It applied the national geopark last year, but it lost lot of chances.

Figure 6. Magic flowstone in Wanhuayan (Photo: Zhang Yuanhai).

3. Analysis

From five cases above, three show caves realized sustainable development, but two failed.to. The obvious reason is that the successful ones had set up good brands, but the other two not.

All the show caves had good development at the early stage of tourism, it is always attractive for tourist because it is a new geotourism site, however it is beautiful or not, wherever it is in small county or big city. It will develop slowly and slowly after the neighbor tourists finish sightseeing. It need further promotion to attract tourists outside the county, for example, it needs to set up a brand to make good promotion, then outside investment and specially new idea can bring into.

The first case of Alugu Dong is a county institution, with unclear property rights, rectitude, property owners and bureaucrat habits, it determined its fate of its development. During its prosperous period, one third of tourists did not buy tickets to visit show cave for their leadership, management loosed over time and the staff did not work actively. The managers are helpless facing heated market competition, when neighbour tourism develops fast.

The last case of Wanhua Yan is also a county institution, it had also disappointing growth even it applied national geopark last year, for it lost the chances to make promotion without much money, and especially it is short of modern management.

Depending the successful geotourism development, it indicated that they had similar growth mode: they carried on a sustainable development through establishment of brands such as geopark, natural heritage and national scenic area. The brands attracted more investment and good management, who explored more geosites and geotourism to achieve big changes from geotourism site to geotourism park, from low level management to modern management, from one county to a province, from independent to cooperation, from single business to multi-business, from bureaucratism to service.

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THE DEVELOPMENT OF CHOM ONG CAVE AS AN ECOTOURISM DESTINATION IN NORTHERN LAOS

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The Chom Ong Cave was identified in 2006 by the provincial tourism department for the purpose of ecotourism as part of rural income creation. The following development was done in cooperation with the German Development Service DED (now GIZ). The Northern Lao – European Cave Project joined later in 2009 for the phase of complete exploration and creation of maps, photos and geological assessment. As a result of this cooperation, promotion material was created which attracted first media appearances. The cave can now be visited on a three day tour program. It is with a length of 17,150 meters the 3rd longest cave of Laos and 10th longest in Southeast Asia.

1. Introduction

The Chom Ong Cave is located in the heart of Northern Laos near the capital of Oudomxay province. It is a region with a major crossroad connecting it to the neighbouring countries of Thailand, China and Vietnam and makes Oudomxay a traditional trading place with large markets. The cave became known when it was identified by the Lao government in 2006 as a potential object for ecotourism development in order to diversify income and reduce poverty in remote areas. Since then, measures were taken to prepare the village for development of the cave in line with principles of ecotourism. This was driven by the Provincial Tourism Department in close cooperation with the advice of the German Development Service (DED, now GIZ) and the local village community in Ban Chom Ong. It coincided with the activities of the Northern Lao-European Cave Project (the project) – an international group of speleologists who have been active in Laos since 2002. Their mission is the exploration and documentation of the major caving areas of northern Laos in cooperation with local authorities and international development organisations.

Figure 1. Location of Chom Ong cave in Northern Laos (star). It is at the center of Oudomxay province which has a road network linking China, Vietnam and Thailand with Luang Prabang.

The project became aware of the existence of caves in Oudomxay province by the promotion of Chom Ong cave on the internet page of the tourism administration as part of ecotourism based trekking activities. It was claimed that this cave is one of the longest in Laos and an end had not been found. This stimulated great interest for proper exploration and the Oudomxay Tourism Department was contacted in December 2008. At this time the first infrastructure work was already finished and the survey of the cave was one of the next planned activities. It was quickly agreed to cooperate and a team of six speleologists arrived mid of January 2009 which was followed by two more visits in 2010 and 2011.

This article provides an overview of the geographical settings, the documentation and survey of the cave as well as the established marketing and promotion material. It summarizes the results of the cooperation and concludes with an outlook on the future perspective.

2. Geographical settings and infrastructure

Ban Chom Ong is situated in Xay District 25 km east of the provincial capital in a highly mountainous area with difficult access of 2.5 to 3 hours by road (Figures 1, 2). This is particularly true in the rainy season when only 4x4 vehicles can travel along the muddy roads. Chom Ong area comprises 5 villages with 353 households and a population of 2,500 people (Fig. 3). The poverty rate is 31 %. The only available occupation is largely subsistent farming. Shifting cultivation (slash and burn) is the common production method, which, due to government regulations is reduced each year. Due to the lack of other income opportunities, farming is the only way for the population in the area to make a living. However, the production is only sufficient for 7 month of the year. Therefore during the rainy season many people have to work at the fields of other villages to earn money or rice.

As first phase of the project, toilet and bathroom facilities were installed, as well as ceramic filters supplying clean drinking water. Later a tourist guesthouse for overnight stays of 15 persons was built (Fig. 4). It is done in local style and consists of traditional interweaved bamboo walls and wooden floors. A separate kitchen area is attached to it. Later as preparation to receive foreign travellers, workshops in tour guiding and cooking were arranged by the GIZ.

Figure 2. Mountainous landscape north of Chom Ong village.

Figure 3. View of Chom Ong village with the surrounding karst hills appearing immediately behind the houses.

Figure 4. Main guest house for overnight stays with the main sleeping and eating room.

3. Cave development

The cave entrance is reached by a scenic path along the fields and later through monsoon forest. During the one hour walk, the river resurging from the lower entrance of the cave is crossed several times. The Chom Ong system stretches along a 4 km long mountain ridge. A river enters through a block fall at the northern end and resurges 4 km later at the southern tip of the ridge. The cave has four entrances with the main entrance being an upper dry passage on the southern end of 8.5 m width and 4 m height (Fig. 5). The ridge hosts impressive river and fossil passages with dimensions 20 m wide and 25 m high (Fig. 6, 7). The cave can be toured as a through trip and the whole traverse takes 3.5 hours with an additional 1.5 hours to return from the northern entrance to Chom Ong village. The cave river and the fossil level are connected by steep passages and shafts in several places. A large tectonic fault resulted in two huge overlaying chambers measuring 100 m by 30 m in length/width and a height of up to 50 m each. From here the cave changes the character to one main river passage with two more upper levels of partial passage. The northern entrance is very narrow due to blockage by stones and mud. It requires some squeezing and is not suitable for normal tourists.

The survey of the cave was performed by using compass and clinometer for horizontal and vertical directions and a laser distometer for distances between the survey points. For each point, horizontal and vertical dimensions were recorded and details sketched at site in a scale of 1:1,000. Three parallel teams took only 5 days until the system was surveyed to a length of 11.3 km. On the last day a connection between the four known entrances was achieved. By 2011 the cave system was extended to its final length of 17,150 m (Fig. 8). It is the 3rd longest cave in Laos and 10th longest in Southeast Asia. The survey is published as atlas and overview map in the Berliner Hoehlenkundlicher Berichte Vol. 44.

The main dry passage was in 2010 equipped with a Lao built solar powered LED spotlight system by the company Sunlaobob. It is installed on the first 450 m and allows the visitor to experience the huge passages in an easy way. The installation consists of a total of 51 LED-lamps (8 pc 15 W, 8 pc 10 W, 10 pc 5 W, 20 pc 3 W, 5 pc 28W) an inverter (1200 VA / 24 V, 960 W) and 4 HBM Solar Panels (110 W 12 V).

The speleologists also took speleothems for paleoclimate studies at the Earth Science Department of Oxford University and recorded temperature profiles in passages close to the entrances. Cave fauna was collected for determination at partner institutes and universities with the focus on spiders which are known to be the one of the largest in the world like heteropoda maxima.

Figure 5. Upper fossil main entrance of Chom Ong on the southern ridge end.

Figure 6. River passage of the Tham Chom Ong.

Figure 7. Main upper fossil passage about 400 m from the entrance.

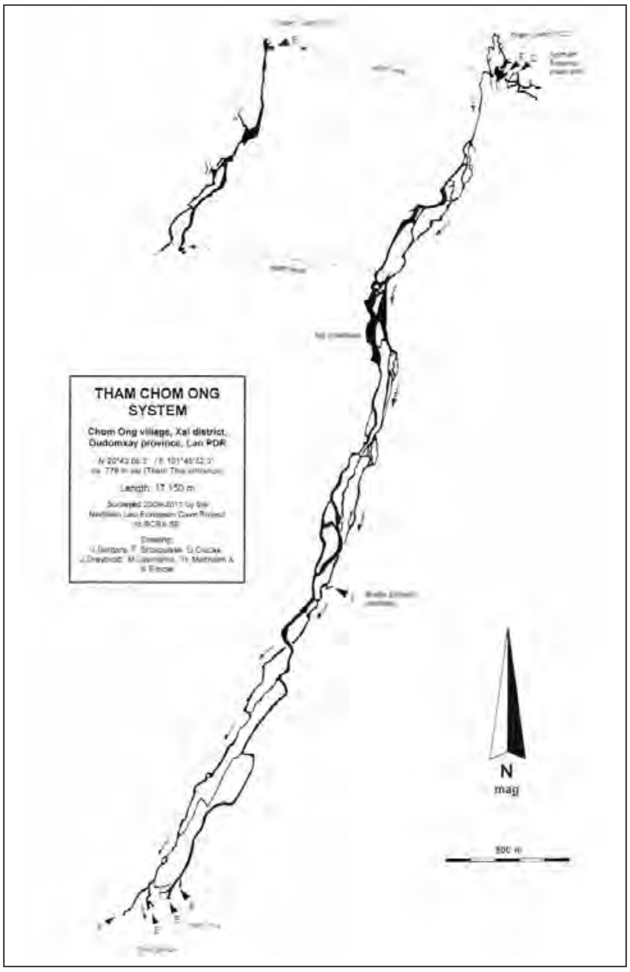

Figure 8. Overview Map of Tham Chom Ong System showing its final length of 17,150 m.

4. Marketing material

The results of the documentation were afterwards used to generate marketing material for promotion of the cave as ecotourism destination. An internet appearance on the provincial tourism office's webpage allows booking of a 3 day tour and has information material for download. This is in the form of a flyer with information and pictures (Fig. 9). A large scale information board near the cave entrance provides further detailed information about the geological background and karst forms, explains some of the formation processes and contains a map of the cave (Fig. 10). Later media coverage by Lonely Planet TV and travel guide books followed enhancing the visibility for the individual tourist. In early 2011 national tour operators started to sell the cave as a destination for both adventure tourism and regular tours to the cave. Reports from Oudomxay Tourism Department confirm that during the high season approximately 2 groups per month visit the cave and the village.

Figure 10. Information board close to the main cave entrance.

5. Conclusion and Outlook

The initial identification of the Chom Ong Cave as ecotourism destination opened the way for the development as ecotourism cave. Within three years from 2007 until 2010, the infrastructure of the village was improved, training to the villagers for hosting international visitors was given and the cave fully explored to its today length of 17,150 m. The base for stimulating interest of visitors is laid by comprehensive and professional marketing and information material. The economical and social impact on the village remains to be seen and will evolve slowly due to the remoteness. Beside external factors it depends strongly on the commitment of the village committee to sustain the infrastructure and to make the cave an attractive long term experience on the agenda of the individual traveller. The impressive passages, beautiful karst landscape in combination with rural village experience (Fig. 11) will convince the tourists by its fascination. Planned access by a more direct and all year round road can further enhance visitor numbers.

We hope this example serves as a useful case-study for other projects and shows what can be achieved by close cooperation between speleologists, authorities and development projects (Fig. 12).

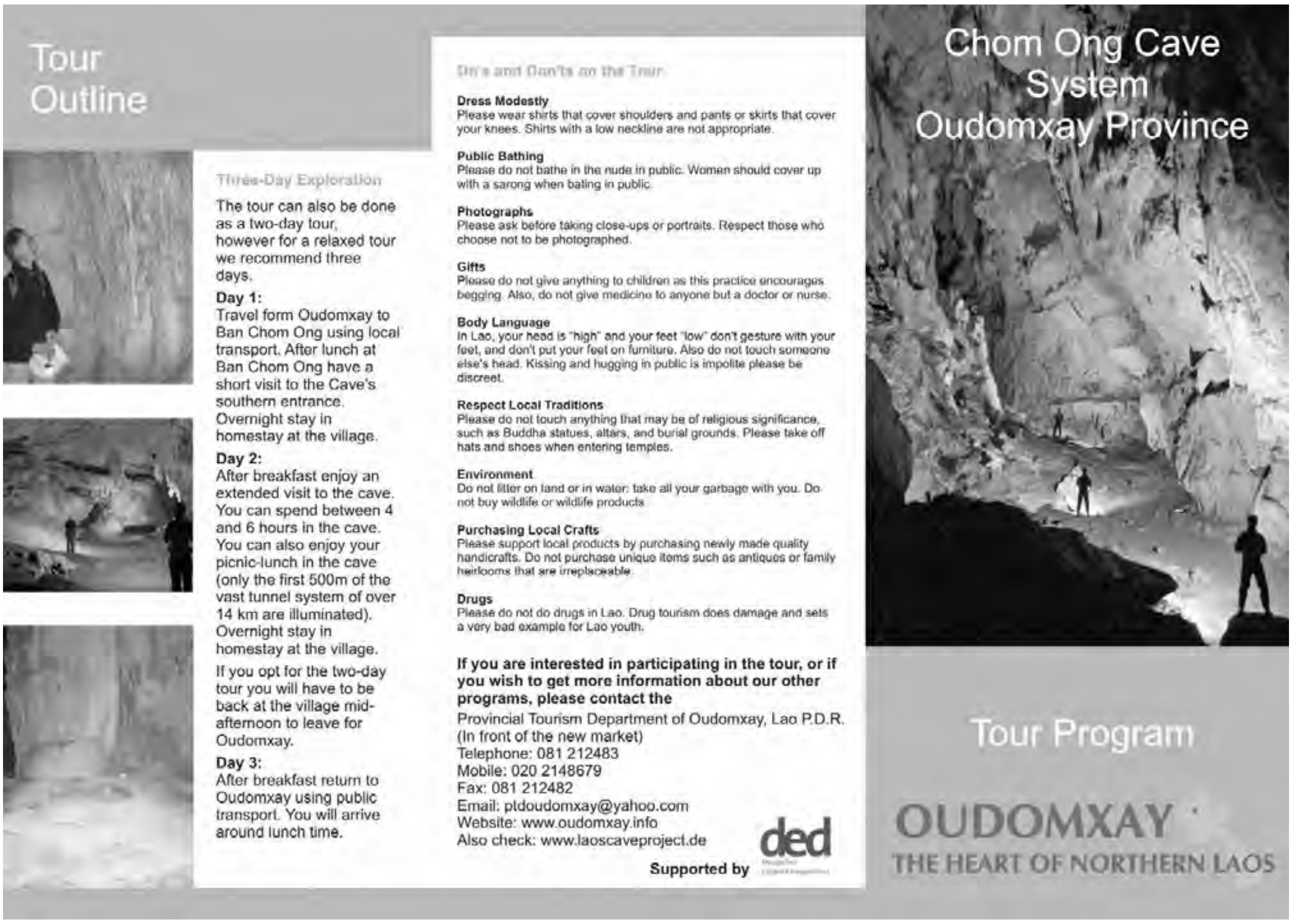

Figure 9. Flyer of the tourism department with detailed tour outline.

Figure 11. Evening entertainment of visitors by traditional flute and songs.

Figure 12. The caving team together with representatives of the tourism department and the German Development Service at Ban Chom Ong village in 2009.

Acknowledgements

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OUTLINE OF ITALIAN REGULATIONS CONCERNING THE DESIGN OR ADJUSTMENT OF TOURIST PATHS IN ITALIAN SHOW CAVES

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Abstract. As regards the rules and regulations concerning the "touristization" of underground environments, both natural and artificial (caves, mines, military fortifications, etc.), it is necessary to ensure the safety of visitors and members of staff. In Italy specific laws were passed with reference to European and international regulations concerning electrical systems, structural work, air monitoring in caves and all matters concerning the safety of those places whose use is comparable to that of a place of public entertainment. Below you will find specifications and law references.

Astratto. Per quanto concerne la normativa relativa alla turistizzazione degli ipogei siano questi naturali o artificiali (grotte, miniere, fortificazioni militari ecc.) deve essere rispettata la sicurezza tanto dei visitatori quanto del personale addetto alla gestione ed accompagnamento dei visitatori. In Italia sono state varate precise leggi che fanno riferimento alle normative europee ed internazionali relative agli impianti elettrici, alle opere strutturali, al monitoraggio dell'aria presente negli ipogei e a tutto ciò che fa riferimento alla sicurezza da adottare in quegli ambienti la cui destinazione d'uso è assimilabile ad un ambiente adibito a pubblico spettacolo. Di seguito si forniscono specifiche e riferimenti legislativi.

1. Introduction

This report aims at introducing the international community to current Italian regulations concerning the adequate design or adjustment of underground tourist paths.

When planning underground tourist paths, or adjusting them to comply with the laws in force, there are two main aspects that need to be taken into consideration:

a) safety, i.e. analysing all possible risks that may arise on the path and providing adequate protection;

b) ergonomics, i.e. making paths and steep gradients as easy as possible, bearing in mind that visitors do not always wear adequate clothing (especially shoes).

Among the visitors using tourist paths there may be children, adults not in an ideal shape and disabled people with reduced motor skills, and this must never be forgotten.

Other users are guides, tour leaders and maintenance staff who need to be able to work in total safety, at the same time protecting their own health.

Therefore, all the measures to be taken must be aimed at both the staff's and the visitors' safety, without forgetting to upgrade the site to the maximum: a safe path together with suitable lighting, able to enhance the characteristics of the environment, are indeed very important pluses.

2. Safety and Environmental Protection Measures

Before and after any maintenance operation it is absolutely necessary to collect all unused materials and take them to the municipal dump, taking great care of polluting, non-inert materials and dangerous substances such as asbestos, acids and other substances described in the rules regulating the disposal of *Dangerous Substances* which may seriously damage health. For the disposal of the latter a special disposal plan must be drawn up by a certified technician. The disposal may be carried out only by registered companies (certified for the disposal of toxic waste), pursuant to Legislative Decree no. 81 of 9 April 2008, Title IX *Dangerous Substances*.

Figure 1. View of the tourist path in Grotta Gigante. Photo by A. Fabbricatore.

3. Staff Safety Measures

As regards staff safety (guides and administrative staff), the employer (which may coincide with the legal representative

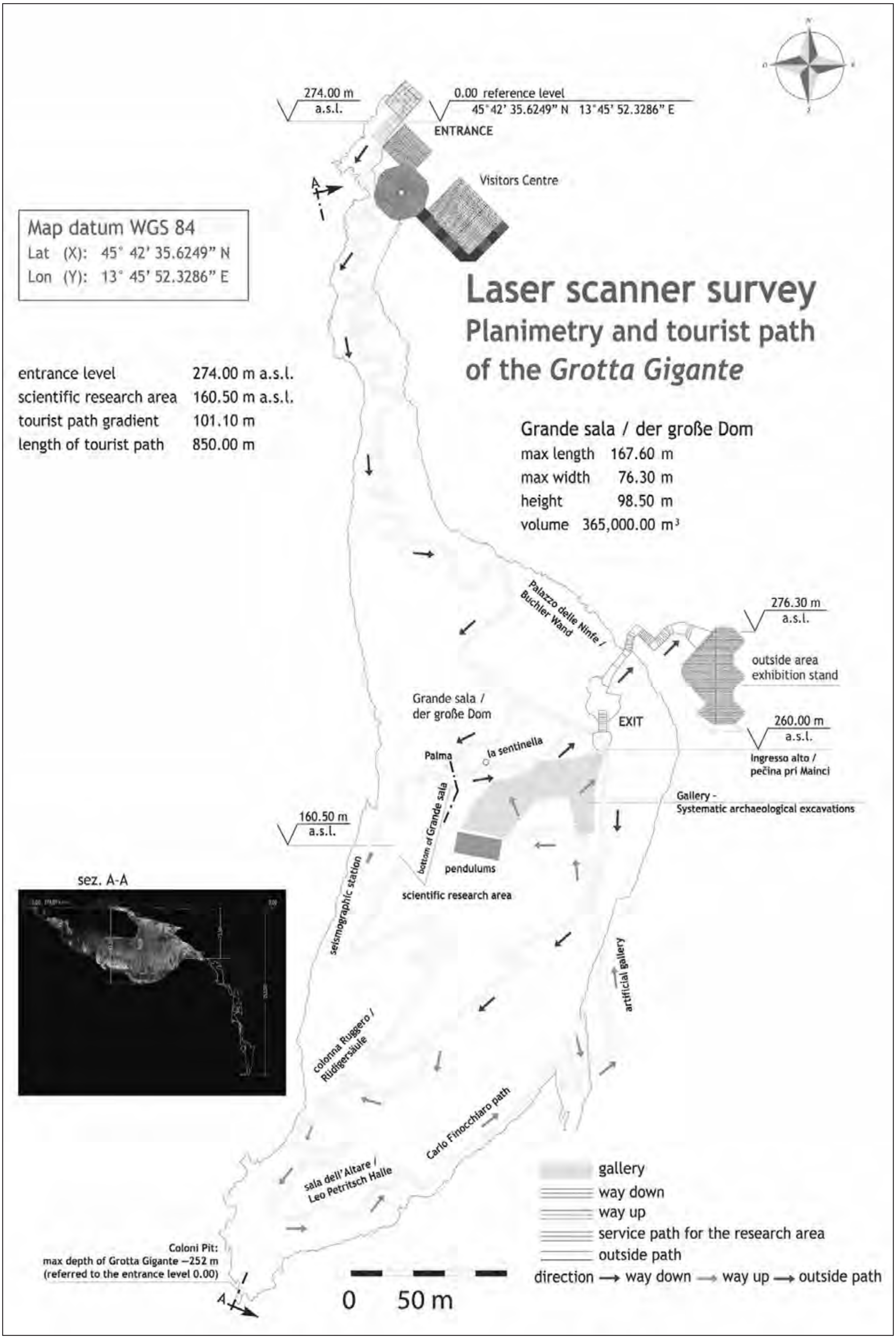

Figure 2. Laser scanner survey.

Figure 3. Railings, banisters and parapets of stairs with vertical posts and emergency lights. Photo by A. Fabbricatore.

of the company) is under an obligation to appoint a *Person in Charge of Safety, Prevention and Protection (R.S.P.P.)* and an *Occupational Physician* in charge of monitoring the staff's health with regard to health problems relating to the type of activity (for example, exposure to video terminals for administrative staff and radon exposure for guides and tour leaders).

Furthermore it is complusory to draw up the *Risk Assessment Document* (D.V.R.), pursuant to the law in force, i.e. Legislative Decree no. 81 of 9 April 2008 (*Implementation of art. 1 of Law no. 123 of 3 August 2007 concerning workplace health protection and safety),* followed by Legislative Decree no. 106 of 3 August 2009 (*Supplementary and corrective measures to Legislative Decree no. 81 of 9 April 2008 concerning workplace health protection and safety).*

In accordance with Legislative Decree no. 241/2000 (*Requirements for workplace radon exposure*) the *becquerels per cubic metre* (Bq/mc) must be monitored by Certifying Agencies or Bodies accredited by a recognized organization and data must be trasmitted to the supervisory bodies (Regional Agency for the Protection of the Environment).

4. Safety of Tourist Paths

4.1. Civil works

Which regulation concerning the safety of tourist paths do underground environments need to refer to? This is not an obvious question at all.

As far as civil works are concerned it is quite easy to answer since these must fulfil well defined requirements for the construction industry and may vary according to regional laws and/or regulations (eg. earthquake-proof building regulations for certain structures).

Of course, any structure, made of wood, concrete or steel, must be designed and assessed by a certified expert and tested by another certified expert according to the laws in force (M.D. 14.01.2008 *Technical building rules*). Great care must be taken with regard to structural elements such as stairs, which are often present *on site*, of which nothing is known from a constructional point of view. In case of doubt, it is advisable to carry out inspections and/or periodical tests on these structures.

In particular, as regards railings, banisters and parapets of stairs and clear spaces (Figure 3), the law provides that vertical posts must be placed at a distance which does not allow a sphere 10 cm in diameter to go through them (children must not be able to climb up retaining bars, which must therefore be vertical, not horizontal or made with steel wires) and must be built so that they do not represent an *added danger* or a *design error*. The rule of the 10 cm-diameter sphere also applies to the space between each step. Steps must have a rectangular shape (no spiral staircases, no steps on landings, no triangular or trapezoidal steps). On the inner side of the stairs (Figure 4) there must not be any overhangs at a distance from the ground which might induce people to rest their feet on them or children to climb over them.

Stairs must always be provided with handrails (on both sides in public areas or if the stairs are wide), which must be uninterrupted along ramps. Parapets and handrails (Figure 5) must be 30 cm longer at the beginning and at the end of the stairs. Parapets must be at least 1 m high (1.10 m if the fall risk is over 3 m) and must resist a horizontal thrust of at least 2,000 N/m (up to 3,000 N/m) on the handrail, pursuant to M.D. 14.01.2008.

Spiral staircases are not advisable, however if they are used steps must be characterized by a minimum tread depth of 10 cm, handrails on both sides and a minimum width of 80–90 cm.

As regards gradients, ramps are the ideal solution (when possible) in order to enable disabled people to visit the place.

Laws regulating flooring, sanitation, balconies and terraces (parapets), horizontal paths, stairs and ramps are M.D. no. 236 of 14 June 1989 (*Technical provisions necessary to*

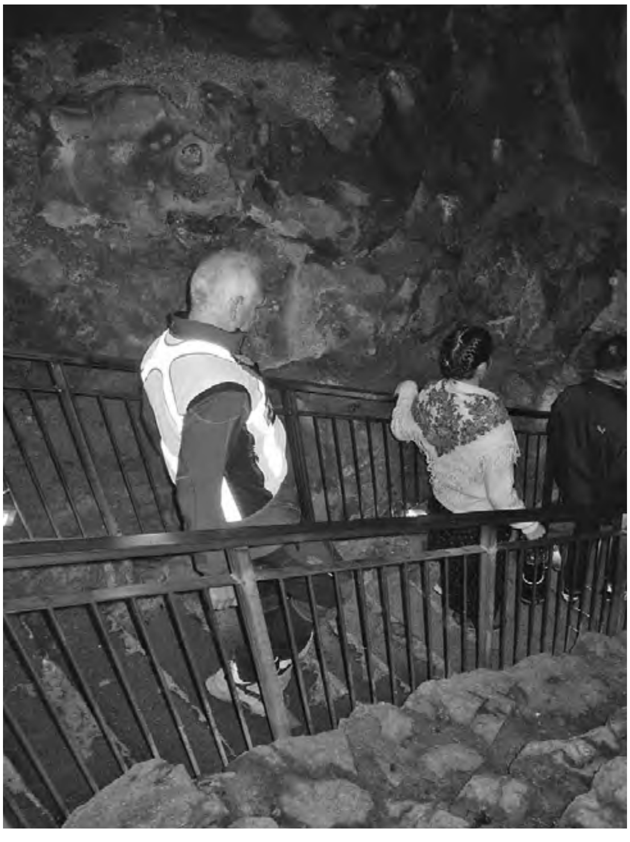

Figure 4. Parapets must be at least 1 m high.

Figure 5. Artificial gallery provided with handrails. Photo by A. Fabbricatore.

ensure the accessibility, suitability and visitability of private buildings and subsidized public residential buildings for the overcoming and removal of architectural barriers) and Presidential Decree no. 503/96 (*Rules for the removal of architectural barriers in buildings, spaces and public services)*.

4.2. Electrical system

With regard to the standard minimum rules concerning the safety of electrical systems it is necessary to point out the obligation to type-approve earthing systems, as established by Presidential Decree no. 462 of 22. 10. 2001, *Rules simplifying the procedure for the registration of lightning protection system and devices, earthing devices for electrical system and dangerous electrical system* (the employer is under a legal obligation to have the systems checked by a certified body or by ASL/ARPA every 2/5 years; if this obligation is not fulfilled the employer shall be held responsible).

4.3. Place for public events and entertainment

Show caves are not exactly "private buildings" and they may be considered as *places for public events and entertainment*.

I the undersigned, as the manager of the *Grotta Gigante/Riesengrotte,* made a request for the type-approval of the earthing system (in compliance with the laws in force) to the A.S.S. of Trieste (the Local Health Authority), in particular to the *Servizio verifiche periodiche (Periodical check service)*. An inspection of the system was carried out by the person in charge, who drew up a report stating that, as regards the use of the *Grotta Gigante* both for guided tours and art performances, its premises are to be considered a "…place for public events and entertainment in compliance with IEC standards no. 64-8/7, paragraph 752.2".

4.4. General features of the electrical system

The criteria for the design of the electrical system in question need to be defined according to the above-mentioned definition.

The source of the electrical installation must be slightly downstream of the electrical power supply point of the distributing company (ENEL), usually inside a concrete box. Inside this box you must find the main switch equipped with an emergency release coil to which the main riser, which consists of FG7 cables, is connected, leading to the main switchboard, located in a special technical room. This switchboard must be equipped with special protections for the entire electrical system, which is usually divided in two main *zones*, one for the circuits of the reception/administrative area and one for the circuits of the cave area. The entire electrical system must be protected by an uninterruptible power supply, always *on-line*, located next to the main switchboard, in the same room.

Another precaution consists in a diesel generating set, placed in a separated room (Figure 6), for emergency use in the event of unavoidable malfunctioning or black-outs of the entire system. The earthing system is connected to the main earthing terminal within the main switchboard, from which the various protective conductors, characterized by the same section as phase conductors, are distributed to the circuits.

Figure 6. Technical room. Photo by A. Fabbricatore.

It is then necessary to carry out the following operations:

a) exactly define and name the devices relating to the circuit within the main switchboard in order to be able to correctly identify the relative downstream circuits;

b) check the mechanical and electrical features of the main supply cable (riser) and measure the isolation voltage, also referring to its junction box. The riser supplies power to the section switchboards;

c) install the section switchboards, which consist of watertight boxes, suitable for their laying position and for housing the protection devices of the various downstream circuits and of the terminal boards for the branch connection from the main riser;

d) install different types of luminous bodies, in particular ones with differentiated optics according to the object or the scene to be lit up, equipped with lamps of different power;

e) install luminous bodies on special supports for emergency and safety lighting of all the cave's pathways that are open to the public using the "always ON" mode, thereby ensuring a minimum lighting level of 5 lux on the steps and 3 lux on the level, 1 meter above the floor.

The functioning of the electrical system must always be assessed in terms of energy saving and lighting performance.

4.5. Certified digital audio amplification system

An audio amplification system, in compliance with IEC 60849 standards, is necessary to provide visitors with adequate information in case of failure or accidents. The system needs to be divided in two racks, one inside the cave, provided with all the power amplifiers, and the other one outside the cave, with the control station, its sources and a microphone for general, pre-recorded announcements, connected to a ring optical fibre system, to ensure the functioning of the system in case of an interruption on the system cable.

4.6. Radio communication system

As regards communication between the inside of the cave and the fixed listening position, located outside the cave, a radio transmission network is ideal and may be provided with auxiliary relays in order to be able to communicate from anywhere inside the cave with the external operator or viceversa.

The system must be designed both for communicating inside the cave and for emergency use. For standard conversations operators can talk to each other from one portable radio to another and also from the base station.

Portable devices must be provided with a *man down* function which automatically generates an emergency call when the portable radio is in a non-vertical position.

In case of emergency, a fixed transmission cycle is activated and whoever is present can voice-communicate with the other devices and with the base station for 15 seconds, after which the radio resets and the base station and the other portable radios are able to communicate with the operator who signalled the emergency.

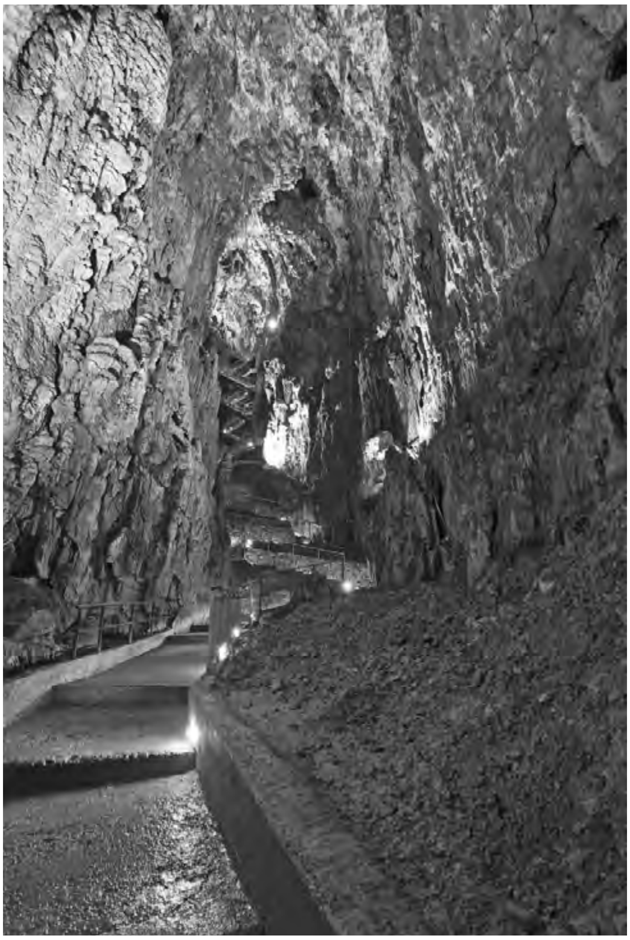

Figure 7. The tourist path in Grotta Gigante. Photo by A. Fabbricatore.

5. *Lamp flora* (photosynthetic organisms that develop near artificial lights)

The development of *lamp flora* (algae, moss, cyanobacteria and other opportunistic plants) is induced by the presence of lights in caves. These photosynthetic species can seriously damage the underground ecosystems. Unfortunately all light sources, LEDs included, cause the proliferation of *lamp flora*. In order to get rid of these undesirable species chlorine products are generally used.

Chemical disinfection, with the use of sodium hypochlorite and chlorine dioxide, is the most common method used for this purpose.

Their sterilizing action mainly affects the surface of bacterial cells and has little effect on viruses, moulds and spores. However, some microrganisms have become resistant to certain disinfectant substances, thereby limiting their bactericidal effect. Organic material reacts with chlorine, forming compounds called chloramines which can irritate eyes and mucus, have a bad smell and, what is more, have a cancerogenic and teratogenic effect. Chemical disinfectants are also highly corrosive and therefore require special measures to protect the health of those working in contact with these substances.

Figure 8. View of the tourist path in Grotta Gigante. Photo by A. Fabbricatore.

Sodium hypochlorite, discovered over two hundred years ago and commonly known as bleach or chlorox, is still the most popular disinfectant. It is available in concentrations varying from 1.5 % to 5 %. Usually it is available in solutions with 3–5 % of active chlorine. According to the EEC standards, products containing less than 5 % of hypochlorite are not classified, those containing 5–10 % must be classified as irritant and concentrations over 10 % must be classified as corrosive. Chlorine is a toxic gas and you must avoid inhaling it and wear safety gloves and glasses when handling it.

An excellent alternative to chemical disinfection, enabling you to avoid using substances which may damage the environment, cave fauna and man, is the use of a fraction of sunlight, UVC rays (wavelength 200–280 nm). UVC rays are able to destroy pathogens and prevent their propagation. They have an effective action on bacteria, viruses, spores, yeasts, moulds, algae and nematode eggs.

On this point, it is worth mentioning, after thorough research and after checking market availability, germicidal lamps, provided with an electronic starter, like *TUV X tra 36W* fluorescent tubes produced by *Philips*, which obtained the *2008 Green certificate* and enable to inhibit the development of *lamp flora*, thereby ensuring an environmentally-friendly use of caves. These lamps need to be turned on when all the other lights in the cave are turned off. When these lights are on it is necessary to wear special safety glasses as their UV rays may cause conjunctivitis when looking at them with the naked eye.

6. Fire prevention and public events

As regards fire prevention, it is worth mentioning Presidential Decree no. 151 of 1 August 2011, which is currently in force: *Rules for the simplification of procedures concerning fire prevention, pursuant to art. 49, par. 4-quater, of Legislative Decree no. 78 of 31/05/2010, as amended by Law no. 122 of 30/07/2010* (for example as far as generating sets are concerned).

As regards public events to be held in caves, such as concerts, projections and other shows, an authorization request must be sent to the Provincial Fire Brigade Headquarters, which then forward it to the Regional Fire Brigade Headquarters, pursuant to the Ministerial Decree of 19 August 1996, *Approval of the technical rule of fire prevention for the design, construction and use of places of public entertainment*.

7. Conclusion

Italian show caves must comply with the above regulations and they undergo regular inspections. Should the inspection authorities discover that a cave does not comply with the safety regulations, the cave will be forced to end its tourist activity.

THE RELATIONSHIP OF KARST LANDFORMS AND LAND USE, KSIROMERO REGION, WESTERN GREECE

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Ksiromero occupies an area of 105 km^2 in the northeast section of the Prefecture of Aitoloakarnania, in western Greece. Its karst is primarily developed on beds of 10–200 m thick Triassic carbonate breccia conglomerates which underlie 70 % of the region. Other karstified units are overlying 200–300 m thick sequences of Upper Triassic to Early Jurassic limestones and dolomites and an underlying 150-m thick Triassic gypsum deposit. Major karst features include dolines and poljes that capture all surface water. Open caves and conduits are rare due to in-fill by residual terra rossa soils.

This study is based on field research and the creation of a geographic information system (GIS) geodatabase that included geology, topography, karst landforms, and land use. The data were compared to reveal a strong correlation between the presence of the breccia conglomerates with cultivated land and between the limestones and dolomites with forests and pastures. This investigation serves as an example for future land use analyses in karst, and as a foundation for more detailed research in to the potential environmental impacts of specific land uses in Ksiromero.

1. Introduction

Thirty-three percent of Greece is karst (Papadopoulou-Vrynioti, 2004) but the country has no specialized governmental or private karst research association. Consequently, knowledge of the country's karst is scattered, and hydrogeological karst investigations are often not based on a clear understanding of karst geomorphology. The objective of this study is to demonstrate how creating a karst geomorphological map and geodatabase of a region in west-central Greece can provide insights into land use and its potential impacts. This paper is primarily based on the larger work of Golubović Deligianni (2011).

2. Regional and local geological setting

This investigation's study area is Ksiromero, which is Greek for "dry place." Ksiromero is an evaporite and carbonate karst region in the northeast section of the Prefecture of Aitoloakarnania, in western Greece (Figure 1). Its 105 km^2 area is bounded by the mountainous area of Akarnanika Ori to the west (Psili Koryfi, the highest peak, is 1,157 m above sea level), the drainage basin of Lake Amvrakia to the east, drainage systems to the Amvrakikos Gulf to the north, and the southern watersheds whose rivers flow to the Ionian Sea through the Department of Akarnania.

The area of Ksiromero is within the Ionian geotectonic zone, part of the External Hellenides Platform that extends west from mainland Greece and appears on the western edge of Peloponnesus. Long thrust faults that trend east-west and northeast-southwest, and long reversed and normal faults that trend northwest-southeast are characteristics of the Ionian zone.

During Permo-Triassic time the Ionian zone was a shallow, restricted, marine basin which accumulated over 150 m of evaporites (Karakitsios, 1992), of which gypsum is notably exposed. Their episodic deposition may have allowed the development of a paleointrastratal karst, as described in other regions by Bosak et al. (1989) although no direct evidence has been found. Triassic Tryphos Formation carbonate breccia conglomerates were deposited over the evaporites, followed by up to 200 m of dolomite and as much as 300 m of the Pandokrator Limestone into the Early Jurassic. At that time, the shallow Tethys Sea covered a continental platform which extended throughout nearly all of western Greece. The carbonate breccia conglomerates are epigenetic, formed during the Triassic from major tectonic activity, diapiric deformation and dissolution of underling evaporites. These conditions continued with small modifications up to the end of the Jurassic. From the Pliocene to the Quaternary, more recent gypsum deformation occurred at the surface due to underlying

Figure 1. Location of study area.

diapiric movement along prominent faults (Underhill, 1988). The Tryphos carbonate breccia is the main karstified rock of the region. It ranges from 10–200 m thick and covers 70 % of the area (Figure 2).

From a hydrological perspective, the region drains internally to where its water is not exploitable for use. The study area is a system of closed karst watersheds whose recharge characteristics are poorly defined and where the downgradient destination of its groundwater is unknown. While recharge occurs through the higher elevation limestones and dolomites, most of it is transmitted though the Tryphos breccia and the underlying gypsum. The highly soluble gypsum matrix of the conglomerate produces a relatively uniform high-permeability surface that minimizes surface runoff. While most karst features of the region are developed in the Tryphos Formation, their density may have been greater if the matrix had been carbonate due to more selective enlargement. Additionally, the occurrence of only a few open caves in the region likely results from the high production of residual terra rossa soils from the gypsum. The soils have accumulated on all surfaces, especially in dolines and poljes, and runoff is insufficient to transport them through the karst to create more open caves.

3. Local karst hydrology

While sea level at the Amvrakikos Gulf is the ultimate base level and the water of Lake Amvrakia suggests it is a major inland base level (~25 m above mean sea level), currently there are no empirical data to identify groundwater levels in Ksiromero, their gradient, or likely areas of discharge. Some shallow wells in the breccia conglomerate serve as small, local water supplies. Annual rainfall averages 1,000 mm while annual evapotranspiration averages 650 mm with the remaining 350 mm water available for runoff and groundwater recharge. Based on the extensive exposure of the Tryphos breccia-conglomerate and its low-slope doline topography, it probably receives the greatest percentage of recharge, with a smaller percentage infiltrating the steeper and less extensive Pandokrator Limestone. However, the absence of clay-rich soils on the Pandokrator may allow more recharge than suggested by the size of its outcrop. In both settings, surface water in the study area flows only after rainfall, which rapidly sinks underground.

Domestically used water is mostly supplied to Ksiromero from a neighboring region. Water for agriculture is stored in more than 387 reservoirs, some natural dolines but most excavated in terra rossa soils of poljes and large dolines. Shallow groundwater occurs in some of the dolines and earthen reservoirs, as well as seasonally captured storm water, but much is pumped in from the other regions or from adjacent wells. The permeability of the terra rossa soils seems generally low. The sparse well data suggest that groundwater occurs in two horizons in some central lower elevation areas. The horizons are separated by a thin bed of clay and marl; the upper horizon is likely perched. The upper horizon is 4–12 m below the surface and the lower is between 15–30 m.

4. Karst Geomorphology and GIS

ESRI ArcGIS® version 9.3.1 geographical information system (GIS) software was used to create a karst geomorphological map (a simplified version is presented in Figure 2). It stored, analyzed and displayed a detailed geodatabase of topographic, morphologic, hydrologic characteristics and established a detailed geodatabase of karst landforms for the region to produce maps and reports. The digital database allows combination of the geodatabase's different layers: topography, geology, hydrology, land use and karst features. For detailed visualization and analysis we digitalized twenty-one 1:5,000 scale topographic sheets of the region at 4 m contour intervals and interpolated to 2 m.

The karst geomorphological map was created from our database of all mapped and categorized karst landforms. Through watershed delineation we identified one large compound karst basin, which includes 13 polje watersheds, and two smaller separate watersheds of groups of dolines.

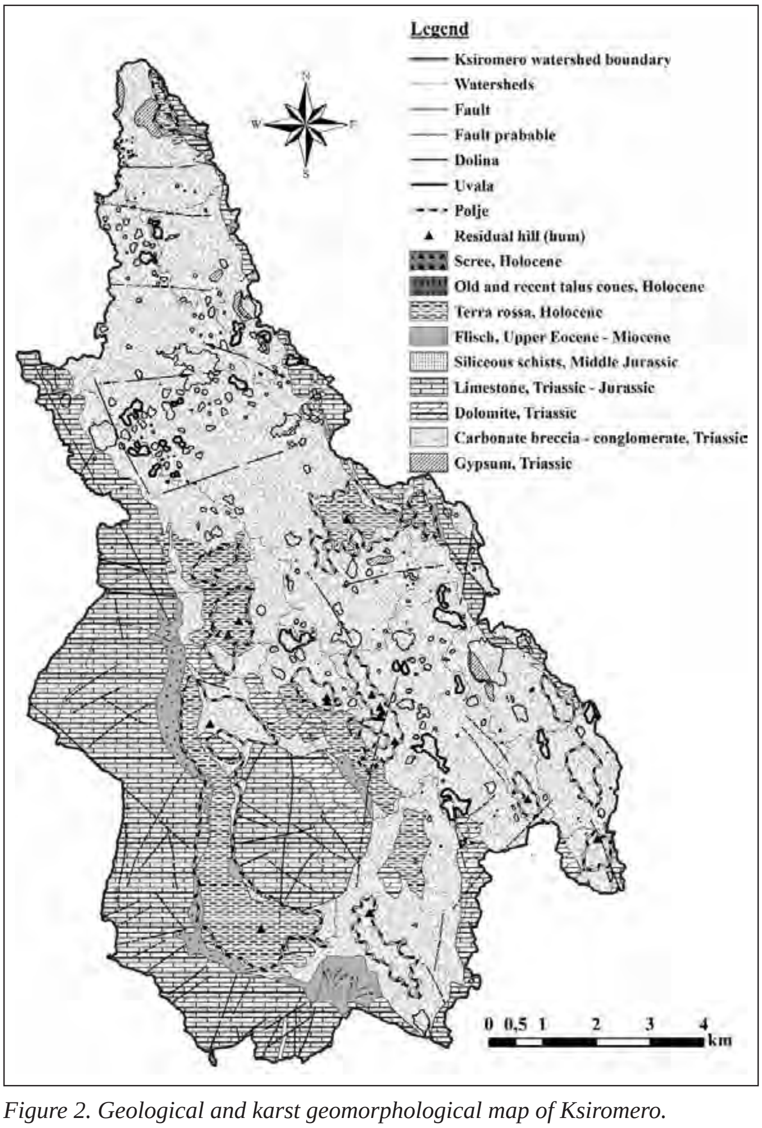

Figure 2. Geological and karst geomorphological map of Ksiromero.

We found 15 residual hills in the poljes, comprised predominantly of limestone intercalated with gypsum and likely the result of lesser solubility than tectonic factors. We identified a total of 267 dolines with funnel, shallow, and a few collapse morphologies. Using Čar's (2001) classification scheme, Ksiromero primarily has broken, broken collapse, near-fault, and fault dolines. We also identified 23 uvalas. With ArcMap → Hydrology we identified 229 ponors that occur at the contact of the limestone with the breccia conglomerates and where they follow faults.

5. Land Use

Digital land use data for the study area was added to the database from the Corine Land Cover Project, version 13 (European Environment Agency, 2000) which identified 11 land uses. Figure 3 illustrates the land use distribution with general karst forms. Table 1 serves as the key, defining the categories and quantifying the area's covers.

Karst landforms that recharge groundwater extend over 98% of the Tryphos breccia-conglomerate. Our results in Table 1 establish that 65% of dolines and 77% of uvalas are overlain predominantly with agriculture and some forests. Individually, these landforms have poorly defined drainage systems and some are covered in thick clay-rich soil which decreases their recharge capabilities. Consequently, they contain at least 55 water reservoirs which are necessary for local

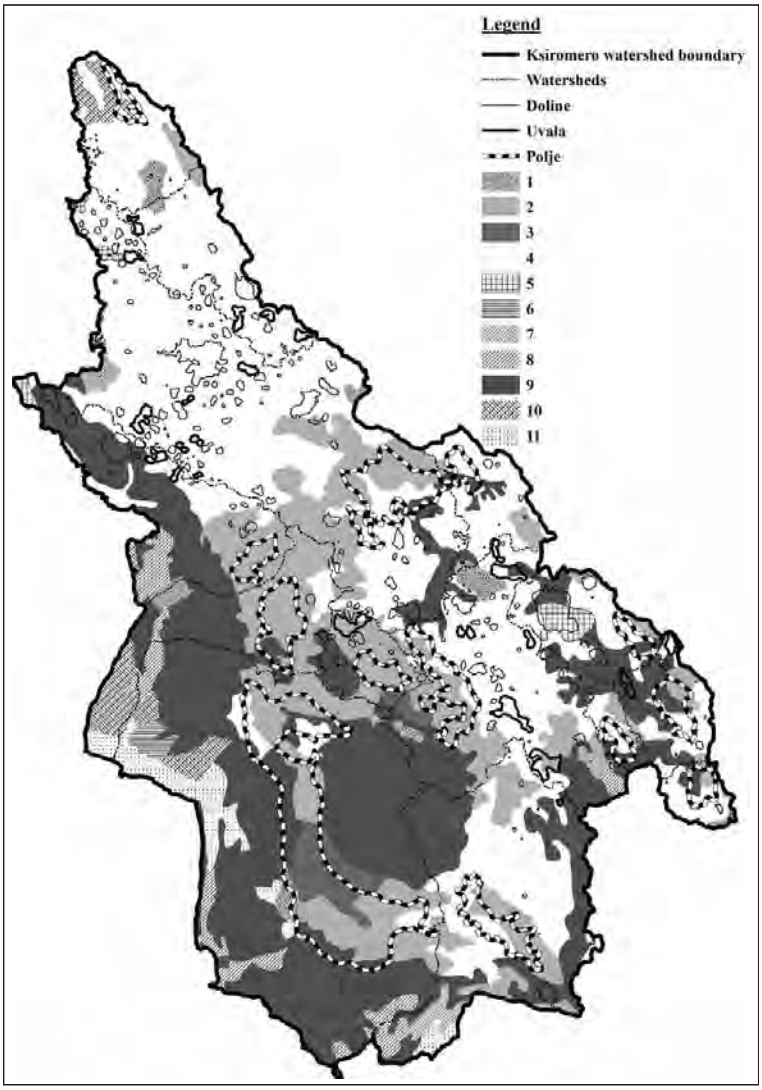

Figure 3. Karst land forms and land uses in Ksiromero (land use numbers keyed to Table 1).

Table 1. Land use distribution by karst land form (land use codes per Corine Land Cover Project, version 13).

No.	Code	Description	Area (km^2)	Area (%)	Dolines (%)	Uvalas (%)	Poljes (%)	Residual hills (Hums) (%)
1.	112	Discontinuous urban construction	1.455	1.39	2	0	0	0
2.	211	Non-irigated arable land	20.149	19.19	8	13	62	85
3.	242	Complex crop systems	1.811	1.73	0	0	7	0
4.	243	Mainly agriculture, with some forest	41.390	39.40	65	77	17	10
5.	311	Broadleaf forest	0.787	0.75	5	1	0	0
6.	312	Conifer forest	0.357	0.36	0	0	0	0
7.	313	Mixed forest	0.415	0.38	0	0	0	0
8.	321	Meadow	2.426	2.30	0	0	0	0
9.	323	Hardleaf vegetation	31.491	30.00	18	9	11	5
10.	324	Transient forests/brush	2.423	2.30	2	0	3	0
11.	333	Thinly vegetated	2.296	2.20	0	0	0	0
∑	Code	Ksiromero watershed	104.997	100	100	100	100	100

agriculture. Most of these reservoirs are fed with water imported from near the village of Achyron, located about 2.5 km west of Ksiromero's west-central border. Some reservoirs are supplied by adjacent wells, rainwater runoff, or groundwater seepage from the upper groundwater horizon in the terra rossa. A few of the reservoirs are natural or modified solution dolines (Figure 4), but most are fully excavated depressions in terra rossa (Figure 5).

Poljes occur only on the breccias-carbonate and are overlain with alluvial deposits created largely by the weathering of the breccia-conglomerate. The alluvium includes silty to sandy-grained residuum, scattered carbonate breccia, and is topped by terra rossa soil. This 5–20 m thick alluvium and soil is poorly permeable, frequently perching groundwater as previously described. At least 98 water reservoirs are known to occur exist in the terra rossa of the poljes. Sixty-two percent of the poljes are covered by extensive agriculture with some forest.

Figure 4. Natural pond in Doline Fraksulis.

The best example of extensive agricultural use of a polje is in Polje Stinadia (Figure 6). Within the polje are 13 dolines, three ponors, and two springs and extends to the lowest elevation of the Ksiromero region at 224 m. Polje Stinadia is only area of Ksiromero containing complex crop systems (Table 1), which demonstrates its suitability for diverse agriculture.

Approximately 98 water reservoirs exist in the terra rossa of poljes and like in case of dolines and uvalas they have key role in existing of agriculture land use.

The residual hills in Ksiromero are composed primarily of breccias conglomerate limestone (90 %) and some gypsum (10 %). They are the result of random erosion patterns or relatively lesser porosity and permeability than the surrounding outcrop. Non-irrigated arable land covers 85 % of these features, suggesting similar properties for agriculture, except for the higher slopes which discourage irrigation.

6. Conclusion

Generalizing data from Table 1 and Figure 2 results in combining the11 land use categories into three main elements, summarized in Table 2: urban (land use code 1), natural vegetation (land use codes 5, 6, 7, 8, 9, 10, 11), agricultural/pasture (land use codes 2, 3, 4).

Figure 5. Excavated water reservoir about 10 m from Doline Fraksulis shown in Figure 4; water elevations differ based on supply and usage.

Analysis of the land use elements shows that the majority of the study area (60.32 %) is covered by agriculture in the thick-soil breccia conglomerates. Almost all of the remaining area (38.29 %) is covered by natural vegetation, located mainly in the steep areas of limestone and dolomite. Only a very small percentage (1.39 %) of the study area is covered by artificial surfaces such as streets and buildings.

It is clear from this study that bedrock geology is the primary factor affecting land use in the Ksiromero region. In addition to the above percentages, environmental pressure led to innovative observation of doline flooding in the breccia conglomerate resulting in at least 387 water cisterns and continued excavation of new reservoirs in its deep soils. Without this geological capacity, above-ground water storage tanks would need to have been constructed to support local agriculture, and at a higher price.

There is an acknowledged lack of information about land use impact in the Ksiromero region. This study demonstrates how land use must be identified and controlled with consideration of karst hydrogeology and its evolution. This study does not evaluate the effects of urbanization, agriculture, quarries, landfills, and sewage. Instead it offers an example of how geologic, landforms, and land use map layers can be evaluated in a geodatabase to identify the relationships between each and to serve as the foundations for future, in depth, research and monitoring.

Figure 6. Sinkhole area inside Polje Stinadia.

Table 2. Combined land use distribution in Ksiromero.

No.	Description	Area (km^2)	Area (%)	Dolines (%)	Uvalas (%)	Poljes (%)	Residual hills (Hums) (%)
1.	**Urban**	1.455	1.39	2	0	0	0
2.	**Agriculture and pasture**	63.350	60.32	73	90	85	95
3.	**Natural vegetation**	40.192	38.29	25	10	15	5
∑	**Ksiromero watershed**	104.997	100.00	100	100	100	100

Acknowledgments

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APPLIED DRAMA: A NEW TOOL OF TEACHING CAVE PROTECTION

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Cave protection and cave protection education are two of the key goals of speleology of the 21st century. Cave as a part of natural environment presents a unique and sensible micro-environment that is significant for humans and their legacy.

It is important to protect cave micro-environment in order to secure a sustainable future for the next generations.

Children and young pupils should be the most important target group of this protection campaign considering two basic reasons: First they are able to learn faster than adolescents or adults and they can also absorb more information. Second, children are the future of each generation and only if these principles are taught from the early years; children can be expected to apply them in their everyday life.

Currently applied drama has been considered as an effective teaching tool that can inspire children to learn through experience and work on difficult meanings, such as peace, collaboration, human rights, environmental protection, and many others that school subjects cannot always cover. As a result nowadays applied drama as a learning medium can aid teachers, educators, artists and tutors, to provide their learners with a great variety of fun, energetic, interactive and participatory activities aiming at a joyful and productive learning procedure.

This poster aims at presenting an innovative way of teaching cave protection in young learners through drama. It presents a sample of activities and some principal thoughts suitable for children aged 4–5 years old, in order to inspire fellow educators, cavers and scientists and suggest new approaches of teaching Cave Protection via Drama.

TEN YEARS OF WWW.SPELEOGENESIS.INFO: CHALLENGES AND PERSPECTIVES

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www.SPELEOGENESIS.info is a non-profit platform aimed to integrate and promote efforts of the international community of cave and karst scholars in information exchange, communication and collaboration. The portal has been first established in 2003 and now advanced to serve various networking and information resources (Speleogenesis Network), functioning as a hub of collaborative activities of 823 individual researchers from 84 countries and numerous academic institutions involved into karst and geospeleology studies. The website operates under an auspice of the UIS Commission on Karst Hydrogeology and Speleogenesis and the IAH Karst Commission.

www.SPELEOGENESIS.info also supports an online scientific journal, "Speleogenesis and evolution of karst aquifers" (journal.speleogenesis.info) that brings together research on developments in geospeleology and karst science pertinent to the origin and evolution of dissolution caves and conduit permeability. The scope of the journal is speleogenesis, the origin and development of dissolution caves.

The major perspective includes among others creating a collaborative platform for karst and cave related projects and building corresponding online community around them. As a step to reaching this goal, a Directory of cave and karst research institutions has been created (speleogenesis.info/institutions/). This directory functions as a collaborative arrangement amongst cave and karst research institutions working together to build a networking infrastructure that would facilitate cooperation and partnership through sharing resources, results, experiences and other research opportunities. At the moment 19 institutions has joined the directory:

- Brazilian Karst Research Institute – Instituto do Carste, Brazil
- Carbonate Aquifer Characterization Laboratory, United States
- Group for Underwater and Speleological Exploration, Romania
- Hoffman Environmental Research Institute, United States
- Institute of Speleology "Emil Racovita", Romania
- Institute of Water Resources Management, Hydrogeology and Geophysics, Austria
- International Research and Application Center for Karst Water Resources, Turkey
- Istituto Italiano di Speleologia, Italy
- Karst & Cave Research Group, University of Akron, United States
- Karst Dynamics Laboratory (KDL), China
- Karst Geomorphology Unit (research and didactic), Poland
- Karst Research Group of Coimbra, Portugal
- Karst Research Group, University of Gadjah Mada, Indonesia
- Karst Research Group, University of South Florida, United States
- Karst Research Institute ZRC SAZU, Slovenia
- Karst Waters Institute (KWI), United States
- National Cave and Karst Research Institute, United States
- Swiss Institute of Speleology and Karst studies (SISKA), Switzerland
- Ukrainian Institute of Speleology and Karstology (UISK), Ukraine

Representatives of above-mentioned institutions while being members of Speleogenesis.info have access to online data related to their organization. They can edit this data as well as add new content.

Directory of world cave and karst science journals is another part of the Speleogenesis project. Right now 16 journals are included:

- Acta Carsologica
- Cave And Karst Science
- Cave Science
- Die Hoehle
- Helictite
- International Journal Of Speleology
- Journal Of Cave And Karst Studies
- Journal Of The British Speleological Association
- Karstologia
- Kras I Speleologia
- NSS Bulletin

• Proceedings Of The British Speleological Association
• Speleogenesis And Evolution Of Karst Aquifers
• Speleology And Karstology
• Transactions Of The British Cave Research Association
• Transactions Of The Cave Research Group Of Great Britain

Representatives of these journals can manage properties of their online resources, submit new publications and update existing ones.

Recently a comprehensive catalog of links to karst and cave-related websites has been created (speleogenesis.info/directory/links). Each member of Speleogenesis.info can add data to this database as well as update outdated links.

Karstbase bibliography is another important part of the portal. This database contains more than 12,900 bibliographical records on karstology and geospeleology. Again as with any other Speleogenesis.info recourse, each member can add/update his or her contribution to the database via specialized tools available from their member page.

Speleogenesis Calendar (speleogenesis.info/directory/calendar/) aims to keep track of karst and care-related events that are taking place within karst research community. Each member can submit an event to the calendar.

The last but not least addition to the portal is the possibility for members to create and maintain their own projects. Such projects can belong to a variety of types. For example, it can be an expedition or a scientific research as well as publication, excursion, conference or exhibition. Project leaders can invite other members to join the project and collaborate with each other by sharing information and project-related data. Shared data types include blog-like text posts, image galleries, files, Google maps, links, etc. Members of the project can communicate within the project timeline by sending private messages or/and emails to other project members. Project administrators can send announcements to all members of the board as well as contact each of them individually. Each project will have its own public page accessible for the rest of the web.

Speleogenesis.info is constantly growing and already is one of the most influential online resources on karstology and speleogenesis.

PROTECTION AND MANAGEMENT OF KARST REGIONS IN INDONESIA

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Indonesia is a country with a wide range of karst area. Indonesia is estimated to have a karst area of 154,000 sq km (Bappenas 2003) spread out almost all over Indonesia. Karst is a term to refer to an area that has a hydrological characteristics and unique natural formations, as a result of the combination of high concentration of rock dissolution and the development of secondary porosity (Ford and Williams 1989). Physically, the karst area has a primary function as an aquifer that meets the needs of water of hundred-thousands of people living in it. Besides, it serves to keep the regional ecosystem balance. However, karst is susceptible to changes. Human activities are the greatest threat to the preservation of karst ecological functions. Loss of ecological function of karst leads to disasters to human life and seems impossible to avoid. Issues on karst conditions in Indonesia are currently indicating degradation by the presence of industries exploiting the natural potentials in the mining sectors that economic, ecologic, and social-based conservations become highly crucial to conduct. Through the karst potentials in building and cement raw materials create beneficial opportunities to industrial sectors. Mining activities in karst areas, besides threatening the availability of the ground water in the surrounding area, they threaten the unique karst geomorphology and biodiversity. This paper will discuss the efforts of the comprehensive management to optimize the potential of karst for beneficial for the survival of the karst ecosystem, either economically, ecologically or socially.

1. Introduction

Karst is a formation in the earth's surface generally characterized by the closed depression, surface drainage, and caves. This area is formed mainly by rock dissolutions, mostly limestone. Karst area formed by dissolution of rock occurs lithologically, especially other carbonate rocks, covering dolomite, evaporite deposits, such as gypsum and halite, in silica deposits, such as sandstone and quartz, and in basalt and granite, a condition of which may tend to be in cave formation.

Indonesia has the carbonate rocks, especially limestone, the largest of which covers nearly all the large and small islands. The area is estimated covering more than 15.4 million hectares and spread almost all over Indonesia, stretches from Sabang to Merauke islands. In Sumatera, karst region lie around Aceh and Medan. In Java Island it spreads across most of the southern coast and the center of Java. In Borneo it covers the east coast. In Sulawesi it lies in Maros (South Sulawesi) and in Papua it is in the mountainous center of Papua Island. Karst landscapes spreading in Indonesian provinces are non-renewable natural resources. The karsts went through a long process of formation, have unique natural phenomena and rare as well as give important values for life and ecosystems that they need to be wisely managed.

2. Method of Research

2.1. Research Techniques

The author uses descriptive method in order to find out the potentials and the management of karst using relevant literatures to the issues discussed.

2.2. Data Collection and Processing

The data collection technique of this research was observation, that is by directly visiting the locations and library research, through relevant books, the mass media and internet sites. The collected data were secondary data. Further, the data were processed using content analysis techniques to come to a conclusion.

3. Results and Discussion

3.1. Karst Potentials

It is currently only a few realize the natural potentials of the karst region in Indonesia and the need for conservation of the karst areas. The potential commonly known is simply as the mineral resources for building materials, cement raw materials. In fact, karst region also has other economic potentials, such as water resources, biodiversity, swallow's nests, a tourist resorts, besides scientific and cultural values. The thing that cannot be ignored of the karst is that its ecological functions in preserving the ecosystem balances of the surrounding. Compared to other types of landscape, karst is a typical and unique that in managing it, the unique values and the ecosystem of karst should be taken into consideration.

Ecological Potentials

In hydrological aspect, endokarst region is highly rich in springs. White (1969, 1977) classifies carbonate aquifer based on groundwater systems and hydrological setting. The groundwater of karst area (limestone) has a different hydrological system from that of non-karstic one. It is closely related to the physical-chemical properties of limestone. The limestone is porous and directly passes the rainwater through the cracks of surface of the land through the cracks of the vertical and horizontal rock coats that does not allow the water remains in the surface. The water, then, flowing under the surface will accumulate in a particular flow-pattern as the river surface does, that is, by running through the cave hallways and becomes the underground river. In dry seasons, the loss of the surface river due to the cracks resembling to caves in the whole region frequently becomes a big problem.

Groundwater is one of the clean water resources to meet the water needs of those, especially of the urban and industrial areas. The wide range of groundwater or aquifer distribution that is relatively impossible to contaminate by the surface pollutants makes the groundwater the essential and strategic water resource. In addition, the groundwater may serve as a surface load-bearing media. Consequently, the exploitation of groundwater should be conducted in an integrated management to ensure a sustainable use. Therefore, karst water system in the region can be made a source of water supply in the dry season for agricultural, consumption, and even industrial purposes. The karst groundwater is in high quality (low turbidity) and slowly fills up the underground rivers that enable it to be available even in the dry season. The ground water, however, is highly dependent upon the vegetation and the limestone cavities in the karst region. As the caves in the karst region are connected one another, they can supply water to other places. In verse, it can be as a water reservoir.

In scientific aspect, karst functions as one of natural laboratory for scientists in biological, geological, and karstological fields due to the fact that the region provides unique things, such as caves and several endo and exokarst flora and fauna habitats. Biodiversity in karst areas is considered endemic; that is to say, a natural phenomenon of a biota to be unique to a particular geographic region. A species can be said endemic if the species is native that can only be found in a particular place and not found in other regions: islands, countries, or particular zones. It is likely wise to say that karst regions should be continuously and seriously conserved to serve the sustainability and food chains.

Economic Potentials

There are two economic potentials of the karst areas, the economic potential of mining and non-mining. The two potentials are so great that a sustainable karst area management becomes a must. The mining potential of karst area covers limestone, the cement raw material. However, the exploitation of this cement industrial sector often degrades the area that threatens the karst area existences. Anthropocentrical limestone exploitations as commonly done result in decreasing other values significantly in a relatively short term.

The non-mining potentials of karst area cover the biodiversity, underground-water, and laboratory scientific studies, such as archeology, speleology, hydrology, as well as forestry. Other potentials of the caves in the karst area include swallow's nests, bats and some other unique animals; the use of the cave phosphates as fertilizers, and area tours (for special interest). Consequently, a wise management of the area by considering the ecological values should be taken in order to meet the economic needs of the local communities.

3.2. Basic management of karst

The biotic and non-biotic components of karst areas serve as life-supports to human beings. In carrying out this function optimally, it is highly required to afford protections to enable the area to contribute significant economic values in preservation. Considering the wide range of Indonesian's karst landscapes, strategic functions – hydrologic and specific functions for flora and fauna habitats, as well as for millions of people relying upon the areas and roles as rainwater absorbent, the conservation regulations are issued by Indonesian government through laws and regulations, among others:

1. Law No. 5 of 1990 on Conservation of Natural Resources and Ecosystems
2. Law Number 26 Year 2007 on Spatial Planning
3. Law No. 32 Year 2009 on Environmental Conservation and Management
4. Indonesian Government Regulation No. 26 Year 2008 on National Spatial Plan
5. Regulation of the Minister of Energy and Mineral Resources of the Republic of Indonesia Number 17 Year 2012 on the Establishment of Karst Natural Landscapes.

3.3. Values of the Natural Caves

There are several values the natural caves can provide, covering:

1. High aesthetic value. Cave with lots of beautiful ornaments (speleothem). The caves are publically potential. The cave figures must be avoided from the visitors' the touch.
2. Caves with underground rivers either those having been or to be used as sources of clean water by the local or the karst region's people. For such caves it should not be used for tourism purposes, to avoid any water contamination.
3. The caves, besides inhabited by hundreds to thousands of bats, swallows and other biota playing highly important roles in preserving the ecosystems, they serve important benefits to sciences. Such a type of cave should not be publically visited because it would disrupt the existence of beneficial creatures. When opened to the public, the ways to the caves must be closed to visitors.
4. Caves may have high scientific-value sediments, because it contains pollen or spores that can be used to analyze past vegetations and climates around the caves, even may contain valuable scientific artifacts, such as fossils or various archaeological findings. Such caves with underground passageways should be closed to those traveling the caves.
5. Caves with historical relics with sacred tombs believed to have mystical worth have ever or still functions as hermitage sites. Such a type of cave should only be developed as a cultural heritage.
6. Caves with strategic values for war in the past should also be closed to public.
7. Caves with economic values in terms of mining (phosphate, etc.) should not be visited, but only be to be mined.
8. Caves with educational values for nature conservation and ecotourism should be provided for research means only.

3.4. Issues on Karst Area Exploitations

Up to now, karst areas in Indonesia are still considered economic natural resources on mining sectors by most people, even by most Indonesian mining geological experts. The resources mined include limestone as raw materials for cement industries, buildings, tiles (marbles), jewelry, and other various industrial purposes. Dolomite and calcite ($CaCO_3$), which has undergone a process of crystallization, are also mined for various industrial means. In addition, the phosphate contained in the sediments of several caves once ever inhabited many bats and swallows are also mined for organic fertilizer production. The direct impact of the uncontrolled karst area exploitation will lead to the decrease or destruction of the natural functions of karst region. Some examples of the impact that may be resulted include:

1. Loss or damage to natural laboratory for the advancement of sciences in karstic fields that has high contribution to Indonesia and world.
2. Loss or damage due to the economic potential due to the destruction of swallow and bat habitats that the colonies reluctantly stay in the karst caves.
3. Loss of water or damage to the water systems due to the haphazard exploitations of the regions, that is in the way without taking into account the sustainability and continuity aspects.
4. Damage to the artistic aspects of a tourist object in the karst area due to irresponsible acts of the visitors.
5. Damage to agricultural land as a source of life to people living in the karst area due to the exploitation of karst areas that ignores the environmental aspect.

3.5. Karst Area Management

Karst management is an activity that includes the establishment of the karst management principles, karst criteria, inventory and investigation, the area and the zone of karst, coaching and development as well as the supervision. Karst Area Management is also meant as efforts of exploiting and preserving the carbonate rocks with karstic morphology in accordance with the functions to support sustainable development of Indonesia. Effort increase in conserving efforts attempting resource utilization and protection of karst morphologies of carbonate rocks according to their functions in order to support sustainable development. Increased efforts to preserve karst area also has high significances in the preservation of hydrogeological functions, geological processes, flora and fauna and historical and cultural values.

The karst region has all the strategic values aforementioned that, in fact, the exploitation of which is fully vested-interests. Moreover, the decentralization is expected to encourage the partial area management based on administrative, instead the ecological boundaries. Suspected, karst mining regardless to the available rules has been threatening the availability of groundwater in the surrounding area of karst (Bappenas 2006).

To cope with the problems it is highly required to develop the zone of the karstic region. The zone development is basically a development effort in an administrative area or particular region to achieve the welfare of the community by taking the advantages of opportunity and the natural resources optimally, efficiently, synergically, and sustainably by encouraging the economic activities, creating conducive climate, and providing facilities and infrastructures.

The utilization of karst area shall be well-planned in advance. All activities must be carried out through processes and procedures in accordance with available regulations. The utilization of karst area itself is a series of development activities to take advantage of the karst in the period set in the spatial plan of the local government. Besides, the exploitation control is highly required, such as by licensing, supervision, and control of the utilization of karst.

The groundwater of the karst regions (limestone) has different hydrological systems from that of non-karstic regions. It is related to the physical-chemical properties of limestone. In dry season, the water shortage problem may arise because of the loss of the surface river due to the cracks in the form of caves in the whole regions. Recorded in 1987, drought caused about 193,900 people in 7 districts. The Local Government of Gunung Kidul Yogyakarta Province has built a model of underground river utilization in Goa Bribin to cope with drought. In the Feasibility Study, the researcher was involved in the project activities. At present, the people in the region has been provided with clean water supply.

Besides for mining purposes, the strategic value of the economic perspective on the karst region is that it can be optimally developed as tourism resorts. It is wise to study earlier to find out the people's readiness and capabilities to actively and positively participate in developing and preserving the karst region. The local people should be fostered in order to be ready to be involved in developing and preserving the tourism resorts as an active, in stead passive role. The people that are possibly loss of their lands, mainly of the landownership status, are discontent with money compensation. The identification of the local people's readiness to be involved in such tourism activities should be considered a priority. Besides, professional management is a high requirement as a basis on the karst area utilization in tourism sector. Tourism objects and good service systems will greatly attract tourists if based on professional management. The tourism development should be oriented to local, regional, national, and even international market demands, especially to meet the needs of tourism objects of special interests. Karst region is specific because the tourism objects are specific, such as cave tourism objects (endokarstic tourisms), rock climbing, tracking, ecotourism and flora and fauna observation (exocarstic tourisms). Several regions developed for tourism purposes cover Gua Gong, Goa Tabuhan and Gua Maharani in East Java, besides for special interest tourisms, such as carving, cave tubing, cave diving, black water rafting in Goa Pindul and Gua Kalisuci of Gunung Sewu karst areas.

To obtain optimal results in the management of karst areas, it takes coordination and cooperation among the various stakeholders, such as government, academia, and environmentalists such as NGOs and mountaineers clubs, communities, and employers, that can become managers. They should share common aspirations and perceptions on karst regions. Several attempts have been made in the framework of coordination include:

1. Meetings on the initiation of the researcher in April 2012, on behalf of the institution through the Directorate General of National Unity and Political Interior Ministry, by inviting representatives of the Secretariat of the State, Cabinet Secretariat, Ministry of Environment, Ministry of Energy and Mineral Resources to coordinate related to the policy of karst areas management.

2. Local government also has conducted workshops or socialization on karst management, among of which as that conducted by the provincial government of East Kalimantan cooperating with the Natural Resources Conservation Center (*BKSDA*) of the Ministry of Forestry in the context of the plan formulation on karst management in Berau – East Kutai, in April and May of 2012, attended by various authorized units of Berau regency, private companies, non-governmental organizations and various community leaders in Berau.

Today Many nature activists clubs focus on actions going through caves, some of which are “Acintacunyata Speleological Club”, “Indonesian.Caver Society”, “Karst Aceh”, “Matalabiogama”, and “Subterra Indonesia”. However, all activities are not well-integrated. Each works by each. In order to contribute properly to breaking down the karst and cave problems in Indonesia, perhaps, it is the time for the cavers to change the paradigms from seeing caving activities merely as adventuring to cave data collection or mapping activities. If a co-ordination between the various parties are properly managed, not only are we engaged in comprehensive understanding on what karst and potentials are to the environment and people’s welfare, but also the public (whether or not those living around the karst areas) are. Joined exploration with research means will be more meaningful and fruitful to make a real contribution. Or, if any speleology organization or club explores and shares information and data, it will be a very advantageous contribution to karst and cave management.

The last thing considered so important to do is to increase the participation of local people in managing the natural resources of karst region, ranging from the planning process, such as scaling up priority to the implementation program phase. Such an act enhances the local people’s economic income. By so-doing the people will participate in preserving the natural resources. One activity will not vanish another. In addition, carrying capacity of resources can be made a reference for all parties in the preparation of karst region planning and development. Through packaged cooperation between the Directorate General of the National and Political Unity of the Internal Ministry and community organizations, the researcher also greatly encourages the organizations to socialize the preservation and conservation of karst areas to the public around Gunungsewu karst areas, precisely in the *Wonogiri* district through media *Wayang Kulit* performances. Through local cultural approach, the people will easily understand and comprehend.

4. Conclusion

Preserving and managing karst wisely is a shared-responsibility, not only of one, but also of various institutions (mining, forestry, agriculture, irrigation, conservation, tourism, socioeconomic and sociocultural services, education officials and scientists from the Science and Knowledge Institution of Indonesia (*LIPI*), universities, and NGOs). The basis of utilization should be prioritized for its sustainability in order directly or indirectly the local people may get the benefits.

Karst region is considered of greatly important potentials in Indonesia in the socioeconomic and scientific as well as the karst hydrological functions to support the survival of lives on it.

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THE DISTRIBUTION, PROTECTION AND UTILIZATION OF KARST CAVES IN HAINAN PROVINCE, CHINA

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Hainan Province is situated in the south of China. Due to its particular tectonic position and geological evolution, Hainan has rich cave resources with special scientific significance and landscape value which are precious nonrenewable geological relics. Hainan Province abounds with cave resources of various types. The caves are widely distributed in Haikou City, Danzhou City, Dongfang City and Changjiang County, etc. which are mainly karst caves formed in carbonate rock stratum with different scales, forms, geologic landforms, hydrological forms and landscape marks. The caves integrate scientific value, humanistic value, economic value and ecological value. At present, Hainan's cave resources have been partly explored and utilized. There are relevant geoparks, natural reserves, cultural relics protection unit and tourist resorts, which has achieved some economic benefits. However, one of the major problems we face is cave resource destruction, and the protection for caves is extremely urgent. In the future, the main issue to be solved on Hainan's cave resources is how to strengthen protection and explore cave resources rationally.

1. Introduction

Hainan Province is located in the most southern part of China. Influenced by plate movement, it has undergone complicated tectonic movement and sea-land changes during geological historical period, and forms geology and landform remains of abundant types and various forms. The representative geological heritages include granitoid, volcanic rocks and water type remains. Besides, the special geographical position and favorable weather conditions contribute to the form of cave, which is a precious geological heritage type. The inartificial underground space resource is of great importance in scientific significance which lies in the study of crustal uplift, tectonic evolution, climate change, organic evolution and hydrologic geology during the Quaternary in Hainan Province and even the South China, and peculiar aesthetic value, which is an important constituent part of South China's tropical karst investigation and an advantageous type of Hainan's tourism resources. It greatly enriches the natural landscape resources of Hainan Province, which is typical and representative in Hainan and even the whole country (Yuan 1993; Fu 2010).

2. General Situation of Cave Resources

A Cave is a natural underground space that is accessible by people. Hainan Province is the only tropical island province in China. According to incomplete statistics, there are hundreds of caves of a variety with strong regional characteristics, for example, the caves are all relatively centralized distribution, in small scale and low altitude area, and short of stalactite. They are distributed in Haikou and western regions of Sanya including Danzhou, Changjiang, Dongfang and Baoting. And the main types are karst caves (Fig. 1).

Sanya City: Luobi Cave. Located in Lizhiwan Town of Sanya, Luobi Cave is a relatively larger karst cave in the most southern part of China with the northern latitude of 18.3°, The famous "Sanya people" site was found in the cave (Hao et al. 1994).

Danzhou City: ShiHua Water Cave and Guanyin Cave: Shihua Water Cave and Guanyin Cave are located in the southern area of Danzhou City, which are provincial geoparks, featuring crystal flower and corrosion forms. They are famous landscapes of Danzhou City.

Dongfang City: Mihou Cave and Shitian Holy Cave. Dongfang City is one of the concentrated distribution areas of karst caves in Hainan Province. The caves are mainly distributed in the southeast of the city. Located along Changhua River basin, there is typical karst landform and complete types of speleothems with high aesthetic appreciation. It's an important destination for tourism and exploration in the province.

Changjiang County: Huangdi Cave and Xinchong Cave. Changjiang County is another concentrated distribution area of karst caves in Hainan Province. The caves are mainly distributed in the southwest of the county which is bounded by Dongfang City. They are important constituent parts of Bawangling National Nature Reserve. The fossils and stone implements in the caves have high value on the research of Quaternary mammals and ancient human evolution. The local news had already reported the caves at the time of its finding, but until now new important progress is not made.

Baoting County: Qianlong Cave. It is located in the northwest of Baoting County, which is an important constituent part of stone forest scenic spot. There is natural and pure underground water body and well developed speleothems in the cave. And acicular stone forests in karst stratum are outside the cave, which are rare in China and have superior research value on the development and evolution of tropical karst landform (Liu et al. 2009).

3. The Landscape in Caves

The landscape in caves is a special unit that takes shape in the process of cave formation and evolution. It is under the influence of human production activity. The landscape is an important embodiment of cave aesthetics, scientific research and cultural value. The cave landscape marks attract people to pay close attention to caves (Zhu et al. 1988; Zhang et al. 1985). The cave landscape marks of Hainan Province enjoy abundant varieties with distinguishing features, including national-level and provincial-level ones (Fig. 2).

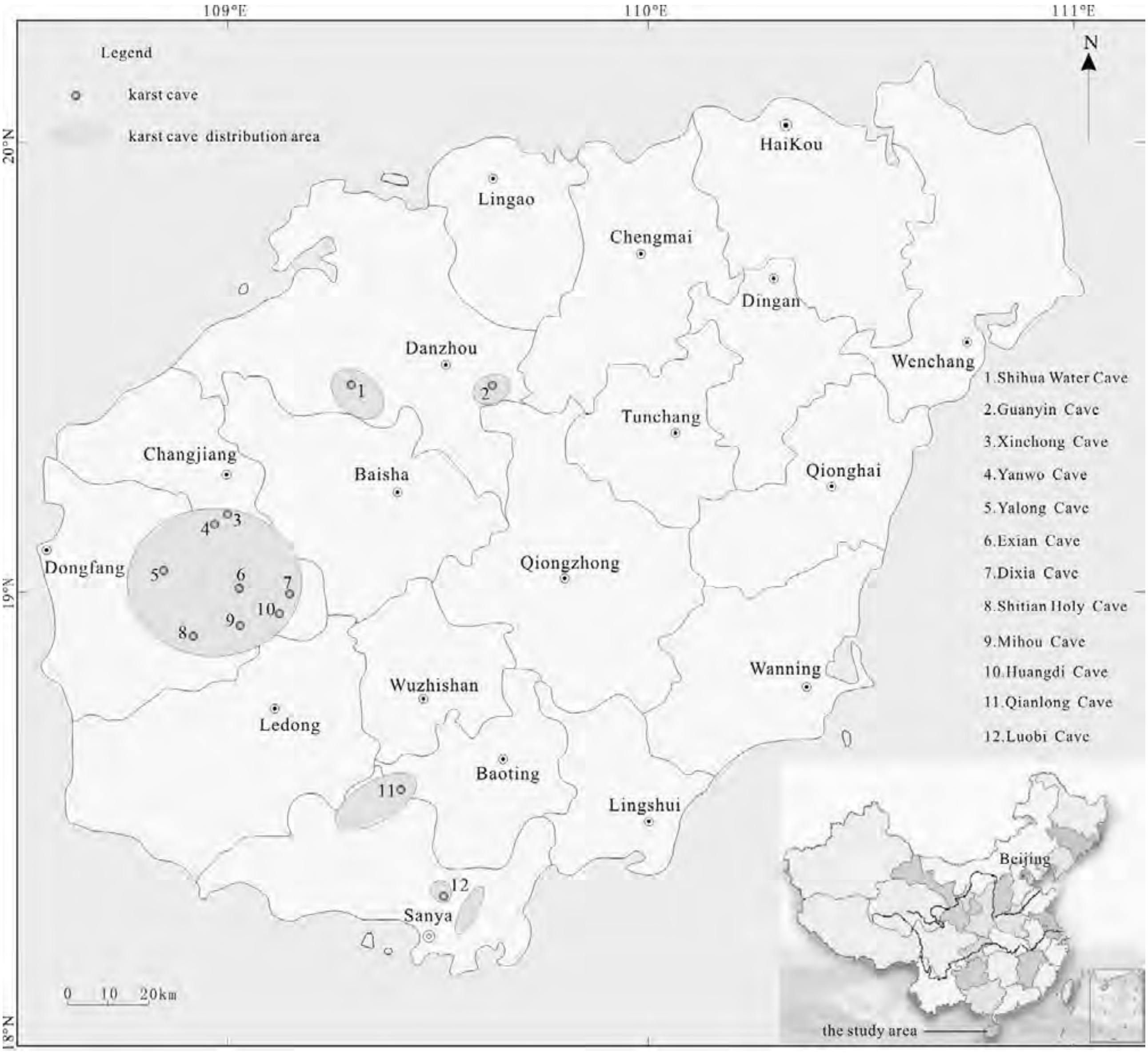

Figure 1. Distribution of typical karst caves in Hainan.

The representative speleothems in karst caves include the crystal flower of calcite, aragonite and helictite in different shapes of Shihua Water Cave. They are crystal clear, delicate and graceful, which are superior in China. The distribution area is over 1,000 m^2. In Shitian Holy Cave, there are large-scale stone terrace, and there are over 60 steps of stone dams in the area of 150 m^2, which is reputed as China's second largest stone terrace by the Magazine of Chinese Geography. The 70-meter-long Mihou Cave boasts abundant stalactite landscapes with large development density, varied types and marvelous forms, which is unique in the province. The cave archaeological sites include Luobi Cave and Xinchong Cave with cave deposit and fossil stone implements inside, which are the fifth and the sixth batch of national cultural relics protection unit respectively. Luobi Cave is the oldest palaeolithic site in Hainan Province at present, which has important significance in the development of prehistoric culture in South China and Southeast Asia during the transitional period from Pleistocene to Holocene. Guanyin Cave boasts religions and temples as landscape marks with rich religious culture atmosphere (Gui 2001).

4. Cave Protection

Cave resource is a peculiar type of geological heritages in Hainan Province, which is a bright pearl of Hainan's tourism landscapes. Due to its rareness and preciousness, the protection for the cave resource is important and necessary. Compared with other geological heritages, the protection for caves started relatively later. Before the year 2000, the caves in Hainan Province are basically in the original natural state. There were two conditions. Firstly, as the closed geographic location led to the inconvenient transport, there were few footsteps to the caves. Affected by the natural forces only, the caves didn't suffer obvious destroy. Secondly, the caves located near residential areas were greatly affected by human activities, which suffered destroy to a greater degree. For instance, some caves in the village of Dongfang City suffered engravings near the entrances and some were used as religious venues. The entrances to some caves were used for storage and hideout, where there were burning marks. Inside the caves, there were also some destroys, such as the polluted water, the destroyed stalactites, the excavated accretions and the quadrate pit with the length of over 2 meters. Under the influence of various reasons such as the poor transport, material lack, especially the lack of protection awareness, few protective measures were taken to the caves except plugging the cave entrance, resulting in the damages of a number of resources.

After the year 2000, the protection for cave resources is obviously improved. The establishment of some geoparks, cultural relics protection unit, natural reserves and scenic areas related with caves makes the protection for caves in

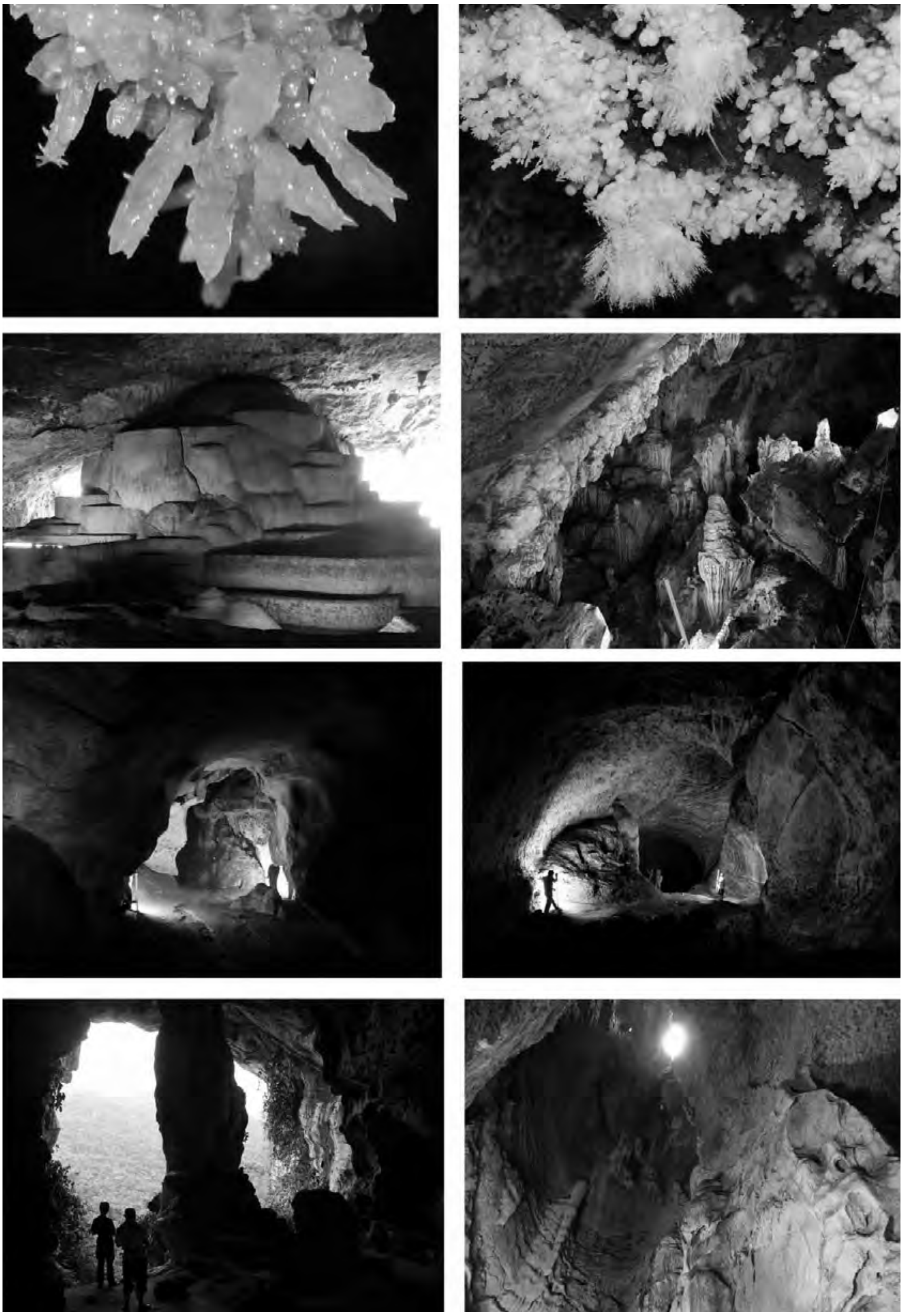

Figure 2. Representatinve cave landscape in Hainan (Photo 1–2, the Shihua Water Cave in Danzhou City; Photo 3, the Shitian Holy Cave in Dongfang City; Photo 4, the Mihou Cave in Dongfang City; Photo 5–8, the Jiangbian Cave Group in Dongfang City).

an artificialization state. For instance, in order to protect the white crystal flower from the influence of weathering, lighting and touch in Shihua Water Cave in Danzhou, glass interlayer has been equipped, and some cave landscapes have been fenced about in order to avoid destroy, which is relatively effective. The protection for caves includes the cave-centered special protection which is supported by the special fund, the protection for a geological relics point in protection zone which is supported by less fund and half protection for some geological heritage that is in course of preparation for declaration and is supported by little fund. In the degree of protection, provincial level protection is dominated and municipal level protection is assisted. There is little national level protection except the Luobi Cave in Sanya. Despite this, the developing of caves caused new exogenous destroy and the vegetations on the tops of some caves were badly damaged which caused soil erosion. Pollutants then would inflow into caves and destroyed the clean environment. Besides, the chimney effect of caves increased and the weathering rate of speleothems sped up, which led to gradual earthy transformation. The endogenous destruction is even more serious. In the development, the blind factitious construction and excavation have greatly changed the initial state inside caves. Besides, rubbishes brought in by people exceeded the self-purification ability of caves, which increased the content of CO_2 in caves and destroyed ambient air quality. As some landscape lightings were equipped unreasonably, lighting plants grew rapidly which led to the qualitative change of landscapes (Yang 1989).

5. Cave Utilization

The year 2000 is also the boundary of the cave utilization of Hainan Province. Before 2000, the cave utilization is mainly on the aspect of original natural attribute, which is in low grade. The caves were used for storage, hide, worship and the source of drinking water, and the users were mainly local residents. After 2000, with the swift development of Hainan's tourism industry and the gradual development of investigation on geological relic resources, cave utilization entered a new stage. Geoparks and scenic areas centered on cave aesthetic appreciation attract tourists to appreciate. Tourism caves become popular in Hainan Province. The cultural relics protection unit, natural reserves and ecological preservation areas are based on the utilization of cave scientific research value, and an increasing number of academic researchers begin to pay attention to the caves in Hainan, which greatly increases the scientific value of caves. The caves with the cultural value of historic relics, historical sources and religious allusions are utilized, and become the ideal venues for cultivating taste and improving quality. The relatively original caves become famous venues for leisure and adventure. At present, cave utilization integrates tourism, scientific research, relaxation and improvement, and the economic attribute is widely explored (Yang et al. 2007).

Cave utilization brings better economic benefit and the protection for caves is improved, which is a powerful measure with virtuous-cycle and sustainable development. For example, the Shihua Water Cave in Danzhou City is developed as a scenic spot when it was found ten years ago, and the income is sustainedly used for the protecion of cave by buying equipment, inviting experts and hiring local people for supervision. At present the cave is the provincial geopark in Hainan.However, compared with the regions with abundant cave resources such as Guangxi Province and Guizhou Province, the explored caves in Hainan are few in number and the utilization of caves are relatively insufficient. As a bright pearl of Hainan's natural tourism resources, the rational exploitation and utilization of cave resources are in prospect (Chen 2006).

6. Conclusions

Hainan Province boasts a large variety of karst cave resource types which are widely distributed, integrating scientificity, appreciation, typicality and diversity. The cave resources can satisfy people's demands of research, tourism and education in many ways, which enjoy great social economic value and play an important role in China's cave research. Because of this, the protection for Hainan's cave resources becomes much more important. The protection and exploitation of caves should band together, in order to realize the effective protection and sustainable utilization of cave resources.

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"proKARSTerra-Edu" – A KARST-EDUCATIONAL PROJECT

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The wide distribution of karst makes topical issues concerning its use and management with a view of sustainable development of these territories. The solution to the problems related to karst depends on effective education and training concerning karst specifics. In this respect protected karst territories acquire high importance: they can serve as sites for karst education so as test grounds for developing models of rational land use in karst environment.

This paper presents a strategy of karst education, entitled proKARSTerra-Edu. Exemplified by model PKT, it integrates the contemporary research concept of "Karst geosystems" (supported by karst cadastre, developed as a result of complex monitoring and data management in GIS environment) and the educational concept of "Life-long education". proKARSTerra-Edu is a part of a pilot model of a methodological platform for modern management and conservation of protected karst territories (based on representative karst geosystems in Bulgaria, the Czech Republic and Japan).

1. Introduction

Karst occupies a significant part of the Earth's land (according to Pulina and Andrejczuk 2000 it occupies about 12% of the Earth's surface) and this specific environment is closely related to the lives of millions of people. Bulgaria is a typical example, where karst is not just a phenomenon of tourist attraction. Because of its wide distribution (ca. 23% of this country, Popov 2002) and heterogeneous diversity, it makes a specific natural environment, inhabited since ancient times. For millenniums both the karst landscapes and people have had mutual impact on each other. Human impact on karst reached especially large scale during the recent decades of increasing economic growth.

Some consequences are evident, such as: destruction of and surface karst forms; pollution and change of regimes of underground karst water; pollution and turning potholes into landfills; destruction of the natural soil cover, followed by accelerated erosion, trampling of soils, succession, etc. These processes result into typological transformation of karst (most often producing bear karst). They change not only the karst landscape (often irreversibly). They reflect both directly and indirectly upon the functioning of karst geosystems. That is why attempts to apply the topical principles of sustainable development disclose serious problems (about some of them society is still not aware of).

Serious problems have been revealed in the management and control of karst territories, the society not being aware of it's. A review of the legislation concerning business and management practices shows that both in Bulgaria and in the world problems still exists in large karst areas, away from the attention and interests of government and society. This alarming fact has been confirmed by specially conducted surveys held by the authors in karst areas. More than 60% of the Bulgarian respondents do not know karst as a phenomenon as well as its related natural features, even though they live in karst regions and use their various services.

It is getting clear that these problems are associated with serious gaps in education and training about karst at all levels – from school to University, at state institutions and specialized institutions that manage karst areas. Paradoxically, at the same time the interest in Karst and Speleological research is increasing, leading to publications. As noted by some American researchers, including the authoritative NCKRI (National Cave and Karst Research Institute) scientific information about karst does not reach people and politicians because of poor dissemination. Moreover, most of the specialized educational initiatives address caves only (example, over 54% in USA, North and van Beynen 2011). Free access to academic resources does not always ensure their proper use in the development of educational and information materials about karst. Work in karst education is also insufficient at the largest international organizations, such as the Geographical and Speleological ones.

Based on this generally negative background some good educational practices concerning karst can be outlined, such as: The group on karst at the University of South Florida, USA (Brinkmann 2010); Ecological educational program focusing on karst in Virginia, USA (Zokaites 2007; http://www.dcr.virginia.gov/ underground.shtml); Karst international schools (for students and young scientists) in Poland (Faculty of Earth Sciences of the Silesian University) and Slovenia (Karst Research Institute of the Slovenian Academy of Sciences and Arts); Specialized educational activities concerning karst mainly in Slovakia (Slovak Caves Administration – Research, monitoring and documentation department) and in the Czech Republic (The Administrations of Moravský kras PLA and Český kras PLA and the Cave Administration of the Czech Republic). Very important, but less known is the experience in specialized training at the Akiyoshi karst park in Japan. Their first step was to teach the locals about the nature of karst. Further they created protected areas in karst regions.

Although the concept of Karst geosystems entered the Geography curriculum for 8th Grade in 1994 and was apprehensively explained in one of the approved textbooks (Geography for grade 8, Publ. House "K & M", Sofia, 1995), Bulgaria still lags far behind the active involvement of karst issues in education. Serious attempt to produce significant changes in this field has been declared in the Final Document of the International Conference on Karst research and management in Shumen (18–21 October 2005, http://karst.iit.bas.bg; Stefanov 2006). In this document it is recommended that the Bulgarian Ministry of Education and Science "reconsiders the topic of karst in the curriculums of Geography and Biology, updating them with studies of karst phenomena and objects, under different forms such as free elective classes, green schools, school trips and other extracurricular training. For this purpose the use of wide opportunities offered by karst areas was recommended, as well as modern information technologies (ICTs and specifically GIS)". Seven years later these ideas were again raised, discussed and developed at the Second International Karst Forum in Shumen (16–20 September, 2012, www.prokarstterra.bas.bg/forum 2012). One of the main topics was the role and the importance of karst in the Education program (Stefanov et al. 2013; Stefanova et al. 2013; Nakano and Iwamoto 2013).

These persistently proposed changes in the Bulgarian Educational system have been based on serious long-term research at some of the representative karst regions in this country. Karst geosystems have been defined and described, experiments have been held, as well as relevant measurements and mapping. Original databases have been developed, by using modern IT and GIS environment, which lead to a serious base for specialized educational programs. In the course of time serious professional expertise has been acquired concerning karst research and education. It involved work with pupils, students, young researchers, as well as enthusiastic teachers with interests in karst. An additional favorable condition has been the growing international cooperation and specialized educational initiatives held at the international Karstologic forums in Bulgaria.

2. The proKARSTerra paradigm

Based on the experience gained along wide-range karst studies, the **paradigm of proKARSTerra** for protected karst territories (PKT) has been developed as a methodological platform for their modern management. It uses the Concept of Karst Geosystems, the specialized Information system of Karst Cadastre in GIS environment and the Complex Monitoring (Fig. 1). The concept of ***Karst geosystems*** has been developed at the Institute of Geography of the Bulgarian Academy of Sciences (now Department of Geography, NIGGG, BAS) since 1980, based on selected representative model karst regions (Stefanov 2004).

According to this concept karst processes have system-forming importance and organize the environmental development in a specific way, creating territorially uniform and complete functional entities, called Karst Geosystems. They consist of mutually related and interacting elements, structured in spatial, functional, dynamic and genetic hierarchies (Voropay and Andreychuk 1985; Mikhova and Stefanov 1993; Andreychuk and Stefanov 2005, 2006; Andreychuk 2006).

Karst geosystems are specific in that they have two main components: surface and underground subsystems. Both exist in paradynamic and paragenetic relations. Material-energetic interactions between them build the nature of karst systems' functions and dynamics. This multilevel structure and functional unity of karst subsystems has been taken into account in creating the two basic principles in protection of karst derived by V. Andreychuk and P. Stefanov (2005, 2006).

The special status of PKT presumably requires a high degree of knowledge about them (including management plans), but karst specificities impose the need of special expertise and conducting of additional specialized research. The practical value of the results obtained depends on their organization into a specialized information system ***(Karst cadaster)*** of PKT. More specifically it means skillful design of this database structure and content; filling out the missing information through inventory updates and additional specialized studies; entering all this data into GIS environment. Another important point is the need to carry out specific ***monitoring*** which in the case of karst landscape should be complex and consistent with the concrete structural-functional features of the respective karst geosystems of PKT.

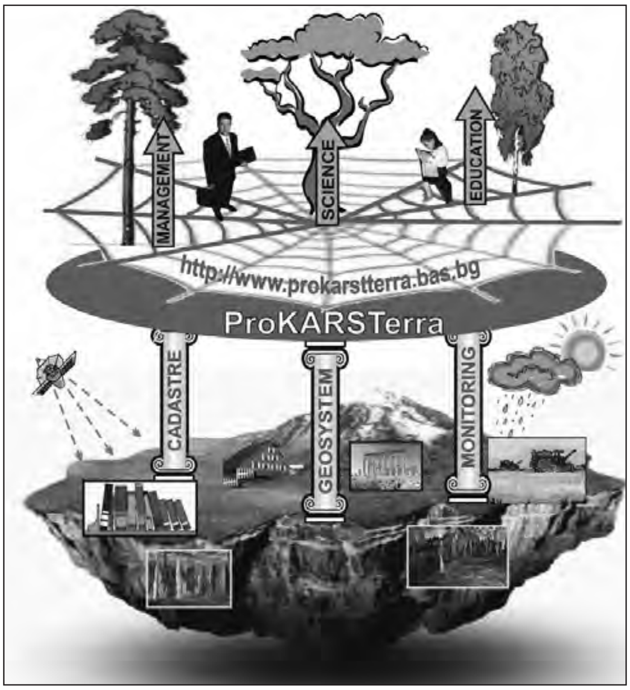

Figure 1. The proKARSTerra strategy.

The pro proKARSTerra paradigm enables the implementation of modern IT technologies for 4-D modeling of karst geosystems, which has very important practical significance to their management and sustainable development. Therefore proKARSTerra is not only a project, it is a strategy (Stefanov et al. 2009, 2013).

It also involves extensive use of the Internet as a powerful information and communication tool. As a first step a specialized MSSQL "proKARSTerra" has been established (Borisova et al. 2013). Its purpose is to: enable promotion, discussion and practical realization of the experimental results of the model for an integrated monitoring of PKT; to offer information concerning various scientific and practical issues in these areas.

A specialized open Internet network "proKARSTerra" has been planned, aiming at coordination of the guidelines for development of PKT, namely building up the "Science-Management-Education" relationships (Fig. 1). It is expected that this network will become a scientific and advisory center for administration of protected karst areas, which will be linked with the appropriate karst specialists (Stefanov et al. 2013). On the other hand, karst experts will have the opportunity to receive feedback on the state of the environment in PKT and the results of solving/or not solving specific problems. This would form a virtual open forum for all interested in karst protected areas. Moreover, the network will compensate some karst-related deficiencies (such as lack of information, political insouciance, regulatory gaps, limited managerial experience about karst specifics, inadequate practices in karst areas, shortage of specialists, etc.) and will enable international exchange and coordination of this type of activity. The designed information network proKARSTerra can be defined as a scientific and applied informational and communication network, as "proKARSTerra-Edu" is one of its important modules (Stefanov et al. 2009, 2013; Stefanova et al. 2013).

3. proKARSTerra-Edu as a strategy

3.1. Strategy development

The strategy of proKARSTerra-Edu which is being experimentally developed in Bulgaria is one of the important aspects of Karstology in this country. The active research during the last 20 years as well as the experiments in representative karst regions have been held within the framework of a series of research projects funded by the National Science Fund concerning (Petrov et al. 1998; Mikhova and Stefanov 1993, 1995 a,b; Mikhova and Stefanov 1999; Stefanov and Mikhova 2000; Stefanov et al. 2002; Stefanov 2004; Stefanov and Iliev 2004; Stefanov et al. 2009):

- Contemporary karst genesis;
- Complex monitoring of karst geosystems;
- Karst cadaster.

These research attempts always had educational purposes, as in some cases this issue has been the leading one (for example introduction of GIS in teaching Geography – "*GIS in the classroom*") (Stefanov 2004; Stefanov et al. 2005; Mikhova et al. 2007). The created scientific base and databases for model karst regions, the acquired expertise, including pedagogical one, make that necessary base, on which the proKARSTerra-Edu strategy has been developed. It uses also rich international expertise through the established contacts and the realization of international initiatives such as scientific-practical forums, international projects, original art competition for children and students.

Overall, the proKARSTerra-Edu strategy is based on (Stefanova et al. 2013):

1. Maintenance and further development of the research infrastructure and the modern information system for complex monitoring of model karst geosystems in PKT, aiming at modeling the contemporary karst genesis in the conditions of clearly expressed global change (fundamental, research direction).

2. Development of a multipurpose educational program using the information resources from research held at model karst geosystems; making available data from the complex PKT monitoring, as well as the outlining trends detected by this monitoring (applied, educational direction) in real time.

Integrating these directions essentially means to integrate the contemporary research concept of Karst geosystems (Fig. 1) with the modern educational concept of "Life-long learning". The latter is well known both from a number of EU educational documents (http://ec.europa.eu/education/pub/pdf /general/eqf/broch_bg.pdf), and from the National strategy of Republic of Bulgaria (http://www.nellii.bg/docs/LLL_strategy_2008-2013.pdf).

Our experience, including also working with children shows that no other scientific field is so attractive and challenging for young people like Karstology. (Especially caves with "white spots" – not studied yet). At the same time as a typical interdisciplinary science it offers ground for disclosure of cross-curricular links and raises awareness of the need to apply the systematic approach of learning.

At this point the experimental integration of both concepts in **proKARSTerra educational model** is based on professional experience, developed research infrastructure and specialized information systems in model karst geosystems for PKT in Bulgaria (Stefanov et al. 2009, 2013), such as: 1) *Natural park "Shumen plateau";* 2) *Natural landmark "Maarata" (*the biggest calcareous tuff cascade in Bulgaria*);* 3) *Natural landmark "Saeva dupka"* (the most visited Bulgarian show-cave); 4) *Protected area "Trigrad Gorge"* (with show-cave "Devil's Throat"). International professional exchange is also of great importance and partners from the Moravsky Kras Protected Landscape Area in the Czech Republic (Štefka 2007, 2011, 2013; Tůma 2013) and Quasi-National karst park Akiyoshi of Japan (Mikhova 2004, 2013; Nakano 2013) participated in the exchange of experience, good practices and comparative experiments.

The choice of model karst geosystems in PKT in the proKARSTerra-Edu strategy has several arguments: it will help to promote specialization of PKT with their attractiveness, representation, tourist infrastructure; in PKT regulated protection, control and security has already been established, which is important for caves with the show-cave infrastructure, educational and research centers of Karstology, etc. On the other hand, specialization of PKT supports and often provokes their effective management and implementation of modern principals of sustainable development. Performance feedback in this process has the meaning of objective control over the PKT environmental state and to improve the undertaken activities. Also, the practical implementation of the Concept of karst geosystems leads to the need for adjustments of PKT borders, which are often not consistent with the karst features.

3.2. Main directions for development of the "proKARSTerra-Edu" strategy

1. Designing specialized information centers (including virtual ones) in models PKT. Designing special scientifically based educational path network for different types of demonstrations and field training ("in situ"). Establishing e-learning and dissemination of knowledge and information from the complex karst monitoring in real time (where it takes place).

2. Development and testing of specialized multipurpose karst educational program based on the established research infrastructure in the model karst geosystems and the information system database.

- Development of a comprehensive concept of karst educational program involving different groups of users – students of different educational levels, teachers, administrative and managerial staff (in karst areas), other individuals ("Life-long learning");
- Development of educational packages with accompanying educational materials for the specialized information centers in PKT; provision of designed scientific-educational trails in them.
- Development, piloting and public presentation of specific e-packages in GIS environment on various topics of Karstology, which are applicable to existing educational programs ("GIS in the classroom");
- Organizing and conducting educational seminars and field demonstration in PKT, involving teachers and initiation of field lessons with students from different schools. Analysis of the results obtained from previously developed training packages;
- Arranging and conducting University students' practices in the PTK network (including international) and attracting graduates in Karstology;
- Organizing and conducting special training course for administrations of PTK and state administrations ("Life-long education");
- Designing, building, testing and maintaining of a special module "proKARSTerra-Edu" within the organized "proKARSTerra" network.

3. Organizing and building up an international network with specialized multipurpose infrastructure (with use of modern ICT and research equipment):**"University of Karst"** (Karst-Uni). At this stage the possibility of involving the already existing places and infrastructure in partner-countries have been assessed. They include the above-mentioned model PKT in Bulgaria; the Akiyoshi-National Karst Park in Japan (with its Natural Science Museum and the Karst Eco-museum, which is a center of educational activities, concerning karst and nature); the Natural reserve Moravsky kras (with its new House of Nature, Štefka 2013) and show-caves in the Czech Republic have been intensively discussed.

4. Dissemination of the results and opportunities for establishing National/International scientific-educational center of Karstology (based on the proKARSTerra strategy), to generate and distribute international initiatives and to involve wider circles of students, researchers, policy-makers at various levels, stake-holders and local communities in the current problems of karst.

- Preparation and publication of specialized scientific and methodological **electronic journal "e-proKARSTerra"** with international editorial board. Three sections can be developed, such as: science, management, education (materials will be published in several official languages);
- Maintaining as traditional (2-year interval) the already established international **competition for students *"Karst under protection – a gift for future generations"*** (organizer Bulgaria, international jury). The competition is held in 5 categories: A) For pupils up to 12 years old (Pictures, Art products with natural materials); B) For students above 12 years of age (Posters/Post-cards, Multi-media presentations, Video-clips); C) University students (Research Essays, Multimedia presentations, Art installations); D) Teachers (My unusual lesson); E) Nature-loving photographers (Photo-composition).

The first two editions of the competition (2005–2012 – in five categories and the traveling exhibition of winning works that sparked considerable interest and achieved serious educational effects (Nakano 2006; Nakano and Iwamoto 2013; Stefanov 2006, 2013). The competition has become a tradition and its third edition is planned for 2014.

- Organizing and conducting (Bulgaria, 2014) an International scientific **forum *"Protected karst territories – training and education"***, to present and discuss models of integration between Karstology and current educational programs world-wide.

4. Conclusions

The proKARSTerra-Edu strategy aims at creating new forms of linking the modern science and education in the field of karst as unique natural phenomenon, resource and living environment. The idea is to carry out this process in the protected karst territories. For this purpose, the existing and new experimental research infrastructure (underground stations) for comprehensive monitoring of model karst geosystems will be used, aiming at studying and modeling the contemporary karst genesis in the conditions of pronounced global change.

At this stage the proKARSTerra-Edu strategy is being developed and experimented on a national level, but it is internationally open (including the planned e-network database). It is also open for discussions and new partners. It is clear that implementation of the ideas, set out in this strategy is a difficult and lengthy process requiring a lot of expertise, broad international cooperation and coordination. Therefore, it is largely supranational. The results of its implementation will be felt in the future and will be achieved by young people, interested in karst and having obtained their education through proKARSTerra-Edu. Of great help might be an eventual success in promoting the idea raised in Bulgaria about declaration of an **International Year of Karst by UNESCO**.

Acknowledgments

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Session:

Karst and Caves: Social Aspects and Other Topics

KARST MORPHOLOGY OF MARTIAN EVAPORITE SURFACES

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During morphological investigation of a Martian surface a karst-like topography characterized by depressions of various sizes and shapes and other karst-like features were detected in locations where evaporite minerals composed the surface. According to OMEGA mineralogical data (OMEGA data orbit 531_3) and further studies the surfaces appears to consist of magnesium sulphate (kieserite) and other evaporite minerals also found on the Earth. Here are presented karst morphologies from three different locations on Mars: evaporite domes from Tithonium Chasma and Coprates Chasma of Valles Marineris and plateau formed of horizontal bedded evaporite rocks from Sinus Meridian, part of the large area known as Terra Meridiani, located near the southwestern margin of Arabia Terra, in the equatorial region of Mars. There is a question are the karst-like features observed true (real) karst features formed due to solution and collapse processes or are pseudo-karst features formed by non-karst processes. In fact, because the high resolution of the newer images available of the Martian surface and precise morphological analyses, the processes formatting the features might be hypothesized as solution and collapse (caused by dissolution of the sulphate rocks). Observations also clearly indicated the presence of selective solution, highlighting that the Martian evaporite surfaces may be formed of different materials (for instance: minerals, grain-size, textures, structures) with different solutional properties. The karst features detected during our analyses were various karren, solution and collapse dolines and cave entrances.

1. Introduction

During the morphological investigation of a Martian kieserite (monohydrate magnesium sulphate) dome located on the bottom of the Tithonium Chasma (TC) canyon a karst-like topography characterized by depressions of various sizes and shapes, solution valleys and other karst-like features were detected (Baioni and Wezel 2008). The authors have chosen to use the term karst-like because the landforms observed on the dome surface strongly appear to be karst landforms but it was not possible to establish clearly the nature of the processes which were involved in their formation and shaping. For some of the landforms observed the images available were not useful to understand clearly if they were made and shaped totally by solutional processes like the karst landforms on the Earth or by other processes as happen in the pseudo-karst landforms on the Earth.

Layered deposits of Mars were first observed on Mariner 9 images and have been reported as thick deposits with internal layering, and a relative high albedo (Lucchitta et al. 1994). Significant deposits occur in almost all deep canyons of the Valles Marineris system where they are called interior layered deposits (ILD). The ILDs have been widely studied in the last few decades, but still they remain among the most puzzling and controversial of the canyons' features (Carr 2006). Recently, observations from the OMEGA spectrometer, on board Mars Express have shown the presence of hydrate minerals, in particular sulphates, in association with ILDs.

Morphological analysis of the available Mars Reconnaissance Orbiter (MRO) High Resolution Imaging Science Experiment (HiRISE) images were performed with the aim of describing surface features and landforms, and, where possible, morphogenetic processes. The morphological features of the selected evaporite surfaces were investigated through integrated analysis of HiRISE, High Resolution Stereo Camera (HRSC), Mars Orbiter Camera (MOC), and Thermal Emission Imaging System (THEMIS) data. The morphometric characteristics of the structures were measured using a topographic map (50-m contour interval) built from HRSC and Mars Orbiter Laser Altimeter (MOLA) data.

Well expressed karst features were detected on evaporite dome in Tithonium Chasma and Coprates Chasma of Valles Marineris graben system and in the northern part of Sinus Meridian a region of Meridiani Planum located at southwestern margin of Arabia Terra.

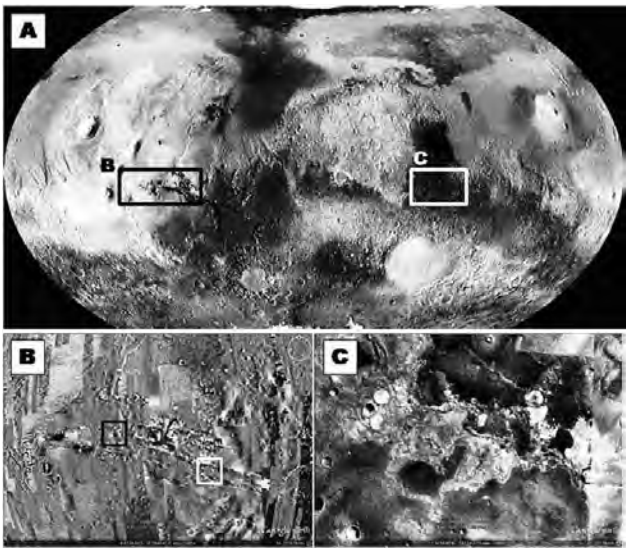

Figure 1. Detected karst areas on Mars: A) Global map of Mars with the areas (boxes) where karst landforms have been surveyed (Image from www.spacedaily.com); B) Valles Mariners region with the locations of the ETD (black box) and the NCD (white box); C) Northern Sinus Meridiani region. (Images B and C are from www.google.com/mars).

2. East Tithonium Dome (ETD)

On the floor at the eastern end of Tithonium Chasma (at about latitude 5° S and longitude 280° E) spectra taken with the OMEGA spectrometer provide evidence of sulphate minerals associated with bright interior layered deposits. The unit shows the dome shape morphology and it is now proven to bear magnesium sulphate (Bibring et al. 2006). The dome rises from the Chasma floor to an altitude of about 3,400 m and shows an elongate, elliptical plane shape.

Figure 2. ETD with the locations (white circles) of the different karst features described (Image from www.google.com/mars).

The dome shows the asymmetric flank topography, with the longest axis of about 23.5 km in a NW-SE direction and width between 10 and 14 km. The crestal region (2,550 m to 2,750 m) lies in the central part of a summit plateau which is about 7 km long displays a very gentle slope of about 6%, and it is surrounded by steep slope flanks. The main flank slopes range between 8% and 33%. The dome flanks are characterized by deep from the margins of the summit plateau.

The mineralogical characteristics of the ETD have been indicated by the OMEGA image spectrometer data that mapped it as a sulphate deposit (OMEGA data orbit 531_3) (Bibring et al. 2006). Studies (Popa 2006; Popa et al. 2007) of the spectral characteristics show clear signatures of kieserite ($MgSO_4 \cdot H_2O$). From morphological analyses it is obvious that also minerals which originated from alteration of kieserite are present on the surface (Baioni and Wezel 2008).

2.1. Karst features of ETD

Features formed by fluvio-erosional and solutional processes are well visible on the ETD. The solutional surface is characterized by landforms typical of the karst morphology such as karren, dolines, collapse dolines and caves (entrances to the shafts and outflow caves).

Various types of *karren* are well expressed on the dome slopes. *Long linear karren* were detected on the western flank of the dome, where long solution runnels of about 15 m are visible also next to some shaft walls or deep depressions. From their position and size we suppose that they were formed as hydraulically controlled karren (in sense of Maire et al. 2009).

On the western flank of the EDT some particular surface landforms, which we named "grape-like" karren can be observed. Patterns of *grape-like* forms are actually covering the bottoms of the depressions in *box-work* form. The elongated wide ridges display more or less smooth surfaces and between two of the longest ridges *stepped pavements* often covered by tracts of karren (grape-like and clint and grikes) can be observed. The whole pattern was probably formed by selective corrosion due to the different mineral composition or their different sizes, or to the presence of areas with a different porosity or textures.

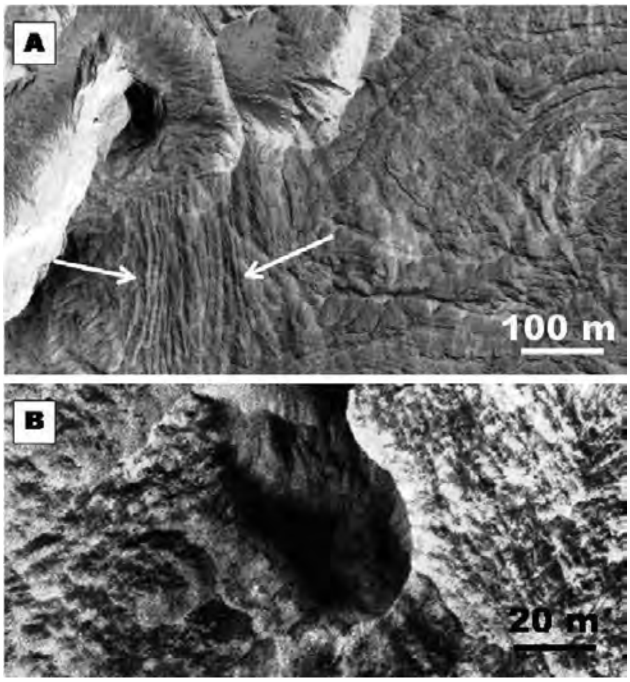

Figure 3. Karst landforms on ETD; a) Long linear karren (white arrows) located in the south-western upper slope (MRO HiRISE PSP_004951_1745; north toward up); b) Doline located in the north-eastern slope (MRO HiRISE PSP_004951_1745; north toward up).

Rounded depressions of different sizes were also detected in the ETD surface. There are small holes for which we are not able to establish if they are dolines or pits. If they are pits, they could be interpreted as *rock-holes* (Jennings 1985; Neuendorf et al. 2005), or they can be just small solution dolines. Larger depressions which we interpreted as *solution dolines* are preset as scattered isolated individuals or as densely packed groups. Some individual solution dolines in the north-eastern part of dome display diameters up to 200 m. Dolines may be so dense packed that they can form typical *polygonal karst* (Williams 1972; White 1988). Dolines are especially dense in the parts of lower inclined ETD slopes, like at: the north-western part, the down slope area in the north-eastern part and in the summit plateau. In the north-eastern part of the ETD sharply divided dolines with over 100 m diameters cover an area of about 2.5 km^2. In the north-western part the polygonal karst cover an area of about 1.5 km^2. Here the depressions appear shallower and smaller, from a few to about 10 m in diameter. In the central part of summit plateau the polygonal karst can be observed in area of about 4 square km. Depressions there are with diameters between 200 m to over 500 m. In the summit plateau and in the north-western areas the divides between adjoining depressions form a cellular mesh pattern just as at the evaporite terrains on the Earth (Ford and Williams 2007).

Collapse dolines of various sizes can be found mainly along the flanks of the ETD. The depressions observed are bowl-shaped or with an elongate shape, wide at the top and narrow at the bottom, or mostly drop-like shaped.

On the ETD slopes we noticed also some entrances to the probable *caves*; to the vertical shafts and to the outflow caves. Of course, the interior of the caves and connections between shafts and outflow caves cannot be seen and it will remain unknown until the day the first Martian speleologists enter these caves. In some cases it is also not obvious if there is really entrance to the cave or it is just shadow in the bottom of the deep depressions. In the upper part of the western flank and in the southern flank of ETD *shaft* entrances can be observed in the bottom of deep depressions. Depression bottoms often cannot be seen, because of the shadow; but erosional features (water channels) leading towards the bottoms can be seen. The presence of the erosional features on the depressions slopes, allow us to suppose that these deep depressions in the ETD might end with vadose shafts, which could be formed by sinking water probably due to ice melting. The analysis of the cave entrances on the southern flank of the ETD indicate due to their location and outflow features on the dome slope below them, that they are probably developed by flowing-water and that they are real *outflow caves*. The cave entrances observed generally display sizes up to 50 m in diameter. No cave entrances (outflow caves) or ponors were detected at the base of the ETD in the border line between the Chasma floor (basalt) and the ETD unit (evaporites).

2.2. Discussion on karst of ETD

The analysis carried out on ETD surface have shown that the observed landforms clearly indicate the presence of solutional processes which also acted in a selective way, highlighting that the dome can be formed of various material (minerals, grain-size, rock structure etc.) with different solutional properties. The results of our observations also suggest that on the dome liquid water (or other solvent) must have existed in the past for enough long time that solution features could be formed. On the Earth cave development in open evaporite domes (salt or sulphate rocks exposed to the surface) is characterized by the formation of linear or crudely dendritic caves, which commonly carry sink streams (Klimchouk 2004). Where the vadose zone is thick, vertical shafts continue as single sub-horizontal passages, leading to the outlets at base level. The lack of karst springs or outlet caves at the base of the ET dome might highlight that water was able to penetrate trough whole ETD and flowed through the roots of the ETD under the basalt covering of the Chasma floor.

3. North Coprates Dome (NCD)

Located next to the Martian equator, the Coprates Chasma is the longest and deepest of the Valles Marineris system troughs. The trough is about 1,000 km long, and ranges in depth from 6 km in the eastern section to over 10.5 km in the west. The main canyon has a floor that displays only a small regional slope, which is relatively free of landslide debris and layered sediments. In the westernmost part of the Chasma in an embayment on the northern wall a mound of layered material rises from the Chasma floor and displays a characteristic dome-shaped morphology; referred as the North Coprates Dome (NCD). The mineral kieserite at the dome and its surroundings has been determined by analysis of the CRISM (Compact Reconnaissance Imaging Spectrometer for Mars) data (image HRL00003752) (Fueten et al. 2010).

The dome rises from the Chasma floor to an altitude of about 200 m that is also the maximum elevation at which the deposits can be identified within the embayment, approximately 3.4 km below the elevation of the plateau (Fueten et al. 2010). The body of the dome has an estimate thickness of about 2,000 m. The dome shows an elongate elliptical plane shape. Its longest axis displays a NNE–SSW-elongated trend with a length of about 17 km, considering as part of the deposits the layers that from its southern edge can be seen extending southwards for several kilometers. Its width varies from 10 to 15 km. The crestal region of the NCD is the central part of the structure and consists of a nearly horizontal summit plateau that is about 5 km long and has a maximum width of about 1 km. It displays a very gentle slope toward south and is surrounded by steeply sloping flanks.

Figure 4. NCD with the locations (white circles) of the different karst features described (Image from www.google.com/mars).

3.1. Karst features of NCD

Typical karst corrosional surfaces formed by sheet and/or channeled water flow can be observed along the NCD flanks such as *karren* and various depressions. In the southwestern region of the dome slope, below the edge of leveled terrace (cuesta like shape), complex giant solutional channels are present down the slope; these channels can be evidence of water flow down the slope.

Leveled surfaces controlled by bedding planes are present on the western slope of the dome steps. The surfaces of the steps and slopes between them are mostly smoothed, as if they were dissolved by melting snow/ice waters; bowl shaped shallow depressions are present on them in some places. Many *closed depressions* of various sizes and shapes exist on the dome flanks. The process of their formation is not easy to be determined. We have no evidence if they are solution or collapse dolines or some solution pans, but their shape is not like of wind scallops at all. The depressions on the eastern and western flanks are either bowl-shaped or rounded; they have diameters up to 50 m, display asymmetrical walls and concave-up or have flat floor geometry. In some cases, like on the western flank, the floors are subdivided into smaller and shallower depressions that have diameters ranging from one to a few meters, highlighting a second generation of solution depressions. *Polygonal-like karst* can be observed on the parts of the NCD that have lower slope angles, such as the down slope region of the southeastern part of the dome. Here depressions entirely pock some parts of the surface and occupy most of its area and have diameters from 30 m to over 100 m. This area has an irregular "egg-box-like" topography and the divides between adjacent depressions form a cellular mesh pattern.

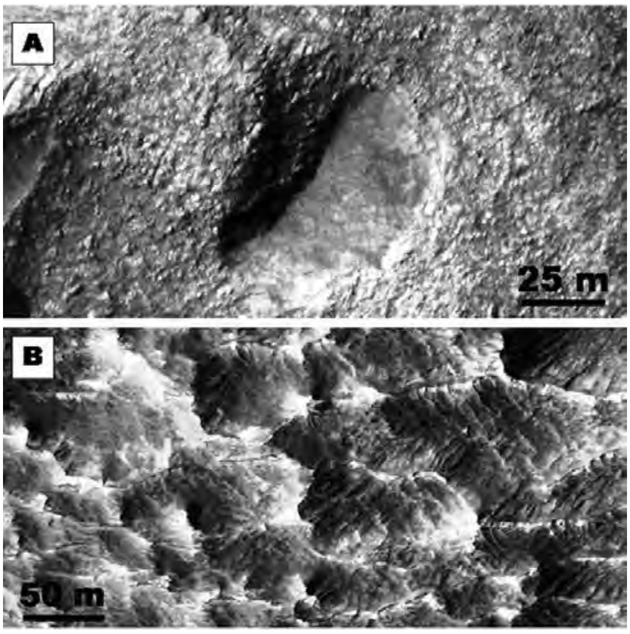

Figure 5. Karst landforms on NCD; A) Doline located in the south-eastern downslope (MRO HiRISE PSP_001456_1695; north toward up); B) Polygonal karst landscape located in the south-eastern slope (MRO HiRISE PSP_001456_1695; north toward up).

3.2. Discussion on karst of NCD

The multiple forms indicate minimum two episodes of water appearance (ice/permafrost melting) on the dome surface and at least two-stage dissolution of evaporite rock during depression formation. On the upper part of the southern flank, where the incline of the slope is higher, depressions have an elongated shape with a wide top and a narrow bottom.

We have no evidence that the water really penetrates into evaporite rock, so the dolines may also be formed like huge solution pans by standing or very slowly flowing water down the inclined slope. Depressions at the edges of the dolines were most likely also influenced by aeolian process, because they are elongated in the wind blow direction and can be compared to the direction of the dunes in the vicinity. Elongated shape of depressions can be also interpreted as hydroaeolian landforms (Maire et al. 2009) formed by horizontal solution accelerated by wind deflection. That means that during water existence on the surface of the NCD strong and permanent winds facilitate laminar flow in direction of wind blow and solution forms are elongated along it.

The karst features on the NCD, which were most likely formed by water during snow, ice or permafrost melting, can be well correlated with the forms typical for high mountain karst regions on Earth, such as, decantation runnels, solutional bevels, tritkarren, and solution ripples.

The analysis shows that the landforms observed clearly indicate the presence of solutional processes. But from extant features we can assume that there was not enough available water to shape more evident relief or that forms were already eroded by some younger processes. The karst landforms investigated at NCD exhibit an older erosional age or shorter than the same landforms studied in a similar dome located within Tithonium Chasma.

4. Northern Sinus Meridiani (NSM)

The Sinus Meridiani area is located near the south-western margin of Arabia Terra in the equatorial region of Mars and it is centered at 5° south and 0° east. In this area several studies showed evidence of past aqueous activity preserved in several distinct units that were identified and classified as layered deposits with monohydrated and poly-hydrated sulfate spectral signatures (Griffes et al. 2007). Further studies on spectral analyses defined and mapped several distinct stratigraphic units in which exposure of hydrate sulfates and Fe/Mg smectites were recognized (Wiseman 2009).

Our studied region is located between 1°20' N to 2° 20' N latitude and 2° 50' W to 1°E longitude and extends about 200 km in east-west direction and about 100 km in north-south direction, covering an area of about 20,000 square kilometers. In the center of the study area on the floor of the northwest-southeast trending valley layered deposits that exhibit hydrated sulfate spectral signatures are mapped as Layered Hydrated Sulfate (LHS) deposits (Wiseman et al. 2010). These deposits, that are about 50 m thick near their northwestern margin and about 150 m thick near their northeastern margin, are texturally and spectrally distinct from the sulfate and hematite rich unit, exhibit spectra indicative of mono- and poly-hydrated sulfates, and erosional pits and grooves at small to intermediate spatial scales (Wiseman et al. 2010).

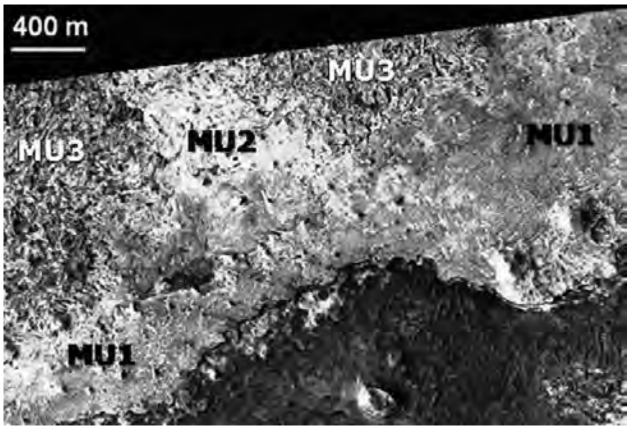

Figure 6. Area of North Sinus Meridian region display all three described Morpho-Units observed (MRO HiRISE PSP_011712_1820; north toward up).

4.1. Karst features of NSM

The study area on hydrated sulfates displays mainly three distinct surfaces, named morpho-units characterized by different degree of karstification. The three morpho-units, which are exposed almost in the whole area, from the stratigraphic point of view can be classified as upper, middle and lower morpho-units. The *upper morpho-unit* often can be observed at the top of the mesas relief located within the study area and displays light brown color in the HiRISE images. At *middle morpho-unit* the HiRISE scale displays polygonal cracking and light bright color. *Lower morho-unit* the HiRISE displays multi level bottomed depressions and light gray color.

Upper morpho-unit (MU1) represents *planated plateau with pavements*. *Dolines* occur as scattered or as isolated and have mainly ellipse shape. They are often located along joints and are connected or by channels that in some cases display a sinuous trend or by straight lineaments. The depressions ranging in length from 10 m to more than 80 m, and from 5 m to 50 m in width. They have steep or vertical walls and flat bottoms. Most of the depressions are covered by dark dust or sediments which often display dune morphology and some of depressions are step sided with well expressed deepest point.

Middle morpho-unit (MU2) pavement is covered by scattered individual depressions along joints/fissures and where textures are well seen in the bedrock. *Dolines* here are bowled or rounded, or rarely with an elongate or drop-like shape. Generally they have diameters up to 20 m and some to 50 m, and display either asymmetrical or symmetrical steep walls with concave-up or flat floor geometry. The depression bottoms are without or with little of dust or sediment accumulations. At this morpho-unit also *small pits* are present. They are smaller than the other depressions and their density is high.

Lower morpho-unit (MU3) represents multi-bottom and step-sided depressions. Overall impression is heavily etched surface with many depressions. *Dolines* are of different shapes; from rounded elongate and elliptical to bowl or rounded shape and polygonal shape. The elongate shaped depressions generally have size between 50 to 150 m in length and between 30 to 100 m in width; while the rounded and polygonal shaped dolines are in diameters from 20 m to more than 50 m. In this lower unit step-sided dolines are very common, indicating different level of ground water (perhaps dropping water table) at which separate leveled bottoms were formed. The highest steps represent the remains of older bottoms of individual depressions. In some of the depressions accumulation of dust or sediments completely buried their bottoms.

4.2. Discussion on karst of NSM

Dolines at MU1 might be developed as thermo-karst features with collapses caused by seasonal permafrost melting like in the cold regions on the Earth; or they were formed as solution depressions developed along master joints on rocky pavement. Surface represents no well expressed karren what gives an idea that available water penetrated underground very fast at the points of maximum vertical permeability along joints and formed solution dolines. For karst development there have had to be time with unfrozen subsurface where water table and/or permafrost was not just below or at surface.

Depressions at MU2 we can interpret as polygenetic: start as big solution pans below water layer (sheet water flow or standing water on the surface) and continuation by developing of individual depressions as solution dolines; where water with dissolved material penetrate into underground. If there was present just sublimation/evaporation of available water, the precipitation of minerals would occur in the form of crusts or mineral grains. Depressions in relief were formed in the places with better vertical permeability or with more suitable mineralogy/texture. In some depressions sharp edges can be observed but there is no evidence of collapse.

The surface of MU3 is well etched; corrosion had to last the longest time. Corroded surface can indicates the closeness of water table or of permafrost/ice layer which caused that water couldn't penetrate underground; or indicates the multiple melting of ice and/or permafrost followed with more events of dissolution or inflows of not completely saturated water from overlaying beds.

Generally the depressions with the sediments in their bottoms are located at the higher elevations than those with bare bottoms. The presence of the sediments in bottoms can be interpreted at least in two ways: as that the dipper depressions with no sediments are younger or that depression bottoms at higher altitudes were more suitable (as sediment traps) for sedimentation of material by wind.

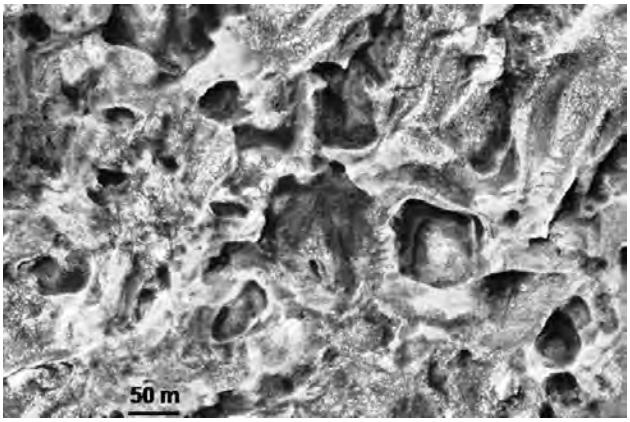

Figure 7. Detail of the Morpho-Unit 3 (MU3) in Northern Sinus Meridiani (MRO HiRISE 008152_1825; north toward up).

5. Discussion and Conclusions

There are many existing definitions of karst from which it can be concluded, that three fundamental conditions must be present for karst formation: soluble rock, water and development of subsurface water drainage. We have to emphasize that karst will only evolve if water can get underground and dissolve caves, which provide conduits for the evacuation of dissolved material in the solution.

The existence of karst forms on Martian surface is result of availability of soluble rocks and water during its geological history. At present time a variety of soluble evaporite rocks which are partly covered by dust or dunes are exposed on Martian surface; there is no liquid water or other solvent; but we can observe morphologies which strongly resembles karst forms on the Earth. Observed landforms on the study areas appear to be formed as a result of flowing water and solution processes as do similar landforms on evaporites on the Earth and that they are typical karst forms. The presence of dolines indicates intense surface dissolution and runoff along the whole area. On Mars the occurrence of rainwater has been only proposed in Noachian and partially in the Hesperian age (Baker et al. 1991) and locally in the early Amazonian (Gulik and Baker 1989). After the early Amazonian there was no rainwater, from that we suppose that the necessary liquid water for stimulating the dissolution processes was probably provided by the melting of frozen groundwater (permafrost), snow cover or ice. So the development of the karst in different Martian evaporite surfaces is triggered by the melting of ice and/or permafrost what provided the necessary liquid water (Baioni and Wezel 2010; Grindrod and Balme 2010; Baioni et al. 2011). We have also to consider that the velocity of dissolution and the formation of the karst features in evaporite rocks are very high; it is not necessary that the amount of available water involved in the solution is big. For instance the solubility of kieserite, which was detected on ETD, is up to 2.5 higher than of halite. The evaporite rocks may dissolve at very high rates if they are in the contact with non-saturated water.

The karst morphologies observed on Mars highlight the significant contribution of karst processes, as they lack evidence of wind action and do not display erosional features that would be associated with the evolution of impact craters.

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ESA CAVES: TRAINING ASTRONAUTS FOR SPACE EXPLORATION

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The first spaceflight was several decades ago, and yet extraterrestrial exploration is only at the beginning and has mainly been carried out by robotic probes and rovers sent to extraterrestrial planets and deep space. In the future human extraterrestrial exploration will take place and to get ready for long periods of permanence in space, astronauts are trained during long duration missions on the International Space Station (ISS). To prepare for such endeavours, team training activities are performed in extreme environments on Earth, as isolated deserts, base camps on Antarctica, or stations built on the bottom of the sea, trying to simulate the conditions and operations of space. Space agencies are also particularly interested in the search of signs of life forms in past or present extreme natural environments, such as salt lakes in remote deserts, very deep ocean habitats, submarine volcanic areas, sulphuric acid caves, and lava tubes. One natural environment that very realistically mimics an extraterrestrial exploration habitat is the cave. Caves are dark, remote places, with constant temperature, many logistic problems and stressors (isolation, communication and supply difficulties, physical barriers), and their exploration requires discipline, teamwork, technical skills and a great deal of behavioural adaptation. For this reason, since 2008 the European Space Agency has carried out training activities in the subterranean environment and the CAVES project is one of those training courses, probably the most realistic one. CAVES stands for Cooperative Adventure for Valuing and Exercising human behaviour and performance Skills, and is meant as a multidisciplinary multicultural team exploration mission in a cave. It has been developed by ESA in the past few years (2008–2011) and is open for training of astronauts of the ISS Partner Space Agencies (USA, Russia, Japan, Canada, and Europe). Astronauts are first trained for 5 days to explore, document and survey a karst system, then take on a cave exploration mission for 6 days underground. A team of expert cave instructors, a Human Behaviour and Performance facilitator, scientists and video reporters, ensure that all tasks are performed in complete safety and guides all these astronauts' activities. During the underground mission the astronauts' technical competences are challenged (exploring, surveying, taking pictures), their human behaviour and decision-making skills are debriefed, and they are required to carry out an operational programme which entails performing scientific tasks and testing equipment, similarly to what they are required to do on the ISS. The science program includes environmental and air circulation monitoring, mineralogy, microbiology, chemical composition of waters, and search for life forms adapted to the cavern environment. The CAVES 2012 Course will be explained and the first interesting scientific results will be presented.

1. Introduction

Space agencies are concerned with the training of their astronauts for future extraterrestrial exploration. Preparing for expeditions to other planets and deep space requires the individuation of space analogue environments in which extreme conditions are encountered, and which replicate stressors similar to those encountered in long duration spaceflight (Morphew 2011).

CAVES (Cooperative Adventure for Valuing and Exercising human behaviour and performance Skills) is the name of a multidisciplinary exploration mission in a cave environment. Developed by the European Space Agency (ESA) since 2008, this course puts together technical challenges, human behaviour and teamwork skills, and a complex scientific programme, run according to space operation protocols. Besides the description of the course concept, this article relates on the first scientific results obtained during the September 2011 and September 2012 CAVES courses, held in Sardinia (Italy).

2. The "CAVES" course concept

Long-duration spaceflight mission crews should spend time together in high-fidelity analogues (Raymond 2011). The need to find relevant terrestrial analogues to prepare teams operating in extraterrestrial environments is driven by extraordinary demands for safety and mission success (Bishop 2011). Space agencies have long struggled to identify best analogues.

Caves are a hostile and dangerous environment that must be dealt with acquired competences on progression techniques and clear operational safety rules. The environment is however just a "container": analogies should be based on similarities in experiences, not just in environment (Bishop 2011).

During CAVES astronauts are trained to use simple rope ascending and descending tools and to negotiate difficult and long traverses rigged with iron cables (Marbach and Rocourt 1980). This technical training resembles skills and protocols that are required to move and operate in extravehicular activity, with reduced field of view, shadows, tri-dimensional progression through viable paths, confused perception of obstacles and distances, and no-touch zones (Figs. 1–2).

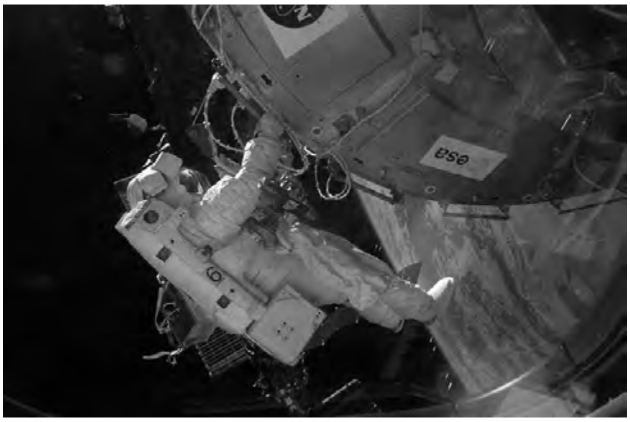

Figure 1. Spacewalking (Credit NASA).

This preparatory training is propedeutical to an extended caves exploration phase, where the astronauts autonomously perform an expedition as a multicultural and multidisciplinary team. For safety, astronauts are followed by instructors and experienced cavers, but they are trained to use a buddy system and to maintain team situational awareness through briefings and debriefings in order to maintain control on the safety of the whole group, to allow informed decision making for each member of the team, and to enable team learning through analysis of failures and successes.

Analogue team training needs to be based on the concept of operations (Raymond 2011), and provide real challenges, stressors and a credible programme. During the CAVES mission, astronauts will explore new branches of the cave, and are required to survey all explored areas, as well as provide photographic documentation of all activities performed.

As for space missions, astronauts are trained to carry out a scientific programme, according to a flexible operational timeline and space-like procedures. Twice/day the astronauts hold planning conferences with a "ground" control team to report on daily achievements and confirm plans ahead.

The scientific tasks that the astronauts are asked to carry out are numerous: microbiological sampling of air, water, and solid material, monitoring of cave air temperature, relative humidity, and wind speed and direction, sampling of waters and minerals for successive laboratory analyses, and monitoring (and, in some cases, sampling) of cave dwelling fauna (mainly troglobites).

Equipment testing is also a common task during space missions. To increase safety of cave exploration operations, a new digital wireless underground radio communication system was also tested.

Figure 2. Cavewalking (Credit ESA – V. Crobu).

3. Methods

3.1. Exploration and survey

Astronauts are asked to make a survey of the areas they explore (Fig. 3). Normal Grade 5 cave mapping techniques with Leica DistoX, handheld Suunto Compass and Clinometer for in cave measurements have been used, with map detail grades 2 and using Compass software for restitution (with loop adjustment and closure) (Grade UISv1 5-2-B, cfr. Haüselmann 2011).

Figure 3. Astronauts surveying the cave (Credit ESA – S. Sechi).

3.2. Mineralogy and Water chemistry

Mineral samples have been taken making use of a steel spoon or a geological hammer (normally scratching of secondary minerals crusts or coatings), placing a few grams of material in a small plastic cylindrical container. A detailed analysis of all the samples under stereoscopic microscope was performed to distinguish and to separate the different mineralogical phases present. Single phases were analyzed by an X-ray diffractometer (Philips PW 1050/25) or in a Gandolfi camera (Ø: 114.6 mm, exposition: 24/48 hrs). Experimental conditions were a 40 Kv and 20 mA tube and CuKα Ni filtered radiation (λ = 1.5418 Å). Chemical qualitative analyses were carried out through an electron scanning microscope (ESEM Philips XL40) with an electronic microprobe (EDS-EDAX 9900) at the C.I.G.S. (Centro Interdipartimentale Grandi Strumenti) of the Modena and Reggio Emilia University.

Water samples were composed of two bottles: a cylindrical one of 250 ml containing unfiltered and unacidified water, and a square one of 100 ml of filtered (0.45 μm) water acidified with 1 ml of concentrated HNO_3. Two water samples are collected at each site (250 ml of normal water and 100 ml of water filtered with a 0.45 µm sterile filter and acidified with 1 ml of concentrated HNO_3). At each sampling site pH, temperature (T), Electrical Conductivity (EC) and Total Dissolved Salts (TDS) are measured in situ with a Hanna HI 991301 portable sensor. Fundamental metals (Na^+, K^+, Mg^{2+} and Ca^{2+}) were analysed with an Atomic Absorption Spectrophotometer (AAS), minor and trace metals and semimetals (Pb, As (tot.), Cu, Zn, Cd etc.) with ICP-OES instead. Major anions (SO_4^{2+}, Cl^-, F^-, Br^- and NO_3^-) were analysed with Ionic Chromatography, the nitrogen species (NH_4^+, NO_2^-) by Colorimetry, Chemical Oxygen Demand (COD) through a return titration after oxidation with Potassium dichromate.

3.3. Cave meteorology

Three Onset HOBO U23 Pro v2 Temperature/Relative Humidity (RH) data loggers have been placed in several spots in the cave during both 2011 and 2012 missions. Sensors have an accuracy of 0.2 °C and 5% RH and measurements were set at 30 minute intervals. The 2011 mission investigated the camp area, with data loggers placed far away or close to the tents and kitchen on a horizontal plane, while in 2012 a vertical log has been made placing the data loggers at the lake level, the safe haven (mid height) and close to the roof above the Camp site.

A CR200 Data logger of Campbell Scientific Inc. equipped with an MP100A Temperature/RH sensor (accuracy 0.5 ºC/2% RH) and a Windsonic ultrasonic wind sensor (accuracy 3º wind direction and 2% of reading in wind speed) has been installed in a windy passage in the summer of 2011 (Fig. 4). Reading interval was set at twice an hour and data were downloaded every 3 months. During the missions astronauts have programmed the station to take measures every minute for 4 to 5 days consecutively, and data were downloaded at the end of this test period, switching the readings back to twice an hour.

3.4. Microbiology

To investigate if humans change the microbial environment by their presence, astronauts were equipped with agar plates containing different nutrient media (Fig 5). At selected places (e.g., camp kitchen area) plates were exposed to cave air for 30 min. For each sample site, temperature and humidity were determined.

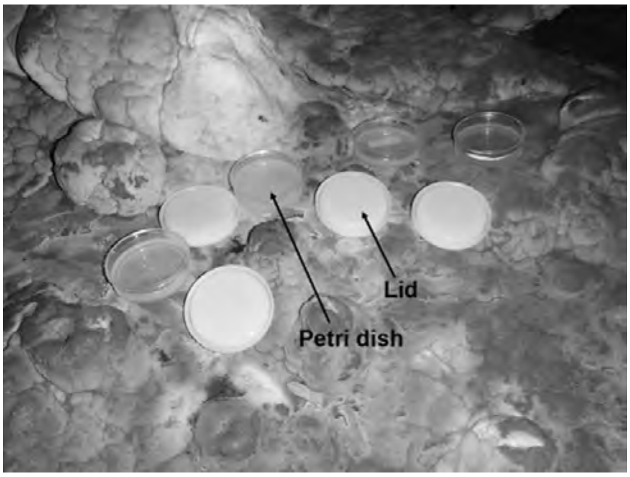

Figure 5. Agar plates exposed to cave air (Credit ESA – V. Crobu).

For follow-up molecular studies, astronauts were asked to collect soil and water samples using special sterile Falcon tubes (Fig. 6). They selected appropriate sampling sites and collected soil or dirt by scrapping the surface with a sterile metal spatula. Genomic DNA was extracted from soil samples using the XS buffer method as previously described (Tillett and Neilan 2000). A nested PCR approach using the

Figure 4. The wind station in the narrow squeeze. (Credit ESA – V. Crobu).

Figure 6. Sampling of soil for molecular analysis (Credit ESA – V. Crobu).

primer combinations E27F / 1492R and 340F/1000R were used to screen for archaeal diversity in the samples. Furthermore, soil samples were plated in the laboratory as well to identify soil associated organisms.

3.5. Biology

Terrestrial and aquatic cave dwelling fauna were attracted using baits composed of liver and/or cheese and placed in plastic containers. Animals were free to enter and exit the containers at all times.

To position the baits, the astronauts have looked out for a wet area, if possible with organic material. Baits have been placed underneath stones and rocks, and the aquatic ones on the bottom of a pool or a lake. Baits have been checked each day, if possible, looking for animals inside the bait, close by and under stones near the station. Species were collected using tweezers or a paintbrush, and put in a bowl for counting, photography, or, in some cases, final sampling.

Also direct sampling has been carried out by astronauts, checking for cave-dwelling animals under stones and pebbles, but also on walls and in protected niches close to organic material (animals often "hide" after lunch). All observation and sampling stations have been localised on a map and linked to the nearest survey station.

Known animals were recognised using a photographic manual and counted, while unknown species were sampled in 100 % or 70 % alcohol in small plastic cylindrical probes (Fig. 7). Samples have been sent to specialists for determination.

Figure 7. Biological sampling (credit ESA – V. Crobu).

3.6. TEDRA communication system test

TEDRA™-S1 (Through Earth Digital Radio Appliance) system is a ground transmission radio device constituted of two units by which voice is carried as electric signal from the emission point to the reception one (Villarroel et al. 2007; Muñoz et al. 2011). This system fed with a 12V power source is able to inject an electric current in the ground in emit mode and to reconstruct the signal of this small voltage variation in receive mode using a LF (70 kHz) carrier wave and single side-band modulation. The amplified signal is transmitted in the ground by electrodes and the electric current lines follow their underground path crossing the whole surrounding medium. Each TEDRA™-S1 unit contains an electronic emission/ reception apparatus, two pair of stainless steel electrodes (2 stakes for thick ground and 2 contact meshes for wet and muddy substrates), cables for connecting the electronic unit and electrodes (two 25-metres cables) and a "push to talk" microphone/speaker.

Thanks to CNSAS cave rescue, who has provided the equipment, one TEDRA™-S1 communication unit has been tested in a variety of in-outside locations and configurations (stake and mesh electrodes, different electrodes distances and orientations, vertical and horizontal lines) during the CAVES 2012 mission.

4. Results and discussion

4.1. Exploration and survey

The survey from the entrance to the Camp area inside the cave, and the area around the Camp site up to the start of the Lake Branch and the Wind Station have been mapped by the instructors for a total length of 600 metres. Starting from these known parts, astronauts explored over 3 km of cave passages in the expeditions of September 2011 and 2012. The first team of 5 astronauts surveyed a total of 700 m of cave, exploring several hundreds of metres without mapping. The 2012 team, composed of 6 astronauts and having one more day underground, surveyed a total of 1.3 km of passages, exploring several hundreds of metres especially in the lake branch. A total of 120 survey shots have been carried out and registered in the Compass software. The 3D model of the mapped cave areas is shown in Figure 8.

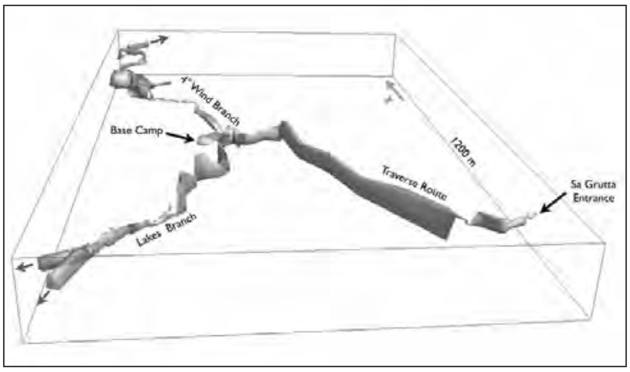

Figure 8. Three-dimensional view of the mapped cave passages.

4.2. Mineralogy and Water chemistry

A total of 6 mineral samples have been collected from the cave, 5 in 2011 and only 1 in 2012. All collected minerals were composed of the common carbonates calcite, aragonite and hydromagnesite. These two last minerals indicate the presence of certain amounts of Mg in the drip waters.

Water samples have been taken in the lakes and in small ponds along the explored cave branches. Most are characterised by the typical calcium bicarbonate chemistry, slightly undersaturated with respect to both calcite and aragonite.

4.3. Cave meteorology

The Temperature and RH measurements on a horizontal and vertical profile have shown the influence of the Camp site to be very minimal and localised.

The wind station, instead, has measured some very interesting data that are still being elaborated (Fig. 9). Wind speed ranges from 0 to 10 m/s in a 0.5 m^2 squeeze. The airflow changes direction when outside temperature becomes close to that of the cave (around 16 ºC), becoming colder or warmer. During winter a temporary sump located some metres further in the cave can fill with water closing the passage completely. These flooding episodes are well recorded by the wind station with a complete stop of all airflows inside the squeeze. The sump lowers and allows airflow to reestablish in less than 2 days time.

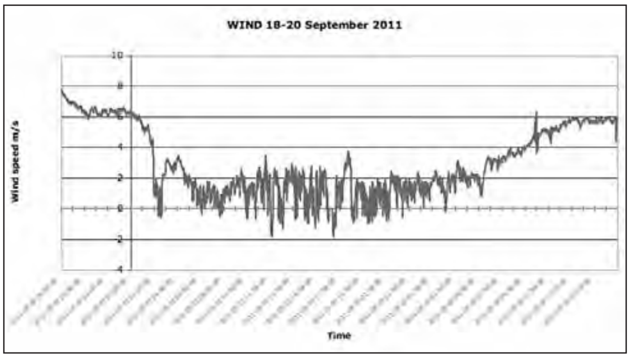

Figure 9. Wind flow in the period 18–20 September 2011, during the astronaut's permanence in the cave. Negative values represent inverted airflow.

4.4. Microbiology

After evaluating the exposed plates, we found that 58 % of all identified bacteria were environmental and 42 % of them were associated with humans (Fig. 10). Species identified belong to the genus *Staphylococcus* and *Micrococcus*. In sharp contrast to these results, plated soil samples showed only 4 % human associated organisms.

The overall bacterial burden in this environment was with 10^4–10^6 cells per milligram of soil lower than normal soil, however, this is not unexpected due to the lack of nutrients. Molecular analysis thus far suggests that there is a diverse pool of archaea present within the cave, however, further analysis is necessary to better characterise the findings.

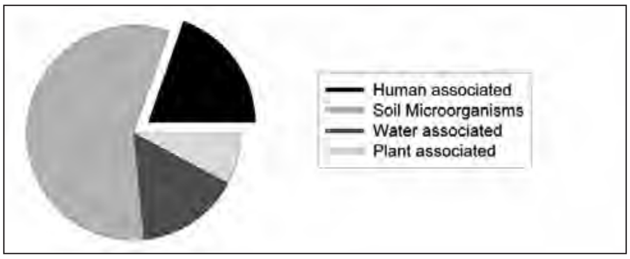

Figure 10. Diagram showing the distribution and association of recovered bacteria.

4.5. Biology

During their stay in the cave, the astronauts have observed, counted and sometimes sampled various specimens belonging to different groups of invertebrates, in particular, Insecta Diplura, Coleoptera and Crustacea.

In each station of sampling, the astronauts have taken note of the kind of substrate, the temperature, and the number of specimens observed. Throughout the whole expedition they have monitored 12 specimens of the crustacean genus *Alpioniscus* (some of which were also sampled), 67 *Ovobathysciola majori* and 5 larval stages of this species, and 12 *Patrizicampa sardoa*.

The Crustacea belong to the Order Isopoda, Suborder Oniscidea, Family Trichoniscidae, and have revealed to be very interesting from the beginning, because of their different morphology, compared to already known species belonging to the genus *Alpioniscus*. The ancestors of these terrestrial isopods seem to have evolved from the aquatic habitat to the terrestrial one. Surprisingly, the astronauts found a species that has returned living in water, completing an evolutionary full circle (Fig. 11). This discovery is very important because the few aquatic woodlice we know of were thought to be primitive forms primarily living in subterranean waters (Vandel 1965). Now it is clear that these animals are specialised forms which have evolved to live in water again. This is demonstrated by the presence of a water conducting system on their 7th pair of legs, a structure that is typical of terrestrial species. This is changing in part the point of view of the specialists on evolutionary processes concerning terrestrial isopods living in an aquatic environment. It also confirms the theory that evolution is not a one-way process but that species can evolve to live in previously forgotten habitats.

Figure 11. The new species of Isopoda discovered in the lake gallery (credit: ESA – M. Fincke).

4.6. TEDRA communications system test

CAVES 2012 extended exploration phase allowed to perform four different TEDRA™-S1 communication tests between underground participants (at the Camp area, Survey Point VE 23 and Survey Point FR 6) and surface support team (at the Mountain peak, a point on the surface that was approximately above the Camp site, and at the Refuge Sa Oche (close to the cave entrance). Subsurface and surface stations distances were 200 metres in depth from the cave to the Mountain peak and around 500 metres at the same altitude from inside to outside. Each test was planned during daily DPC and also arranged in progress during TEDRA communication, after the first contact, in function of the cave exploration (Fig. 12).

The surface antenna length was 10 metres at the Mountain peak and 15 metres at the Refuge Sa Oche, whereas the subsurface antenna length varied from 50 to 25 metres. Both the stakes and the contact meshes were used as electrodes within the cave, while only the stakes were used outside. To optimise the electrical contact with the dry substrate, some water was poured to moisten the electrodes. The electrodes have been placed within the cave grounds in large and flat bedrock covered by several centimetres of loose but moist dust and soil at the Camp site, in a wide field of boulders cemented together with thick mud, with significant vertical height changes and uneven terrain at the Survey Point VE 23 and in loose gravel of various size, extending to a considerable depth at the Survey Point FR 6.

Figure 12. Using the TEDRA communication system (credit: ESA – V. Crobu).

On the surface, the Mountain peak is constituted by a 10 m large valley with limestone bedrock covered by a few centimetres of loose and dry soil while the Refuge Sa Oche substrate was large and flat bedrock covered by few centimetres of dense and dry soil. Regarding the orientation of the electrodes of each TEDRA unit, the angle was chosen in a way that both lines were as parallel as possible, with 10° of tolerance.

Clear and audible communication was always established from the Cave to the Mountain peak, both stakes and meshes were used as electrodes. The exception was Test 3, during which reception was initially understandable but not as good as previous tests, due perhaps to a significant echo effect in the narrow cave. Changing the installation from a full antenna length of 50 m to 40 m, the radio contact was degraded but still possible, but became impossible when the antenna length was further decreased to 34 m and then increased to 50 m again. The degraded communication was attributed to the graveled substrate where stakes were buried.

Very clear and audible TEDRA™-S1 performance was established from cave to the Refuge Sa Oche too, using antenna lengths of both 50 m and 25 m.

5. Conclusions

CAVES has been recognized by all participant astronauts and, in particular, by experienced spacefares as a very realistic spaceflight analogue, providing a unique ISS-representative multicultural operational team training opportunity, where experienced flown astronauts can share their knowledge with younger crewmates.

The cave environment requires adaptation and induces stress and fatigue, requiring constant attention to operational safety procedures. Exploration and documentation tasks and scientific activities provide a realistic set of technical challenges, which carried out in spaceflight-like format, allow the build-up of spaceflight operationally relevant expertise. Behavioural briefings and debriefings enable an invaluable team learning experience, carried out in an environment where the effects of mistaken decisions can have severe impact on safety and mission goals.

The scientific programme not only offers a set of realistic tasks and objectives, but it also provides really interesting scientific results. Multidisciplinary researches allow a continuative and detailed study on the caves visited during the course. The environmental monitoring and the geological and geochemical studies are giving important information about the cave environment in this karst area of Sardinia. Moreover systematic microbiological and biological researches provide new information on these peculiar ecosystems, even discovering previously unknown species. All these important scientific goals were achieved thanks to the careful astronauts' performance of strict scientific protocols and delicate procedures.

In addition CAVES represent an opportunity to test new cave-dedicated technologies, like for the TEDRA™-S1 communications test.

Acknowledgments

Thanks to CNSAS for making available the TEDRA™-S1 devices.

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STUDY OF PULMONARY FUNCTIONS OF TOURIST GUIDES IN THE CAVES

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Park Škocjan Caves is located in South Eastern part of Slovenia. Due to their exceptional significance for cultural and natural heritage, the Škocjan Caves were entered on UNESCO's list of natural and cultural world heritage sites in 1986.Caves have always been special places for people all over the world. There has been a lot of research done in the field of speleology and also in medicine in relation to speleotherapy. There is still one field left partial unexplored and its main issue covers the interaction between special ecosystems as caves and human activities and living.Implementing the Slovene legislation in the field of radiation protection, we are obligated to perform special measurements in the caves and also having our guides and workers in the caves regularly examined according to established procedure. The medical exams are performed at Institution of Occupational Safety, Ljubljana in order to monitor the influence of Radon to the workers in the cave. Park Škocjan Caves established research monitoring projects such as caves microclimate parameters, quality of the water, every day's data from our meteorological station useful tool in public awareness related to pollution and climate change. Last year a special study was started in order to evaluate pulmonary functions of persons who work in the caves and those who work mostly in offices. Two groups of tourist guides from Škocjan Caves and Postojna Cave were included in the study. The promising results will highlight the need of medical survey of people working in the caves and help managers of the caves to adopt reactive management process. In order to facilitate decision process related to protection of people and caves environment, special recommendation in form of index of environment's use will be proposed after the study.

1. Introduction

Caves have always been special places for people all over the world. There has been a lot of research done in the field of speleology and also in medicine in relation to speleotherapy. There is still one field left partial unexplored and its main issue covers the interaction between special ecosystems as caves and human activities inside and around them. The aim of this study is to present the broad field of interactions between man and nature strictly related to the ecosystem services and evaluation of encumbrance caused by human activities. Caves microclimate is special and important unit of caves ecosystem and it encompasses several parameters which are distinguished by its own biological activity. The complexity of joint action of these several factors represents a challenge in searching for methods and explanations of effects, which by endogenous and exogenous factors influence the response of people to specific environment. The study is focused on pulmonary functions of tourist guides in the caves, who are daily exposed to microclimate parameters and radon as a specific factor in environment. According to the Slovene legislation, established by the Ministry of Health and Office for Radiation Protection, Official Gazette RS, No. 05/03, 48/04 tourist guides are registered as people working with sources of radiation (1,2). The study was designed as a proposal for detailed epidemiological studies for larger population of workers in the cave in order to estimate the positive and negative effects of special working conditions. In this project institutions with main activities in caves tourism, speleotherapy and pulmology and occupational safety, have joined their knowledge, experiences and good will, Turizem Kras Postojna Cave, Park Skocjan Caves, Hospital Sezana and Institute of Occupational Safety.

2. Methods

The sample consisted of tourist guides from Skocjan Caves and Postojna Cave, the control group was presented by persons who work in the same place but in the management of both sites. In the group from Skocjan Caves there were 15 guides, 15 directorate personnel. There were 7 man and 8 women in first group and 6 men and 9 women in second group. Average age of the guides was 35.1 and directorate personnel 37.7. In the group of Postojna Cave there were 15 guides and 13 directorate personnel, 13 man and 2 women in first group, average age 37.5, and 4 man and 9 women in second group, average age 45,6. There were 45 smokers and 13 non-smokers included in spiro metrical testing. It was performed in Hospital Sezana on spirometer Ganshorn PowerCube LF8, 5E Release 3.

Pulmonary functions were estimated by following parameters,VC vital capacity, FVCex forced expiratory vita capacity, FEV1 forsed expiratory volume in first second, PEF peak expiratory flow and FEV1/FVCex, FEV1/VCin, FEV1/VCmax (3). Regarding the Decree Uv2 and Rule Sv5 radiation monitoring in two caves in Slovenia, Skocjan Caves and Postojna Cave, is going on. In the period from January to December 2007 measurements of radon and radon daughter concentrations on different locations on the route for visitors in Skocjan Caves and Postojna Cave have been investigated. For long term radon concentration, exposure period of one month or more, track etch detectors from Gammadata, Sweden, were used. Short term radon concentrations, several days, were performed quarterly by electronic devices, Alphaguard, Genitron, Germany, RAD7, USA, System30, Scintrex, Canada, working level monitor WLM 30, Scintrex, Canada and Doseman Pro, Sarad, Germany.

For the estimation of effective doses the model ICRP32 was adopted. Data obtainde by the spirometrical testing, time spent in caves and effective doses were then statistically analysed in Excell and SPSS. Levens test, ANOVA, t test and HocPic tests were used.

3. Results and discussion

Figures No.1 and No.2 show radon concentrations in Skocjan cave and Postojna cave. Radon concentration is different on different locations through cave and it depends on the period of the year. In winter radon concentrations are much lower than in summer. The reason is changing of temperature in outside air. Higher temperatures in summer time prevent air to flow from the cave and radon concentrations are high. During winter the opposite phenomena occur. Cave air can easily flow from the cave and radon concentrations are lower. Radon daughter concentration in caves changes through the year because different air exchange in different periods of the year.

Equilibrium factor F between radon daughter and radon concentrations changes from 0.10 up to 0.81. Our dose calculation is based on Jacobi Eisfeld Model. For attached radon progeny concentration we take into account values, measured on different locations in caves. Annual dose for workers in caves are going up to 12 mSv per year. About 25 % of workers reach effective dose higher than 6 mSv per year. Pulmonary functions are decreasing with age as seen in FVCex, FEV1/VCmx and in FEV1, which is increasing with body mass index. Also PEF is increasing with BMI, slightly shown also positive effect of hours spent in the cave ($p < 0.1$). With 10 % of risk we can confirm that PEF is different among the groups ($F=2.197$, $p < 0,1$).The values of pulmonary functions are slightly higher in group of guides but cannot be statistically significant. We can confirm that positive connection exist among PEF and time spent in caves and thus also the effective dose (r 0.39, $p < 0.05$) as seen in table 3 and figure 3 and 4. For all other functions we cannot confirm that are related to time spent in caves, though in SVC, FVCex, IVC, FEV1 slight positive connection is observed, but Pearsons coefficient is lower than 0.3.

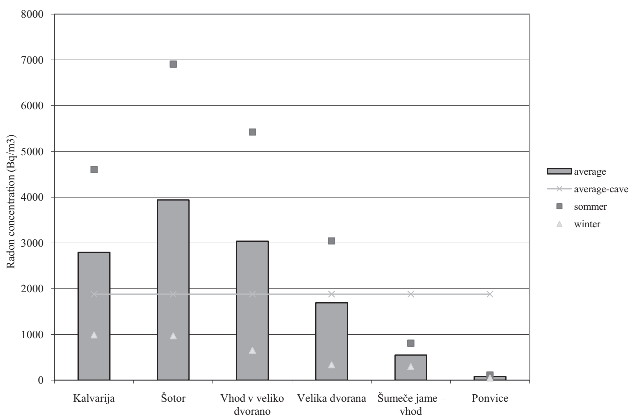

Figure 1. Average concentration of Rn at different locations in Škocjan Caves.

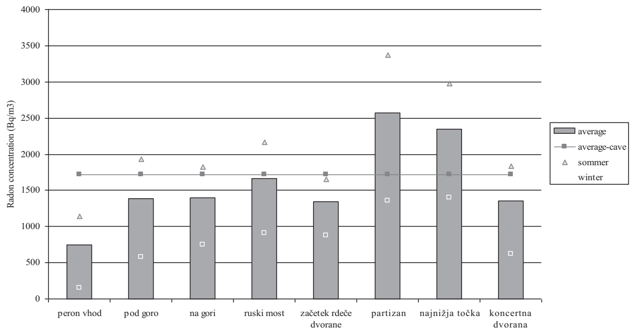

Figure 2. Average concentration of Rn at different locations in Postojna Cave.

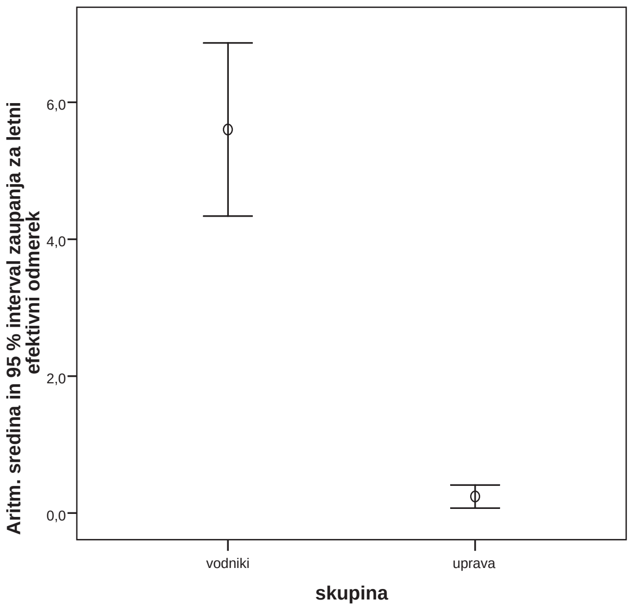

Figure 3. Arithmetical average and 95 % confidence interval for annual effective dose in guides and people employed at directorate.

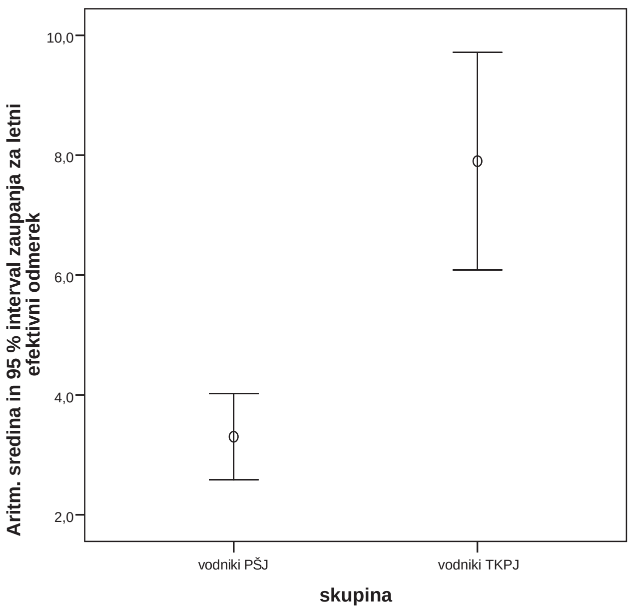

Figure 4. Arithmetical average and 95 % confidence interval for annual effective dose in guides in Škocjan Caves (PŠJ) and guides in Postojna Cave (TKPJ).

4. Conclusions

The guides in the caves are submitted to special legislation in terms of medical exams and education as stated in the law for radiation protection. Due to the radon in the caves chromosome aberrations were evaluated in guides. This test is now used only exceptionally when effective dose is exceeded. Our study gives an insight in pulmonary function of healthy people working in caves and can not confirm harmful effect of special climate condition. PEF values that are higher in guides but might be further investigated due to higher level of physical activity in comparison to group of persons who work in office. Any how detailed epidemiological studies might be done in future to establish the adaptation of man to special working condition and to help managers of the site with proper arrangement of working process. The carrying capacity that is crucial for nature protection, especially in vulnerable environment as caves are, should on the other hand include also the impact of radon to man and not only the impact of human activity to the natural site. We propose the continuation of the study with a larger sample in away that tourism carrying capacity in caves should include also the health hazards for guides that might be presented as Cave Use Index, showing the relationship among ecological carrying capacity, radon concentration and effective dose specific for a cave.

5. Summary

Caves environment is extraordinary ecosystem. The research study deals with impact of caves microclimate from the aspect of preservation of humans' health and quality of ecosystem services.

Sample was performed by tourist guides, working in Škocjan Caves and Postojna Cave and employees of managing authority. The latest was established as a control group, since most of the working time is spent outside the cave regarding to the group of guides, who spent most of the working time in the caves.

Observed values of pulmonary functions were slightly higher in group of guides, but the difference was too small to be confirmed with precision.

The biggest difference, but statistically not confirmed, is shown between guides and administration in SVC and FVCex, where guides show higher values.

Regarding the values of percentage of predication from normative value, there have been statistically higher values in administration.

Positive connection with hours in the caves can be confirmed also in the case pf PEF, but at weaker level ($r=0.39$, $p<0.05$).

For the rest of pulmonary function we can not confirm the connection with hours in the caves though at SVC, FVCex, IVC, FEV1, positive connection is suggested.

Possible mechanisms of caves microclimate effects are shown. The carrying capacity of environment is presented.

Acknowledgments

We wish to thank all people who participate in this project and started a friendly cooperation between two most important tourist caves in Slovenia and personnel of Sezana Hospital, who shared with us their highly professional knowledge.

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A VIRTUAL DISTRIBUTED CAVING LIBRARY

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Thanks to recent developments in Internet editorial information sharing, a prototype of a caving reference bibliography and virtual library for the Lombardia region (Northern Italy) is proposed. It relies on the following components: 1) the Google Earth© tool as a user interface, in order to position caves on the land and as a starting point toward bibliographic queries; 2) static generation of web pages representing single caves bibliography and references to titles; 3) Internet references (URL) pointing to specific titles available in the Internet, so as to quickly browse them. Presently, the Lombardy caving bibliography collects 4,800 references related to 4,200 caves. Books or magazines related to 1,150 references are freely available in the Internet. Problems and potential developments are discussed.

1. Introduction

A specific bibliographic collection is essential to every serious researcher. In speleology, the BBS is an extremely powerful tool to gain knowledge about specific disciplines, areas or keywords at a worldwide level.

A detailed caving bibliographic system would require a review of the publications content in order to collect and arrange information about referenced caves and their specific data. In the past, some printed catalogues were produced. In Lombardia (Northern Italy) Pavan and Tirini Pavan (1954) collected 746 references about 695 caves, with detailed listings of specific references. Of course, a digital data-base is much more powerful: specific queries can be run, to get the list of papers in which a specific cave is referenced, its survey is published, palaeontological data are provided, etc.

Furthermore, researchers can presently find a huge amount of books and magazines in the World Wide Web. Older, public domain publication were scanned and freely provided by several virtual or real libraries. On the other side, many scientific and caving club magazines are presently published on-line, mainly in order to spare money. This means that a fair percentage of references can be perused directly on-line.

2. Materials and methods

A prototype of virtual distributed caving library is presented. The prototype is: **virtual**, that is the system is fully digital; **distributed**: the library contents are provided by several kinds of publishers: large real libraries, virtual library systems, commercial publishers, research institutions, mountain clubs, caving clubs, etc. The single content is hosted in the provider web site.

The prototype contains data about caves in Lombardia, a region in Northern Italy where caving started in the XIX century. Gruppo Grotte Milano, the first caving club in Lombardia, was established in 1897. Presently, about 4,000 caves are registered.

The system relied on the seminal work by Pavan and Tirini Pavan (1954) and on unpublished collections of references by Alfredo Bini and Alberto Buzio. The system builds on four data layers.

2.1. Bibliographic references

Plain bibliographic references from several sources are collected and added to the data-base. Books and magazine papers are considered as sources. Some 400 newspaper articles are inserted too. Most of them show an historical relevance: they were published before WWII. Web pages are not considered. A flag is used to mark references review status: green for reviewed ones vs. red for unchecked ones. Presently, title references are 4,800. Reviewed ones are 2,800 (58 %). However, more than 100 titles await insertion and of course new publications appear continuously.

Table 1. Cave references categories.

Category
Cave Register
Access Route
Description
Survey
Picture
Bibliography
Exploration
Rigging Chart
History
Archeology
Biology
Folklore
Geology
Hydrology
Meteorology
Paleontology
Paletnology
Cave Rescue
Tourism
Cave Diving
Simple or undetermined reference

2.2. Cave references

A list of caves is maintained. Each reviewed title is checked against specific references to caves. Table 1 lists the reference categories. Each cave reference is represented by a triple: Cave ID – category – pages. In Italy, registered caves are identified by a regional abbreviation, Lo for Lombardia, and by a progressive number. Referenced caves could miss the cave register number. Possible reasons are: cave is not registered yet, register number is unknown, cave cannot be registered, due to too small size or to intervening destruction. In order to cope with unidentified caves, a small trick is employed: negative integer numbers are

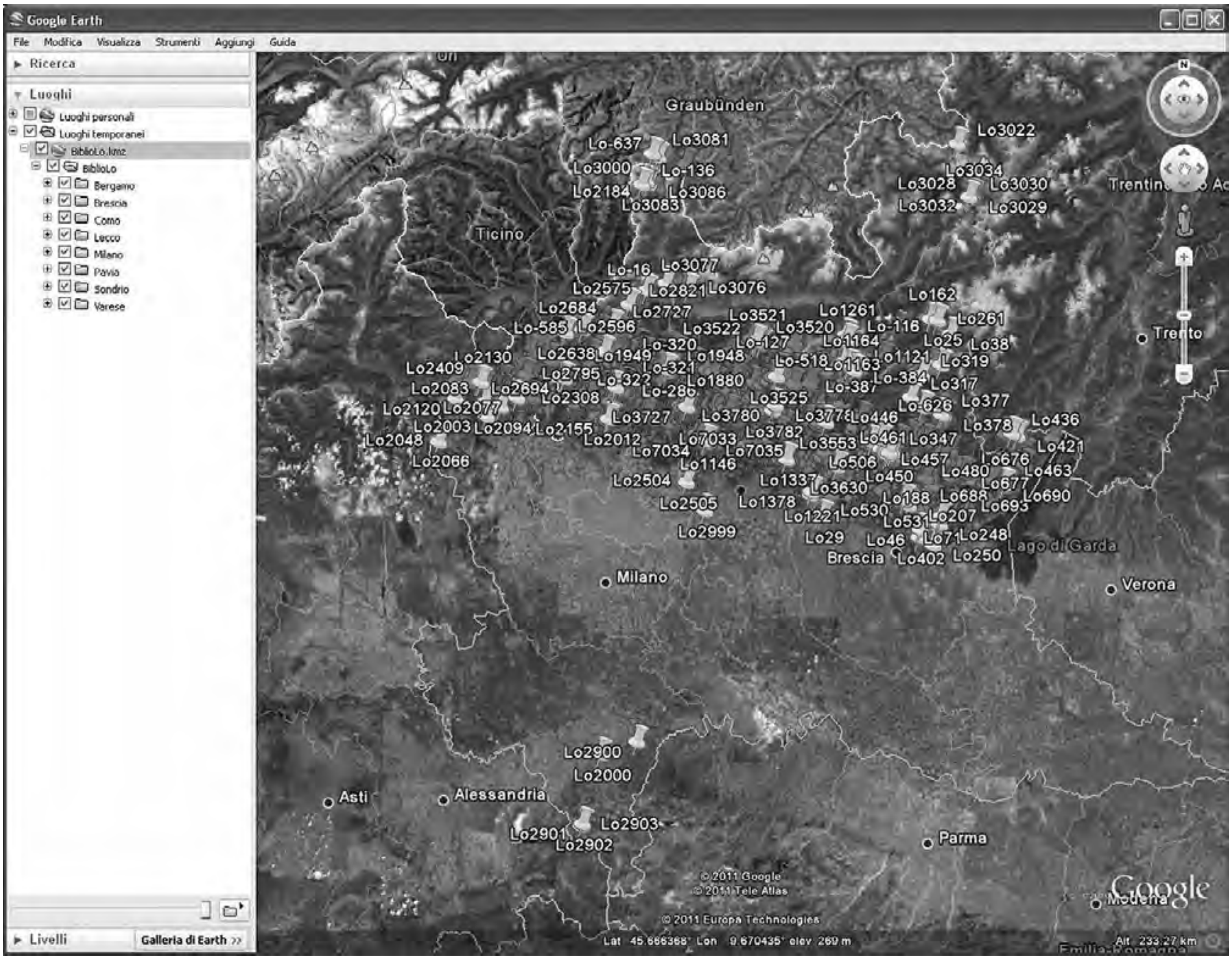

Figure 1. Lombardia with 3,600 cave placemarks.

provisionally assigned. So an example of registered cave reference is: Lo2000 – D(escription) – 34. Presently, collected caves are 4,200; 725 of them are provided with a negative ID. The collected triples are more than 41,000.

2.3. Web links

Each bibliographic reference which is freely available on the Web is provided with the link (URL – Uniform Resource Locator) of the relevant web resource. Presently, 1,150 references are linked to their resource (24% of the total references).

2.4. Cave positions

Finally, published cave positions are collected. Unfortunately, they are expressed in several different geographic reference systems and formats. A little public domain conversion program is employed to automatically translate cave positions into a single system and format. Presently, 3,600 caves are provided with position out of 4,200 total.

3. Results

The whole data-base can be locally consulted and queried by a custom-made application designed on Windows systems. A similar application is employed for data insertion and update.

However, the whole virtual distributed library power is exploited by a three-layered system.

3.1. Google Earth ® placemark file

Cave positions can be used to produce a KML (Keyhole Markup Language) file with a placemark for each cave. The file can be loaded into Google Earth to generate a map with the cave positions (Fig. 1). As usual, the user can navigate and zoom in the map.

3.2. Cave bibliography web pages

Clicking on a placemark opens a cave specific caption (Fig. 2). Its contents are defined in the KML file. In the present version, just the cave name and number are inserted, together with a link to a bibliography web page. Clicking on the link opens the page in a browser embedded in Google Earth. The web page is a statically generated one with the list of titles in which the selected cave is referenced. The page is hosted on a protected server and it cannot be accessed in other ways. Titles are arranged by reference category. Since 3,600 caves are positioned, 3,600 cave bibliography web pages were produced (Fig. 3).

3.3. Titles web pages

Each title entry in a cave bibliography page contains a link to the title web page. This one contains the full

Figure 2. A cave caption in Google Earth.

bibliographic reference of the publication and the list of referenced caves (Fig. 4). 4,800 web pages were produced. If the publication is freely available on the Web, the link is inserted in the page, so the user can directly jump at the content (Fig. 5).

A system excerpt was presented in 2007 (Buzio and Ferrari 2010), limited to the bibliographical components (sections 2.1. and 2.2) and to titles with archaeological references. A detailed description (in Italian) of the whole system was presented in 2011 (Ferrari 2011). Recently, the KML file was loaded in a Google Earth version on tablet. This means that, provided a mobile internet connection is present, the virtual library can be searched just in front of a cave entrance.

Figure 3. A cave web page embedded into Google Earth.

4. Discussion

The prototype is quite a powerful tool designed to enhance data mining procedures in the bibliographic data base.

However, several issues are far from optimal. The following list points out the most important ones.

The bibliographic management component is custom-made. Presently, several commercial bibliographic systems are an-the-shelf. A defined standard could be adopted and introduced.

Figure 4. A title web page embedded into Google Earth.

Large part of the data, both in the titles and in the caves areas, is to be checked and updated.

Reference categories are not neatly defined.

Data structure in the Google Earth interface provides just a very simple geographical model. Complex queries must be performed with the local Windows application.

Static web pages generation is an out-of-date process. A dynamical generation should be provided, via real-time queries to the data-base.

Persistency: links to web librarian resources could broke when the resources are moved or removed.

Copyright and Privacy: all data in the system are public domain, but publication of the KML file on the web means freely distributing the positions of 3,600 caves. Often this is a potentially dangerous actions.

Figure 5. A survey published in 1897, embedded into Google Earth.

5. Conclusions

The system is just a prototypical one, but it proved to be very useful in search and in exploration too. However many improvements are needed to improve the system and the underlying data. The Google Earth interface enables people, who are not confident with full-featured Geographic Information Systems, to get a dramatic insight into geographic information. Georeferentiation applied to bibliographic information could be employed in many other geographic-related fields.

However, several problems must be coped with: copyrighted publications and cave positions.

Acknowledgments

Alberto Buzio began collecting bibliographical information about Lombardia caves more than 20 years ago. He provided an initial bibliographic data-base with more than 2,000 references. He allowed also unconditioned access to his own caving library, with more than 4,000 books and magazines.

Daniela Pani provided invaluable assistance in the coordinate conversion process together with several useful suggestions.

A large number of web sites provide free access to cave related publications. The list is too long. Among the major general purpose libraries: Google Books, www.archive.org, Bibliothèque nationale de France, Bayerische StaatsBibliothek.

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HALOTHERAPY AND HALO HEALTH IMPROVEMENT

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The halotherapy technology was developed by Professor P. Gorbenko in 1984 and was the first in the world. Halotherapy is developed on the basis of our own experience in building and managing one of the world's best Speleological Therapeutic Hospital (240 beds) – Allergic Republican Hospital of the Ministry of Health of the Ukrainian SSR, based in the salt mines of the village Solotvyno Transcarpathian region, Ukraine.

High effect speleotherapy (significant improvement and improvement) was observed in 87–95% of adults and 95–98% of children and limited access to the hospital raised the issue of creating an artificial climate of salt mines microclimate and its widespread use. Curative therapeutic microclimate of underground salt mines was re-established in 1985 in the world's first experimental Halocamera, at the Scientific Research Institute of Pulmonology, Department of Health, Soviet Union.

In 1989, the Ministry of Health has approved for widespread use of halotherapy methods developed by Prof. P. Gorbenko and of the device for its implementation – Halocamera: Guidelines "Halotherapy in the prevention and treatment of respiratory diseases. Leningrad, 1989."

In 1991, the General Directorate of Health approved the quidelines "Halotherapy in the treatment of allergic respiratory diseases in children. L., 1991", authorizing the use of techniques of halotherapy on children.

Also in 1991, the Ministry of Health of the RSFSR letter № 1004/21-03 "On the order of implementation of halotherapy methods and technical means for its implementation" obliged to use the technique of halotherapy with Halocamera salt chamber and with the drug "AEROGALIT" ® that meet the health relevant and technical requirements.

Long experience of the St. Petersburg Institute of Preventive Medicine for halotherapy use in patients with the lung diseases and other respiratory diseases, allergies and skin diseases, reduction of general and local immunity of the body, as well as the development of the modern halotherapy technology allowed to create a more expanded list of indications for halotherapy use in the medical and health purposes.

Technology of halotherapy and halo health improvement whose creation began twenty-five years ago are actively being developed by professor P. P. Gorbenko and K. P. Gorbenko and is now been universally recognized and distributed in many European countries and in the rest of the world. Nowadays it is difficult to imagine a modern health spa, clinic, wellness center, recreation and wellness center without a halochamber.

Halotherapy technology was developed by Professor P. Gorbenko in 1989 and was the first in the world. The work was based on his own experience in building and managing one of the world's best Speleological Therapeutic hospitals – Republican Allergic Hospital with 240 beds in the salt mines of the village Solotvino Transcarpathian region, Ukraine (Ministry of Health of the Ukrainian SSR, P.P. Gorbenko, chief medical officer of the Republican Allergic Hospital 1975–1981) and development of technology of speleotherapy patients with bronchial asthma, chronic bronchitis, chronic obstructive pulmonary disease, psoriasis, eczema, etc.

High speleotherapy effect (a significant improvement and improvement) was observed in 87–95% of adults and 95–98% of children. A limited patient capacity in the hospital raised the question of creating an artificial climate, similar to microclimate of salt mines and its wide application.

Therapeutic climate of medical chambers in an underground salt mine has been recreated in the world's first experimental halochamber in 1985, the All-Union Scientific Research Institute of Pulmonology of the Ministry of Health (Professor P. Gorbenko – Deputy Director for Science 1981–1991).

In 1989, the USSR Ministry of Health has approved a broad application of halotherapy method and apparatus for its implementation – halochamber, developed by Professor P. Gorbenko, in guidelines "Halotherapy in prevention and treatment of respiratory diseases. L., 1989".

Figure 1. Halochamber for kids.

In 1991, the General Directorate of Health adopted a Guidelines "Halotherapy in the treatment of allergic respiratory diseases in children. L., 1991", authorizing additionally the use of halotherapy for children.

In the same 1991 letter from the Ministry of Health (RSFSR № 1004/21-03 "On the order of implementation techniques halotherapy and technical means for its implementation" tied the use of halotherapy technique with halochambers and preparation "AEROGALIT" ®, answering to the medical and technical requirements.

Figure 2. Halochamber.

Many years of experience in the St. Petersburg Institute of Preventive Medicine with application of halotherapy in patients with lung diseases and other respiratory diseases, allergies and skin diseases, reduction of general and local immunity, as well as development og third generation halotherapy technology, helped to create an expanded list of indications for halotherapy use in medical and recreational purposes.

Indications for the halotherapy are:

I. Respiratory diseases
1. Bronchial asthma
2. Chronic obstructive pulmonary disease
3. Chronic asthmatic bronchitis
4. Chronic obstructive bronchitis
5. Nonobstructive chronic bronchitis
6. Recurrent bronchitis
7. Acute bronchitis is a protracted

II. Diseases of the cardiovascular system
1. Neurocirculatory dystonia (hypotonic and hypertonic types)

III. Upper respiratory
1. Allergic rhinitis, hay fever
2. Subacute or chronic sinusitis.
3. Subacute or chronic tonsillitis.

IV. Skin diseases
1. Psoriasis
2. Atopic dermatosis, diffuse and exudative form of the stabilization stage
3. Eczema
4. Pustular skin lesions, acne
5. Baldness

V. Reduction of general and local immunity
1. Individuals often and / or long-term ill acute respiratory infections
2. Persons working in hazardous working conditions (dust, gas, smoke, chemicals, temperature of the ambient air, small doses of radiation)
3. Individuals who smoke tobacco or smoked in the past. Facilitating smoking cessation

St. Petersburg Institute of Preventive Medicine, established by the Ministry of Health of the Russian Federation in 1989, is the leading organization in the country to introduce techniques of halotherapy (in accordance with the decree of the Ministry of Health of the Russian Federation № 1004/21-03 on 13.2.1991).

Founder of the institute, Doctor of Medical Sciences, Professor P. Gorbenko is an author of halotherapy technology and a creater of the world's first halochamber (Author's certificate number 1225569, 1984).

St. Petersburg Institute of Preventive Medicine has been continuously developing and improving the technology of halotherapy for twenty years and has accumulated a unique research and production experience. There have been created halochambers of three generations, the total number of which in Russia is more than three thousand.

Based on the high medical and health-effectiveness of the technology, we have developed the technology of halotherapy and halo health improvement, which is highly appreciated by patients and professionals around the world.

Today, St. Petersburg Institute of Preventive Medicine under the direct supervision of P. Gorbenko is developing and manufacturing the innovative quantum energy halochamber halogenerators of third generation and has created technology halotherapy and halo health improvement that is suitable for almost everybody. Institute is managed by Gorbenko Konstantin Pavlovich.

Halochamber "Standard" is a second generation complex, which creates a therapeutic climate. It is implementing the standard halotherapy technology and creates standard micro-climatic conditions. The main curative factor of halochamber "Standard" is a standard aerodispersed environment, rich with highly ionized dry aerosol of sodium chloride in an amount of 1–5 mg / m ł of air and having a stable humidity (45–55 %) and temperature (from +20 to +23 °C). This distinguishes it from first generation halochamber, where an expensive set of controlled therapeutic microclimate and aerodisperse environment was used.

Salt aerosol is produced by halogenerator. From halogenerator via "fluidized bed" the flow of dried air, saturated with highly ionized aerosol of sodium chloride, comes into the halochamber room. To clear the air and to maintain the normal pressure in the halochamber, when the halogenerator is working, the exhaust ventilation is installed in halochamber. Ventilation operates in the active (airing between sessions) and passive (during the session halotherapy) modes.

Halogenerator is working on a natural product called "AEROGALIT" ®.

The relaxation chairs are used to accommodate patients in halochamber. For one patient there should be at least 6 m ł of air volume in halochamber. A range of specially developed psychotherapy and audiovisual programs has an additional psycho suggestive effect on the patients.

Halochamber “Quantum Energy” The third generation halochamber allows you to fully reproduce the distinct therapeutic and healing effect of the best underground salt clinics.

This innovative halochamber created by opening the effect of “How to maintain the energy balance of rights (patent RF No. 2288751, 2003) and identifying the leading medical factor in underground salt hospitals polarized infrared radiation from a wide range, reaching from the Earth’s core”

In the third generation halochamber – Quantum Energy halochamber P. Gorbenko (patent RF № 31961, № 45085, № 291317), along with an aerosol of sodium chloride, the main acting factor of the microclimate is the quantum energy in the form of polarized infrared radiation.

Figure 3. Halochamber in Spa.

“Quantum Energy halochamber PP Gorbenko” is a recreational and therapeutic room with walls covered with a special multi-salt-coating, a halogenerator of third generation, ventilation and air conditioning system, as well as sources of quantum energy – the special long-wavelength emitters (RF Patent No. 64463).

Wellness and curative effect in halochamber achieved by creating a microclimate similar to the microclimate of underground clinics in salt mines, which is characterized by the presence of concentrated quantum energy in the range of infrared radiation the average wavelengths, by highly ionized dry sodium chloride aerosol, energized quantum energy, by aeroionization, enhanced by quantum stream, and by hypoallergenic and hypobacterial air environment.

Halogenerator “AGG-03” contains a modernized system of production of highly ionized sodium chloride aerosol “Fluidized bed” which allows you to receive medical ionized aerosol of the necessary fractional-disperse composition and mass concentration.

This is the ionized aerosol that has a pronounced therapeutic effect, in contrast to hydro aerosel or to simply spraying of pre-shredded salt.

Also, the principal feature of halogenerator “AGG-03” is the existence of a special air purification systems. As a result, the aerosol undergoes a special bactericidal treatment while being transferred from the operator in a medical room. Thus, we achieve the maximum effect due to the concentration ionized aerosol in complete sterility in the treatment room.

Bacterization air supply system and an improved high-efficiency aerosol delivery “fluidized bed” ™ technology and are copyright protected by patent RF № 97870.

Benefits of innovation halogenerator “AGG - 03”:
• Production of high-performance medical aerosol
• Cleaning mode the supply air
• Quiet Operation – 35 dB
• Low power consumption – 70 Watts
• Serviceability
• Automatic control system
• Compact size
• Reliable Performance ®
• Modern design

“AEROGALIT” ® is a quality product, designed for creating of dry fine ionized sodium chloride aerosol by using Halogenerator AGG - 03.

The drug “AEROGALIT” ® manufactured by special technology of the natural salt from salt mines in Solotvyno (Ukraine), sterilized and packed in a sealed container – a glass bottle of 10 ml. The size of the main share (90 %) of particles is particles less than 5 microns.

With high fractional-disperse composition, “AEROGALIT”® allows you to quickly re-establish halochamber therapeutic atmosphere of underground salt hospitals and retains its high efficiency throughout the entire period of storage.

Long-term clinical and laboratory studies confirmed the high efficiency of halotherapy using the drug “AEROGALIT”®, and allow them to prove the mechanism of its therapeutic action in an artificial therapeutic microclimate created by a halochamber.

Technology halotherapy and halo health improvement whose creation began twenty-five years ago, which are actively being developed by Professor P. Gorbenko and K. P. Gorbenko, at present, have been universally recognized and distributed in Russia and many countries worldwide. Now it is difficult to imagine modern clinic, health center, spa center, a recreation and wellness center without halochamber.

INN VALLEY UNDERGROUNDS: THE FIRST ANTHROPOSPELEOLOGICAL CONCEPT OF SHOW CAVES

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Abstract. The project "inn valley undergrounds" about local cave routes was realised with EU fundings in the years from 2008 to 2012 in the border area between Bavaria (Germany) and Tyrol (Austria). In order to create a common walking experience, four places were connected: the well-known Wendelstein Show Cave at the summit of 1834 m above the town of Brannenburg in the Inn valley, the highly medieval cave castle Grafenloch, located spectacularly above the town of Oberaudorf, the prehistorically significant Tischofer Cave in the famous Kaisertal Valley near Ebbs-Kufstein as well as the fairly elevated and spectacular Hundalm Ice Cave above Wörgl-Angerberg, which was also reconstructed into a show cave.

"Man & Cave" is the general topic. Different aspects such as "experience caves", caves as living places, caves as prehistoric places of discovery or caves as the difficult-to-conquer-wildness below the ground are being addressed. A uniform signpost and visitor guidance system was developed. Innovative and new kinds of media were used wherever possible. For example, on their way through the Wendelstein Cave, visitors have access to four interactive touch screens, which inform them in several languages about the four unusual topics psychology, biology, geology and philosophy.

So far the response has been overwhelmingly positive. Visitors show interest in unusual kinds of information as well, so this demonstrates their long-lasting fascination with cave-related topics. For show cave operators and speleologists alike, this should be understood as a driving force for breaking fresh ground in public relations.

Abstrakt. Das Höhlenwegprojekt inntaler unterwelten wurde zwischen 2008 und 2012 in der Grenzregion zwischen Bayern (Deutschland) und Tirol (Österreich) mit Förderung durch EU-Gelder realisiert. Vier Objekte wurden zu einem Erlebnisweg verbunden, die altbekannte Schauhöhle Wendelsteinhöhle in der Gipfelregion des 1834m hohen Wendelsteins oberhalb Brannenburg im Inntal, die hochmittelalterliche Höhlenburg Grafenloch, in spektakulärer Lage oberhalb Oberaudorf, die prähistorisch bedeutsame Tischoferhöhle im berühmten Kaisertal bei Ebbs-Kufstein sowie die hochgelegene, spektakuläre Hundalm-Eishöhle oberhalb Wörgl-Angerberg, ebenfalls schon als Schauhöhle ausgebaut.

Das Generalthema lautet dabei Mensch & Höhle, verschiedene Aspekte wie "Erlebnis Höhle" an sich, die Höhle als Wohnstätte, die Höhle als prähistorische Fundstätte, die Höhle als schwer zu erobernde Wildnis unter der Erde, werden thematisiert. Ein einheitliches Beschilderungssystem und Besucherleitsystem wurde erarbeitet. Wo möglich wurden innovative, neuartige Medien eingesetzt, in der selbständig durchwanderbaren Wendelsteinhöhle etwa informieren vier interaktive Touch-Screens die Besucher mehrsprachig zu den vier ungewöhnlichen Themen Psychologie, Biologie, Geologie und Philosophie.

Die bislang ausgezeichnete Resonanz zeigt, dass Besucher vom Thema Höhle unvermindert fasziniert sind, sie nehmen auch ungewöhnliche Informationen interessiert auf. Das sollte Schauhöhlenbetreiber und alle Speläologen in der Öffentlichkeitsarbeit ermuntern, neue Wege zu gehen.

1. The Project Inn Valley Undergrounds

The project inn valley undergrounds about local cave routes in the border area between Bavaria and Tyrol from Rosenheim to Kufstein and Wörgl was realised from 2008 to 2012 and considerably supported with EU fundings. The idea was born already in 2005, when the author cooperated with the cog railway Wendelsteinbahn GmbH, the operating company of the Wendelstein show cave, to present his book about the inn valley caves. This company wished to modernise the show cave with a didactical concept.

Searching for financing opportunities, the cooperating partners discovered the EU Interreg funding programme, which supports cross-border projects and inspired them to connect four unique single caves under one concept.

The focus on the general topic man & cave, on the one hand, was due to the author's and initiator's field of interest and major research. On the other hand, it resulted from the fact, that at least three of these four caves are unique for these aspects. Additionally, the Wendelstein Cave, as a high alpine chasm cave, needs explanations for the visitor (without dripstones it seems to be "uninteresting" for lay people, but it may be visited alone and is therefore predestined to realise an exceptional concept).

As a result the inn valley undergrounds now are four caves in the Bavarian Tyrolean inn valley, inviting the visitor to an exciting anthropological and speleological experience trip which, in the author's opinion, is unique so far…

2. An Impressive Quartette

The **Wendelstein Cave** in the Wendelstein peak area is the beginning of the **"journey of discovery into darkness"**, the claim for this logo. Four stops with interactive screens do not only explain this cave's characteristics. The visitor, moreover, experiences the various perspectives of the

Figure 1. View from the rear part of the Wendelstein Cave with the new LED-lighting-system (Photo P. Hofmann).

underground. The rather unusual topics of "biology", "psychology", "geology" and "philosophy" offer surprising points of view. The visitor will undoubtedly leave the cave with the knowledge that this topic is more comprehensive than he or she could ever imagine and that he or she would like to get more information.

The **Grafenloch Cave** is a culture-historical attraction of the community of Oberaudorf, particularly since the cave house **Weber an der Wand** is on the hiking trail – another exceptional historical place. The visitor may be inspired by **"monks and knights"**. The latter once lived in the cave castle Grafenloch. Recent archeological studies have shown, that it dates back to the 10th up to the early 13th century, and it is far more significant than has been supposed until now – many historical details will certainly still remain undiscovered. The history of the Weber an der Wand, however, was completely established in recent times. Nevertheless, there are still some legends about the hermit monk, one of the first people, who lived there. A visit to the museum of local history with the archeological findings may complete the family hike.

An excursion to the **Tischofer Cave** leads to one of the most beautiful valleys of the Alps, and you are directly **"on the traces of prehistoric times".** The impressive huge hall is one of Tyrol's most important fossil sites. More than three hundred cave bears must have died there in the course of time. The visitor is fascinated from the place, where his Bronze Age ancestors made tools about 1,800 before Christ.

Figure 2. The Tischofer Cave (HDR-Photo P. Hofmann).

The last excursion is the **Hundalm Ice Cave,** which leaves the impression of an archaic **"wilderness of rock and ice"** for the mountain loving people. Indeed, you need two and a half hours to reach the cave, but it is worth being visited. Simply by its trails, the tour in the origin of the earth, guided by experienced speleologists, may be an exciting experience. Certainly, the efforts and idealism of the explorers and first explorers of this underground desert in everlasting darkness will be more respected.

3. Realisation and Partners

This project was funded within the scope of the EU programme Interreg Euregio Inn Valley. 60 % of the projected total expenses of approximately 650,000 € were subsidised. Having completed the project and made the final settlement in November 2012, we stated that the costs were in fact lower than expected. About 100,000 € were used for marketing, the remaining funds for path constructions and renovations.

Four project partners have founded a partnership for its realisation.

The Wendelsteinbahn GmbH, represented by Florian Vogt, is the the project's managing partner, the Audorf project was realised by the community of Oberaudorf with its first mayor Hubert Wildgruber, the hiking trail to the Tischofer Cave is supervised by the community of Ebbs, which is represented by its mayor Josef Ritzer, and Renate Tobitsch, female speleologist and chairlady of the registered speleology association of Tyrol, is responsible for the Hundalm Ice Cave.

Realisation was characterised by different activities.

The steep path to the Tischofer Cave was thoroughly renovated to enable, that the cave may be reached again safely by everybody. The visitors are mainly guided by means of panels with local information – and most detailed directly in front of the cave. The latest scientific results were integrated, and a chronological table with archeological findings was updated, which was supported by the speleologist Prof. Dr. Ch. Spötl, Innsbruck. Certainly, a project has sometimes to cope with setbacks. So, we did not succeed in motivating the people responsible for the fortress museum of Kufstein, which shows the cave's findings, to join our project.

The Hundalm Ice Cave's paths were renovated, and particularly the interior trails, which led to a high financial expenditure. Besides, the hiking trails had to be reconstructed to a considerable extent under difficult circumstances and against the resistance of the land owning farmers. The renovation of the area directly in front of the cave completes the works. We wish the speleologists of the National Speleology Association of Tyrol every success, since they have been taking all efforts for this show cave for many years and, independent of that, have not been able so far to stop the dramatic declining number of visitors.

The access to Grafenloch and its ladder with a length of 6 m directly in front of the cave had to be secured as well and in parts to be renovated, and suitable route signs were realised, which start in the village centre. The local museum was involved, and the people responsible used the opportunity to instal an interactive screen with information about the museum and the cave path as well. Thus, the Audorf cave path is presented as a really consistent circular route of approximately 3 hours, ideal for families. On the way you may visit the local museum, two natural caves, a cave castle and a spectacular cave house – a probably unique combination. Unfortunately, we did not succeed in motivating the cave house's private owner to open the interior rooms with the small natural cave behind.

The cog railway Wendelsteinbahn GmbH, operating company of the Wendelstein Show Cave, had to deal with the most extensive investments.

The cave is situated on the Wendelstein peak area at an altitude of 1711 m above sea level. The visitable Wendelstein Cave's part, 170 m long, got a new LED-illumination. After longer tests the products of GermTec GmbH & Co. KG, Herborn, were used for realisation (www.cavelighting.com) – without doubt the best and most advanced technology, which is currently available. The cave has one stop, where the visitor, in certain submenus of the touch screens, may even adjust the cave's lighting conditions.

Figure 3. One of the four touch-screen-stations of the Wendelstein Show Cave, situated in the last room of the public part called dome (Photo P. Hofmann).

Finally, the screens were the major challenge. Up to now, they seem to resist the weather – though a large part of the cave freezes completely during winter! The user interface's design enables a very easy handling, also with gloves. It is not too comprehensive to avoid that the visitor will stay more than 5 minutes with a screen which is not desirable. So we tried to present different ideas as exactly as possible. Each of the four topic screens is subdivided into five topics (again with various subscreens), e.g., the major topic psychology into:

FASCINATION

"Cave" means emotions for most people, they have certain feelings and attitudes in this respect. What's the reason? Visitors' associations for a cave are presented.

SENSES

Our six senses: our means of communication with social environment, essential in each second of our existence.

What is our senses' response in a cave: visual sense, hearing sense, smelling sense, sense of taste, sense of touch, sense of balance?

DISCOVERY

One of a cave's most fascinating aspects is the discovery of new territory. Where can you still find unexplored terrain throughout our world? Pictures of recently discovered cave parts are shown which will remain inaccessible to the visitor.

LANGUAGE

The two most ancient archetypes of the language, the most ancient words humans were able to pronounce, are BA and KALL: cellar (Keller), cave (Höhle), hole (Loch), scuttle (Luke): It has been demonstrated for more than 200 languages, that derivations of the archetype word kal mean something round, hollow, deepened – just something cavernous!

PERCEPTION

In what way do humans intuitively perceive the cave interior? What is the most essential aspect of a cave? Children are versed in abstraction. Therefore, childrens' drawings are presented, which were all made in caves!

4. Communication Concepts

Nevertheless, decisive for the visitor is the overall communication concept, which he sees, which attracts him and is of interest. It was created just from the beginning by Hans W. Lehmann, Munich, speleologist, now free-lancer, at the project's start still creative director of the Munich advertising agency idee & concept, which was responsible for realisation.

In addition to a common marketing (very comprehensive and informative flyer and website) a layout for information system was created which guides and accompanies the

Figure 4. The Logo of the whole project.

visitor on his way. The specific name and a suitable logo are the communication concept's basis, and certain graphic elements appear repeatedly – on the internet, the flyer, the information panels outside or the interactive screens, which guarantees to easily identify the topic.

After a development period of approximately three years, the modernised Wendelstein Cave and Tischofer Cave were reopened ceremoniously in 2010. In spring 2011 the Grafenloch Cave followed, and the Hundalm Ice Cave was inaugurated on Pentecost 2012 with a mass celebration.

Our successes have been encouraging so far. The visitors of the Wendelstein Cave increased from approximately 23,000–25,000 in the years before its renovation to 28,000 in the year of reopening and to 34,000 in 2011, the first year thereafter. Lots of visitors are registered in the Grafenloch and Tischofer Caves. They are not counted, since the access is free. Up to now, the Hundalm Ice Cave is not as successful as desired. The press response was overwhelming with more than 100 reports.

It is obvious, that the topic of a cave attracts visitors as an experience and with respect to culture historical findings. The visitors' response is generally positive – a questionnaire at Wendelstein demonstrates this fact.

Further information (only in German language):

www.unterwelten.de

www.tropfstein.de

5. Conclusion

The positive response to the project shows, that the topic of a cave continues to be fascinating as up to now. People responsible should definitely dare unusual approaches. It is possible, without doubt, to offer laymen successfully unusual detailed information beyond the general stereotyped ideas (a positive aspect considering our cursory digital information). The cave is simply a great and exciting phenomenon, which has still been unexplored in many respects!

Figure 5. Example of the information system: one of the many panels, here at the entrance to the cave house "Weber an der Wand", part of the cave-walk of Oberaudorf on the way to the Grafenloch Cave (Photo P. Hofmann).

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BIOLOGICAL EVALUATION OF THERAPEUTIC PROPERTIES OF SALT MINES

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To solve the existing problems in allergy, pulmonology and medical recovery field and for use of natural therapeutic factors in patient treatement with different pathologies, international scientific community reviewed the therapeutic properties of caves and salt mines. Our objective was to explore the effects of speleotherapy on cellular morphology and physiology of pulmonary and dermal fibroblasts obtained from tissues of Wistar rats, in normal and Ovalbumin challenged, "asthmatic" conditions. 60 Wistar rats of 75–100 g weight were divided in two lots: control and ovalbumin challenged animals. Ten animals of each lot were send to Cacica, Turda and Dej Salt Mine for 14 days and maintained in the salt mine medium, as in speleotherapy treatment. Pulmonary and dermal fibroblasts cultures were prepared from Wistar rat lung and respectively dermal tissue. The complex picture of results was analysed and explained through biological mechanisms comparing to the control cell cultures obtained from healthy, untreated Wistar rats. In this article we describe the supposed biological mechanisms that explain the protective effects of speleotherapy. Speleotherapy induces changes on the morphology and protein expression of pulmonary and dermal fibroblasts in vitro, and these changes – by comparing with ovalbumin sensitised animals, supports the beneficial effects of speleotherapy.

1. Introduction

Speleotherapy – a special kind of climatotherapy, uses the certain conditions of caves and salt mines to cure several diseases, especially respiratory and skin diseases. The cave air is very low on dust, which could cause allergic reactions or asthmatic attacks. This fact reduces any kind of irritation; the symptoms of the diseases are reduced or eliminated completely, while the patient is in the cave. But that does not explain how it should have a longer lasting effect. Curing asthma involves spending 2–3 hours a day underground in subterranean caves or salt mines over a 1–2 month period. An old study describes a speleotherapy course, which was 4 hours a day for 6–8 weeks, with 100 COPD (Chronic Obstructive Pulmonary Disease) and asthma patients and reported improvement that lasted 6 months to 7 years (Skulimowski 1965).

Asthma is a disorder characterized by chronic inflammation of the airways, airways hyper-responsiveness, and changes in airway architecture, termed remodeling. The cells responsible for maintenance of lung structure are the parenchymal cells of the lung, including epithelial cells, mesenchymal cells, and endothelial cells. Recent studies have suggested that the function of epithelial cells, smooth muscle cells, and fibroblasts cultured from lungs of individuals with asthma differs from the function of cells similarly cultured from individuals without asthma. These functional differences, particularly as they relate to repair and remodeling, could contribute to airway structural alterations (Sugiura et al. 2007).

Therapy with bronchodilators, corticosteroids, leukotriene inhibitors, mastoid cells stabilizers and recent with IgE receptor antagonists have been shown an improvement of asthma symptoms. The new scientific and practical directions in therapy of the most severe allergic deseases – bronchial asthma – use underground medium of salt mines and caves. This therapy method was name speleotharapy from greece "spelaion"-cave, gap and "therapy"-treatment.

Today the speleotherapy is regognized as therapy in underground of salt mines and caves with natural theraoeutic factors for many deseases (Iu.Simionca şi al. 2005, 2008). Primary cell cultures can readily be obtained from human and animal skin using the explant method or trypsynisation. Full thickness skin, also called the integument, is a composite of three tissues (epidermis, dermis and subcutaneous tissue), none of which constitutes a homogenous entity. Epidermis normally is composed of keratinocytes, which represent the largest population numerically, and lesser numbers of melanocytes, Langerhans'cells, and occasional cells of the lympho-reticular system, which are, however, transient members of the community.

Although the bulk of the dermis is noncellular (collagen and ground substance), within this compartment is also a variety of cell types, including fibroblasts, histicytes, mast cells, macrophages, lymphocytes and Schwann cells, endothelial cells of blood vessels and lymphatics, striated muscle cells of erector pili muscles, and smooth muscle of blood vessels. The subcutaneous tissue includes most of the dermal cell types and fat cells as well (Flaxman, 1974).

The current study was designed to investigate the influence of salt mine medium from Cacica, Turda and Dej Salt Mines upon the cell morphology and electrophoretic expression of pulmonary and dermal fibroblasts in vitro obtained from Wistar rats tissues, in normal and Ovalbumin – "asthmatic" conditions.

Fibroblasts were cultured from lung and dermal parenchyma of control, ovalbumin-sensitized, and speleotherapy treated rats after ovalbumin-sensitization. Fibroblasts shape in culture can vary in accordance with the substrate, which on they is growing, and the space they have for movement.

Using pulmonary and dermal fibroblasts cultures to verify the therapeutic properties of saline mines medium represents an innovative and scientific new way to establish the medical methodology of preventing, treating and recovery of patients with various skin and pulmonary problems.

2. Geography and geology

TURDA SALT MINE is one of the historical monuments of Romania, from Cluj and a touristic attraction at national and international level especially for Bai Sarate Turda, Durgau salted lakes and the ruins of Potaissa roman castrum where was stationed the Vth Macedonica Legion 2000 years ago.

The exploitation of salt from Turda in current microdepression of Baile Sarate has a special interest during the roman occupation in Dacia. The first documentary of mine attestation dating from XII century when avid rocks, minerals and fossils collector – Joanne Fridvaldscky says – “is so famous that has no equal in all eastern”.

Turda Salt Mine joined to touristic circuit in 1992 (Ov. Mera si al. 2010) and benefit from EU funding under PHARE CES Programme 2005 through “Improving the attractiveness of the tourist potential of the balneray resort Lacurile Sãrate-Zona Durgãu-Valea Sãratã and Turda Salt Mine” project; modernization works of Turda Salt Mine has start in 2008 and have lasted two years.

Turda Salt Mine has legally all prerequisites, for therapeutic use: mines with furhished rooms, tailored for both tourists and sick persons, including disabled persons, mines rooms are large space, isolated rooms; no exploition activities; in Terezia Mine there are a salin lake adapted for recereation.

Official opening of modernized Turda Salt Mine took place on 22 January 2010.

Figure 1. Turda Salt Mine.

CACICA SALT MINE – it is situated in the locality with the same name, in the N-E part of the Romania, at 42 km W from Suceava Town and the 17 km N from Gura Humorului. The air strongly ozonized, the purity and beauty of nature, make from this place an attractive destination in any season, both for rest, pleasure and the treatment of respiratory disorders.

The entrance into the salt mine is made on fir tree stairs that are over 200 years old, mineralized by the salty water that penetrated the wood. The work by chisel gab and sledge hammer of the miners that ones worked here left real works of art, that bear the seal of the talent access stairs cut in the salt massif, vaulted ceilings or huge galleries. The real measure of the craftsmanship of those who dug the salt with the hammer is given by the small church built in salt at a depth of 27 metres and the dance hall located at a depth of 37 metres. The Catholic chapel sanctified in 1,800 has been gathering all the inhabitants, for the last two centuries, on the feast of Sf. Varvara protector saint of the miners.

OCNA DEJ SALT MINE is located in Romania, in the iddle of the Transylvanian Basin 3 km from the city of Dej and 60 km from Cluj-Napoca. Importance of salt in the development of human civilization and the exceptional quality of the salt deposit made the salt to be exploited since antiquity in Ocna Dej. The first statement concerning the Ocna Dej salt exploitation dating from Roman times can be observed today in the form of excavation remains clogged.

Today, Ocna Dej salt mine is part of National Salt Company SA and its main activity is extraction, preparation and marketing of gemstones salt. The Ocna Dej salt mine is characterised by: temperature: 12.4–14.5 °C, pressure: 1,018–1,020 hPa, humidity: 65–71 %, the presence of saline aerosols, lighting artificial and own ventilation system. A higher concentration of NaCl is ensured by continuous operation of the mine. These environmental conditions provided by the Ocna Dej salt mine led researchers to undertake studies on evaluating the possibility of using this mine, not only for salt extraction, but also for the development of the radon therapy and speleotherapy in Romania (Calin and Calin 2010)

3. Methods

Materials: Phosphate Buffer Solution (PBS: NaCl 0.13 M + KCl 2.6 mM + Na_2HPO_4 x12 H_2O 8 mM + KH_2PO_4 1.4 mM); HAM-F12 culture medium (Sigma); penicillin 100 U/ml, streptomycin 100 µg/ml; neomycin 50 µg/ml, fetal bovine serum (Sigma). Rat Wistar Model of Allergic Asthma – Wistar rats of 75–100 g weights were sensitized to Ovalbumin by i.m. injections.

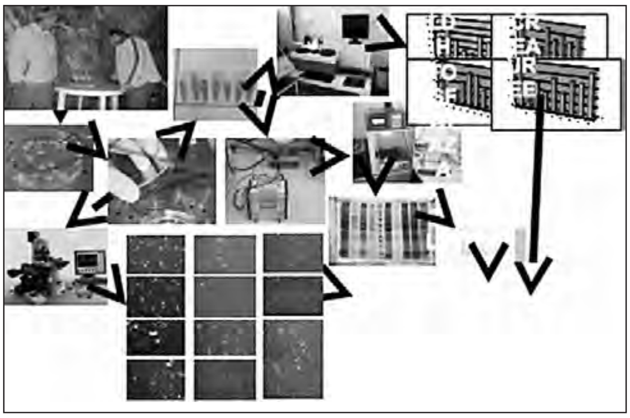

Figure 2. Experimental Design.

3.1. Primary pulmonary fibroblasts culture

After anaesthesia with chloroform, rats were killed. The thorax was opened and then the lungs were removed en bloc in a laminar flow hood using sterile technique and put into ice-cold sterile Phosphate Buffer Solution (PBS: NaCl 0.13M + KCl 2,6mM + Na_2HPO_4 x12 H_2O 8 mM + KH_2PO_4 1.4 mM). 1mm tissue pieces were suspended in 0.125 % trypsin and 0.001 % DNase and repeatedly stirred for 6 minutes and centrifuged at 1,000 g. The pellet was resuspended in HAM-F12 medium with 4,500 mg/l glucose, 25 mM HEPES, 100 U/ml penicillin, 100 µg/ml streptomycin and 50 µg/ml neomycin and 10 % fetal bovine serum (Sugiura et al. 2007; Foster et al. 1990; Nunez et al. 1995).

3.2. Primary dermal fibroblasts culture

After anaesthesia with chloroform, rats were killed. Skin sampels were removed en bloc in a laminar flow hood using sterile technique and put into ice-cold sterile Phosphate Buffer Solution (PBS: NaCl 0,13M + KCl 2,6mM + Na_2HPO_4 x12 H_2O 8 mM + KH_2PO_4 1,4mM). 1 mm tissue pieces were suspended in 0.125 % trypsin and 0.001 % DNase and repeatedly stirred for 6 minutes and centrifuged at 1,000 g. The pellet was resuspended in HAM-F12 medium with 4,500 mg/l glucose, 25 mM HEPES, 100 U/ml penicillin, 100 µg/ml streptomycin and 50 µg/ml neomycin and 10 % fetal bovine serum (Sugiura et al, 2007; Foster et al, 1990; Nunez et al, 1995).

Phase contrast microscopy, first described in 1934 by Dutch physicist Frits Zernike, is a contrast-enhancing optical technique that can be utilized to produce high-contrast images of transparent specimens, such as living cells (usually in culture), microorganisms, thin tissue slices, lithographic patterns, fibers, latex dispersions, glass fragments, and subcellular particles (including nuclei and other organelles).

3.3. SDS-PAGE Electrophoresis

The proteins electrophoresis from the total homogenate has as the purpose to establish the changes, which are revealed at the proteic level of fibroblasts cultures obtained from rats held on saline mine medium for the speleotherapy.

The proteins electrophoresis in gel of polyacrylamide was done in the denaturated conditions in the conformity with the techniques described by Laemmli (1979). The cultures have been washed with PBS, curetted from the culture plate and lyzed in buffer containing 0,5M Tris-HCl, pH 6,8 + 0,05 % BPB + 10 % glycerol + SDS 10 %.

Samples of 10µl were loaded into wells in the gel. One lane was reserved for Sigma molecular markers mixture of 205; 116; 97; 66; 55; 45; 36; 29; 24; 20,1; 14,2 and 6,5 KDa

Following electrophoresis, the gel was stained with Coomassie Brilliant Blue R-250, that allowed visualization of the separated proteins. After staining, different proteins appeared as distinct bands within the gel (Towbin et al. 1979).

Analysis with GeneTools version 4 software from SynGene of each track of the electrophoresis, allowed us to compare the profiles of the total proteins expression.

4. Resuls

4.1. Speleotherapy results on dermal fibroblasts

Control skin cells culture of 7 days has a heterogenic aspect with a high pre-confluence level. The cell division is to a high level and the cell morphology shows a typical microscopic view, described in the specific literature. There are two types of cells: epithelial and fibroblastic.

Skin cells cultures of 7 days obtained from Ovalbumin sensitized rats presents many morphological changes from the control skin cell culture, being observed an sensible number reducing of dermal fibroblasts in culture, the diminished cellular dividing frequency and an accentuated cellular morphopathology of the cells in culture. After 7 days of culturing, the pre-confluence level is much lower than in the control case.

Skin cells cultures of 7 days obtained from Ovalbumin sensitized rats and treated by speleotherapy in Cacica Salt Mine shows an improvement of the morphological parameters of the cells comparative with the cultures obtained from Ovalbumin-challenged rats. By phase contrast microscopy, it is possible to observe a rising of the cells number.

Skin cells cultures of 7 days obtained from Ovalbumin sensitized and treated by speleotherapy in Dej Salt Mine shows also an improvement of the morphological parameters of the cells comparative with the cultures obtained from Ovalbumin-challenged rats. It is observed the rising of the cell population density and that of cell viability.

Skin cells cultures were homogenized with Laemmli buffer pH 6.8, and the proteins of the obtained homogenate were separated by 10 % SDS polyacrylamide gel electrophoresis that maintains polypeptides in a denatured state once they have been treated with strong reducing agents to remove secondary and tertiary structure.

4.2. Speleotherapy results on pulmonary fibroblasts

Control pulmonary fibroblasts culture of 9 days has a homogenic aspect with a high pre-confluence level. The cell division is to a high level and the cell morphology shows a typical microscopic view, described in the specific literature.

Pulmonary fibroblasts cultures of 9 days obtained from Ovalbumin sensitized rats presents many morphological changes from the control pulmonary fibroblasts culture, being observed an sensible number reducing of pulmonary fibroblasts in culture, the diminished cellular dividing frequency and an accentuated cellular morphopathology of the cells in culture. After 9 days of culturing, the pre-confluence level is much lower than in the control case.

Pulmonary fibroblasts cultures of 9 days obtained from Ovalbumin sensitized rats and treated by speleotherapy in Cacica Salt Mine shows an improvement of the morphological parameters of the cells comparative with the cultures obtained from Ovalbumin-challenged asthmatic rats. By phase contrast microscopy, it is possible to observe a rising of the cells number.

Pulmonary fibroblasts cultures of 9 days obtained from Ovalbumin sensitized and treated by speleotherapy in Dej

Salt Mine shows also an improvement of the morphological parameters of the cells comparative with the cultures obtained from Ovalbumin-challenged asthmatic rats. It is observed the rising of the cell population density and that of cell viability.

5. Discussion

The present study evaluated morphological phenotypes related to repair and remodeling in fibroblasts and epithelial cells obtained from control Wistar rats and from Ovalbumin-sensitized and -challenged rats.

Compared with control culture, cells cultures from Ovalbumin-sensitized rats and Ovalbumin-sensitized treated in Cacica, Turda and Dej Salt Mines rats demonstrated the positive role of the saline medium for the sensitized rats.

The current study focused on skin and pulmonary cells, which are believed to play a major role in the organism – environment interaction. In this context, fibroblasts are believed to play a key role in maintaining and altering tissue structure. The ability of fibroblasts to migrate in response to chemotactic stimuli and to proliferate in response to specific growth factors is believed to control their accumulation at sites undergoing tissue repair. The ability of fibroblasts to produce and remodel extracellular matrix is thought to contribute to tissue structural changes. Remodeling of tissues likely involves fibroblast contractile activity.

In summary, the present study supports the concept that phenotypically altered fibroblasts can contribute to lesion repair in dermatological and pulmonary problems. Cells cultured from the skin of chronically OVA-sensitized and -challenged animals demonstrated consistently augmented repair responses for a number of functional assays (Sugiura et al. 2007).

6. Conclusions

Phase contrast microscopy analyses of primary skin cells cultures reveals an cellular regeneration after animal exposure to saline medium in Cacica and Dej Salt Mines, comparative with the cells morphology of cultures from Ovalbumin sensitised rats.

The morphological observations are confirmed by the electrophoretic analyses, which demonstrate through rising of the expression of many proteins and of total protein amount that the exposure of Ovalbumin-sensitised animals to the saline medium from Cacica and Dej Salt Mines is reversing the cells morphopathology of skin cells in cultures;

Wistar rats sensitised with Ovalbumin have a low number fibroblasts in skin cells cultures, with a more sensitive morphopatologic level.

Phase contrast microscopy analyses of primary fibroblasts cultures reveals an cellular regeneration after animal exposure to saline medium in Cacica and Dej Salt Mines, comparative with the cells morphology of cultures from Ovalbumin rats.

The morphological observations are confirmed by the electrophoretic analyses, which demonstrate through rising of the expression of many proteins and of total protein amount that the exposure of Ovalbumin-sensitized animals to the saline medium from Cacica and Dej Salt Mines is reversing the cells morphopathology of pulmonary fibroblasts in cultures;

Wistar rats sensitized with Ovalbumin have a low number pulmonary fibroblasts output cultures, with a more sensitive morphopatologic level.

Acknowledgments

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HISTORICAL WATER QUALITY DATA FROM CERNA VALLEY / BAILE HERCULANE – ROMANIA

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1. Geographical settings

Baile Herculane is located in the Cerna Valley in the South-western part of Romania, near the border with Serbia. Thirty-one thermal springs and wells are near the Cerna River as a result of a geothermal anomaly developed along a narrow graben (Simion et al. 1979).

2. History

In late 1970s the Romanian government began the construction of a hydro-power system on the Cerna-Motru-Tismana. On each of those rivers, including their main tributaries, dams were built and the waters from Cerna Lake were funnelled through tunnels to Motru Lake and then to Tismana Lake, where the power station is located (Ponta et al. 2006, 2013).

Figure 1. Hygeia Spring.

The volume of water in the recharge area for the thermal water reservoir was substantially diminished. A study was requested by the government, to determine the effects of water withdrawal from the Cerna River on the thermal water reservoir and to evaluate potential hydrogeologic connections between the Cerna River, its tributaries, and thermal water reservoirs. The project was conducted by the Intreprinderea Geologica de Prospectiuni pentru Substante Minerale Solide/Geological and Geophysical Prospecting Company (I.G.P.S.M.S.), Romania (Ponta et al. 2006).

3. Water sampling and results

The activities related to this study included a karst inventory, dye studies and water sampling. The results of the water samples collected in the sixties and seventies from thirty-one springs (Figures 1 and 2) and wells located along the Cerna Valley are presented in Table 1. The period of record varies for each station; the springs and wells located in the Baile Herculane area were sampled with the same frequency. The table represents the most comprehensive data set available for that period of time. The location of the sampling points is shown on Figure 2.

Figure 2. Neptun (right) and Venera Springs (left in the Cerna River).

To comply with the congress publication guidelines, only a shorter version of the table is part of this article. The digital version of the proceedings includes the complete table as shown in the 1979 report.

The paper provides previously unpublished water quality data for the thermal water reservoir at Baile Herculane. This data, collected in the 1960s and 1970s, is now available for use by students and researchers working in the area.

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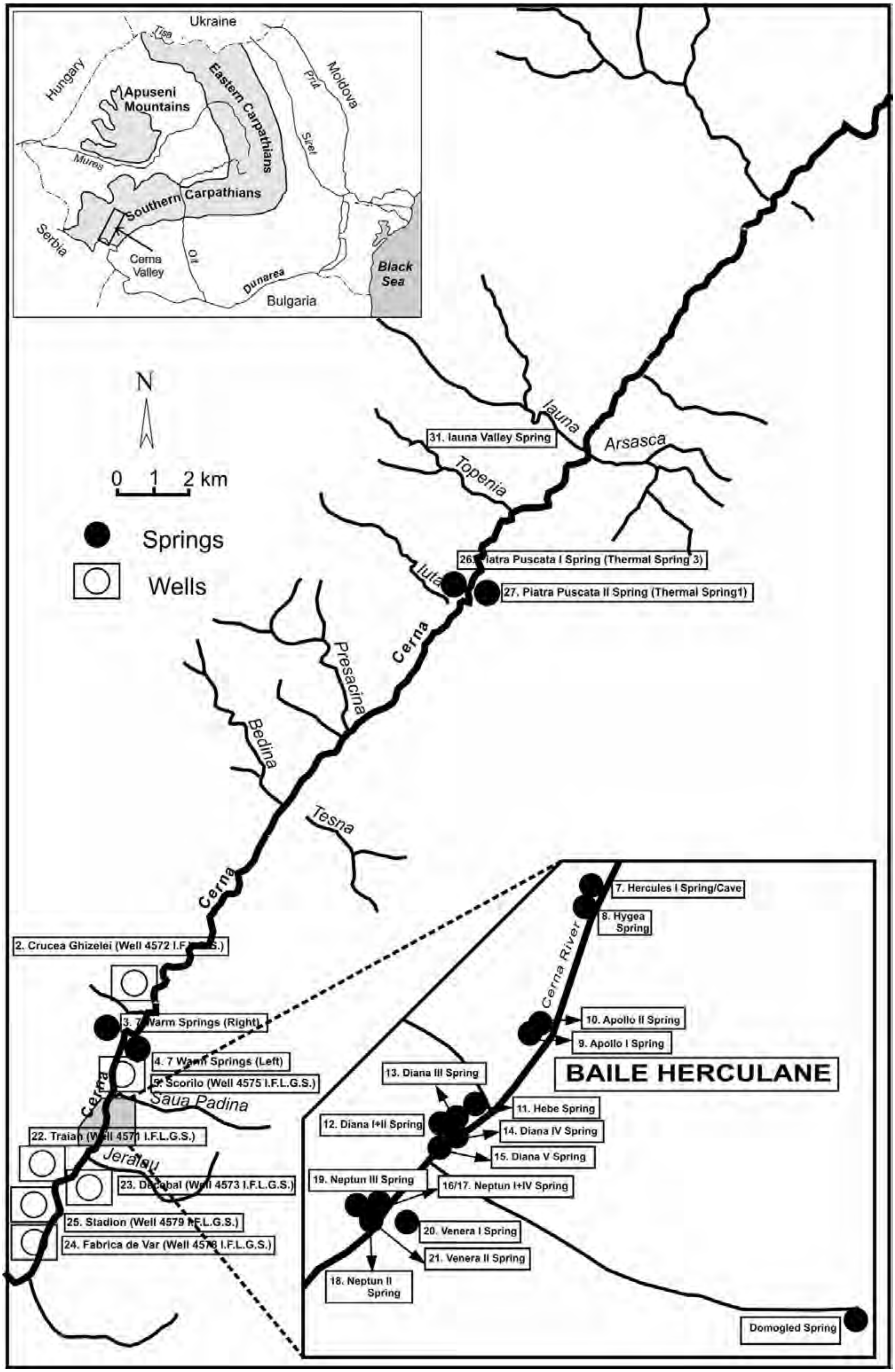

Figure 3. Location of the study is within the Baile Herculane/Cerna Valley, Romania.

Table 1. Summary of Water Quality Data in Cerna Valley – Baile Herculane, Romania.

NO	LOCATION	COMPANY COLLECTED WATER SAMPLES	DATE	ANIONS						CATIONS					
				Cl_2	Br	I	NO_2	SO_4	HCO_3	Na	K	NH_4	Ca	Mg	Fe
				mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
1	Valea Slatinic*	I.G.P.S.M.S.	June 1978	177.00	ND	ND	ND	288.00	122.00	260.00	7.00	ND	296.00	ND	0.30
			October 1978	177.00	ND	ND	ND	109.00	61.00	163.00	5.00	ND	20.00	ND	0.30
			December 1978	166.00	ND	ND	ND	124.50	85.40	168.00	5.00	1.00	24.00	ND	0.10
2	Crucea Ghizelei (Well 4572 I.F.L.G.S.)	I.G.P.S.M.S.	1969	7.00	ND	ND	ND	1.00	244.00	13.00	ND	ND	37.00	21.00	ND
			1974	7.00	ND	ND	ND	7.00	244.00	7.00	0.60	ND	55.00	15.00	0.10
			1976	7.00	ND		ND	9.00	256.00	3.00	0.80	ND	53.00	21.00	0.10
			1977	7.00	ND	ND	ND	ND	219.00	5.00	0.40	ND	53.00	10.00	0.10
			1977	7.00	ND	ND	ND	3.80	305.00	1.60	0.20	ND	63.30	25.00	0.15
			June 1978	10.00	ND	ND	ND	ND	244.00	4.50	0.80	ND	58.00	14.00	0.20
			November 1978	7.10	ND	ND	ND	2.90	225.00	5.00	0.40	ND	53.00	15.00	0.20
			December 1978	14.00	ND	ND	ND	1.90	219.00	5.00	1.10	1.00	57.00	10.20	0.10
			August 1979	14.00	ND	ND	ND	7.70	305.00	6.00	ND	ND	68.00	13.00	0.20
3	Spring I	I.G.P.S.M.S.	1974	205.00	ND	ND	ND	120.00	97.00	198.00	6.00	ND	21.00	ND	0.10
			1976	198.00	ND	ND	ND	120.00	122.00	191.00	9.00	ND	30.00	ND	0.10
			1977	170.00	ND	ND	ND	109.00	73.00	174.00	6.00	ND	10.00	ND	1.00
			1977	184.00	ND	0.10	ND	98.00	122.00	179.30	6.00	5.00	20.80	ND	0.20
			June 1978	177.00	ND	ND	ND	211.00	73.00	201.00	7.00	ND	32.00	ND	0.30
			November 1978	184.00	ND	ND	ND	175.00	97.00	161.00	3.90	ND	29.00	5.00	0.20
			December 1978	173.00	ND	ND	ND	119.00	85.40	165.00	5.00	1.00	27.00	ND	ND
			August 1979	191.00	ND	ND	ND	99.00	170.80	172.30	9.00	15.00	40.00	ND	0.20
			November 1979	170.20	ND	ND	0.40	161.30	97.70	155.50	6.00	1.00	38.80	ND	0.10
	Spring II	I.G.P.S.M.S.	1961	175.00	0.20	ND	ND	101.00	85.00	158.00	12.00	ND	17.00	4.00	0.20
			1974	170.00	ND	ND	ND	119.00	48.00	163.00	7.00	ND	16.00	ND	1.00
			1976	205.00	ND	ND	0.10	144.00	97.00	222.00	7.00	ND	30.20	ND	0.20
			1977	184.00	ND	ND	ND	109.00	61.00	180.00	6.00	ND	9.00	ND	0.10
			1977	184.00	ND	0.10	ND	103.00	73.00	166.00	5.00	ND	23.20	ND	0.20
			June 1978	184.00	0.50	ND	ND	103.00	73.00	167.00	4.00	ND	21.60	0.90	0.30
			November 1978	198.00	ND	ND	ND	111.40	73.00	177.00	5.00	ND	20.00	3.20	0.30
			August 1979	198.60	ND	ND	ND	115.20	42.70	170.30	6.80	ND	21.20	0.90	0.30
			November 1979	198.50	ND	ND	0.50	164.60	109.60	213.30	6.20	ND	28.80	ND	0.10
	Spring III	I.G.P.S.M.S.	1961	191.00	2.00	ND	ND	115.00	67.00	171.00	11.00	ND	15.00	4.00	0.30
			1974	184.00	ND	ND	ND	109.00	73.00	169.00	7.00	ND	22.00	ND	0.10
			1976	184.00	0.50	ND	ND	144.00	48.00	132.00	7.00	ND	25.00	21.00	0.10
			1977	202.00	1.00	ND	ND	86.00	61.00	171.00	7.00	ND	15.00	1.00	0.20
			1977	191.00	ND	ND	ND	122.00	85.00	185.30	5.00	ND	32.00	ND	0.20
			June 1978	184.00	0.50	ND	ND	99.00	79.00	169.00	4.00	ND	21.00	ND	0.30
			November 1978	191.00	ND	ND	ND	111.00	73.00	178.00	5.00	ND	20.00	ND	0.30
			December 1978	187.00	ND	ND	ND	122.00	73.00	180.50	5.00	1.00	22.00	ND	0.10
			August 1979	198.60	ND	ND	2.20	107.50	97.00	168.40	5.00	ND	40.10	5.30	0.30
			November 1979	198.60	1.00	ND	ND	109.40	85.40	171.90	6.10	ND	25.60	2.90	0.20
	Spring No. 4	I.G.P.S.M.S.	1974	177.00	ND	ND	1.00	155.00	73.00	166.00	7.00	ND	24.00	ND	0.10
			1976	212.00	ND	0.10	ND	105.00	207.00	213.00	6.00	ND	18.00	15.00	0.10
4	Spring (pool under the bridge)	G. Ciortan	1937	266.00	ND	ND	ND	114.00	39.00	257.00	ND	ND	52.00	1.00	0.20
		I.G.P.S.M.S.	1961	280.00	ND	0.20	ND	111.00	67.00	203.00	16.00	ND	27.00	8.00	0.10
			1974	120.00	ND	ND	8.00	117.00	61.00	120.00	7.00	ND	27.00	ND	0.10
			1976	269.00	0.50	ND	2.00	110.00	73.00	210.00	7.00	ND	35.00	ND	0.10
			1977	241.00	1.00	ND	ND	109.00	61.00	198.00	5.00	ND	25.00	ND	0.30
			1977	226.00	ND	ND	ND	115.20	73.00	179.60	5.00	ND	29.60	6.00	0.30
			June 1978	241.00	1.00	ND	ND	99.80	85.00	195.60	5.00	ND	27.20	2.00	0.30
			November 1978	212.00	ND	ND	ND	113.00	61.00	166.00	5.70	1.00	38.50	ND	0.10
			December 1978	219.00	1.00	ND	ND	119.00	85.00	193.00	6.00	1.00	29.60	ND	0.10
			August 1979	241.00	ND	ND	ND	111.00	54.00	180.00	8.00	ND	33.30	3.00	0.30
			November 1979	241.00	ND	ND	ND	107.00	73.00	196.00	6.00	ND	28.80	ND	0.30
	Spring on granite rock	I.G.P.S.M.S.	November 1978	212.00	1.50	ND	ND	105.60	79.30	184.00	5.40	ND	27.20	ND	ND
			December 1978	205.00	ND	ND	0.20	107.50	85.00	181.00	5.40	1.00	27.20	ND	0.10
			November 1979	212.00	ND	ND	ND	103.70	73.20	179.00	5.30	ND	26.40	ND	0.30

Table 1. Summary of Water Quality Data in Cerna Valley – Baile Herculane, Romania.

NO	LOCATION	COMPANY COLLECTED WATER SAMPLES	DATE	ANIONS						CATIONS					
				Cl_2	Br	I	NO_2	SO_4	HCO_3	Na	K	NH_4	Ca	Mg	Fe
				mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
			1970	1,020.00	0.50	ND	ND	182.00	109.00	292.00	9.00	ND	30.00	13.00	0.50
			1974	1,418.00	ND	ND	ND	115.00	61.00	251.00	8.00	ND	36.00	ND	0.10
			1976	297.00	1.00	0.10	ND	122.00	61.00	236.00	7.00	ND	24.00	ND	0.10
			1977	297.00	1.00	0.10	ND	113.00	61.00	237.00	7.00	ND	24.00	ND	0.10
5	Scorilo (well 4575 I.F.L.G.S.)	I.G.P.S.M.S.	1977	312.00	15.00	0.10	ND	134.00	48.00	238.00	6.00	ND	37.00	ND	0.20
			June 1978	304.00	1.00	ND	ND	115.00	48.00	239.00	6.00	ND	34.00	1.90	3.00
			November 1978	283.00	ND	ND	ND	86.00	54.00	188.00	7.00	1.00	45.00	ND	0.10
			December 1978	319.00	ND	ND	ND	128.00	48.00	243.00	7.00	1.00	33.00	ND	0.10
			August 1979	304.00	ND	ND	ND	119.00	48.00	225.00	7.00	ND	35.00	1.00	0.30
			November 1979	319.00	ND	ND	ND	119.00	48.00	240.00	6.00	ND	32.00	ND	0.30
			1951	33.00	ND	ND	ND	13.00	119.00	13.00	1.00	ND	45.00	2.00	0.60
		I.G.P.S.M.S.	1955	620.00	0.10	3.00	ND	92.00	138.00	344.00	21.00	ND	247.00	7.00	ND
			1961	418.00	ND	0.20	ND	42.00	184.00	170.00	22.00	ND	131.00	13.00	0.80
		I.B.F	1963	1,949.00	2.00	0.70	ND	128.00	73.00	752.00	64.00	ND	481.00	5.00	ND
			1974	191.00	ND	0.10	ND	43.00	170.00	83.00	6.00	ND	89.00	10.00	0.10
			1978	1,099.00	1.00	ND	ND	67.00	122.00	482.00	1.00	ND	262.90	ND	0.20
7	Hercules I Spring/Cave		November 1978	1,773.00	1.00	ND	ND	103.00	97.00	726.00	31.00	ND	412.80	9.00	0.20
			December 1978	1,702.00	1.00	ND	ND	103.00	97.00	643.00	34.00	1.00	385.90	63.00	0.10
		I.G.P.S.M.S.	August 1979	1,524.00	1.30	0.10	ND	111.00	109.00	595.00	30.00	ND	392.80	11.00	0.20
			1976	1,502.00	1.00	0.20	ND	122.00	97.00	645.00	24.00	ND	344.00	8.00	0.10
			1977	822.00	2.00	0.20	ND	57.00	115.00	344.00	10.00	ND	208.00	8.00	0.10
			1977	1,616.00	2.00	0.30	ND	109.00	24.00	509.00	24.00	ND	400.80	19.00	0.15
			August 1978	1,549.00	ND	0.10	ND	74.00	103.00	618.00	31.00	ND	365.00	10.00	0.20
		I.B.F.	1951	675.00	4.00	ND	ND	57.00	12.90	306.00	1.00	ND	16.00	6.00	0.20
8	Hygeia Spring		1961	1,614.00	3.00	80.00	ND	154.00	97.00	713.00	34.00	ND	357.00	17.00	ND
		I.G.P.S.M.S.	1974	744.00	1.00	2.00	ND	80.00	134.00	306.00	14.00	ND	210.00	8.00	0.03
			1977	1,007.00	1.70	5.00	ND	80.00	122.00	401.00	16.00	ND	286.50	ND	0.02
		I.B.F.	1951	1,773.00	1.00	0.30	ND	126.00	63.00	725.00	43.00	0.30	412.00	3.00	0.60
			1961	2,202.00	40.00	0.30	ND	22.00	48.00	840.00	42.00	ND	504.00	7.00	ND
			1976	1,347.00	2.00	0.60	ND	107.00	122.00	576.00	19.00	ND	298.00	2.00	0.20
			1977	1,418.00	4.00	3.00	ND	86.00	109.00	610.00	28.00	ND	297.00	14.00	0.20
9	Apollo I Spring	I.G.P.S.M.S.	1977	1,425.40	2.00	0.40	ND	119.00	109.00	443.00	215.00	ND	312.60	42.00	0.15
			June 1978	1,382.00	1.00	ND	ND	153.00	103.00	503.00	282.00	ND	393.00	9.00	0.50
			December 1978	1,562.00	1.50	ND	0.20	195.80	85.30	616.00	29.00	ND	416.80	1.20	0.20
			August 1979	1,304.00	ND	ND	ND	-	103.00	492.00	27.00	1.00	316.60	20.00	0.10
			November 1979	1,687.00	ND	0.15	ND	168.00	122.00	668.00	33.00	ND	378.00	45.00	0.10
			1974	1,524.00	1.00	0.40	ND	107.00	85.00	645.00	23.00	ND	360.00	ND	0.10
			1976	1,175.00	4.00	0.50	ND	130.00	37.00	646.00	21.00	ND	298.00	22.00	0.20
			1977	1,524.00	2.00	0.30	ND	105.00	73.00	678.00	32.00	ND	299.00	13.00	0.10
10	Apollo II Spring	I.G.P.S.M.S.	June 1978	1,468.00	4.00	ND	ND	124.00	48.00	632.00	23.00	ND	37.00	17.00	0.20
			November 1978	1,468.00	1.00	0.20	ND	111.30	54.00	637.00	28.00	1.00	323.00	ND	0.10
			December 1978	1,453.00	1.00	ND	ND	138.00	39.00	595.00	33.00	1.00	322.00	17.00	0.10
			August 1979	1,595.00	1.00	0.10	ND	99.00	36.60	509.00	31.00	1.00	400.00	ND	0.10
			November 1979	1,510.00	1.50	0.40	ND	107.00	3.70	652.00	31.00	2.50	312.60	7.00	0.50
		I.B.F.	1951	779.00	0.03	0.40	ND	16.00	16.00	307.00	14.00	ND	214.00	10.00	0.50
			1961	561.00	ND	0.07	ND	9.00	257.00	172.00	3.00	ND	158.00	17.00	ND
			June 1978	1,276.00	0.15	ND	ND	82.00	122.00	518.00	12.00	ND	296.00	25.00	0.40
11	Hebe Spring	I.G.P.S.M.S.	November 1978	1,113.00	1.50	ND	ND	69.00	146.00	519.00	23.00	ND	246.00	4.80	0.30
			December 1978	1,205.60	1.00	ND	ND	84.50	15.60	485.00	21.00	ND	291.80	26.00	0.60
			August 1979	42.00	ND	ND	ND	36.00	390.00	0.10	3.10	1.00	84.00	34.00	0.10
			November 1979	1,198.00	1.00	0.30	ND	46.00	207.00	489.00	23.00	4.00	295.00	13.00	1.60
		I.B.F.	1951	3,277.00	9.00	0.60	ND	16.00	122.00	1,297.00	56.00	0.20	744.00	2.00	0.20
			1961	3,287.00	5.00	0.20	ND	39.00	ND	1,519.00	57.00	ND	730.00	28.00	ND
			1977	3,475.00	2.00	0.50	ND	96.00	97.00	1,492.00	64.00	10.00	676.00	9.00	0.20
			1977	3,333.00	2.50	0.90	ND	84.00	48.00	1,358.00	61.00	1.00	702.00	7.00	0.20
12	Diana I + II Springs		June 1978	3,510.00	3.00	ND	ND	117.00	ND	1,431.00	56.00	ND	757.00	ND	0.20
		I.G.P.S.M.S.	November 1978	3,546.00	1.00	0.70	ND	159.00	ND	1,373.00	61.00	1.00	841.00	ND	0.10
			December 1978	3,404.00	2.00	ND	ND	138.00	ND	1,358.00	52.00	ND	734.00	22.00	0.30
			August 1979	3,546.00	1.00	0.50	ND	101.00	48.00	1,406.00	72.00	1.00	801.00	ND	1.40
			November 1979	3,368.00	1.00	0.50	ND	46.00	122.00	1,370.00	50.00	10.00	707.00	14.00	0.30

Table 1. Summary of Water Quality Data in Cerna Valley – Baile Herculane, Romania.

NO	LOCATION	COMPANY COLLECTED WATER SAMPLES	DATE	ANIONS						CATIONS					
				Cl_2	Br	I	NO_2	SO_4	HCO_3	Na	K	NH_4	Ca	Mg	Fe
				mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
13	Diana III Spring (I.B.F. Well)	I.B.F.	1960	2,150.00	0.70	0.50	ND	7.00	122.00	900.00	37.00	ND	445.00	3.00	6.00
			1961	2,187.00	0.50	0.10	ND	17.00	18.00	984.00	39.00	ND	439.00	13.00	ND
		I.G.P.S.M.S.	1974	2,127.00	1.00	0.50	ND	155.00	37.00	912.00	44.00	ND	464.00	ND	0.10
			1976	2,092.00	2.00	1.00	ND	115.00	36.00	945.00	28.00	ND	355.00	29.00	2.00
			1977	2,127.00	1.00	0.50	ND	ND	109.00	952.00	41.00	7.00	372.00	4.00	0.10
			1977	2,099.00	1.00	1.00	ND	88.00	244.00	999.00	26.00	2.00	400.00	9.00	1.00
			June 1978	2,056.00	3.00	ND	ND	155.00	ND	930.00	36.00	ND	399.00	ND	0.20
			November 1978	2,960.00	1.00	0.30	ND	57.00	109.00	1,309.00	46.00	7.00	555.00	2.00	0.20
			December 1978	2,092.00	1.00	ND	ND	130.00	ND	882.00	36.00	2.00	426.00	14.00	0.70
			August 1979	2,092.00	1.00	0.20	ND	97.00	12.00	881.00	68.00	ND	428.00	ND	0.10
			November 1979	2,085.00	4.00	0.30	ND	28.00	ND	950.00	37.00	14.00	352.00	7.00	0.40
14	Diana IV Spring	I.G.P.S.M.S.	1974	3,056.00	3.00	5.00	ND	100.00	97.00	1,302.00	59.00	ND	637.00	ND	0.10
			November 1978	2,198.00	1.00	ND	ND	92.00	48.00	778.00	39.00	1.00	557.00	24.00	0.10
15	Diana V Spring	I.G.P.S.M.S.	1974	2,815.00	1.00	0.50	ND	115.00	134.00	1,172.00	48.00	ND	599.00	22.00	ND
			1976	2,588.00	2.00	1.00	ND	46.00	134.00	1,070.00	28.00	4.00	488.00	52.00	0.20
			December 1978	2,822.00	1.00	ND	ND	63.00	45.00	1,129.00	45.00	2.00	579.00	48.10	0.10
			August 1979	2,340.00	2.00	0.10	0.70	96.00	73.00	512.00	39.00	4.00	901.00	7.00	0.70
			November 1979	2,978.00	1.00	0.50	ND	65.00	122.00	1,226.00	52.00	10.00	644.00	ND	0.30
16	Neptun I Spring	I.B.F.	1951	3,753.00	3.00	0.40	0.30	32.00	128.00	1,470.00	1.00	ND	861.00	4.00	1.00
			1961	3,772.00	3.00	2.00	ND	133.00	24.00	1,500.00	49.00	ND	833.00	13.00	0.40
		I.G.P.S.M.S.	November 1978	3,687.00	1.50	0.70	ND	163.00	ND	1,449.00	60.00	1.00	857.00	ND	0.50
			August 1979	3,581.00	1.50	0.40	ND	192.00	ND	1,424.00	61.00	1.00	825.00	ND	0.10
			November 1979	2,801.00	1.00	0.20	ND	115.00	73.00	1,013.00	48.00	ND	737.00	ND	0.10
17	Neptun I + IV Springs	I.G.P.S.M.S.	1974	3,772.00	1.00	0.70	ND	63.00	73.00	1,439.00	66.00	ND	894.00	ND	ND
			1976	3,687.00	2.00	1.80	ND	61.00	10.90	1,445.00	70.00	4.00	764.00	49.00	0.20
			1977	3,723.00	40.00	0.70	ND	345.00	97.00	1,748.00	63.00	ND	763.00	ND	0.10
			1977	3,687.00	2.00	1.00	ND	124.00	48.00	484.00	66.00	1.00	806.00	5.00	0.20
			June 1978	3,581.00	1.50	ND	ND	167.00	ND	1,342.00	56.00	ND	895.00	ND	0.10
			December 1978	3,634.00	2.40	1.00	ND	153.00	ND	1,416.00	67.00	1.00	800.00	20.00	0.30
18	Neptun II Spring (stomach)	I.B.F.	1951	3,780.00	2.00	0.60	ND	2.00	132.00	1,452.00	66.00	ND	880.00	5.00	ND
			1961	3,780.00	5.00	0.20	ND	1.60	36.00	1,593.00	59.00	ND	794.00	13.00	ND
		I.G.P.S.M.S.	1974	3,957.00	1.00	0.80	ND	114.00	109.00	1,561.00	64.00	ND	862.00	46.00	ND
			1976	3,829.00	2.00	1.50	ND	42.00	122.00	1,497.00	73.00	4.00	745.00	78.00	0.20
			June 1978	3,794.00	1.00	ND	ND	134.00	24.00	1,436.00	57.00	ND	927.00	ND	0.10
			November 1978	3,129.00	2.00	0.20	ND	134.00	48.00	1,664.00	56.00	4.00	737.00	9.00	0.20
			August 1979	3,847.00	1.00	0.30	ND	138.00	ND	1,579.00	62.00	ND	811.00	5.00	0.70
			November 1979	3,808.00	3.50	0.50	ND	23.00	158.00	1,557.00	60.00	30.00	756.00	7.00	0.40
19	Neptun III Spring (eyes)	I.B.F	1951	3,722.00	5.00	0.60	ND	95.00	75.00	1,419.00	66.00	ND	888.00	3.00	ND
			1961	3,627.00	2.00	0.20	ND	91.00	36.00	1,530.00	61.00	ND	770.00	8.00	ND
		I.G.P.S.M.S.	1974	3,673.00	2.00	0.70	ND	195.00	84.00	1,489.00	64.00	ND	817.00	ND	ND
			1976	3,652.00	3.00	1.00	ND	188.00	ND	1,444.00	69.00	ND	729.00	72.00	0.20
			1977	3,687.00	6.00	0.60	ND	107.00	97.00	1,499.00	67.00	6.00	80.10	7.00	0.10
			1977	3,811.00	2.00	0.90	ND	182.00	73.00	1,475.00	67.00	1.00	854.00	10.00	0.10
			June 1978	3,653.00	15.00	ND	ND	184.00	ND	1,370.00	57.00	ND	197.00	ND	0.10
			November 1978	3,687.00	6.00	3.00	ND	168.00	ND	1,481.00	55.00	1.00	828.00	9.00	0.20
			December 1978	3,811.00	2.50	ND	ND	119.00	24.00	1,454.00	103.00	1.00	848.00	26.00	0.30
			August 1979	3,652.00	2.50	0.90	ND	163.00	ND	1,408.00	64.00	ND	857.00	9.00	1.00
			November 1979	3,652.00	1.50	0.30	ND	151.00	61.00	1,305.00	60.00	ND	969.00	ND	0.10
20	Venera I Spring	I.B.F	1951	4,113.00	20.00	0.80	ND	27.00	98.00	1,578.00	49.00	0.90	944.00	23.00	0.20
			1961	3,999.00	25.00	0.20	ND	49.00	100.00	1,465.00	69.00	ND	1,049.00	22.00	0.50
		I.G.P.S.M.S.	1976	4,184.00	1.00	1.00	ND	56.00	134.00	1,660.00	73.00	15.00	909.00	6.00	0.10
			1977	4,077.00	4.00	0.80	ND	49.00	122.00	1,621.00	78.00	17.00	876.00	10.00	0.10
			1977	4,077.00	2.50	3.00	ND	207.00	146.00	1,661.00	61.00	ND	920.00	24.00	0.15
			June 1978	4,148.00	1.50	ND	ND	105.00	24.00	1,516.00	64.00	ND	1,006.00	22.00	0.20
			November 1978	4,184.00	3.50	0.30	ND	230.00	ND	1,779.00	56.00	ND	873.00	5.00	0.30
			December 1978	4,184.00	2.50	ND	ND	61.00	122.00	1,616.00	63.00	10.00	929.00	29.00	0.70
			August 1979	3,705.00	2.50	0.60	ND	107.00	12.00	1,366.00	70.00	0.50	881.00	19.00	0.70
			November 1979	4,148.00	1.00	0.50	ND	42.00	158.00	1,599.00	68.00	1.00	989.00	ND	0.10

Table 1. Summary of Water Quality Data in Cerna Valley – Baile Herculane, Romania.

NO	LOCATION	COMPANY COLLECTED WATER SAMPLES	DATE	ANIONS						CATIONS					
				Cl_2	Br	I	NO_2	SO_4	HCO_3	Na	K	NH_4	Ca	Mg	Fe
				mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
21	Venera II Spring (foot/legs)	I.G.P.S.M.S.	1961	3,879.00	3.00	0.20	ND	43.00	119.00	1,156.00	66.00	ND	896.00	32.00	0.50
			1974	3,950.00	1.00	0.70	ND	36.00	134.00	1,521.00	67.00	ND	599.00	22.00	ND
			1976	3,687.00	1.00	1.00	ND	92.00	122.00	1,485.00	69.00	4.00	641.00	113.00	0.20
			November 1978	3,829.00	1.00	ND	ND	88.00	79.00	1,430.00	61.00	3.00	945.00	ND	0.10
			December 1978	2,865.00	3.00	ND	ND	138.00	48.00	1,573.00	59.00	ND	857.00	ND	0.30
			August 1979	3,670.00	1.50	0.20	ND	111.00	18.00	1,428.00	68.00	3.50	814.00	16.00	0.30
			November 1979	3,758.00	1.50	0.60	ND	76.00	122.00	1,447.00	63.00	10.00	841.00	27.00	0.30
22	Traian (Well 4571 I.F.L.G.S.)	I.G.P.S.M.S.	1969	4,521.00	ND	1.00	ND	268.00	232.00	2,052.00	120.00	2.00	873.00	9.00	3.00
			1976	4,521.00	1.00	1.50	ND	67.00	109.00	1,808.00	80.00	980.00	5.00	0.10	-
			1977	4,503.00	1.00	1.00	ND	19.00	109.00	1,799.00	82.00	6.00	941.00	19.00	0.10
			1977	4,397.00	2.00	1.20	ND	92.00	78.00	1,762.00	78.00	ND	993.00	ND	1.00
			June 1978	4,545.00	1.50	ND	ND	115.00	48.00	1,925.00	57.00	ND	977.00	ND	0.10
			November 1978	4,397.00	5.00	0.90	ND	72.00	12.00	1,592.00	64.00	1.50	973.00	22.00	0.20
			December 1978	4,457.00	1.00	ND	ND	172.00	61.00	1,759.00	63.00	1.50	1,002.00	24.00	0.10
			August 1979	4,432.00	1.70	0.40	ND	103.00	12.00	1,759.00	57.00	ND	994.00	ND	0.10
			November 1979	4,432.00	1.00	0.50	ND	153.00	122.00	1,707.00	88.00	1.00	1,032.00	ND	0.10
23	Decebal (Well 4573 I.F.L.G.S.)	I.G.P.S.M.S.	1970	4,509.00	5.00	0.40	ND	177.00	366.00	2,598.00	90.00	ND	370.00	72.00	0.10
			1974	4,751.00	6.00	0.70	ND	249.00	122.00	1,967.00	84.00	ND	1,074.00	ND	0.10
			1976	4,581.00	4.00	2.00	ND	307.00	73.00	1,782.00	84.00	ND	1,002.00	37.00	0.10
			1977	4,538.00	5.00	1.00	ND	57.00	122.00	1,790.00	87.00	20.00	955.00	24.00	0.10
			1977	4,609.00	1.00	0.70	ND	109.00	122.00	1,843.00	88.00	ND	1,010.00	14.00	0.10
			June 1978	4,538.00	1.00	ND	ND	103.00	134.00	1,748.00	68.00	4.00	1,074.00	48.00	0.10
			November 1978	4,580.00	5.00	14.00	ND	151.00	ND	1,952.00	55.00	ND	975.00	45.00	0.20
			December 1978	4,609.00	2.00	0.70	ND	139.00	18.00	1,746.00	56.00	1.50	1,112.00	ND	0.10
			August 1979	4,457.00	1.30	0.40	ND	107.00	24.00	1,698.00	37.00	ND	997.00	51.00	0.20
			November 1979	4,503.00	1.00	0.20	ND	119.00	73.00	1,678.00	75.00	ND	1,120.00	ND	0.10
24	Fabrica de Var (Well 4578 I.F.L.G.S.)	I.G.P.S.M.S.	1975	4,787.00	2.00	2.00	ND	61.00	73.00	1,883.00	75.00	ND	787.00	175.00	0.20
			1977	4,787.00	3.00	1.00	ND	ND	85.00	1,914.00	78.00	7.00	998.00	16.00	0.10
			1977	4,787.00	1.00	1.40	ND	80.00	85.00	1,927.00	79.00	ND	1,058.00	ND	0.10
			June 1978	5,106.00	1.00	1.00	ND	259.00	85.00	2,208.00	62.00	1.00	1,055.00	ND	0.10
			November 1978	4,893.00	4.00	0.40	ND	142.00	ND	2,119.00	55.00	ND	1,033.00	7.80	1.30
			December 1978	4,680.00	2.50	1.00	ND	128.00	ND	809.00	6.00	1.50	1,088.00	ND	0.40
			August 1979	5,744.00	1.50	0.50	ND	126.00	ND	2,592.00	70.00	2.00	1,002.00	ND	0.10
			November 1979	4,964.00	1.50	0.30	ND	65.00	97.00	1,919.00	65.00	8.00	1,027.00	68.00	0.70
25	Stadion (Well 4579 I.F.L.G.S.)	I.G.P.S.M.S.	1977	4,645.00	2.00	1.50	ND	75.00	55.00	1,851.00	75.00	7.50	1,009.00	15.00	0.10
			June 1978	5,389.00	1.00	1.00	ND	105.00	73.00	2,395.00	68.00	ND	945.00	24.00	0.10
			November 1978	4,538.00	5.00	0.70	ND	113.00	ND	1,748.00	54.00	1.50	930.00	75.00	0.20
			December 1978	4,503.00	1.00	1.00	ND	74.00	97.00	1,806.00	63.00	1.00	1,001.00	ND	0.10
26	Piatra Puscata I Spring (Thermal Spring 3)	I.G.P.S.M.S.	November 1978	23.00	ND	ND	ND	19.00	109.00	19.00	7.70	ND	33.00	5.00	0.20
			December 1978	24.00	1.00	ND	ND	28.00	183.00	26.00	1.50	1.00	38.00	14.00	0.10
			1979	21.00	ND	ND	ND	35.00	122.00	15.00	1.40	ND	40.00	ND	0.10
27	Piatra Puscata II Spring (Thermal Spring 1)	I.G.P.S.M.S.	November 1978	28.00	ND	ND	ND	23.00	122.00	21.00	2.00	ND	37.00	5.40	0.20
28	7 Warm Springs (Right) - Spring No. 5*	I.G.P.S.M.S.	November 1978	191.00	ND	ND	ND	97.00	109.00	172.00	5.00	ND	23.00	5.40	0.30
			December 1978	191.00	ND	ND	ND	119.00	85.00	177.00	5.10	0.50	28.00	ND	0.10
29	Jack Spring*	I.G.P.S.M.S.	December 1978	159.00	ND	ND	ND	117.00	85.00	151.00	5.50	0.50	31.00	ND	0.10
30	7 Warm Springs - Downstream Spring*	I.G.P.S.M.S.	December 1978	194.00	ND	ND	ND	122.00	109.00	117.00	5.10	0.50	37.00	ND	0.10
31	Spring	I.G.P.S.M.S.	November 1978	7.10	ND	ND	0.10	96.00	36.00	5.50	0.40	ND	14.00	ND	0.30

I.G.P.S.M.S. Intreprinderea Geologica de Prospectiuni pentru Substante Minerale Solide

I.B.F. Institutul de Balneologie si Fizioterapie

* Not shown on the map

NATURAL AND CULTURAL HERITAGE VALUES OF THE YONGCHEON LAVA TUBE CAVE ON JEJU ISLAND, REPUBLIC OF KOREA

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The Yongcheon Cave (lava tube cave) was explored and investigated to understand the total length, origin of lavas and microtopographic features, distribution and origin of carbonate speleothems, distribution and cultural significance of archaeological remains, distribution and meaning of animal bones, distribution of cave fauna and the monitoring of cave atmosphere. The total length of the cave was mapped and is ca. 3 km but it can be longer after mapping the submerged passage. The cave shows typical microtopographic features of lava tube caves decorated with carbonate speleothems only within the passages underlain by overlying carbonate sand dunes. Archaological remains can provide very significant historical evidence that was not known from historical documents about 1,200 years ago. Only 19 species of cave fauna are discovered. Many animal bones were found and they were accidental visitors. Recently blind fish was found at the end of the submerged passage which is the first discovery of blind fish in Korean caves.

1. Introduction

The objectives of this study are to explore the total passage of the cave including submerged passage, to investigate the origin of carbonate speleothems related to overlying carbonate sand dunes, archaeological remains, cave fauna, animal bones and to infer scientific and cultural heritage values of the Yongcheon Cave.

2. Location

Jeju Island is located about 100 km south of Korean Peninsula. Jeju Island is a volcanic island with an elliptical shape (74 km from east to west and 41 km from north to south). The island lies on continental shelf and was formed by volcanic activities during the Quaternary, thus the surface of the island mostly consists of volcanic rocks such as basalt and trachyte. Yongcheon Cave is located in the northeast part of Jeju Island. It is a typical lava tube cave formed by lava flows which are between 200,000 and 300,000 years. The cave that is about 2,960 m long was accidently discovered during driving the electrical pole into the ground. Various micromorphological forms and lava speleothems are present throughout the cave. Of special is carbonate speleothems distributed in two parts of the passage on which carbonate dune sediments are present. Carbonate sediments have been transported by wind since ca. 5,000 yr BP (Ji et al., 2008). Carbonate speleothems started to grow from the supply of calcium and carbonate ions dissolved from carbonate sands by meteoric water (e.g., Woo et al., 2008b).

3. Results and discussion

3.1. Cave mapping

Cave map was significantly modified from the initial version (ca. 2.4 km). Cave diving was carried out to explore new passage and ca. 600 m long passage was discovered. Detailed mapping of the submerged part is necessary in the future. One longitudinal cross section and 85 transverse cross sections were measured. Based on the re-survey of the cave, total length of the Yongcheondonggul Lava Tube is about 2,960 m, including 2,590 m long main passage and about 370 m long branches. Only 100 m long submerged passage is included in the total length because it was the only partly measured. It is expected that over the 3,000 m long passage will be mapped after the completion of underwater survey.

3.2. Cave atmosphere

Cave temperature ranges from 15 to 21 °C and it is relatively a narrow range considering that this is a lava tube cave. Especially, the upstream passage is less susceptible to the outside than the downstream passage. Humidity in the cave tends to be higher during summer, however temporary abrupt increase was observed after rain. Partial pressure of carbon dioxide is always much higher than that of the outside atmosphere and it is also higher during summer. The temperature of cave water ranges from 16 to 19 °C and seasonal variation is very little. Cave water pH tends to be higher during summer when the input rate of groundwater is high due to less buffering time with overlying carbonate sands. Stable isotope compositions of oxygen and hydrogen and trace element contents of lake water suggest that the lake water is slightly mixed with seawater. Salinity tends to become higher toward the bottom of the lake.

3.3. Microtopography and speleothems

Various microtopographic features are found. These features include various lava-coated features as well as thermally eroded features. Microtopographic features on the floor include pahoehoe lava, aa lava, rockfalls, lava falls, lava benches, gutters, levees, tube-in-tubes and lava benches. Lava flowline is prominent on the wall. In addition, false floor, anastomosing branches, lava bridges, multiple leveled floors, and lakes are special morphological features. Beautiful carbonate speleothems are growing in the cave. They are soda straws, stalagmites, columns, cave corals, draperies, flowstone, rimstone, moonmilk and so on. Some soda straws, stalactites and stalagmites have erratic forms because they are just the coating of calcite over plant roots.

3.4. Cave fauna and animal skeletons

Only 19 species of cave animals are found during this study. It is probably because the food supply into the cave for these animals is too little. Troglobites are *Epanerchodus clavisetosus* Murakami et Paik and two species of *Tomocerus* sp. Troglophiles are Trechinae gen. sp. and *Nesticella quelpartensis* Paik et Namkung. Recently, blind fish was discovered at the end of the submerged passage near the sea. Various animal skeletons are distributed throughout the cave. 11 and 42 sites are discovered in the upstream and downstream passages, respectively. Among them, rat skeletons are the most common.

3.5. Archaeological remains

Archaeological remains are present, and they include numerous charcoal fragments, mollusks, potteries, animal bones, steel rods and a stone tower. It is suggested that most potteries were used for religious services. It is also very noteworthy that numerous potteries are present in the lake. Radiocarbon dating indicates that the age of charcoal fragments, mollusks and tree fragments is between 1,290 and 1550±40 yr BP, between 1,670 and 1,690 yrs BP, and between 1,310 and 1,390 yr BP, respectively.

4. Conclusions

The Yongcheon Cave includes numerous invaluable geological and archaeological heritage values. It is strongly suggested that this cave should be more thoroughly investigated in the near future and should be monitored continuously for protection of natural cave environments.

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TEMPERATURE AND AIR HUMIDITY IN THE ICE PASSAGE OF THE PIKOVÁ DÁMA CAVE, MORAVIAN KARST (CZECH REPUBLIC)

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Air temperature and relative humidity were measured in the Ice Passage of the Piková dáma Cave (Moravian Karst, Czech Republic). This cave is solitary in the Czech Republic, representing probably the only karst ice cave. Air temperature and air humidity were measured due to character of the cave during winter season. The HOBO U10 Data Logger was used. The highest air temperature was 2.7 °C and the lowest -1.0 °C, and air humidity ranged between 67% and 100% in the Ice Passage. The monitoring period, based on temperature and humidity measurements in the cave, was divided into five periods characterized by values and changes of measured parameters. The first period, when climatic parameters in the cave do not change, can be regarded static. The change of temperature on the surface is caused by beginning of dynamic air exchange in the cave. The second period characterized by slow decrease of air temperature and constant air humidity in the cave begun on November 22, 2011. External temperatures in the beginning of period decreased below -2 °C for the whole day and dropped down to -5 °C. In the third period both air temperature and air humidity in Ice passage rapidly decreased. In the beginning of period external temperature dropped below -10 °C and did not rise above zero. The length of such a period can be regarded as the decisive factor of the overall decrease of temperature and humidity in the cave. During the fourth period, air temperature mildly decreased and air humidity rapidly increased. This period was shortest and lasted only 12 days. External air temperature varied near zero, from +5 °C to -12 °C. During the last fifth period, the temperature in cave did not decrease, but, in contrast, increased. This increase was small, however continuous and it can be assumed, that temperature kept rising after the end of measurement too. During the fifth period in the beginning of April temperature surpassed 0 °C and since this date the ice decoration practically could not form. If a decoration had appeared prior to this date, it begun to melt. During the fifth period air humidity increased to 100% and more changes have not been recorded. External air temperature in this interval only exceptionally decreased bellow zero, however it reached up to +30 °C. During the measurement, 19 accessions into the Ice Passage were registered. The small temperature increases could be related to influence of the visitors.

1. Introduction

Microclimate of caves is an important element of their formation and existence and it influences many karst processes. Air circulation, temperature and humidity influence the creation and corrosion of speleothems. Yet greater is the importance of microclimate in caves with ice decoration, where the temperature smaller than 0 °C is the condition for decoration's existence. In the Czech Republic, there are no caves with permanent ice, however parts of some caves are ice-covered seasonally. Just in these caves, the length of period with temperature smaller than 0 °C is the decisive condition for ice formation. Climatic change can change this temperature in caves (Badino 2004).

Microclimate has been one of the criteria for classification of caves. Classification after cave temperatures and their development is today replaced by classification according to air circulation (Jančařík in Přibyl et al. 1992). This division is not unambiguous, and various authors understand it differently. Historically, caves were ideally divided into static with one entry and dynamic with more entries. Static caves with one entry or more entries in little different heights can be cold (ice caves), drawing external cold air and cooling in the winter season. Inversely work the warm static caves, lying above the entry level and warming up in the summer season. Jančařík (in Přibyl et al. 1992) characterizes static caves by air exchange only during one half of the year and stagnation during the second one.

Dynamic caves have two or more entries with different altitudes. There are contrasting directions of circulation in summer and in winter. In the summer season the rock is heated and humidity increases, in winter season cooling and drying proceeds.

Also combination of abovementioned cave types may exist, namely the statodynamic cave. It is virtually a dynamic cave, which has during a part of the year closed the connection between the upper and lower entry. Some authors use different division, and it depends on the concrete cave, which never represents ideal type.

Whether the cave is static or dynamic, the circulation has not one beginning and one end with constant flow. It may change in dependence on external conditions. The air circulation may oscillate in the range from several seconds (Faimon et al. 2012) to days. Suitably selected measurement methodic is a condition to obtain such oscillations.

Measurement of microclimate in cave is no easy issue. The cave climate is frequently regarded as constant, because its changes are small compared to the outer temperature. Thus measurements inside the cave require adequate equipment with necessary precision and long time, because the changes may occur in an unexpected moment too.

2. Study site

Temperature and air humidity were measured in the Ice Passage of the Piková dáma Cave ("The Queen of Spades"). The Piková dáma Cave lies in northeastern part of the

Moravian Karst, which belongs to the geomorphological unit Drahanská vrchovina Highland (Štogr and Kučera 1997; Vít 1998). The cave system was created in Devonian limestone of the Macocha Formation. The cave entry formed by a shaft with a centering lies near the village Holštejn in the Hradský valley in altitude 462 m a. s. l. The 70 m deep cave is interconnected with a nearby Spirálka Cave. These two caves form a large labyrinth of several levels, connected with the central Studna Abyss on a expressive joint, and with an old stream bed. The entry into the Ice Passage, where the measurement proceeded, is located above the bottom of the Studna. Beginning of the Ice passage has the form of a wide water channel with numerous facets. In the walls and roof are located openings of corridors and shafts leading from adjacent parts of the cave. The bottom is covered by little lakes, and an intermittent stream flows there. The Ice Passage ascends, at the beginning slightly, then in cascade stages. It is terminated by a labyrinth of small phreatic tunnels and a stack of blocks leading into the half-blind Holštejn Valley near the ponor of the Bílá voda River. The Holštejn Valley near Stará Rasovna Cave belongs to the coldest sites of the Moravian Karst, which is determined by forest stand in the surroundings and by the valley orientation. Into this valley flows the cold air and snow accumulates here, which lies here significantly longer time than in the surroundings. The Ice Passage of the Stará Rasovna Cave, as the entry for the cold air, directly links up the Ice Passage of the Piková dáma Cave. Cold air flows through the Ice Passage, firstly of the Stará Rasovna Cave and then of Piková dáma Cave, to the central abyss, through which the already warmed air flows up and is blown out by an entry situated by 20 m higher and by the nearby blower Křížový kluk. This arrangement in connection with form of the cave enables cooling of the Ice passage and formation of ice decoration in the spring, when water begins to flow into the cave as a consequence of spring thawing. The greatest ice decoration is here usually during the end of April and beginning of May. This cave is solitary in the Czech Republic, where it is probably the only karst ice cave. Faimon et al. (2012) and Litschman (2012) studied microclimate in nearby caves.

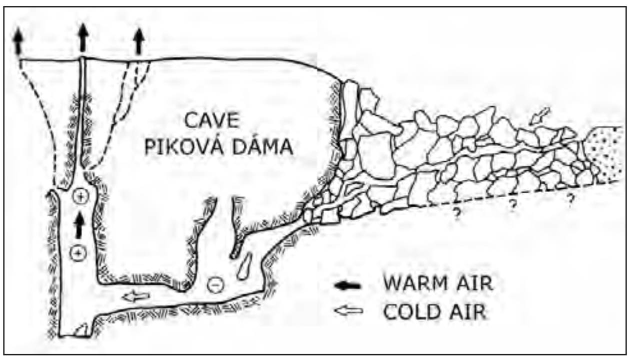

Figure 1. Scheme of air circulation in the Stará Rasovna – Piková dáma cave system (winter). +, - describe plus and minus temperatures in the cave (section after Vít 1998).

3. Methods

Air temperature and relative humidity were measured due to character of the cave during winter season from November 13, 2011 to May 9, 2012. Measurement interval was set on 15 minutes. In the Ice Passage was located HOBO U23 Pro v2 Data Logger (Onset Computer Corporation, Inc., Massachusetts; Range: Temperature: -20 to 70 °C, RH: 25 % to 95 % RH, Accuracy: Temp: ± 0.53 °C from 0 to 50 °C, RH: ± 3.5 % from 25 % to 85 % over the range of 15 to 45 °C, ± 5 % from 25 % to 95 % over the range of 5 to 55 °C). The HOBO U10 Data Logger of the same producer, placed near the cave entry, was used for measurement of external air temperature and relative humidity. For specification of the measurement methods, the Methodic of monitoring of microclimatic conditions in cave systems (Hebelka et al. 2011) was used.

Data processing was performed by softwares: HOBOware lite, Microsoft Excel and STATISTICA.

4. Results

Temperature and air humidity measurements have proven great influence of seasonality. External air temperature ranged between -18.5 °C and 32 °C, external air humidity between 34 % and 99 %. In Ice passage the highest air temperature was 2.7 °C and the lowest -1.0 °C, and air humidity ranged between 67 % and 100 %.

Based on temperature and humidity measurements in the cave, the monitoring period was divided into five periods characterized by values and changes of measured parameters. Between these periods there were yet four transitional periods, when characteristics of temperature and air humidity were changing.

1st Period: constant temperature and air humidity. This period lasted from the onset of measurement to November 18, 2011. During this time interval there was constant air temperature 2.6 °C and constant air humidity 100 %.

2nd Period: slow decrease of air temperature, constant air humidity. This period lasted from November 21, 2011 to January 24, 2012, in total of 65 days. Air temperature during this period decreased by 0.97 °C from 2.6 °C to 1.6 °C, the mean daily decrease being 0.015 °C. In the whole period air humidity was 100 %.

3rd Period: rapid decrease of both air temperature and air humidity. This period lasted from January 28, 2012 to February 12, 2012, in total of 16 days. Air temperature decreased during this period by 1.9 °C from 1.5 °C to -0.4 °C, the mean daily decrease being 0.12 °C. Air humidity decreased by 31 % from 100 % to 69 %. Mean daily decrease of humidity was 1.95 %.

4th Period: medium decrease of air temperature, rapid increase of air humidity. This period lasted from Februray 13, to 24, 2012, in total of 12 days. Air temperature decreased during this period by 0.6 °C from -0.4 °C to -1.0 °C, the mean daily decrease being 0.06 °C. Air humidity increased from 68 % to 85 %. Mean daily increase of humidity was 0.8 %.

5th Period: it is characterized by a long and slow increase of air temperature and four different changes of air humidity. This period lasted at least until the end of measurement, i. e. 75 days. Temperature increased from 1.0 to 1.1 °C, the mean daily increase being 0.03 °C. From the viewpoint of air humidity, this period can be further divided into four parts. The first one lasted one day, February 25, 2012, when air humidity increased by more than 5%. The second part lasted 19 days from February 26 to March 15, 2012, when air humidity increased from 88% to 95%, on average by 0.3% daily. The third part lasted 32 days from March 16 to April 16, 2012, air humidity increased from 95% to 100%, on average by 0.2% daily. In addition to slow increase, regular daily cyclical variation of air humidity by approx. 1% is characteristic for the third part. The fourth part started on April 17, 2012, when air humidity 100 was measured, which has not changed.

These five periods were separated by four transitional periods, which were short-term and they have no key importance from the viewpoint of total measurement duration. Parameters of temperature and air humidity were changing during these periods and they cannot be unequivocally described. Duration of the first period was two days and duration of the second period was three days. The third and fourth transitional periods were shorter than one day and they were included into major periods.

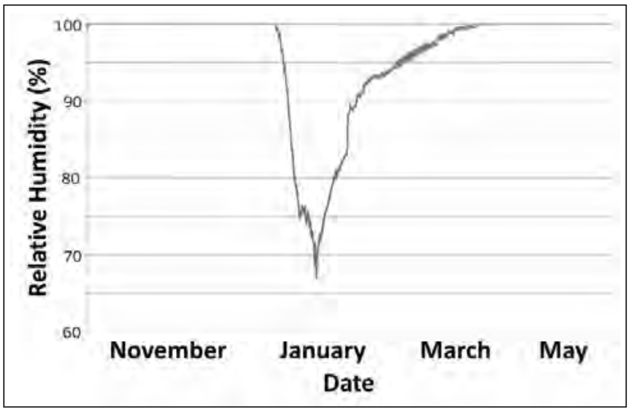

Figure 2. Relative humidity in the cave.

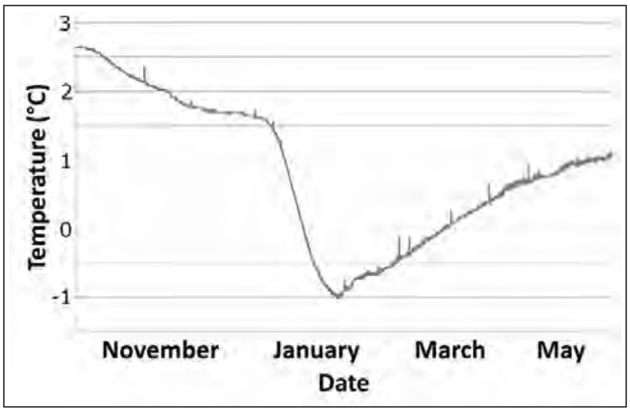

Figure 3. Temperature in the cave.

5. Discussion

The Ice Passage of the Piková dáma Cave was objected to temperature and humidity measurements already in the past (Štogr and Kučera 1997; Vít 1998). Common thermometers and Assman aspiration psychrometer were used, measurements were not continual, nevertheless they give good material for comparison. Based on these measurements authors assumed, that the Ice passage begins to freeze, when the frost stronger than -10 °C occurs daily for ca. one week.

The lowest temperature measured in our study was -1.01 °C (Feb. 23, 2012). Vít (1998) presents minimum temperatures most frequently during February and March with values -5 °C to -6 °C. Krbeček (in Vít ed. 1998) presents lowest measured temperature -7.1 °C in 1985, -4.1 °C in 1986, -6.1 °C in 1987 and 1.4 °C in 1988. Such low temperatures have not been measured in the year 2012. The main causes may include too short duration of low external air temperatures. It cannot be excluded, that some of the floods in past years has also changed the situation in air circulation.

The lowest air humidity of 67% was measured on Feb. 13, 2012. Krbeček (in Vít ed. 1998) documents lowest air humidity of 50% (Jan. 6, 1985), in following years he measured lowest humidity values of 85%, 69% and 94%. It is possible, due to short duration of the lower humidity, that in case of measurement only in certain interval the lowest value of air humidity is not recorded.

The most important factor influencing temperature and air humidity in the cave is the external air temperature. The first period, when climatic parameters in the cave do not change, can be regarded static. For the dynamic air exchange in the cave to happen, temperature on the surface must change. Then, besides low temperature also works together inertia of the air mass flowing through the cave, and surface air temperature is not the only criterion of air exchange.

The second period characterized by slow decrease of air temperature and constant air humidity in the cave begun November 22, 2011. External temperatures in the beginning of period decreased below -2 °C for the whole day and dropped down to -5 °C. In course of the second period temperatures ranged between +8 and -9 °C, but most of the time varied around zero. The external air humidity in this period ranged between 70% and 100%. These conditions led to intensive air circulation in the cave and changed the cave character to the dynamic one.

In the third period both air temperature and air humidity in Ice passage rapidly decreased. In the beginning of period external temperature dropped below -10 °C and did not rise above zero. In following days the lowest diurnal temperatures ranged between -14 and -18 °C and the highest ones between -4 and -11 °C. This period and its length 16 days had the major influence on the temperature and humidity decrease. Vít (1998) states, that "During a common winter the space of the Ice Passage begins to freeze after roughly one-week lasting nocturnal frost stronger than -10 °C." The length of such a period can be regarded as the decisive factor of the overall decrease of temperature and humidity in the cave.

During the fourth period occurred medium decrease of air temperature and rapid increase of air humidity. This period was shortest and lasted only 12 days. External air temperature varied near zero, from +5 °C to -12 °C. The external air humidity rose and ranged between 60 and 100%.

During the last fifth period, the temperature in cave did not decrease, but, in contrast, increased. This increase was small, however continuous and it can be assumed, that temperature kept rising after the end of measurement too. Another measurement continues, however it has not been evaluated until submission of this paper. During the fifth period in the beginning of April (4, 2012) temperature surpassed 0 °C and since this date the ice decoration practically could not form. If a decoration had appeared prior to this date, it begun to melt.

Although the fifth period was homogenous from the viewpoint of air temperature, it can be divided into four parts from the viewpoint of air humidity. In the first part, lasting one day, air humidity steeply rose by 5%. Due to the fact that this day temperature as well as humidity was similar to previous days, the cause of this "jump" cannot be unequivocally determined.

The second interval of the fifth period is characterized by gently increase of temperature and air humidity in the cave. Within 19 days, nearly regular increase of measured values begun. Temperature of external air in this period was mostly above zero, ranging between -10 °C and +10 °C.

In third part of the fifth period besides gradual rising of temperature and general increase of humidity also regular diurnal variation of humidity roughly by on percent occurred. This variation exactly corresponded to the variation of external air humidity, which varied between 20 and 100%. Based on these simultaneous changes it can be assumed, that during this period air in Ice passage was influenced by the air from surface too. External air temperature in this period was above zero, on average around 5 °C. It decreased rarely down to -5 °C and increased above +20 °C.

During the fourth part of the fifth period air humidity increased to 100% and more changes have not been recorded. External air temperature in this interval only exceptionally decreased bellow zero, however it reached up to +30 °C.

The Piková dáma – Spirálka cave system is relatively frequently visited. Thus the question suggests itself, what influence do the visits in cave have on the temperature and air humidity. The study of the Excursion day books and evidence of all visits in the cave represented the first step to evaluate the influence of visits in the Ice Passage. Sudden, short-term and uncommon temperature increases were identified in the temperature data. The interest was concentrated mainly on non-working days, when the most of visits happen. The influence on temperature and humidity changes in the cave can be assumed by the presence of persons in limited cave room as well as by opening the entrance, when the port is enlarged from the the size of 25 × 45 cm to the whole diameter (1 m) of the entrance and enables easier air flow.

During the measurement, 19 accesses into the Ice Passage were registered, only three accesses happened in working days. The greatest temperature increase of 1.09 °C, occurred on November 20, 2011 and lasted for 1.5 hour. This measurement, however, was intentionally influenced by visitors, who increased temperature of the sensor by their breath. Mean increase of air temperature caused by visitors in other 18 cases was 0.13 °C. The smallest measured temperature increase was 0.05 °C and the largest one 0.31 °C. The observable temperature alteration lasted on average 1.2 hour, the shortest one lasting 0.5 and the longest one 2.25 hours. Due to the fact, that most of temperature increases determined in this way corresponded to the records in excursion day book, these small temperature increases can be related to influence of the visitors. If the opened cave entrance should have impact, the temperature should probably decrease. No influence of visitors on air humidity in the cave was realized.

6. Conclusions

The Piková dáma Cave is a cold static cave, which probably as the only karst one in the Czech Republic has ice decoration in certain part of the year. From that reason it became object of humidity – and air temperature measurements in its coldest part, the Ice passage. These measurements operated in the past already, however they were not continual due to the technical equipment. Today's equipment is able to measure temperature with step 0.02 °C and to record all changes. Measurements processed in this article proceeded in the winter season from November 13, 2011 to May 9, 2012 with interval of 15 minutes.

Authors, who measured temperature and humidity in the locality of interest earlier, assumed that for freezing of the Ice Passage, external temperatures dropping bellow -10 °C each night for at least one week are necessary. This assumption has been confirmed, however it is not the only one. In the monitoring period as low temperatures as in the years 1985–1987 (down to -7.1 °C) were not reached. The lowest temperature measured was only -1.0 °C. In addition past measurements recorded lower minimum values of air humidity: 50% compared to 67% measured in this study. Two causes of this fact can be assumed: shorter period of low temperatures and change of the situation in air circulation as a consequence of some of past floods.

Five different periods were identified in the Ice passage. The first one, when climatic parameters in the cave do not change, can be considered static. As soon as the external temperature decreased bellow -2 °C for the whole day, the second period started, characterized by slow decrease of air temperature and by constant air humidity. Third period is the most important for freezing of the cave. After external temperature dropped bellow -10 °C, rapid decrease of both air temperature and air humidity started. In the course of fourth period the decrease of air temperature slowed down and a rapid increase of air humidity begun. External air temperature varied around zero. In the fifth period temperature slowly increased and humidity increased to 100%.

In the monitored period the conditions suitable for the appearance of ice decoration existed for relatively short time and finished in the beginning of April. At rare visits in the cave, ice decoration has not been recorded. The visits had only small and short-term influence on changes of humidity and air temperature in the cave.

The measurements described enabled a continual monitoring of temperature and humidity in Ice passage of the Piková dáma Cave. Due to close dependence on external conditions it is possible, that in other years lower temperature and humidity will be reached. In connection with other parameters, only further measurements may answer that.

Acknowledgments

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ANALYSIS OF THE EFFECTS OF THE NICOYA 05 SEPTEMBER 2012 EARTHQUAKE IN "TERCIOPELO" CAVE AND THE KARST OF "CERRO BARRA HONDA", NICOYA, COSTA RICA

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Abstract. Costa Rica is a country of high seismicity and several earthquakes affected the caves of the country, particularly the event of September 5, 2012 of 7.6 in the seismologic scale of magnitude/moment hit the country and has had effects in the caves of Barra Honda National Park. The earthquake originated at 08:42 local time (UTC-6) and its epicenter was located 8 kilometers from Sámara in the province of Guanacaste (about 33 km from Barra Honda). It is considered the second largest earthquake in the history of Costa Rica and with the inspection fractures were observed in stalactites, the collapse of part of the roof, the "bombardment" of the walls, that can all be clearly attributed to the earthquake. The purpose of the study was to observe the effects of the earthquake in the Terciopelo Cave, to determine whether there is a risk to tourist visitation and the recommendation has given to close part of the sections of the tour where structures were seriously affected. Glass platelets have been installed to control fractures and the basis for future studies and monitoring of affected speleothems has been established.

Resumen. Costa Rica es un país de alta sismicidad y varios terremotos registrados han afectado las cuevas del país, en particular el evento del 5 de septiembre del 2012 de 7,6 grados en la escala sismológica de magnitud de momento que golpeó al país y que ha tenido efectos en las cuevas del Parque Nacional Barra Honda. El sismo se originó a las 08:42 hora local (UTC-6) y su epicentro se localizó a 8 kilómetros de Sámara en la provincia de Guanacaste (a unos 33 km de Barra Honda). Es considerado el segundo terremoto más fuerte en la historia de Costa Rica y con la inspección se han observado fracturas en estalactitas, el colapso de partes del techo, el "bombardeo" de las paredes que se pueden claramente atribuir al evento sísmico. La finalidad del estudio ha sido observar los efectos del sismo en la caverna Terciopelo, para definir si existe riesgo para la visitación de turistas y se ha dado la recomendación de cerrar parte de las secciones del recorrido donde se encontraron estructuras seriamente afectadas. Se han instalado plaquetas de vidrio para control de fracturas y se han establecido las base para futuros estudios y un monitoreo de los espeleotemas afectados.

1. Introduction

The Barra Honda National Park (PNBH) was created by Law No. 5558 of August 20, 1974; it consists of a large limestone cave system, located in the Barra Honda and adjoining hills, with a maximum altitude of 423 m, located 22 km northeast of Nicoya, in the province of Guanacaste. The protected land has an area of 2,295.5 hectares. At least 40 caves have been identified in it, among them Santa Ana, La Trampa, Pozo Hediondo, Nicoa, Terciopelo and La Cuevita caves. The latter two are used for the entry of tourists.

On October 5, 1950 took place an earthquake in the Nicoya Peninsula, as a result of the subduction of Cocos Plate beneath the Caribbean Plate, which reached a magnitude of 7.7 on the Richter scale. It is the largest magnitude earthquake recorded in Costa Rica in the twentieth century. Events like this had happened in the years 1853 and 1900, in periods of about every 50 years.

This earthquake caused a sharp rise along the west coast of the Nicoya Peninsula, between Cabo Velas to the north and Cabo Blanco to the south. In this subject there are stories of neighbors indicating the lifting the coast at about one meter between Samara and Nosara (Marshall and Brenes 1989; Marshall and Anderson 1995, cited by Protti 2001, p. 48, p. 73). Another effect that characterized this earthquake the generation of a small tsunami, observed on the west coast of the peninsula; it is estimated that the maximum height reached by the waves was between 2 and 4 m. There are stories from locals and those who lived near the river mouths about the impact of the tsunami on coastal daily activities.

2. Background

Most of the recognized karst phenomena that occur in the Tempisque area of the province of Guanacaste developed in the limestone of the Barra Honda Formation, consisting of "platform limestones" (Mora 1981; Calvo 1987), to which Bandini et al (2008) assigned an Upper Paleocene age. The karst of this area is characterized by the presence of "*Mogotes*", which stand isolated on the immediate plains and have significant colluvial deposits that smooth their morphology. Also present are lapiaz fields, conical karst, travertine waterfalls, sinkholes, Resurgences or springs, blind streams and caves (Wells 1974; Mora 1978 1981; Rivier 1983; Hempel 1989; Goicoechea 1989).

In this karst area, 40 caves have been recognized and registered in the National Karst Registry (RKN), which is run by the Anthros Speleological Group (GEA). The caves of Barra Honda present a significant vertical development, with a large number of pits and are mostly controlled by fractures and faults (Mora 1981). The wells are characteristic of the vadose zone and usually are blocked by mud and rocks at depth and so far the water table has not been reached (Hempel 1989). The deepest well registered is the “Santa Ana-Pozo 110” System, with -125 m (Hapka et al. 1992). There’s presence of stalactites, stalagmites – (usually white, but colors range from orange to red) – large flowstone columns, pillars and calcareous pearls, among other speleothems (Mora 1981; Hempel 1989).

The “Terciopelo” Cave (RKN registration number CR009) is located in the south-eastern highlands of “Cerro Barra Honda”, in the National Park of the same name. This cave was discovered by the Speleological Group of the Mountaineers Club of Costa Rica (GE.CMCR) on February 23, 1968. Currently “Terciopelo” and another small cave, “La Cuevita”, are the only two whose tour is authorized by the National Park’s Administration.

During March 2003, the Anthros Speleological Group (GEA) conducted a study of the conditions of this cave, constructing also the trails through which the visitors must travel. The work was complemented by the design and installation of a metal ladder that helps to descend the entrance pit of -17.40 m. They also generated and delivered the respective “Use and Maintenance Guide” for the facilities. In March 2004, the GEA visited the cave in order to inspect the staircase; this visit revealed an inadequate maintenance of the structure and a detailed report was given to the PNBH administration. In May 2006, the GEA elaborated the “Study of the Supporting Capacity of Terciopelo Cave”. They have also produced several Inspection Reports of the facilities constructed, besides giving Training Courses to the authorized Park Guides.

2.1. Earthquake of September 5

On September 5, 2012 there was an earthquake of = 7.6 Mw on a portion of the fault that lies beneath the Nicoya Peninsula. The quake struck at 8:42 local time and was felt throughout the country, with reports of the earthquake reaching even as far as Nicaragua. The Nicoya peninsula had been recognized as a “seismic gap” in which since October 5, 1950 there was no release of energy in the form of a large earthquake, as occurred on September 5, 2012. Much of the work of recognition of the Nicoya seismic gap was conducted by scientists of the Volcanological and Seismological Observatory of Costa Rica National University (OVSICORI-UNA) in the early nineties and since then a follow-up of its development over the Nicoya peninsula has been conducted.

At 5:30 pm on Wednesday, September 5 the number of registered aftershocks with magnitudes greater than 2.0 was 230. A greater magnitude replica was recorded at 9:12 am, with a magnitude of 4.7. At 4:11 pm there was another aftershock of magnitude 4.6. Five days after the earthquake the seismic network (OVSICORI-UNA) had registered a total of 1,450 aftershocks. From 4:00 pm on September 8 to 10:00 am on Sunday, September 9, 2012 the automatic earthquake system had registered a total of 200 movements, most of them with magnitudes between 2 and 3 degrees, located mainly in the province of Guanacaste. The replica of greatest magnitude occurred on Saturday September 8 at 2:29 pm, with a magnitude of 5.6 degrees, 14 miles southwest of Sámara (Source: OVSICORI, http://www.ovsicori.una.ac.cr/ – Amended by the authors).

Figure 1. Map of seisms posterior to the Nicoya 05 September, 2012 earthquake (Source: OVSICORI, September 20, 2012).

3. Justification

To ensure the safety of tourists and the staff of the PNBH after the strong earthquake of September 5, 2012 in the Nicoya Peninsula, the Park’s Administration requested Anthros Speleological Group to conduct a preliminary visual inspection of the area and of the caves subject to visitation and their facilities, in order to identify potential risks in the structure of the cave, make safety recommendations and other elements considered relevant.

4. Methodology

A specific study methodology was designed, consisting of 10 consecutive and independent steps, in order to guide the analysis and start monitoring (Didonna 2013). The overall focus of the inspection was the direct observation and measurement of various parameters at different points inside and outside the cave. Also evaluated was the current status of the cave’s entrance ladder. To do this we used the following tools and supplies: altimeter, GPS, clinometer, topographic tape, digital camera, topographic map of the cave, area map, glass platelets 2,6 × 7,6 cm and contact cement, field notebooks and of course, full caving equipment.

The field team, composed of cavers Gustavo Quesada, Antonio Paz, Mariángela Vargas and Esteban Zárate entered Terciopelo cave on September 23 at 8:30 am, accompanied also by Dorian Méndez (Park Manager) and Yow Cardenas, a guide member of the Park’s Guides Association. The team split into two: Team 1, composed by G. Quesada and M. Vargas inspected the cave, starting with Room No. 1, establishing a security zone in case of earthquake and venue and then proceeded to inspect the cave’s morphology. Dorian and Yow joined this team, showing some findings obtained in their visit a couple of days before. Team Nr. 2, composed of A. Paz and E. Zárate made an inspection of the structure and anchors of the entrance ladder. They all came out of the cave at 13:30, being notified of an earthquake that was felt very strongly in the foothills at 9 am. None of the participants felt this quake; it is considered relevant to include this data, because apparently there was a decrease in the energy that allowed this shock to be isolated in the core of the mountain.

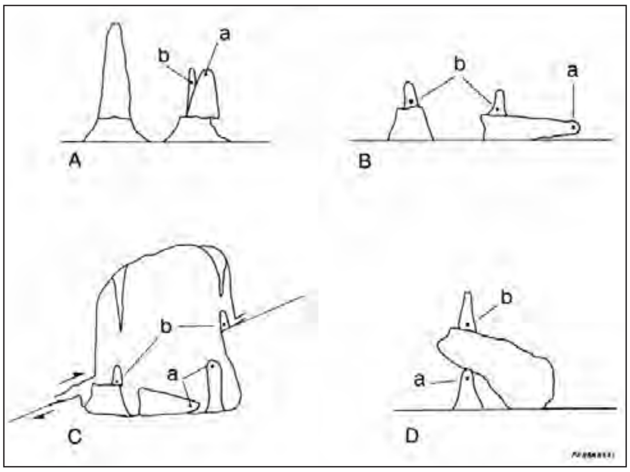

Figure 2. Examples of speleothems affected during the tectonic movements. Legend: From A to D, "a" indicates rupture by seism or displacement of speleothems by fracture and "b" indicates new formations growing around old fallen speleothems (Source: Forti, 2001).

4.1. "Terciopelo" Cave

The cave was entered by a means of a rope placed next to the entrance stairs. During the vertical descent, we verified for the possible presence of cracks or unstable blocks, and made a quick inspection of the state of the ladder itself. Once inside the cave a preview tour was conducted to determine a security zone in case of an earthquake during the inspection and to define the most relevant sites. Afterwards a more detailed inspection was carried out, looking for formations such as stalactites, stalagmites, curtains or others presenting obvious fractures or differences in their alignment to determine possible shifting or landslips (see Fig. 2).

In addition, observations were made of blocks, rocks and other items that might have recently fallen. Particular interest was given to the presence of fragments, powder or white surfaces that would indicate the recent breaking of the block, rock or formation. For very obvious cracks a description was made (location on map and size) and a glass plate of 2,6 × 7,6 cm was installed, using an epoxy resin. The plate was installed perpendicular to the direction of the crack, so that it can detect any movement of the blocks separated by the crack, if the plate is broken. Topography tape was placed with the platelet number to identify it. Each relevant point observed or where a plate had been placed was marked in the map and photographed.

5. Results

The Terciopelo Cave reaches a depth of -41 m and its longitudinal development is 134.60 m. It extends along two main axes, one with an east / west direction and the secondary with an N 45° E azimuth. It has two main Rooms and another which is an apophysis of the first; the cave contains a profusion of varied speleothems of a wide range of form and style (Source: National Karst Registry, GEA).

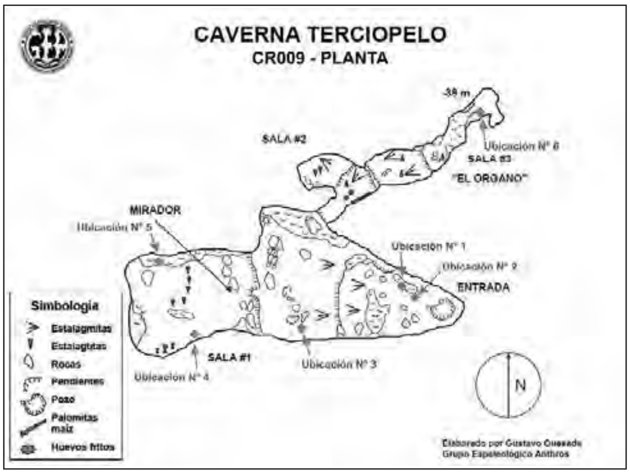

Figure 3. Map of the cave with the location of the findings (Source: Anthros Speleological Group).

5.1. Surface Inspection

During the climb to the cave there was no significant alteration in the surface morphology that could be related to recent seismic activity. Team 1 conducted an inspection around the entrance of the cave for possible landslides, boulders, unstable rocks or other hazards. There was a zone of instability located at coordinates N 1139988 and 1561200 E (WGS 84, error of ± 4). The area corresponds to an opening on the cave's roof, through which were introduced cables from a solar panel placed near the site to provide illumination to the cave. Near the said opening there are loose rocks 30 to 40 cm in diameter that could eventually fall into the cave. Furthermore, a relatively unstable rock was found in the middle of the opening. Also noted was an unstable rock, which could be a risk to people entering the cave. The possibility of moving it with levers was discussed, but it could destroy the ladder when falling (see Fig. 4).

Figure 4. Zone of instability in the surface near the cave entrance: unstable rock that may fall inside the cave (Photo: G. Quesada).

5.2. Internal inspection

A traverse through the three rooms that make up the cave was done, looking for cracks, fissures, recent changes in morphology, landslides and collapses, among others. Additionally speleothems were observed in search of fresh fractures. We identified a total of six sites within the cave

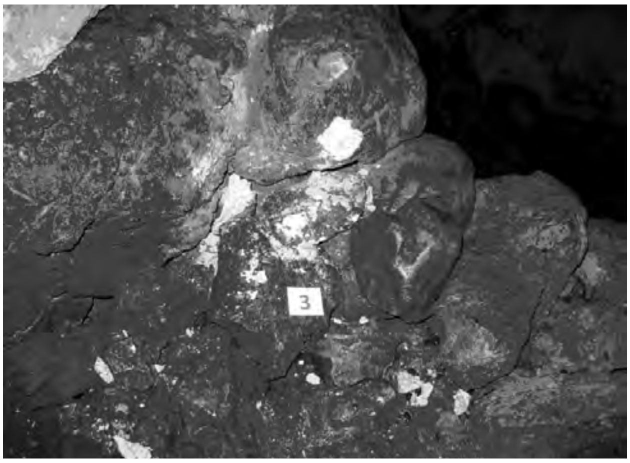

Figure 5. Evidence of collapse from the roof in Room No. 1 (Photo: G. Quesada).

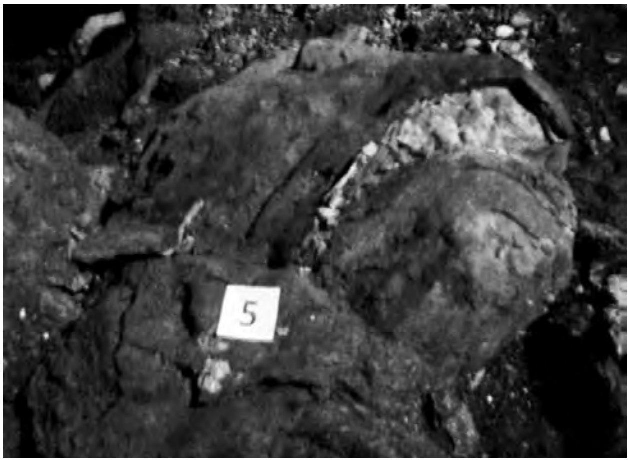

Figure 6. Evidence of collapse from the roof in Room No. 1: Broken rock surface located on the floor of the cave (Photo: M. Vargas).

that definitely show recent changes that can be attributed to the effects of the earthquake. The places where these sites are located are identified in the cave's planimetric map (see Fig. 3).

Fallen rocks were observed on the floor of the eastern section of the Hall 1, near the foot of the staircase (Location No. 1, Fig. 3), due to the impact of a stalactite that fell off the roof, crashing to the ground. Nearby, in the Location Nr. 2 (Fig. 3) a broken rock of recent aspect was located; this type of damage is considered minor but should be quantified and taken into account in the final report.

Fractures in the walls: there is a 30 mm crack in the wall in Location Nr. 3. At this location a glass was installed to monitor any future changes in the crack. In the Location Nr. 4 (Fig. 3) a 4 mm crack was found in a formation and a glass plate was installed to monitor any future changes.

Figure 7. Left: Fissures in one of the columns of "The Organ", in Room Nr 3. Right: Marking of the inferior fissure in a column of "The Organ".

Fractures in a column. On location Nr. 6, in Room No. 3, a recent crack in the base of one of the columns of the well known formation called "The Organ" was located. This crack in its base is 2.5 mm wide and a glass plate was placed to monitor future changes. Additionally, a crack was observed in the upper section of the same column, which endangers the total detachment of the column (see Figs. 7, 8).

6. Comments

According to Gilli (Gilli 1994) in Barra Honda recent movements are observed due to:

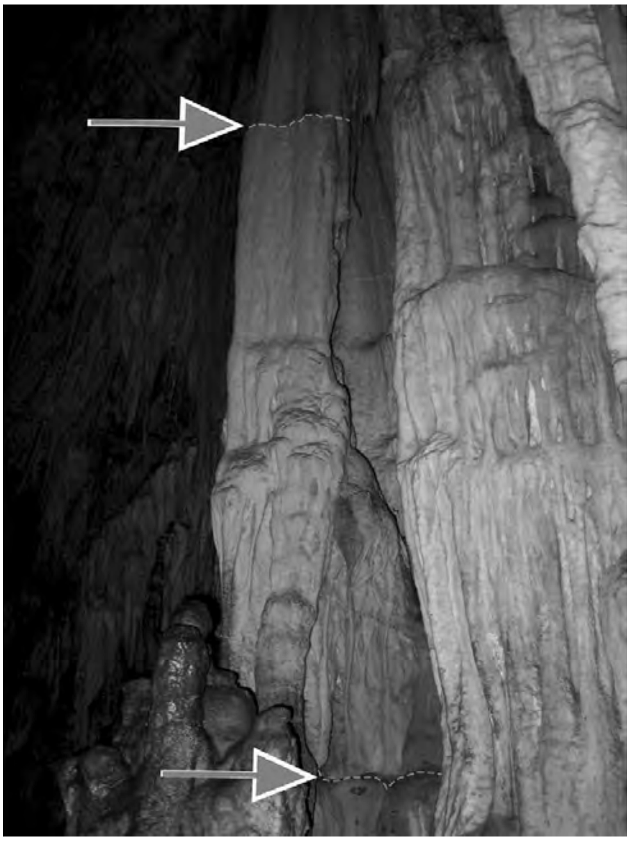

Figure 8. Complete details of the cracked column on both sides of the formation known as "The Organ" (Photo: G. Quesada).

- The tilting of stalagmites, falling of stalactites, the collapse of parts of the roof and the "bombardment" of the walls are all attributed to seismic events.
- A quick collapse of the circulation reflects a regional uplift.
- Changes in the direction of the axis of growth of stalactites and stalagmites or changes in flow direction may reflect a regional tilt.
- Fault movements result in the fracturing of the speleothems and changes in the sections of the galleries.

In this study a purely qualitative analysis of Terciopelo cave has been performed, which was done at the request of the Park's Administration, without any retribution for Anthros, to give a general idea of the overall condition of the cave and of the existing staircase. Indeed part of the phenomena mentioned by Gilli has been observed and this inspection is a starting point for future specific studies. The comments, conclusions and observations are made based on the findings during the visual inspection requested by the Park's Administration.

For this inspection no geological, seismological and structural study was conducted; neither does it allow to identify potential risks that can not be known by simple observation.

The inspection made does not contemplate any cleaning, preventive and corrective maintenance or repair of the staircase currently used by the tourists to enter Terciopelo cave. These tasks are the responsibility of the Administration of the Barra Honda National Park.

The observations were made on September 23. Therefore, any events subsequent to that date could have adverse effects on the Terciopelo Cave, its entrance, the staircase, the staircase leading to Room Nr. 2 and the cave formations. Such effects have not been considered in this report, which refers only to the observations made during the said inspection.

Generally there will be differences between the effects or risks detected visually and the total effects or risks, given the nature of the request by the Park Administration, the methodology used and the instability of the area and of the formations.

7. Recommendations

A series of recommendations were given, aimed at the improvement of the security of the speleological site:

• Unstable rock at the entrance (Fig. 4): it is recommended that it be anchored with a steel cable to a stable structure of higher strength and weight, to prevent it from collapsing into the cave's entrance and destroying the staircase.

• The loose rocks just next to where the electrical cord enters the cave must be removed.

• It is recommended to avoid direct entry into Room Nr. 3, where "The Organ" is located, due to the instability that now affects one of his columns.

• It is recommended that an inspection of the cave be made every time a major seism occurs, to verify that there are no hazards from landslides or the potential collapse of formations.

• It is recommended to continuously monitor all the platelets installed at the critical sites of the cave and to report to Anthros Speleological Group in case any is broken, to give continuity to the ongoing study.

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SOME ASPECTS OF THE GEOGRAPHICAL DISTRIBUTION OF BUDDHIST CAVES

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The religious use of caves is an integral part of Buddhist culture. Seeking refugee in the interior of caverns for meditation is an ancient practice, dating back to the life of Siddartha Gautama. This paper focuses on studying some aspects of the geographical distribution of Buddhist cave-temples, especially in Asia, exploring its association with dominant schools and geological features. Results reveal an uneven geographical distribution, not accounted for by the size of countries, nor their population, much less by the historical dispersal of Buddhism. Physical feautes, in turn, play a major role in the geography of Buddhist cave-temples.

1. Introduction

There are many historical evidences of caves being used for contemplation, meditation and spiritual elevation worldwide. In fact important religious figures spent crucial moments of their personal lives, marking the history their religions, inside caves giving rise to a rich and colorful tradition of religious use of caverns.

Zoroaster during the 7th Century B.C. developed the habit of seeking refugee inside certain caverns of ancient Persia in order to meditate, and many of these reflections were recorded in the holy book of Avesta (Cervantes 2011).

Caves were also relevant in the development of the Judaic-Christian tradition, as the Dead Sea scrolls, for instance, were found inside the caves of Qumran. It is also worth pointing out that in response to the Roman persecution many of the first Christians sought refuge inside the caves of Cappadocia (Travassos 2011).

Mohamed also developed the habit of meditating inside the cave of mount Hira, where he received from angel Gabriel the first verses of Koran as vastly registered in the literature and by Cervantes (2011) and Travassos (2011).

There are also strong historical evidences that Siddhartha Gautama, the founder of Buddhism, spent decisive moments of his live inside the caves of NW India, where he meditated about the nature of human suffering (Fig.1). The practice of meditation inside caves became a relevant aspect of Buddhism, giving rise to the construction of numerous the cave-temples throughout the past 2,500 years in various parts of the world. This paper brings preliminary results of a survey of the most relevant Buddhist cave-temples seeking to map their location and classify them with respect to predominant geological features and associated Buddhist schools.

2. Geography of Buddhism

Buddhism is a religion developed in Northeast India approximately 2,500 years ago. Nowadays its adherents add up to millions of peoples spread throughout the world, but with a very strong presence on the Asian continent. Buddhism is not a monolithic entity, but a family of religions and philosophies. As it spread geographically it incorporated many aspects of local cultures, thus producing a vast array of schools and sects.

Estimates on the number of Buddhists worldwide range between 230 and 500 million people (Adherents 2012), fact that makes Buddhism one of the most expressive religions, congregating not less than 6% of the world population, falling short of Christianity (32%), Islamism (19%) and Hinduism (13%) (Religious Tolerance 2012). Nonetheless, Buddhists are not evenly distributed as the largest populations are found in China, Japan, Thailand and Vietnam.

The historical figure of Siddhatta Gautama, also known as the Buda, did not registered its ideas, but its teachings were passed on orally for many centuries, being formally recorded by some of his followers at least four hundred years after its physical passing. His teachings contemplate psychological, philosophical and moral aspects and the Buda is customarily portrayed as a master, a thinker, a wise man and sometimes even as a scientist (Silva & Homenko 1978).

The three major schools of Buddhism are Theravada, Mahayana and Tibetan. These schools represent different expressions of the teaching of Buddha. The separation of schools can be traced back to the year 383 B.C. when the second Buddhist council took place in India demanded by the growing conflict about the interpretations of Buddha's teachings, in which a group of monks demanded the relaxation of monastic rules. For the traditional group, the Theravadins, Buddha was a human being who achieved enlightenment – a deed possible as long as monks followed the monastic rules established during the first Buddhist council. Thus, the Theravada school, also known as the Teachings of the Elders and Hinayana, is associated with Southeast Asia, being found especially in Sri Lanka, Cambodia, Laos, Burma, and Thailand. This is the eldest and probably the closest to Buddha's original teachings (Humphreys 1990).

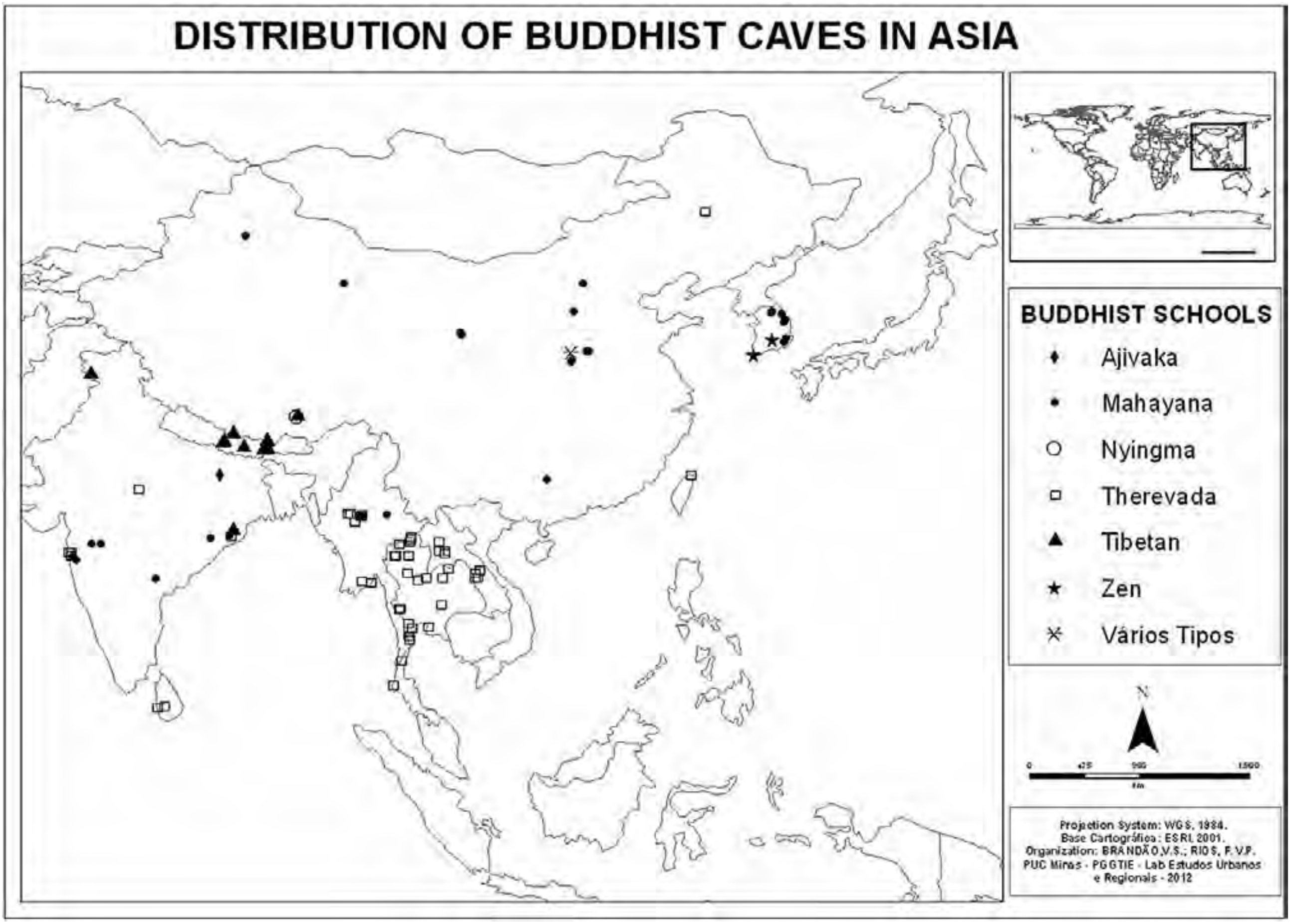

Figure 1. Location map of some Buddhist caves in Asia.

On the other hand, a dissident group named Mahasamghikas understood the traditional monastic ways as individualistic and selfish, proposing monastic rules less rigid and accessible to a larger group of people (Humphreys 1990). The Mahayana school, also known as the Great Vehicle encompasses a vast array of sub-groups ranging from the Pure Land sect, whose essential teaching is that salvation can be attained only through absolute trust in the saving power of Amitabha, longing to be reborn in his paradise through his grace, which are found in China, Korea and Japan, to the Ch'an and Zen Buddhism of China and Japan, which are basic meditation schools. According to these schools, to look inward and not to look outwards is the only way to achieve enlightenment, which to the human mind is ultimately the same as Buddhahood.

Although some consider it as part of the Mahayana tradition, Tibetan Buddhism includes elements of the Buddhist doctrine and preexisting shamanism and indigenous animism that is practiced in the Himalayas of Tibet, Bhutan, Nepal and northern India (particularly in Arunachal Pradesh, Ladakh, Dharamsala, Lahaul and Spiti in Himachal Pradesh, and Sikkim), but it is also present in Mongolia and certain parts of China and Russia.

3. Methods

In order to accomplish the goals of this paper a thorough search was conducted in the web and Buddhist publications in order to identify major cave-temples worldwide. Throughout this process geographical location and Buddhist affiliation of each cave-temple were recorded. Eventually, a location map was produced and superimposed upon geological maps in order to collect data on the predominant types of rocks upon which cave-temples were erected. Results are presented in table and cartographic formats.

4. Results

Results indicate a tremendous variation in the spatial distribution of Buddhist caves. Overall, Thailand holds the largest number of cave-temples, comprising 27 of such religious features; followed by India with 20 cave-temples. China holds 14 cave-temples; Laos counts on 12; while Burma and South Korea hold 9 each; Sri Lanka 2; and Taiwan one single cave-temple (Table 1).

Table 1. Number of Buddhist caves by country.

Country	Total of caves
Thailand	27
India	20
China	14
Laos	12
Burma	09
South Korea	09
Tibet	03
Nepal	03
Sri Lanka	02
Taiwan	01
Total	**100**

Curiously, the vast majority of cave-temples were developed in carbonate rocks (78), followed by basaltic rocks (9), granitic rocks (6); sandstones (4), and conglomerates (1). We were also able to identify at least one major artificial cave (Table 2).

Table 2. Number of Buddhist caves by rock type.

Rock type	Total of caves
Sandstone	04
Limestone	73
Basalt	09
Carbonate	06
Granite	06
Conglomerate	01
Not applicable (man made)	01
Total	**100**

It is also worth mentioning that among the predominant Buddhist schools, 53 were devoted to Therevada; 27 to Mahayana; and 12 to its Tibetan version (Table 3).

Table 3. Number of Buddhist caves by Buddhist Tradidion or School.

Buddhist tradition	Total of caves
Therevada	55
Mahayana	28
Tibetan	12
Ajivaka	01
Nyingma	01
Zen	02
Various types	01
Total	**100**

5. Discussion

Preliminary results suggest that total population and the cheer size of countries are not determinant factors in the geographical distribution of Buddhist cave-temples.

China and India, although displaying considerable amounts of such features are overshadowed by Thailand, a country with much more modest population and territory.

Another aspect which seems to play a secondary role in this distribution is the history of Buddhism and its diffusion throughout the world. Buddhism spread slowly from Northeast India, first penetrating the neighboring territories of south-central India between the 5th and 2nd centuries B.C. With Emperor Asoka's proselytism Buddhism reached Sri Lanka in the years 200 B.C. Following the Silk Road the religion reached the Bamiyan valley during the same time (Diniz 2010).

From then on two important eradiating centers were developed. One in Central Asia from which Buddhism spread to China in the 1st century A.D., and from there reached Vietnam in the 2nd century A.D., Korea in the 4th century A.D., and from Korea it arrived in Japan in the 6th Century A.D. Tibet experienced Buddhist influence only during the 7th century A.D.

The second important eradiating zone was developed in Sri-Lanka from where the Hinayana tradition reached Myanmar during the 5th century A.D. and Indonesia, during the 6th Century A.D. Thailand and Cambodia were only influenced by Buddhism much latter, respectively during the 9th and 13th century of the Christian Era (Diniz 2010).

Based on this historical account it would be expected that India, Sri-Lanka and Central Asia, more specifically what is today known as Afghanistan, to hold the largest number of Buddhist cave-temples. Nonetheless, Thailand once again overshadows the other nations.

When we turn to the types of rocks upon which Buddhist cave temples were erected one gains an important perspective on understanding why Thailand, with much smaller population and territory and a much younger Buddhist tradition displays such a prominent role in the geographical distribution of cave-temples. As the vast majority of such caves fall in carbonate areas, southern Thailand has the vast majority of its territory under the influence of Karst features, partially explaining why the country has such a noticeable concentration of cave temples.

This overall understanding is amplified when we add the results on predominant schools of Buddhism associated with surveyed cave-temples. As Theravada is the predominant form of the Buddhism in Thailand, and since Thailand holds the largest number of cave-temples it is natural that most Buddhist caves follow the Theravada tradition.

6. Conclusions

Preliminary results indicate that Buddhist cave-temples are unevenly spread throughout the Earth, being heavily concentrated in the Asian continent, most specifically in its southeastern corner. This uneven geographical distribution cannot be explained by country size or population, much less by the history of Buddhism and its dispersion. Instead, this distribution is associated with two important features: the presence of karstifiable rocks and the Theravada Buddhist tradition.

This unequivocal association adds empirical evidence to the Geographical Possibilist approach, which faces nature as a provider of innumerous possibilities and stimuli for human populations. According to the approach these possibilities, in turn, will be explored by social groups depending on their own culture, values, and technology.

Karst landscapes and their associated physical features offer Buddhists a vast array of opportunities to exercise an important aspect of their religious tradition, initiated by Lord Buddha himself millennia ago: that of meditating inside caves.

It is also important to mention that in this brief paper, many cave-temples are still missing and some of them needing confirmation of their location, especially in Southeast Asia and China.

Acknowledgments

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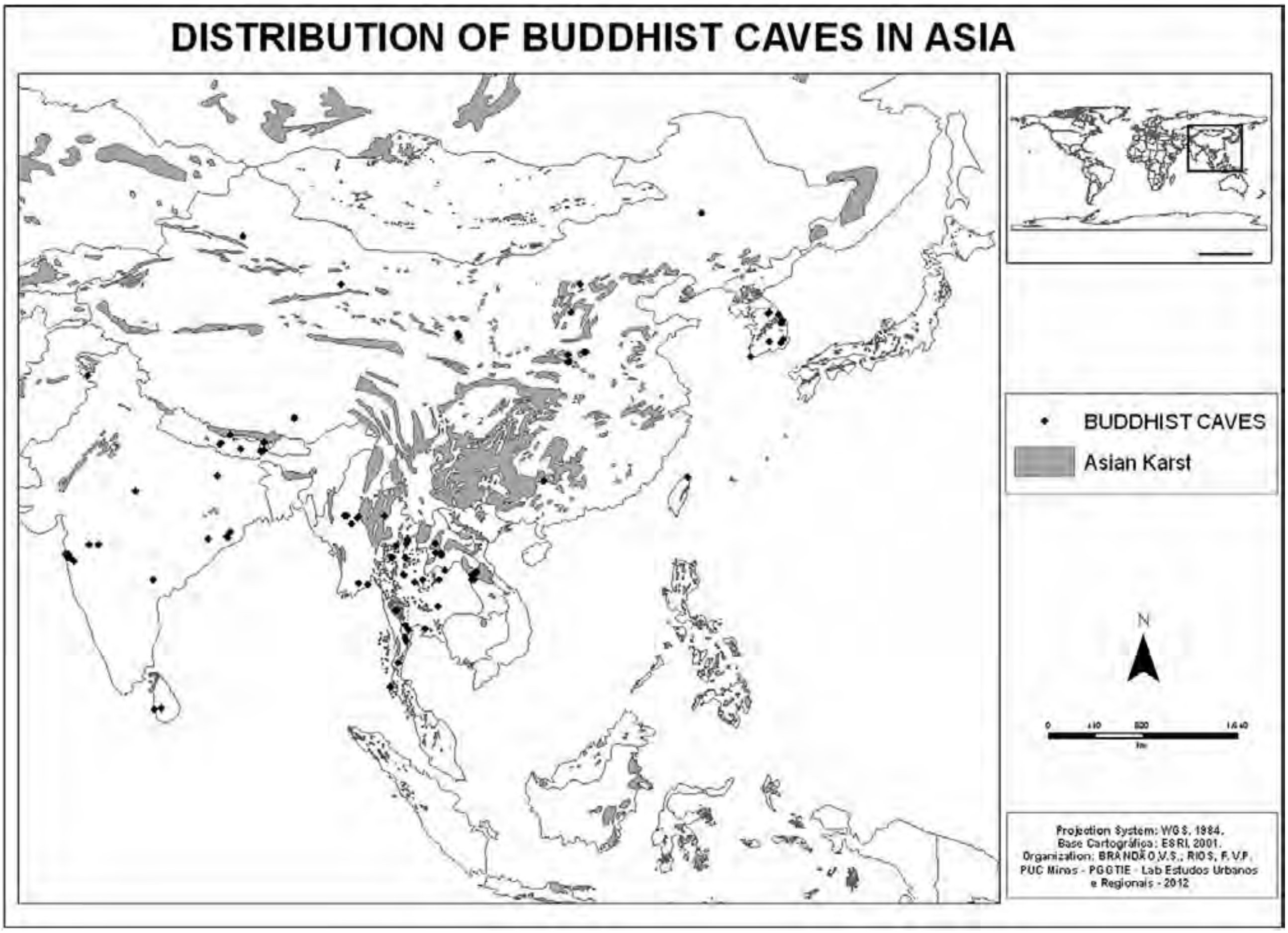

Figure 2. Location map of some Buddhist caves by Tradition or School.

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IMPROVEMENT OF CAVING AS A FORM OF PHYSICAL ACTIVITY

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Caving is an interdisciplinary science – sport discipline that deals with research of various underground facilities (caves, catacombs…). Recognized as specific sports skills and complex belongs to the so-called extreme sports, and a prerequisite for practicing this skill the appropriate level of general fitness. In the literature there is little information about spelunking in terms of physical activity, and physical condition of cavers should be improved through various training models.

In this research we used the method of theoretical analysis, which includes search available literature dealing with the analysis of caving in terms of physical activity.

Theoretical analysis of the available literature shows that the caving team sports skills, in which respect the sport and the rules and principles of caving, and where there is competition with nature and with ourselves. Dealing with caving involves knowledge of various techniques and submission prolonged physical exertion, which is not typical of many sports. Since physical abilities is the most important cardiovascular endurance, but come to the fore strength, flexibility, coordination, balance, agility, quickness. These physical abilities can be developed outside the field conditions, ie. simulation in terms of characteristic ways of moving at various gyms. During the last decade developing caving – tourism, which opens the possibility of practicing in recreational caving.

Given the small amount of information that indicate physical activity spelunking, this skill provides the ability to research different aspects of sports, which could be favorable physical preparation methods, and led to the development of model training. In this way, these skills will bring a number of future athletes, and increase number for recreation.

CAVES AND PROTECTED AREAS IN SARDINIA (IT): THE EXAMPLE OF THE GROTTA DEL PAPA CAVE SYSTEM IN THE ISLE OF TAVOLARA

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Some preliminary results of analysis of the Grotta del Papa Cave are summarised. The cave is located on the Isle of Tavolara, a peculiar small island off the northeast coast of Sardinia (Italy). Amongst the numerous caves that noticeably characterise the carbonate massif of the island, the Grotta del Papa Cave (GdP Cave), although still poorly studied and documented, certainly represents the most scientifically and archaeologically valuable karst site of all Tavolara. The GdP Cave is one of the most important Mediterranean sites for the Neolithic culture, boasting precious cave paintings; for nesting the most important breeding Manx Shearwater population in the world and other vertebrate and invertebrate species; for the geological and paleontological content, for the speleological features. Due to the complex accessibility to the cave (only by boat and under favourable weather conditions), and due to the strict management policies issued by both the Marine Protected Area, established in 1997, and the military district, since the early '60*s*, this cave has been subjected to very incomplete studies, and its scientific and archaeological content has yet to reveal all its features. The natural frame of GdP Cave has, however, never in the past prevented this valuable site from destruction of any sort, that over time have devastated its biological, geological and archaeological contents. As a result of the recent military and institutional settlements, heavily limiting the cave fruition, the damage activity is ceased, however resulting into a critical stop of all scientific activities.

The current research project, here briefly documented, is framed within the context of a systematic scientific exploration and measurement survey, originally commissioned by the Marine Protected Area and currently carried out by a multidisciplinary team of experts from the University of Cagliari, the CINSA, SSI and FSS, the Archaeological Superintendence, with the valuable contribution of the laboratory of the ENEA Marine Environment Research Centre, and the patronage of the UNESCO Italian Commission (CNI).

1. Introduction

Located nearby the northeaster coast of Sardinia (Italy), the Isle of Tavolara represents the main features of this astonishing Mediterranean area.

Amongst the numerous caves that characterise the carbonate massif of the Isle of Tavolara, the Grotta del Papa Cave, although still poorly studied and documented, certainly represents the most scientifically and archaeologically valuable karst site of all island: a real natural speleological laboratory. The lack of knowledge of this potentially rich scientific natural laboratory could be only apparently attributed to two main reasons, the first being the complexity of accessing the cave, as it is reachable only by boat. Moreover, as a result of the geographical configuration of the main entrance, continually exposed to winds and sea storms, accessing the cave is allowed only under the most favourable local weather conditions. The second reason relates to the fact that the cave is cartographically and administratively included into the full protection zone boundaries (ZONA A, in Figure 1) of the Isle of Tavolara and Coda Cavallo Cape Marine Protected Area classification, also including the relevance territory of the NATO Joint Military District area, which oversees the island since the early '60s of last century.

The Marine Protected Area, established in 1997, extends from Ceraso Cape to Coda Cavallo Cape, boasting several inlets, beaches, bays, and promontories of unrivalled natural value (Fig. 1).

Most of the Tavolara inhabitants were displaced in 1962, when the NATO radio goniometric station was built on the easternmost side of the island. The aerials are visible from quite a distance, and that entire half of the island is currently restricted to military personnel.

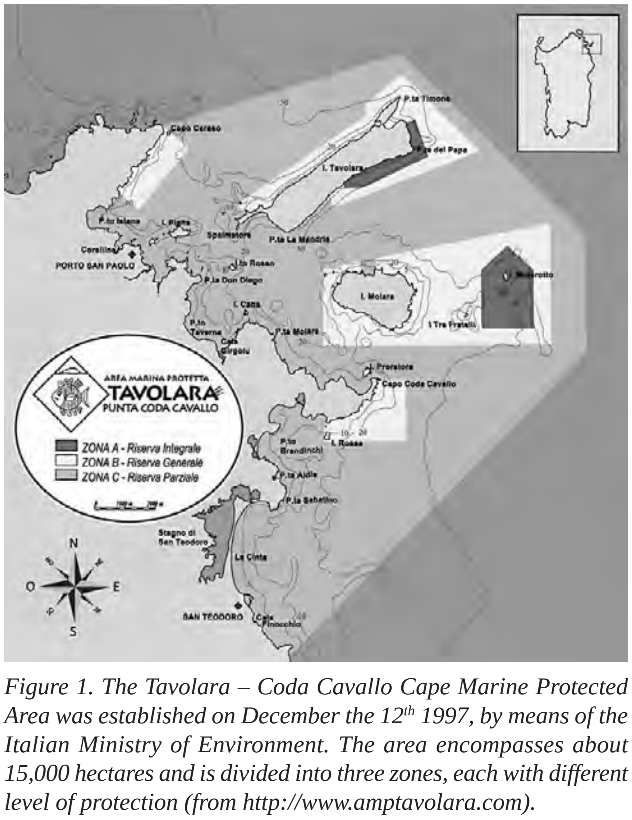

Figure 1. The Tavolara – Coda Cavallo Cape Marine Protected Area was established on December the 12th 1997, by means of the Italian Ministry of Environment. The area encompasses about 15,000 hectares and is divided into three zones, each with different level of protection (from http://www.amptavolara.com).

The GdP Cave natural frame and its exposure to strong winds have, however, never in the past prevented this valuable site from destruction of any sort, that over time have obliterated its biological, geological and archaeological contents. As an important result of the recent military and institutional settlements, heavily limiting the cave fruition, the damage activity is ceased, yet resulting into a significant stop of any scientific research.

The current research project is framed within the context of an almost unprecedented systematic scientific exploration and geophysical measurement survey, originally commissioned by the Marine Protected Area, and at present undertaken by a multidisciplinary team of experts from the University of Cagliari, the Interdepartmental Centre for Environmental Science and Engineering (CINSA), Italian Speleological Society (SSI) and Sardinian Speleological Federation (FSS), the Sassari-Olbia Archaeological Superintendence, with the valuable contribution of the laboratory of the ENEA Marine Environment Research Centre, and the patronage of the UNESCO Italian Commission (CNI).

The very first and solely scientific investigation of the numerous Tavolara Island caves, specifically the GdP Cave limited to its outer part, was carried out during the late 50'*s* by a speleological working group managed by a keystone person of the Sardinian speleological history, the canonical scientist Father A. Furreddu (Furreddu et al. 1964).

Whilst protecting the Gulf, the Tavolara is itself very exposed to wind: there are often strong surf and dangerous wind vortices between Punta Timone and the Papa Cape (Figs. 1, 2, 7).

The Tavolara island represents a proper limestone massif 5 km long and 1 km wide, with spectacular steep cliffs all along the whole coastline, with the exception of its far western edge. The limestone lies on a granitic-pegmatitic bed, aged about 225 million years (Fig. 7).

The highest point, the Cannone Mount, is almost 600 m a.s.l. Little bays and a beach occurs at each tail of the island, Spalmatore di Fuori to the northeast, and Spalmatore di Terra to the southwest.

The Papa Cape is the south-east head of the island.

The gigantic limestone spire on the south-easternmost part of the island, resembling a human figure, is known as "the Stone Sentry" or "Pope Rock."

3. Cave description and exploration

The GdP Cave is located on the north-eastern coast of Tavolara; the toponym refers to the huge limestone spire that marks the south-eastern cape of the island, whose double pinned shape of the top evokes the papal mitre.

Figure 2. Geographical location of the Isle of Tavolara and the Grotta del Papa Cave.

2. Geography and geomorphology

The northern most part of Sardinia, the Gallura region encompassing the Island of Tavolara, is geomorphologically vast and diversified, and is mainly characterised by the occurrence of pinkish granite outcrops, quartz-feldspar beaches, and carbonate (limestone-dolostone) reliefs of the Tavolara and the promontory of the Figari Cape. These reliefs represent the only limestone rock formations occurring in the Gulf of Olbia and, together with the granitic Ceraso Cape, form a big natural barrier protecting the gulf against marine storms and winds, except those blowing from the East.

Already in the early nineteenth century this point was quite well known and visited by foreign.

The main entrance is about 100 m apart from the Papa Cape, to the North (Fig. 2); it is currently at sea level, and it is only accessible by boat. During the Palaeolithic period, the sea level was approximately -15 m lower than present (Antonioli et al. 2005), and even though during the prehistoric phase the cave entrance certainly lied several metres apart from the current shore line, accessing to the cave was still a difficult task.

The up-to-now known cave development includes 5 main settings (Fig. 3): a fairly high and peculiar portal and a wide corridor quickly open towards the first room, which leads through a narrow and low corridor, to the second room. Passing by through the corridor is made complicated by a shallow freshwater dripping lake. Ancient pottery fragments are spread all over nearby lake while, in the first room, a fireplace and other Nuragic and Phoenician pottery remains are still visible. Moreover, fragments of crushed burned bones, as well as skeletal remains of the Sardinian pika *(Prolagus sardus)*, occur in several areas of the cave, sometimes embedded into the calcite concretions. A small entrance leads to the second room, characterised by a large deposits of pure clay (Fig. 4).

Towards the end of the "red clay room", to the north, a huge stalactite helps climbing the wall to enter the last surveyed area of the GdP Cave, a large and marvellous chamber completely enriched by speleothemes of any sort and beauty; excellent displays of the granitic basement-dolostone and limestone contact layer, with significant Jurassic and Quaternary fossiliferous outcrops. Moreover, the macroscopic analysis of the e biological content of this long lasting isolated hypogeal ecosystem has already highlighted the occurrence of unknown invertebrate species. A systematic and detailed biological sampling is needed and already scheduled as one of the next project activity.

During the August 2012 expedition, a new development branch has been discovered. A wide opening very closed to the ceiling of this last chamber seems to lead to a development with a general east-west direction. This point indicates the currently known exploration limit of the GdP Cave, and the starting point for the next speleological research.

The Neolithic paintings occurs very close to entrance in the upper part of the northern side of the portal; a ten metres thick deposit of breccias from the Tyrrhenian interglacial period here forms a natural suspended terrace that, nowadays as then, allows reaching the painted walls (Fig. 6).

4. Biology and Palaeontology

The GdP Cave biological features have been very partially surveyed: the fauna characteristics has yet to reveal the most. No systematic study on the fauna has never been yet carried out and the current knowledge refers to the macroscopic aspects only. As far as vertebrate fauna is concerned, the cave is the preferred site for bird nesting, both for the common wild pigeon (*Columba livia*) and especially for the petrel seabird Manx shearwater (*Puffinus yelkouan*). Both on Tavolara and the nearby Molara Island, this Petrel accounts the most important breeding population in the world, accounting the presence of about 10,000 to 13,000 of pairs. For nesting, the shearwater chooses dark and inaccessible niches, and in the GdP Cave the nests are represented by small holes on the cave walls just above the floor. The nests currently in use inside the cave are ten, while others are settled onto hollows adjacent to the main cave.

Bats also continuously dwell the site; no reliable data about type of species and figures are, however, available.

The use of the GdP Cave by the Mediterranean monk seal, as reported in some literature, is unlikely to be believed, given the particular cave entrance context, certainly very different from those usually populated by this pinniped. For

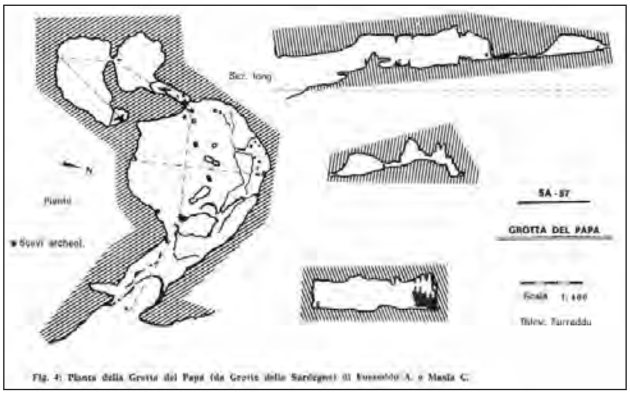

Figure 3. The GdP cave survey (A. Furreddu and C. Maxia, 1964).

sure, several sightings nearby the cave were recorded towards the end of the '70*s* of the last century.

Finally, the frequent discovery of Sardinian pika (*Prolagus sardus)* remains, especially skulls, should be highlighted. Most of the bones fragments are covered or embedded within the calcite deposits, while others are still at a subfossil phase. The presence in this cave of the Sardinian pika bears important implications, one being related to the "giant rats of Tavolara" tale, completely dismissed by the Cetti in 1700 by erroneously attributing the pika bone remains to rats. The extinction period from Tavolara of this lagomorph, that lived in total isolation on the island from 8,000 years ago onward is, however, still an open question.

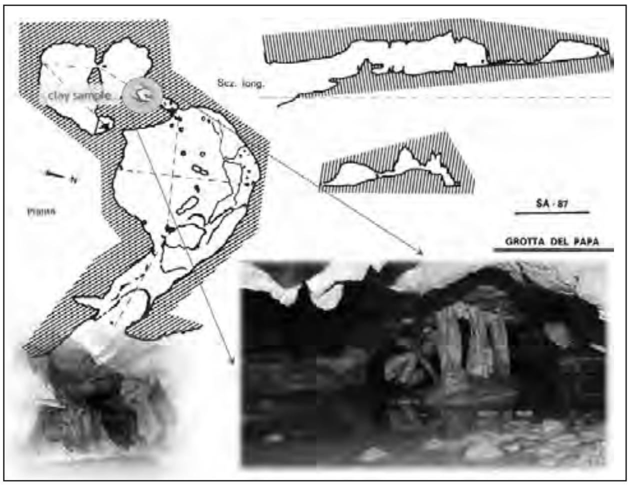

Figure 4. Clay sampling: the red circle in the planimetric survey indicates the analysed clay sample location.

The general knowledge of the invertebrates occurrence in the several little openings of the cave chambers is also little, and the scientific data available are limited.

5. Geochemistry

In August 2012 some rock samples have been collected in several sites of the cave, from and nearby the large clay deposits in the second chamber of the GdP Cave, with the aim of both characterising the mineralogical and geochemical nature of the clay deposits, and proving the close relationship between the clay deposits available in the cave and the clay used for paintings. This link, seemingly obvious, is not easily acclaimed and, indeed, the first results

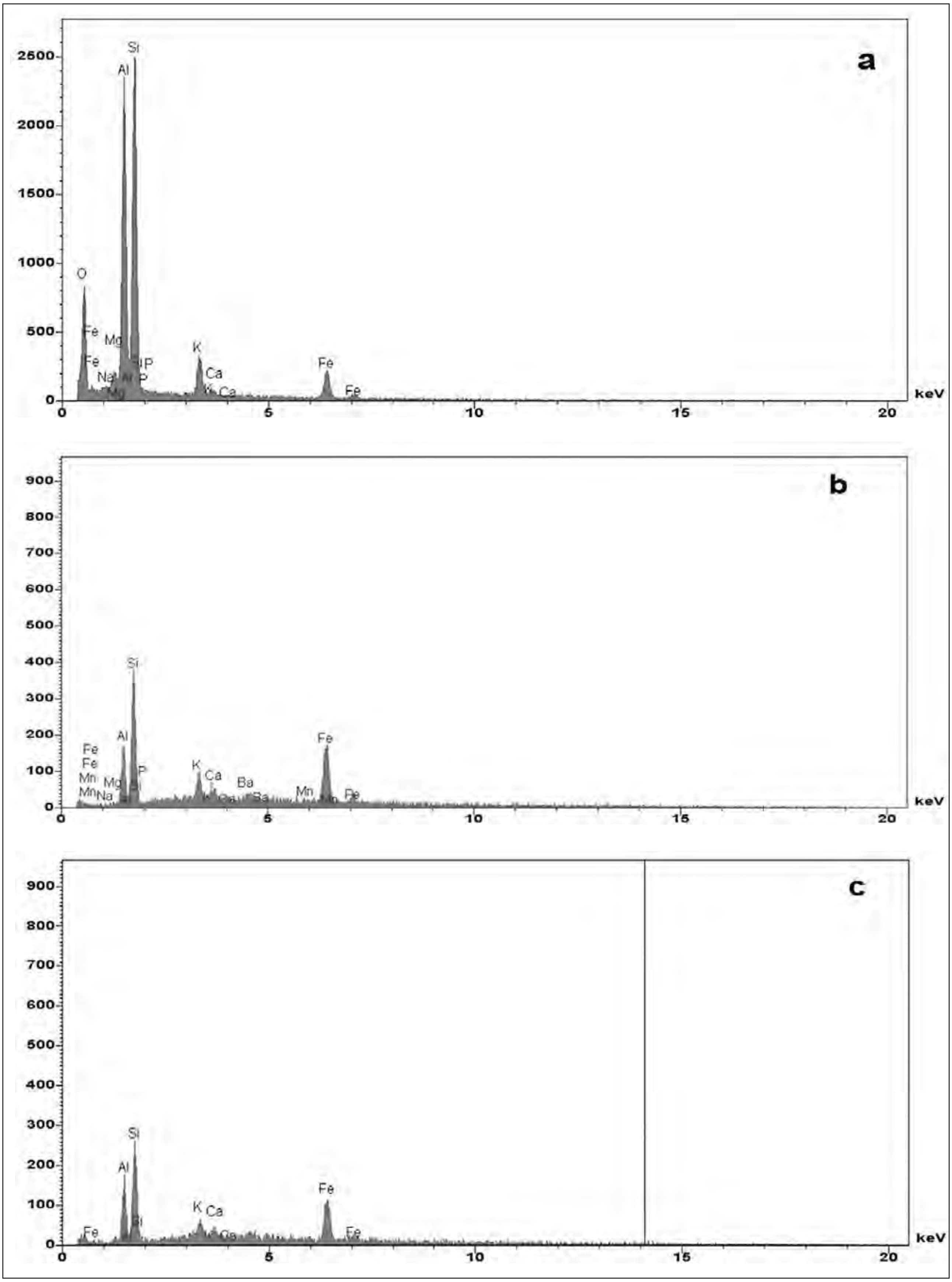

Figure 5. The EDS microanalysis for the three identified areas: white area (a), light gray area (b), dark gray area (c).

of the analyses described below, seem to open new areas of archaeological hypothesis.

Figure 4 shows the location of the analysed clay sample.

A chemical composition and the microstructure of the rock sample were characterised by X-ray diffraction (XRD) (Philips 1830 diffractometer using CuK Ni-filtered radiation), scanning electron microscopy (SEM), and electron dispersive spectroscopy (EDS) microanalysis (HITACHI S 4000 Field emission equipped with a KEVEX SIGMA 32 probe at a resolution of 142 eV).

To identify the main crystalline phases of the solid samples, XRD patterns were obtained in the 2 range of 10° and 60°.

The powders were placed on the sample holder under air atmosphere. Figure 8 shows the obtained XRD pattern. The detected phases are kaolinite, quartz, magnetite, iron phosphate and iron phosphate hydroxide, aluminium silicate and aluminium silicate hydroxide, and calcium carbonate. The significant occurrence of iron phosphate hydroxide should be pointed out, mainly as far as the depositional environment of the clays deposits is concerned.

For analysing the morphology of the clay components and to identify the related chemical composition, SEM and EDS analyses were carried out. Dry powders were placed onto a cylindrical stub and fixed by graphite adhesive tape. Three different areas were selected: the light gray, the dark gray and the white ones.

From the images obtained in backscattered electron mode it is possible to observe areas with a different atomic number. The EDS microanalysis highlights the related distribution of species in the near-surface region, as reported in Figure 5. In particular, it can be assumed that the white area is mainly composed by Si, Al and O; the occurrence of quartz, kaolinite and, in general, aluminium silicates is also confirmed. In the gray region of the image, the decrease of both Al and Si peak intensity as well as the equivalent increase of the Fe peak intensity, confirms the presence of magnetite and iron phosphate.

6. Archaeology

The cave has already been archaeologically studied, especially in relation to the findings belonging to the Phoenician-Punic age (Furreddu 1964).

The Neolithic anthropomorphic paintings occurring in the GdP Cave, reported for the first time in 1992 (D'Oriano 1996), have been surveyed and scientifically analysed for the first time in July 1997 (D'Arragon 1997). The Neolithic paintings occurs very close to entrance in the upper part of the northern side of the cave portal, which opens into the sea with the entrance facing east, and located in the upper part of the room.

In the other cave chambers, as already described, the remains of a large fireplace with charred bone remains and fragments of pottery from the prehistoric era, probably Middle Neolithic, Phoenician-Punic, and Roman age, are found. In the innermost room of the cave many Phoenician-Punic artefacts were found, that could indicate a religious use of the cave; unfortunately the notifications available in the literature about these archaeological discoveries are not compliant with the current scientific-archaeological research standards.

The Neolithic painters have used the smooth parts of the wall to paint the figurines. They represent pretty lively anthropomorphic figures, which are embedded in a context of Mediterranean rock art, generally interpreted as scenes of dance portrayals. It is commonly acknowledged by archaeologists that these paints were originally part of a wider painting set, with a numerous group of paints no longer legible, all representing dancing human beings. It should be noted that, unlike other painted shapes of the central Mediterranean, the GdP Cave ones do not have the indication of the male gender. It is, however, difficult to provide a precise indication about a possible identification of the paintings to feminine figures, although the great figure in red appears rounded, perhaps pregnant (Fig. 6).

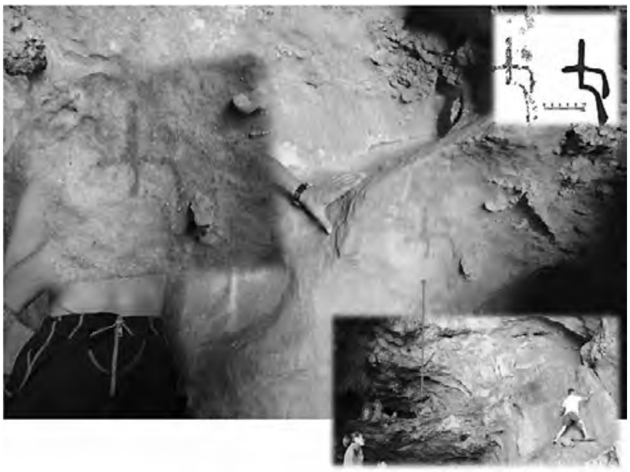

Figure 6. The GdP cave Neolithic painting site.

7. Conclusions

The GdP Cave in the Isle of Tavolara, although still poorly studied and documented, certainly represents the most scientifically and archaeologically valuable karst site of all Tavolara. Due to the difficult natural accessibility and to the strict management policies issued by both the Marine Protected Area and the military NATO district, this cave has been subjected to very incomplete studies and its important scientific and archaeological content still needs to be investigated.

Some preliminary results related to the analysis of the GdP Cave rock samples are here reported. From the first mineralogical analysis some interesting information are emerging. In particular, the consistent presence of iron phosphate hydroxide can be reasonable plausible if considering the lithologic and geomorphologic context of the site. Iron phosphate presents a variety of genesis, in the case of the GdP Cave sample most likely being the deposition of clay in organogenic lacustrine water for action of iron phosphate materials rich waters. Another possibility is that it derives from the alteration of primary phosphates included in the pegmatite composing the crystalline basement of the carbonate island. The chemical pattern resulting from the present project analysis seem not to match with the qualitative chemical analysis results performed in 1997 on some fragment of cave painting samples.

A systematic and detailed micro and macro biological, paleontological, speleological, and archaeological research in tight collaboration with the Marine Protected Area is already planned and scheduled for the short term project activities, as well as the volumetric laser scanning survey of the main cave chambers.

Acknowledgments

The authors are sincerely grateful to Dr. Augusto Navone, Director of Tavolara Marine Protected Area for issuing the entry permits and commissioning the research; the National Italian Commission UNESCO for the project patronage;

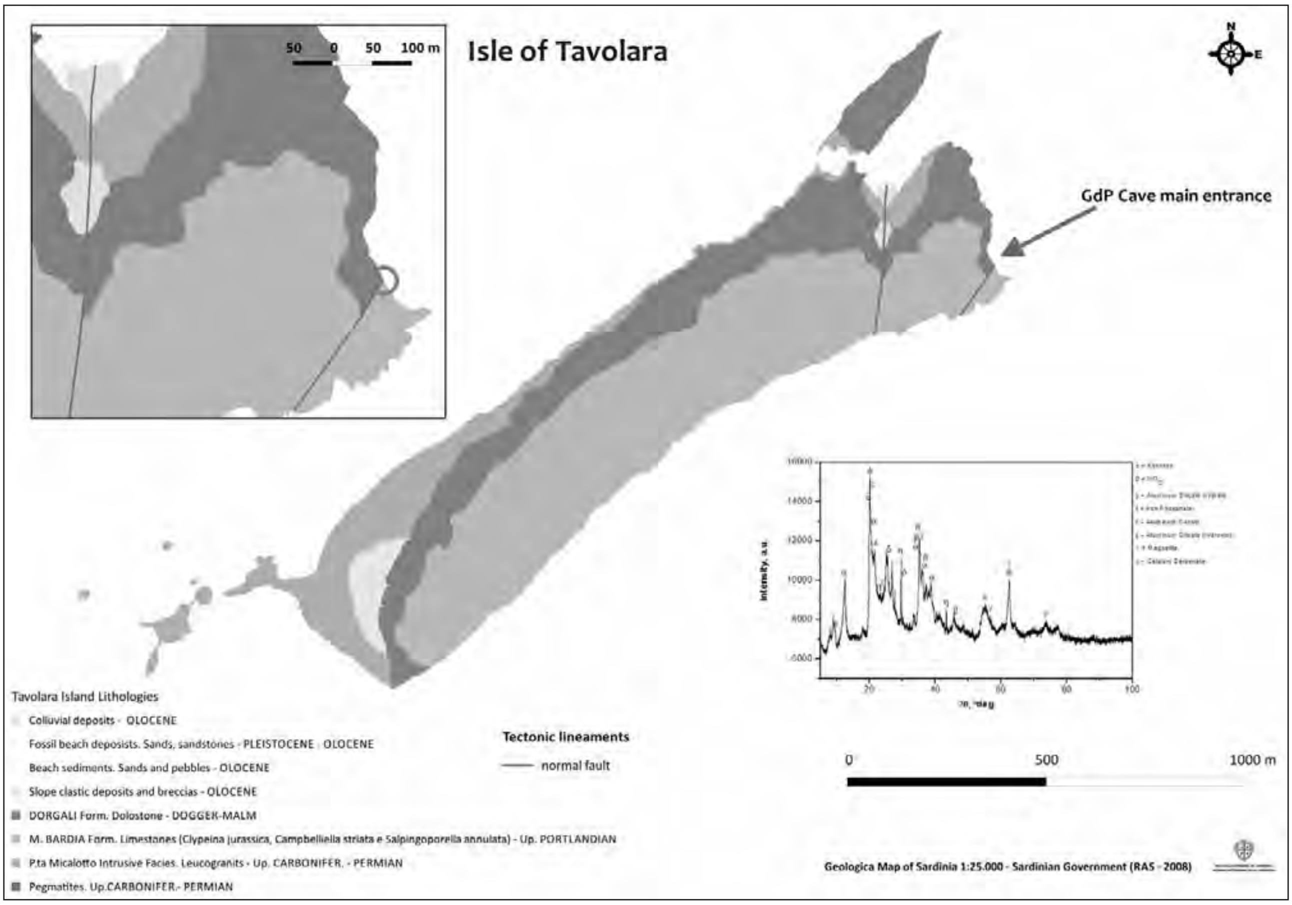

Figure 7. Geological sketch of the Isle of Tavolara and location of the GdP Cave. On the right hand site, the clay sample XRD pattern, explained in Figure 8.

Silvia Arrica, responsible for the Sardinian Speleological Library, for supplying the historical documentation; Mario Pappacoda for the photographs, and Dr. Arrigo Cigna for supporting the gamma spectrometry analysis making the ENEA laboratory facilities available for the project.

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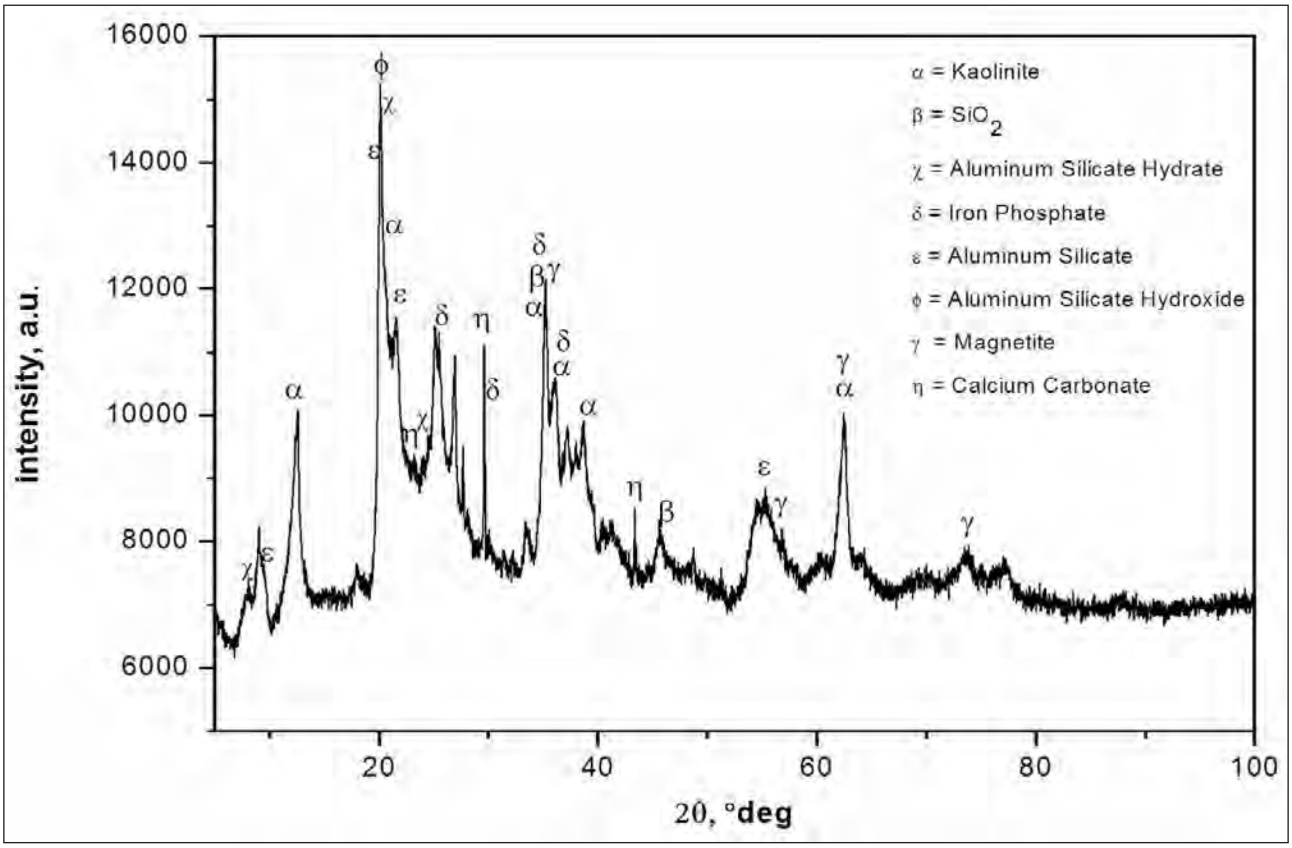

Figure 8. The XRD patterns of the clay sample. The detected phases are kaolinite, quartz, magnetite, iron phosphate and iron phosphate hydroxide, aluminium silicate and aluminium silicate hydroxide, and calcium carbonate. The EDS microanalysis for the three identified areas: white area (a), light gray area (b), dark gray area (c).

DOUBLE CAVE MAPS OF TURKEY

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In Turkey, many double cave maps are drawn in years for different causes. In this poster; although the double maps drawn because of newly found galleries or small corrections such as Yarimburgaz or Dongel maps are presented, the main weight is given to the different maps of the same caves that are drawn non-contemporarily and without being aware of each other for many years. It is an interesting fact that; of all the caves, Tinaztepe and Golcuk are re-explored and re-mapped not just twice, but for four times.

Different from that paper, 25 double map samples will be emphasized in the poster presentation. While the important mistakes in those maps will be probed, by the thought of the essential reason of the different maps of the same caves are drawn is the fact that it is not known if the cave is explored before, TAY Cave Inventory of Turkey which is published in both printed and online (www.tayproject.org), will be introduced and the benefits of a general cave inventory will be emphasized.

1. Introduction

There can be several reasonable causes for mapping a cave for a second time: either there are new galleries that are explored and the announcement of those explorations are made with a new map, or the former map of a cave is so erroneous that it became essential to make a new survey. On the other hand, there can be a less reasonable, even a tragicomic third reason for mapping a cave for a second time: exploring the same cave without being aware of the fact that it was actually explored and mapped before and, on the top of it, mapping it again!

This poster presentation brings a brief analysis why the cave maps are duplicated and brings some examples from the karst areas of Turkey.

2. Maps

2.1. Golcuk Sinkhole

One of the best examples of Turkish caving and cave mapping history. There are Italian, French, English and German maps of the same cave. Every team which passed from that “easy to reach” area re-explored Golcuk Sinkhole and draw a new map. Even the depths of the cave is different (Agnoletti et al. 1970; Chabert 1972; Schmitt 1976; Stratford et al. 1992).

2.2. Inogu Cave

Those 2 maps, which were drawn by Claude Chabert and Fiorentini Rusconi within 5 years apart seems more or less same except the west gallery which was not explored by the French. Though there are slight differences between the profiles, compared with our other double map examples, that difference is nothing (Agnoletti et al. 1970; Chabert 1979).

2.3. Balatini Cave

MAD’s (Cave Research Association) map dated 1982 and Swindon Speleological Society’s map dated 1992. In order to make both maps within the same direction, MAD’s map had been turned to same direction to Swindon’s. Both maps are more or less same within the first glance but, the second gallery towards north in Swindon’s map is much shorter in MAD’s map. Presumeably, MAD cavers were too tired to continue on that gallery (Stratford et al. 1992).

2.4. Tınaztepe Cave

Another strange example: French, English, Spanish and German maps of that difficult cave system which has a depth of -153 m and a length of 1650 m. You may feel pity for their useless efforts. On the other hand, they are so different from each other that, after all those maps we still don’t know which one is more correct (Bakalowicz 1968; Agnoletti et al. 1970; Boley 1978; Schmitt 1986).

2.5. Sofular Cave

Those are Sofular Cave maps of MAD (Cave Research Association) and MTA (General Directorate of Mineral Research and Exploration). MAD team, working together with Kaufmann and Laumanns, published this map in their Bulletin no. 7 at 1990. MTA survey, dated 1995, is 170 m longer and had a huge eastern gallery, which is completely missed by MAD. Just like the other samples, those cave maps, which become longer as the years passed, creates suspicions about the survey quality and precision (Laumanns et al. 1990; Nazik et al. 1995).

2.6. Ilgarini Cave

Within the first glance they look like each other. If they look like each other, then its really difficult to explain the 10 m depth and 273 m length difference between the BUMAK (Bogazici Univ. Caving Club) and LUSS (Leicester University Speleological Sociey) maps which were drawn 8 years apart. If you look carefully you may realize that they are not very similar. Take a closer look to LUSS’s profile: There is another descent and 3 question marks after that descend, which do not exists in BUMAK map. On the other hand, what can be said to this sketch quality map of LUSS with a “BCRA 5B” standard (Ulkumen 1983; Kay 1990)?

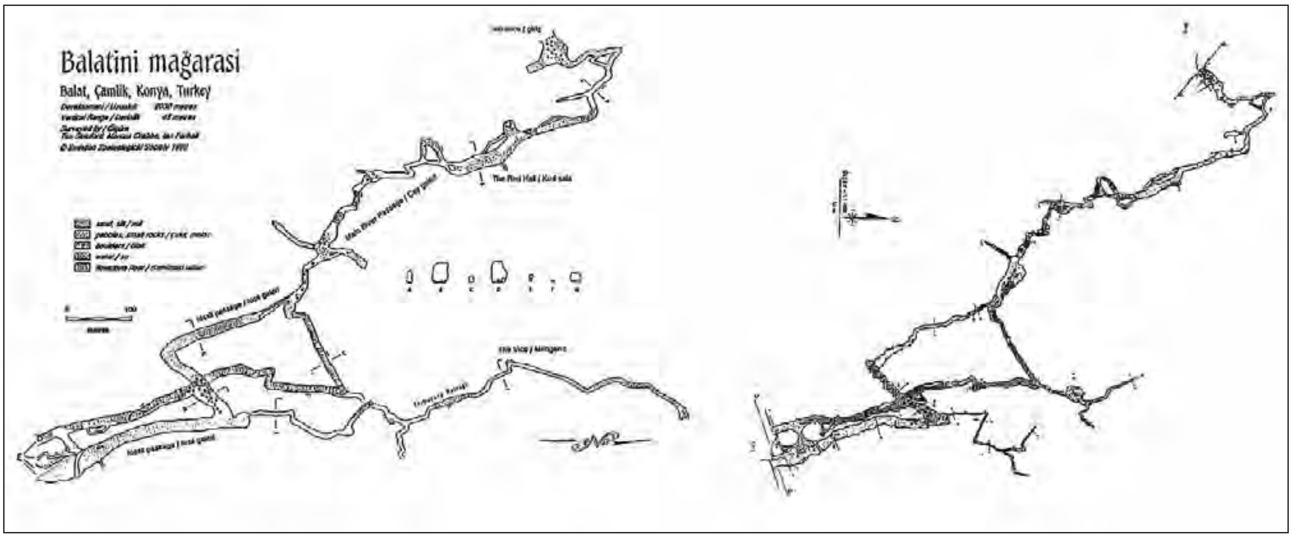

Figure 1. Balatini Cave; left Swindon Speleological Society, right MAD maps.

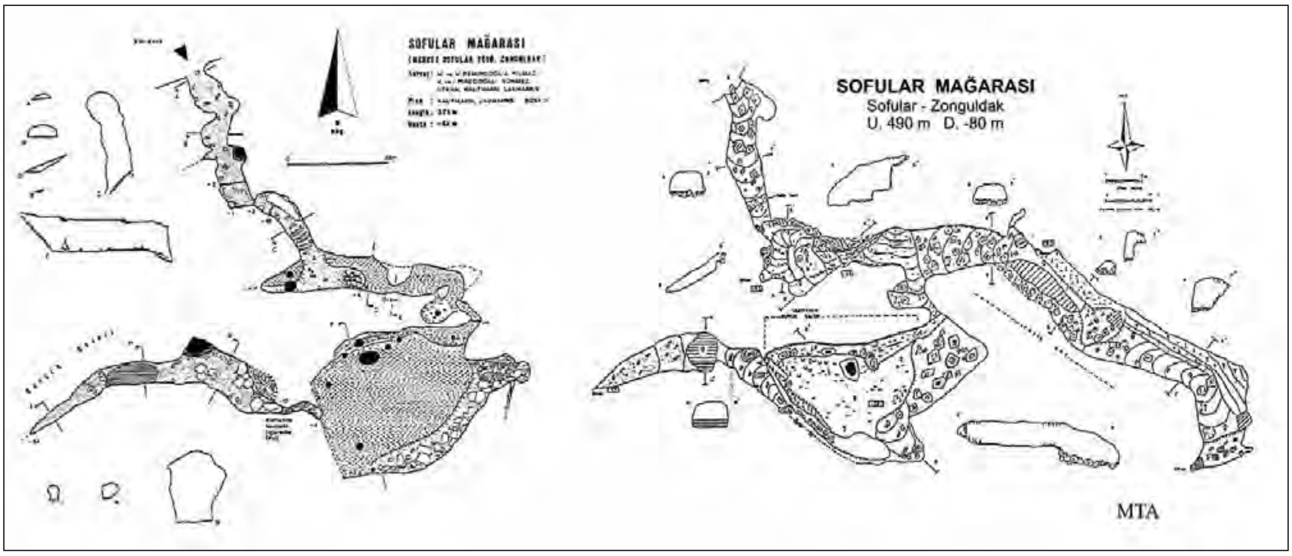

Figure 2. Sofular Cave; left MAD, right MTA maps.

2.7. Dongel Cave

Another example of careless survey. Though other parts of that cave, which is in Kahramanmaras – Turkey, are more or less same in both maps, its obvious that during the MTA (General Directorate of Mineral Research and Exploration) survey of 2008, they completely missed a small opening which leads to a gallery longer and larger than the main gallery as shown on the right map of OBRUK Cave Research Group, which had explored and mapped the cave only 2 years after MTA (Tork et al. 2008; Yamac 2011).

2.8. Kadipinari or Kadiini Cave

If there are no other caves around Alanya, southern Turkey, around the villages of Degirmendere and Catak, with a name begining with "Kadi", those two maps must belong to the same cave. 20 years after being explored, surveyed and named as "Kadipinari Cave" by MTA (General Directorate of Mineral Research and Exploration) during 1987, AKUMAK (Akdeniz University Caving Club) visited and measured the cave again. In their map, the cave is named as "Kadiini Cave". The cavers of AKUMAK found a small entrance on the west wall of the main chamber and pushed the length of that cave from 110 m to 1,500 m, with beautiful formations and archaeological findings in those new galleries. But, in this presentation, you only see the maps of main chamber. Even in that 110 m chamber of the cave, the differences are so huge that, we still are not sure if they're the same caves (Guldali et al. 1987; Akdeniz University Caving Club 2008).

2.9. Uluyayla Cave

That travers cave, which was surveyed in 1989 by BUMAK (Bogazici Univ. Caving Club) was re-surveyed and drawn again at 2002 by MTA (General Directorate of Mineral Research and Exploration). Two side branches which were very clear in MTA map; one near to exit and the other one in the middle of the cave, at the south wall were completely missed in BUMAK map. If the faults were limited with those two branches we could call them "missed", but the angle of diversion of the cave after 100 m from the entrance and the width was so different that, within such a short and comperatively "easy to survey" cave, those differences are unbelievable (Albukrek et al. 1993; Nazik et al. 2003)

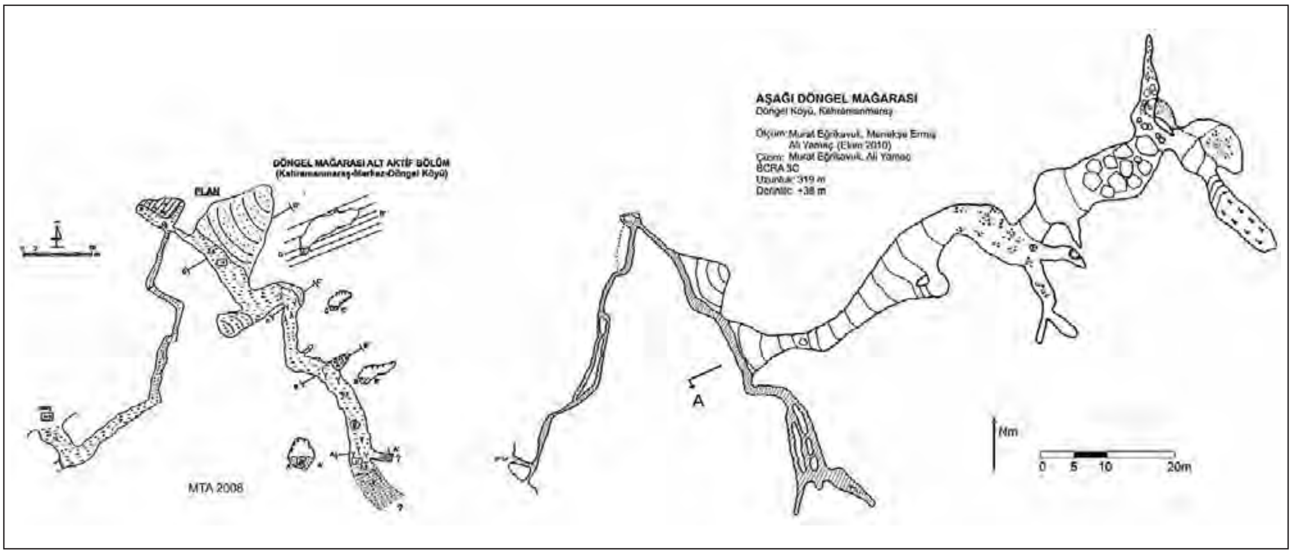

Figure 3. Dongel Cave; left MAD, right OBRUK maps.

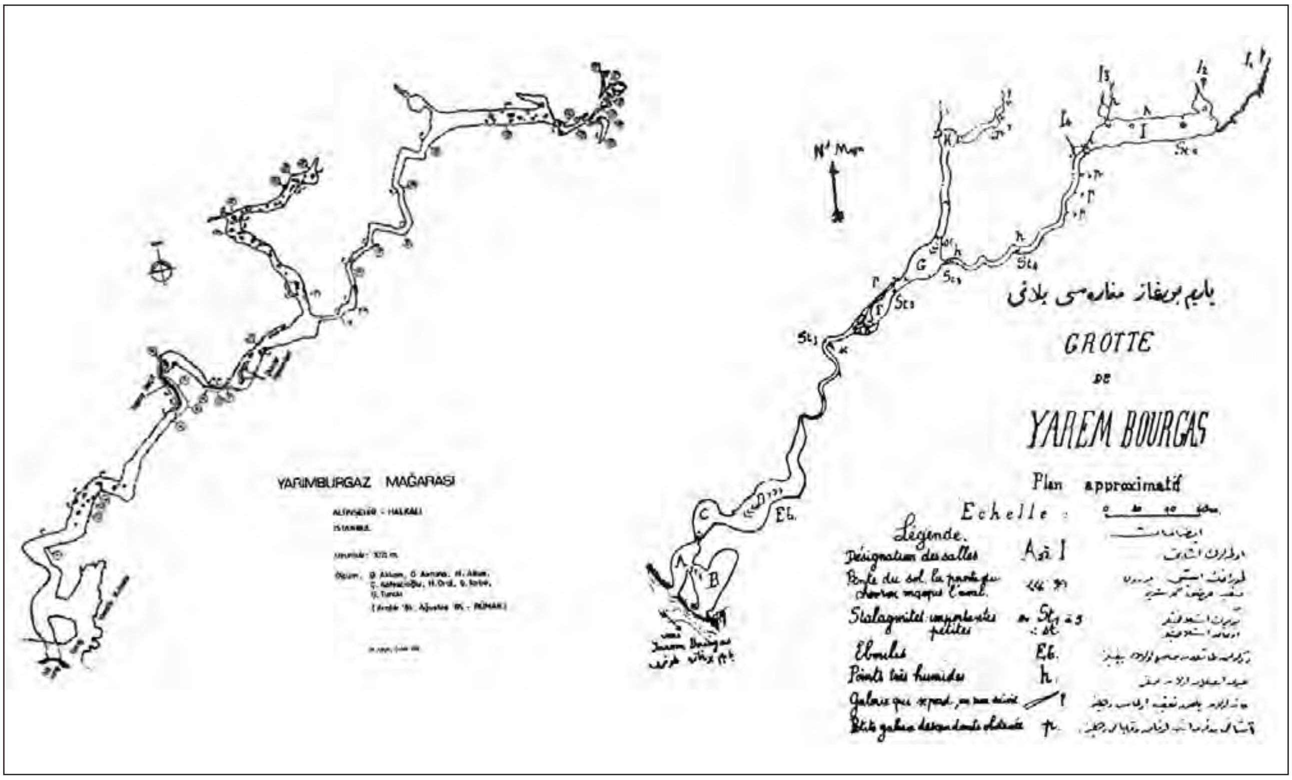

Figure 4. Yarimburgaz Cave; left BUMAK, right Hovasse maps.

2.10. Yarımburgaz Cave

And finally, not a bad, but a very beautiful example for “Double Cave Maps of Turkey” poster: On the left side BUMAK (Bogazici University Caving Club) and, on the right side Prof. Raymond Hovasse’s maps of Yarimburgaz Cave, which is in Istanbul-Turkey. Hovasse’s map was drawn at 1927, making it one of the earliest cave maps of Turkey. There is roughly 60 years difference between those two cave maps. BUMAK measured the cave as 1021 m. If you consider that Hovasse surveyed that long and difficult cave only with 2 other people and with very simple equipments of that time, you may only congratulate that geography professor’s effort and unbelievable precision (Hovasse 1927; Altun 1993)

3. Conclusion

As it is obvious within the few examples above, double maps are drawn because of two different reasons:

“Re-exploring” a cave due to lack of bibliographical and inventory research previous to field work or due to major faults during the previous survey.

So, we strongly believe that; an inventory check before the explorations and a better, precise survey during the explorations will solve that simple but, energy and time consuming problem.

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Session:

Biospeleology, Geomicrobiology and Ecology

CHASE IN HISTORY AFTER THE ENDEMIC *NIPHARGUS* (CRUSTACEA: AMPHIPODA) SPECIES OF HUNGARY

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From the 1920's, speleozoology was a prosperous discipline in Hungary due to the work of Endre Dudich and to other associate researchers. In 1958 Dudich established a biospeleological laboratory in Baradla Cave, which he continued to manage until his death in 1971. In spite of its promising beginnings, the last few decades has seen little investigation and research on the invertebrate fauna of the Hungarian caves.

A blind amphipod genus *Niphargus*, one of the most popular aquatic troglobiont, can serve a typical example: its current status in Hungary has been largerly neglected. While globally, number of the *Niphargus* species and subspecies has reached 300, taxonomic status of the few species described from Hungary have remained uncertain. When the descriptions were published, many of the Hungarian caves known today were undiscovered, which had limited the chance of finding new populations and even new species. Most of the descriptions operated with insufficient morphological information and few drawings, and often the type locality cannot be exactly identified. In most cases the holotypes are no more available in the type collections either for they were sent abroad and never returned or perished in the fire which ravaged the Hungarian Natural History Museum during the revolution in 1956.

The checklist of Hungarian Malacostraca published by Ilona Muskó in 2007, lists 15 *Niphargus* species. The checklist gathers all the mentions in the available literature, yet without rating their validity. We started with a re-examination of actual distributional records and revision of taxonomic status of the respective 15 species with particular focus to the species endemic to Hungary. Some of the 15 mentioned species were excluded because of translocation of country boundaries, while others were excluded because of misidentifications or using synonym names.

All in all, 9 species have remained in the list of valid taxa ever confirmed to occur in Hungary. Out of them, five species of *Niphargus* described from Hungary were found endemic to that country. *Niphargus forroi* Karaman, 1986 was described from a cave of the Bükk Mts., *Niphargus hungaricus* Méhely, 1937 was first found in a spring of the Kőszegi Mts. *Niphargus molnari* Méhely, 1927 and *Niphargus gebhardti* Schellenberg, 1934 are endemisms of the caves of Mecsek Mts. *Niphargus thermalis* Dudich, 1941 was described from a thermal lake of Budapest and supposedly has subterranean populations as well in the cave connected to the thermal lake.

Further step of the research will be focused to resampling the population of the above mentioned endemic species including all their type localities and providing detailed taxonomic revisions and redescriptions needed for a robust comparative information on the respective taxa.

MINERAL PRECIPITATION *IN VITRO* USING ISOLATED BACTERIAL STRAINS FROM SYNDAI CAVES, MEGHALAYA

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Geomicrobiological studies from the Syndai caves were carried out to evaluate the microbial role in mineral precipitation *in vitro* using strains isolated from the stalactites. The Syndai caves are 128 km from Shillong, situated in the western most area of Jaintia Hills (N 25°15' to 25°15' and E 92°00' to 92°15'), 1,500 m above sea level in Meghalaya, northeast India. The region has cascading waterfalls, numerous caves, high plateaus, rippling rivers, and exotic biodiversity.

To isolate microorganisms that may be involved with or mediating carbonate mineral precipitation in caves, stalactites were sampled over a distance of ~15 m for the present study. The stalactites were small (2–5 cm in length and 1–2 cm in diameter), moist, whitish and constantly covered with dripping water. The drip water was pH 7.2–7.5 at 15 ºC, and had varying element concentrations (80 ppm Ca, 17.7 ppm Mg, 1.28 ppm Si, 19 ppb Sr, 12 ppb Ba, 1ppb Cu, 2 ppb Cr). The stalactites had a total organic carbon content of 1.77 wt %.

Examination of freshly broken stalactites using scanning electron microscopy (SEM) revealed the presence of morphologically diverse putative cells, including coccoidal, filamentous, and rod-shaped structures (~0.5–2 μm) (Figure 1A). In addition, hollow tubular filaments, possibly microbial in origin, were observed (Figure 1B). Microcrystalline fibers (1–2 μm in diameter and 10–50 μm in length) were observed, which are reported to be precipitated or calcified microbes in association with different stages of biomineralisation (Verrecchia and Verrecchia 1994; Melim et al. 2001).

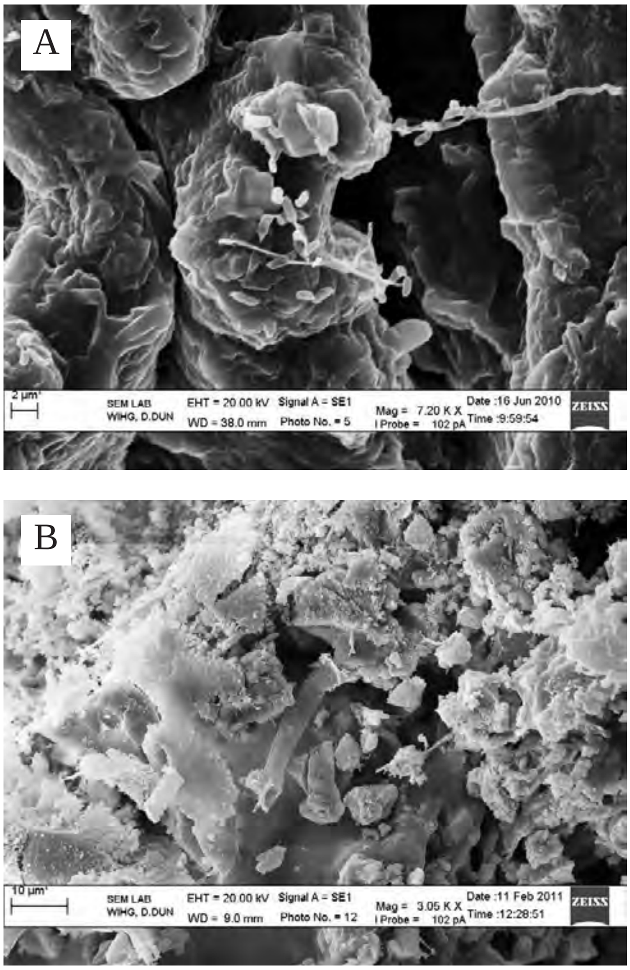

Figure 1. SEM micrographs showing (A) structures showing filaments, cocci, bacilli, stubby rods, filamentous microbes (B) hollow tubular structures thought to be microbial in origin.

Enrichment culturing was done with two different media (Boquet et al. 1973). The microbial population densities were fairly high, ca. 4.8×10^4 g l^{-1} using nutrient agar and 5.6×10^4 g l^{-1} on B4 medium. The maximum amount of freshly precipitated crystals was obtained from B4 medium when compared to the nutrient agar. The pH of the liquid B4 broth increased that bacterial strains increased the pH (from pH 7.5 to 8.7), making the media alkaline along with the increase in bacterial growth. In order to identify the genus of the strains, some basic morphological (Gram stain), physiological (growth at different pH 4–9, growth at different concentrations of NaCl 2–10 %, growth at different temperatures 8–52 °C) and biochemical tests (Methyl red, Voges-Proskauer, oxidation-fermentation, starch hydrolysis) were done on the isolates (MTCC Microbial Type Culture Collection and Gene Bank, Institute of Microbial Technology (IMTECH), Chandigarh, India). The biominerals were identified as calcite using SEM EDX and XRD (scanned between 4° and 64° 2θ at 1° 2θ min^{-1}) using the JCPDS–ICDD, XRPD database (2000).

Twelve different strains that had the ability to precipitate calcite belonged to the *Bacilli* spp. The strains were able to precipitate calcite under controlled experimental conditions and the optimal amount of precipitation was between 22–25 °C. At the end of 30 days, the crystals precipitated by different isolates weighed ~ 100 mg. Experiments to test the effect of varying concentrations of calcium acetate in the B4 media showed that 1.5–2 % calcium acetate concentrations gave the best results in terms of crystal yield.

Our results indicate that bacteria promote alkalinization of the growth solution during the assimilation of organic materials, which can cause local supersaturation of carbonate minerals, such as calcite, on the bacterial cell surfaces. It has been reported that microbial activities are capable of modifying media, which subsequently leads to the precipitation of minerals (Cañaveras et al. 2001). Clearly, the results from the current study, as well as previous research, are classic examples of passive carbonate precipitation pathways commonly reported from karst caves (Castanier et al. 2000). Similar observations have been reported by other investigators (Cacchio et al. 2003; Lee 2003; Rivedeneyra et al. 2004; Zammareno et al. 2009). In summary, these studies strengthen the perception that microbial metabolic activity is of significance in initiating mineral formation in natural environments.

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TERRESTRIAL MESOFAUNA BIODIVERSITY IN UNIQUE KARST ENVIRONMENTS IN SOUTHERN AFRICA

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Subterranean environments play host to unique and vastly undiscovered habitats, creating niches for distinctively adapted biota. These environments, in particular cave systems, allow the minds of evolutionists, ecologists and taxonomists to dwell nearly endlessly; allowing interesting finds and knowledge gained about the structured life of bizarre and singular species. In this study, a zoological approach was followed in determining the biodiversity of terrestrial mesofauna from six caves of which four are in South Africa and two in Botswana. Each of these six caves is distinctive from one another, but one cave (Diviner's cave in northern Botswana) is exceptional. Isolated and locked away 50 meters below surface, with no natural opening and a hot, humid and carbon dioxide pressurized atmosphere most likely never before studied habitat, was found. By applying several sampling and extraction methods, various trophic groups of nematoda, arachnida, myriapoda and hexapoda were collected from the six caves. Peculiar specimens of organisms found were sent to various specialists all over the world for identification. To date at least five expected and two confirmed new species of organisms were recorded as a result of this study.

1. Introduction

A great diversity of fauna such as birds, insects, mites, spiders, crayfish, harvestmen, centipedes, millipedes, reptiles, nematodes and even mammals naturally occur in caves (Romero 2009). Nematodes, generally known as round worms, play an important role as part of the food chain in caves. Some species feed on bacteria found in bat guano and in turn serve as a food source for mites and other arthropods. Although free-living nematodes are commonly found in karst environments (Romero 2009) such as the Bakwena Cave (Irene, South Africa), Durand et al. (2012) also listed a range of plant-parasitic nematodes that were present in the latter cave. Parasitic nematodes are, however, believed to enter cave systems by accident as a result of host plants and/or water that get flushed into cave openings (Romero 2009; Durand et al. 2012). Mites and spiders (Class Arachnida) constitute another diverse class of organisms that occurs in cave systems worldwide. Various species have been recorded from Southern African caves, e.g., mites such as *Chiropturopoda coprohila*, *Laelaps* sp., *Sancassania* sp. as well as 41 spider species of which only 10 were classified as true cave dwellers (Dippenaar-Schoeman and Myburgh 2009). Arachnid cave representatives commonly present troglobitic characteristics and their feeding habits include predation, parasitism and consumption of detritus (Romero 2009). Other organisms identified from the local Bakwena Caves in South Africa are insects such as *Monopis cf. transeans* (guano moth: Lepidoptera) and Crustacea (Amphipoda, Copepoda and Ostracoda) as well as bat flies (family Nycteriibidae). In terms of microbial organisms, eight fungal genera and some bacteria have also been identified from this cave (Durand et al. 2012). Another group of organisms found in cave environments, are the worm-like arthropods. They are classified as Myriapoda and are generally associated with decaying material (Romero 2009). Hexapoda represents the final group of cave organisms and is the greatest representative complement. Hexapod cave representatives include diplurans, insects and springtails (collembola) of which some species are abundantly found in cave environments (Romero 2009).

Since limited information on cave-dwelling organisms is available in Southern Africa, this study was conducted. The study follows a zoological approach by focusing on the biodiversity of five groups of microorganisms that are associated with caves, namely chelicerata, crustacea, hexapoda and myriapoda as well as nematodes, in unique karst environments. Six caves, including three from the old Transvaal region in South Africa and three from the Gcwihaba district in Botswana were selected for investigations. One of the caves in Botswana, named Diviner's cave (Figure 1), was only recently drilled open.

Figure 1. Surface opening of borehole penetrating Diviner's Cave. (Photo: Roger Ellis 2012).

This enabled significant atmospheric interchange possibly for the first time in thousands of years. The result of being insulated for thousands of years created a carbon dioxide enriched, hot and humid environment. Also, gene flow between epigean and hypogean species was restricted, if not completely disrupted.

It was hypothesised that a great diversity of species, some being true cave dwellers, would be identified. In addition, it was predicted that new and peculiar species would be found especially in the unique cave environment of Diviner's Cave. The value of caves, especially in Southern Africa, has to the opinion of the author, not been fully encompassed as part of conservation efforts and public awareness campaigns. By gaining information about these unique environments and the bios hosted within, it is perceived that contributions towards the better understanding and greater appreciation for subterranean environments will be made.

2. Geography, geology and site description

All of the caves relevant to this study occur in dolomitic rock and extends both horizontally and vertically. It should be noted that the depth of development, dimensions and extent of each cave are unique to that system.

All of the South African caves relevant to this study are natural caves and permit interaction with the surface environment and epigean biota. Most of these caves have similar atmospheric conditions. The average temperature of these cave systems were measured at 18 °C with a possible 2–3 °C fluctuation by using a simple thermometer during sampling periods. Although normal oxygen concentrations are found in most of the cave systems, it should be noted that elevated levels of carbon dioxide occur in the deeper sections of Gatkop 2 Cave. This was confirmed by monitoring carbon dioxide concentrations with a gas meter as well as observed heavier breathing by the cavers. The terrestrial environments of the South African caves are mostly semi-arid like with the possibility of some water drips present. Guano heaps are abundant and usually found in association with established bat colonies. An estimated 2,000 m² lake can be found in Knockingshop Cave and some rimstone pools in Gatkop 2 Cave.

Bone Cave and Blue Cave, located in the Gcwihaba district of north-western Botswana, are both natural caves that also permit interaction with surface environments and biota. Although guano is frequently found in both systems, the deeper section of Bone Cave contains none and mostly consists of sandy slopes; a drastic difference compared to the rest of the cave's typical environment.

Diviner's Cave is unique and completely separable from all the other caves. This is the only cave that does not have a natural opening, but rather a 600 mm man-made borehole that allows limited interaction with the surface atmosphere. A relative humidity and temperature meter was used to determine the atmospheric conditions. With an average temperature of 28 °C and relative humidity of 96 %, the conditions in Diviner's Cave are much more extreme than that of the other cave systems. Before penetration, the cavity was pressurized with a carbon dioxide enriched atmosphere and remnants of these elevated levels of carbon dioxide can be found in the lower lying areas of the cave system.

3. Methods

A general biodiversity sampling approach was implemented; aimed at sampling most cave biota (bats, fungi and bacteria were not included) present in each cave system. Sampling commenced at the entrance/twilight zone of each system and continued until the respective turnaround point for each cave was reached.

3.1. Sampling of Nematoda

Nematodes were sampled by acquiring soil and guano samples by using a small hand shovel and placing 500 g of substrate in a sealable plastic bag. A sample was made up of a representative portion of the first 30 cm of topsoil/guano. In order to avoid contamination between samples from different sites, a clean plastic cover/bag was placed over the shovel with each sampling instance. After sampling was completed, each sample was labelled, placed in an insulation box and transported to the Nematology Laboratory (NWU, Potchefstroom campus) for extraction and analysis. Nematodes were extracted within three days of sampling by using the decanting and sieving method, followed by the sugar-flotation method (Hooper et al. 2005), as well as by means of the modified Baerman-tray method (Hooper and Evans 1993).

Nematode data for the genera, species and or families identified from each of the caves were used for the calculation of prominence values (PV). The following equation was used to calculate the PV (Keikantsemang et al. 2012):

$$PV = population\ density\ x\ \sqrt{Frequency\ of\ occurence}\ /10$$

3.2. Sampling of Arthropoda

All arthropods were sampled using a simple "catch by hand" technique, as well as by stationed baited/non-baited pitfall traps and baiting areas as described by Hunt and Millar (2001). When using the "catch by hand technique" invertebrates with a size of 1 mm and larger were mostly caught. A sufficient light source, synthetic fine-haired brushes, research tweezers and vials/jars filled with a 70–80 % ethanol solution were used to sample and preserve organisms directly from all surfaces (Hunt and Millar 2001). By using dissection microscopes, the contents of each jar and vial were separately analysed at the NWU (Potchefstroom campus).

Peculiar invertebrate specimens were sent to various taxonomic specialists all over the world to assist with identifications.

4. Results and discussion

4.1. Nematoda

Nematodes were found in four of the six caves, representing various groups from both plant-parasitic and free-living (bacteriovores, predators and fungivores) trophic levels (Table 1).

Table 1. Trophic classification of nematode groups identified from samples obtained from all six caves.

Nematode representatives	Trophic group	Nematode representatives	Trophic group
Aphelenchoides	Fungivore	*Neoactinolaimus*	Predator
Cephalobus	Bacteriovore	*Panagrolaimus*	Bacteriovore
Criconema	Plant-parasitic	*Paracrobeles*	Bacteriovore
Dorylaimida	Predator	*Prismatolaimus*	Bacteriovore
Helicotylenchus	Plant-parasitic	*Rhabditis*	Bacteriovore
Meloidogyne	Plant-parasitic	*Xiphinema*	Plant-parasitic
Monhysteridae	Predator	*Zeldia*	Bacteriovore

The diversity analysis of the gathered data (Figure 2) indicated a great difference in diversity and prominence of nematode groups when the different cave systems are plotted together. When considering Diviner's Cave, a relative high diversity of nematode trophic groups was present, but only a few groups were prominent. Similar results were found by Jansen van Rensburg (2010) since a total of 27 nematode genera were recorded from the six sampling sites in Bakwena Cave. Some of the latter species found are new to science and two species from the genera *Panagrolaimus* and *Plectus*, respectively, were described.

The data from Diviner's Cave further indicated that *Prismatolaimus* spp. (bacteriovores) and *Panagrolaimus* spp. (bacteriovores) proved to be equally prominent. Also, compared to the natural caves, Diviner's Cave had an exceptionally high diversity of nematode groups with more than one prominent group. Although the *Panagrolaimus* (bacteriovores) population found in Gatkop 2 Cave is the most prominent of all samplings, the cave had a very low nematode diversity and was dominated by this single genus. Ultimately bacteriovores dominated the community structures of all the cave systems included in this study.

Taking into consideration the results discussed above, it is clear that the nematode community structure of Diviner's Cave is much different from that of a typical natural cave and irrelevant to its geographic location. It seems that in natural caves various nematode genera may be found, but most likely only one will dominate the system. This contradicts the findings from Diviner's Cave since it was not dominated by a single nematode group, but rather by a few. The data suggests that a complex and dynamic community structure exists in Diviner's Cave. This creates the opportunity for investigations through which a better understanding of the community interactions and interactions with other biota can be gained as well as determining by what means these specific nematodes utilize energy sources.

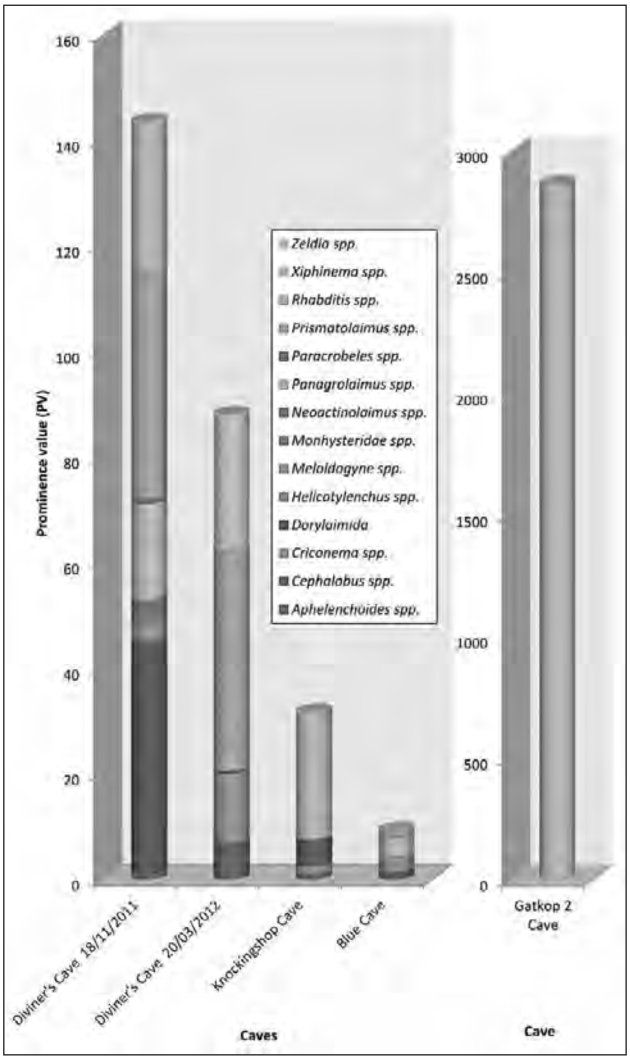

Figure 2. Graph illustrating prominence values of nematodes in the caves sampled during this study.

It is clear that further research aimed at studying nematode communities in cave systems is required. This especially since the literature on cave nematodes are scarce (Durand et al. 2012) and an international publication by Romero (2009) states that only 20 nematode species are worldwide known to occur in caves systems. Jansen van Rensburg (2010) suggested that indeed a vast number of cave nematode species have yet to be discovered. In recent times Borgonie et al. (2011) found a new bacteriovore nematode species, *Halicephalobus mephisto*, 3.6 km underground in mine water in South Africa. This discovery was groundbreaking since it was the first multicellular organisms to be obtained from such depths and serves as proof that not only caves, but also other subterranean environments provide scientists with the opportunity to make great and new discoveries.

4.2. Arthropoda

When the collective findings are considered, representatives of 18 families were sampled and represented by four Arthropod subphylums namely Chelicerata, Crustacea, Hexapoda and Myriapoda. Hexapods, belonging to 11 different families, occurred in three caves. In Bone Cave representatives of the families Blaberidae, Carabidae, Formicidae, Gryllidae and Reduviidae were found; in

Diviner's Cave from Japygidae and Termitidae and in Gatkop 2 Cave from Blattidae, Nicolettidae and Staphylinidae. According to Romero (2009) Hexapoda is one of the most well represented taxonomical groups in caves and consists of numerous orders represented in the hypogean environment. Chelicerata were represented by six families in four caves. From Bone Cave an *Argas* sp. (Argasidae) was retrieved; in Diviner's Cave a representative from Ideoronicidae; in Gatkop 2 Cave from Uropodoidea and in Blue Cave three different Araneae species namely *Loxosceles* sp. (Sicariidae); *Selenops kruegeri* (Selenopidae) and *Smeringopus sambesicus* (Pholcidae) were found. Both the Crustacea and Myriapoda subphylums were represented by a single family and only found in Diviner's Cave. These two families are Cryptopidae and Platyarthridae respectively. According to Gunn (2004) representatives from several of the groups relevant to this study have been found in Southern African caves, but mostly only once or on a few occasions. This is most likely due to the lack of research in African subterranean environments. There is thus a great need to further explore Southern Africa's hypogean environments in search for new and peculiar species.

Various peculiar specimens were sent to numerous taxonomists all over the world. Currently three probable and two confirmed new species are considered. All of these specimens were collected from a single cave namely Diviner's Cave. The *Cryptops* sp., Japygidae representatives and *Microtermes* sp. (Chilopoda) are most likely new to science and with further efforts to identify the species, this might be confirmed. Gunn (2004) states that only one troglobitic Japygidae representative has been recorded in Zaire and no Centipedes (Myriapoda) from Africa. It is thus most likely that these specimens sampled are new to science and the first to be found in southern Africa. The *Trichorhina* sp. (Figure 3), as well as the Ideoronicidae representative (Figure 4) are confirmed new species and the manuscript for the publication describing the latter is currently being written. During sampling and identification it became clear that various caves host a great diversity of invertebrates. However, if the collection of organisms found in one cave is compared to that of another, it seems that the community is endemic to a specific system. Also, when the biota from Bone Cave and Blue Cave are considered, initial investigations indicate that similar level of adaptation and taxonomical groups are present if these systems are compared. However, the biota found in Diviner's Cave illustrate troglobitic characteristics such as depigmentation and the loss of eyesight; and are seemingly completely unique to the general karst landscape. Since all three of these caves are located in the same area, these results suggest that the geographical location does not play a significant role in the occurrence of single characteristics in the cave biota of Diviner's Cave, but rather the unique environment present in the system. At present it is suggested that the main drive resulting in the higher level of adaptation of species found in Diviner's Cave, is the very limited opportunity for gene flow to occur.

Figure 3. Lateral view of Trichorhina *sp. found in Diviner's Cave. (Photos: Gerhard du Preez 2012).*

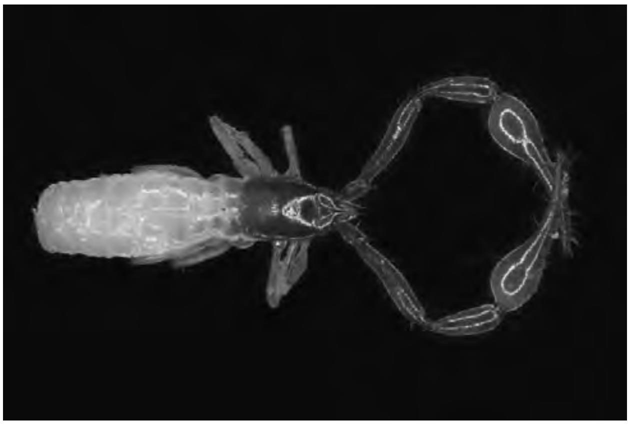

Figure 4. Ideoronicidae representative found in Diviner's Cave. (Photo: Gerhard du Preez 2012).

5. Conclusion

The findings from this study clearly indicated that a wide diversity of unique and peculiar species occur in subterranean environments in southern Africa. Biospeleology is one of the most understudied fields of science and presents many opportunities for new and singular discoveries. It is concluded by stating that a great diversity of species were sampled of which some present peculiar characteristic traits and may be/are new species to science.

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MICROBIAL PROCESSES IN SULFIDIC HYPOGENE KARST

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Hypogene karst systems develop at or below the water table due to the action of rising fluids. In air-saturated conduits of hypogene systems, processes like condensation and replacement-solution occur. Microorganisms are ubiquitous in these actively forming systems, from filamentous biofilms on aquifer rock surfaces, on secondary mineral deposits (e.g., gypsum), and as microbial mats in cave streams, pools, and sediments. Microbes are also found in association with organic-rich snottites or microbial draperies on cave-wall surfaces. Planktonic microbes occur in sulfidic groundwater, in meteoric water mixing at the air-water interface, and microbes are also present in cave air. Since the 1980s, the microbial diversity of hypogene karst has been the center of research, especially from systems with reduced sulfur gases dissolved in groundwater, like hydrogen sulfide (H_2S). There has also been some emphasis on understanding how microbes influence hypogene reactions, particularly by studying the geochemistry of hypogene systems and experimentally manipulating microorganisms to differentiate abiotic from biotic reactions. Three microbial habitat types are examined in this review: a sulfidic karst aquifer setting, a water-table system where the hypogene meets the epigene, and cave-wall rock surfaces from a sulfidic cave. From these studies, microbes affect hypogene karst development by metabolizing solutes in the water (or air) and by scavenging nutrients from rocks by producing acidic byproducts, including sulfidic acid, carbonic acid, and organic acids. Moreover, the extensive biofilms on rock and mineral surfaces change the physical surface chemistry of the solids by being hydrophobic. The hydrophobic barrier causes surface disequilibria between the surrounding fluids at the air-water or water-rock interface, which can result in mineral dissolution or precipitation. In summary, microbially induced reactions overcome kinetic barriers that should be considered when explaining hypogene karst development and modification processes over time.

1. Introduction

For the most part, recognizing whether a cave formed from hypogene processes is still a matter of debate. Active hypogene caves are rare compared to their epigene counterparts, but hypogene processes are probably important to nascent karst development and conduit inception. Because tectonic activities and climate forcing can affect watershed hydrology, epigene processes (e.g., sedimentation due to surface-subsurface drainage, speleothem formation) can overprint evidence pointing to past hypogene development. From a geobiological perspective, changes from hypogene to epigene conditions, or vice versa, may impact the source of microbes to a karst system, as well as affect the distribution patterns of microbiota that occupy the subsurface. Populations could become isolated due to the geologic and geomorphic processes that influence the cave and karst habitat.

However, understanding the role of microbes in hypogene processes has been limited to a few investigations from actively forming sulfidic caves and karst aquifers. Early research describing the microbiology of sulfidic caves and stratified systems (e.g., cenotes, sinkholes, and anchialine caves) was based on microscopy or culturing-based approaches. Genetic methods and molecular approaches have significantly expanded the known microbial diversity from cave and karst systems, not just hypogene settings. Unfortunately, because some systems are unique habitats, many groups are only known from gene sequences and we have no idea of their metabolisms, or even how broadly or narrowly distributed they may be in karst settings.

This extended abstract reviews three microbial habitats – a karst aquifer, stream microbial mats, and cave-wall biofilms – from two systems, and summarizes the known microbial diversity. Over a decade of research describing the role of microbes in hypogene karst processes is also described.

2. Microbial habitats and diversity in hypogene karst

Microbes in active hypogene systems have been described from filamentous biofilms on aquifer rock surfaces, microbial mats in cave streams and pools, stream and spring sediments, secondary mineral deposits, such as gypsum, and as organic-rich snottites or microbial draperies on cave-wall surfaces.

2.1. Edwards Aquifer – an example of a hypogene karst aquifer setting

The Edwards Aquifer in Central Texas (USA) is one of the most important karstic aquifers in the world that supplies fresh water to nearly two million people. But, the aquifer has geochemically distinct shallow and deep zones, with the shallower freshwater having total dissolved solids (TDS) from 250 to 300 mg/L. The eastern edge of the aquifer is marked by a steep freshwater to saline water interface, with saline water having TDS ≥1,000 mg/L and high concentrations of H_2S that is attributed to groundwater mixing from down-dip oil-field brines. The juxtaposition of these geochemically distinct waters is linked to a diverse aquifer ecosystem, with >50 aquifer adapted, endemic, threatened, or endangered species. Of the endemic species associated with the geochemical interface, endangered catfishes are found (*Trogloglanis pattersoni* and *Satan eurystomus*) at 480–580 m depths near the saline water zone.

White filamentous biomass has been observed from wells completed in the saline water, and the microbial communities from the saline water are distinct from those in the freshwater, although both communities are dominated by Proteobacteria (Engel and Randall, 2011; Gray and Engel, 2013). Saline water white filaments are dominated by several groups of sulfur-oxidizers, including the *Epsilon*-, *Gamma*-, *Beta*-, and *Alphaproteobacteria*, and sulfate-reducers belonging to the *Deltaproteobacteria* and Firmicutes. In several wells, *Alphaproteobacteria* closely related to known sulfur-oxidizing bacterial groups dominate the saline water. Additionally, the relative abundance of Chloroflexi is higher in the saline waters. Non-sulfate-reducing Firmicutes, *Pseudomonas* spp., and Actinobacteria – groups common to soils – dominate the freshwater, along with oligotrophic *Caulobacterales* (*Alphaproteobacteria*) (Gray and Engel, 2013).

2.2. Lower Kane Cave – an example of a water-table system with active subaerial processes

Lower Kane Cave (LKC) is located in the Bighorn Basin near Lovell, Wyoming, adjacent to oil fields and localized sulfidic thermal and non-thermal springs. The age of LKC can be loosely constrained from river terraces attributed to one of two glaciations, either at 40 to 130 ka or at 10 ka. Microbial mats are associated with four springs that discharge anaerobic circumneutral spring water ($Ca\text{-}HCO_3\text{-}SO_4$ type) with >35 µmol/L total dissolved sulfide into the cave. The source of the spring water has been traced to meteoric recharge that has mixed with thermal water and nearby oilfield brine that has migrated up fractures. LKC is actively forming from subaqueous and subaerial processes linked to sulfuric acid speleogenesis.

Thick carpets of filamentous microbial mats occur along the outflow streams discharging from each spring (Figure 1). The sulfur-oxidizing bacteria at LKC are dominated by *Epsilonproteobacteria* at the mat surfaces, with *Thiothrix* spp. (*Gammaproteobacteria*) (Engel et al., 2004; Engel et al., 2010). Although *Epsilonproteobacteria* have been found in numerous sulfidic cave systems and sulfidic groundwater (Porter and Engel, 2008), little is known about the ecophysiology of these groups, as many have not been cultured; from the research that has been done, these bacteria metabolize at low oxygen tensions, like the anaerobic to disaerobic cave waters.

These sulfur-oxidizers directly influence the chemistry of the microbial mats and ecosystem function by colonizing the nutrient-poor habitat, providing an energy source as chemolithoautotrophs, forming a dense mat because of the filament structure, and consuming oxygen (Engel et al., 2010). Chemolithoautotrophy in a cave system is important because it serves as the base for the cave food web. Consumption of oxygen at the mat surface creates an oxygen-deprived habitat within the mat interior to make a more suitable habitat for anaerobic microbial groups. The mat interior is anoxic ~3 mm beneath the surface. Sulfate-reducing and fermenting bacterial groups, ~50 % each of members of the class *Deltaproteobacteria* and unculturable members of the Chloroflexi phylum, dominate the mat interior. Rarer groups also include Planctomycetes, Bacteroidetes, Chlorobi, Verrucomicrobia, *Alphaproteobacteria*, Spirochaetes, Actinobacteria, and Acidobacteria (Engel et al., 2010).

Three predominate cave-wall solid phases are present: limestone, gypsum, and organic coatings. Unaltered host limestone is exposed at the entrance, but with increasing distance from the entrance, limestone is rarely found freshly exposed at the cave walls. Where the limestone walls and ceiling are replaced by gypsum, the gypsum crusts can reach 10 cm thickness. When very moist, gypsum occurs as a paste that appears to hang or ooze from the cave walls and ceiling (Figure 2); occasionally, the paste is associated with selenite (gypsum) needles on the surface that range from a few mm to 1 cm in length.

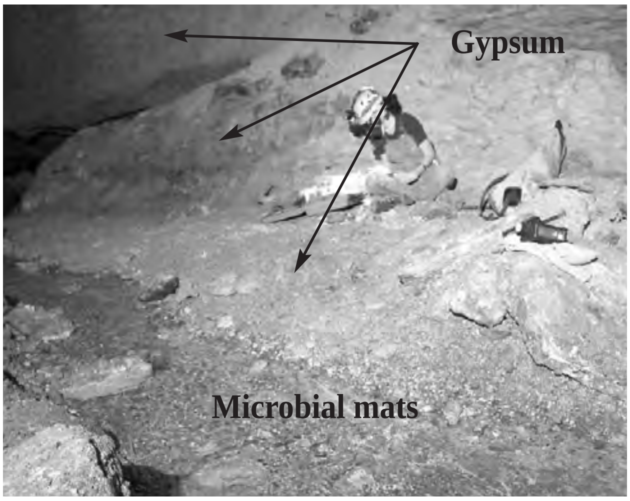

Figure 1. Cave stream with filamentous microbial mats in Lower Kane Cave, Wyoming (USA).

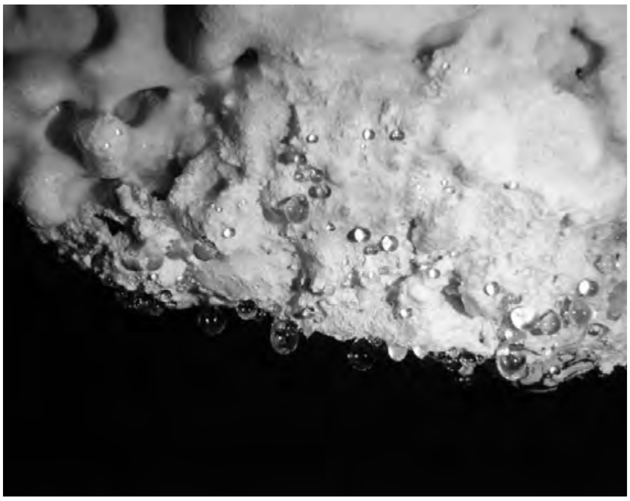

Figure 2. Condensation droplets on gypsum paste in Lower Kane Cave, Wyoming (USA). Droplets are about 1 cm wide.

Although it is possible that the gypsum paste may completely fall from the cave wall to the floor, most of the removal of gypsum from the cave walls appears to be due to spalling from the walls and ceiling (Figure 1). Organic coatings exist as discontinuous reddish-brown, paper-thin material covering gypsum on the cave walls. Most of these coatings are found near the spring orifices, and are not found on limestone. Away from the springs, coatings are desiccated and friable to the touch.

Thermal gradients between the cave air, cave walls, and spring water promote condensation predominately near the spring orifices. Condensation forms on nearly all surfaces in close proximity to the springs, and droplets are evident on the moist and dry brown coatings. Conden-sation can occasionally be found near the entrance, usually in the winter, and is likely controlled by the air temper-ature difference inside and outside of the cave. The con-densation associated with the biofilms has pH values between 0 and 4, with lower pH values (<2) from brown coatings and higher pH values (>2 to 4) on gypsum. All droplets are undersaturated with respect to calcite, but droplets originating from gypsum were in approximate equilibrium with respect to gypsum.

Based on DNA sequencing, the brown coatings are composed of microbes belonging to the Actinobacteria phylum, including the *Actinomadura*, *Mycobacterium*, and "Ferrimicrobium acidiphilum" groups, as well as the *Gammaproteobacteria* and *Alphaproteobacteria*, dominated by the *Acidithiobacillus* and *Acidophilium* spp., respectively. Many of the groups decompose complex carbon compounds, including humics, and produce copious amounts of extracelluar polymeric substances (EPS). Other groups (e.g., *Mycobacterium*) have quite high cell hydrophobicity due to mycolic acid production. *Acidithiobacillus* spp. have been identified from microbial draperies, or snottites, in active sulfidic caves in Italy and Mexico, among other places around the world. These chemolithoautotrophic bacteria oxidize reduced sulfur or iron and produce EPS. Another group of uncultured bacteria, members of the Candidate Division TM6, are abundant, and have been identified from other sulfidic cave-walls and snottites. Filamentous fungi and protists have also been described from cave-wall biofilms.

3. Geomicrobiology of active systems

3.1. Edwards Aquifer – carbonate dissolution and gypsum precipitation

Geochemical differences between the fresh and saline waters in the Edwards Aquifer have been interpreted almost exclusively in the context of abiotic processes controlled by the dissolution and precipitation of specific minerals. The impact of microorganisms on carbonate geochemistry, specifically limestone and dolomite dissolution, has been examined using in situ microcosm experiments done in aquifer fresh and saline water wells (Engel and Randall, 2011; Gray and Engel, 2013). Regardless of being fresh or saline water, waters are supersaturated or in equilibrium with respect to carbonate minerals. The fresh and saline waters are also undersaturated with respect to gypsum, although high TDS saline waters approach equilibrium with gypsum. Supersaturation with respect to carbonate is likely due to the common ion effect because gypsum dissolution contributes excess Ca. Regardless, the aqueous geochemistry suggests that abiotic dissolution of carbonate minerals would be unlikely over the period of the experiments (from 1 to 3 months).

Experimental minerals that are colonized by microbes have more mass loss than minerals that are sterile and where microbes are kept from colonizing the experimental surfaces (e.g., by using dialysis tubing). Based on microscopy, cells are associated with dissolution features on the experimental minerals, and dissolution pits are smaller and deeper when cells are nearby compared to larger, broader areas of dissolution observed where there are no cells observed (Engel and Randall, 2011). More cells per surface area are found on dolomite compared to calcite for almost every well that has been used for experimentation. Increases in the average mass loss of calcite, but not dolomite, weakly correlate to higher biomass (measured quantitatively as the number of cells on the surfaces). For some saline water wells, calcite surfaces have euhedral gypsum crystals, despite the aquifer fluids being undersaturated with respect to gypsum (Gray and Engel, 2013).

For active karst formation, fluids should be undersaturated with respect to carbonate minerals, typically because of processes that alter ion activities and P_{CO2} balance. Fluid geochemistry alone suggests that carbonate dissolution may not be active. This conflict suggests that studying aquifer fluids alone may not be a good indicator of reactions and processes involving carbonate geochemistry. The experiments with and without microbes indicate that calcite dissolution is possible when surfaces are colonized by microbes, even if fluids are supersaturated with respect to carbonate phases. The results also suggest that the mineral surfaces are not in equilibrium with the aquifer fluids. Microbial metabolic activity focused at the mineral surface, however, increases the degree of undersaturation with respect to calcite and supersaturation with respect to gypsum at the mineral-water interface. Both carbonate dissolution and gypsum precipitation are possible, through excess proton production and a surplus of sulfate, because of microbial oxidation of reduced sulfur compounds (Engel and Randall, 2011). Consequently, extensive biofilms developed on aquifer surfaces may result in diminished carbonate dissolution rates over time because the biofilms with gypsum form a barrier between the aquifer fluids and the carbonate rocks.

3.2. Lower Kane Cave – cave stream dissolution

The sulfuric acid speleogenesis model was developed from LKC, first considered to be based solely on the degassing of H_2S from the sulfidic groundwater to the cave atmosphere, and H_2S autooxidation to sulfuric acid on the moist cave walls, summarized as:

$$H_2S + 2O_2 \leftrightarrow H_2SO_4 \quad (1)$$

The acid reacts with and replaces carbonate with gypsum,

$$H_2SO_4 + CaCO_3 + H_2O \leftrightarrow CaSO_4{\bullet}2H_2O + CO_2 \quad (2)$$

Gypsum readily dissolves into groundwater, which is undersaturated with respect to gypsum. This removes mass and increases void volume from the passage. Cave formation, or specifically cave passage enlargement, due to sulfuric acid speleogenesis has now been recognized in many active sulfidic cave systems, and is a process that is linked to the development of at least 10 %, or even more, of carbonate karst systems worldwide.

But, some of the microbes living in the microbial mats in the sulfidic cave stream produce sulfidic acid (among other acids) as a byproduct of their metabolism (Engel et al., 2004; Steinhauer et al., 2010). Evidence that the sulfur-oxidizing bacteria play such a dramatic role to carbonate dissolution in the cave stream comes from the fact that, although H_2S enters the cave at the springs, the measured sulfide concentration decreases more rapidly than would be predicted from what is modeled as volatilization or autooxidation mechanisms. Sulfide is absent downstream of the springs, only several meters after entering the cave and flowing through the mats. In short, if sulfur-oxidizing microbes were not consuming the sulfide, then there would be higher sulfide at the end of the microbial mats. The rapid loss of sulfide caused by the microbes, such as the *Epsilonproteobacteria* and other sulfur-oxidizing groups, directly influences the production of acidity from sulfuric acid (Engel et al., 2010). Dissolution experiments with in situ microcosms placed in the cave stream provide similar results to the research done in the Edwards Aquifer. More dissolution occurs on surfaces that are colonized by microbes (Engel et al., 2004).

3.3. Lower Kane Cave – cave-wall hypogene processes

Biofilms on subaerial cave-wall surfaces, referred to as microbial draperies, cave-wall biofilms, or snottites, have been described from the several active sulfidic caves. Although some of the longest can reach up to 10 cm in length, cave-wall biofilms typically occur as discontinuous patches of droplets or unnoticeable moist biofilms on insoluble crusts. In LKC, there are no extensively developed draperies, only cloudy droplets approximately the same size as condensation droplets. The composition of the brown coatings covering gypsum in discontinuous patches averages 39 %, although some samples have as much as 80 % organic carbon by dry weight. Because the coatings are associated with solution pH values ~2, the precipitation of humic substances is promoted, which may explain why it is possible that the higher organic carbon concentrations correlate to increased humic acid content. At lower carbon contents, which also correlate to coatings that are more dessicated, microbial activity may be less from those parts of the cave. An interesting consequence of the organic-rich coatings is that they form hydrophobic surfaces, which is why the condensation droplets are visible on the coatings more so than on the gypsum, which is considered to be hygroscopic. Increased hydrophobicity of the surface correlates to lower pH in the condensation on those surfaces, and is likely linked to changing electrolyte adsorption and protonation of organic functional groups.

By growing on the cave walls, the microbial biofilms serve as a hydrophobic barrier that keeps the air moisture from condensing onto fresh rock surfaces and reacting with the rock, even abiotically (although abiotic reactions have been modeled as being kinetically very slow to result in the amount of gypsum observed). As biofilms develop and acidophilic microbes produce acidity (e.g., sulfuric or carbonic acid), dissolved organic matter precipitates out of the low pH solutions and a crust forms. This further separates potential condensation from the underlying rock, and even the secondary gypsum that would serve to buffer the pH to around pH 4, or even pH ~2 because of the sulfate: bisulfate acid-base pair.

The results imply that subaerial processes in active, sulfidic hypogene cave systems are episodic, and may not be related to the reactions operating in the cave streams, or even in the aquifer.

4. Conclusions

Understanding how microbes are involved in active hypogene reactions will begin to help in determining where microbes were involved in relict hypogene processes. Microbes in hypogene systems affect karst development by changing the physical surface chemistry of the solids, just by their presence and the formation of a hydrophobic barrier. The microbes metabolize solutes in the water (or air), and scavenge nutrients from rocks, with reaction rates that exceed abiotic mechanisms. Dissolution at rock and mineral surfaces is focused by microbial cells, caused by a local lowering of pH, which would otherwise not be detected in the bulk aquifer or cave stream fluids when sampled. Future studies should continue to investigate the microbial diversity of hypogene settings to establish rates of dissolution or other reactions that could begin to place speleogenetic processes into a temporal framework.

Acknowledgments

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THE RESOURCES, ENVIRONMENT AND DEVELOPMENT IN KARST AREA: A CASE STUDY IN FENGSHAN GEOPARK (CHINA)

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A karst area of the Poxin subterranean river catchment in the Fengshan County with landform of typical peak-cluster and depression is discussed for its successive experience of development. It is also a part of Leye-Fengshan Geopark. The project for developing includes many kinds of work such as traffic construction, education, medical treatment, energy, environment, tourism, and drinking water supply, which are all necessary and eager to be resolved in the developing rural region. The characteristics of karst water, geomorphology and speleology were studied in order to find out the special resources and environment problems. The environment still suffered from many problems such as soil erosion, flood, drought, and rock desertification. Three types of soil erosion related to karst were discussed: allogenic soil erosion, autogenic soil erosion, and conduit soil erosion. Flood in karst depressions became more serious due to sediment blocking in conduits, and moreover, low discharge capacity of tributary conduits may also lead to flood. One of conduit was dredged for removing block in throat. But this kind of engineering was often hard and expensive. Epikarst flow was utilized for drinking water supply by building thousands of small domestic water tanks. Biogas was gradually popularized instead of traditional charcoal, which did good to vegetation recovery. Splendid karst landscape was protected by a way of admission of Geopark. This is also a good way for economic development. The complex methods play better in the rebuilding of the degradation ecological environment.

1. Introduction

Karst environment has not been defined strictly. It includes much scope with variable types. In common sense karst environment is made of soil, karst landscape, atmosphere, karst water, and biosphere (Yuan et al. 1988). The five parts connect and impact each other, and the combination of them is different according to geomorphology and geology. Many environmental problems happen in the vulnerable karst environment and have been discussed much in literatures (Yuan 1988; Waele 2008). Deforestation, soil erosion (Turnage et al. 1997), rock desertification (Hu et al. 2004; Wang et al. 2004), flood and drought (Andriani 2008), sinkhole collapse, water pollution (Kacaroglu 1999) occurs frequently in karst area. Although these problems can also happen in the other type of environment, they concentrate and are related to fragile karst environment and impact of human activity is important. This paper gives analysis of reasons and answers of soil erosion, flood, drought, deforestation and development in a subtropical karst region.

2. Geography and geology

The Fengshan County lies in west of Guangxi province, China. It owns a national geo-park in 2005, which was ranked as a member of the world geo-park in 2010 for its beautiful and typical karst landscape including karst springs, huge collapse depressions, caves, natural bridges, karst windows. However poverty stands here for many years and series of environmental problems affect local people.

Fengshan karst area is within subtropical climate, with annual precipitation of 1,550 mm, annual temperature of 19 degree. The elevation changes from 700 m to 1,100 m. It is an anticline in geological structure (Fig. 1). Triassic sandstone closes Permian and carboniferous limestone. Plenty of allogenic water coming from sandstone areas is important for karst formation. The area of peak cluster is 400 km^2. Karst conduits are about 90 km long, and half of them are measured. Karst groundwater is discharged from Poxin spring with base flow discharge of 4.2 m^3/s.

Economy of Fengshan County is undeveloped. The establishment of Fengshan Geopark is believed to bring hopes for the County; however karst environmental management is important for sustainable development.

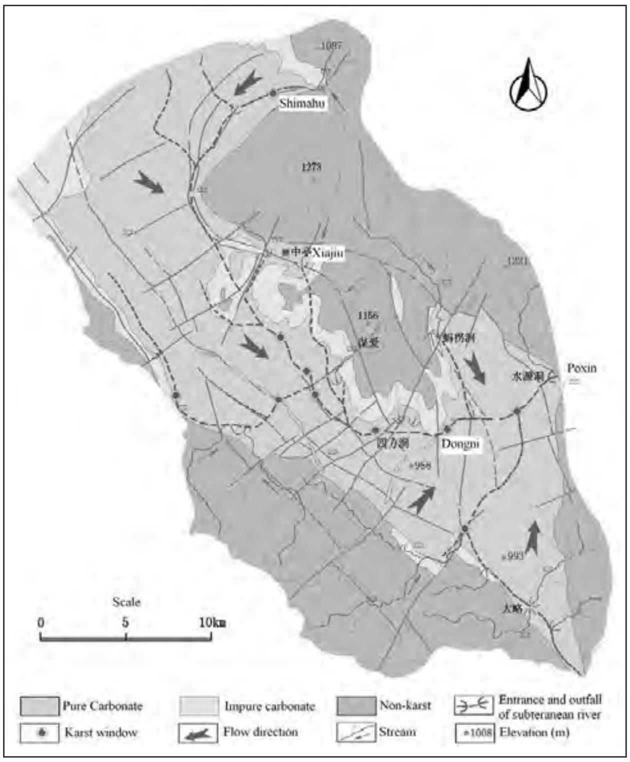

Figure. 1 The hydrogeological map of the Poxin subterranean river.

3. Methods

When in the national plan of "the Western Development Drive", the Chinese Geological Survey organize hydrogeological surcey project in the karst area of southwestern China as coordination. The poxin subterenean river catchment is planed as the area for the survey in 2006. The main target for the project is that to identify the storage condition of karst water in karst aquifer, and to identify related environmental geological problems and their reason. The survey is done in the scale of river basin. The methods of survey include much technique and sciences, such as date collection, field survey in hydrogeology and geomorphology, hydrological monitoring, hydrochemical sampling, speleological survey, interview and so on.

There are few excellent land resources and little available drinking water in karst mountain area, but many people choose living here. Most of land surface in Fangshan is covered by shrub and forest. Cultivated field distributes in bottom and slopes of depressions. Small paddy field lies in a few poljes where soil and allogenic water are sufficient. People live on cultivated field. Their agriculture activity induces many environmental problems.

4. Results

4.1. Soil erosion

Both of slope cultivation and deforestation induce soil erosion. Soil erosion is accelerated by steep sloops of peak cluster and frequent storms in monsoon climate. It leads to series of problems. The soil loss in storms happening in border depressions leads to mudslides, not only destroying farmland (Fig. 2A), but also blocking conduits (Fig. 2B). The soil erosion happening in peak cluster leads to soil denudation and forming rocky desertification. This is mostly an irreversible process. The denuded land in slope is covered by little soil and full of stone teeth (Fig. 2C).

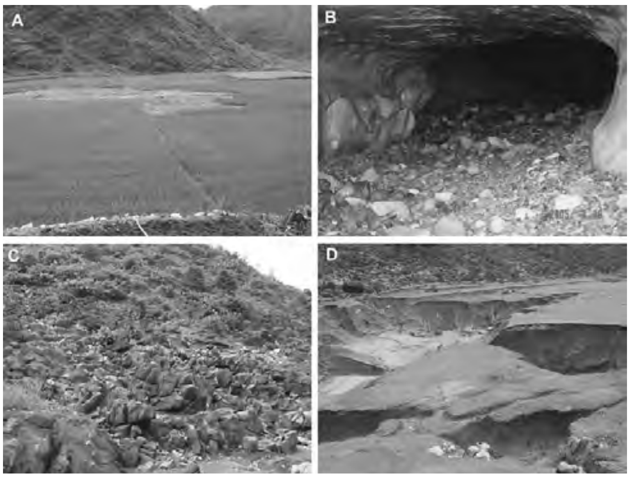

Figure 2. Ssoil erosion in karst area, A: paddy field buried by allogenic soil erosion; B: big blocks in allogenic soil erosion; C: slope eroded by autogenic soil erosion, only stone teeth remained; D: depression eroded by conduit soil erosion.

Three types of soil erosion are related to karst: allogenic soil erosion, autogenic soil erosion, and conduit soil erosion. Allogenic soil erosion is caused by allogenic rivers, autogenic soil erosion is made by epikarst flow and bypass flow being recharged by epikarst flow, and conduit soil erosion is induced by conduit flow and surface stream converted from conduit flow in depression (Fig. 3).

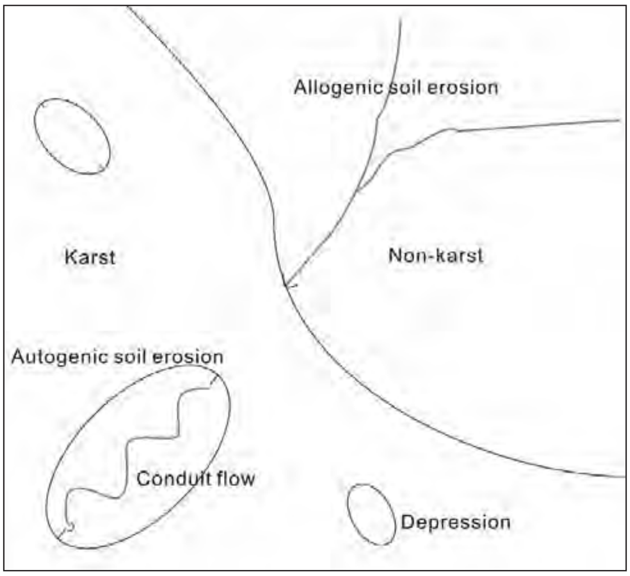

Figure 3. Soil erosion in karst area, three types of soil erosion is related to karst.

In poljes or depressions near non-karst area it usually suffered from allogenic soil erosion. Allogenic soil erosion leads to debris flow which buries the precious farmland. The suspended particles from non-karst area are made of clay, sand and scree, and sometimes also including wood and chunks of junk. The debris flow enters into swallow hole and suspended particles deposit somewhere which makes the conduits blocked. Once it happened flood will occur in the poljes and depressions. Cropland in several poljes has been destroyed completely by iterative flood, where it was ever productive.

Autogenic soil erosion usually happens in storm. Although it is still unclear how the erosion happens in karst peak slope, at least epikarst flow and bypass flow play key role in the process for the erosion and overland flow has little impact on it. Intensity of erosion is related to rainfall, vegetation style and slope degree. Cultivation and cutting on slope will make this kind of erosion quicker. Suspended particles related to autogenic soil erosion are mainly clay and some block of limestone. They stop moving and deposit at the bottom of depression or near sinkhole. Autogenic soil erosion leads to one kind of serious environmental problem in south of China, and it is called rocky desertification.

A depression above main conduit may suffer from conduit soil erosion. Overflow in rainy season from sinkhole or karst windows at bottom of the depression become an intermittent stream. The stream takes away soil along the bank of channel and forms a deep valley at the bottom of depression. The elevation of bottom surface in some depression has been lower about 5m in the past 20 years. The land was eroded gradually in planar (Fig. 2D).

4.2. Flood in depressions

Flood in depressions and poljes makes huge damage. This special hydrological phenomenon is related with underground conduits in karst aquifer. In general allogenic stream enters into karst aquifer by swallow hole in poljes. However it is stopped to form a transient lake around the hole when the conduit is too small to permit such large discharge of flow to pass after intensity rainfall. For more serious case, conduits which enlarged by karstification of allogenic stream can be blocked by river sediment and collapse rock from the ceiling of cave. Blocking of conduit is a common reason for flood. Then in order to eliminate flood determining the location of block is the first important thing for opening conduits.

Roughness of conduits inner surface impacts the capacity of conduit discharge. Wall of conduit should be smooth with wash of water, but cave chemical precipitation and sediment of mash, sand or gravel in the floor increase the roughness and decrease of flow velocity. On the other hand water moving together with gravel makes the flow slower. Moreover sediments usually reduce the hydraulic radius of the conduit. So except for blocking conduit at some points, sediments reduce flow by increasing roughness or decreasing hydraulic radius.

For example the Shima Polje is the largest one in Poxin karst spring catchment, which suffers from flood. There were ten million tons of capacity as reservoir and 150 ha of land in 1976, but it couldn't be used because of flood. The flood in the polje comes from streams in sandstone area with the area of 44 km^2, which means large drainage area for the polje. The conduit can't be examined for finding block pots because it is always filled by water. In order to control the flood a tunnel was built for enhancing drainage capacity, however the flood still can't be removed completely. Moreover flood time becomes longer and longer from 1970s to now, for continues deposition. The Shima Polje is becoming a really permanent lake. So someone gives suggestion that it is better for the Shima Polje to being a lake or reservoir than returning to farmland.

Flood in the Shima Polje had been studied from 1970s. A tunnel was built to increase the discharge of conduits. However the conduits were still blocked somewhere, which is not clear downstream. So the flood hasn't been solved completely now. There are six connected swallow holes in the Shima Polje. Before the further project for flood controlling water table in these holes was monitored for finding the possible blocks in conduits which connected the swallow holes. It was found that water table in Ping cave was 3 m higher than that in others when only Ping cave accepted allogenic streams, but no difference for water table in the caves when all swallow holes accepted rivers. So it could be concluded that there was block in conduit between Ping Cave and others, however some blocks unknown still existed behind the swallow holes. The tunnel was built connecting Ping cave and others. It discharged small flood but large flood is remained unsolved (Fig. 4, Fig. 5).

Collapse of rock in conduit induces flood too. The method for flood controlling in the block type is also building tunnel. For example the tunnel was built in collapsed detritus for discharge flood in the Dongni depression in

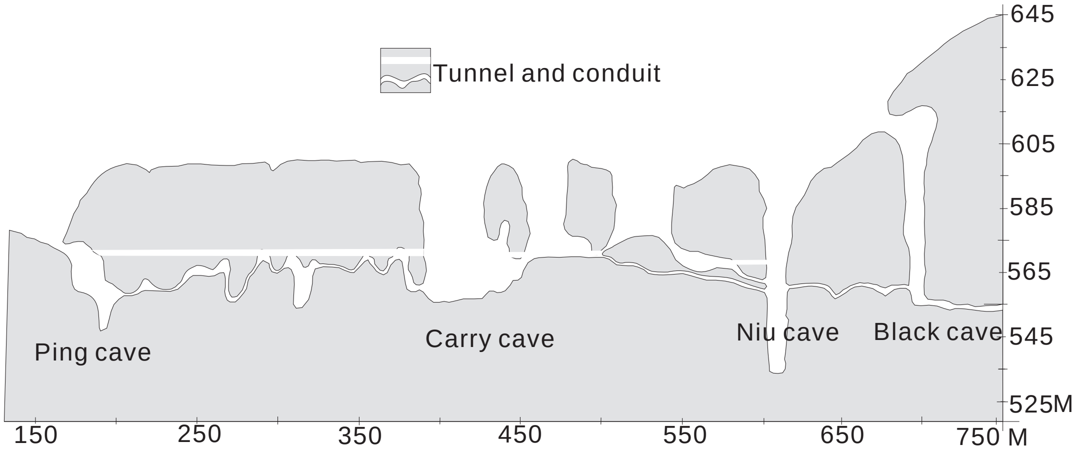

Figure. 4 Swallow holes in the Shima Polje, a tunnel was built to discharge flood, the flow is from Ping Cave to Black Cave.

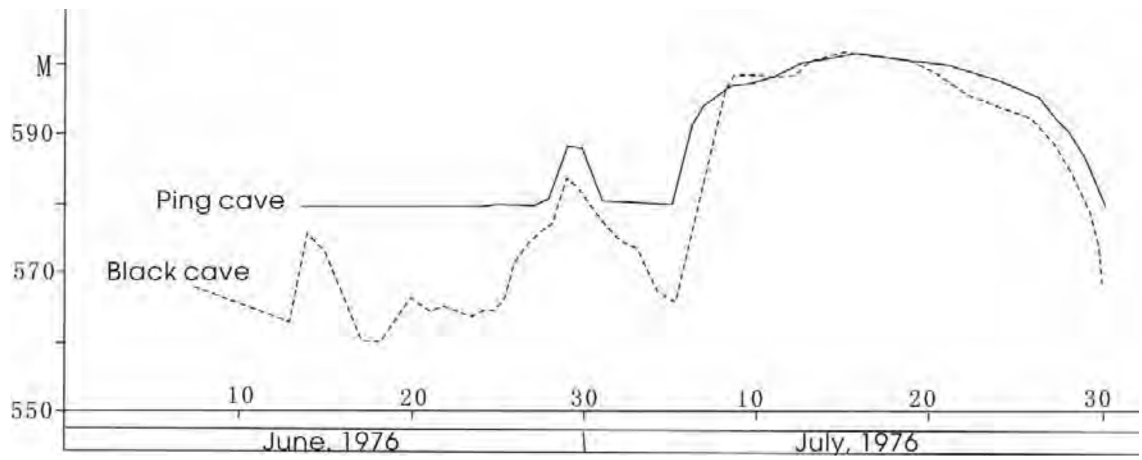

Figure. 5 Water table changes in swallow holes, which indicates the location of blocking in conduit.

1960s. The collapsed detritus was formed at the gate of cave below a cliff. It is the erosion of an intermittent stream in the depression which leads to instability and collapse of conduit. A new sinkhole formed after collapsing, however which can't discharge the flood by time. The tunnel built in collapsed detritus was very effective, and flood in the depression and depressions upstream was even diminished (Fig. 7A).

The Xiajiu depression with the flat area fitting farmland of 75 ha has a drainage area of 21 km^2 distributed in non-karst. A stream from non-karst area flows through the depression and disappears in a swallow hole. The flood at the stream together with many trees and a rice mill flows into conduit in 1979, when a new road was being built. And from then on there is always flood lasting 1 to 4 months in the Xiajiu depression every year. In order to control the flood and recover land for farm in the depression a clean conduit project (CCP) is designed and done in the Xiajiu depression.

There are two block points at 360 m and 600 m in the conduit which is about 2,000 m long by cave mapping. The cave is 1–18 m wide and 2–6 m high and big enough for flooding discharge except for the two block points. So the key problem of the CCP is removing the blocks.

The block at 360 m is silted up by incompact sediment, which is easy to remove. The block at 600 m is a converse siphon. It is filled always by water. Only single person can climb through it at one time. For this kind of block dynamite is needed to clear rock. Excluding CCP, prevention debris project (PDP) is designed together. PDP is made of 4 parts, which are a dam for debris, a channel for flood drainage, a pool for sand deposition and a fence for prevention of plant and other large piece of junk.

The regime of tributary conduits group may also leads to flood. It is found that flood occurs along the tributary in north of the main conduit, while there is little flooding in the south tributary. The southern tributaries are recharged by larger allogenic streams. Moreover they have smaller length and bigger hydraulic grads. So the flood in southern tributaries comes earlier than the north, which may enhance the head in the main conduit and prevent flow in the northern conduits (Fig. 6).

4.3. Drought

The average discharge of the Poxin spring is 6 m^3/s. Its drainage area is 803 km^2 with about half of carbonate rock and half of non-carbonate rock. Allogenic streams from non-carbonate rock recharge karst aquifer by swallow holes. Rainfall recharges karst aquifer through epikarst, sinkhole and fractures. There are little rivers in karst area, while karst groundwater is plentiful. However it is difficult to use karst groundwater, because of its heterogeneous and deep water table. Finding groundwater is mostly impossible in most area except in some karst windows and sinkholes. Local people living far away from groundwater have to build small water tanks for harvesting rainfall.

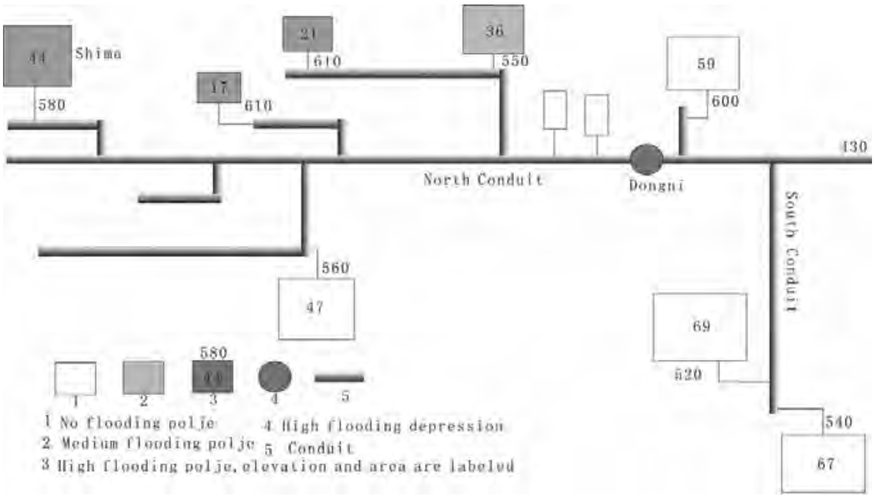

Figure 6. Integration of conduit in the Poxin spring catchment, tributary conduits are all recharge by allogenic streams.

Figure 7. Flood in karst area and engineering for flood discharge, A: tunnel in the Dongni for discharge flood in the depression; B: flood impacts paddy field in polje.

Thousands of water tanks have been built in the past ten years. Almost every family own at least one water tank, and some of them build big one for several families. Water shortage for life is resolved by this way, moreover people build water tanks near their farmland for irrigation. By this method corn field is changed into paddy field.

Water quality in the water tanks is possibly polluted by bacteria and turbidity under high temperature and heavy rainfall. The treatment is necessary before water is harvested, and the environment surrounding of the water tank is also important for improving water quality. The sources of water tank are overland flow, epikarst flow and rainfall. The adequate drainage area for water tank is also important. Epikarst flow has better quality and longer flow time, so it is best source for water tanks. Forest covering for epikarst can clean water, cut flood peak and increase base flow in epikarst (Fig. 8).

Figure 8. Water tanks harvesting rainfall, epikarst flow and overland flow in karst area, a piece of paddy field among corn is irrigated by the cellars.

4.4. Resources

Epikarst water

The perched and saturated zone near surface in peak and depression is called epikarst. Epikarst is charactered by intensified dissolution and corresponding high porosity because of high CO_2 concentration in soil and low saturation index of calcaite in rainfall. The storage of epikarst and its regulation for rainfall recharge make it possible to use epikarst water. Somewhere small springs are formed in the process of epikarst evolution. These springs are sensitive for rainfall, and they flood soon after rainfall, while their base flow continued several months. But their discharge usually attenuates to zero in dry season, so a small water tank is needed, which regular flood for water supply in dry season. Comparing with water in the saturated zone, the utilization of epikarst water is cheaper and feasible.

Plants

Many kinds of plant in karst area are useful raw material for Chinese herbal medicine. Some of them are only adapt to karst environment or are better than that growing in other geological environment. Wild herb is precious and expensive in market, so it has been over picked in the past. The government organizes people to crop herb for business. This work not only brings money for local people but also does well to wild vegetation protection.

Tourism

The poxin subterranean river becomes famous because of the establishment of national geopark. The geopark own splendid karst geomorphology, including huge and long caves, big karst windows, splendid stalagmite, and long life old people. There are the most long life old people here in the world. The secrecy of long life is related with its special geological environment. Several tipical landscapes have been viewpoints for besiness, which accelerates the ecomonic development.

Energy

Although the soil is thin or even lack here, rocky slope can still be covered by shrubs and bush if there is no cultivation and over cutting. Production of vegetation is much because of much sun light and rainfall. These grass or shrub is used to feed poultry and livestock like pigs, goat, horses and cows. The government organizes technician to help people to build biogas digester. It uses manure of the poultry and livestock as raw material, and it is very effective for environmental protection. Biogas will replace firewood as main family energy in the future.

4.5. Development

The Fengshen is poverty-stricken county, where per capita income of people is below 1500RMB. The government spends much money in improving traffic, education and health. Tourism has been developed largely since the beautiful karst landscape is found. The orchard is planted in denudated sploe land in large scale. It brings hope for local people. And the return of the large investment will gradually come into being in the future.

Practices for poverty alleviation should be environment-friendly. The best management practices are needed for environmental protection during developing. Soil erosion should be controlled according to its character. More strict vegetation protection practices are necessary for non-karst area, where the sediment comes. A buffer zone near swallow hole can intercept big sediment from allogenic rivers. Conversion of cropland to forest in slope may reduce rocky desertification, which also control autogenic soil erosion. Conduit flow soil erosion can be prevented by building concrete bank. It is difficult to open it once conduit is blocked.

Removing stem from conduit by engineering technique is effective sometime, but which is impossible when the conduit is long and filled by water. Opening a new tunnel may be useful but only when proper location is determined.

5. Conclusions

Poverty elimination work in karst area of South China should be done with proper ways. Traditional business can not be encouraged because it is inefficient and unsustainable. New business for example biogas, reversion cropland to forest, and tourism not only does well to environmental protection but also enhance earning for local people. Karst environment is charactered by thin soil, little water resources on surface, and long underground conduit net. It is very fragile. Cultivation and deforestation intensify soil erosion; soil erosion induces flooding and water shortage, and then induces poverty; poverty induces cultivation and deforestation. This is a vicious circle, and should be replaced by sustainable way.

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UNRAVELLING UNDERGROUND ICE MICROCOSMS

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Scărişoara Cave (located in NW Romania) is one of the best-known limestone caves with perennial ice. Extensive geological/paleoecological studies have been performed on the ice block–the largest underground ice deposit known in the world. To date, the Scărişoara ice block has never been studied from a microbiological point of view, and therefore our research aims to characterise the microbiota (Archaea, Bacteria, as well as eukaryotic microorganisms) present in the ice sediments of different ages. The intention is that correlation of the structure of the microbial communities within an ice layer of a specific age with the known climate patterns will lead to the identification of climate biomarkers. Moreover, among the identified microorganisms, some might prove to be economically advantageous. Chemical analysis of ice sediments of the different ages indicated a decrease in salinity, oxygen chemical consumption, and nutrient concentrations that correlated with the age of ice layers. To investigate if microorganisms are present in the ice block we used culture – dependent methods, as well as microscopy and molecular techniques. Cultivated strains were obtained from melted ice inoculated on various solid growth enrichment media using Ecoplates (Biolog), as well as agar plates, incubated at two different temperatures (4 °C and 10 °C). The bacterial growth was monitored spectrophoto-metrically and comparisons of the growth curves from these strains revealed different nutritional preferences, suggesting the presence of different bacterial communities in each age layer. Moreover, the differences in the growth rate between 4 °C and 10 °C indicate that psychrotolerant microorganisms are prevalent over psychrophilic groups from the 900 year old ice, whereas psychrophilic and psychrotolerant species are equally distributed in the 450 and 1 year old ice layers. The presence of both bacteria and archaea was also confirmed by amplifying the 16S rRNA gene from total DNA extracted from ice samples, as well as from bacterial cultures with specific primers. A 16S rRNA gene sequence clone library of 180 bacterial clones was obtained, and several bacterial strains were identified by pyrosequencing.

The diversity of bacterial communities was further indicated by **Amplified Ribosomal DNA Restriction Analysis** (ARDRA). Cyanobacteria from the sun exposed ice samples were also visualised by epifluorescence microscopy.

The presence of eukaryotes (i.e. algae) in the samples was confirmed by using specific primers to amplify the eukaryotic 18S rRNA gene from total DNA. Moreover, dead and living cells were visualized by epifluorescence using propidium iodide and with SybrGreen, respectively. In summary, phototrophic microorganisms (both cyanobacteria and algae) are present and alive in the sun-exposed samples, the ice of a specific age is populated by a great diversity of microbial communities (PK/EK), and that there are differences in between the communities inhabiting different aged ice layers.

BAT COMMUNITIES OF CZECH CAVES OVER 45 YEARS OF CONTINUOUS MONITORING

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As in other regions of Central Europe, in the Czech Republic bats colonize caves exclusively as hibernacula and/or places of seasonal swarming (with a single exception: a hydrothermal cave Hranická propast which hosts a breeding colony of *Myotis myotis*). Structure and long-term changes of bat populations in particular underground hibernacula became there a subject of a standardized monitoring which started already in 1969 (then with 16 sites). Since then extent of the project enlarged essentially – now it covers almost 800 sites including nearly 300 caves in all major karst region of the country, all controlled once (or twice) per winter period with visual identification of bats and excluding any distrubance. 20 (of 26) local bats species were found to hibernate in underground hibernacula, *Myotis myotis, Rhinolophus hipposideros* and *Myotis daubentoni* being the most common. In most species, dramatic abundance changes were recognized, e.g., a drastic drop in 70' in *R.hipposideros* with its disappearance from almost all non-karstic region, followed by a slow recovering in late 80' and 90' and radical abundance increase during the last decades. With certain delay, the same trend appeared also in *M,myotis*. An abrupt abundance increase synchronous with positive trends in the former species occurred in *M.emarginatus,* formerly a rare thermophilous species, now often a dominant elements in hibernacula of the Eastern part of the country. In contrast, some species show no similar trends and the others, such as *Plecotus austricus,* are in continuous decline. A large number of monitored sites enabled to quantify these trends and to distinguish the phenomena of general significance from locally specific situations and/or the changes in community structure driven by anthropogenic impacts in cave interior and/or setting of cave entrances. Such phenomena, clearly associated with extensive rearrangements in structure of hibernating community are demonstrated in details for two caves of Bohemian karst (Koněpruské, Srbské) – responding in both to the anthropogenic effects upon entrance design, air currents and thermal properties of the respective caves. In one case, these caused considerable increase of abundance and diversity of hibernating community, while in the other the trends were exactly reversed. Worth mentioning is that the above mentioned general abundance development has not been affected by increasing incidence of geomycosis in hibernating bats (presence of mycelia of *Geomyces destructans* causing the White nose syndrome). The incidence of geomycosis has been quantitatively monitored since 2009/2010 and proved in a considerable part of monitored sites. In contrast to North American hibernacula, no mortality directly caused by geomycosis was confirmed. Both incidence and prevalence of geomycosis show considerable interregional differences – the pattern of them seems to be nearly identical in all four winter of its monitoring.

FOOD CHAIN LENGTH IN GROUNDWATER: PATTERNS IN $\delta^{15}N$ RANGE

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There is a large body of empirical and theoretical literature on historical and environmental determinates of food chain length (FCL), but these have not been assessed in groundwater habitats. Stable isotope analysis of nitrogen in animal tissues provides an inexpensive measure of FCL. Trophic level and uncertainty in trophic level was estimated for 19 stygobiont species from two geochemically distinct sites in the Edwards Aquifer of South-Central Texas, USA. Isotopic data revealed large uncertainty associated with intraspecific $\delta^{15}N$ variability and low sample sizes, but species averages span 9‰ and strongly suggest the presence of 2° predators; unusual for groundwater foodwebs that are typically assumed to contain few obligate predators. A literature review revealed 10 additional isotope studies of groundwater foodwebs (excluding hyporheic habitats). Simple linear regressions and Akaike Information Criterion suggested that ecosystem age ($r^2 = 0.66$, $F = 18.26$, $p < 0.01$), and to a lesser extent, ecosystem size ($r^2 = 0.52$, $F = 10.75$, $p = 0.01$) and the presence of vertebrates ($F = 9.98$, $p = 0.01$) are all positively correlated with FCL. However, incomplete sampling of taxa for isotope analysis obfuscates the strength of these relationships. Groundwater habitats are ideal systems to study the relative importance of factors influencing food chain length using a stable isotope approach, but future studies should include larger sample sizes, more complete sampling of taxa, and body mass measurements.

1. Introduction

Little attention has been given to the historical and current environmental conditions controlling food chain length (FCL) in subterranean habitats. Although research on subterranean food web structure supports the paradigm of truncated food webs (Gibert and Deharveng 2002), there is both empirical and theoretical literature on historical and environmental controls of FCL in non-subterranean habitats (Post 2002a; Takimoto and Post 2012), and the factors influencing variation in FCL in subterranean systems are ripe for investigation. Because they have been summarized elsewhere (Post 2002a), potential determinates of FCL will only be introduced here. At least 5 major controls on FCL have been discussed at length in the literature, including productivity (Kaunzinger and Morin 1998), ecosystem size (Schoener 1989; Post et al. *2*000; Post 2007), ecosystem age (Kitching 2001), predator-prey mass ratios (Hastings & Conrad 1979), and disturbance (Pimm and Lawton 1977).

Groundwater habitats are ideal for studying the relative importance of historical and environmental factors influencing FCL because of relatively simple food chains (Gibert and Deharveng 2002) and because of the global distribution of groundwater communities often comprised of similar species (e.g., crustaceans) inhabiting aquifers with a broad range of historical and environmental characteristics. Stable isotope ratio analysis of nitrogen (N) in animal tissues is commonly used as a measure of FCL (Takimoto and Post 2012), although isotope data alone should be interpreted with caution (Post 2002b). Further, because groundwater foodwebs are relatively simple, erroneous trophic level estimates due to differences in the proportional contributions of multiple resources to primary consumers (Hoeinghaus and Zeug 2008) are minimized. We present N isotopic data from subterranean aquatic species (stygobionts) from the Edwards Aquifer of South-Central Texas, USA. Based on habitat stability, age, size, and predator-prey mass ratios, it was predicted that the Edwards should have a long FCL relative to other groundwater communities. Secondly, we synthesize the isotopic literature on stygobiont food webs, excluding hyporheic and soil groundwater systems, with the aim of assessing the relative importance of these factors on stygobiont FCL.

2. Methods

The Edwards Aquifer of south-central Texas is exposed to epigenic dissolution along a narrow escarpment and recharge zone on the northern and western margin of the aquifer (Barker et al. 1994). South and east of the escarpment, Edwards limestones are confined below non-karstic carbonates and clays. Farther south and east, oxygenated, low total dissolved solids (TDS) water rapidly changes to anoxic, sulfide-rich, high TDS waters at a transition zone called the freshwater-saline water interface (FWSWI) (Oetting et al. 1996, includes map).

Two sites (an artesian well and Comal Springs) were chosen for repeated sampling of stygobionts because of their hydrological and geochemical distinctiveness, ease of access, and faunal diversity (Longley 1981; Gibson et al. 2008). The artesian well is in the confined portion of the aquifer approximately 0.5 km from the FWSWI. Comal Springs is a series of springs at the base of the escarpment between the unconfined and confined portions of the aquifer. Discharge at the springs averages 9 m^3s^{-1}. At both sites, animals were collected (USFWS permit# SPR-0390-045) multiple times between June 2010 and March 2012 using 250 μm or 500 μm nets left in place between 4 and 24 hrs. Animals were identified to the lowest possible level (usually species) and kept in filtered spring water for ~5 hrs to allow digestive tracts to clear. Animals were dried at 40 °C for 24–48 hrs. 1mg of dry mass was used for isotope analysis, and multiple individuals were pooled to attain adequate mass for small species. Snails were removed from their shells prior to analysis. N isotope analyses were conducted at the UC Davis Stable Isotope Facility.

For each animal, trophic level was estimated using a Bayesian extension of Post's equation where trophic level of animal $j = 2 + (\delta^{15}N_j - \delta^{15}N_{base})/\Delta\delta^{15}N$, where $\delta^{15}N_j$ and

$\delta^{15}N_{base}$ are the stable N isotope ratios for species *j* and primary consumers, respectively, and $\Delta\delta^{15}N$ is the per trophic level enrichment in N isotope composition (Post 2002b). Trophic level 1 is defined as primary producers. A Bayesian approach allows uncertainty in the estimate to be quantified by treating all three variables as normal distributions with associated means and precisions estimated using sample data ($\delta^{15}N_j$ and $\delta^{15}N_{base}$) and published values ($\Delta\delta^{15}N$). Published values for $_i$ were obtained from McCutchan et al. (2003) and Caut et al. (2009) for guanicotelic and ammonotelic freshwater and terrestrial invertebrates (Vanderklift and Ponsard 2003). Uninformative priors are given for population level means (normal distribution with $\mu = 0$, $\tau = 1e^{-6}$) and precisions (gamma distribution with $\alpha = 0.001$, $\beta = 0.001$). To estimate possible effects of infrequent feeding or nutritional stress, trophic level estimates were also calculated by setting $\Delta\delta^{15}N_{starvation} = \Delta\delta^{15}N + 1.34‰$ based on the observed 1.34‰ increase in $\Delta\delta^{15}N$ due to starvation in a lycosid spider observed by Oelbermann and Scheu (2002). The posterior probability distribution for the trophic level of species *j* was estimated using a Markov Chain Monte Carlo (MCMC) procedure. Two MCMC chains were run, each with 500,000 iterations, a thinning rate of 50, and a burn-in of 1,000. Plots of parameter estimates as a function of MCMC iteration were assessed for adequate burn in, and MCMC convergence was assessed using Gelman and Rubin potential scale reduction factors (Gelman and Rubin 1992). Analyses were run in R v2.15and JAGS v3.2.0.

To search for stable isotope studies of groundwater foodwebs, Google Scholar (http://scholar.google.com) was searched using the words isotope, troglobite, and stygobite simultaneously and the words isotope, troglobiont, and stygobiont simultaneously. Results were cross-referenced for additional studies. In several instances, isotope data were available only as a figure. In these instances, values were estimated by overlaying the figure on a grid with grid size = 0.1‰ in Adobe Illustrator CS. FCL was defined as maximum average species $\delta^{15}N$ – minimum average species $\delta^{15}N$. In instances in which more than one site was sampled, the site with the largest FCL was used for analysis, or if two distinct food webs were indicated, both were used. Individual measurements were used in one instance, when a single species was analyzed. Simple linear regressions were run to assess correlations among $\delta^{15}N$ range and covariates. Covariates included species richness, ecosystem size, ecosystem age, the presence of vertebrate stygobionts, and ecosystem stability. Ecosystem size was modeled as an ordinal variable with four size classes corresponding to systems with a 2 dimensional extent of less than 10 km^2, tens of km^2, hundreds of km^2, and >1,000 km^2. Ecosystem age was estimated as the approximate age of initial karstification, which represents the earliest date in which colonization of a site can begin, whether by epigean or groundwater species. In several instances in which a precise age of karstification was unknown, the beginning of the appropriate epoch was used (e.g., 23.8 mya for Miocene). Ecosystem age was square root transformed for normality. Presence or absence of vertebrate stygobionts was used as a qualitative measure of predator-prey mass ratios. Ecosystem stability was modeled as an ordinal variable with 4 classes defined using the following equation: stability = 1 + 1 if food web is partially or wholly dependent on chemoautotrophic production + 1 if site was not exposed to late Cenozoic glaciations or marine embayments + 1 if karst is partially confined. To assess whether $\delta^{15}N$ ranges were an artifact of incomplete sampling, $\delta^{15}N$ range was also regressed against the proportion of total stygobionts recorded from the site that were included in the isotope analysis (coverage). Multiple regressions were run to assess the interaction between covariates and coverage, but interactions among covariates was not assessed. Significance was adjusted for multiple comparisons using the false discovery rate method of Narum (2006). Akaike information criterion for finite samples size (AICc) was used to evaluate model fit. Analyses were run in R v2.15.

3. Results

163 individuals from 10 different species and 213 individuals from 14 different species were collected from Comal Springs and the artesian well, respectively (Table 1). The asellid isopods *Lirceolus spp.* and the hadziid amphipod *Mexiweckelia hardeni* from Comal Springs and the snails *Phreatodrobia spp.* and the hadziid amphipod *Texiweckelia texensis* from the artesian well were assigned to trophic level 2 for trophic level estimates. One species, the crangonyctid amphipod *Stygobromus russelli*, represented by 2 individuals at the artesian well, had lower $\delta^{15}N$ values than *Phreatodrobia spp.* or *T. texensis* but was not assigned to trophic level 1 because of 1) small sample size, 2) a large body size (11.75 mm), and 3) higher $\delta^{15}N$ values from individuals collected at Comal Springs. The exclusion of *S. russelli* leads to more conservative (i.e. lower) trophic level estimates for other species. Inspection of $\delta^{13}C$ and $\delta^{15}N$ biplots for both sites (data not shown) showed no indication of more than one food chain or evidence that species were feeding on different basal resources. 65 estimates of $\Delta\delta^{15}N$ between -3.2‰ and 8.6‰ were used for trophic level estimates. The mean of the posterior probability ($E(\Delta\delta^{15}N)$) in guanicotelic and ammonotelic terrestrial and freshwater invertebrates = 2.81‰ with 95% equal-tail credible intervals (95% ETCI) = 2.31–3.31‰. Assuming additional 1.34‰ enrichment due to infrequent feeding, $E(\Delta\delta^{15}N_{starvation})$ = 4.15‰ (95% ETCI = 3.65–4.65‰). Stygobionts in the Edwards Aquifer occupied approximately 4 consumer trophic levels assuming trophic enrichment similar to values reported in the literature or 3 consumer trophic levels assuming higher $\Delta\delta^{15}N$ due to infrequent feeding (Table 1). 95% ETCIs for trophic level estimates typically spanned 2 trophic levels, depending on sample size and variability among individuals.

The literature search revealed 10 previous stable isotope studies from subterranean aquatic environments (excluding hyporheic systems), and 5 of these studies analyzed stygobionts from more than 1 site. Three studies were excluded from analysis. Neisch et al., (2012) analyzed 2 anchialine sites in the Yucatan, Mexico but one site had been previously investigated (Pohlman et al. 1997), taxonomic resolution was poor, and whether reported values were for individuals or species means was not specified. Paoletti et al. (2011) investigated one fully aquatic isopod *Monolistra lavalensis*, but $\delta^{15}N$ range could not be calculated because individual values were not reported.

*Table 1. Sample size, $\delta^{15}N$, and mean trophic level estimates for species sampled from an artesian well and Comal Springs, Edwards Aquifer Texas, USA. Estimates are based on published $\Delta\delta^{15}N$ and $\Delta\delta^{15}N$ + 1.34‰, for infrequent feeding. ETCI = equal tail credible intervals. *indicates that multiple individuals were aggregated for samples.*

Species	N	$\delta^{15}N$ (± SD)	Trophic level (95 % ETCI) $E(\Delta\delta^{15}N)$ = 2.81‰	Trophic level (95 % ETCI) $E(\Delta\delta^{15}N)$ = 4.15‰
		Artesian Well		
Artesia subterranea (Amphipoda)	5	14.06 (±1.43)	5.3 (4.32–6.47)	4.23 (3.6–4.92)
Eurycea rathbuni (Caudata)	2	12.28 (±0.95)	4.66 (1.58–7.86)	3.80 (1.72–5.93)
Stygobromus flagellates (Amphipoda)	23	10.82 (±3.46)	4.14 (3.3–5.12)	3.45 (2.89–4.05)
Allotexiweckelia hirsute (Amphipoda)	1	10.47	3.72	3.16
Texiweckeliopsis insolita (Amphipoda)	8*	9.61 (±0.91)	3.71 (3.01–4.52)	3.16 (2.69–3.65)
Lirceolus spp. (Isopoda)	4*	9.08 (±0.91)	3.52 (2.71–4.44)	3.03 (2.48–3.61)
Cirolanides texensis (Isopoda)	20	8.85 (±1.13)	3.44 (2.78–4.19)	2.97 (2.53–3.45)
Palaemonetes antrorum (Decapoda)	22	8.23 (±1.33)	3.22 (2.56–3.96)	2.83 (2.38–3.30)
Moorbdella sp.(Hirudinea)	3	7.77 (±1.38)	3.05 (1.71–4.47)	2.71 (1.81–3.65)
Haedioporus texanus (Coleoptera)	9*	7.49 (±0.43)	2.95 (2.32–3.65)	2.65 (2.22–3.09)
Holsingerius samacos (Amphipoda)	4*	6.75 (±3.61)	2.69 (0.44–4.88)	2.47 (1.03–3.93)
Phreatodrobia spp. (Gastropoda)	1*	5.67	2.31	2.21
Texiweckelia texensis (Amphipoda)	4*	5.62 (±1.79)	2.29 (1.11–3.51)	2.2 (1.4–3.01)
Stygobromus russelli (Amphipoda)	2	2.74 (±0.01)	1.27 (-1.45–1.94)	1.50 (1.03–1.96)
		Comal Springs		
Cirolanides texensis (Isopoda)	2	12.99 (±0.56)	5.10 (3.33–7.08)	4.10 (2.91–5.40)
Sphalloplana sp. (Tricladida)	1	12.46	4.91	3.97
Artesia subterranea (Amphipoda)	1	10.68	4.28	3.55
Stygobromus pecki (Amphipoda)	26	9.92 (±0.79)	4.01 (3.61–4.54)	3.36 (3.13–3.64)
Haedioporus texanus (Coleoptera)	1*	6.66	2.85	2.58
Stygobromus russelli (Amphipoda)	3	6.56 (±1.37)	2.82 (1.58–4.09)	2.55 (1.72–3.40)
Comaldessus stygius (Coleoptera)	1*	6.45	2.78	2.53
Stygoparnus comalensis (Coleoptera)	2*	5.52 (±2.95)	2.44 (-6.5–11.68)	2.30 (-3.73–8.50)
Mexiweckelia hardeni (Amphipoda)	3*	4.75 (±0.89)	2.17 (1.36–3.00)	2.12 (1.56–2.67)
Lirceolus spp. (Isopoda)	6*	4.02 (±0.97)	1.91 (1.46–2.37)	1.94 (1.64–2.25)

Finally, Roach et al., (2011) analyzed insects and a poeceliid fish in a cave in Tobasco, Mexico, but no species were stygobionts. The remaining 7 studies sampled freshwater and saline phreatic and vadose karst groundwater habitats with a broad range of faunal characteristics. These include 1) Peştera Movile and a nearby sulfidic well in Constanţa, Romania (Sarbu et al. 1996), 2) the Frasassi Cave System in Marche, Italy (Sarbu et al. 2000), 3) Cave Springs Cave Arkansas, USA (Graening et al. 2003), 4) the upper Floridan aquifer in Georgia, USA (Opsahl and Chanton 2006), 5) Organ Cave in West Virginia, USA (Simon et al. 2003), 6) Bundera Sinkhole in North Western Australia (Humphreys 1999), and 7) the Mayan Blue cenote in Quintana Roo, Mexico (Pohlman et al. 1997). Table 2 summarizes characteristics of these systems and results of the isotope studies.

11 regressions were run, so significance was set at $p \leq 0.017$. Statistical analysis revealed significant positive relationships between $\delta^{15}N$ range and ecosystem age (r^2 = 0.66, F = 18.26, df = 1 & 8, p < 0.01), ecosystem size (r^2 = 0.52, F = 10.75, df = 1& 8, p = 0.01), and the presence of vertebrates (r^2 not estimated, F = 9.98, df =1 & 8, p = 0.01) (Fig. 1) but not with stability, species richness, or sample coverage. Significant interactions between coverage and age (r^2 = 0.80, F = 36.78, df = 1 & 8, p < 0.001) and between coverage and vertebrates (r^2 = 0.69, F = 10.82, df = 2 & 7, p = 0.007) were detected. AICc suggested that the ecosystem age * coverage model was the best fit, being 5.3 times more likely than the next best model (ecosystem age). The remaining models were highly unlikely to be the best fit models (AICc Δ > 8).

4. Discussion

Analytical solutions for trophic level using fixed values for $\Delta\delta^{15}N$ and trophic base ignore uncertainty in both parameters and provide little information on confidence in trophic level estimates (Post 2002b). 95 % ETCIs for

*Table 2. Published species average $\delta^{15}N$ ranges and covariate data used for linear regressions. Proportion of species is the proportion of total species recorded from the site that were analyzed for stable isotope composition. See text for isotope study references. *indicates $\delta^{15}N$ range for a single species. Covariate references available on request.*

System	$\delta^{15}N$ range	Age (mya)	Stability	Species richness	Ecosystem size	Vertebrate stygobionts	Proportions of species
Comal Springs	9.0 (4.0–13.0)	23.8	4	16	4	1	0.63
artesian well	8.4(5.62–14.06)	23.8	4	22	4	1	0.64
Peştera Movile	3.7(-4.75– -1.05)	5.2	4	20	2	0	0.15
sulfidic well, Romania	4.5(0.2–4.7)	5.2	4	20	2	0	0.15
Frasassi Grotto del Fiume	1.6 (-5.5– -3.9)*	0.2	2	3	1	0	0.33
Cave Springs Cave	6.6 (10.7–17.3)	5.0	1	4	2	1	0.50
Radium Springs	6.3 (11.8–18.1)	3.4	3	4	4	0	0.75
Organ Cave	3.8 (12.2–16)	5	1	8	2	0	0.38
Bundera sinkhole (deep)	7.5 (4.8–12.3)	23.8	2	8	3	1	0.38
Mayan Blue Cenote	4.9 (8.4–13.3)	14	2	19	4	1	0.42

trophic level estimates from Edwards Aquifer fauna typically span approximately one trophic level on either side of the mean. This has important implications for interpretation of food web structure. For example, *Lirceolus spp*. has a slightly higher mean trophic level than the larger cirolanid isopod *Cirolanides texensis*. However, the 95% ETCIs for these estimates overlap, and given the observed data, it is not unlikely that *C. texensis* occupies a higher trophic level than *Lirceolus spp*.

The high $\delta^{15}N$ values observed in some species strongly suggest that their diet is dominated by other predators. This is especially true of the artesiid amphipod *Artesia subterranea*, from the artesian well, and is likely true of several other species, although small sample size precludes a confident estimate of trophic level (e.g., the plethodontid salamander *Eurycea rathbuni* and the flatworm *Sphalloplana sp.*). Despite the surprisingly high trophic level estimate for *A. subterranea*, a 3° predator seems unlikely in a groundwater habitat, even though they occur in other habitats (Vander Zanden and Fetzer 2007). Two possibilities could lead to erroneous trophic level estimates. $\Delta\delta^{15}N$ for these stygobionts may be higher than average values reported for ammonotelic and guanicotelic organisms from freshwater and terrestrial environments. Several studies have discussed potential sources of variability in $\Delta\delta^{15}N$ (Scrimgeour et al. 1995; McCutchan et al. 2003; Vanderklift and Ponsard 2003; Caut et al. 2009). There is no *a priori* evidence for nutritional stress or some other mechanism that would lead to higher $\Delta\delta^{15}N$ in stygobionts, but if the estimated $\Delta\delta^{15}N$ due to infrequent feeding ($E(\Delta\delta^{15}N_{starvation})$ = 4.15‰) more closely approximates actual enrichment in the Edwards Aquifer, the highest trophic level is approximately 4. This still suggests the presence of 2° predators: a departure from typical groundwater foodwebs. However, the mechanism by which these “apex” predators selectively feed on 1° predators is unknown. These data also suggest that animal tissue (either through predation or scavenging) is an important dietary component for several small or presumably detritivorous species such as *Lirceolus spp.* and the atyid shrimp *Palaemonetes antrorum*.

Incorrect assignment of trophic level 2 species would also produce erroneous trophic level estimates. Average $\delta^{15}N$ of fine particulate organic matter in the Edwards Aquifer is 2.28‰, but it is spatially and temporally variable with measured values bracketing values of trophic level 2 species (data not shown). If species such as *P. antrorum, C. texensis,* and *Lirceolus spp.* are primary consumers, species such as *A. subterranea* and *E. rathbuni* would feed approximately at trophic level 4 or 3 depending on $\Delta\delta^{15}N$. This does not explain the lower $\delta^{15}N$ values observed in several other species and would require that those other species are not consumed by other members of this food web.

On a global scale, analysis of $\delta^{15}N$ range revealed important differences among sites, but incomplete sampling of species for isotopic measurements (coverage) significantly interacted with other covariates, resulting in uncertainty in the strength of interactions between $\delta^{15}N$ range and covariates. Nevertheless, ecosystem age appeared to be the most important factor influencing FCL in the stygobiont dominated communities assessed, despite the effect of incomplete coverage. Relatively young habitats may not have had the time necessary for colonization by the species required to fill specific trophic niches and create complex food chains. This may explain the low $\delta^{15}N$ range observed in the productive Frasassi Caves and Radium Springs in the upper Floridan aquifer, but it contrasts with findings from lakes, in which older systems had shorter food chains (Doi et al. 2012). As seen in other systems (Sabo et al. 2010), FCL is also correlated with habitat size. This may be, in part, through interaction with other important mechanisms such as mitigating the negative effects of disturbance (Sabo et al. 2010) or affecting nutrient availability (Post 2002). Severely nutrient limited systems likely do not have adequate resources to maintain viable populations of higher trophic level species regardless of age or size. FCL in temperate cave systems dependent on allochthonous input, including Organ Cave and Cave Springs Cave, may ultimately be limited by resource availability. Data were not available to assess productivity in this study, but in surface habitats, support for a productivity – FCL relation has been weak (Post et al. 2000;

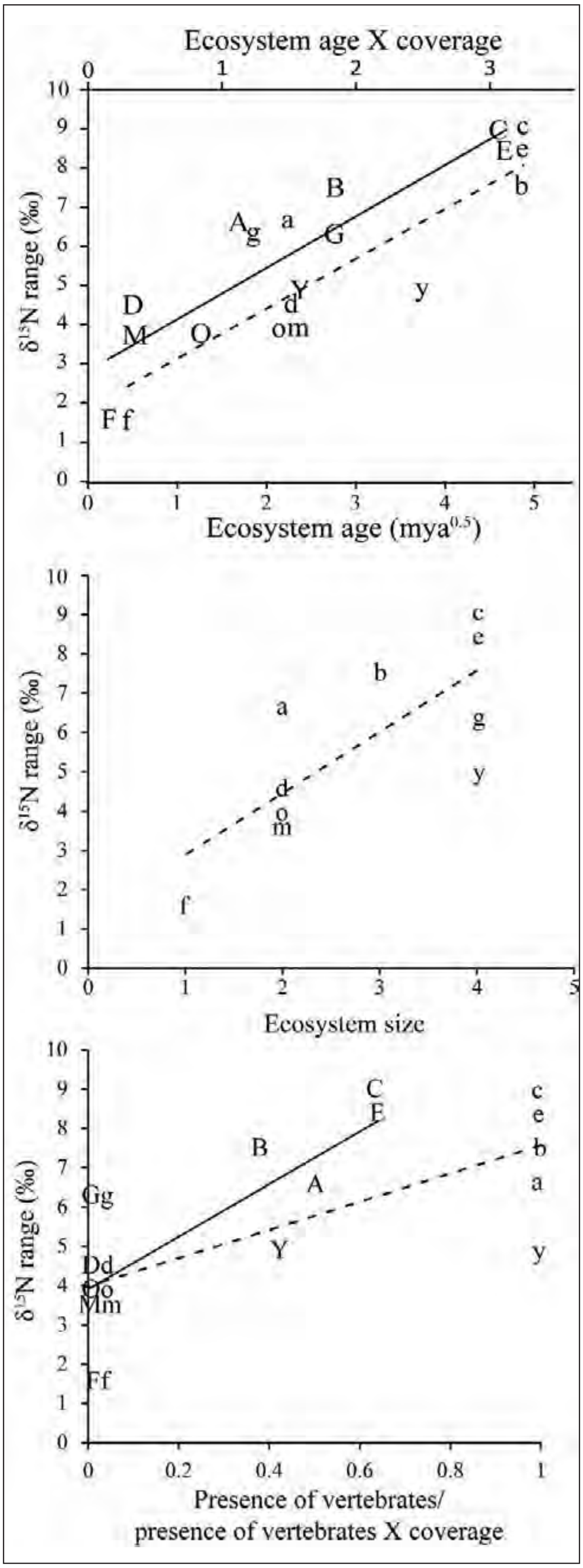

Figure 1. Significant regressions of $\delta^{15}N$ range versus A) ecosystem size, B) ecosystem age, and C) the presence of vertebrates. Solid regression lines, capital letters, and top X axis on pane A are for interaction effects models and dashed lines and lower case letters are for simple linear regressions. A = Cave Springs Cave; B = Bundera Sinkhole; C = Comal Springs; D = sulfidic well; E = artesian well; F = Frasassi Grotto del Fume; G = Radium Springs; M = Pestera Movile; O = Organc Cave; Y = Mayan Blue Cenote. See text for citations and regression statistics.

Sabo et al. 2010, but see Takimoto and Post 2012). No relation between species richness and FCL was observed, but the relation between species richness and diversity is neither direct nor monotonic (Cardinale et al. 2009). In old and productive systems, long food chains are still unlikely when size differences between primary consumers and predators are small. This may be the case for Movile Cave, where the largest predators (the hemipteran *Nepa anophthalma* and the leech *Haemopis caeca*) are small relative to large decapod crustaceans or vertebrate predators present in other groundwater habitats. However, the presence of vertebrates is a poor measure of predator-prey mass ratios, and its affect was also dependent on coverage, so additional data is necessary to better understand the importance of this covariate. In old, large, and productive systems with taxa exhibiting a diverse range of body sizes, FCL may be determined by the long-term stability of the system. FCL in the Edwards Aquifer ecosystem appears to be longer than FCL in the Mayan Blue Hole and Bundera Sinkhole ecosystems, and this may be due to the semi-confined nature of the Edwards Aquifer and its distance from Pleistocene shorelines. The latter systems are both anchialine, having connections to the surface and the ocean. The “openness” of anchialine habitats makes them susceptible to disturbance associated with variability in temperature, precipitation, and allochthonous input and to fluctuating sea levels during the Pleistocene.

5. Conclusions

Determination of $\delta^{15}N$ range in stygobiont tissues is a simple and inexpensive method for quantifying FCL. $\delta^{15}N$ values for stygobionts from the Edwards Aquifer suggest the longest FCL yet reported from a groundwater system. These data strongly suggest the presence of secondary predators, which is unusual for subterranean systems. Quantifying the relative importance of historical and environmental factors influencing groundwater FCL is limited by the small number of foodweb studies, incomplete sampling of taxa, and potential covariance among predictor variables. Nevertheless, available data suggests that ecosystem age and, to a lesser extent, ecosystem size and predator-prey interactions influence FCL in groundwater habitats. Because of their relatively low diversity and limited number of potential food resources relative to epigean habitats, groundwater ecosystems are ideally suited to large scale analyses of historical and environmental influences on FCL.

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CAVE-DWELLING FAUNA FROM KARST AREAS OF PORTUGAL

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Karst areas of Portugal occupy a considerable part of the territory and harbor more than 2,000 known caves. The complex biogeographical history of the Iberian Peninsula allowed the survival of several relict arthropod refugees in the subterranean environment. The knowledge about cave-dwelling fauna from karst areas increased significantly in the last six years. The cave-dwelling fauna of main karst areas of Portugal is presented.

1. Introduction

Although the first published register of cave-dwelling fauna from Portugal was in the monograph "Trechorum oculatorum" (Putzeys 1870), the pioneer of the Portuguese subterranean biology is considered António de Barros Machado, an eminent arachnologist that began the methodical exploration of caves in Portugal in the late 1930's, performing an intense sampling effort on terrestrial cave-dwelling fauna along the karst caves of Portugal (Gama and Afonso 1994; Reboleira et al. 2011a). Together with his brother Bernardino de Barros Machado, they described more than 300 caves in the "Inventário das cavernas calcárias de Portugal" (Machado and Machado 1941). In the same decade, the discovery of *Proasellus lusitanicus* (Frade 1938) from the Alviela spring in the Estremenho karst massif, paved the way for the study of stygobionts in the following decades by researchers of the former Instituto de Zoologia "Dr. Augusto Nobre" from Porto University, such as José Braga, Amilcar Mateus or Odette Afonso (Reboleira et al. 2012a).

The research in troglobiont fauna almost stopped for three decades and despite of several intents along this period, only in the last six years it has been increasing

More than 14 karst units are known from Portugal, the most important are Jurassic limestones and dolomites: Estremenho (Serras de Aire e Candeeiros), Algarve, Sicó-Condeixa-Alvaiázere, Arrábida and Montejunto, while some caves are found in Cambrian limestone and marbles in Estremoz and Adiça in the Alentejo, and in Vimioso on the northeast region (Reboleira et al 2011). Caves are found from the sea level in Arrábida, Boa Viagem and Algarve up to the higher karst point at 679 meters in Serra de Aire.

2. Methods

During the last six years more than 60 caves in the main karst units (Fig. 1) have been sampling by direct search combined with the use of baited traps, in main karst areas of Portugal (for detailed information see Reboleira 2012). Collected animals were sorted and identified.

3. Results and discussion

3.1. Physical parameters

The largest known cave in Portugal is Gruta do Almonda, with more than 14 km and the deepest is currently Algar do Palopes around -260 m. The air temperature of thermically isolated areas of studied caves ranges from 11 ºC in caves located in the north, to 21.5 ºC in caves at sea level in Arrábida and Algarve.

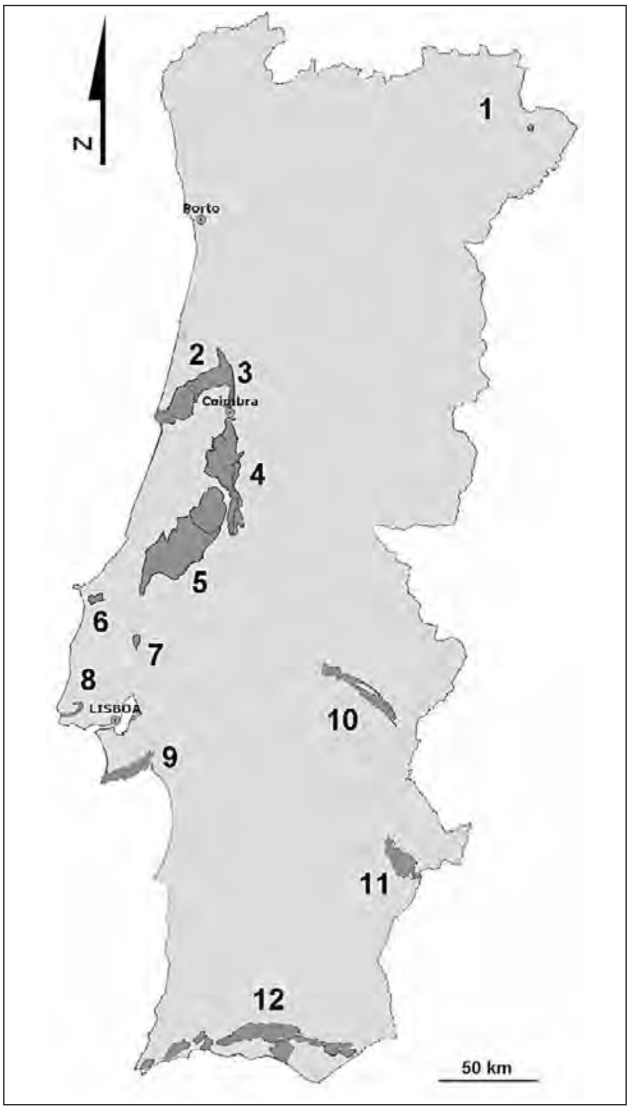

Figure 1. Main karst units of Portugal. 1 – Dine and Vimioso; 2 – Outil-Cantanhede; 3 Mealhada; 4 – Sicó; 5 – Estremenho; 6 – Cesaredas; 7 – Montejunto; 8 – Lisbon Peninsula; 9 – Arrábida; 10 – Estremoz-Cano; 11 – Adiça-Ficalho; 12 – Algarve.

3.2. Cave-dwelling fauna (Table 1)

Only 68 cave-adapted species have been found so far in Portuguese karst caves, including described and undescribed species. Troglobionts represent 81% and stygobionts 19% of the cave-dwelling from karst areas of Portugal.

The Algarve, located in the south of the country is the richest massif of Portugal, followed by Sicó and Estremenho massifs. It harbours the most remarkable biogeographic relicts, i.e. species with no relatives at surface in its geographical realm, such as the pseudoscorpions *Titanobochica magna* and *Lusoblothrus aenigmaticus*, the terrestrial isopod *Troglarmadillidium machadoi*, the dipluran *Litocampa mendesi* or the nicoletiid thysanuran *Squamatinia algharbica* (Reboleira et al. 2010a, 2010c, 2012b, Reboleira and Enghoff 2013; Enghoff and Reboleira 2013). Concerning aquatic cave-dwelling fauna, several works have been done regarding micro a macrocrustaceans (Lescher-Moutoué 1981) but only one species of *Stenasellus* has been identified as truly stygobiont (Reboleira 2012).

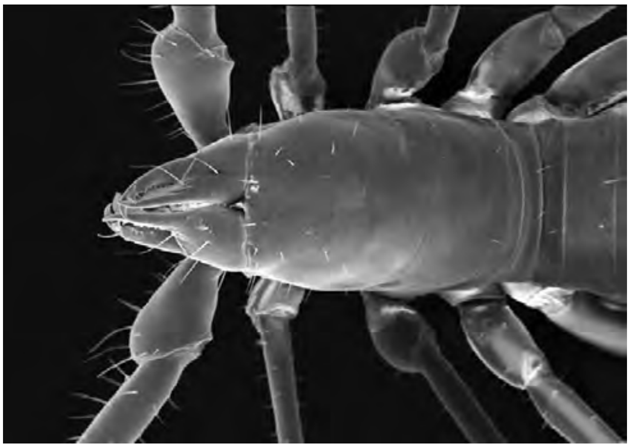

Figure 2. Carapace of cave-dwelling pseudoscorpion ***Titanobochica magna*** *Zaragoza and Reboleira, 2010.*

Sicó is the richest massif of the central Lusitanian karsts, it has several interesting cave-dwelling species, such as several species of pseudoscorpion *Roncocreagris* or the recent discovery of the staphylinid beetle *Domene lusitanica* (Reboleira et al. 2011b). This massif is linked with the karsts of the Cantanhede-Outil-Mealhada, located at north of Mondego river, where the species of terrestrial isopod *Porcellio cavernicolus* is also distributed.

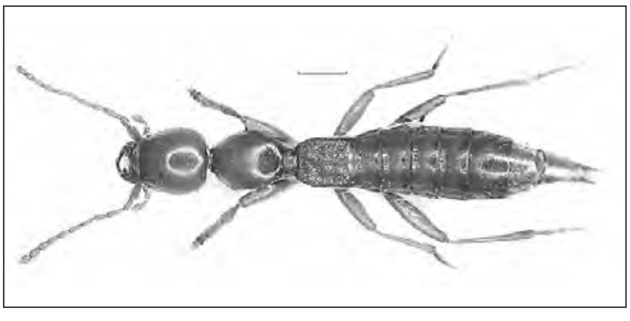

Figure 3. The beetle ***Domene lusitanica*** *Reboleira and Oromí, 2011, scale 1 mm.*

Estremenho is the largest karst massif of Portugal with major number of known caves, but it is the third in cave-dwelling richness (Reboleira 2012). Three species of beetles from genus *Trechus* are known, with allopatric distribution in each subunit of this massif (Reboleira et al. 2009). The spider *Nesticus lusitanicus* is found regularly in caves of this massif (Reboleira 2007; Reboleira et al. 2013a). Five

Figure 4. The stygobiont ***Proasellus lusitanicus*** *(Frade 1938).*

species of stygobionts are known from Estremenho, the annelid *Rhyacodrilus lindbergi* and four crustaceans, isopods of the genus *Proasellus* (Fig. 4) and amphipods of the genus *Pseudoniphargus* (Reboleira et al. 2012a).

Montejunto, is located at south of Estremenho massif and only five species of cave-dwelling animals are known, being the opilion *Iberosiro distylos* and the beetle *Trechus tatai* (Reboleira et al. 2010b) the only described so far.

The Cesaredas plateau is a karst located near Montejunto that share with it some species of cave-dwelling pseudoscorpions and it harbours the northen cave-dwelling a thysanuran of the Iberian Peninsula (Reboleira et al. 2012a).

In the Lisbon Peninsula there are several small karst areas. In Cascais there is a cave-dwelling species of isopod of the genus *Troglonethes* and in Assafora, species of crustaceans *Proasellus assaforensis* and of the genus *Pseudoniphargus* are found in the subterranean pounds (Afonso 1988; Reboleira et al. 2012).

In Arrábida massif two anchialine caves are known, along the coastline. A cave-dwelling beetle and two spiders are know, *Teloleptoneta synthetica* and *Anapistula ataecina*, as well as stygobiont crustaceans of the genus *Pseudoniphargus* (Reboleira et al. 2012a).

Along the Alentejo province, there are two main karst areas: Estremoz-Cano massif and Adiça-Ficalho, with several cave-dwelling species, with more affinities to the endogean habitats.

In the north of the country there are a few caves in small karst areas and one species of cave-dwelling species is known, the isopod *Trichoniscoides serrai* (Reboleira 2012).

Our knowledge about faunistics of cave-dwelling species of Portugal increased considerably in the past six years and this important part of speleological heritage is endangered due to antropogenic pollution and quarrying activities in several karst areas.

Table 1. Cave-dwelling species described from karst areas of Portugal. T, troglobionts, S, stygobionts.

Group	Family	Species	T/S	Massifs
Annelida	Tubificidae	*Rhyacodrilus lindbergi* Hrabe, 1963	S	Estremenho
Pseudoescorpiones	Chthoniidae	*Chthonius cadosoi* Zaragoza, 2012	T	Arrábida, Montejunto
	Neobisiidae	*Roncocreagris blothroides* (Beier, 1962)	T	Sicó
		Roncocreagris cavernicola (Vachon, 1946)	T	Sicó
	Bochicidae	*Titanobochica magna* Zaragoza and Reboleira, 2010	T	Algarve
	Syarinidae	*Lusoblothrus aenigmaticus* Zaragoza and Reboleira, 2012	T	Algarve
Araneae	Dysderidae	*Harpactea stalitoides* Ribera 1993	T	Algarve
	Leptonetidae	*Teloleptoneta synthetica* (Machado, 1951)	T	Arrábida, Alentejo,
Algarve				
	Nesticidae	*Nesticus lusitanicus* Fage, 1931	T	Estremenho
Opiliones	Sironidae	*Iberosiro distylos* Bivort and Giribet, 2007	T	Montejunto
	Symphytognathidae	*Anapistula ataecina* Cardoso and Scharff, 2009	T	Arrábida
Chilopoda	Lithobiidae	*Lithobius dimorphus* Machado, 1946	T	Algarve
Diplopoda	Paradoxosomatidae	*Boreviulisoma barrocalense* Reboleira and Enghoff, 2013	T	Algarve
	Blaniulidae	*Acipes bifilum* Enghoff and Reboleira, 2013	T	Algarve
		Acipes machadoi Enghoff and Reboleira, 2013	T	Algarve
Amphipoda	Melitidae	*Pseudoniphargus mateusorum* Stock, 1980	T	Arrábida
Isopoda	Asellidae	*Proasellus arthrodilus* (Braga, 1945)	T	Sicó
Isopoda	Stenasellidae	*Stenasellus galhanoae* Braga, 1962	S	Algarve
	Asellidae	*Proasellus arthrodilus* (Braga, 1945)	S	Sicó
		Proasellus assaforensis Afonso, 1988	S	Lisbon Peninsula
		Proasellus lusitanicus (Frade, 1938)	S	Estremenho
		Proasellus spinipes Afonso, 1979	S	Estremenho
	Porcellionidae	*Porcellio cavernicolus* Vandel, 1946	T	Sicó
	Trichoniscidae	*Trichoniscoides broteroi* Vandel, 1946	T	Sicó
		Trichoniscoides subterraneus Vandel, 1946	T	Estremenho
		Trichoniscoides meridionalis (Vandel, 1946)	T	Sicó, Cesaredas
		Trichoniscoides ouremensis (Vandel, 1946)	T	Estremenho
		Trichoniscoides serrai Cruz, 1993	T	Vimioso
	Armadillidae	*Troglarmadillidium machadoi* (Vandel, 1946)	T	Algarve
Collembola	Onychiuridae	*Onychiurus confugiens Gama, 1962*	T	
Diplura	Campodeidae	*Podocampa* cf. *fragiloides* Silvestri, 1932	T	Central massifs, Algarve
		Litocampa mendesi Sendra and Reboleira, 2010	T	Algarve
Zygentoma	Nicoletiidae	*Squamatinia algharbica* Mendes and Reboleira, 2012	T	Algarve
Coleoptera	Carabidae	*Trechus gamae* Reboleira and Serrano, 2009	T	Estremenho
		Trechus lunai Reboleira and Serrano, 2009	T	Estremenho
		Trechus machadoi Jeannel, 1942	T	Estremenho
		Trechus tatai Reboleira and Ortuño, 2010	T	Montejunto
	Staphylinidae	*Domene lusitanica* Reboleira and Oromí, 2011	T	Sicó
	Leiodidae	*Speonemadus angusticollis* (Kraatz, 1870)	T	Algarve

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BIOSPELEOLOGICAL RESEARCH IN THE LAO P.D.R.

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Laos, together with neighbouring Vietnam, has been recognized as one of the hotspots of biodiversity in the recent years. Many of the new species found are associated with karst, thus a similar high biodiversity is to be expected from the cave fauna. The first cave species from Laos was described in 1920, in the 80 years to follow a mere four further cave species have been described. The discovery of the Giant Huntsman Spider, *Heteropoda maxima*, described from museum material in 2001, constitutes a turning point in the research of the Lao cave fauna, since it triggered a still ongoing survey of the Lao spider fauna, including many cave species. It was also the starting point of the biospeleo-logical research presented here. Within the framework of the Northern Lao-European Cave Project and the French Khammouane Expedition, collection of cave fauna during the annual expeditions yielded to date a total of 24 species new to science. Included are major discoveries like a blind cave fish, an ancient scorpion, a new huntsman spider of the genus *Heteropoda* and several *Sinopoda*. A summary of our research on the Lao cave fauna is presented here.

1. Introduction

The People's Democratic Republic of Laos is a small land-locked country in Southeast Asia, which only recently has been recognized as a hotspot of biodiversity, like its neighbour Vietnam. Both countries are home to extensive karst landscapes, which constitute some of the habitats least accessible to man, and thus offering essential refuges for wildlife. Thus it doesn't come as a surprise that several of the newly discovered species seem to be associated with karst. The most well-known example is the rock rat *Laonastes aenigmamus*, others are the Limestone Leaf Warbler *Phylloscopus calciatilis*, the Bare-faced Bulbul *Pycnonotus hualon*, the Gymnure *Hylomys megalotis*, the two rats *Saxatilomys paulinae* and *Tonkinomys daovan-tieni* and the pit viper *Triceratolepidophis sieversorum* (Steiner 2012). Naturally, these karst landscapes are riddled with caves, ranging from foot caves a few meters long to giant caves like Tham Xe Bangfai with its tunnels up to 80 meters wide and high or the Tham Nam Non system with a length exceeding 30 kilometers. An equally divers cave fauna is thus to be expected. However, very few researchers have taken up the challenge so far. Biospeleological research in the Lao P.D.R. is thus still in its infancy. The present article will give an review of the cave species known and the research done in Laos so far, and summarize the results of our ten years of surveying cave fauna in Laos.

2. Historic overview

The first description of a species from caves in Laos, was a cave cricket, *Diestrammena vitalisis*, published by Chopard (1920). Of the locality, only the province is stated, Xieng Khouang. It was followed by another cave cricket, *Eutachycines cassani* from two caves in Khammouan, published also by Chopard (1954).

In the 1990's, a woodlouse, *Exalloniscus bessoni*, from Tham Rusi, Luang Prabang Province, was described (Dalens 1992), a record of birds reported the swift *Apus pacificus* from caves in Khammouane Limestone NBCA (Duckworth et al. 1998), without naming specific ones, a report on shrews mentiones several species found in caves in Khammouan Province (Smith et al. 1998). Next, WWF published a wildlife report (Duckworth et al. 1999). It includes a section on bats, many stated to roost in caves, but usually without naming specific caves. Finally, a new crab, *Erebusa calobates*, was described from three caves in Khammouan Province (Yeo and Ng 1999), and the first cave fish from Laos, *Troglocyclocheilus khammouanensis* was described from Tham Khoun Don, Khammouan Province (Kottelat and Bréhier 1999).

Thus, for the first 80 years, beginning with the first cave record, a mere five new species from caves in Laos have been described, and only marginally more known species were reported. With the gradual opening of the country to tourism, records of cave species and discoveries of new cave species started to increase.

The year 2000 saw a bat survey of Khammouan Province published (Robinson and Webber 2000), including several cave records, and the description of the first two cave beetles, *Laosaphaenops deharvengi* and *Eustra lao* from caves in Vientiane Province (Deuve 2000). The Dutch AMIS expedition 2000 to the area around Nong Khai, Luang Prabang province included also a thorough bat survey of the surveyed caves (Damen et al. 2003).

The Lao chapter of the Encyclopaedia Biospeologica (Besson et al. 2001) gave the first overview of the state of knowledge regarding the biospeleology of Laos, though many of the records were of specimens not or only tentatively identified.

In 2002, a second cave fish, *Schistura kaysonei* was published from Laos (Vidthayanon and Jaruthanin 2002). The locality stated, Phu Tham Nam Cave in Khammouan Province, is somewhat obscur. The coordinates given are in an unlikely area, a hill of this name is found in Khammouan at a different position, but no cave in this hill is known to any of the speleologists working in Khammouan province.

The following year, *Hipposideros scutinares*, a new species of bats was described from caves in Bolikhamxai and Khammouan Province (Robinson et al. 2003) as well as *Leptogenys khammouanensis*, probably the first cave-associated ant worldwide, found in Khammouan Province (Roncin and Deharveng 2003).

A major impact has the description of the huntsman spider *Heteropoda maxima* from museum material in the Natural History Museum in Paris, which was collected in the 1930's (Jäger 2001). It was popularized as the largest spider in the world, based on the legspan of a male specimen, measuring 30 cm. It triggered an ongoing research of the spiders of Laos, which yielded many cave records and new cave species. This research also brought the auther to Laos in the first place.

3. Methods

Cave fauna was recorded and collected by the author from 2003 to 2008 within the frame of the French Khammouan Expedition, and from 2003/04 to date as part of the Northern Lao-European Cave Project. Invertebrates and fishes were sampled by hand and preserved in 70–90% alcohol. Vertebrates other than fishes were only photographed. Additionally, skulls or mumies of bats and other mammals, which were found on the ground, were also collected. The specimens were determined by various specialists as far as possible, these remained in their rerspective collections. All records, own as well as those gleaned from the literature, are stored in a relational data base.

4. Results and discussion

Currently, 273 taxa determined at least to generic level are known from caves of the Lao P.D.R. 134 of these taxa were collected or recorded during our research. A total of 24 new species were described from cave specimens collected during the present surveys or including cave material collected during the present survey (Table 1). Annotations to some of the species or groups are given in the following. Reviews of the cave fauna of Laos are found in Besson et al. (2001), Boonman and Steiner (2005) and Steiner (2008, 2010).

4.1. Bats and other mammals

Larg bat colonies are rarely encountered in Laos. The local population is hunting bats for food, and accessible caves are always known to the villagers. Thus usually only few individuals of bats remain. A lot of caves show signs of hunting in the form of scaffolding, entrances closed by branchwork or long bamboo poles found for knocking down bats. The few larger colonies we have seen were hanging in inaccessible places, either above deep shafts or above a river, where they are safe from hunting, since killed animals can't be retrieved. Unfortunatly, it's equally impossible to find skulls of dead bats in these locations. In total, we were able to record 16 different species of bats (Steiner 2010).

Rats were regularly encountered in Lao caves. They are probably conspecific with *Leopoldamys sabanus*, identified by skulls found in caves in Luang Namtha Province, and also reported by Smith et al. (2004).

Tracks and quills of porcupines are found sometimes quite deep inside the caves, and tracks and droppings of the serow in entrance areas of caves with large portals.

4.2. Reptiles and amphibia

We found the the pit viper *Triceratolepidophis sieversorum* up to several hundred meters inside several caves of Khammouan Province. Other snakes encountered are probably only accidential visitors. Geckos or gecko eggs were regularly seen in the entrance areas but none could be identified with any certainty.

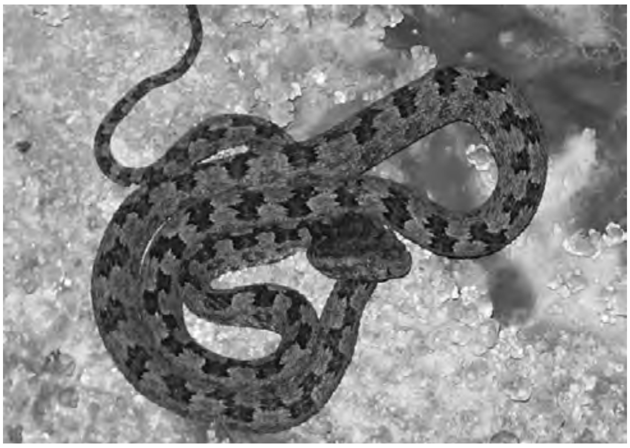

Figure 1. Triceratolepidophis sieversorum.

Frogs are frequently found in the entrance areas of damp caves or even deep within in river caves. Species identified from pictures belonged to the *Rana chloronata*- and the *R. nigrovittata*-complex.

4.3. Fish

Laos is a country with abundant rivers and large kast areas. It is thus astonishing that only two species of cave fish have been reportet so far. Many caves are crossed by allochthonous rivers, fishes are regularly seen there, the few species who were identified are all surface species.

Figure 2. Bangana musaei.

However, in 2007 and 2008, we collected white cave fishes in the Grotte des Nuages and Tham Pong. The fishes have been described as a new species, *Bangana musaei* (Kottelat and Steiner 2010), the third cave fish from Laos. It is without eyes, the smallest known species of the genus and also the first cave species. The fish has been observed only in a single residual pool in each cave. This is probably not their primary habitat but the only one where they are accessible to humans Nothing else is known of its ecology.

4.4. Spiders

One of the most characteristic species found in the caves of Laos are the large huntsmen spiders of the genus *Heteropoda* in the family Sparassidae. They are usually up to a good hand-size and can be often seen from several meters away by their blueish eye-shine. They are found in almost all caves. Four species are found regularly in caves, *H. aemulans, H. maxima, H. simplex* and *H. steineri*, show a clear geographical distribution pattern.

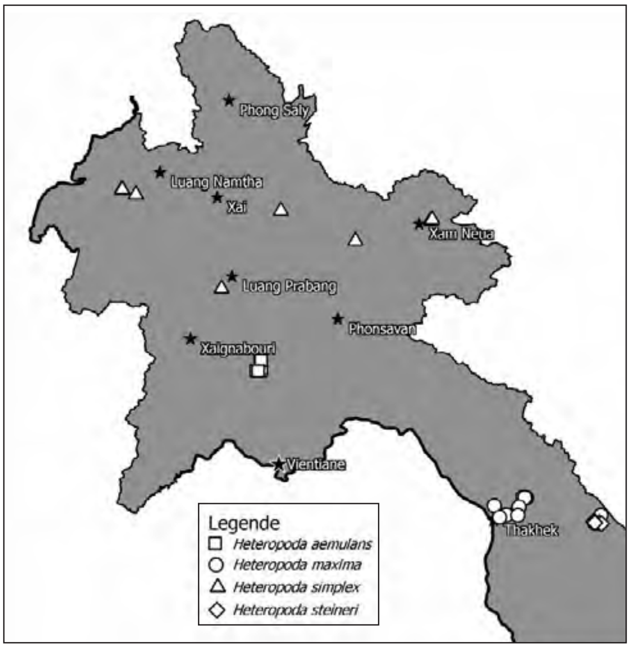

Figure 3. Distribution of cave Heteropoda species.

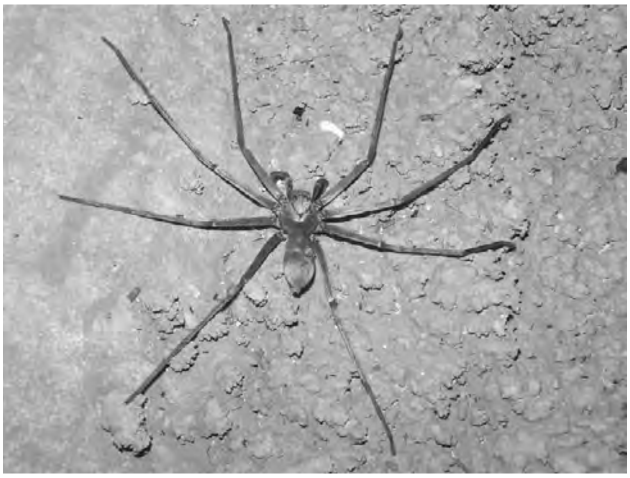

Figure 4. Heteropoda steineri.

H. aemulans is restricted to the karst area around Vang Vieng (Vientiane Province), *H. maxima*, as the largest species, also occupies the area of the largest caves, i.e. Khammouan and Bolikhamsai Province, *H. steineri* has so far only been found at the upper reaches of the Xe Bangfai river in Khammouane. Interestingly, *H. maxima* and *H. steineri* share a sympatric distribution, and have both been seen in the same cave (Tham Xe Bangfai and Grotte de Nuages). However, they seem to occupy different ecological niches. *H. maxima* was found in these cave only close to the entrances or daylight openings, while *H. steineri* was always deep within the cave. It is the only *Heteropoda*-species which shows troglomorphic traits like a uniform color and reduced eyes. All 3 species have not been found outside of caves and should be regarded as troglophilic at least. *H. simplex*, originally described from Japan, covers the whole north of Laos from Luang Namtha to Huaphan Province. It is found outside of caves as well, but mostly in dark and humid places. For literature, see Bayer and Jäger 2009; Jäger 2001, 2007; Jäger and Praxaysombath 2009; Steiner 2010.

The genus *Sinopoda*, closely related to *Heteropoda*, but more strongly cave adapted, was only recently found to be most divers in Lao caves (Jäger 2012). With the exception of *Sinopoda tham*, each species seems to be restricted to a single cave (Fig. 6). *Sinopoda scurion* from the so-called Sinopoda Cave, the only of these species not collected by us, gained fame as the first blind cave spider from Laos.

Figure 5. Sinopoda tham.

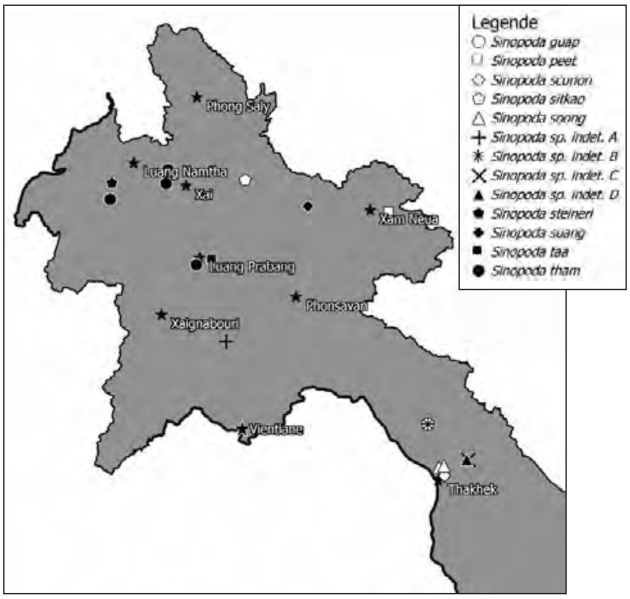

Figure 6. Distribution of Sinopoda species.

Two further spider families were shown to be rather divers in Lao caves, with several new species described: The Psechridae (Bayer and Jäger 2010; Bayer 2012) and Pholcidae (Huber 2005, 2011).

Other spiders described from Lao caves are found in Logunov and Azarkina 2007, Jäger (2007), Jäger and Praxaysombath (2009, 2011) and Wang et al. (2008).

4.5. Other arachnids

A very large whip scorpion, *Typopeltis magnificus* has been described from caves in Khammouan Province (Haupt 2004). It is not uncommon, and usually found in assemblies of several individuals, an unusual behaviour for whip scorpions (Jäger, pers. comm.)

Two small scorpions collected at Tham Xe Bangfai during the French Khammouan Expedition proved to be a scientific sensation. They were described as *Troglokhammouanus steineri* and placed in a family thought to be very ancient, which previously consisted of a single member from central Asia (Lourenço 2007). Following this discovery, two further species of this family have been found in caves in heighbouring Vietnam, and a third one, *Vietbocap lao*, is reported from Tham Nam Lot, Khammouan Province (Lourenco 2012). This genus shows stronger troglomorphic features than the first.

Figure 7. Troglokhammouanus steineri.

Opiliones are commonly found in most of the Lao caves, due to a lack of specialists, they remain unidentified so far.

4.6. Insects

Cave crickets, most probably species of the genus *Diestrammena* and related genera, are characteristic of Lao caves. They are usually the most common animal, found virtually in all caves, and probably also the most common prey of all predators in the cave. At least three different species, probably many more, were collected.

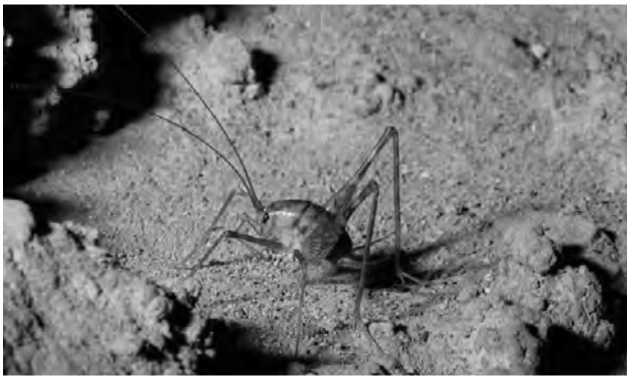

Figure 8. Cave cricket.

The specimens are currently studied at the Russian Academy of Science in St. Petersburg, identifications are still pending.

A rather conspicious moth, *Erebus macrops* (family Noctuidae) is often seen on cave walls close to the entrance in Northern Laos. Larvae of tineids or the cases they build are regularly found in guano, but none could be raised to the imago and thus identified. The association of tineids with caves respective guano itself is well known. All other moths are probably accidential visitors.

A cockroach found in Tham Peung at the Xe Bangfai, Khammouan, has been described as *Rhabdoblatta memnonia*, together with epigean material from Vietnam (Anisyutkin 2009).

A wide variety of other insects have been collected during these our expeditions, including beetles, earwigs, cock-roaches, flies, fruit flies, mosquitos, fungus gnat and other dipters, assassin bugs, water bugs, cicada and other bugs, ants, termites, ant lions and collembola. None of these has been identified so far.

4.7. Other invertebrates

The long-legged cave centipede, *Thereuopoda longicornis* (fam. Scutigeridae) (P. Stoev, pers. comm.), is another character species of Lao caves. It's distribution ranges from all of Southeast Asia to Australia and Papua New Guinea. In the literature, it is often confused with *Scutigera decipiens* (a nomen nudum).

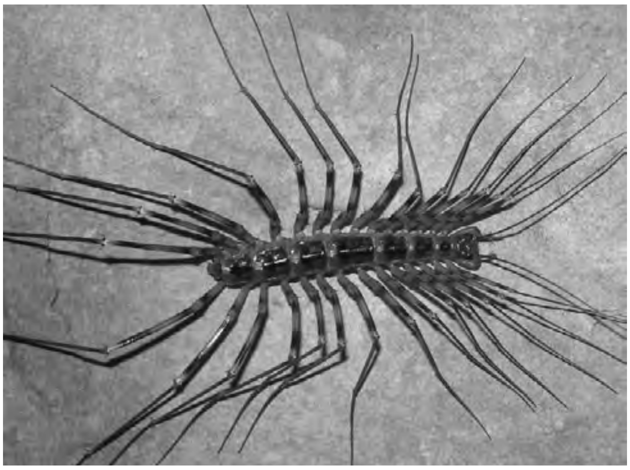

Figure 9. Thereuopoda longicornis.

Millipedes were common in all but the very dry of the Lao caves, sometimes assemblies of quite large numbers were found. However, most of the specimens are still awaiting identification. *Plusioglyphiulus steineri* (family Cambalopsidae) from Tham Kamuk, Khammouan Province (Golovatch et al. 2009) and *Sinocallipus steineri* (family Sinocallipodidae) from Tham Gia, Luang Prabang Province (Stoev and Enghoff 2011) have been described as new species.

Shells of snails are commonly found in caves, though it is usually impossible to determine whether they have just been washed in or not. From living specimens, four new species have been described from cave entrance areas of Luang Namtha Province, one named in honour of our expedition member Liz Price, *Sinoennea lizae* (Maassen 2008).

Grey and pink leeches were found in 2006 in Tham Nam Rok, Vieng Phoukha area, and 2007 in Tham Deu (Phou Khoun area) and Tham Thia Thong (Vieng Thong area). They most probably belong to a species which has been described as *Haemadipsa cavatuses* from specimens of a Chinese cave. It is reported to feed on bats (Borda and Sidall 2010) We also found the same species in caves in Myanmar. A new family, Titetrabdellidae, will be created to accommodate the new species and its sister taxon.

Table 1. New species described from or including cave specimens from the present research.

Group	Family	Species	Cave
Fish	Cyprinidae	*Bangana musaei* Kottelat and Steiner, 2010	Grotte de Nuages, Tham Pong
Cockroach	Blaberidae	*Rhabdoblatta memnonia* Anisyutkin, 2009	Tham Peung
Spider	Sparassidae	*Heteropoda steineri* Bayer and Jäger, 2009	Tham Xe Bangfai
		Sinopoda steineri Jäger, 2012	Tham Nam Eng
		Sinopoda tham Jäger, 2012	Tham Chom Ong
		Sinopoda sitkao Jäger, 2012	Tham Doun Mai
		Sinopoda taa Jäger, 2012	Tham Nguen
		Sinopoda suang Jäger, 2012	Tham Ho Neung
		Sinopoda peet Jäger, 2012	Tham Ma Liong
		Sinopoda guap Jäger, 2012	Tham Nam Non
		Sinopoda soong Jäger, 2012	Tham Pha Yot
	Pholcidae	*Pholcus steineri* Huber, 2011	Tham Chom Ong, Tham Na Thong, Tham Mokfek
		Pholcus namou Huber, 2011	Tham Muay, Tham Roj Ru
		Pholcus thakek Huber, 2011	Tham Kamuk
		Pholcus bangfai Huber, 2011	Tham Xe Bangfai
		Pholcus namkhan Huber, 2011*1*	Tham Pha Man
		Pholcus jaegeri Huber, 2011	unnamed cave at Ban Tham
	Psechridae	*Psechrus steineri* Bayer and Jäger, 2010	Tham Pha Leusi
		Psechrus ancoralis Bayer and Jäger, 2010	Tham Mue, Tham Na Thong, Tham Seua-Tham Nam Lot
	Salticidae	*Spartaeus banthamus* Logunov and Azarkina, 2007	Tham Pha Ban Tham
	Amaurobiidae	*Notiocoelotes laosensis* Wang, Xu and Li, 2008	Tham Kamuk
Scorpions	Pseudochactidae	*Troglokhammouanus steineri* Lourenço, 2007	Tham Xe Bangfai
Millipedes	Cambalopsidae	*Plusioglyphiulus steineri* Golovatch, Geoffroy, Mauriès,& Van den Spiegel 2009	Tham Kamuk
	Sinocallipodidae	*Sinocallipus steineri* Stoev and Enghoff, 2011	Tham Gia

5. Discussion and Conclusions

Although a substantial amount of information on the cave fauna has been gathered so far, the biospeleology of Laos is still in the stage of simply compiling an inventory of the cave fauna. We are just beginning to understand the geographic patterns of the first groups. The caves of the Upper Xe Bangfai seem to be a hot spot with several new species. There also seems to be a tendency towards giantism, represented by worlds largest spider *Heteropoda maxima*, the whip spider *Typopeltis magnificus*, the longlegged centipede *Thereuopoda longicornis* and a yet undiscribed giant harvestman, which made headlines recently for its leg span of more than 30 cm.

However, we are still far away from describing even parts of the cave ecology of Laos – the ultimate goal of biospeleology. Ecological informations, apart from some chance observations, are still completely lacking. Thus there is still abundant work to be done, and a wide untrodden field for the interested researcher. It is to be hoped that more cavers will take up this most exciting research in one of the most exciting countries on earth.

Acknowledgments

The author wishes to express his gratitude to the many specialists who identified and described all the specimens. Most of them are found in the References. I would like to name two which are not listed, Paul Bates of Harrison Institut who identified all bats and other mammals, and Thomas Ziegler of the Cologne Zoo who identified reptiles and frogs from photographs. I also wish to thank my fellow cavers for their patience with the critter collection during the expeditions. Above all, I wish to thank the people and authorities of the Lao P.D.R. for their warm welcome and unfailing support.

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STUDY OF A BACTERIAL COMMUNITY ON THE SURFACE OF A STALAGMITE IN HESHANG CAVE, CENTRAL CHINA

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Heshang Cave is an oligotrophic karst cave located in the middle reach of the Yangtze River, central China. The cave is about 250 m in length and harbors well preserved stalagmites (Hu et al. 2008). Previously microbial lipids were detected in the stalagmite that closely correlated with climatic events throughout the Holocene (Xie et al. 2003; Xie et al. 2005). Since that time, research has been done to narrow down the origins of the microbial lipids (Yang et al. 2011) and to figure out how microbes response to climate change. It may be possible that the microbes originate from soils and other surface environments, and are brought into the cave via dripping water, surface stream, air current, or animals (Engel et al. 2010). Indegineous microbes might also contribute to the microbial lipids trapped in stalagmite. Even though some bacteria have been isolated from the dripping water in Heshang cave (Liu et al. 2010), it still merits study of the microbial community due to the very low percentage of cuturable microbes in natural environment. Thus, to investigate the microbial communities, their possible source and microbial role in the subsurface ecosytem in the cave, we comparatively studied the bacterial communities on the surface of stalagmite in Heshang Cave and in the overlaid soils via molecular techniques. Microbial samples on the surface of the stalagmite were collected with an aseptic funnel into aseptic bottles by eluting the surface with sterilized water and thoroughly brushing. The eluate was carried back to the lab within 24 hrs on ice and subject to filtration through 0.22 μm membrane. DNA extraction was conducted with the membrane. Soil sample were collected with sterialized 50 ml falcon centrifuge tubes and 0.5 g sample was used for DNA extraction. 16S rRNA gene amplification was conducted with bacterial universal primers 27 F and 1492R with an effendorf thermalcycler. The target DNA was cloned and sequenced with the ABI3730 machine (Genscript Company of Nanjing). The valid DNA sequences were subsequently analysied with a series of software including RDP 10 (http://rdp.cme.msu.edu/), NCBI (http://www.ncbi.nlm.nih.gov/), Dotur (http://schloss.micro.umass.edu/software/), Libshuff (http://www.arches.uga.edu/whitman/libshuff.html), and MEGA4.

Abundant clones were retrieved from the surface of the stalagmite with a Shannon–Weaver index of 2.95. The bacterial community was dominated by γ-Proteobacteria, Acidobacteria, β-Proteobacteria and α-Proteobacteria, with a relative clone abundance of 30.2 %, 16.7 %, 11.7 %, and 11.1 %, respectively. In contrast, the bacterial community in the soil above the cave was dominated by Acidobacteria, Bacteroidetes, β-Proteobacteria and γ-Proteobacteria, with a relative clone abundance of 34.3 %, 15.0 %, 11.3 %, and 11.3 %, respectively. Most of the bacterial clones recovered from the surface of the stalagmite were heterotrophs, with a wide distribution in natural environments. Some oligotrophic gruops were also detected. The bacterial clones might play important roles in elemental cycles in Heshang Cave. For example, some clones could be involved in ammonium oxidation, Fe(III) reduction, and chlorate reduction. Others are possibly fix atmosphere gases. These results offer further insight into the subsurface biosphere and provided information on the ongoing biogeochemical processes in oligotrophic karst caves. The results also shed light on deciphering the microbial information trapped in the stalagmite. Although some bacterial phyla were shared between the communities on the surface of the stalagmite and in the surface soil, LIBSHUFF analysis at the species level indicated remarkablely different origins for the two bacterial communities (p-value < 0.001). Given and the succession of environmental factors, microbial communities could change greatly over the distance down to the cave. However, it still merits further investigation to confirm the relationship between the microbial communities in the overlying soil and in Heshang Cave.

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THE CAVE FAUNA OF LUXEMBOURG

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Abstract. From 2007 to 2011, animals were collected from 82 natural caves and artificial caverns in the Grand Duchy of Luxembourg. More than 90,000 specimens in 512 species were collected, comprising 516 snails, 205 pseudoscorpions, 2,687 spiders, 370 opiliones, 2,776 isopods, 130 amphipods, 12 symphylans, 817 millipedes, 160 centipedes, 37 diplurans, 48 archaeognathans, 916 springtail, 8 bugs, 100 staphylinid beetles, 74 scarabs, 39 ichneumon wasps and 40 other hymenoptera, 110 psocids, 5 crane flies, 1,012 short-palped craneflies, 1,800 winter gnats, 2 flutter-wing flies, 1 wood gnat, 125 moth flies, 2,163 fungus gnats, 7,000 black fungus gnats, 26 Drosophilidae, 5,115 lesser dung flies, 122 Lonchopteridae, 582 Heleomyzidae, 1 Muscide, 1 Anthomyide, 1 Fanniide, 143 butterflies, 3 amphibians, 217 bats, 6 other mammals.

The black fungus gnats *Lycoriella (Lycoriella) weberi* Menzel and Heller spec. nov.; *Corynoptera antennaria* Menzel & Heller spec. nov.; *Leptosciarella (Leptosciarella) reducta* Heller and Menzel sp. nov. are new to science.

201 species were found the first time in Luxembourg. 73 species are subtroglophile, 94 eutroglophile, and 13 eutroglobiont.

End of 2012 the results were published in a Ferrantia book with 37 articles. The book comprises a CD containsing all data as pdf-files.

Abstrakt. Von 2007 bis 2011 wurden in 82 Höhlen und künstlichen Hohlräumen des Großherzogtums Luxemburg Tiere erfasst. Unter den rund 90.000 gesammelten Individuen konnten 512 Arten nachgewiesen werden aus folgenden Tiergruppen: 516 Schnecken, 205 Pseudoskorpione, 2.687 Webspinnen, 370 Weberknechte, 2.776 Asseln, 130 Flohkrebse, 12 Zwergfüsser, 817 Doppelfüsser, 160 Hundertfüsser, 37 Doppelschwänze, 48 Felsenspringer, 916 Springschwänze, 8 Wanzen, 100 Kurzflügler, 74 Blatthornkäfer, 39 Schlupfwespen und weitere 40 Hymenopteren, 110 Staubläuse, 5 Schnaken, 1.012 Stelzmücken, 1.800 Wintermücken, 2 Zitterfliegen, 1 Fenstermücke, 125 Schmetterlingsmücken, 2.163 Pilzmücken, 7.000 Trauermücken, 26 Taufliegen, 5.115 Dungfliegen, 122 Lanzenfliegen, 582 Scheufliegen, 1 Muscide,1 Anthomyide, 1 Fanniide, 143 Schmetterlinge, 3 Amphibien, 217 Fledermäuse und 6 sonstige Säugetiere.

Drei Trauermücken-Arten sind Erstnachweise für die Wissenschaft: *Lycoriella (Lycoriella) weberi* Menzel and Heller spec. nov.; *Corynoptera antennaria* Menzel and Heller spec. nov.; *Leptosciarella (Leptosciarella) reducta* Heller and Menzel sp. nov.

201 Arten sind neu für Luxemburg. 73 Arten sind subtroglophil, 94 eutroglophil und 13 eutroglobiont.

Ende 2012 wurden die Ergebnisse in einem Ferrantia-Buch mit 37 Einzel-Artikeln veröffentlicht. Das Buch enthält auch eine CD mit der gesammten Fundliste als pdf-File.

Abstrait. Entre 2007 et 2011 des animaux ont été récensés dans 82 cavités naturelles et artificielles du Grand-Duché de Luxembourg. Parmi les 90 000 animaux collectés, 519 espèces ont été trouvées.

En détail, les gloupes suivantes ont été trouvées: 516 gastropodes, 205 pseudoscorpions, 2 687 araignées, 370 opilions, 2 776 cloportes, 130 amphipodes, 12 symphyles, 817 mille-pattes, 160 centipèdes, 37 double-queues, 48 archaeognatha, 916 collemboles, 8 punaises, 100 staphilinides, 74 scarabéides, 39 ichneumonides et des autres 40 hymenoptères, 110 psocoptères, 5 tipulides, 1 012 limoniides et pedicides, 1 800 trichocérides, 2 pallopterides, 1 anisopodides, 125 psychodides, 2 163 mycetophilides, 7 000 sciarides, 26 drosophilides, 5 115 sphaerocerides, 122 lonchopterides, 582 héléomyzides, 1 Muscide,1 Anthomyide, 1 Fanniide, 143 papillons, 3 amphibiens, 217 chauves-souris et 6 autres mammifères.

Trois Sciaridae sont première découvertes pour la science: *Lycoriella (Lycoriella) weberi* Menzel and Heller spec. nov.; *Corynoptera antennaria* Menzel and Heller spec. nov.; *Leptosciarella (Leptosciarella) reducta* Heller and Menzel sp. nov.

201 espèces ont été trouvées pour la première fois au Luxembourg. 73 espèces sont subtroglophiles, 94 sont eutroglophiles, 13 sont eutroglobiontes. Les résultats sont publiés dans une œuvre de Ferrantia avec 37 articles et une CD ci-jointe qui contient la liste complète des animaux collectés comme fichier pdf.

1. Introduction

The Grand Duchy of Luxemburg is a state in the center of Europe.

From 2007 to 2011, animals were collected from 82 natural caves and artificial caverns in Luxembourg. The Ösling is the Northern part of Luxembourg and mainly consists of Devonian schist. Specimen were collected there from 5 railway tunnels, 6 schist mines, 5 copper mines and 4 other subground excavations. The Gutland covers the Southern 2/3 of Luxembourg. Collections were undertaken in 1 natural cave in limestone, and 7 natural caves in calcareous sandstone, 2 gypsum mines, 6 sandstone mines, 3 railway tunnels 1 other object as well as 6 casemattes (subterranean defensive fortifications) of Luxembourg City. Only a small part of the Mosel valley is part of Luxemburg. In this valley, collections could be done in 2 natural limestone caves and 3 dolomite mines. One focus was the Minette region, located in the very south of Luxembourg with 14 processed iron mines and 2 railway tunnels.

2. Methods

Collections were normally done fourtimes a year by using Barber traps as well as collections by hand using paint brushs. Sieving of water was an exception.

Figure 1. Collecting by hand in the Mechelslee. Foto: Harbusch.

Figure 2. Barber trap in the Méischtrefer Hiel. Foto: Boes.

Figure 3. Sieving trap in the Kofferminn Stolzebuerg. Foto: Zahlmann.

More than 90,000 specimens were collected, comprising 512 species. 201 of them were found the first time in Luxembourg; 3 are new to sciences. 73 species are subtroglophile, 94 eutroglophile, and 13 eutroglobiont.

3. Results

In detail the following specimen were found:

516 snails in 28 species, thereof 3 cavernicolous,

205 pseudoscorpions in 9 species, thereof 6 cavernicolous and 4 first records for Luxemburg,

2,687 spiders in 72 species, thereof 25 cavernicolous and 7 first records for Luxemburg,

370 opiliones in 15 species, thereof 4 cavernicolous and 1 first record for Luxemburg,

2,776 isopods in 17 species, thereof 8 cavernicolous and 2 first records for Luxemburg,

130 amphipods in 3 species, thereof 2 cavernicolous,

12 symphylans in one species,

817 millipedes in 19 species, thereof 14 cavernicolous and 4 first records for Luxemburg,

160 centipedes in 8 species, thereof 6 cavernicolous,

37 diplurans in 7 species, thereof 3 cavernicolous and 7 first records for Luxemburg,

Table 1. List of eutroglobiont species.

Arachnida
Araneae
Improphantes improbulus
Porrhomma rosenhaueri
Crustacea
Amphipoda
Niphargus schellenbergi
Isopoda
Proasellus cavaticus
Trichoniscoides helveticus
Myriapoda
Diplopoda
Brachychaeteuma bagnalli
Diplura
Litocampa humilis humilis
Insecta
Psocodea
Prionoglaris stygia
Diptera: Mycetophilidae
Speolepta leptogaster
Diptera: Sciaridae
Camptochaeta ofenkaulis
Diptera: Sphaeroceridae
Terrilimosina racovitzai
Diptera: Heleomyzidae
Heteromyza atricornis
Oecothea praecox

Figure 4. Trichoniscoides helveticus in the Schifergrouf vu Pärel. Foto: Zahlmann.

48 archaeognathans in one species,

915 symphypleonid and one neelipleonid springtail in 7 species, thereof 4 cavernicolous species and 3 first records for Luxemburg,

8 bugs in one species,

100 staphylinid beetles (thereof 8 determined to species level) in 4 species, thereof 2 cavernicolous and 1 first record for Luxemburg,

74 scarabs in 1 cavernicolous species,

39 ichneumon wasps in 7 species, thereof 5 cavernicolous and 3 first records for Luxemburg,

40 other hymenoptera that could be determined to family level, thereof one to species level determined first record for Luxemburg,

110 psocids in 5 species, thereof 3 cavernicolous and 1 first record for Luxemburg,

5 crane flies in 3 species,

1,012 short-palped craneflies (apart from several 10,000 not collected specimen) in 10 species (9 Limoniidae, 1 Pediciidae), thereof 1 cavernicolous and 5 first records for Luxemburg,

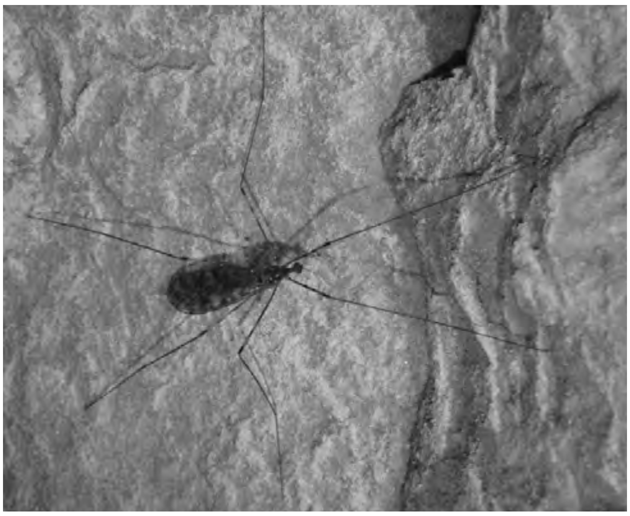

Figure 5. Limonia nubeculosa in the Dolomitgrouf Fronay. Foto: Zahlmann.

1,800 winter gnats in 3 species, thereof 2 cavernicolous and 3 first records for Luxemburg,

2 flutter-wing flies in one species, which is new to Luxembourg,

1 wood gnat, which is new to Luxembourg,

125 moth flies in 15 species, thereof 6 cavernicolous and 13 first records for Luxemburg,

2163 fungus gnats in 72 species, thereof 20 cavernicolous and 70 first records for Luxemburg,

7,000 Black Fungus Gnats in 38 Species, thereof 14 cavernicolous and 37 first records for Luxemburg and three first descriptions for science: *Lycoriella (Lycoriella) weberi* Menzel and Heller spec. nov.; *Corynoptera antennaria* Menzel and Heller spec. nov.; *Leptosciarella (Leptosciarella) reducta* Heller and Menzel sp. nov.

26 Drosophilidae in 6 species, all first records for Luxemburg,

5,115 lesser dung flies in 21 species, thereof 15 cavernicolous and 21 first records for Luxemburg,

122 Lonchopteridae in one species, that is cavernicolous and new to Luxemburg,

Figure 6. Heleomyzidae in the Schifergrouf vu Pärel. Foto: Zahlmann.

2,000 Heleomyzidae (thereof 582 determined to species level) in 12 species, thereof 8 cavernicolous and 11 first records for Luxemburg,

1 Muscide, which is new to Luxembourg,

1 Anthomyide, which is new to Luxembourg,

1 Fanniide,

to family level determined Ptychopteridae, Dixidae, Thaumaleidae, Ceratopogonidae, Chironomidae, Bibionidae, Cecidomyiidae, Dolichopodidae, Lauxaniidae, Pallopteridae, Chloropidae, Lonchaeidae, Tachinidae, Hippoboscidae, Calliphoridae, Empididae, Syrphidae, Stratiomyidae, Conopidae, Culicidae, Dolichopodidae,

143 butterflies in 18 species, thereof 5 cavernicolous,

3 amphibians in 2 species, both cavernicolous,

217 bats in 8 species, all cavernicolous, and

6 other mammals including 1 cavernicolous species

Beginning of 2013 the results were published in a Ferrantia book with 36 articles dealing with animal groups, and one with description of new species. The book comprises a CD containsing all data as pdf-files.

Table 2. List of eutroglophile species.

Gastropoda
Boettgeriella pallens
Discus rotundatus
Limax maximus
Oxychilus cellarius
Oxychilus draparnaudi

Arachnida
Pseudoscorpiones
Chthonius (Chthonius) ischnocheles
Chthonius (Ephippiochthonius) boldorii
Neobisium (Neobisium) carcinoides
Neobisium (Neobisium) simile
Roncus lubricus
Araneae
Lepthyphantes leprosus
Tenuiphantes zimmermanni
Harpactea hombergi
Nesticus cellulanus
Centromerus prudens
Diplocephalus cristatus
Micrargus apertus
Mioxena blanda
Pseudomaro aenigmaticus
Palliduphantes pallidus
Porrhomma convexum
Porrhomma egeria
Saaristoa abnormis
Tenuiphantes flavipes
Meta menardi
Histopona torpida
Metellina merianae
Malthonica silvestris
Cicurina cicur
Amaurobius fenestralis
Opiliones
Mitostoma chrysomelas

Crustacea
Isopoda
Haphlothalmus mengii
Trichoniscus pusillus
Oniscus asellus
Cylisticus convexus
Porcellio scaber
Armadillidium nasatum
Amphipoda
Gammarus fossarum

Myriapoda
Symphyla
Scutigerella immaculata
Diplopoda
Baniulus guttulatus
Chordeuma sylvestre
Craspedosoma rawlinsii
Glomeris marginata
Orthochordeuma germanicum
Polydesmus angustus
Propolydesmus testaceus
Proteroiulus fuscus
Cylindroiulus vulnerarius
Tachypodoiulus niger
Proteroiulus fuscus
Chilopoda
Cryptops parisi
Lithobius aeruginosus
Lithobius macilentis
Lithobius crassipes
Lithobius dentatus
Lithobius forficatus

Diplura
Campodea (Campodea) lankesteri
Campodea (Campodea) wallacei

Collembola
Neelus murinus
Arrhopalites principalis
Arrhopalites pygmaeus
Disparrhopalites patrizii

Insecta
Coleoptera: Staphylinidae
Quedius mesomelinus
Psocodea
Psyllipsocus ramburii
Bertkauia lucifuga
Diptera: Trichoceridae
Trichocera (Saltrichocera) maculipennis
Trichocera (Saltrichocera) regelationis
Diptera: Bolitophilidae
Bolitophila (Bolitophila) cinerea
Diptera: Mycetophilidae
Tarnania fenestralis
Tarnania nemoralis
Diptera: Sciaridae
Bradysia forficulata
Corynoptera cavipes
Corynoptera antennaria
Corynoptera spoeckeri
Corynoptera subforcipata
Cratyna (Cratyna) breviflagellata
Epidapus (Epidapus) atomarius
Epidapus (Epidapus) schillei
Leptosciarella (Leptosciarella) rejecta f. echinata
Lycoriella (Lycoriella) felix
Lycoriella weberi
Pnyxia scabiei
Diptera: Sphaeroceridae
Herniosina bequaerti
Limosina silvatica
Leptocera caenosa
Apteromyia claviventris
Telomerina flavipes
Spelobia pseudonivalis
Herniosina pollex
Diptera: Heleomyzidae
Heleomyza captiosa
Heleomyza serrata
Gymnomus amplicornis
Scoliocentra villosa

5. Discussion and Conclusions

Due to the intensive research from 2007 – 2011, Luxembourg could be developed from a biospeleological dead spot to one of the best investigated areas in the center of Europe.

The cave fauna composition shows apart from widely spread middle European species, also deviations to the neightbouring regions like Belgium or Rheinsh-Palatinate (Germany). Especially in Luxembourg City, some south European species were found assumed they are introduced by garrisons in the last centuries. Endemic species are missing.

The relatively small number of eutroglobiont species might be caused by the lack of water in the greater part of the investigated caves and artificial caverns. Therefore stygobiont species are missing in these caves.

The high relative amount of eutroglophile (18 %) and subtroglophile (14 %) species compared to other regions in the neiborhood might be apparent: In Luxembourg, mainly caves above 50 m length were investigatet, while in other regions also many short caves and rock shelters with apparently more eutrogloxen species where included in the studies.

In Luxembourg, there are still caves and mines unexplored and animal groups waiting for determination. Therefore, the research will be continued.

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NEW DATA TO THE DISTRIBUTION OF FOUR AQUATIC TROGLOBIONT MACROINVERTEBRATE SPECIES IN THE CAVES OF THE MECSEK MOUNTAINS (SW HUNGARY)

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Present paper provides new faunistical data on the occurence of four aquatic troglobiont macroinvertebrate species (*Protelsonia hungarica*, *Bythiospeum hungaricum*, *Niphargus gebhardti* and *Niphargus molnari*) from the caves located in the Mecsek Mountains, SW Hungary. Sample collection was carried out in 7 caves between May 2010 and October 2011. Apart from the Abaligeti Cave and the Mánfai-kőlyuk Cave, where previous research have been conducted, 5 others were included which were unexplored from a biospeleological aspect up to now. *P. hungarica* occured in 4 caves, *B. hungaricum* in 2 caves, while the two *Niphargus* species occured in 6 caves. The Abaligeti Cave still provides suitable habitat for the different troglobiont invertebrate taxa. Lack of *Niphargus* populations from the Mánfai-kőlyuk Cave could be related to the utilization of waterworks.

1. Introduction

Over the past decades number of biospeleological research in Hungary has significantly decreased. Yet, caves provide unique conditions which effect the development of a highly specific invertebrate fauna. The obligate cave–dwelling animals have the greatest importance in biospeleology. A species or a population with strict boundries to a hypogean habitat is called troglobiont (Sket 2008). Common features of these animals are depigmentation, thinning of integument, reduction of eyes and elongation of appendices (Dudich 1932).

Among the more than 250 caves situated in the Mecsek Mountains only two, the Abaligeti Cave and the Mánfai-kőlyuk Cave have been previously examined in invertebrate faunistical studies (Bokor 1924; Verhoeff 1928; Gebhardt 1933, 1934, 1963; Farkas 1957). As a result of this extensive research more troglobiont endemic macroinvertebrate species had been described. The blind aquatic isopod, *Protelsonia hungarica* Méhely 1924 (Figure 1) was found for the first time in the stream in the Abaligeti Cave in October 1923 by E. Bokor and L. Méhely. Later on further *Protelsonia* specimens were discovered in the Mánfai-kőlyuk Cave which resulted in the description of a new subspecies, *P. hungarica robusta* Méhely 1927 (Méhely 1927). From the Abaligeti Cave two blind amphipod species were collected by E. Dudich and A. Gebhardt (Gebhardt 1963). *Niphargus molnari* Méhely 1927 was found in the stream of the main passage, while *Niphargus gebhardti* Schellenberg 1934 (Figure 1) colonised small pools created from dripping water. *N. molnari* was collected from aquatic habitats in the Mánfai-kőlyuk Cave as well. The famous blind aquatic snail, *Bythiospeum hungaricum* (Soós 1927) (Figure 1) was first found in the stream in the Abaligeti Cave in 1927 and was described in that same year by L. Soós originally as *Lartetia hungarica* Soós 1927 (Soós 1927). Based on the specimens collected from the Mánfai-kőlyuk Cave, H. Wagner considered it reasonable to create a new species, which was named in honour of the collector *Paladilhiposis gebhardti* H. Wagner 1931 (H. Wagner 1931). However three decades later L. Pintér (1968) has shown that there is no significant morphological difference between the specimens collected from the two caves and pointed out that the locus typus of *gebhardti* is conspecific with the locus typus of *hungaricum* (Fehér et al. 2004).

Since these investigations, the original conditions of the two caves have been affected by human impact. The Abaligeti Cave has been developed for the public, attracting thousands of tourists, while the Mánfai-kőlyuk Cave has been utilized by waterworks and has completely lost its natural character. Considering that these changes could influence the diversity of the caves, repeated sample collection was reasonable. Our additional aim was to find the above mentioned aquatic troglobiont macroinvertebrate species in other caves in the Mecsek mountains which were until now, unexplored biospeleologically.

2. Material and methods

Samples were collected between May 2010 and October 2011 in seven caves from Western–Mecsek (Figure 2). Most of the examined caves were sinkholes with various length and vertical extensions (Table 1.). Samples were collected by hand collecting with the help of forceps, as well as using a plankton net and water traps (punched nylon packages filled with leached leaves and submerged into the water). Specimens were fixed and stored in 96 % ethanol. The following experts assisted with species identification: Florian Malard (Université Claude Bernard – Lyon1) – Stenasellidae, Zoltán Fehér (Hungarian Natural History Museum) – Hydrobiidae, Cene Fišer (University of Ljubljana) – Niphargidae. Most of the Niphargus specimens were identified by the authors, useing the following protocol for the dissection (Fišer et al, 2009). Specimens were placed in glycerol for two hours, partly dissected and mounted on slides in a glycerol-gelatine medium. Some individuals were cooked in 10 % KOH solution, rinsed with HCl and washed in distilled water. Cleared exoskeletons were stained with chlorazol black in glycerol, than dissected and made slides as it is written above.

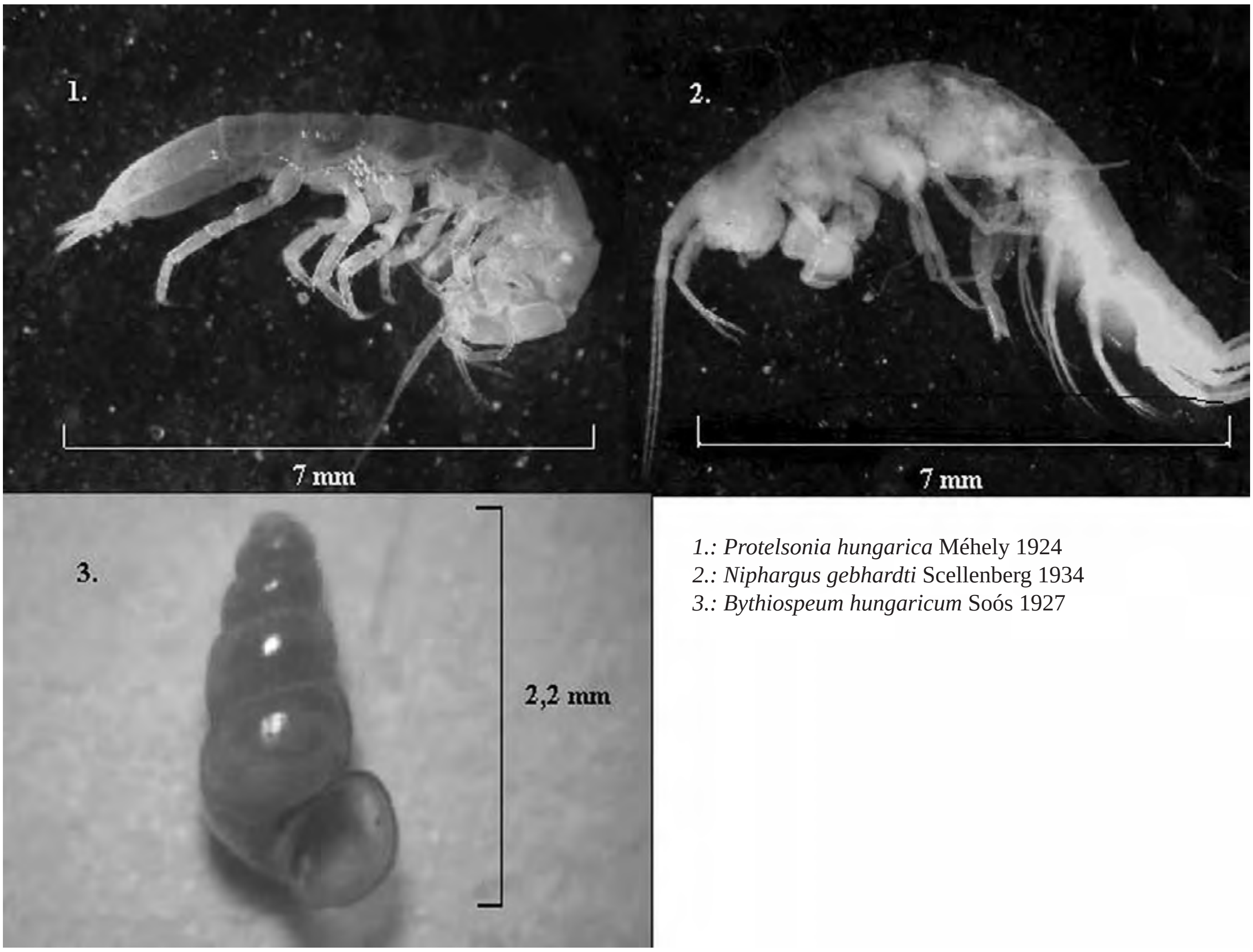

Figure 1. Images of Protelsonia hungarica, Niphargus gebhardti and Bythiospeum hungaricum. Photos were taken by Katinka Varga and Dorottya Angyal.

3. Results

All the four troglobiont aquatic macroinvertebrate species were found in some of the examined caves. P. hungarica occured in four caves, in the Vadetetős Cave and in the Spirál Cave these are the first records of the species. Among the two Niphargus species occur in the Mecsek mountains, N. gebhardti was the more frequent. It was found in six caves mainly in small pools created by dripping water, however it also occured in streaming water in one case. In the Vadetetős Cave we found a pool where permanent coegsistence of N. gebhardti and P. hungarica was observable. The other Niphargus species, N. molnari was collected from three caves. However in these caves both species were found, their populations were separated from each other in all cases. N. molnari was not occured in the Mánfai-kőlyuk Cave, from where the species was originally described. The blind snail B. hungaricum was collected only from the two previously researched caves (Table 2).

4. Discussion

Considering this new data it seems that exploration of the troglobiont invertebrate fauna in more of the caves in the Mecsek Mountains is required. Presence of the same species in different caves could be the proof of subterranean connection via fissure system. The fact that populations of all the four previously described taxa have remained in the Abaligeti Cave is the proof of the importance of leaving cave water systems intact. A massive population of *P. hungarica* still exists in the stream and those parts of the cave which are closed from the visitors provide various microhabitats for the invertebrates. Though, it cannot be said about the Mánfai-kőlyuk Cave, where the intrusive introduction of waterworks has led to the disappearance of endemic fauna elements and the inclusion of perturbated, urban habitat–dwelling species (Angyal 2012). It is sad that in lack of natural microhabitats, rare troglobiont species like *P. hungarica* and *B. hungaricum* are forced to colonize in a concrete water-collecting canal as an ultimate shelter. It may be hypothesized that populations of *N. molnari* did not manage to adapt to the changing conditions and have completely disappeared from the cave. To conserv the remained aquatic troglobiont invertebrate species, rehabilitation of this cave would be important.

Acknowledgments

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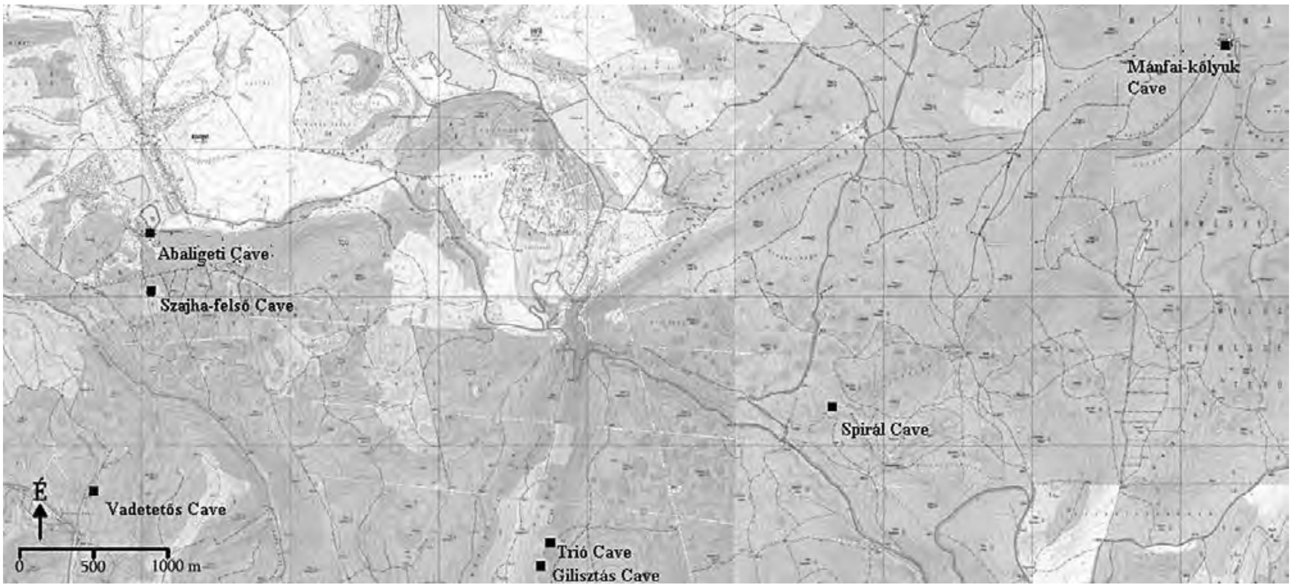

Figure 2. Location of the 7 examined caves in the Mecsek Mountains.

Table 1. Some data of the examined caves.

Name of cave	Type of cave	Cadastre number	Entreance's altitude above sea level (m)	Y (Decimal degree)	X (Decimal degree)	Length of cave (m)	Vertical extension of cave (m)
Abaligeti Cave	spring cave	4120-1	218,770	578056,429	88434,520	1,712	48,7
Mánfai-kőlyuk Cave	spring cave	4120-2	240,121	585324,364	89720,420	180	12
Vadetetős Cave	sinkhole	4120-27	320,701	577872,842	86795,058	177	35
Trió Cave	sinkhole	4120-71	301,035	580722,262	86347,182	250	58
Gilisztás Cave	sinkhole	4120-70	307,704	580693,262	86268,727	134	51,1
Spirál Cave	sinkhole	4120-130	350,280	582719,925	87242,072	1,000	86,4
Szajha-felső Cave	sinkhole	4120-16	283,508	578056,137	88041,665	98	40

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Table 2. Collected troglobiont macroinvertebrates and some data about the collection.

Collected taxa	Cave's name	Date of collection	Location in cave	Collecting method
(Sub)species: ***Protelsonia hungarica* Méhely 1924** Genus: *Protelsonia* Mehely 1924 Family: Stenasellidae Order: Isopoda	Mánfai-kőlyuk Cave	11/12/2010	upper passage (artificial tunnel), in a concrete water collecting tube	hand collecting with forceps
	Mánfai-kőlyuk Cave	11/12/2010	upper passage (artificial tunnel), next to the tunnel ending's spring on a flat stone covered with water	hand collecting with forceps
	Vadetetős Cave	08/12/2010	In a lateral chamber after 4th room in a pool	hand collecting with forceps
	Vadetetős Cave	08/12/2010	in a streamlet	hand collecting with forceps
	Abaligeti Cave	22/09/2010	in main passage's stream, 220 meters from entrance	hand collecting with forceps
	Abaligeti Cave	12/10/2010	in Western-2 collateral in the stream	hand collecting with forceps
	Abaligeti Cave	25/11/2010	in Western-2 collateral in a puddle	hand collecting with forceps
	Spirál Cave	13/03/2011	In "Heart of Spirál" room in a sinter pew	hand collecting with forceps
Species: ***Bythiospeum hungaricum* (Soós 1927)** Genus: *Bythiospeum* Bourguignat 1882 Family: Hydrobiidae Order: Neotaenioglossa	Abaligeti Cave	26/09/2010	in main passage's stream on stream bed 330 meters from entrance	plankton net
	Abaligeti Cave	26/09/2010	in main passage's stream on stream bed 440 meters from entrance	plankton net
	Abaligeti Cave	11/10/2010	in main passage's stream on stream bed and at the bottom of some stones, 220 meters from entrance	plankton net and hand collecting with forceps
	Abaligeti Cave	11/10/2010	in main passage's stream on stream bed, 330 meters from entrance	plankton net
	Mánfai-kőlyuk Cave	22/12/2010	upper passage (artificial tunnel), in a concrete water collecting tube	hand collecting with forceps
	Mánfai-kőlyuk Cave	21/10/2011	upper passage (artificial tunnel), in a concrete water collecting tube	hand collecting with forceps
	Mánfai-kőlyuk Cave	21/10/2011	lower passage, at the beginning of the passage on shallow water	hand collecting with forceps
Species: ***Niphargus gebhardti* Schellenberg 1934** Genus: *Niphargus* Schiodte 1849 Family: Niphargidae Order: Amphipoda	Trió Cave	05/08/2011	In the first room in a small pool	hand collecting with forceps
	Trió Cave	05/08/2011	After "Furnance" in a small pool	hand collecting with forceps
	Gilisztás Cave	05/08/2011	Before cave's ending in a small pool	hand collecting with forceps
	Spirál Cave	13/03/2011	In "Heart of Spirál" room in a sinter pew	hand collecting with forceps
	Vadetetős Cave	08/12/2010	Between 4^{th} and 5^{th} room in streaming water	hand collecting with forceps
	Vadetetős Cave	08/12/2010	In a lateral chamber after 4^{th} room in a pool	hand collecting with forceps
	Szajha-felső Cave	11/12/2010	Under excavation-rail in a small pool	hand collecting with forceps
	Abaligeti Cave	22/09/2010	In a small pool in a lateral chamber on the right of "Karthago's ruins"	hand collecting with forceps
	Abaligeti Cave	28/10/2010	In a small pool in a lateral chamber on the right of "Karthago's ruins"	hand collecting with forceps
Species: ***Niphargus molnari* Méhely 1927** Genus: *Niphargus* Schiodte 1849 Family: Niphargidae Order: Amphipoda	Spirál Cave	13/03/2011	At the beginning of the streamy-branch on a big sinter pew	hand collecting with forceps
	Vadetetős Cave	08/12/2010	In an excavated crevice after "Lunch-room"	hand collecting with forceps
	Abaligeti Cave	12/10/2010	At the end of Western-2 collateral in a sinter pew	hand collecting with forceps

MOLECULAR ANALYSIS OF MICROORGANISMS DIVERSITY FROM PERRENIAL UNDERGROUND ICE SEDIMENTS

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Cave glaciers represent an important environment for paleoclimate and exobiology studies. There are almost no reports on microbial biodiversity from underground ice sediments. In this study, we are interested in characterizing the prokaryotic and eukaryotic microbial communities in different aged ice layers from Scărişoara Cave, in determining their chronological distribution, and in identifying climate biomarkers. Scărişoara Cave hosts the largest (>100,000 m^3, 22 m thick) and oldest (>10 ka yrs.) subterranean perennial ice block in the world (Perşoiu and Pazdur 2010; Feurdean et al. 2011). The exposed wall in the Little Reserve displays a well-marked succession of clear ice and sediment-rich (i.e. cryogenic carbonates and organic matter) layers, recently radiocarbon dated to ca. 1,200 years BP (Perşoiu et al. 2011).

The analysed samples from different ages (900 years, 450 years, and 1 year) were located in light/sun exposed sites (Great Hall), as well as in complete darkness (Little Reserve). The presence of microorganisms in the ice layers was assessed by culture-dependent methods and molecular analysis of genes. Cultivation of ice-contained microorganisms at 4 °C and 15 °C, performed in various liquid media revealed a different growth rate as a function of cultivation conditions. Accordingly, a higher diversity resulted at 15 °C than that obtained at 4 °C, independently from the ice age, suggesting the prevalence of moderate psychrophiles in this habitat. 16S and 18S rRNA genes were amplified by PCR from total DNA extracted either from ice samples or different culture media using specific GC-clamp primers. Prokaryote and eukaryote diversity in the ice samples was also investigated by molecular approach using denaturing gradient gel electrophoresis (DGGE) profiles of the rRNA small subunit (SSU). The DGGE profiles indicate a high variety of microorganisms in each ice layer, resulted from the different number and position of DNA amplicons. A SSU-rRNA clone library was obtained from the oldest ice and will be further identified by pyrosequencing.

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BRYOPHYTES AT LAMPS IN SELECTED PUBLIC CAVES IN THE CZECH REPUBLIC – PAST AND PRESENT

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Bryophytes growing close to lamps in regular use were studied in show caves. The present-day data were collected in 2004 and in 2011, 2012 in four caves open to the public: Balcarka Cave, Kateřinská Cave, Javoříčko Caves and Punkva Caves. They are situated in Moravia, the Czech Republic. All of them are formed in Devonian limestone. The cave environment has an even temperature and high air humidity.

Previous investigations of the lamp flora were done in the 1960s–70s. The management of public caves (illumination, chemical removal of plants) has changed since that time. The aim is to compare the bryophyte lamp flora in the 60s–70s and the present one – 2004, 2011–2012. During the previous investigations 51 species of bryophytes (only mosses) were recorded. In the present day 45 mosses were recorded, 35 mosses in 2004 and 30 in 2011–2012. Overall, 45% of the bryophyte flora remains the same as in the past. 23% of the bryophyte flora belong to newly recorded species and 32% represent species recorded in the 60s–70s. Frequently observed mosses – both in the past and in the present – were *Amblystegium serpens*, *Brachythecium velutinum*, *Bryum* spp. and *Leptobryum pyriforme*.

PATTERNS OF MISSING LEGS IN *HADENOECUS SUBTERRANEUS* CAVE CRICKETS AND REDUCTION OF FORAGING SUCCESS

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One way insects can reduce predation is by autotomy, the voluntary loss of a limb if an insect is caught by a leg. Missing legs in insects are known to reduce activity, escape speed, and increase energy requirements for movement. As part of long-term biomonitoring at managed and unmanaged entrances in Mammoth Cave National Park, we included a census of crickets missing legs for adult *Hadenoecus subterraneus* cave crickets for five years. In the summer months, *H. subterraneus* showed variable percentages of leg loss, with averages from 8.82 to 19.57 %, ranging by cave from a low of 3.18 % to a high of 28.00 %. Variability in winter was much lower, with an average of 18.64 % of the adult population missing legs and a range by cave of 16.67 % to 24.61 %. The number of crickets missing more than one leg was low, and averaged from 0.76 % to 1.82 % of the populations with a by cave range of 0.00 % to 6.06 %. No differences due to sex were noted. Crickets missing legs are more likely to stay closer to entrances to reduce distances they have to travel. Between-cave variability in crickets missing legs showed some patterns, with the lowest average from Violet City, the highest average for Frozen Niagara, and percentages from Carmichael in between. Winter averages were high and consistent (17.39–24.61 %) for all three locations. Foraging efficiency was determined by comparing the amount of food in the crop based on a regression of crop-free live weight to Hind Femur Length. In general, females have more food in their crops than males. Crop weights as an indicator of effective foraging were significantly reduced in crickets missing one or both hind legs ($P < 0.006$). Are these differences related to specific cave locations, to weather patterns, to seasons? Reducing the percentage of a population missing legs is desirable, but how to manage the entrances to ensure optimum fitness?

1. Introduction

Insects have a variety of ways to reduce predation on them, including escape, physical modifications like a tough exoskeleton and spines, protective coloration, chemical defenses, and autotomy. Autotomy is the voluntary loss of a limb. The limb is usually released at the coxa, where the limb joins the body. Insects walk using a tripod gait, where a triangle formed by the front and hind limb on one side of the body move in concert with the middle limb on the other side of the body. Loss of a limb will have the greatest effect on walking at higher speeds. Insects jump using thrust from the larger hind legs. Loss of a hind leg will impact both walking and jumping.

Loss of limbs affects the insect in a variety of ways. House crickets (*Acehta domestica*) with one missing hind limb had reduced escape speed and decreased ability to jump, and showed a reduced ability to escape predation by lizards and mice (Bateman and Flemming 2006). Field crickets (*Gryllus bimaculatus*) with one missing hind limb showed the same pattern and were slower in general, moved shorter distances, and used more energy than field crickets with no hind limbs missing (Fleming and Bateman 2007).

As a part of long-term biomonitoring, we census populations of organisms at nine entrances within Mammoth Cave National Park, and at two deep cave sites. Management of the entrances range from natural open and unmanaged, to manmade, gated entrances. We record census data on cave cricket distribution, population size, age structure, and missing limbs in adult cave crickets (Fig. 1).

Figure 1. An adult female cave cricket, Hadenoecus subterraneus, missing her left hind leg. (Photo by E. Lavoie).

Hadenoecus subterraneus cave crickets are a keystone species in many caves in the North American Southeast. They must forage on the surface at night when surface conditions are favorable with temperature and humidity close to cave values of 15 °C and 98 % RH (Studier et al. 1986; Studier and Lavoie 1989; Lavoie et al. 2007). Cave crickets are at increased risk of predation when they leave the cave. Mice preferentially include cave entrances in their home ranges as a reliable source of food (Viele and Studier 1990). Our study extended on preliminary data (Lavoie et al., 2007) and focused on the frequency of missing limbs and impacts of missing one or both hind legs on foraging efficiency.

2. Materials and Methods

We visually classify cave crickets into four size classes (Lavoie et al. 2007) based on length of the hind femur: Class 1 HFL 5-10 mm; Class 2 HFL 10-15 mm; Class 3 HFL15-20 mm, and Class 4 mature adult crickets with HFL of 20 mm or greater (Studier *et al.*, 1986). Inter-rater reliability is good. Sex can be determined easily for size Class 3 and 4 crickets by the presence of an ovipositor on females (see Fig. 1). Immature crickets of Class 1 and 2 are not sexually dimorphic. Adult *H. subterraneus* cave crickets are recorded by sex and whether they have all the legs, are missing which leg or part of a leg, and if they are missing multiple legs.

For the crop fullness study as an indicator of effective foraging, adult cave crickets were collected in the Frozen Niagara entrance to Mammoth Cave. We recorded their sex, weighed them by gram to four decimal places on an electronic balance, and measured their HFL using a caliper. Studier et al. (1986) determined a regression for HFL and crop-empty live weight in *H. subterranues* that has a high reliability (r = 0.91). It is possible to weigh a cricket, measure its HFL, and calculate how much of its total weight is crop contents by subtracting the predicted crop-free live weight. Only crickets naturally missing hind limbs were included in the study. For the crickets missing both hind legs we used the average of 22 mm for males and 23 mm for females for the calculations. A typical hind leg weighs 0.0382 g and we adjusted the total weight by that amount for each missing hind leg.

3. Results and Discussion

Results of the missing leg census for *H. subterraneus* are shown in Table 1 for summer (May or June) 2007, 2008, 2009, and 2012 and winter (Dec 2009). Hind legs are autotomized significantly more often than other legs ($F = 34.069$, $P < 0.001$). For the four summer census dates, the average % of crickets missing legs ranged from 8.82 % to 19.57 %, with the lowest averages seen in Summer 2012.

Table 1. Patterns of missing legs in Hadenoecus subterraneus *cave crickets for five census dates. ND = Not Determined.*

Census Date	# Total Crickets (n= # of sites)	# Intact	# Missing Legs	% of Total Missing Legs	# Missing Multiple Legs	% of Total Missing Multiple Legs
May 2007	1,077 (n=8)	915	159	14.75	ND	ND
May 2008	1,376 (n=4)	1,147	229	16.64	25	1.82
May 2009	792 (n=9)	637	155	19.57	12	1.52
Dec 2009	1,320 (n=7)	1,082	246	18.64	10	0.76
June 2012	1,293 (n=9)	1,215	114	8.82	10	0.77

Seasonal averages comparing data from May 2009 and December 2009 (Table 1) show a fairly consistent average percentage of crickets missing legs, 19.57 % and 18.64 %, respectively, but a much broader range from 5.26 % to 23.86 % in May 2009 compared to a narrower range of 16.67 % to 24.61 % in Dec 2009.

Crickets missing multiple legs are always present ay a much lower frequency (Table 1), with an average ranging from 0.76 % to 1.82 %, across all census dates. The range of cave crickets missing multiple legs by cave was 0.00 % to 6.06 %. Anecdotally, crickets missing multiple legs are noticeable thinner, and are usually found within 20 m of the entrance.

Comparing the range of data across all caves for each census date in Table 2 shows that a range of 3.18 % to 28.00 % of the populations are missing legs. It is almost always the entire leg that is missing. Crickets missing only a part of a leg averaged less than 0.001 % of the population.

Table 2. Average and range of Hadenoecus subterraneus *cave crickets missing legs by census date.*

Census Date	% Total Missing Legs	Low % for Census Date	High % for Census Date
May 07	14.75	6.16	28.0
May 08	16.64	8.33	19.17
May 09	19.57	5.26	23.86
Dec 09	18.64	16.67	24.61
June 12	8.82	3.18	19.35

At the Frozen Niagara entrance the percentage of crickets by sex missing legs is inversely proportional to the distance from the entrance. For male crickets, 31.9 % of crickets within 10–30 m of the entrance were missing legs compared to 14.6 % of males 60–80 m from the entrance. For females, 30.4 % of crickets within 10–30 m of the entrance were missing legs compared to 20.7 % of females 60–80 m from the entrance. We conclude that crickets missing legs stay closer to the entrance to reduce the distance they have to travel to leave the cave for their next foraging bout. Crickets close to an entrance are less likely to reproduce than crickets found deeper into the cave (Cyr et al. 1991).

Within-cave variability is summarized in Table 3 for three locations that were censused on all of the census dates. Summer results show that Frozen Niagara has a higher proportion of crickets missing legs (14.51 % to 22.84 %) than Violet City (6.90 to 8.70 %. Carmichael is typically in between these two extremes. The percentage of crickets missing legs is the highest for each cave in Dec 2009.

Table 3. Percentage of H. subterraneus *cave crickets missing legs for three cave locations by census dates compared to the average number of crickets missing legs for that census date.*

Census Date	% Total Missing Legs	Carmichael % Missing	Frozen Niagara % Missing	Violet City % Missing
May 07	14.75	6.16	14.51	6.90
May 08	16.64	13.79	19.17	8.33
May 09	19.57	16.67	22.84	8.70
Dec 09	18.64	17.39	24.61	18.75
June 12	8.82	14.29	22.84	8.70

There is no consistent difference in the frequency of crickets missing limbs in males *vs.* females. Since the winter 2009 data showed the least variability, we present the results for all caves censused that date in Table 4. No pattern of differences in males and females are noted.

Table 4. December 2009 H. subterraneus *cave crickets missing leg data separated by sex for all study caves censused.*

Location	Sex	Total #	# Intact	# Missing Legs	% Missing Legs	# Missing Multiple Legs	% Missing Multiple Legs
New Discovery	M	107	90	17	15.89	0	0.00
New Discovery	F	133	110	23	17.29	0	0.00
Carmichael	M	25	22	3	12.00	1	4.00
Carmichael	F	21	16	5	23.81	0	0.00
Frozen Niagara	M	113	90	23	20.35	1	0.88
Frozen Niagara	F	178	154	24	13.48	1	0.56
Floyd CCC	M	33	27	6	18.18	0	0.00
Floyd CCC	F	37	29	8	21.62	0	0.00
Violet City	M	5	4	1	20.00	0	0.00
Violet City	F	10	9	1	10.00	0	0.00
Great Ony	M	48	39	9	18.75	0	0.00
Great Onyx	F	36	29	7	19.44	0	0.00
White Cave	M	368	298	70	19.02	3	0.82
White Cave	F	305	257	48	15.74	4	1.31
Total/Averages		1419	1174	245	17.27	10	0.70

Do missing legs negatively impact the ability to find food? In general, females have more crop contents than males since they can consume more in a single feeding bout (Studier et al., 1986; Studier and Lavoie, 1989). Crop weight (Figure 2) as a measure of success at foraging was significantly reduced in crickets missing one or both hind legs (P<0.006). Since all crickets were wild caught, we have no way of determining the length of time that an individual cricket had been missing a leg or legs or how recently they had left the cave to feed.

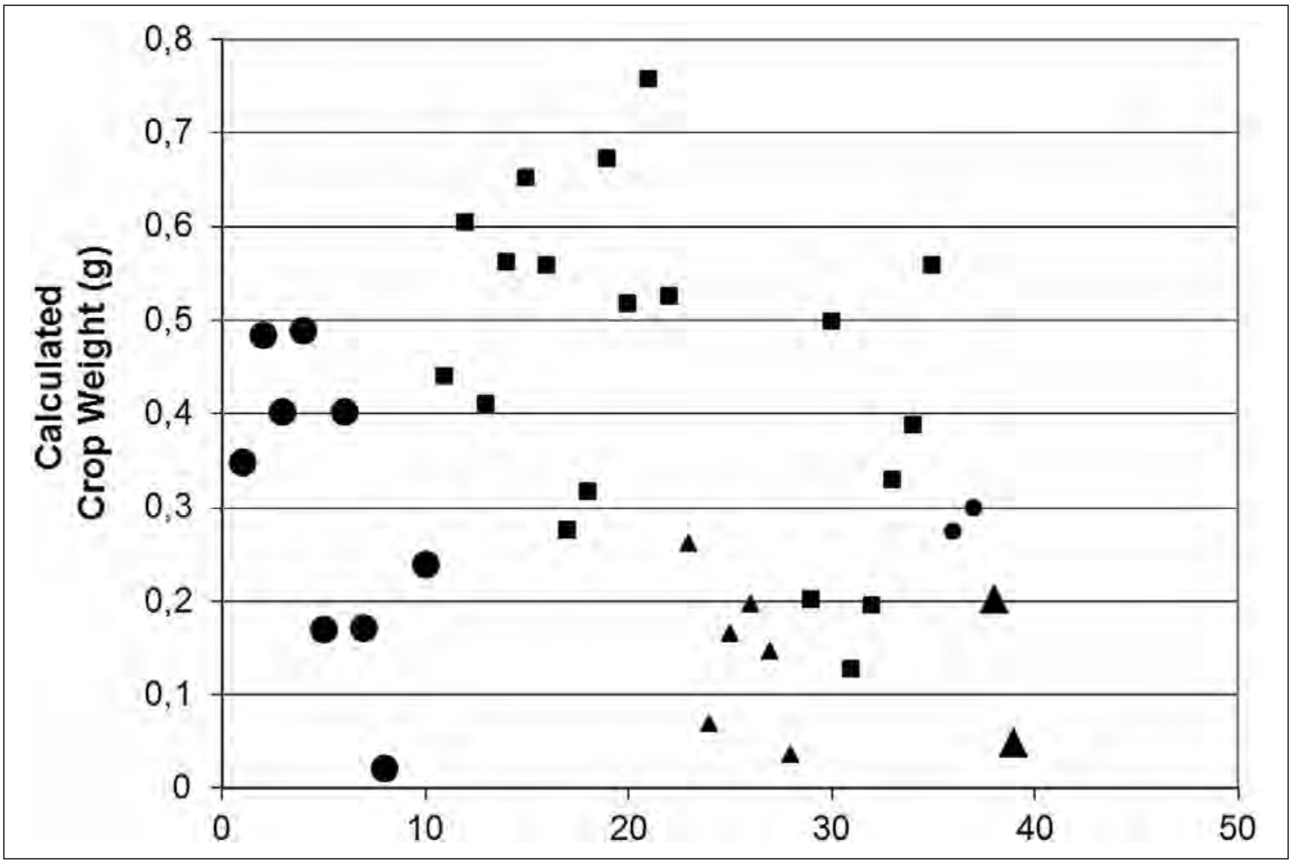

Figure 2. Effect of missing hind limbs on crop weight as a measure of foraging success in the cave cricket Hadenoecus subterraneus. *Calculated crop weight by individual male and female crickets with all legs, and missing one or both hind legs. Missing legs is associated with reduced crop contents (P < 0.006).*

● *= males, intact (n=10);* ■ *= females, intact (n=12).*

▲ *= males, missing one hind leg (n=6);* ■ *= females missing one hind leg (n=7).*

● *= males missing both hind legs (n=2);* ▲ *= females missing both hind legs (n=2).*

4. Conclusions

The frequency of leg loss in *H. subterraneus* cave crickets is variable, but often high and shows consistency from specific caves across census dates. In general, average percent leg loss is consistent from summer to winter, but the range of variability is reduced in the winter. Crickets missing legs are more likely to be found closer to entrances to reduce the distances they have to travel, but which also reduces their success at reproduction which is higher deeper into the cave. Lower crop contents were significantly associated with missing legs (P<0.006) in male and female cave crickets, showing that missing legs decreases the ability of crickets to find food, and may negatively impact fitness.

Are differences in leg loss rates related to specific cave locations, to weather patterns, to seasons, and/or other factors? Reducing the percentage of a population missing legs is desirable since loss of legs reduces success at foraging and overall fitness. Can we manage entrances to reduce loss of legs?

Further study will continue on frequency and distribution of *H. subterraneus* crickets with missing legs. Analysis of data from 2010 and 2011 will help us determine if the patterns reported here are consistent. Additional studies will determine if stamina for walking and jumping are affected by missing legs.

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CAN COMMENSAL FUNGAL POPULATIONS PROTECT BATS FROM *GEOMYCES DESTRUCTANS* INFECTION?

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Since the emergence of White-nose Syndrome (WNS) in 2006, North American bat populations have experienced devastating population declines. WNS is caused by *Geomyces destructans* (*Gd*), a psychrophilic fungus that invades the wing tissues of bats during their naturally immune-depressed state of torpor. Some species, including the Indiana bat (*Myotis sodalis*), appear to have reduced mortality from WNS despite close association in hibernacula with affected bats experiencing high WNS mortality. In order to test whether Indiana bats may be naturally resistant to WNS we analyzed the culturable and non-cultural fungal communities of bat fur in an attempt to determine whether commensal populations could limit *Gd* growth. Identifying mechanisms of WNS resistance in bats could help in our understanding of the emergence of *Gd*, the future of the disease, and potential biological controls.

1. Introduction

White-nose syndrome (WNS) is a cutaneous fungal disease of hibernating cave bats, named after the powdery white growth of *Geomyces destructans* (*Gd*) on their muzzles, ears, and wing membranes (Blehert et al. 2009). WNS was first documented in Howe's Cavern in 2006 (Blehert et al. 2009) and since then has spread across the eastern United States and into Canada, killing more than 5 million North American bats (Meteyer et al. 2012). Eleven species of bat currently hibernate within the epizootic range of WNS, seven of which are impacted by WNS: the big brown bat (*Eptesicus fuscus*), the tri-colored bat (*Perimyotis subflavus*), the eastern small-footed bat (*Myotis leibii*), the gray bat (*Myotis grisescens*), the Indiana bat (*Myotis sodalis*), the little brown bat (*Myotis lucifugus*), and the northern long-eared bat (*Myotis septentrionalis*) (Wibbelt et al. 2010).

Several important factors have been proposed that may affect the severity of *Gd* infection in bats, including hibernacula conditions (Grieneisen 2011), acquired immune responses (Bouma et al. 2010), and body mass (Reeder et al. 2012). The prevailing hypothesis is that death is due to a physiological impairment caused by the cutaneous invasion of *Gd* that is reflected by an increased frequency of arousals. Because wing membranes are critical for gas exchange and maintenance of water balance, *Gd* invasion may damage the wing membrane to the point where osmotic balance and homeostasis can no longer be maintained, resulting in an increased frequency of arousals due to dehydration (Cryan et al. 2010; Reeder et al. 2012).

The Indiana bat, *M. sodalis,* is an endangered bat species found throughout the eastern United States (Kurta and Whitaker 1998). Although *M. sodalis* has been affected by WNS, the population has experienced a reduced mortality (mortality rate 21 %) compared to other species, such as *M. lucifugus* (mortality rate 91 %) (Turner et al. 2011). The differences in bat mortality may indicate that *M. sodalis* are either resistant to infection, *Gd* pathology, or hibernate under conditions that are not conducive to *Gd* growth. We hypothesize that *M. sodalis* may be resistant to WNS through the role of commensal populations and species-specific innate immunity. In this study we examined the culturable and unculturable commensal fungal populations of bat pelage in an attempt to understand what factors could affect fungal growth and resistance to WNS.

2. Materials and Methods

Samples were collected from Cuijo's (CUGA) and Salt Petre (SPC) caves, Virginia, USA and from caves in Canoe Creek State Park (CCSP), Pennsylvania, USA. For fungal profiles, fur was collected from the following species: *M. lucifugus, M. sodalis, and P. subflavis.* Approximately 10 mg of fur was collected with sterile scissors from between the shoulder blades of bats and stored in γ-irradiated vials for DNA extraction. For cultivation, bats were swabbed with moistened cotton tipped applicators for cultures along the forearm and around the muzzle and ears. Swabs were used to inoculate potato dextrose agar (PDA) plates consisting of 4 g potato extract, 20 g dextrose, and 15 g agar per liter of water (pH 6.8–7.0). All samples were collected under the auspices of the Virginia Department of Natural Resources and the Pennsylvania Game Commission, following all local and Federal collection permits. See Table 1 for a summary of samples collected by site, species, and sex.

Total DNA was isolated from bat fur using the YeaStar genomic DNA kit (Zymo, Irvine, CA) according to the manufacturer's instructions using the chloroform-free protocol (Protocol II) and eluted in 20 µl dH_2O. Fungal DNA was amplified using PCR with fungal-specific primers for the internal transcribed spacer (ITS) 18S gene sequence. Nested PCR was performed using an external pair of primers to amplify the template, followed with a second round of PCR using internal primers. The first round of amplification was carried out using the external forward primer NSA3 (5'-AAACTCTGTCGTGCTGGGGATA – 3') and external reverse primer ITS4-B (5' –CAGGAGACTTG TACAC GGTCCAG – 3') using 1 µl of DNA template, 10 µl Taq 2X master mix, 300 mM NSI1and ITS4-B, and dH_2O to a final volume to 20 µl. The second-round PCR reaction was performed using internal forward primer ITS5 (5' – GGAAGTAAAAGTCGTAACAAG G – 3') and internal reverse primer ITS4 (5' – TCCTC CGCTTATTGATATGC – 3') using 1µl of first round PCR product as the template as described. The thermal cycling parameters for the first reaction was a hot start at 94 °C for

5 minutes, followed by 36 cycles of 94 °C for 45 seconds, annealing at 56 °C for 1 minute, and 72 °C for 1 minute 30 seconds. Second round thermal cycling paramaters were identical except an annealing temperature of 60 °C was used. PCR products were purified using a Genomic DNA Clean & Concentrator kit (Zymo, Irvine, CA), eluted in 6 µl dH_2O, and cloned using the TA Cloning Kit (Invitrogen, Grand Island, NY) following the manufacturers' protocols. Clones were sent to Advanced Genetics Technology Center (AGTC) (http://www.uky.edu/Centers/AGTC/) for sequencing. Sequences were aligned using the multi-sequence alignment function in Geneious Pro (Biomatters Ltd., Auckland, New Zealand). Consensus sequences were generated and compared against all sequences available in Genbank (NCBI) using the BLAST algorithm (Johnson et al. 2003).

Table 1. Summary of the samples collected by location and whether Geomyces species were detected by cultivation. LB = M. lucifugus*; BB* = E. fuscus*; IND* = M. sodalis*; TRI* = P. subflavus.

Cave	Species	Gender	*Geomyces*
CCSP	LB1	M	+
CCSP	LB2	M	-
CCSP	LB3	F	+
CCSP	LB4	M	-
CCSP	LB5	M	-
CCSP	LB6	F	+
CCSP	LB7	M	NA
CCSP	LB8	M	NA
CCSP	BB1	F	-
CCSP	IND1	NA	+
CUGA	LB1	NA	+
CUGA	LB3	NA	+
CUGA	TRI1	NA	-
SPC	LB3	NA	-
SPC	IND1	NA	-
SPC	IND2	NA	-
SPC	IND3	NA	-
SPC	TRI2	NA	+
SPC	TRI3	NA	-

Culture plates were analyzed for the presence of *Geomyces* species after ~1 month of growth at 10 °C using colony morphology and microscopy, via staining with lactophenol cotton blue. Positive identification of a *Geomyces* species consisted of visualization of characteristic branched conidiophores with individual spores or chains of spores (~2 µm in diameter) attached directly to the branches and branch tips. Samples positively identified were subcultured and maintained at 10 °C as part of a fungal culture library. For species identification, the genomic DNA was extracted using a Fungal/Bacterial DNA kit (Zymo, Irvine, CA) following the manufacturer's recommended protocol. The ITS sequences were than PCR amplified, sequenced and identified using BLAST as described.

3. Results

3.1. Culturable Fungi

None of the bats we sampled came from caves infected with *Gd*, allowing us to examine the non-WNS fungal populations of healthy bats. We examined the culturable and non-culturable fungal profiles of representative *M. lucifugus, M. sodalis, and P. subflavus* (Tables 1 and 2). Our results demonstrate that the fungal communities of bats show species specific variation, with *M. lucifugus* supporting a much more varied community of fungi. Five of nine *M. lucifugus* analyzed (56%) were positive for members of the *Geomyces*, whereas only one of the *M. sodalis* (25%) supported the growth of this genus. The *M. lucifugus* also supported more diversity in the species of *Geomyces* species than *M. sodalis.*

None of the *M. sodalis* from CUGA and SPC caves demonstrated the presence of *Geomyces* species on their fur, and we wanted to determine whether this was due to the absence of *Geomyces* in the environment or that these bats did not support the fungus. We therefore compared the *Geomyces* seen on bats from CUGA and SPC with the total cultured fungal population from these caves, as determined from a separate study (Kaiser et al. unpublished results) (Table 2). The results suggest that even though *Geomyces* are present in this cave, they could not be detected on *M. sodalis* fur, whereas the *M. lucifugus* had a fungal population in the fur that more closely reflected the fungal diversity of the cave (Table 2).

3.2. Molecular Data

Cultivation is a fairly restrictive procedure, only allowing the identification of fungal species able to grow under the conditions used. We therefore decided to examine the fungal communities of bat fur using molecular techniques, which allows us to determine whether non-culturable *Geomyces* are present and what proportion of the population they represent. To this end, we created a clone library from a *M. lucifugus* bat from CCSP. The results (Table 3) demonstrate the high diversity of fungi on this bat, although none of the fungal species identified matched those seen using cultivation techniques. It is interesting to note that *Geomyces* were not detectable using this technique, suggesting that this genus may not represent a significant population on this bat's fur.

4. Discussion

WNS is the first documented case of an invasive fungal epidemic in endothermic organisms, although bats are functionally exothermic during their long periods of torpor (Cryan et al. 2010). Torpor is a metabolically depressed state which mammals enter in order to conserve energy and cope with periods of scarce food supply (Bouma et al. 2010), lasts days to weeks, and is regularly interrupted by periods of arousal (Geiser and Ruf 1995). During torpor metabolic rates can decrease to <5% of basal metabolic rate with a corresponding decrease in body temperature (T_b) to near ambient temperatures. In bats, T_b is approximately 2–8 °C during torpor (Reeder et al. 2012), while *Gd* has optimal growth at ~10 °C. Torpor is also associated with suppression of the immune system including severe leukopenia (Bouma et al. 2010), reduced acute complement production, and reduced phagocytic capabilities (Bouma et al. 2010), allowing a window of opportunity for infection. However, bats are not entirely susceptible to infection during these periods, with some amount of protection being

Table 2. Distribution of cultured fungi from cave environments (SPC and CUGA) and bats (LB = M. lucifugus*: TRI =* P. subflafus*; IND =* M. Sodalis*). Grey = positive.*

Species	SPC	CUGA	LB	TRI	IND
Aspergillus aureolatus	+			+	
Funal endophyte isolate 9021	+		+		
Fusarium sp. SZ1		+		+	
Isaria farinosa	+	+	+	+	+
Geomyces destructans-like		+	+		
Geomyces pannorum strain VKM FW-751	+				
Geomyces destructans-like 20674-10		+	+		
Geomyces sp. FFI 30 5.8S	+			+	
Geomyces pannorum		+	+		
Mucor circinelloides PG5(3)		+	+		
Mucor circinelloides	+	+	+		
Mucor fragilis	+		+		
Mucor hiemalis	+	+	+	+	
Mucor racemosus strain KUC6001		+	+	+	
Mucor racemosus strain UWFP 1084		+	+	+	
Mucor racemosus strain ATCC 42647		+	+		
Mucor ramossisimus	+	+	+	+	
Mucor sp. JJP-2009a	+	+	+		
Mucor sp. 02MIN3S1		+	+		
Penicillium brevicompactum		+	+		
Penicillium brevicompactum strain FRR 66	+			+	
Penicillium camemberti	+				
Penicilium camberti isolate 313		+	+		
Penicillium commune	+	+		+	
Penicillium commune isolate wb319	+	+	+	+	
Penicillium concentricum	+	+	+		
Penicillium concentricum strain NRRL 2034	+	+	+	+	
Penicillium echinulatum	+	+	+	+	
Penicillium glandicola strain NRRL 2036		+	+		
Penicillium lanosum		+	+		
Penicillium lanosum isolate 929		+	+	+	
Penicilllium sclerotiorum strain FRR 1202	+			+	
Penicillium solitum strain FFR 937		+	+		
Penicillium solitum		+	+		
Penicillium sp. CCN24		+	+		
Penicillium verrucosum	+			+	
Uncultured fungus	+	+	+		
Uncultured fungus clone OTU29		+	+		
Zycomycete sp. FFI 6	+				

present from commensal populations and functional components of the innate immune system.

The protective nature of commensal microbial populations, which includes limiting colonization by pathogenic organisms, is well understood in humans. Although the commensal population of bats is as yet unidentified, our results show that bats play host to a multitude of fungal species, including species of the genus Geomyces, although the types of fungi vary by bat species. Our identification of *Geomyces* species on bats and within the cave environment is in agreement with other studies (Larcher et al. 2003; Wibbelt et al. 2010); however, our molecular work suggests that *Gd* may be a minor component of the bat fungal population, identified only by the selective conditions for the growth of the fungus (PDA media at 10 °C). In some species, neither of our assays detects *Geomyces* on these individuals, suggesting that conditions may not be conducive to the growth of *Geomyces* on all individuals. The reduced incidence of *Geomyces* on *M. sodalis* correlates well with the low mortality seen in these species, although we will have to greatly expand this data set to demonstrate a significant correlation between fungal population and bat species.

Our preliminary results suggest that the majority of fungal species found on bats do not represent commensal populations but represent saprophytic species found from cave and forest environments. This implies that bats may pick up fungal species from their surroundings and act as passive transporters rather than actively supporting a growing fungal population. To determine whether the commensal populations are involved in *Gd* resistance, our next step is to take cultures of fungi found on *M. sodalis* and determine if they inhibit the growth of *Gd* in competition assays. IF we find that the normal microbiota of some bats is able to limit colonization by *Gd,* this will greatly expand our understanding of how commensal populations and the innate immune system increase resistance to WNS. Such information could help us understand the emergence of this pathogen, the future of the disease among the bat population, and the potential for biological control.

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Table 3. Distribution of fungal phylotypes found on M. lucifugus *(LB8) fur using PCR analysis.*

Genus	Number	Closest Phylotype Relative	Identity
Ascomycota			
	4	Limestone ascomyte CR-2004	98%
	4	*Toxicocladosporium irritans* strain CBS	99%
	3	*Cladosporium sphaerospermum* strain HD8	99%
	2	*Ascomycete* sp. VTT D-041035	99%
	2	*Alternaria alternate* strain SS-S4	97%
	1	Uncultured *Ascomycete* ITS	80%
	1	*Agaricomycete* sp. 7406	99%
	1	*Dactylaria ampulliformis* strain ICMP3660	79%
	1	*Cladosporium cladosporioides*	89%
	1	*Eutypella scoparia* isolate SB9053a	100%
Basidiomycota			
	6	*Sporidiobulus salmonicolor* strain MYA-4550	99%
	3	*Trametes gibbosa* strain xsd08138	99%
	1	*Skvortzovia furfurella* isolate 1725	99%
	1	*Botryobasidium botryosum* isolate AFTOL-ID	99%
	1	*Pleurotus floridanus* strain dd08070	99%
	1	*Rhodocollybia butyracea*	99%
	1	*Ceriporipsis pannocincta*	99%
	1	*Bulleribasidium oberjochense* strain CBS9110	99%
	1	*Skeletocutis nivea* isolate DLL2010-087	88%
	1	*Trametes betulina*	99%
	1	*Gleoporus dichrous* isolate DLL2009-167	99%
	1	*Perenniporia narymica*	99%

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MICROFUNGAL COMMUNITY OF MOVILE CAVE, ROMANIA

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Movile Cave, an unique ground-water ecosystem in southern Romania, was discovered in 1986. This chemoautotrophic cave contains an abundant and diverse fauna with terrestrial and aquatic invertebrate communities including 24 endemic species. In the past, several studies were focused on cave chemoautotrophic bacterial community, nevertheless microfungal community was so far neglected.

Microscopic filamentous microfungi were studied in 2011 (upper dry level of cave system from cave air, cave sediments, corroded limestone walls, and isopod faeces and isopod and spider cadavers) and 2012 (upper level of cave system and submerged part – airbell – from cave sediment and microbial mat). The gravity settling method for the estimation of air-borne microfungi, the dilution plate method, and direct isolation were used as isolation methods. The cave microfungal community was also compared with above environment (outside air-borne and soil-borne microfungi). Results show a broad microfungal spectrum in cave air and cave sediments including several species of the genus *Aspergillus* (e.g., *A. baeticus*, *A. ustus*, *A. creber*) and *Penicillium* (e.g., *P. manginii*, *P. chrysogenum*, *P. expansum*), *Purpureocillium lilacinum*, *Microsporum gypseum*, *Myriodontium keratinophilum*, *Oidiodendrum griseum*, *Spiniger meineckellus* etc. *Trichoderma* species dominated in microfungal community in cave sediment and microbial mat collected in the second airbell, microfungal communities include *Penicillium glucoalbidum*, *Cladosporium* sp., *Mortierella* sp., sterile dark pigmented mycelia, and undetermined basidiomycete species (cave sediment), and *Doratomyces stemonitis* (microbial mat).

MICROBIAL IRON CYCLING AND BIOSPELEOGENESIS: CAVE DEVELOPMENT IN THE CARAJÁS FORMATION, BRAZIL

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The Carajás Formation in northern South America is a banded iron-formation (BIF) that contains a large number of iron caves (>1,000), although the geologic basis for speleogenesis remains unclear. Given the organic-rich environment that could drive microbial processes, we examined these caves using a variety of techniques to determine whether biospeleogenesis was responsible for cave formation. Within the caves we examined the geochemistry to determine if it could support microbial growth and iron cycling. We also identified microbial activity and pendulous biofilms (snottites) within the cave that included recognized iron-oxidizing species, as well as the presence of iron-reducing bacteria within sediments. The observed conditions and microbial communities suggest that iron cycling by iron-reducing microorganisms could convert insoluble $Fe(III)_s$ into soluble $Fe(II)_{aq}$, which would lead to the mobilization of iron. A secondary metabolic pathway then seems to re-oxidize this reduced iron back into $Fe(III)_s$, which may explain the presence of high grade iron ores associated with cave locations. Once cavities are enlarged in the BIF via microbial activity, groundwater flow could remove bulk $Fe(II)_{aq}$, allowing passage enlargement and cave formation in the Carajás region.

1. Introduction

The Archean Earth was anoxic in nature until photosynthetic *Cyanobacteria* began to produce oxygen during the great oxidation event approximately 2.45 Gyr ago (Buick 2008; Sessions et al. 2009). It is speculated that the influx of oxygen into the atmosphere oxidized Fe(II) present in the oceans, which precipitated as banded iron deposits comprising Fe_2O_3 (hematite), FeO(OH) (goethite) and Fe_3O_4 (magnetite) with alternating layers of SiO_2 (Beukes and Klein 1992; Klein and Ladeira 2002). This ancient process led to the worldwide accumulation of >1 Gyr old banded iron formations (BIFs).

The Archean Carajás Formation (ACF), commonly referred to as the Carajás BIF, is located in the Northern Brazilian state of Para (Trendalla et al. 1998). The ACF is ranked among the most substantial iron ore deposits on Earth, reaching a thickness of 300 m and containing an approximated 17.8 billion tons of ore (Guedes et al. 2003). The ACF is predominantly iron in composition (17–43 % wt/wt), although iron content can reach 66 % (Klein and Ladeira 2002; Guedes et al. 2003).

The Carajás region is also one of the most cave dense areas of Brazil, although it is completely devoid of carbonates and the high iron content would generally limit dissolution (Piló and Auler 2009). To explain this speleogenetic anomaly, in 1987 Mcfarlane and Twidale proposed that microbial activity may be playing a role in the formation of these iron caves, although no mechanism was suggested. The recent advent of molecular microbiology has allowed microbiologists to describe iron-oxidizing and reducing microorganisms under a number of environmental conditions (Hedrich et al. 2001; Jahn et al. 2006). With this information, we hypothesize that the iron caves in the Carajás region are formed by microbial iron cycling, wherein $Fe(III)_s$ is mobilized by reduction to the soluble $Fe(II)_{aq}$ form. It is the aim of this research to test this hypothesis.

2. Material and Methods

Five caves were identified in the Carajás formation in Parauapebas, Para, Brazil, for research activities, ranging from a short paleo system up to an ~500 m long system with an active stream. Samples were taken from all five caves, although it was apparent that extant microbial activity was only occurring in N4WS-067 and GEM-1753. Geologic samples were collected as hand samples, while samples for microbiological analysis were collected using aseptic technique.

The pH and temperature were recorded using a SevenGo Pro pH/Ion meter (Mettler Toledo, Columbus, OH). Total iron was determined using the colormetric *2*,*4*,*6*-*Tri*-(*2*-pyridyl)-*5*-triazine] method (Iron test kit IR-21, Hach, Loveland, CO). Dissolved iron was calculated by filtering water through a 0.1 µm filter and comparing to the total iron concentration. For total organic carbon, water was filter sterilized via a 0.1 µm filter into a plasma cleaned glass vial (Thermo Scientific, Miami, OK), followed by analysis on a Shimadzu TOC-V analyser (Shimadzu, Columbia, MA).

Cultures were inoculated from sediments into PIPES buffer (25 mM, pH 6.8) liquid medium that contained ammonium chloride (10 mM), magnesium chloride (2 mM) trypticase soy broth (0.2 g/l), and vitamins and trace metals as described by Tanner (1997). H_2 was added as the electron donor and 25 mM hydrous ferric oxide (HFO) as the acceptor. Cultures incubated at 25 ºC under low light conditions for six months, though growth was seen in 14 days. Fe(III) reduction was determined by quantification of Fe(II) by ferrozine assay (Lovley and Phillips, 1987).

Genomic DNA extraction was performed in the field using an Xpedition soil/field DNA Mini Prep PowerSoil DNA Kit (MolBio Labratories Inc, Carlsbad, CA) following the manufacturer's standard protocol. Community pyro-sequencing of each sample was carried out by Research Testing Services (Lubbock, TX) with over 60,000 tag-sequence reads per sample, including a preparation control.

The sequence data analysis was accomplished by removing poor-quality and chimeric reads using QIIME and comparing against the NCBI sequence database via BLAST (Caporaso 2010).

Mineralogic studies were performed on a Phillips 3100 automated diffractometer using CuKα radiation. Samples were scanned at 2θ of 2º to 70º, with an accelerating voltage of 40 kV at 35 mA. Intensities were measured with a 0.02º step size and 1-s counting time per step. Sample spectra were then compared to reference spectra to identify mineral phases (Bertel et al., 2011). For elemental mapping, thin sections of rock samples were visualized on a Quanta 200 D7756 ESEM (FEI, Hillsboro Oregon) and elemental distributions in the thin sections were evaluated with an EDX attachment.

3. Results

In order to determine whether the host rock of the cave could support microbial activity, it was first necessary to determine the geochemical conditions present. We recorded a number of geochemical parameters for each site, although only those for GEM-1753 are presented here (Table 1). A stream ran through GEM-1753, with numerous pools fed by drip-water coming into the system. Along the surface of one wall the water created a biofilm that terminated in a pendulous biofilm, known as a snottite in sites where similar biofilms have been observed (Figure 1).

Table 1. Physicochemical characteristics of sample sites.

Sample	TOC (mg L^{-1})	pH	Temp	Total Fe (mg L^{-1})	Soluble Fe (mg L^{-1})
Stream	57.00	7.14	24.4 ºC	0.24	0.17
Low Iron Pool	0.54	4.36	25.1 ºC	0.01	0.00
Low pH Pool	13.00	2.11	25.1 ºC	3.47	2.57
Snottite	7.91	6.11	24.6 ºC	0.17	0.05

The stream runs through GEM-1753 cave, presumably draining from the jungle floor above the cave. The TOC of this stream (57 mg L^{-1}) was much higher than we have recorded in cave streams elsewhere. The stream was also neutral, having a pH likely buffered by interaction with the soil (Braids and Swarzenski 2009). The stream water also had an elevated iron content, with a relatively high percentage of soluble iron (71 %) suggesting that iron was mobilized within this water. Within the cave pools there were dramatically different results. Within the first pool (Low Iron Pool), there appeared to be a lining of biological material, although TOC indicated that there was little organic carbon within this water (0.54 mg L^{-1}). The pH was also acidic (pH 4.36) and both total and soluble iron were low. This is in contrast to another pool that contained bat guano (Low pH pool). This had high organic carbon (13 mg L^{-1}) and an extremely low pH (pH 2.11). Indeed, this pool had the lowest pH of any pool examined during extended sampling. This low pH also correlated with high total iron, of which >74 % was in a soluble form (Table 1). We also examined the water flowing out of the snottite. While in other caves these pendulous biofilms drop water at a slow rate (cc m^{-1}), within GEM-1753 the snottite had a very high flow-rate (dc m^{-1}), limiting the ability of the snottite to change the chemistry of the water flowing over it. Nonetheless, the TOC of this water was elevated (7.91 mg L^{-1}) and the pH and total iron were reduced when compared to stream water.

Figure 1. Pendulous biofilms (snottite) in cave GEM-1753.

The water chemistry suggests that sufficient organic carbon was coming into the cave system to power iron reduction by microbial activity; however it does not mean that the iron was in a bioavailable form. To test this, we examined the mineralogy of the host rock. The caves are formed at the contact between the canga and the host BIF. To examine the geochemistry of the host BIF, a hand sample was examined by XRD and EDS analysis. The results (Figure 2) demonstrate a diffraction pattern that almost exactly matches with hematite, with no additional peaks, while the EDS analysis suggests the dominance of iron and a carbon-rich material (Figure 3). It is likely that the host rock BIF is more complex than in this sample, with silicates interbedded within the iron; however, the particular sample collected appeared to be almost pure hematite by XRD (Figure 2). We were unclear as to the origin of this carbon. If it represented carbonates, it could represent an entirely different mechanism of speleogenesis, with the acidic water dissolving interbedded carbonates, leading to cavity formation and enlargement. However, carbonates are not known in this region. To determine the origin of this carbon, we carried out elemental mapping of a thin-section of this rock (Figure 4). The thin-section analysis appears to be of an enriched iron-oxide sample that is interbedded with carbon-rich material, but lacking calcium. Our best analysis of this finding is that we are observing deposited iron, banded with organic material (Figure 4). We are currently examining this material to determine if it represents fossilized bacterial material.

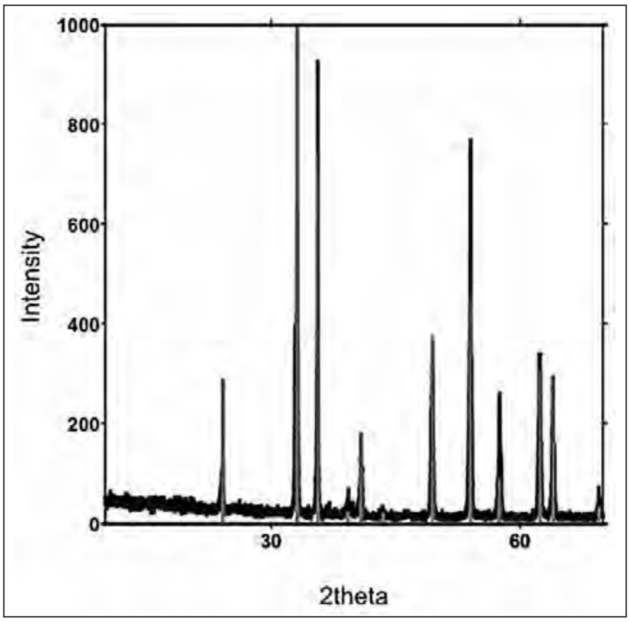

Figure 2. X-ray powder diffraction of sediment spectra (black). The hematite fingerprint has its peaks overlaid from American Mineralogist Chrystal Structure Database (gray).

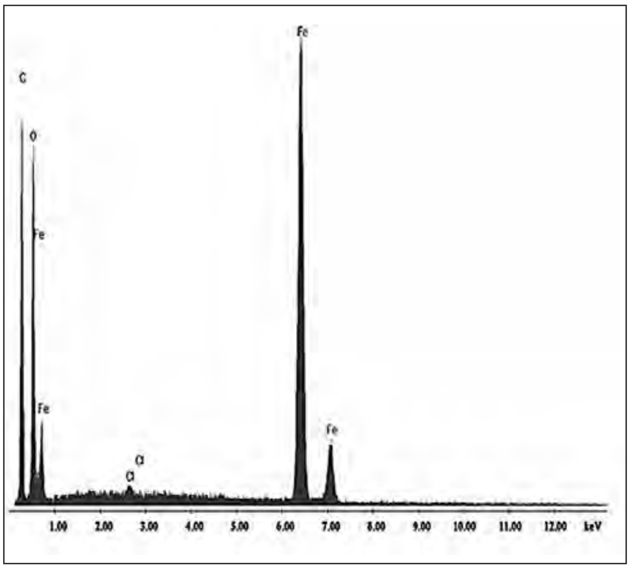

Figure 3. Energy-dispersive X-ray spectroscopy (EDX) was preformed on thin section sediments. The spectra show the presence of iron, oxygen, chloride and carbon, the chloride being nearly background.

The presence of organic carbon and a bioavailable iron suggests that microbial activity can occur within the cave. In order to determine what microorganisms are present within the cave, DNA was isolated from each of the sample sites and examined via 454-tag sequencing. Phylotypic grouping of the tag sequences via BLAST analysis allowed compiled taxa summaries were generated (Figure 5). Analyzing these communities at the division level demonstrated that the majority of these environments contained a high percentage of Archaea (Figure 5). Indeed, the snottie was dominated by members of the Archaea, an usual finding in any environment. A simple analysis of microbial communities based on phyla demonstrated dramatic differences between all environments examined (Figure 6).

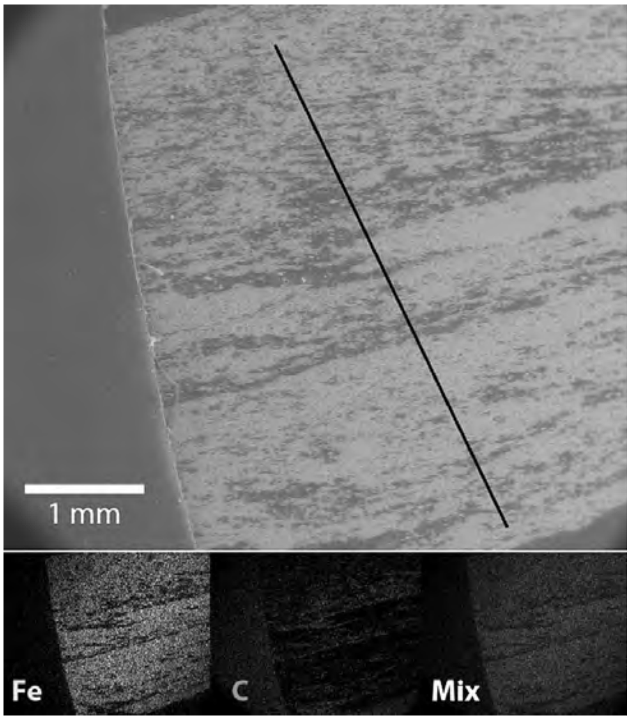

Figure 4. EDS map of thin-section. A) Back scatter electron (BSE) analysis of thin-section. The line indicates the region analyzed to generate the spectra seen in figure 3. B) The three panels indicate elemental mapping for iron (Fe), carbon (C) and the overlaid mix of iron and carbon (mix).

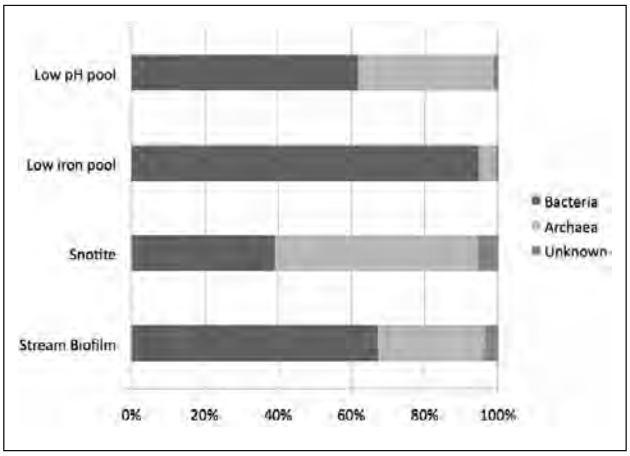

Figure 5. Total bacterial, archaeal and unknown sequences are presented along with the total of all populations.

The phylogenetic work suggests that presence of both iron-reducing and iron-oxidizing bacteria. To determine whether iron-reducing organisms capable of dissolving iron were present, we established cultures under iron-reducing conditions where hydrogen served as an electron donor and the only acceptor available was anhydrous iron oxides (which are more bioavailable than hematite). The cultures were incubated under cave conditions for 6 months, during which time the HFOs turned from a reddish color to a darker grey/brown, suggesting iron-reduction was occurring. Fe(III) reduction was certified by the accumulation of approximately 10 mM Fe(II) in the medium, confirm via a colorimetric assay. Fe(II) accumulation was not detected in uninoculated medium, suggesting that $Fe(III)_s$ had be reduced to $Fe(II)_{aq}$ by microbial activity.

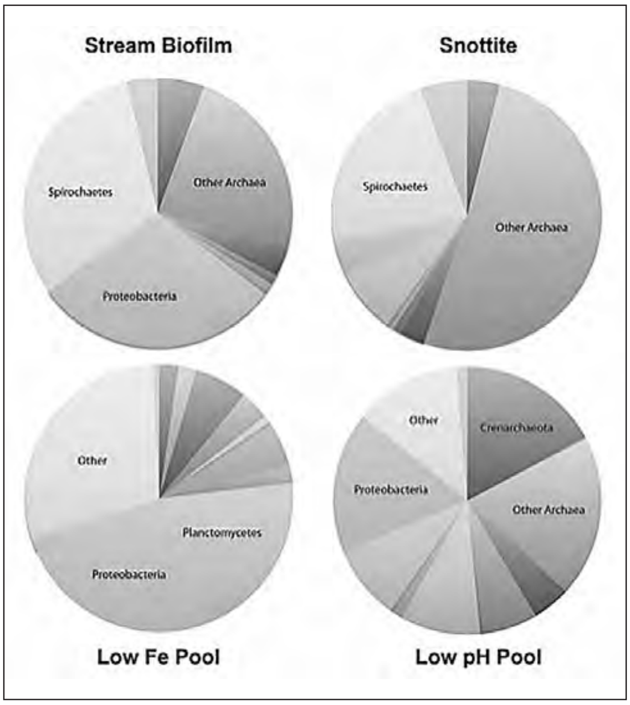

Figure 6. Microbial distribution patterns in each of the environments tested (biofilm was collected from the stream for analysis) based on Phylum-level classifications. Only the dominant microbial phyla in each environment is indicated.

4. Discussion

The aim of this study was to determine whether or not microbial iron-reduction is a plausible explanation for the numerous caves seen in the Carajás BIF of Brazil. Our preliminary data suggests that the geochemical conditions are conducive to microbial iron reduction, including a source of energy (organic carbon) and iron as the electron acceptor, an we have demonstrated the ability of microorganisms isolated from the cave to mobilize oxidized $Fe(III)_s$ to reduced $Fe(II)_{aq}$. Presumably, as water flows through these systems, this mobilized iron will be carried away from the system and allow cavity enlargement.

In the course of this study, we also identified the first recorded instance of snottites within iron caves, whereas these biofilms have only previously been described in sulphuric-acid systems (Jones et al., 2012), although these biofilms are dominated by bacterial species in these systems. The finding of archaeal-dominated biofilms such as this is unusual and, as in the case of snottites, likely reflects a structure directly related to the physiology of these species (Jones et al., 2012). Given the iron-reducing capabilities of members of the Archaea, we predict that the microorganisms within these biofilms are likewise recuing iron, although this will need to be determined.

While we have been able to describe the presence of iron-reducing species, the presence of iron-rich deposits associated with these caves (Figure 4) suggests that iron-oxidizing microorganisms may be taking advantage of this reduced iron under anoxic conditions to drive additional metabolic activity.

While this study suggests a biospeleogenetic model for formation of the iron caves within the Carajás Formation, much remains to be done to determine the predominant species involved, the sources of N and P that support these activities, the mechanism of oxidize deposition and how microbial metabolic activity leads to the geomorphology observed.

Acknowledgments

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PREDATION MEDIATED CARBON TURNOVER IN NUTRIENT-LIMITED CAVE ENVIRONMENTS

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Cave environments provide unique systems for the study of microorganisms, due to their nutrient limitations and isolation from surface derived energy inputs. Heterotrophs colonizing these environments rely on autotrophs for the production of organic carbon; however, the exact mechanism for carbon turnover for heterotrophic growth is still unclear. To investigate a possible mechanism for the turnover of carbon in cave systems, we studied the predatory bacterium, *Ensifer adhaerens*. Predatory bacteria assimilate carbon and energy by attacking prey bacteria. We hypothesize that through the predation process, carbon-containing compounds are returned to the environment, which provides nutrient and energy sources for other microorganisms. In this study, assays were designed to assess the nutritional conditions required to facilitate predation activity. Preliminary data suggest that predation by a cave-isolated strain of *E. adhaerens* is optimal under conditions similar to the cave system. The results allow us to determine if predatory activity is involved in carbon turnover and establish a role for predatory bacteria in cave microbial ecosystems.

1. Introduction

Cave systems were once thought to be devoid of microbial life due to their extreme starvation and isolation from surface-derived energy; however, in examining these environments through culture-dependent (i.e. growth) techniques and electron microscopy, microbiologists realized that caves were in fact a rich habitat for microbial communities (Cunningham et al. 1995; Barton and Northup 2007). The development of molecular-based techniques in microbial identification has expanded our ability to describe a variety of microorganisms inhabiting cave environments (Barton and Northup 2007). By combining our understanding of the geochemical conditions in a cave with culture-dependent and independent methods, researchers have begun to describe the important roles that microorganisms might play in the cave ecosystems (Barton, 2006 and references therein; Barton and Jurado 2007; Barton and Northup 2007). What remains challenging is how these microorganisms are surviving under the intense nutrient limitation of a cave environment.

In isolated caves such as Lechuguilla, microorganisms cannot use sunlight energy or the input of organic carbon sources for growth – the geologic isolation of a cave simply limits this energy input (Barton and Northup 2007). Instead, these organisms rely on alternate sources of energy, such as the organic products of autotrophic organisms living in the environment. Our question is how organic carbon from the autotrophic organism is released back to the ecosystem: whether this carbon becomes available through metabolic production or by other methods, such as predation by other microorganisms. Evaluating the mechanisms of carbon turnover in cave communities may lead to a better understanding of how essential nutrients (e.g., N, S, P) are cycled through the ecosystem.

In past cultivation work, we identified *Ensifer adhaerens* LC11 from Lechuguilla Cave, Carlsbad Caverns National Park, New Mexico (USA). Members of the *Ensifer* genus are predatory bacteria that obtain nutrients through cell-to-cell adhesion to bacterial prey organisms, whereby nutrients are released. It is the aim of this study to gather baseline data about the optimal predation conditions for *E. adhaerens* using cultivation-based techniques, which can be used to develop further experiments to determine whether predatory behavior by *E. adhaerens* leads to carbon turnover. The process, whereby a bacterium becomes one of the top predators in a microbial ecosystem would be a unique system, as protozoa generally dominate such ecosystem interactions.

2. Materials and Methods

2.1. Sample sites and bacterial strains

Sample Site. All bacterial strains were collected from wall scrapings from Lechuguilla Cave (under permit # CAVE-00031). The identity of these isolates was confirmed through PCR amplification of the 16S rRNA gene, DNA sequencing and comparative phylogenetic analysis (Bhullar et al. 2012). The average temperature at the sample site is 20 °C, with 99.9 % relative humidity, and a measured pH of 8.0.

Bacterial Strains. The bacterial strains used in this study were the Gram negative *E. adhaerens* (LC11) and the Gram positive *Micrococcus luteus* (LC524), the characteristics of which are summarized in Table 1. All strains were cultivated at room temperature (20 °C) on 50 % tryptic soy agar (TSA). All stock cultures were stored at -80 °C in 50 % TSA with 25 % glycerol. *M. luteus* was used as a prey species due to the unique Gram staining and colony morphology of this organism when compared to *E. adhaerens.*

Table 1. Bacterial strain characteristics.

Name	*Ensifer adhaerens*	*Micrococcus luteus*
Strain Designation	LC11	LC524
Predator/Prey Designation	Predator	Prey
Gram Reaction	Gram Negative	Gram Positive
Morphology	Rod	Cocci
Appearance on 50% TSA	Mucoid, White to Tan Colonies	Small, Yellow Colonies

2.2. Determining predation conditions

An assay was designed to determine the proper pH and nutrient concentration that would cause predation of *M. luteus* by *E. adhaerens*. All assays were carried out in brain heart infusion (BHI) broth, a suitable growth medium for both organisms (Difco, Detroit, MI). BHI broth at varying concentrations was prepared and adjusted from pH 1 to 12 using 0.1 M NaOH or 0.1 M HCl and aliquoted into individual test tubes and autoclaved. LC11 and LC524 were grown separately, shaking overnight in 100 ml of 1:100 BHI (150 mg L^{-1} TOC). The optical density of the starter cultures was measured at a wavelength of 600 nm using a spectrophotometer and the cultures were diluted to achieve ratios of 1:1, 1:10, and 1:100 predator to prey cells. The cultures were vortexed and allowed to incubate at 20 °C, the average temperature in Lechuguilla Cave. At various time points, 200 µl of culture was removed to determine cell number via colony forming units (CFUs) for each organism. These results were plotted over time to determine whether predation was occurring.

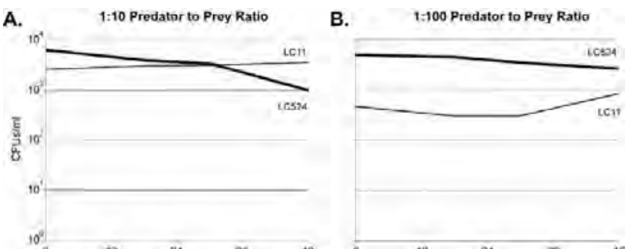

Figure 1. Line graphs showing the variation in CFUs/ml of LC11 and LC524 under the same nutrient conditions but different ratios of predator to prey. (A) 15 mg/L TOC at pH 6.0 with a ratio of 1:10 predator to prey. (B) 15 mg/L at pH 6.0 with ratio of 1:100.

3. Results

At the beginning of our experiments, we wanted to see what ratios of predator to prey allowed the largest observable predation activity. Predator to prey ratios of 1:1, 1:10, 1:100 were examined under various concentrations of carbon (15–1,500 mg TOC L^{-1}). The best predation was observed at a TOC of 15 mg L^{-1}.

When grown at 15 mg L^{-1} TOC at pH 6.0, with a ratio of 1:10 predator to prey CFUs, there was an increase in the number of predator CFUs and a decrease in the number of prey following inoculation (Figure 1A). A similar trend was observed at pH 6.0 with a ratio of 1:100 predator to prey CFUs; however, the shift in population size of the predator to prey took much longer, exceeding 48 hours (Figure 1B). We then examined the influence of pH on predation, as a previous study by Casida (1982) found that *E. adhaerens* isolated from soil would predate at pH 6.0–6.5. We carried out the predation assays under a range of conditions from pH 1 through pH 12. Under these conditions we only observed predation under a pH range of 6–8. We therefore examined predation at pH 6.0, 6.5, 7.0, 7.5 and 8.0. Our results demonstrated that at pH 6.0 there was an increase in the number of predator cells over prey by 30 hours (Figure 2A). Predation occurred across the pH range of 6–8; however, the predator population exceeded the prey population much earlier under pH 8.0 conditions (Figure 2B). There was also a more dramatic increase in population size at this higher pH (Figure 2B). In another preliminary study, we found that the soil-isolated *E. adhaerens* ATCC 33212 was capable of predating at pH 6.0, but not at pH 8.0 (data not shown).

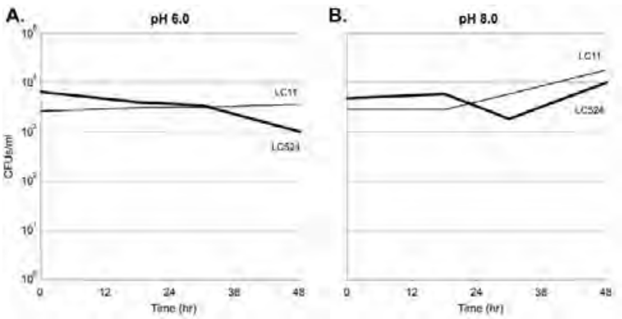

Figure 2. Line graphs showing the variation in CFUs/ml of LC11 and LC524 at different pH levels. (A) 15 mg/L TOC pH 6.0 with a ratio of 1:10 predator to prey. (B) 15 mg/L TOC at pH 8.0 with a ratio of 1:10 predator to prey.

4. Discussion

E. adhaerens was first identified in 1982 from soil, in which it employs a cell-to-cell contact strategy for predation by adhering to the prey cell wall (Casida 1982; Martin 2002; Wang et al. 2011). Specifically, from electron microscopy observations, a cytoplasmic bridge extends from the polar end of cell and attaches to the prey cell. It is believed that the predator cell then punctures the prey cell wall allowing for the transfer of nutrients (Martin, 2002; Jurkevitch 2007; Wang et al. 2011). The attachment of *E. adhaerens* to the prey cell wall forms a "picket-fence" arrangement around the prey cell, and this is required for predation activity and leads to prey cell death (Casida, 1982; Martin, 2002); however, this can also lead to a reduced cell count via our colony counting assay, as dozens of *E. adhaerens* around a single prey cell would appear as one colony on an agar plate. It is therefore possible that the ratio of predator to prey in our assays may be much greater than observed. During our cultivation studies we isolated *E. adhaerens* from numerous oligotrophic cave system across the United States, including Lechuguilla Cave in New Mexico and Wind Cave in South Dakota. The presence of *E. adhaerens* in these geologically diverse caves indicates that cave isolated *Ensifers* may play an important role in cave ecosystem dynamics. The finding that these isolates predate more readily under cave conditions (pH 8.0), while surface soils maintain a pH of 6.0–7.0, suggesting that the *E. adhaerens* strain we have isolated may be adapted to the cave environment. This idea is further supported by predation assays occurring under lower nutrient conditions, at 15 mg L^{-1} TOC; Lechuguilla cave has <1 mg L^{-1} TOC, while surface soils often exceed 1,000 mg L^{-1} TOC (Barton et al., unpublished results; Ozulu and Ozaytekin 2011). The observation of predation occurring at lower nutrient concentrations also supports the hypothesis that the predator (*E. adhaerens*) is switching from available carbon and energy to the prey as a source of nutrients.

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