Cave and Karst Science

The Transactions of the British Cave Research Association

Volume 21 Number 3 June 1995

BCRA

Cave and Karst Science

Authors are encouraged to submit articles for publication in the Transactions of the British Cave Research Association under four broad headings:

1. Mainstream Articles
Scientific papers, normally up to 6,000 words, on any aspect of karst/speleological science, including archaeology, biology, chemistry, conservation, geology, geomorphology, history, hydrology and physics. Papers should be of a high standard and will be subject to peer review by two referees.

2. Development Articles
Shorter papers, normally 500-3,000 words, on aspects of karst/speleological science listed above, or more descriptive material such as caving expedition reports and technical articles. These will be reviewed by the editorial board unless the subject matter is outside their fields of expertise, in which case appropriate expert assessment will be sought.

3. Forum
Personal statements of up to 1,000 words on topical issues; discussion of published papers and book reviews. Statements should put forward an argument and make a case, backed-up by examples used as evidence.

4. Abstracts
Authors (or supervisors) of undergraduate or postgraduate dissertations on cave/karst themes are asked to submit abstracts for publication. Please indicate whether the thesis is available on inter-library loan. Abstracts of papers presented at BCRA and related conferences or symposia will also be published.

Manuscripts may be sent to either of the Editors: Dr. D J Lowe, British Geological Survey, Keyworth, Nottingham, NG12 5GG, UK, and Professor J Gunn, Limestone Research Group, Department of Geographical and Environmental Sciences, The University of Huddersfield, Queensgate, Huddersfield, HD1 3DH, UK. Intending authors are welcome to contact the Editors, who will be pleased to advise on manuscript preparation.

NOTES FOR CONTRIBUTORS

These notes are intended to help the authors to prepare their material in the most advantageous way so as to expedite publication and to reduce both their own and editorial labour. It saves a lot of time if the rules below are followed.

All material should be presented in a format as close as possible to that of *Cave and Karst Science* since 1994. Text should be typed double-spaced on one side of the paper only. Subheadings within an article should follow the system used in *Cave and Karst Science*; a system of primary, secondary and if necessary, tertiary subheadings should be clearly indicated.

Abstract: All material should be accompanied by an abstract stating the essential results of the investigation for use by abstracting, library and other services. The abstract may also be published in *Caves and Caving*.

References to previously published work should be given in the standard format used in *Cave and Karst Science*. In the text the statement referred to should be followed by the relevant author's name and date (and page number, if appropriate) in brackets. Thus: (Smith, 1969, p.42). All such references cited in the text should be given in full, in alphabetical order, at the end. Thus: Smith, D.E., 1969. The speleogenesis of the Cavern Hole. Bulletin Yorkshire Caving Assoc., Vol. 7. p.1-63. Books should be cited by the author, date, title, publisher and where published. Periodical titles should be abbreviated in standard style, or, where doubt exists, should be written out in full.

Acknowledgements: Anyone who has given a grant or helped with the investigation, or with the preparation of the article, should be acknowledged briefly. Contributors in universities and other institutions are reminded that grants towards the cost of publication may be available and they should make the appropriate enquiries as early as possible. Expedition budgets should include an element to help publication, and the editor should be informed at the time of submission.

Illustration: Line diagrams and drawings must be in black ink on either clean white paper or card, or on tracing paper or such materials as Kodatrace. Anaemic grey ink and pencil will not reproduce! Illustrations should be designed to make maximum use of page space. Maps must have bar scales only. If photo-reduction is contemplated all lines and letters must be large and thick enough to allow for their reduction. Letters must be done by stencil, Letraset or similar methods, not handwritten. Diagrams should be numbered in sequences as figures, and referred to in the text, where necessary, by inserting (Fig. 1) etc. in brackets. A full list of figure captions should be submitted on a separate sheet.

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Approximate locations for tables, plates and figures should be marked in pencil in the manuscript margins.

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Speleological expeditions have a oral obligation to produce reports (contractual in the case of recipients of awards from the Ghar Parau Foundation). These should be concise and cover the results of the expedition as soon as possible after the return from overseas, so that later expeditions are informed for their planning. Personal anecdotes should be kept to a minimum, but useful advice such as location of food supplies, medical services, etc. may be included, normally as a series of appendices.

Authors will be provided with 20 reprints of their own contribution, free of charge, for their own private use.

We prefer articles to be submitted on disk if possible, although paper copy is also acceptable. We can read most PC based word processing packages but if in doubt please consult one of the Editors. Apple Mac disks are accepted as a last resort!

If you have any problems regarding your material, please consult either of the Editors in advance of submission.

Cave and Karst Science

TRANSACTIONS OF THE BRITISH CAVE RESEARCH ASSOCIATION

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Cover photo:
Rectilinear caves in the Escrivania cliff, Brazil. (Note the horizontal lake level mark.)
Photo by A. Auler (see article by Augusto Auler).

Editors: Dr. D. J. Lowe — British Geological Survey, Keyworth, Nottingham, NG12 5GG.
Prof. J. Gunn — Limestone Research Group, Department of Geographical & Environmental Sciences, The University of Huddersfield, Queensgate, Huddersfield, HD1 3DH.

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EDITORIAL

John Gunn and David Lowe

This issue completes the first Volume of Cave and Karst Science and marks a halfway point in reducing the backlog of overdue issues. We apologise to those authors who have waited far too long to see their hard work appear in print, particularly to Trevor Faulkner and Dr. T J Lawson, whose respective papers on caves in Norway and Scotland will be published in Volume 22, Number 1.

Although several papers are already with us, or have been promised, we would encourage continued submission of new material, to help us keep the content of Cave and Karst Science as varied and interesting as possible. We would also appreciate constructive feedback on the balance of interests presented by the papers in this and the previous issue. A readers' request that we have been considering is for the inclusion of a glossary of scientific terms. The need for such a glossary will be at least partly fulfilled by a BCRA Cave Studies Series volume, on cave and karst terminology, that is scheduled to appear during 1995. However, if it is felt that this type of information would be helpful, and assuming there is not too great an overlap with the Cave Studies volume, it could be included in the Forum section on a regular basis, subject to space being available.

This Issue includes the remaining contributions from the International Symposium on Changing Karst Environments (as described in Volume 21, Number 2). Papers from the Symposium by Audra, Bayari, Rojsek, Webb and Zhang, are accompanied by other mainstream articles by Auler and Zhang. The full range of topics therefore includes research undertaken in seven countries - a healthy spectrum of international coverage that we hope will be maintained in future issues.

The Issue is completed by a Forum section that includes details of two thesis abstracts, as well as short contributions on a wide variety of topics. As with the longer, mainstream, articles discussed above, we encourage authors to send short contributions on any karst related topics for potential inclusion in Forum.

Finally, since taking over the role of editing Cave and Karst Science we have been considering and trying various ways of improving production efficiency. In this issue, for the first time, we have experimented with the use of image scanning for setting the non-photographic illustrations. The success of using this technology depends to a very large extent on the legibility and overall quality of the master drawings supplied by authors, so it may be impossible to assess the success of the trial objectively. Nonetheless, as with all other aspects of the production, we welcome any constructive feedback on the overall standard of the text figures.

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Alpine karst speleogenesis: case studies from France (Vercors, Chartreuse, Ile de Crémieu) and Austria (Tennengebirge)

Philippe AUDRA
U. R. A. 903 du CNRS, AIX-EN-PROVENCE. Laboratoire de géographie physique appliquée, Institut de géographie, Université Bordeaux III, 33405 TALENCE Cédex, France.

Abstract: Speleological research has been carried out in the Tennengebirge area of Austria and in the Ile de Crémieu, Vercors and Chartreuse areas of France. The main underground sediments are of palaeoclimatic and hydrodynamic significance, corresponding to hot, stable or in disequilibrium (flowstones, reworked weathered rocks) and cold environments (carbonated varves, glacial pebbles). Each massif has its own evolutionary history, depending on its structural characteristics, its altitude, and its position in relation to successive base levels. Nevertheless there is a more global outline, with underground karstification having occurred during the Palaeocene and evolved into cone karsts, associated with horizontal cavities, during the Miocene. From the Pliocene onwards, large horizontal networks were formed. These were broken up with uplift and were re-cut by the vertical "alpine" shafts. Thus, two fundamental successive conditions can be contrasted, fluvio-karsts and perched karsts. It would seem that large underground alpine networks, including horizontal perched levels and vertical conduits, can be closely linked to the Plio-Quaternary period. Their formation can be explained as a combination of progressive uplift with inputs of fluvial or glacial allogenic discharge.

INTRODUCTION

This article outlines the main results obtained from research carried out in certain alpine karsts, containing large underground networks, principally (Fig. 1) : the Cosa Nostra - Bergerhöhle system, located in the Tennengebirge massif (2431 m) in the limestone high Alps near Salzburg, Austria; in the Prealps (Isère, France), the Vallier cave in the Vercors (2341 m), and the Dent de Crolles system in Chartreuse (2084 m); and in a lower plateau of the southern Jura, on the alpine piedmont (Isère, France), the Ile de Crémieu (427 m), with the La Balme cave.

The research was concerned with surface karst morphology, as well as that at depth, together with a detailed study of the underground sediments. These studies have enable the tracing of the main axis of karst genesis, since the beginning of the Tertiary, in relation to the regional evolution, as well as enabling the pinpointing of successive phases and speleogenetic conditions, in particular since the end of the Neogene (Audra, 1994). Certain large types of sediments, common to the whole networks studied, appear to each have a specific palaeoclimatic significance. When looked at closely, the evolutionary history of the networks consists of characteristics linked to the local conditions, whether it is the altitude of the massifs, their individualization during successive uplifts and their position in relation to the base level. Finally, a global approach enables the principal milestones in the evolution of alpine karsts to be looked at in the light of studied examples and thus to be able to differentiate two fundamental states of karst: fluvio-karst and perched karst.

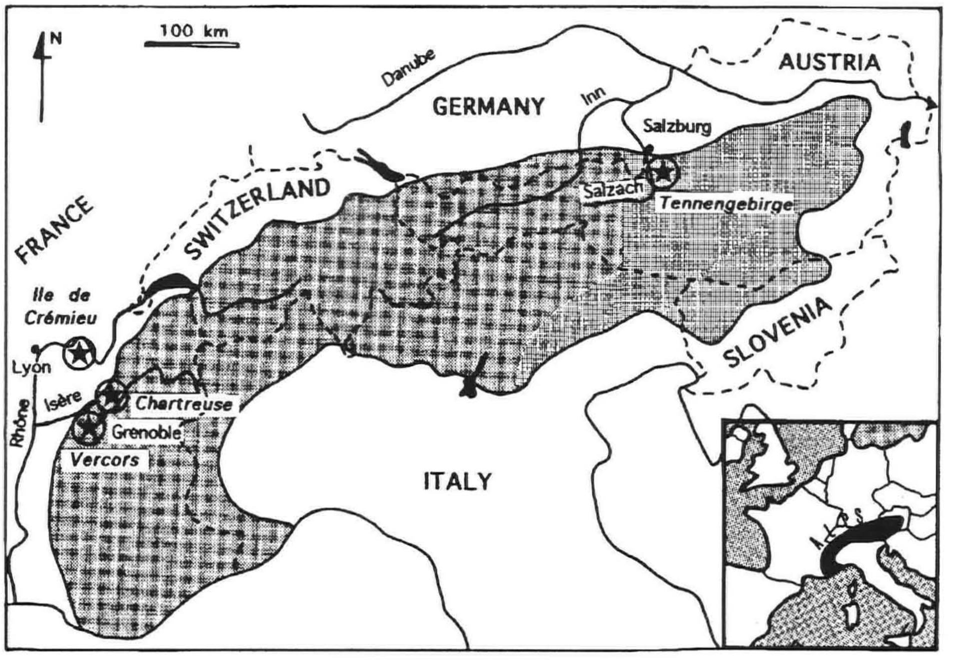
KARSTIC SEDIMENTS AS PALAEOCLIMATIC MARKERS

Four main types of sediments are frequently found in alpine underground networks. The first two owe their origin to old "hot" climatic periods, whilst the other two are typical of glacial environment.

1. Reworked weathered rocks

During the Tertiary, the warm and damp climate was responsible for intense chemical corrosion, which gave rise to thick covers of residual weathered rocks. The weathered rocks, consisting mainly of clays, round quartz and iron oxide marbles (Plate 1), were reworked, transported, and then trapped in the karst where they form the basis of the first sedimentary sequences of the various infillings. These are the oldest deposits found in the studied cavities and some can even be linked to the first stages of the networks development. This weathered rock has been

Figure 1 : Location of the studied alpine karsts.



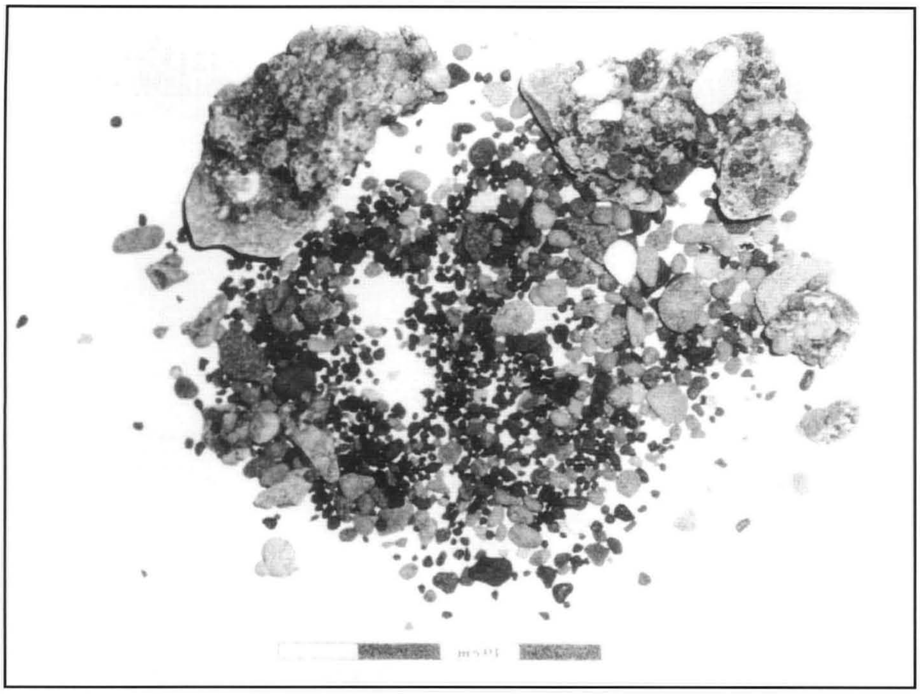


Plate 1 : Vallier cave sediments (Vercors), consisting of reworked weathered rocks. The dark iron oxide grains and the quartz marbles can be distinguished.

trapped in the cavities, following the removal of the superficial covers. This erosion can be linked to changes in the precipitation regime in the Neogene, as far as the Tennengebirge is concerned, whilst in the Vercors and the Chartreuse, it can be linked to climatic deterioration at the end of the Pliocene. In both cases, erosion of climatic origin was greatly enhanced by ongoing uplift process. The cave deposits provide evidence of previously existing old weathered covers, which in most cases have completely disappeared from the karst massifs surface, especially in the pre-alpine research sites. The stripping of these covers, followed by their trapping within the karst, seems to be a common characteristic of Plio-Quaternary evolution of temperate mountain karsts (Maire, 1990).

2. Calcite deposition in warm / temperate periods

The growth of flowstones is to a large extent a function of the activity of the vegetational cover and hence of climate (Quinif, 1992). Because of this, they do not develop in the high altitude karst. Their complete absence in the Cosa Nostra Loch can be seen to be an evolutionary indicator within the context of a glacial mountain. On the contrary, the flowstones which developed close to this shaft (Fig. 2), in the perched horizontal galleries linked to the Neogene such as Horn Höhle, bear witness to warmer palaeoclimates. The large Vallier cave flowstones (Fig. 3), located at the base of a stepped mountain karst (1900 m high), can be seen as being of Pliocene and lower Pleistocene interglacial origin (palaeomagnetic dating; Audra and Rochette, 1993). At the present time, calcite deposition, not including that of the stripped high karsts, develops strongly as soon as vegetational cover is present. At the Vallier cave, it has evolved to the western perimeter of the network, where the latter stretches out beneath the wooded Moucherotte slope, at less than 1400 m altitude (Fig. 3). It is equally abundant at the La Balme cave, on the Ile de Crémieu, where the altitude does not exceed 400 m (Fig. 4).

The crystalline morphology explains the environment characteristics of the flowstone formation. A transparent calcite is synonymous with growth within a biostatic environment, with a thick vegetation cover. This blocks the descent of detrital elements at depth, giving rise to very incrustant waters, susceptible to triggering a rapid growth. This is especially the case of the first flowstone generations of Vallier, Bergerhöhle and Eisriesenwelt. The first two are linked to the Pliocene, and the last with the Miocene. This can also be used as an age gauge, because in the mountains these biostatic conditions have existed for a long time. Conversely, the presence of brown or red impurities and a succession of multiple micro-bed growths, suggests formation within an unstable environment, with migration of the soil cover into the karst and frequent interruption of calcite deposition. The sudden acceleration of the morphogenetic processes, found in the flowstones of the old Tennengebirge caves, can be linked to the changing of precipitation regimes, either during long periods of drought as was the case in the Neogene, or during a general cooling, as experienced several times in the Pleistocene.

The surface aspect of the flowstones is a recorder of events following their growth. An eroded surface means that the cavity returned to a regime of plentiful discharge, after the calcite deposition phase. Most of the Tertiary cavity flowstones harbour scars, signs bearing witness to the complicated Neogene cycles, or even to the reactivation of the networks during glaciations, such as in the Vallier, Eisriesenwelt and Bergerhöhle locations. The dating of flowstones, when precise enough, confirm the climatic influence with regards to their formation. Thus, a stalagmite from the Dent de Crolles system dated to 370 (+58/-36) kyr, could correspond to the interglacial of isotope stage 11.

3. Glacial carbonated varves

Glacial abrasion operating on limestone massifs detaches rock particles which are then transported into the karst by sub-glacial streams. These particles consist of calcite flakes (35-62% $CaCO_3$), as well as angular quartz granules brought by the glaciers. Summer glacial fusion gives rise to a build up of water which the karst cannot get rid of, and which floods the network sometimes to a height of several hundred meters. The calcite particles are transported in "uniform suspension" (Riviere, 1977; after Passega) within all the conduits flooded by these turbid waters. Then they are laid down in a calm environment, without any current, during the slow winter drainage. They are deposited according to dark and light laminas, each corresponding to successive hydraulic regimes of the glacial karst. Thus, these lacustrine seasonal deposits, of glacio-karstic origin, can be described as varves (Maire, 1990). Because of this, they are uncontestable evidence of glaciations.

Due to the lack of current and taking into account their over-saturation in $CaCO_3$, the erosive capacity of glacial originating discharges, in the phreatic and temporarily phreatic zones was very weak. Their main speleogenetic role was in clogging up the networks. The lack of erosive capacity can be seen because the older flowstones are only slightly eroded. Therefore, this suggests that these deep networks are in a large part older than the glacial phases responsible for the silted varves. Mostly, they give evidence that the networks were hollowed out by other kinds of discharges, under different environmental conditions.

4. Large glacial sediments of the vadose area

Those conduits within the vadose zone which were located close to glacial meltwater inputs contain easily identifiable detrital sediments. Having originated from the washing out of moraines, these have a similar sedimentology. Their greatly varying petrography consists of a number of crystalline and metamorphic elements, brought down from alpine peaks and transported by the large valley glaciers. These underground streams were highly efficient, which enabled them to transport pebbles several tens of centimetres long, such as at Brünnecker or at the La Balme cave.

CHARACTERISTICS OF THE STUDIED KARSTS

1. The Tennengebirge: a high mountain karst with a long evolution

The Tennengebirge is distinctive in that it has a great thickness of limestone layers, of a locally strong pendage. Thanks to this thickness, in conjunction with successive uplifts and intervening periods of stability, the massif has recorded all of the karstification phases clearly, laid out as distinct shelved layers (Fig. 2). The glacio-karstic forms are very spread out, given their altitude, but the long development dampened at the end of the Palaeogene, leaves an example of Tertiary morphological heritage. Due to this, the Tennengebirge is different to the high-alpine Franco-Swiss karsts, where karstic evolution only occurred after the end of the Miocene and sometimes only at the beginning of the Pleistocene (Maire, 1990). The evolution of the Tennengebirge, in relation to the Cosa Nostra - Bergerhöhle system is summarised in Fig. 2.

Karstification began during the Oligocene, beneath a cover of detrital deposits, known as the Augensteine (1), which was progressively stripped from the Lower Miocene onward. During the Miocene, the deep karst developed, thanks to the input of alpine discharges, which fed into the networks (2). These horizontal levels, developed during periods of tectonic stability, have been shelved by successive phases of uplift (3). The oldest and highest (2100 m) are found amongst old Tertiary cones (Kuppen), correspond to the Ruinenhöhlen (4), cavities which are currently being broken up by erosion (Horn Höhle). Between 1500 m and 1700 m, large labyrinthine networks stretch out (5), known as the Riesenhöhlen (Eisriesenwelt). Following strong uplift during the Pliocene, the torrents from the Alps could no longer reach the karst. The essentially vertical alpine networks developed, resulting from a much larger potential (6). Their formation quickened during glaciations, under the influence of local ice caps, and that of the Salzach valley glacier. The Cosa Nostra - Bergerhöhle system includes several generations of networks. The entrance of the Cosa Nostra Loch can be reached by a tubular gallery, of Miocene origin, which contains reworked weathered sediments (7). The rest of the network is of Plio-Quaternary origin. The shaft zone, up to 750 m deep in places (6), is then linked to the Bergerhöhle - Bierloch tubular horizontal network (8). During the Pliocene, the base level was at 1000 m and the network was fed by meltwater, transporting Jurassic pebbles (9). With the lowering of the water table, the network dried up, and the detrital sediments were then overlaid by a first generation of large flowstones. During the glacial periods, the deep karst was flooded to over 600 m high, and a thick sedimentation of carbonated varves occurred, dated by palaeomagnetism as being from the Middle Pleistocene. These varves cover older sediments. The bottom of the network is linked to the 700 m high phreatic zone (10), which during high water pours into the Brünnecker cave, where the discharge finally ends up at the present 500 m high Salzach base level (11). Brünnecker contains granite pebbles originating from old Salzach glacial meltwaters, which are responsible for a canyon and rock basin morphology. At present, a second generation of less abundant flowstones is developed beneath the wooded area, at the foot of the massif, in the Bierloch and Brünnecker.

2. The large French northern pre-alpine Plio-Quaternary networks

In the Prealps, horizontal networks, dating from the end of the Miocene and the beginning of the Pliocene, are disorganised and perched, as a result of corniche retreat following sinking of the Isère valley during the Pliocene. However, they may have been reactivated, during the Pleistocene, by lateral losses from the Isère glacier, as at the Vallier cave. These galleries are also transected by vertical alpine shafts of Plio-Quaternary age (Delannoy et al., 1986). Thus, large networks consist of horizontal shelves transected by shafts and meanders, the best example being the Dent de Crolles system (Lismonde and Delannoy, 1990). Unlike at Tennengebirge, interpretation of the layers is difficult because there are impermeable lithological horizons, making the interpretation of karstification levels more difficult. The evolution of the North Eastern Vercors in relation to the Vallier cave system is summarised in Fig. 3.

During the Eocene, karstification developed under a thick sediment cover. Sands were trapped in pockets (1). During the Miocene, molassic sedimentation filled the syncline bottoms (2). The emerged anticlines underwent karstification, which led to the progressive stripping of the Eocene covers. During the Lower Pliocene, following the Miocene uplift, the networks spread in function of the new overthrusting structure, and of a base level in the Val de Lans, determined by the molasses at current

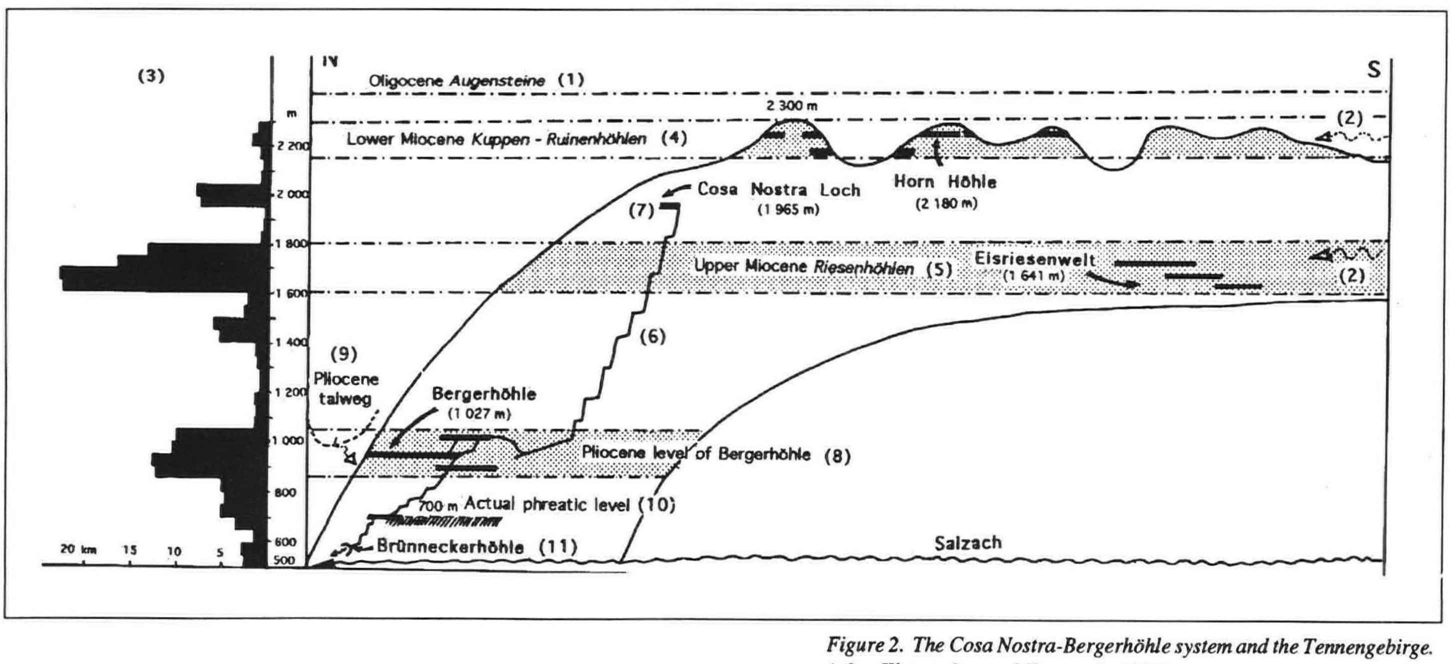


Figure 2. The Cosa Nostra-Bergerhöhle system and the Tennengebirge. (after Klappacher and Knapczyk, 1985)

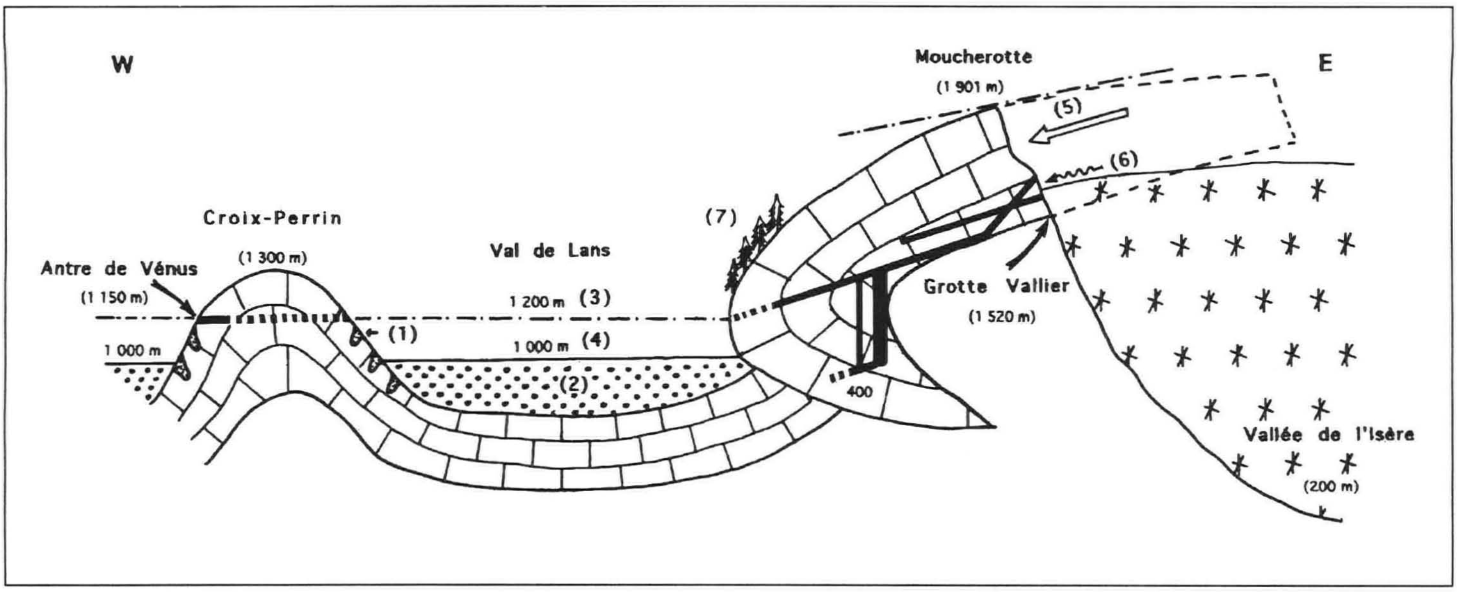


Figure 3. The palaeogeographic evolution of the North Eastern Vercors in relation to the Vallier cave system.

altitude of 1200 m (3). To the east, the Moucherotte plateau is drained by the Vallier cave, containing sediments which came about as the weathered rock covers were eroded. To the west, the presence of molassic pebbles in the "palaeo tunnel-cave" in the antre de Vénus (Delannoy, 1992) provides evidence that the molassic synclines are hydraulically linked across the Croix-Perrin anticline. During the Upper Pliocene, development of the hydrographic network led to lowering of the local base level at 1000 m, due to the erosion of the molasse (4). The Eocene palaeokarsts were exhumed (1) and the antre de Vénus was disconnected, remaining perched. The drainage basin of Vallier cave disappeared with the corniche retreat (5), following the hollowing out of the Isère valley and Vallier cave dried up. Large amounts of flowstone were deposited (the $^{234}U/^{238}U$ balance). During the Lower Pleistocene, Vallier cave was reactivated by meltwater from the Isère glacier (6), which brought in and laid down carbonated varves (palaeomagnetism shows reversed polarities; Audra and Rochette, 1993). From the end of the Lower Pleistocene, due to the hollowing out of the Isère valley, the glacier was beneath the Vallier cave, which remained dry. A second generation of speleothems developed (palaeomagnetism indicates reversed polarities; U/Th dating > 350 kyr). At present, calcite deposition is limited to the western extremity of the network, located beneath the wooded area (7).

3. The Ile de Crémieu: a lower plateau karst of the Southern Jura

Unlike the preceding examples, the Ile de Crémieu has always been a lower plateau karst, in the vicinity of or at the base level. This can be seen as a predominance of horizontal networks. The karst has been scarred by the lowering as well as the rising of the base level, especially during the Pliocene transgression, and under the influence of alternating glaciations and deglaciations of the Pleistocene. This can be seen in the form of the clogging or unclogging of the networks, as well as by organisation of unclear shelves (Fig. 4).

During the Palaeogene, an erosional surface developed (1). It was sprinkled with "siderolithic" weathered deposits. During the Oligocene, the overstretching movements of the rhodanian rift divided the massif into a series of panels, deforming the old surface (2). To the south of the plateau, a pre-Miocene cone karst has been partially exhumed from the molasse (3). This is associated with palaeokarsts dated by faunal remains. During the Messinian, the river Rhône dug a canyon hundred of metres deep which was filled up during the rise of the base level at the beginning of the Pliocene. Simultaneously, the consequences of the alpine movements reactivated Oligocene faults. The networks must have developed during this period, in relation to the moderate uplift. The La Balme cave consists of layered galleries, over a height of 50 m (5). The perched levels contain massive speleothems, laid down either during the Pliocene, or during the Lower Pleistocene (6). During the Pleistocene, the plateau was covered by the advancing Rhône glacier which was responsible for clogging up the karst with morainic deposits (7). During one or several old glaciations, The La Balme cave was reactivated by absorbing subglacial streams. The discharges hollowed out pot-holes, eroded old flowstones, polished the caves walls and transported morainic pebbles. The water was expelled via a lower network, which would correspond to a lower base level. This network is today hidden by clogging, which occurred when there was a rise in the post-glacial base level (9). During a phase previous to the last glaciation, the present entrance was opened, thus perching the upper series (10). Morainic clogging of the superficial karst was probably responsible for the limited functioning of the La Balme cave during the Würm phase (there are archaeological pre-Würm deposits laid out close to the underground river bed). At present, an important amount of calcite deposition is occurring. This can be related to Holocene tufa deposits, commonly found on the outside. The lower active gallery has sandy sedimentation, linked to fluctuations of the water table (11).

THE EVOLUTION OF ALPINE KARSTS

Characteristics of the main karstification phases and associated sediments

The known alpine cave networks are mainly of Plio-Quaternary origin, but the remains of older karstifications permit study of the main characteristics of karstic evolution since the beginning of the Tertiary.

1. Karstification during the Palaeogene

The Palaeogene is characterised by karstification at low altitude, close to the base level, beneath thick weathered detrital covers of allogenic origin. These are the Austrian Oligocene "Augensteine", which came from central Alps (Seefeldner, 1961), the Jurassic "siderolithic" deposits, found on the Ile de Crémieu, derived from in-situ weathering of the Upper Cretaceous layers (Bienfait, 1991), or the Eocene sands of the Vercors, which are in part from the Massif Central, and in part from local weathered materials. These correlative sediments are today trapped in karstic pockets. These old covers can be linked to karstic levelled topography which is generally associated with this period. On the Ile de Crémieu, there are large stretches of this sort of topography (Enay, 1980), but now these can only be seen as fragments on pre-alpine crests. When the Tennengebirge is looked at, it can be noted that the upper level of

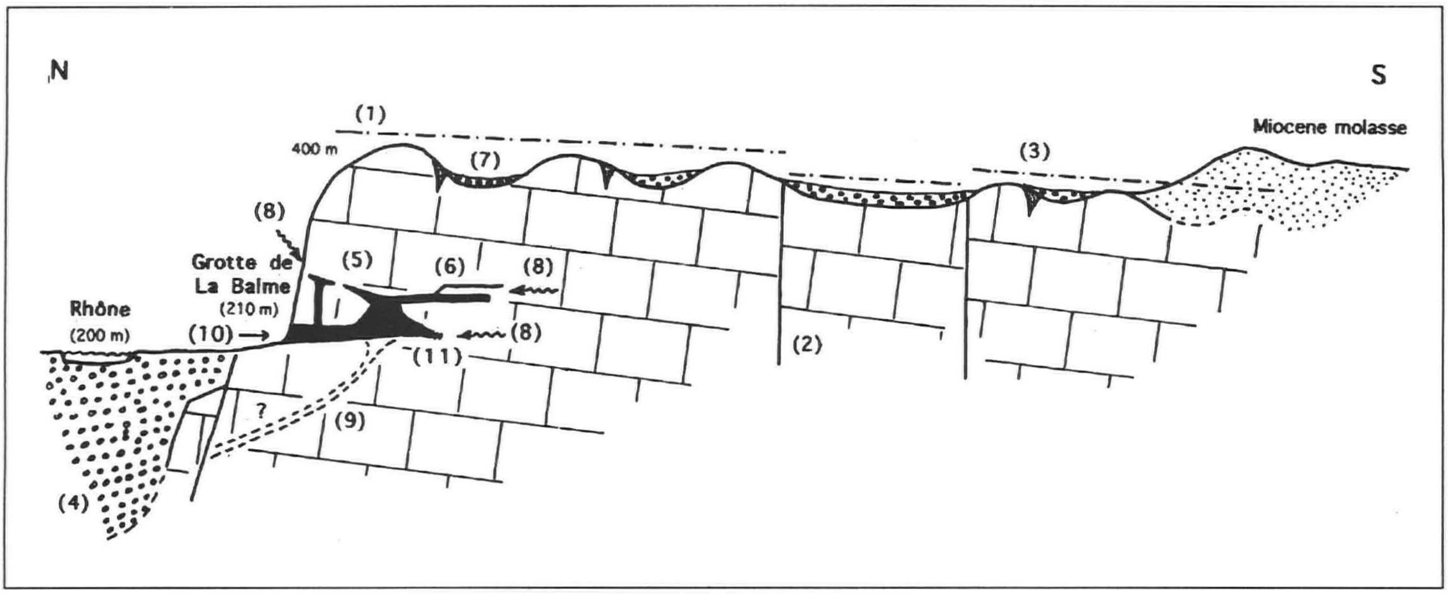


Figure 4. The palaeogeographic evolution of the Ile de Crémieu and the La Balme cave network.

accumulation surface of the Augensteine is located above the highest summits.

2. Miocene cone karsts and horizontal networks

The Lower and Middle Miocene saw the development of cone karsts, always within a faint topography framework, such as the Kuppen of the Tennengebirge (Götzinger, 1913); the cones exhumed from the molasse found to the south of the Ile de Crémieu (Pelletier, 1979); or the Coulmes massif cones to the west of the Vercors (Delannoy et al., 1988). Thanks to the large autogenic drainage basin, as well as the input of allogenic discharges, there were large amounts of water, available for karstification. This gave rise to the development of large horizontal networks, especially in the Tennengebirge (Eisriesenwelt). In these areas, in conjunction with phases of uplifting, clearly layered networks evolved (Toussaint, 1971). The underground sedimentary sequences corresponding to this period consist of fine detrital levels which are very weathered (clays, iron oxide particles, resistant heavy minerals) and which originated from the reworking of superficial weathered rocks (Horn Höhle). There are less weathered fragments of metamorphic rocks in the cavities fed by streams of alpine origin at the end of the Miocene, such as Eisriesenwelt. These are overlapped by great amounts of calcite deposition. The surface of these flowstones is often eroded by latter discharge.

3. A new generation of networks, at the end of the Miocene

During a period of tectonism in the Upper Miocene and the Lower Pliocene, large horizontal networks developed in conjunction with the new structural set up, especially in the Prealps, as exemplified by the Vallier cave in the Moucherotte's recumbent fold and the Trou du Glaz in the Dent de Crolles synclinal network. Their size can be explained by the fact that the catchment areas were much larger than today. Fluvial losses helped create the Bergerhöhle network in the Tennengebirge. The abundance of water temporarily flooded the networks. Due to their aggressivity, the discharges had a great karstification potential. This runoff helped tap the old weathered covers, which can be found in the cavities in the form of large, iron oxide and quartz rich, detrital levels.

4. Uplift and disorganisation of the horizontal networks during the Upper Pliocene

At the end of the Lower Pliocene and during the Upper Pliocene, strong alpine uplift was simultaneously followed by down cutting of the valleys. The predominantly horizontal networks were recut by alpine shafts and meander networks. The hollowing out of pre-alpine valleys caused the retreat of the limestone corniches. The Dent de Crolles and Vallier cave were decapitated and perched. Thus, they evolved independently with some very small drainage basins. On top of this, the loss of the source area caused them to dry up, leading to a large amount of calcite deposition. These covered the old detrital sediments, such as at Bergerhöhle.

5. Reactivation of older networks, during the Pleistocene glaciations

During the Pleistocene, glaciers caused large scale erosion. Superficial stripping occurred several dozen meters deep, especially in the massif's glacial valleys and dales. Glacial losses fed the underground karst, which helped shape the networks. The obstructing of the outlets by the valley glaciers led to seasonal flooding and the clogging of older networks which were temporarily flooded. In the vadose zone, the runoff was not stalled and heavily loaded discharge fed through the conduits giving rise to significant mechanical erosion. The sedimentary sequences consist of detrital deposits of varying size. Sands and pebbles derived from leaching of the moraines were deposited in the vadose zone, as well as in the conduits containing heavy amounts of discharge. The temporarily phreatic zone, waterlogged due to glacier melting, was clogged with carbonated varves. These detrital layers were covered with flowstone floors, formed during the warm interglacials, or during the Holocene in the case of conduits located beneath wooded areas.

Fluvio-karst and perched karst: two fundamental states of alpine karstification

There are two main opposing alpine karst morphogenetic types: slightly raised fluvio-karsts and perched karsts.

1. Fluvio-karsts

Fluvio-karsts are lower mountain or lower plateau karsts. The limestones lie at great depth beneath the base level. The removal of cover materials is incomplete as these occupy large areas in the structural low points. The surface streams can develop in these sometimes large impermeable basins and the allogenic inputs feed into the karst at the contact with the limestones. These are partially responsible for the large labyrinth like layered horizontal networks. As the base of the limestone lies at great depth, the structural characteristics play only a minor role in the general organisation of the networks. It is the altitudinal potential between the different drainage basins and waterways which is responsible for the underground circulation. This also determines the aspect of the networks, from their orientation to their slope and morphology (Audra, 1994). The Chinese limestone plateaux (Guizhou) are a very good example of these slightly raised karsts, with underground and surface streams, where runoff varies seasonally, covering large networks susceptible to being flooded during the rainy season (Audra, 1987). Other things being equal, the alpine karsts of the Miocene and of the Lower Pliocene must have had very similar aspects.

2. Perched karsts

Perched karsts not only differ from fluvio-karsts in height, but also because of their more developed hydrographic network, which frequently flushes out the impermeable basement of the karstic strata. The structural parameters are therefore very important in the organisation of the networks. The underground drainage can be found in the form of collectors at the base of the limestone, in contact with the impermeable basements. These collectors are founded in synclines, at the foot of anticline hinges or along abnormal contacts determined by faults. Due to the fact that they are perched, these karsts usually have only autogenic inputs. The vertical networks have a great input potential. They often contain horizontal perched levels, which date from more ancient phases, such as the ones previously described. These mountain networks have experienced large runoff inputs during the Quaternary glaciations. In most cases this is still the case, thanks to snow melt inputs and sometimes but rarely glacial meltwater inputs, depending on the altitude. The current alpine and pre-alpine karsts correspond to this type. In the Alps, the majority of karsts have experienced this sort of evolution, whereby a karstification begins close to the base level, followed by an altitudinal evolution as a result of the uplift occurring at the end of Miocene (Maire, 1990). The piedmont karsts, such as the Ile de Crémieu, which were moderately affected by the uplift, have remained at the first stage of development. Finally, there are high-alpine karsts, of a second kind, which have not undergone the first stage of development at a lower altitude, such as those of the Swiss Oberland and the inner French Alps (Maire, 1990). Therefore, karstification can only have begun during the Pliocene, after the erosion of the impermeable sedimentary covers as a result of alpine uplift.

CONCLUSIONS

Although there is evidence of older networks, such as in the Tennengebirge, the genesis of the large alpine systems is nevertheless closely linked to the Plio-Quaternary period, as demonstrated in the French northern Prealps. Although possibly initiated at the end of the Miocene, their origin dates back to the beginning of the Pliocene, before the large amount of uplift occurred during the Pliocene. The faint topography enables the large scale development old horizontal drains. Progressive uplift led to the galleries being perched and they were then recut by sub-vertical networks. These alpine shafts began their formation from the Upper Pliocene onward, the Pleistocene glaciations accelerating their evolution. Thus, the transition from fluvio-karst with large horizontal networks to perched karsts with vertical drainage, encompassing old horizontal networks, was made. The macro-scale aspect of these networks is largely due to allogenic water inputs. During the Neogene, there were fluvial inputs to which autogenic inputs from the large karstic basins, less fragmented than today, were added, and during the Pleistocene these were glacial inputs.

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An Inventory of Karstic Caves in the Taurus Mountain Range (Southern Turkey): Preliminary Evaluation of Geographic and Hydrologic Features

C. Serdar BAYARI[1] and Onur ÖZBEK[2]
[1] International Research and Application Center for Karst Water Resources, Hacettepe University 06532 Beytepe, Ankara-Turkey
[2] Cave Research Association, P.O. Box 670, Kizilay 06421, Ankara-Turkey

Abstract: The Taurus karst range extending along the Mediterranean coast of Turkey, has been dominated by humid and semi-humid climate conditions which favour cave development since Pliocene. An inventory of the karstic caves distributed throughout the Taurus Mountain Range has been prepared using the data from available published and unpublished reports. There are more than 600 caves reported in the Taurus Range but only 283 caves with reliable data have been included in the inventory. The data concerning the location, altitude, depth, length, types and age of the lithology in which the caves developed have been compiled for each cave. Information regarding the hydrologic features such as, sinks, sumps, resurgences and underground streams have also been included in the inventory. Most of the caves in the inventory (ca. 180 caves) are <250 m long and most are between +25 m and -50 m deep. The maximum length and depth of the caves evaluated are around +10000 m and -400 m, respectively. Although, several caves exceeding these limits were also reported in recent years, they have not been considered in this study. Caves occur at all elevations between sea level and over 3000 m but evaluation of mean cave length and mean cave depth for every 500 m altitude interval indicates that there is a sharp boundary between altitude ranges in which the caves are clustered. This boundary extends roughly from 1500 to 2000 m and is also the upper limit of the tree-line. Mainly horizontal caves are characteristic of the altitude ranges below 1500 m and mainly vertical caves prevail at elevations exceeding 2000 m. Almost all the hydrologic features such as, sumps, sinks, underground streams and resurgence are observed in caves located below 2000 m. These features also concentrate in caves located between 1000 m and 1500 m altitudes. Most of the caves evaluated were developed in carbonate rocks with a limited number in carbonate cemented conglomerates and in travertines associated with karstic springs. The lithology in which 15% of the caves were developed, is not exactly known. Among the caves having reliable geologic information, 65% are in Mesozoic carbonates, while the number of caves developed in Palaeozoic and Tertiary formations are nearly equal (10% each). A detailed evaluation of the distribution of cave lithology by geologic age indicates that the Jurassic-Cretaceous and Cretaceous carbonates comprise about 55% of the caves developed in Mesozoic carbonates.

INTRODUCTION

Though, there is ever increasing interest on cave research and caving in Turkey, only a few attempts have been made to establish a complete inventory of the caves that have been explored so far. Since most of the cave research has been carried out in Taurus karst range the inventories, like this one, comprise information mostly on the caves located in this range. Probably the first inventory of Turkish caves was that of Bakalowicz (1970). Later on, this preliminary work has been enlarged by C. Chabert, another French caver who spent long time in Taurus Range. (Chabert, 1988). Meanwhile, some cavers from the Cave Research Club of the Bosphorus University (BUMAK) have also started to develop the Chabert's inventory and moved the information into computer media as a data-base (Aktar and Kara, 1990). Apart from these studies, Dr. N. Güldali, ex-head of Cave Research Project in the Mineral Research and Exploration Institute of Turkey (MTA), also developed another inventory which is mostly based on the MTA's work on cave research (N. Güldali, pers. comm). One of the latest attempts regarding the construction of an inventory of caves in Turkey has been made by Özbek (1990) as a part of his M.A. thesis work on the prehistoric settlements in some Turkish caves. The present study is essentially based on the information gathered in his inventory (Appendix-I). Apart from the previous inventory studies in which only a list of information is given, here some evaluations regarding physical and geographic properties have been made. It is believed that this preliminary evaluation of the geographic and hydrologic properties of the Taurus caves would be helpful to the cavers in the organization of their future research activities.

HISTORY OF CAVE RESEARCH IN TURKEY

First Era (Preliminary Studies)

In Turkey, the first cave research study found in literature has been carried out by G. Moretti (1923), an Italian scientist, in the Kocain Cave located 45 km north of Antalya City, western Taurids. R. Hovasse, professor of zoology at the Istanbul University, also studied the cave animals of the Yarimburgaz Cave located 50 km west to the Istanbul (Hovasse, 1928). In 1943, Cahit Alagöz, professor of geography at the University of Ankara published his benchmark book entitled "An investigation on the karst events in Turkey" (Alagöz, 1943). Lindberg (1952) also published his findings on the cave creatures animals living in several Turkish caves.

Second Era (Initiation of Systematic Research)

After the reorganization of governmental institutions in charge with the development of land and energy resources in early 1950's, first systematic karst research studies have been initiated. In conjunction with these, first national cave exploration has been carried out by Temuçin Aygen on Mahraspoli Cave located in the middle Taurids in 1955 (Aygen, 1984). The period between 1955 and 1964 was subject to extensive cave research throughout the Taurus Range. Several foreign cave research teams have been invited to help Turkish cavers in these research studies. Many exploration studies have been carried out jointly with French, British, Italian and Spanish teams till 1980's. In 1965, the Speleo-Club de Paris was carried out the first major cave research in the western Taurids region. Chabert (1979) and Bakalowicz (1970) did detailed karst surveys including the exploration of some major caves. The first national cave research team, Turkish Cave Research Association (MAD), has been established in 1965.

Third Era (Present Day Research by National Teams/Institutions)

After the establishment of MAD, national interest regarding caves has been intensified and resulted in the foundation of other teams and groups. Cave Research Club of the Bosphorus University (BUMAK) was the first university club. Later on, in 1979 an official attempt entitled "Cave Research Project" has been made by Mineral Resources Research and Exploration Institute of Turkey (MTA). The establishment of the International Research and Application Center for Karst Water Resources (UKAM) at the Hacettepe University has speeded up the cave research studies in Turkey. In recent years, the increasing number of the hydrogeologists dealing with karst science and caving has changed the direction of cave research studies from merely sportive activities towards scientific studies. An address list of the recently active cave research groups is given in Appendix II.

OUTLINES OF TAURUS KARST

Because little information about the characteristics of Turkish karst is available in the international literature, a summary is given in the following paragraphs to provide the reader with the basic information.

Widespread and extensive karstification is present in Turkey, approximately one third of the country's surface (ca. 250,000 km^2) comprising karstified rock units. Eroskay and Günay (1980), considering the tectonic regions of the country, distinguished four different karst regions, namely, Taurus Mountain Range, Southeastern Anatolian, Central Anatolian and Northwestern Anatolian-Thrace. Recently, the Black Sea region has also been added to these regions (Nazik, 1993). Although, karstification is seen in every part of the country, it is most prevalent in the Taurus Mountain Range of Southern Turkey (Fig. 1).

The Taurus Mountains, which are made up mainly of carbonate rocks and ophiolite complexes, are the eastward extension of the Alpine-Himalayan orogenic belt in the area between Aegean Islands of Greece and the Zagros Mountains of Iran. Taurus Karst Belt, with peaks over 3500 m, has a width of approximately 200 km between the Mediterranean Sea and the Central Anatolian Plateau and extends over 500 km along the sea coast. Since the range was formed as result of the closure of the southern rim of Neo-tethys Ocean (Sengör, 1980), the structure is quiet disordered and lots of dislocations, such as overthrust, upthrust and strike-slip faults are present throughout the region. Together with the ophiolitic rocks, the autochthonous and allochthonous rock units of Pre-Cambrian to recent age compose of the whole range. The Palaeozoic comprises recrystallized limestones, marbles, calcschists and other kind of metamorphic rocks. The Mesozoic compose mostly of carbonate rocks and also includes clastics such as, shale and sandstone. Mesozoic limestones and dolomites, in which benthonic facies are widespread, reach a thickness of more than 1000 m at most places. The ophiolitic rocks, the remnants of Neo-tethys ocean, act as impervious barriers and hence, they have a strong role over the karst ground water flow. Major karst springs discharge from Mesozoic and Tertiary carbonate rocks where they meet the impervious formations. The mean discharge of the major karst springs range between 1 m^3 sec^{-1} and 35 m^3 sec^{-1}. The Dumanli karst springs, which is now 120 m below the maximum water level of Oymapinar Dam, was reported to be the world's largest karst springs discharging from a single orifice (Karanjak and Günay 1976). The most extensive cave development in Turkey is seen along the Taurus karst range (Fig. 2). This should be not only due to the abundance of carbonate rocks in this region but also the existence of favourable climatic conditions and vegetation cover during the period between Late Miocene and Pleistocene. Even today, this region is still more humid than most of the other geographic regions of country. Mean annual precipitation exceeds 1000 mm in some places. It was also suggested that the rate of karstification, as it was in most other temperate karst regions of the world, was higher than today during the pluvial periods of Pleistocene (Erol, 1990).

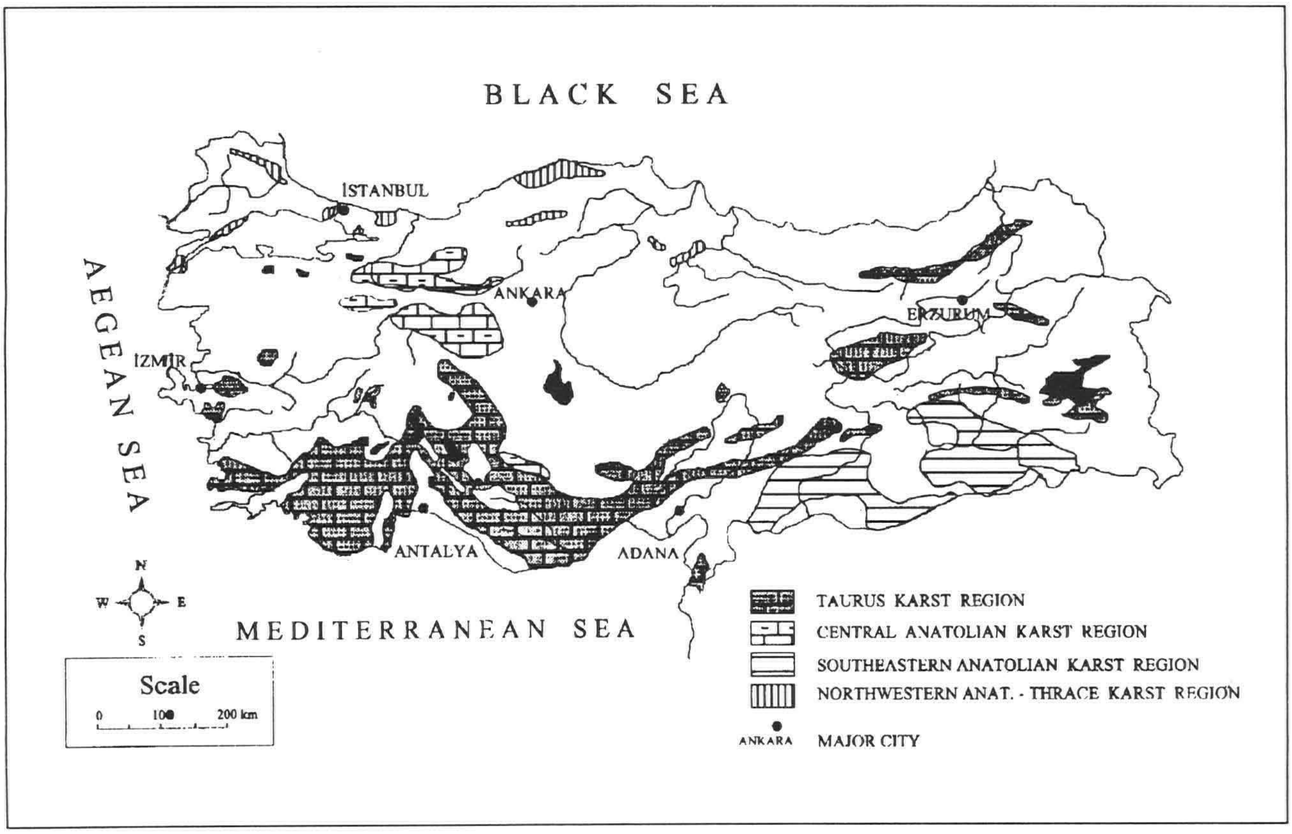
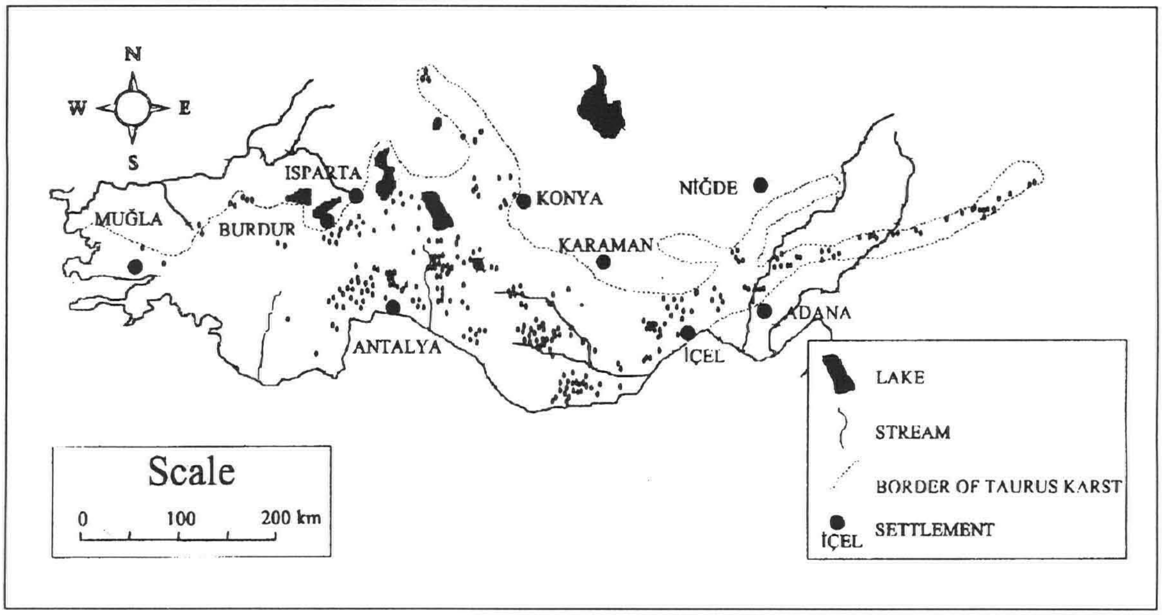


Figure 1. Karst regions of Turkey (modified after Eroskay and Günay, 1980).

Figure 2. Geographic distribution of the caves along the Taurus karst range (modified after Basar, 1972).



CAVE INVENTORY

The present inventory comprises information about the location, altitude, length, depth, lithology and hydrologic properties (i.e. sumps, underground rivers, etc.) of the caves explored so far in the Taurus karst range. The information presented in this inventory have collected from a wide variety of sources including books, papers, published and mostly unpublished cave research reports. Since most of the cave research studies concentrate merely on visiting, photographing and/or mapping the explored cave, sometimes the complete information about a cave can not be found. In this case the missing information have been picked up from different sources such as topographic and geologic maps and reports. The information concerning the type and age of the lithologic units in which the caves developed were taken from geologic and hydrogeologic maps. For caves for which the lithology and age data are not available, this information left blank.

The accuracy and precision of the topographic measurements carried out in each cave differs in a wide range. Depending on the experience of cave research teams and the physical conditions prevailing in each individual cave, the quality of mapping (and of the length and depth data) is assumed to vary between the whole range of BCRA classification. The elevation data for each cave have been picked up from the 1/25,000 and 1/100,000 scale topographic maps in which the contour intervals are 10 m and 50 m, respectively. Hydrologic features such as, sumps, sinks, cave streams and resurgences, have been determined from the cave maps and survey reports. The original inventory, as prepared by Özbek (1993), contains information about more than 600 caves. However, only 283 caves have been included in this paper, because some caves in the original inventory are located in places outside the Taurus range and others have poor data quality and unreliable information.

EVALUATION OF GENERAL PROPERTIES

The data from the present inventory have been evaluated to determine the significant characteristics of cave development in the Taurus range. The distribution by geographic location, rock type and age of lithology in which each individual cave was developed, the range of depth and length and the effect of altitude upon the length/depth of caves and also on the number of hydrologic features existing in the caves have been evaluated.

Range of Length

The range of cave length is shown in the frequency diagram given in Fig. 3. As inferred from the diagram, some caves in the Taurus range are over 10,000 m long although most (about 75%) are shorter than 200 m. Pinargözü cave, located 20 km west to the Beysehir Lake, is the longest cave in Turkey (Bakalowicz, 1972). This cave which goes upward from the entrance point has a depth (or height) of about 700 m. The entrance point of this cave, from which ground water with a temperature around 6°C discharges, is a typical siphon with a 0.5 m^2 opening at the top. Due to the temperature difference between the high altitudes from where snow melt water infiltrates into the cave through chimneys and the lower entrance point from where the ground water discharges, a very strong wind blows out of the cave. Bakalowicz (1972) measured the velocity as 166.3 km/h. A non-linear relationship between the number of caves and the length intervals is also observed in Fig. 3. The decrease in the number of caves with increasing length indicates that the development of karst in Taurus Range has a non-linear nature. Field studies indicate that caves over 300 m long have been developed under very rare geologic conditions. From this observation we may deduce that the environmental conditions (e.g. lowering speed of regional ground water table or karst erosion base) mostly allow the caves to develop until they reach a length of around 300 m. Nazik (1993) in his PhD work on the geomorphologic evolution of a karst terrain just at the south of Beysehir Lake, western Taurids, suggests that there is a strong relationship between the altitudes at which most of the caves are located and the denudation surfaces. This implies that the lowering speed of karst erosion base has strong control on the cave development and on the length of any individual caves as well.

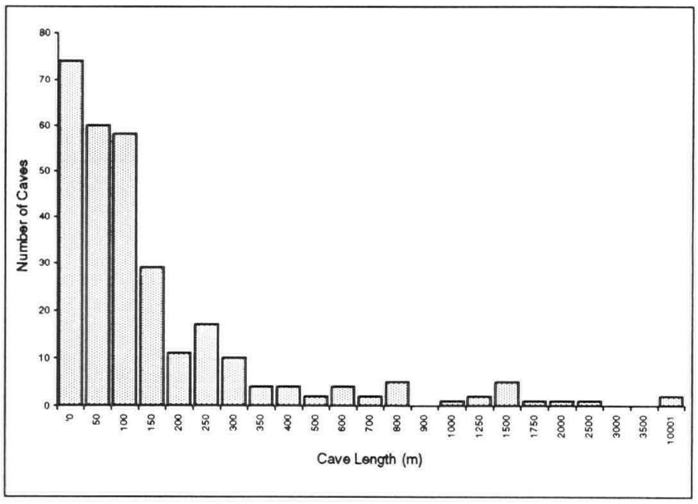


Figure 3. Variation of cave length in the Taurus karst range (note that horizontal scale changes).

Range of Depth

The depth of the Taurus Range caves varies between -400 m and +600 m (Fig. 4). Although, there have been extensive studies in recent years on the deep caves of Taurus Range, these were not included in this paper. The deepest cave is Çukurpinar Cave, (-1190 m), discovered and explored by BUMAK between 1989 and 1992. The second deepest (-700 m) was found in Lower Zamanti Basin by Bayari (1991) and mapped recently by MAD. More than half of the caves in Taurus Range have a depth magnitude between -50 m and +25 m. As it is hard to explore the upward and downward passages in caves, they are sometimes neglected and left unexplored. Therefore, it is believed that the real depth range is quite beyond these limits. Another reason leading the narrow depth range of the explored caves is the difficulty of reaching the sites where deeper caves are located. The two deepest caves cited above are located at high elevations (ca. 2000 m). Since the deep caves, as one may expect, are located in mountainous areas to where access is restricted due to the weather conditions and logistic reasons, the explorations in these areas have been quite limited until recent years. As the caving expeditions are much time consuming in mountainous areas, the interest of foreign teams has also been limited. Depending on the increase in the number of well-trained Turkish cavers and their equipment potential, these areas have been started to be explored in recent years.

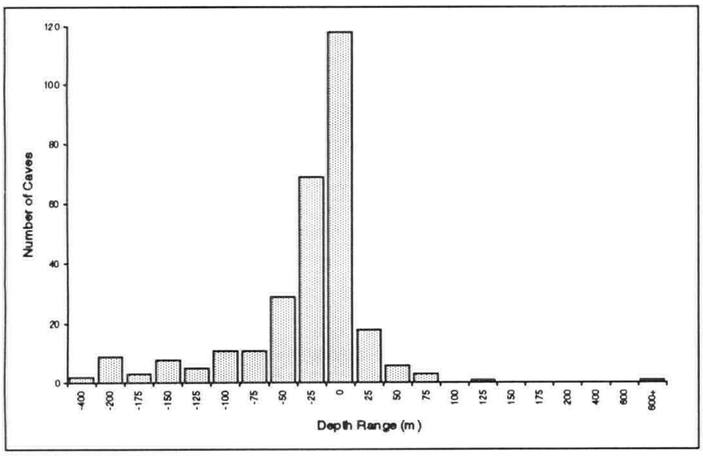


Figure 4. Variation of cave depth in the Taurus Karst Range (note that horizontal scale changes).

Variation of Average Depth and Length by Altitude

The variation of average cave length/depth for predefined altitude intervals is shown in Fig. 5. The average depth and average length parameters for a given altitude interval are defined as the total depth or length of the caves located at a given altitude interval divided by the number of caves. The figure implies that there is a threshold altitude interval of 1500-2000 m above which the caves are depth-dominated while below it the length dominates the dimensions of caves. It seems that there is a remarkable negative correlation between the average cave length and the average cave depth within the altitude intervals evaluated. Average cave length gradually decreases from the threshold altitude interval towards sea level. Above this zone, the average cave length does not show a gradual variation. On the other hand, the average cave depth is greater in the upper zone where the average depth is smaller. It appears that the elevation difference between the cave entrance and the local karst ground water table (or local erosion base) is the primary reason of this situation. Since the distance to local ground water table is greater at higher altitudes, the infiltrating water should have a stronger tendency to flow downward rather than flowing horizontally. On the contrary, at lower elevations, the distance between the surface and the local ground water table (or erosion base) is smaller as compared to higher altitudes. Therefore, the ground water flow should have a stronger horizontal component. Although, these explanations seem to be in accordance with the general rules of karst ground water flow, it is interesting to note that the boundary between these depth and length dominated regions is quite

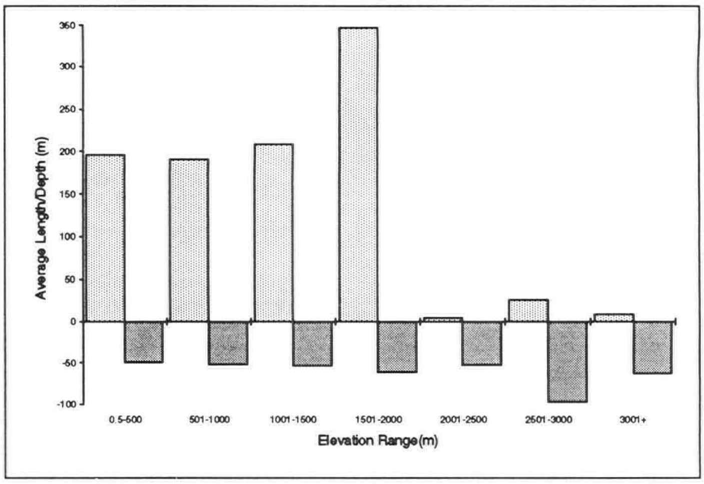


Figure 5. Variation of average depth and average length by altitude.

sharp. This information seems to be an important guide for the cavers dealing with vertical caving in Taurus Range.

Variation of Hydrologic Properties by Altitude

The definition, hydrologic properties, includes the ground water associated features such as sump, sink, resurgence and under ground stream existing in caves. The sumps are under ground lakes. They exist either as a part of siphons or simply as ground water outcrops in the caves. The term sink implies the points where the ground water flowing through the cave is suddenly or gradually lost along its course. Usually the sinks are in the form of small cracks or fractures. The term resurgence indicates that the ground water appearing in the under ground flows out of the cave mostly in the form of a stream. The 'streams' are underground creeks flowing inside the cave. Most of the hydrologic features existing in Taurus caves are observed in those of located below 2000 m (Fig. 6). Only a few hydrologic feature has been observed above the altitude of 1500 m. This indicates that the downward percolation of ground water in this zone is quite rapid and, the aquifer is drained almost completely within a short period of time. The non-existence of resurgences from caves within this altitude range can also be accepted as a supplementing evidence for this conclusion. On the other hand, the hydrologic features are mostly concentrated in caves located between 1000 m and 1500 m altitudes, indicating that this zone is hydrological most active. From this altitude interval down to the sea level the number of sumps and sinks decreases gradually. The number of sumps is usually greater than that of sinks. However, the number of resurgences and under ground streams does not show a similar trend within the altitude range of 1500 m and the sea level. Only a few resurgences and under ground streams are observed in caves located between 500 m and 1000 m altitudes.

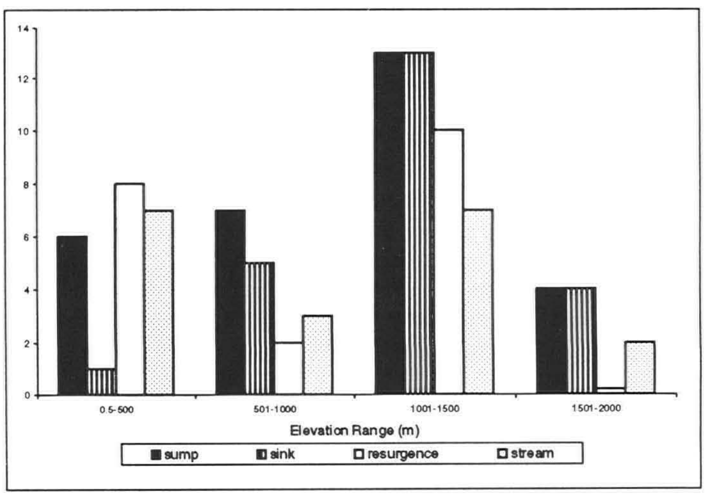


Figure 6. Variation of hydrologic properties by altitude.

Distribution by Geographic Location (Province)

The provinces are the major administrative sub-divisions in Turkey. Since the administration efficiency is essentially based on communication and transportation possibilities existing in a specific area, the province boundaries are mostly controlled by topographic conditions. Therefore, the distribution of caves by provinces does not have a special meaning from the hydrogeological point of view. However, the distribution by province is also given in Fig. 7 to provide an insight to the reader on the location of caves that have been discovered so far. As seen from the figure, most of the caves have been explored so far are located in Antalya, Konya (including Karaman) and Isparta provinces. This is due to the fact that most of the hydrogeological and associated speleological research have been carried out so far has been concentrated on the region where these provinces extend over. This part of the Taurus Range, called Western Taurids, were subject to extensive hydrogeological research since there is an accountable water potential to be used for hydro-power production. As this region have been studied in more detail, the recent caving interest has been shifted towards east where two deepest caves were discovered currently. However, as demonstrated by a joint caving expedition by UKAM and Manchester Polytechnic in 1987, there are still lots of unexplored caves in this region (Degirmenci et al., 1994).

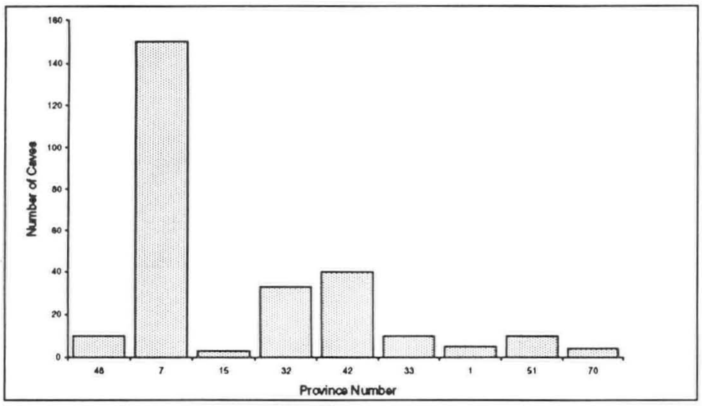


Figure 7. Distribution of caves by province (Province names; 1: Adana, 7: Antalya, 15: Burdur, 32: Isparta, 33: Mersin, 42: Konya, 48: Mugla, 51: Nigde, 70: Karaman).

Distribution by Rock-type and age

Along the Taurus karst range the major lithologic units exhibiting karstification are limestones-dolomitic limestones, carbonate cemented conglomerates and travertines. The limestones and dolomitic limestones are scattered throughout the Taurus Range while the conglomerates (Köprüçay Formation) are mostly located within the Köprüçay Basin. On the other hand, the major travertine outcrop with an areal extension of ca 650 km^2 lays over the Antalya Plain. As inferred from Fig. 8, the major lithology in which 95% of the caves are developed is limestone. Only several caves have been developed in conglomerates and travertines. Apart from the limestone and conglomerate caves, the caves in travertines are usually formed by precipitation processes rather than dissolution. That is, they are formed in cascades where a layer of travertine covers the top of the space between the bottom and the crest of a cascade. A present day example of this process can be seen in Düdenbasi waterfall of Antalya Plain.

Distribution of caves by the geologic age of the lithology in which they are developed is shown in Fig. 9. As inferred, a great deal of the caves in Taurus Range are developed in the Mesozoic limestones. Although, the ages of the lithology of about 17% of the caves are not exactly known, it is believed that they are mostly associated with the Mesozoic limestone. Palaeozoic and Tertiary aged lithologies contain only 20% of the caves known so far.

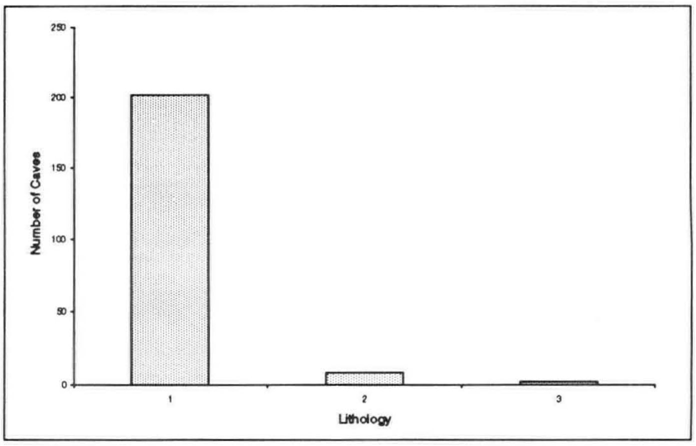


Figure 8. Distribution of caves by lithology (Lithologies; 1: Limestone, 2: conglomerate, 3: travertine).

Of the caves developed in Mesozoic strata, 65% are located in Jurassic-Cretaceous and Cretaceous limestones. The number of the caves located in other lithologies are nearly equal. Since, the Jurassic-Cretaceous and Cretaceous limestones cover wide areas throughout the Taurus Range, one may deduce that it is quite normal that most of the caves are hosted by these lithologies. However, the field observations suggest that these units are more susceptible to karstification due to their textural and compositional properties. Moreover, Jakucz (1978), on the basis of his observations on hundreds of limestones of various ages, also indicate that due to microfissuration in a limestone, the permeability is a function of geological age. The interrelation among the geological age, the permeability and the density of open and closed fissures in the limestones is illustrated in Fig. 10. Presuming that his observations are mostly based on limestones in Hungary which is a part of Alpine-Himalayan orogenic belt like the Taurus Range, we may deduce that his results are equally well applicable to Taurus Range. As inferred from the graph, the highest permeability values are encountered in the Mesozoic aged limestones, especially in the ones Jurassic. Since the permeability of the limestone is one of the most fundamental prerequisites of karstification, we may deduce that the cave development would be more rapid and extensive in Mesozoic aged carbonates. When Fig. 9 and Fig. 10 are compared, a noteworthy correlation between the Jakucz's results and the number of caves developed in limestones of various ages is observed. It seems that this situation is one of the primary controls of cave development throughout the Taurus range.

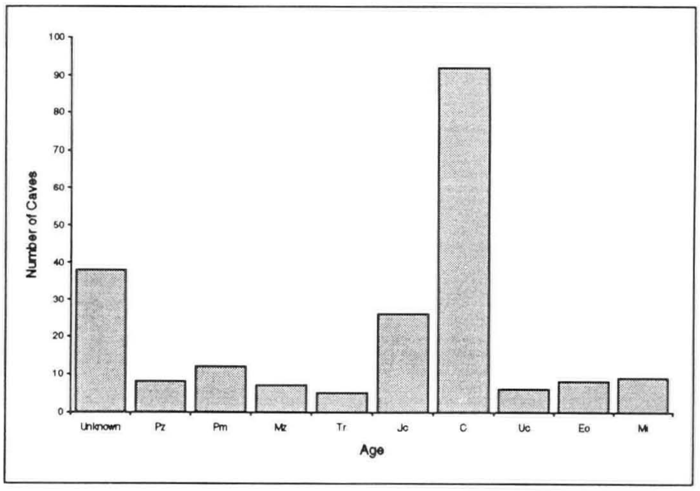


Figure 9. Distribution of caves by geologic age of the lithology (Abbreviations: PZ: Palaeozoic, PM: Permian, MZ: Mesozoic, TR: Trias, JC: Jurassic-Cretaceous, C: Cretaceous, UC: Late Cretaceous, EO: Eocene, MI: Miocene).

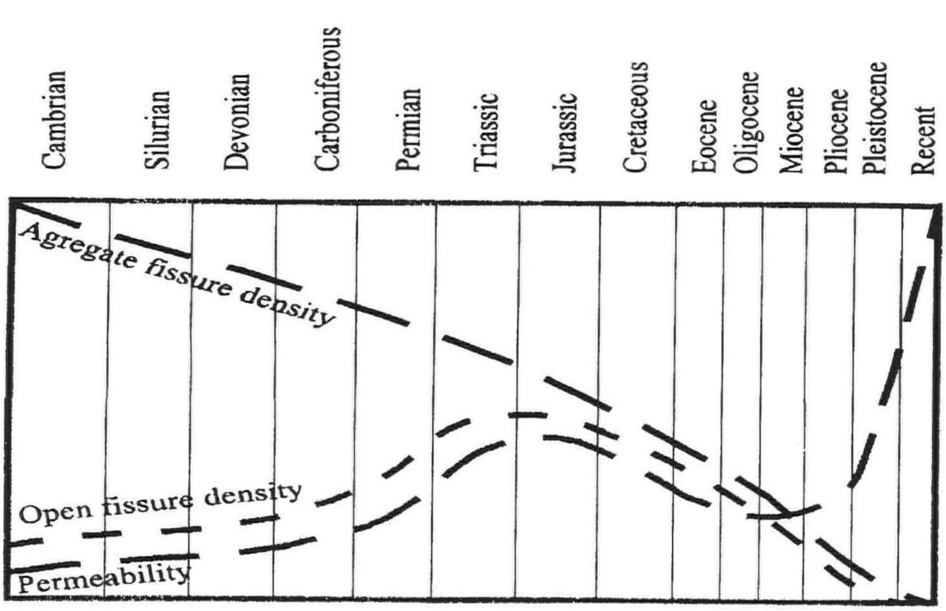


Figure 10. Variation of limestone permeability, open and closed fissure density by the geological age (after Jakucz, 1977).

CONCLUSIONS

A preliminary evaluation of the geographic, physical and geologic properties of the caves developed along the Taurus karst range of Southern Turkey reveals that development of caves is not a random event but, controlled by a number of factors such as, altitude, lithology and the position of local ground water table. Most of the caves have a depth range between -50 m and +25 m while the average length is around 300 m. An inverse relationship exists between the average cave length and average cave depth within the altitude range of 0 m - +3000 m. Highest average values are observed within the altitude range of 1500-2000 m. The caves located below this range are length dominated. Average depth dominates over the average length above this altitude interval. The hydrologic features such as sinks, sumps, under ground streams and resurgences appears in the caves located between the 2000 m and the sea level. Most of the hydrologic features are observed in the caves located in the altitude range between 1000 m and 1500 m, indicating that this zone is hydrologically more active. A great deal of the caves in inventory are located within the boundaries of Antalya, Konya and Isparta provinces. More than 95% of the caves have been developed in limestones while, there are also some caves in conglomerate and travertine formations. The Mesozoic limestones, especially Jurassic-Cretaceous and Cretaceous aged ones are the primary host lithologies for the cave development. It appears that the relatively high permeability of these units are the main governing factor of such a broad cave development.

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APPENDIX I: CAVE INVENTORY OF THE TAURUS KARST RANGE (SOUTHERN TURKEY)

Notes: Caves are listed in alphabetical order for each province.

EXPLANATIONS:

A: Inventory order no.
B: Code number of the Province where the cave is located.
Province names:
- 1: Adana
- 7: Antalya
- 15: Burdur
- 32: Isparta
- 33: Mersin
- 42: Konya
- 48: Mugla
- 51: Nigde
- 70: Karaman

C: Name of the cave
D: Name of the county (sub-province) where the cave is listed
E: Altitude of the cave entrance (m, a.s.l.)
F: Length (m)
G: Depth (m)
H: Lithology in which the cave developed
- 0: unknown
- 1: limestone
- 2: conglomerate (carbonate cemented)
- 3: travertine

I: Geologic age of the lithology
- 0: unknown
- 1: paleozoic
- 2: permian
- 3: triassic
- 4: jurassic-cretaceous
- 5: mesozoic
- 6: upper cretaceous
- 7: miocene
- 8: pliocene
- 9: eocene

FEATURES:
en: endogene; ex: exogene; fr:phreatic; ml: multi-level; sea: sea cave; anm:ancient mining activity; h: horizon (inclination smaller than 45°); v: vertical (inclination greater than 45°); ac: air current inside; sk: sink inside; rc: resurgence; as: under ground river; swa: seasonal ground water activity.
be: big entrance (larger than 2m x 5m); se: small entrance; otk: autochthonous sediment inside; alk: allochthonous sediment inside; sm: sump inside; mak: macro bones inside; mik: micro bones inside; cr: ceramic artifacts inside; a: prehistoric tools inside; str: man-made structure inside.

APPENDIX I: CAVE INVENTORY OF THE TAURUS KARST RANGE (SOUTHERN TURKEY)

A	B	C	D	E	F	G	H	I	FEATURES			
1	1	AKKOPRU-SEKERPINAR	POZANTI	870	6	0	1	1	en	fr	rc	str
2	1	CAMLIKOY SUBATANI	POZANTI	1800	0	-379	1	4	en	sk	otk	
3	1	CIN	DUZICI	600	60	-30	0	0				
4	1	MAZMILI I DUDENI	POZANTI	1800	65	-26	1	4	sk	swa		
5	1	SUTLUK SUBATANI	POZANTI	1800	0	-70	1	10	v			
6	7	AGLICA	GUNDOGMUS	450	52	-19	1	2	otk			
7	7	AKBEL	KALKAN	350	24	-12	1	5	v	otk		
8	7	AKDAG DUDENI 1	MANAVGAT	1570	30	-93	1	4	v			
9	7	AKPINAR	IBRADI	950	288	0	1	4	en	str	rc	
10	7	ALABELEN	KAS	535	41	-32	1	10	f	v	otk	
11	7	ALTINBESIK	AKSEKI	510	2500	101	1	6	en	h	str	
12	7	ARITASI	AKSEKI	1260	99	-60	1	7	v	otk		
13	7	ARKAKAPICIK	MERKEZ	327	4	-27	1	0	f	v		
14	7	ASAR	AKSEKI	2000	0	-50	1	6	v			
15	7	ASARONU ERENKUYUSU	FINIKE	300	0	-82	1	6	f	v		
16	7	ASIKLAR DENIZ	ALANYA	10	50	0	1	2	sea	h		
17	7	ASIRLIADA	KALE	30	33	0	1	10	d	h		
18	7	AYIINI	KUMLUCA	310	137	-35	1	6	v			
19	7	B-1	AKSEKI	0	0	-30	0	0				
20	7	B-2	AKSEKI	0	0	-23	0	0				
21	7	B-3	AKSEKI	0	0	-50	0	0				
22	7	BAYRAMYUVASI DUDENI	IBRADI	970	33	-31	1	4	f	v		
23	7	BESIKDAG	IBRADI	0	150	-80	1	0	v	sm		
24	7	BUYUKDIPSIZ	MERKEZ	260	40	-20	1	6	f	h	otk	
25	7	BUYUKDUDEN	IBRADI	1140	178	0	1	6	h	swa		
26	7	BUYUKDUDEN	IBRADI	950	0	-10	0	0	v			
27	7	CALDAMI DELIGI	AKSEKI	1320	0	-16	0	0	ac			
28	7	CAMLICA	KALE	25	80	-11	1	10	swa	h		
29	7	CARKINI	MERKEZ	500	40	0	1	6	f	h	be	
30	7	CATDERE	AKSEKI	1150	90	-4	1	6	h	swa		
31	7	CAYIRONU	AKSEKI	1050	250	-155	1	6	swa	v		
32	7	CEVIZDIBI DUDENI	AKSEKI	1540	154	-43	0	0	v			
33	7	CEVIZLI GOLET DUDENI	CEVIZLI	1050	48	-29	1	0	v	swa		
34	7	CEYIZ	GUNDOGMUS	860	136	-28	1	0	f	h	otk	

A	B	C	D	E	F	G	H	I	FEATURES		
35	7	CIMENINI	ALANYA	530	109	10	1	2	h	otk	
36	7	CIVGUS DUDENI	ELMALI	2070	85	-68	1	6	v	db	
37	7	COBANOLUGU OBRUGU	AKSEKI	1950	0	-79	1	6	v		
38	7	CULA DELIGI-1	AKSEKI	1695	60	-31	0	0	v		
39	7	CULA DELIGI-2	ELMALI	3000	29	17	0	0	f	v	se
40	7	CULA DUDENI	IBRADI	1250	10	-21	1	0	v		
41	7	CULA OBRUGU	AKSEKI	2250	0	-32	1	6	v		
42	7	DAGBASI DUDENI	IBRADI	500	5	-35	0	0	v		
43	7	DAMLATAS	ALANYA	10	70	-8	0	0	swa		
44	7	DEDETEPE DIPSIZI-1	ALANYA	680	17	-17	1	2	f	v	
45	7	DEGIRMENLIK	AKSEKI	1100	185	9	0	0	h	swa	
46	7	DEGIRMENLIK DERE	KAS	30	10	-2	1	6	f	h	be
47	7	DEGIRMENOZU	MANAVGAT	500	60	-6	1	4	h	rc	
48	7	DERI OBRUGU	AKSEKI	2000	0	-14	1	6	v	otk	
49	7	DERYA	MERKEZ	32	124	32	1	9	v	otk	
50	7	DIM	ALANYA	250	357	-26	1	2	en	h	str
51	7	DIVLE BOGAZI	KALE	645	16	-6	1	10	str	sc	
52	7	DIYREKDIBI OBRUGU	AKSEKI	2000	0	-32	1	6	v		
53	7	DUDENCIK	AKSEKI	1040	750	-331	1	6	en	sk	v
54	7	DUMANLI-1	MANAVGAT	60	150	0	1	6	en	str	rc
55	7	DUMANLI-2	MANAVGAT	130	95	0	1	6	en	str	rc
56	7	DUNEKDIBI	AKSEKI	2140	0	-192	1	6	v		
57	7	DUNEKDIBI OBRUGU	AKSEKI	1900	0	-192	1	6	v		
58	7	ERKECALANI OBRUGU	AKSEKI	1100	0	-30	1	2	v		
59	7	ERKIBET DUDENI	IBRADI	1290	25	-55	1	0	v	sc	
60	7	FEYZULLAH DUDENI	IBRADI	1050	400	0	1	6	h	sk	
61	7	FILOS DUDENI	IBRADI	1000	25	-9	0	0	f	v	
62	7	G JOINT	MANAVGAT	38	58	-8	1	1	h	swa	
63	7	GAVURINI	AKSEKI	1150	80	0	0	0	h		
64	7	GEYIKBAYIRI	MERKEZ	560	120	-7	1	2	en	h	se
65	7	GOKTEPE K-8	AKSEKI	1300	0	-135	1	5	v		
66	7	GOLCUK OBRUGU-1	AKSEKI	1980	55	-83	1	6	v		
67	7	GOLCUK OBRUGU-2	AKSEKI	1980	0	-35	1	6	v		
68	7	GOYNUK	KEMER	60	549	7	1	4	swa		
69	7	GURLEVIK	MANAVGAT	1350	35	-5	1	4	en	h	rc
70	7	GUVERCIN OBRUGU	AKSEKI	850	0	-120	0	0	v		

APPENDIX I: CAVE INVENTORY OF THE TAURUS KARST RANGE (SOUTHERN TURKEY)

A	B	C	D	E	F	G	H	I	FEATURES
71	7	GUVERCINLIK	AKSEKI	1370	0	0	0	0	
72	7	GUVERCINLIK	MERKEZ	350	85	-55	1	0	h sm
73	7	HANDOS	IBRADI	500	57	-50	1	6	en v rc
74	7	HIDRELLEZ	KAS	20	350	0	1	4	h
75	7	HOCASALMA	ALANYA	140	49	-3	1	2	cn h otk
76	7	HOMA DUDENI	MANAVGAT	85	220	-65	2	8	en h sk
77	7	HONAZ DELIGI	SERIK	520	670	24	2	8	h swa
78	7	IT CUKURU	AKSEKI	1850	0	-68	1	6	v
79	7	K-1	AKSEKI	1800	0	-101	1	6	v
80	7	K-10	AKSEKI	1500	0	-14	1	6	v
81	7	K-11	AKSEKI	1300	0	-37	1	6	v
82	7	K-2	AKSEKI	1800	0	-35	1	6	v
83	7	K-3	AKSEKI	1860	0	-25	1	6	v
84	7	K-4	AKSEKI	1800	27	-17	1	6	v
85	7	K-5	AKSEKI	1820	0	-32	1	6	v
86	7	K-6	AKSEKI	1850	35	0	1	6	
87	7	K-7	AKSEKI	1800	0	32	1	6	v
88	7	K-9 MELIK	AKSEKI	1300	0	-18	1	6	v
89	7	KADIINI	ALANYA	140	49	-30	1	2	cn str pt
90	7	KAKLIK DELIGI	IBRADI	910	45	-8	0	0	
91	7	KAPALI DUDEN	AKSEKI	1800	0	-16	1	6	v
92	7	KAPUTAS	KAS	0	75	0	1	6	sea rc be
93	7	KARAAGACLI DUDENI	AKSEKI	900	43	-22	1	6	v swa
94	7	KARABACAK DUDENI	IBRADI	950	211	-122	1	6	v alk
95	7	KARADAG	IBRADI	1335	350	0	0	0	f h str
96	7	KARADELIK	KALE	30	32	-9	1	5	h se
97	7	KARAGOL DUDENI	ELMALI	1025	203	-19	1	7	en h swa
98	7	KARAIN	MERKEZ	410	100	-15	1	6	
99	7	KARANLIK DELIK	IBRADI	400	100	-35	1	6	h be
100	7	KARATOP K-12	AKSEKI	1300	0	-47	1	6	v
101	7	KARLIK	AKSEKI	1675	91	-63	0	0	
102	7	KAVANOZ	IBRADI	950	22	-28	0	0	v
103	7	KAYAAGIL CUKURU	AKSEKI	1200	500	-160	0	0	
104	7	KECI OBRUGU	AKSEKI	2000	0	-54	1	6	v
105	7	KELEBEKLI	AKSEKI	800	100	-47	1	0	en h swa
106	7	KIRKGOZLER MEVLANA	MERKEZ	340	300	-20	1	6	f en h otk

A	B	C	D	E	F	G	H	I	FEATURES
107	7	KIRKMETRE OBRUGU	AKSEKI	2000	0	-38	1	6	v
108	7	KISMIR DUDENI-1	IBRADI	945	0	-12	1	6	v
109	7	KIZILIN	MERKEZ	360	35	-22	1	6	f v be
110	7	KIZLAR OBRUGU	AKSEKI	2000	0	0	0	0	
111	7	KOCA OBRUK	AKSEKI	1090	0	-27	1	7	v swa
112	7	KOCADUDEN	AKSEKI	1050	295	-119	1	7	en v swa
113	7	KOCAIN	MERKEZ	788	744	-91	1	6	f h be
114	7	KOSTAK DUDENI	IBRADI	935	22	-16	1	6	v
115	7	KOYUNGOBEDI	AKSEKI	1080	250	-210	0	0	v
116	7	KUCUK HALLAC OBRUGU	IBRADI	1300	0	-42	1	6	v sk
117	7	KUCUK OBRUK	AKSEKI	1075	60	-31	1	7	v swa
118	7	KUCUKDIPSIZ	MERKEZ	370	74	-28	1	6	f h otk
119	7	KUCUKIN	AKSEKI	2000	60	0	1	6	h
120	7	KURUKOPRU	SERIK	130	530	-30	2	8	swa
121	7	MAHRUMCALI	MANAVGAT	580	157	-36	1	1	en h otk
122	7	MANDALDAG OCAK	AKSEKI	1250	120	-10	1	2	h
123	7	MOLLA DELIGI	KEMER	910	549	-21	1	4	en h sm
124	7	MUSTANINI	MERKEZ	340	205	-15	1	6	f h swa
125	7	OKUZ INI	MERKEZ	320	60	0	1	6	f h be
126	7	ONBASIDUSEN	SERIK	790	50	-16	2	8	v sk
127	7	ORUC DUDENI	IBRADI	970	6	-52	0	0	v
128	7	OYMAPINAR DAM M-1	MANAVGAT	46	106	-11	1	1	h swa
129	7	PAPAZKAYASI	MERKEZ	20	149	0	3	9	h otk
130	7	PESENEK OBRUGU	AKSEKI	2000	0	-20	1	6	v
131	7	PEYNIR DELIGI	KEMER	720	74	-19	1	6	h otk
132	7	PEYNIR OBRUGU	AKSEKI	2000	0	-14	1	6	v
133	7	PINARLI DUDEN	AKSEKI	1080	116	-65	0	0	v
134	7	R-JOINT	MANAVGAT	130	46	-7	1	1	h swa
135	7	RUZGARLI DUDEN	IBRADI	950	200	-49	1	6	v
136	7	SABIR OBRUGU	AKSEKI	2000	0	-71	1	6	v
137	7	SAKALTUTAN DELIGI	AKSEKI	1650	1425	-302	0	0	v swa
138	7	SAKALTUTAN DUDENI	AKSEKI	1650	1455	-303	0	0	v swa
139	7	SALYANGOZ DUDENI	IBRADI	950	0	-16	0	0	v
140	7	SEDIRDIBI OBRUGU	AKSEKI	1750	0	-31	1	6	v
141	7	SEYCAGIZI	AKSEKI	1360	60	-14	1	4	otk
142	7	SISMANIN	AKSEKI	1320	40	-35	1	4	v swa

APPENDIX I: CAVE INVENTORY OF THE TAURUS KARST RANGE (SOUTHERN TURKEY)

A	B	C	D	E	F	G	H	I	FEATURES
143	7	SOGUK DELIK	ALANYA	890	56	18	1	2	h otk
144	7	SUGOZU	ALANYA	120	231	2	1	2	en h str
145	7	SULTAN OBRUGU	AKSEKI	2000	0	-32	1	4	v
146	7	SULUIN	FINIKE	18	128	-64	1	4	en sm otk
147	7	SULUIN	MERKEZ	320	300	-40	1	0	en h str
148	7	TABAK	MERKEZ	340	200	-40	1	0	en h
149	7	TEPEARASI	FINIKE	821	60	-31	1	4	v otk
150	7	TEPEKLI	IBRADI	610	267	-147	2	8	v se
151	7	TILKILER	MANAVGAT	150	5500	-66	2	8	en h ac
152	7	TURBE DUDENI	IBRADI	1130	64	-9	1	0	h vk
153	7	ULUCUKUR	ALANYA	790	67	-23	1	2	swa sm
154	7	URKUTEN-1 OBRUGU	AKSEKI	2300	0	-243	1	6	v
155	7	URKUTEN-2 OBRUGU	AKSEKI	2300	0	-37	1	6	v
156	7	YALANDUNYA	GAZIPASA	360	250	-27	1	3	en f h otk
157	7	YATAKYERI DELIGI-3	AKSEKI	1530	0	-23	0	0	v
158	7	YATIRTAS DUDENI	IBRADI	980	101	-31	0	0	en v sm
159	7	YAVU DUDENI	KAS	455	60	-46	1	10	v swa
160	7	YESILBAG	EGIRDIR	910	150	-10	2	8	h swa
161	7	YUKARICAYIR DUDENI	IBRADI	1210	0	-21	1	6	v
162	7	YUKARIDAG OBRUK	AKSEKI	1117	0	-60	1	6	v
163	15	INSUYU	MERKEZ	1250	700	0	1	5	en 2k
164	32	AYIINI	YALVAC	1900	372	0	1	4	
165	32	BELBASI	EGIRDIR	1400	59	-35	1	5	v otk
166	32	CIV	AKSU	2000	0	-238	0	0	en v swa
167	32	CULAKINI	EGIRDIR	1180	38	-32	1	6	v
168	32	DEDEGOL-3	YENISARBADEMLI	2220	0	-30	1	0	v
169	32	DEDEGOL-5	YENISARBADEMLI	1800	0	-30	1	3	v
170	32	DELIKONU	MERKEZ	1040	71	0	0	8	v
171	32	DELIKTAS	GELENDOST	1200	85	3	1	0	h rc
172	32	ERENLER	EGIRDIR	1500	57	-4	1	4	h otk
173	32	GOLLU	YENISARBADEMLI	1136	55	0	1	6	v swa
174	32	GUHERCILE	YENISARBADEMLI	1610	70	-20	1	0	h be
175	32	GUMUSINI	AKSU	1720	201	1	1	0	h swa
176	32	ICMEPINARI	SARKIKARAAGAC	1300	40	0	1	0	h se
177	32	KADIDELIGI	SUTCULER	790	81	-33	1	6	v otk
178	32	KAPIKAYA	MERKEZ	1450	67	23	1	6	h be

A	B	C	D	E	F	G	H	I	FEATURES
179	32	KAPIZINI	EGIRDIR	950	63	-21	1	6	h be
180	32	KARATASTAKI IN	YENISARBADEMLI	2300	50	-112	1	0	v ac
181	32	KOCAKIR	EGIRDIR	1160	47	-11	1	4	h se
182	32	KUZ	SUTLUCE	760	224	0	1	6	h
183	32	OSSEKCI	SARKIKARAAGAC	1430	53	0	0	0	h
184	32	PEYNIRINI	SENIRKENT	1365	46	-20	1	4	v
185	32	PINARGOZU	YENISARBADEMLI	1550	10000	662	1	3	en h str
186	32	SAHNE	SUTCULER	325	110	-38	1	6	h otk
187	32	SALUR	SARKIKARAAGAC	1455	121	0	0	3	v
188	32	SORGUN	AKSU	1440	302	-12	1	3	h str
189	32	SU INI	EGIRDIR	910	0	0	0	0	
190	32	TASKAPI	SUTCULER	1020	161	-18	1	6	h otk
191	32	TIRTIL	AKSU	2000	0	-100	0	0	en v
192	32	TUZLA	EGIRDIR	1600	120	0	0	0	h cr
193	32	ULUBORLU	ULUBORLU	1995	0	0	0	0	
194	32	YARIKKAYA	SUTCULER	825	49	-20	0	0	v
195	32	YAYLA OBRUGU	GONEN	1875	48	-15	1	4	v
196	32	YEMISLIOGLU	EGIRDIR	680	75	0	1	4	h swa
197	32	YESILBAG DUDENI	EGIRDIR	915	95	-62	2	8	v sk
198	32	ZINDAN	EGIRDIR	1300	740	21	1	6	en h rc
199	33	CATIRIK	SILIFKE	1570	20	-88	0	0	v swa
200	33	CEHENNEM	SILIFKE	150	0	-70	1	8	v alk
201	33	CENNET	SILIFKE	150	220	-165	1	8	str str
202	33	CINGOREZ UCURUMU	TARSUS	500	0	-40	1	1	v
203	33	CUKURPINAR	ANAMUR	1880	0	-1040	1	0	en v otk
204	33	DIPSIZ	TARSUS	453	0	-100	1	0	v swa
205	33	ESKIORUK	ANAMUR	100	250	0	0	0	en ml h swa
206	33	HISAR	ERDEMLI	720	130	0	0	0	h be otk
207	33	MEYDANCIKKALE	GULNAR	710	30	10	1	8	str se
208	33	NARLIKUYU	SILIFKE	170	240	32	0	8	otk
209	33	SAY	TARSUS	170	255	0	1	8	h otk
210	33	SINABIC	MUT	600	120	0	0	0	h
211	33	TEKNELI OBRUK	TARSUS	475	60	-8	1	1	h otk
212	42	ALADAG	HADIM	1150	180	15	1	0	h otk
213	42	ARPALIK-1	SEYDISEHIR	1600	165	-32	1	4	v otk
214	42	ARPALIK-2	SEYDISEHIR	1610	77	1	1	4	en h otk

APPENDIX I: CAVE INVENTORY OF THE TAURUS KARST RANGE (SOUTHERN TURKEY)

A	B	C	D	E	F	G	H	I	FEATURES			
215	42	BALATINI	DEREBUCAK	1390	1536	45	1	6	en	sm	h	sk
216	42	BICAKCI	DEREBUCAK	1300	100	0	1	6	h	rc		
217	42	BORAZ MAKKA	HADIM	1800	95	-21	0	0	h	otk		
218	42	CAKALLAR	HADIM	900	60	-30	0	0	h			
219	42	COBANYATAGI	SEYDISEHIR	1500	75	0	1	6	h			
220	42	DEDETARLASI DUDENI	DEREBUCAK	1300	150	0	1	6	en	h	str	
221	42	DOLONU INI	DEREBUCAK	1350	130	0	1	6	en	f	h	sm
222	42	DUDENYAYLA DUDENI	BEYSEHIR	1580	60	-70	1	6	v	sk		
223	42	DUZENCIK	SEYDISEHIR	1650	170	-44	0	0	h	db		
224	42	EKSIELMA	HADIM	1900	597	5	0	0	en	h	sm	
225	42	EVREAGAC	SEYDISEHIR	1650	104	-15	0	0	h	swa		
226	42	FASIH DUDENI	SEYDISEHIR	1150	130	-51	1	6	en	v	rc	
227	42	FELENGI	DOGANHISAR	1155	250	-170	1	1	en	sm	ac	
228	42	FERZENE	SEYDISEHIR	1470	364	-5	1	4	f	h	swa	
229	42	GEVENESIGI-1	SEYDISEHIR	1550	140	-65	0	0	v			
230	42	GEVENESIGI-2	SEYDISEHIR	1550	40	-23	0	0	v			
231	42	GEVENESIGI-3	SEYDISEHIR	1550	73	-35	0	0	v	ac		
232	42	GEVENESIGI-4	SEYDISEHIR	1550	49	-18	0	0	v			
233	42	GOLCUK DUDENI	SEYDISEHIR	1565	285	-245	1	6	v	sm		
234	42	GUVERCINLIK-1	SEYDISEHIR	1212	223	-85	1	0	v	otk		
235	42	GUVERCINLIK-2	SEYDISEHIR	1217	276	-3	1	0	en	h	otk	
236	42	HACIAKIF ADASI	BEYSEHIR	1180	250	0	1	6	h	ma		
237	42	INONU INI	BEYSEHIR	1200	225	-30	1	4	h	otk		
238	42	INSU	BEYSEHIR	1115	55	-35	0	0	v	otk		
239	42	ITALYAN INI	SEYDISEHIR	1600	44	-138	1	0	v			
240	42	KIZIL	BEYSEHIR	1027	66	-44	0	0	v	alk		
241	42	KOCAIN	EREGLI	1290	152	-20	1	3	en	h	otk	
242	42	KORUKINI	DEREBUCAK	1200	1320	0	1	6	en	h	sk	
243	42	KUCUK TINAZTEPE	SEYDISEHIR	1533	105	5	1	6	f	h	otk	
244	42	MADA ADASI	BEYSEHIR	1135	15	-7	0	0	swa			
245	42	MELIKTASLAR ALANI IN	SEYDISEHIR	2215	46	-34	0	0	v	ac		
246	42	MORCUKUR DELIGI-1	SEYDISEHIR	1500	145	-57	0	0	v			
247	42	MORCUKUR DELIGI-2	SEYDISEHIR	1500	8	-45	0	0	v			
248	42	MORCUKUR DELIGI-3	SEYDISEHIR	1500	50	-35	0	0	v			
249	42	MORTAS ALANI INI	SEYDISEHIR	1530	47	-25	0	0	v			
250	42	SULUIN	DEREBUCAK	1200	330	0	1	6	en	h	sk	

A	B	C	D	E	F	G	H	I	FEATURES			
251	42	SUSUZ	SEYDISEHIR	1160	1351	-33	1	7	en	h	str	
252	42	T-1	SEYDISEHIR	1625	90	-105	1	6	v			
253	42	T-2	SEYDISEHIR	1615	40	-60	1	6	v			
254	42	TINAZTEPE	SEYDISEHIR	1540	1015	-58	1	0	en	h	swa	
255	42	TINAZTEPE DUDENI	SEYDISEHIR	1500	750	-153	1	0	en	v	sk	
256	42	TURBETEPE DUDENI	SEYDISEHIR	1700	25	-35	0	0	v	sk		
257	42	UZUNSU	DEREBUCAK	1250	100	0	1	6	h	str		
258	42	YAGCI KOYU	HADIM	1800	103	-51	0	0	h	otk		
259	42	YERKOPRU DUDENI	HADIM	900	1090	-166	0	0	h	v		
260	42	YERKOPRU-1	HADIM	900	490	0	1	0	h	sk		
261	48	ARMELLI	MARMARIS	150	95	62	1	6	f	h	v	
262	48	ASAR INI	MARMARIS	490	26	-45	1	0	f	v	otk	
263	48	DELIKBELEN DUDENI	FETHIYE	700	11	-24	1	6	v	otk		
264	48	GELME CINGIREK	MARMARIS	65	24	-52	1	6	v			
265	48	KARADIKEN DUDENI	MARMARIS	400	13	-36	1	6	v			
266	48	KECIBUKU CENGIREK	MARMARIS	35	0	-35	1	6	v			
267	48	MAHALBASI CENGIREK	MARMARIS	430	39	-102	1	6	v			
268	48	PEYNIR INI	MERKEZ	600	46	-24	1	5	v	h		
269	48	PEYNIRLIK DUDENI	MERKEZ	750	63	-17	1	5	h	swa		
270	51	CIYAKDELIGI	ULUKISLA	2000	0	-80	0	0	v	alk		
271	51	DIDIER CUKURU	ULUKISLA	1560	0	-31	0	0	v	sc		
272	51	INGILIZIN DIPSIZI	ULUKISLA	3070	0	-92	1	0	v			
273	51	INLIK DUDENI	CAMARDI	1650	0	-115	1	10	v			
274	51	KARACAYLAK DUDENI	CAMARDI	1800	12	-33	1	10	v			
275	51	KIZLAR KELERI	ULUKISLA	1440	110	-36	0	0	f	h	swa	
276	51	MADEN	ULUKISLA	1865	150	-15	0	0	ml	anm	h	
277	51	TAHIR TEPESI DIPSIZI	ULUKISLA	3110	0	75	0	0	v			
278	51	TOYISLAM	ULUKISLA	1890	1000	0	0	0	anm	h	otk	
279	70	ASARINI	TASKALE	1630	793	-3	1	8	en	h	swa	
280	70	HASILAYIK	AYRANCI	1940	260	-54	0	0	en	h	str	
281	70	INCESU	MERKEZ	1615	1356	-22	1	8	h	swa		
282	70	MARASPOLI	ERMENEK	1400	1800	10	1	8	en	ml	h	be
283	70	SUBASI KAYNAK	AYRANCI	0	260	-54	0	0	en	h	v	

APPENDIX II: CAVE RESEARCH SOCIETIES OF TURKEY

INSTITUTES

DSI State Hydraulic Works, Dept. Of Groundwater and Geotechnical Research, Karst Research Section
(Devlet Su Isleri, yeraltisulari ve Jeoteknik Hizmetler Dairesi, Karst Arastirma Subesi, Yucetepe, Ankara)

MTA Mineral Resources Research and Exploration Institute, Cave Research Project
(Dr. Lufti Nazik, Magara Arastirma Projesi, Ankara)

MAD Cave Research Association
(Magara Arastirma Dernegi, P.O. Box 670, Kizilay 06421, Ankara)

UKAM International Research and Application Centre for Karst Water Resources, Hacettepe University
(Prof. Dr. Gultekin Günay, Director, Beytepe 06532, Ankara)

UNIVERSITY CLUBS

BUMAK Bosphorus University, Cave Research Club
(Bogazici Universitesi, Magara Arastirma Klubu, Etiler, Istanbul)

DOST Bilkent University, Nature Sports Club
(Bilkent Universitesi, Doga Sprolari Klubu - DOST, Bilkent Ankara)

HUMAK Hacettepe University, Cave Research Club
(Hacettepe Universitesi, Magara Arastirma Klubu, Sihhiye, Ankara)

ZOMMAK Karaelmas University, Cave Research Club
(Karaelmas Universitesi, Magara Arastirma Klubu, Zonguldak)

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The western Visoki kras of Slovenia - A park ?

Daniel ROJSEK
Zavod za varstvo naravne in kulturne dediscine Gorica iz Nove Gorice, Delpinova 16, Nova Gorica, Slovenia 65 000.

Abstract: The upland karst massifs of Banjsice, Trnovski gozd, Gora, Javornik, Hrusica and Nanos are the most northwestern outgrowths of the Dinaric mountain system. They are called Visoki kras in the Slovene geographical literature. The Visoki kras eastern upland karst massifs of Sneznik and Javorniki should be protected together with Cerknisko jezero and Planinsko polje by The Notranjska regional park. The Trnovski gozd massif was proposed to be protected as a national park in 1961, but the proposal was rejected. Three landscape parks Juzni obronki Trnovskega gozda in Gore (Southern foot-hills of Trnovski gozd and Gora), Juzni in zahodni obronki Nanosa (Southern and western foot-hills of Nanos) and Zgornja Idrijca (The upper Idrijca river) have been proclaimed since 1984. A new procedure to prepare special groundwork for the regional park legislation started in the spring of 1994. The geographical characteristics of the Visoki kras region, natural features, threats and other reasons to protect the area are presented.

INTRODUCTION

Slovenia is a karst land, the region of maticni Kras - the Mother or Classical Karst. In the country karstic drainage occurs or predominates in 43 % of the area (7200 km^2 limestones; 1600 km^2 dolomites, (Gams, 1974)). There is a need to protect karst areas in the country. The high mountainous karst of the eastern Julian Alps, the karst in slopes of Logarska dolina and Robanov kot, the Golte massif, the Planinsko polje, the Rakov Skocjan karst valley, the Glinscica and the Lahinja fluvio-karst drainage basins, the Vremscica hill, Masun in the Sneznik massif, Postojnski kras with the cave system, Skocjanski Kras with the cave system and the Velika voda - Reka karst canyon and few hundreds caves and cave systems are protected by laws or decrees in Slovenia. The most northwestern outgrowths of the huge Dinaric mountain system are called Visoki kras together with the massifs of Javorniki and Sneznik. Three landscape parks and 38 units of natural heritage are proclaimed by decrees of the communes Ajdovscina (1987), Idrija (1993), Nova Gorica (1985) and Postojna (1984). There is a need to proclaim a regional park in western Visoki kras by a law.

GEOGRAPHICAL CHARACTERISTICS

The Visoki kras lies in west Slovenia and is divided into six upland karst massifs: Banjsice, Trnovski gozd with Gora, Javornik, Hrusica, Zagora and Nanos. The Cepovanski dol dry valley is one of the biggest and best developed in Slovenia). The valley divides Banjsice and Trnovski gozd (Fig. 1). Cretaceous, Jurassic and Triassic limestones with dolomites dominate in Visoki kras (Fig. 2). There are different theories about the geomorphological history of the area (Habic, 1968). The geomorphogenesis has been interpreted as being due to the pushing of the Adriatic plate northwards where the Eocene flysh of the Vipavska dolina underlies the Mesozoic rocks (mainly limestones and dolomites). The Visoki kras climate is transitional between the alpine and the continental on the northern side and sub-mediterranean on the south. The wettest region is the highest part of the Trnovski gozd massif with a long term average annual precipitation in excess of 3000 mm. Precipitation in the other parts of the massif exceed 2000 mm per annum and daily rainfalls in excess of 300 mm are common. The precipitation maximum occurs in autumn but all seasons are wet with snow in winter. The highest parts

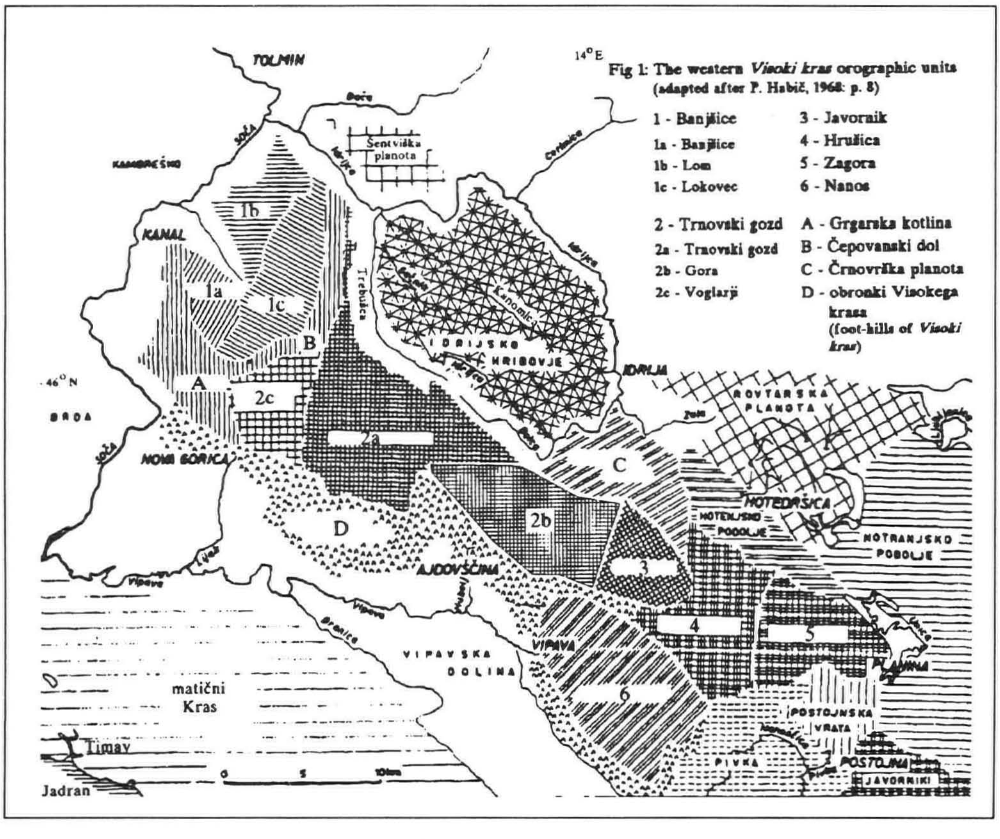


Figure 1. The western Visoki kras orographic units.
(adapted after P. Habic, 1968)

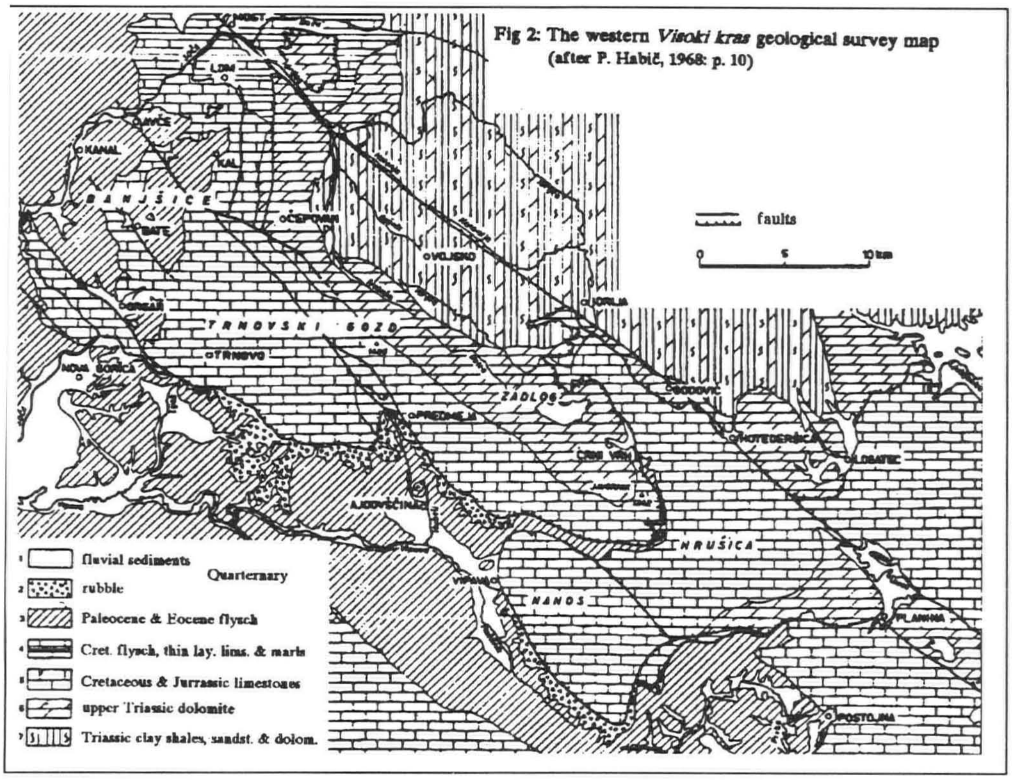


Fig 2: The western *Visoki kras* geological survey map (after P. Habič, 1968: p. 10)

Figure 2. The western Visoki kras geological survey map. (after P. Habic, 1968, p. 10)

were covered by glaciers in the Pleistocene but corrosion is the most important of the recent geomorphological processes. Many karst phenomena can be found in the area: karst poljes, dry valleys, glacio-karstic depressions, dolines, pothole dolines, karren, limestone pavements, caves and potholes, many of them with permanent snow and ice. Large karst springs emerge at the foot-hills (Fig. 3).

The area is covered with fir-beech forest (Abieti-fagetum dinaricum) and islands of spruce (Piceetum subalpinum dinaricum) and beech forests (Piceetum subalpinum dinaricum). Plant species include endemic (Primula carniolica and x venusta, Hladnikia pastinacifolia), alpine (Gentiana clusii, acaulis and lutea, Leontopodium alpinum, Viola pinnata, Primula zauricula), sub-mediterranean and mediterranean (Anthyllis jacquinii, Genista holopetala, Quercus ilex) which grow in separate but relatively close places. Several of these species are inscribed in the Red Data Lists (1989, 1992). There has been little research on the areas fauna although there are abundant wildlife. Species inscribed in Red Data Lists (1989, 1992) which are present include brown bear (Ursus arctos), wolf (Canis lupus), wild cat (Felis silvestris), Tetrao urogallus, about 10 species of bats and the golden eagle (Aquila chsryaetos). Underground such species as Proteus anguinus (protected), Leptodirus hochenwarti and Oryotus schmidti were found. One of the advantages to proclamation of a regional park is the sparse settlement of 30 villages and many solitary farms with a total population of only 7053 in 1991. The central part of the area is unpopulated (Fig. 4).

NATURAL HERITAGE

The area belongs to four communes: Ajdovscina, Idrija, Nova Gorica and Postojna. Natural heritage inventories were undertaken in Ajdovscina and Nova Gorica (Gorkic et al., 1985 and 1988; Rojsek, 1992), 184 units being inventoried. The units belong to all five groups of natural heritage (Rojsek, in press). Most units belong to the first group (some elements of relief or geological and geomorphological heritage) where bigger karst caverns dominate with 115 representatives. Designations of many units of the area are published (Rojsek, 1992). Five units: the nature reserves Paradana and Golaki with Smrekova draga, the high karst polje Vodice, the glacio-karstic depression Smrecje and Mount Kucelj (1237 m) with Avska gmajna (Fig. 3) are chosen to be shortly introduced.

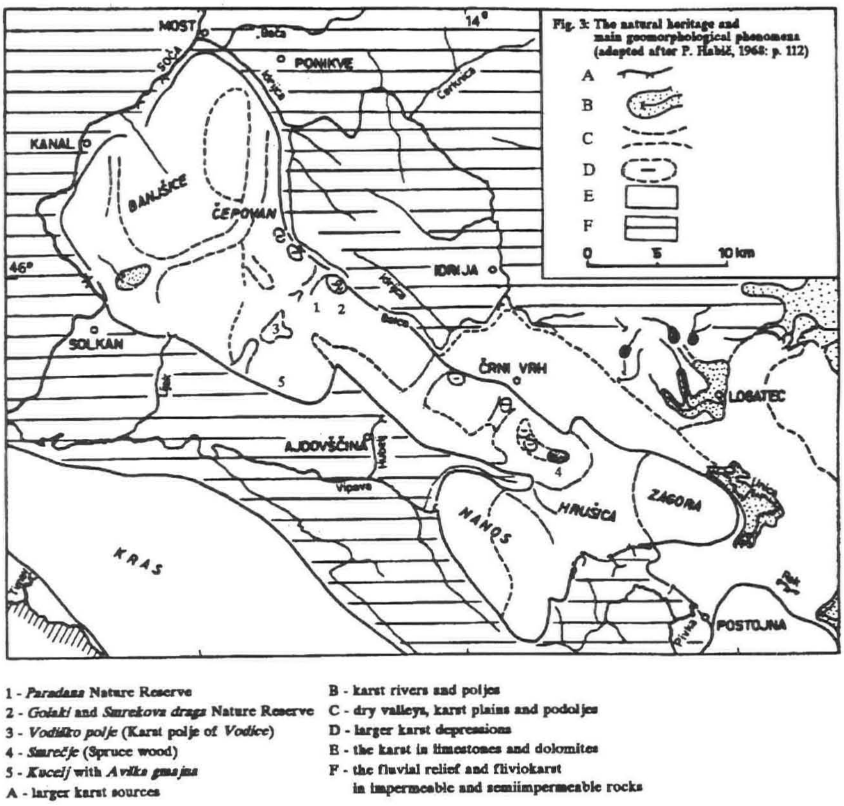
Paradana Nature Reserve

Not far from Lokve, the popular winter sports centre for Nova Gorica and Gorica - Gorizia lies Paradana Nature Reserve which covers an area of 18 ha. Its name derives from the area under Golaki (1495 m), the highest summit of Trnovski gozd. Within the nature reserve are botanical and forestry reserves and natural monuments: glaciokarst depressions and Velika and Mala Ledena jama (Big and Small Ice Cave). It has an extremely rich natural heritage which could be classified as rare even on a world scale. The most important point of interest in the reserve is the intermingling of superficial and underground karst with the remains of glacial activity and also temperature and vegetation inversions. At an altitude difference of a hundred meters the following belts occur (Beck, 1906): fir-beech (Abieti - Fagetum dinaricum), spruce (Piceetum subalpinum dinaricum), willow-tree (Salicetum appendiculatae), dwarf-trees and mountainous meadows, mosses, snow and permanent ice in the entrance to the cave system. Deeper inside the cave ice is no longer present as the temperature rises by 1°C/100 m. The Paradana cave system consists of three as yet unconnected caves: Velika Ledena jama (385 m deep, 1550 m long; total length of the potholes 650 m); Mala Ledena jama (40 m deep and 60 m long) and Jama pri Mali Ledeni jami (29 m deep and 125 m long). The variety of the different passages some covered by ice, others ice-free, shafts, ox-bow passages and sharply turning channels with strong draughts is very interesting. The ice table fluctuation is considerable; sometimes the passages into ice-free parts of the system are completely blocked. Once the ice was exported to Egypt, as the locals had produced some inventive technical devices which have unfortunately not been preserved. On the trees along the road and in the permanent ice remain parts of the old cable-way which was active in the 1950's when ice was still used for cooling fruit from the area which was intended for export. The people from Lokve are rightly proud of Velika Ledena jama as it is an important part of their cultural heritage.

Golaki and Smrekova draga Nature Reserve

The highest part of Trnovski gozd, named Golaki is a protected nature reserve (forestry and botanical). Within the nature reserve is the glaciokarst depression called Smrekova draga. Mali Golak (1495 m) is the highest peak of Trnovski gozd and one of rare Slovenian non-alpine summits reaching the secondary tree limit. The summit is covered by dwarf-pines

Figure 3. The natural heritage and main geomorphological phenomena.
(adapted after P. Habic, 1968, p. 112)



(Pinetum mugi) and high mountainous grass (Caricetum firmae). Golaki was glaciated during the Pleistocene and the results of glacial activity are well preserved. Smrekova draga is one of the biggest glaciokarst depressions in Trnovski gozd. It is of particular interest because of the temperature and vegetation inversions. In ground-plan the depression has an irregular oblong form and a 1500 m long axis oriented in a Dinaric direction. Smrekova draga is 140 m deep and its bottom (1110 m a.s.l) and slopes are covered by rubble and vegetation. The plant succession is similar to that in the Paradana Nature Reserve with the exception of two very remarkable spruce (Piceetum) and dwarf pine (Mugetum) belts. The majority of the vast bottom is covered by peat mosses and dwarf-pines (Sphaguetum pinetosum mugi).

Vodisko polje (Karst polje of Vodice)

The karst area of Vodice developed on flysch in the middle of various limestones. Springs and ponors are formed at the contact of permeable and impermeable rock. A small sinking stream flows over the sediments at the Polje's bottom, which is partly swampy and periodically flooded. Higher parts are cultivated - there are fields and meadows, and woods grow on the borders. Northeastwards the area opens into a broad valley separated by only a low pass. The karst polje of Vodice is one of the highest in Slovenia at 900 m a.s.l.

Smrecje (Spruce wood)

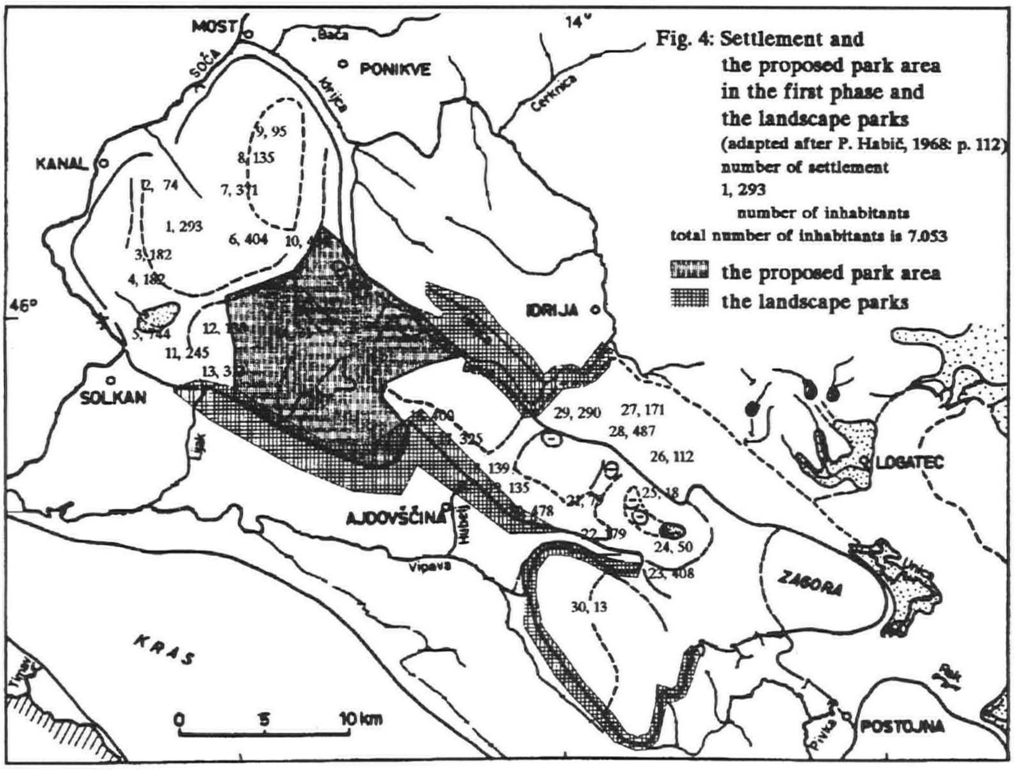
Smrecje is a large glaciokarst depression of an irregular shape, oriented northeast-southwest. It consists of three units: Mala and Avska lazna, and Smrecje itself. Due to natural karst processes the rim and the bottom of the depression are very dissected. The bottom is covered by sand deposits with dolines and intermediary hummocks. In Smrecje the temperature and vegetation inversions are well expressed. Beech-fir woodland (Abieti-fagetum dinaricum) changes into spruce wood (Luzulo albidae - Piceetum) according to the conditions. Among the rare plants are Listera cordata, Galium saxatile and Gentiana kochii. One unusual feature is that the acidophilous Gentiana kochii grows in this carbonate region. This is possible because of the acidulous soil on silica sand and clay deposits of Mala lazna. The only other site in Slovenia where Gentiana kochii is known to grow is on the magmatic rocks of Mount Smrekovec in the north.

Kucelj with Avska gmajna

Avska gmajna lies at the north foot of Mount Kucelj (1237 m). A variegated lithologic basis with unique geomorphological phenomena and a mixture of alpine and sub-mediterranean botanical species are peculiarities of the area. The mountain is pyramidal shaped and withdrawn on the horizon of the Vipava valley. Eocene flysch on the southern foot is followed by Quaternary rubble and Mesozoic rocks on the top. The Avska gmajna north foot spreads on karstified Jurassic limestones. Dolines and intermediary hummocks with karren dominate amongst karst phenomena. The abundance of botanical species is reflected by number of species and by great number of single species specimens. It is amazing to admire thousands of high mountainous plants such as Primula auricula, Gentiana clusii, Viola pinnata and Leontopodium alpinum, just quarter of an hour walk from the road. Representatives of sub-mediterranean (Anthyllis jacquinii, Genista holopetala) and endemic (Hladnikia pastinacifolia) species also grow in the area.

CONSERVATION OF THE AREA

The procedure to proclaim a national park in the Trnovski gozd massif started in 1955. The proposal was submitted in 1961, but it was rejected in 1962, because of pressure from the Ministry for Agriculture and Forestry, the Ministry for Common Economy, the Regional Department for Economy, the Establishment for Forest Economy and the Slovene Association of Hunters. Inventories of natural heritage in the communes of Nova Gorica and Ajdovscina began in 1983 and in 1985. Proposals to proclaim natural monuments and reserves and two landscape parks (southern foot-hills of Trnovski gozd with Gora and eastern, southern and western foot-hills of Nanos; Rojsek, 1992) were prepared. Three decrees were promulgated in 1984, 1985 and 1987. In the northern foot-hills of Trnovski gozd landscape park Zgornja Idrijca was proclaimed in 1993. However, the soft conservation regimes do not provide sufficient protection for the area and new procedures to proclaim the regional park Trnovski gozd started in March 1994.



1 - Banjšice	6 - Lokovec, Grudnica	11 - Ravnica	16 - Predmeja	21 - Malo polje	26 - Lome
2 - Kanalski vrh	7 - Kal nad Kanalom	12 - Voglarji	17 - Otlica	22 - Vitaje	27 - Predgriže
3 - Bate	8 - Kanalski Lom	13 - Trnovo	18 - Kovk	23 - Podkraj, Hrušica	28 - Črni vrh
4 - Grgarske Ravne, Dragovica	9 - Tolminski Lom	14 - Nemci	19 - Gozd	24 - Vodice	29 - Zadlog
5 - Grgar	10 - Čepovan, Puštale, Dol, Vrata	15 - Lokve	20 - Col	25 - Kanji dol	30 - Nanos

Figure 4. Settlement and the proposed park area in the first phase and the landscape parks.
(adapted after P. Habic, 1968, p. 112)

Key-points in proclamation of the park were:

- the value of the Visoki kras from the viewpoints of natural history (geology, physical geography, karstology, hydrogeography, hydrogeology, biology, forestry)
- the threats to nature and the natural heritage from uncontrolled visits by numerous motorised tourists (motocross, cross-country vehicles) and by harvesting of forest fruits
- the proclaimed landscape parks
- the roles of locals and publicity during and after designation

The first phase will be conservation of the 110 km^2 of state forest in the area where there will be no problems with private property owners. The area is very sparsely settled with only two settlements, Lokve and Nemci with 168 inhabitants. After this part has been shown to function successfully, the other parts of Visoki kras should be gradually proposed.

CONCLUSION

There are many reasons to protect the high karst in western Slovenia. The value of the Visoki kras from the viewpoints of natural history (geology, physical geography, karstology, hydrogeography, hydrogeology, biology and forestry) together with the threats to nature and the natural heritage from uncontrolled visits by numerous motorised tourists (motocross, cross-country vehicles) and by harvesting of forest fruits. The proclaimed landscape parks, the roles of locals and publicity in the procedure and after it and the proposal for a national park from 1961 have to be mentioned, too. First of all the regional plan of the area has to be replenished with the proposed regional park. Contemporary special basis for conservation of the Trnovski gozd should be prepared together with researching of "status zero" (ecological parameters, human impact on the karst geoecological system and similar).

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Conservation of limestone pavement

Simon WEBB
English Nature, Blackwell, Bowness-on-Windermere, Cumbria, England

Abstract: In 1990 when a limestone pavement project was established to protect British limestone pavements, the pavement resource had already been extensively damaged to meet the demand for decorative garden rockery stone. The background to protective Limestone Pavement Orders and the five year mapping project undertaken by English Nature and the Countryside Commission is described. Identification of vulnerable sites and the pattern of damage to limestone pavements has been an important part of the conservation process. The selection of pavements for the protective Orders, and the inclusion of other karst features within protected areas is explained. Local Planning Authorities have now been notified of 100 areas which are of special interest and worthy of Limestone Pavement Orders. The field survey and pavement mapping associated with this work provides a more accurate total of the extent of the British resource. The new total of 2600 ha includes wooded and coastal pavements which have been excluded from previous estimates. The success of the project is reviewed and future conservation initiatives identified. Publicity, education and interpretation, coupled with statutory protection, would seem the most appropriate way to secure the longer term future of this restricted landform.

INTRODUCTION

The limestone pavements of Britain are a scarce and non-renewable resource which has been extensively damaged and destroyed to meet the demand for decorative rockery stone.

The special interest of limestone pavements lies in their unusual plant assemblages, their geomorphological and geological features and their landscape attributes. Pavement grikes and other solution features support rare and scarce species such as rigid buckler-fern (*Dryopteris submontana*), downy currant (*Ribes spicatum*), baneberry (*Actaea spicata*) and dark-red helleborine (*Epipactis atrorubens*). Gilbert (1970) considers that 80% of the rigid buckler-fern population is confined to limestone pavement. The Yorkshire pavements are known to contain a significant proportion of the baneberry population. Limestone pavements are also of interest as glaciogenic landforms which are restricted to areas of hard, well-bedded limestone. Their morphology reflects both glacial scouring and post-glacial sub-aerial weathering. There is an onus on the conservation organisations to protect this habitat which, having a total area well below the 10,000 hectare threshold is regarded as nationally rare (NCC, 1989).

The importance of limestone pavements, their distribution and the extent of damage to them is described by Ward and Evans (1976) who conducted a comprehensive national survey of open pavements. Their survey calculated the extent of pavements and compiled damage estimations for the 537 pavements that were visited. Many of the pavements were found to be damaged by removal of clints, frequently for sale as decorative water worn rockery stone. The proportion of pavements at which no damage was detected was a mere 3% whilst the proportion considered to be 95% or more intact was only 13% (Plate 1).

The extent of the damage is of particular concern because of the non—renewable nature of the resource. Once damaged, limestone pavement will not reform. The main process responsible for its formation is glacial scouring, which is no longer occurring in the British Isles. Although the weathering processes which have created the grikes and runnels are still taking place, these features have formed over thousands of years.

Plate 1. Limestone pavement at Newbiggin Crags, Farleton Fell, Cumbria. One of the few undamaged pavements mapped by Ward and Evans (1976)

THE LIMESTONE PAVEMENT PROJECT

English Nature and the Countryside Commission have recently completed a five year partnership project to survey and evaluate all limestone pavement in England. The function and remit of these two bodies is described in Appendix 1. The aim of the survey was to identify pavements of special interest, by reason of their flora, fauna, geological or physiographical features. Local planning authorities (County Councils or National Park Authorities) were notified of this special interest and can make a Limestone Pavement Order, designating the land and prohibiting the removal or disturbance of limestone. The Orders are made under Section 34 of the Wildlife and Countryside Act 1981.

The first Limestone Pavement Orders (LPOs) were made in response to direct threat. The Nature Conservancy Council and Countryside Commission responded to ongoing site damage and notified areas such as Hampsfield Fell (South Cumbria), Beescroft and Foredale (Horton, Yorkshire), Blasterfield Farm (Eden District), and Farleton Knott (South Lakeland).

In contrast to the historical use of pavement for walling or gateposts, the new powerful JCB type excavators were damaging large areas of pavement (Plate 2). Pavement clints were being removed on a large scale for use as rockery stone. It became increasingly apparent that a more thorough and systematic approach was required to fulfil the duty imposed by Section 34 and notify all areas of special interest. The first priority was to survey and evaluate the pavements of the Yorkshire Dales National Park, especially those around quarry sites. Here extractors legitimately stripping pavement as overburden from areas prior to quarrying, did not always restrict their activities to areas with planning permission. The upland open nature of the Yorkshire Dales pavements meant that areas where pavement destruction was occurring could however be rapidly targeted for survey and Order making.

The second stage of the project examined the lowland wooded pavement on the fringes of Morecambe Bay specifically within the Arnside and Silverdale Area of Outstanding Natural Beauty. The survey revealed that large areas of the wooded pavement characteristic of this area had been lost. Removal of pavement had continued hidden within woods for many years. In an effort to avoid detection whilst working without planning permission, some extractors had even camouflaged their diggers. The project has subsequently given wooded pavement the highest priority when surveying Cumbria, because of the inherent vulnerability of wooded sites. The identification of the pattern of damage to limestone pavement has thus been an important part of the conservation process.

The results of the survey have been used to identify 100 areas of special interest which lie within the counties of Cumbria, Lancashire and North Yorkshire. These sites have all been notified to the planning authorities who are now completing the process of making Limestone Pavement Orders. The legislation itself offers no guidance about selection of pavements for notification, other than to require, that in the opinion of English Nature or the Countryside Commission, they are of special interest. Special interest is not further defined in the Act, but guidance is available from the records of Parliamentary debates when the legislation was drafted. The debates, recorded in Hansard (30 July 1981) state that all areas of limestone pavement were regarded as being of special interest and that all areas of pavement in the north of England should be included. English Nature considers that the national rarity of limestone pavement merits this approach.

Within limestone areas, karst features such as scars, screes and shakeholes are often of interest on landscape, botanical, geological or geomorphological grounds. Whilst it may be seen as desirable to protect them, it must be borne in mind that this is not the purpose of Section 34, unless such features form an integral part of a limestone pavement. This can often be the case where a scar forms the leading edge of a pavement, and there will be cases where inclusion of such features within the area of a notification is incidental and protection will ensue.

PROBLEMS WITH THE ORDERS

A number of problems have been encountered with the use of LPOs to protect this restricted habitat. The majority of the sites are in private ownership and landowners or occupiers have the right to object to the Order. There have been few objections considering the large number of Orders and the numerous owners and occupiers involved. Over 450 owners and occupiers have been contacted for access permission. Every effort is made to explain the implications of the Orders and identify potential problems at an early stage.

Problems with selection of the Order boundary appears to be a recurrent theme. It is important that boundaries, which are determined by a field visit, are clearly definable on the ground and are readily recognisable to owners and occupiers. To fulfil this requirement, permanent and prominent features are desirable. Suitable features include field boundaries, roads, tracks, or major landforms.

Plate 2. Removal of limestone pavement, Yorkshire Dales.

It is therefore usually the case that some non-pavement land is included within the notification area. This is avoided where possible, but the discontinuous nature of pavements, and the need to select suitable boundary features make this inevitable. An Order has no effect on non-pavement land which is generally pasture or wood.

The inclusion of non-pavement land was a feature of the 1982 Lake District Special Planning Board Hampsfield Fell LPO Public Inquiry, and was the main reason for the 1992 Cumbria County Council Bolton Heads Inquiry. In both cases the Inspector confirmed the need for a well defined and easily recognisable boundary. Both Orders were confirmed by the Secretary of State without modification.

OTHER RESULTS OF THE SURVEY

The Limestone pavement project and survey was established for the purposes of identifying pavements of special interest and notifying these to the planning authorities. The results of the survey however give us a valuable overview of English pavements, their character and condition.

The variation in character between the Morecambe Bay lowland wooded pavements and the upland open or treeless pavements of the higher Pennines has been a distinctive feature illustrated by the survey. Pavements vary in altitude between 2-3 m above OD at Humphrey Head and Jenny Browns' Point (Morecambe Bay), 580 m at High Cup Plain on the North Pennine ridge and 683 m on Simon Fell, Ingleborough. Over three quarters of our pavement is open or treeless with vegetation confined largely to the grikes. The five large sites of Ingleborough, Scales Moor, Malham-Arncliffe, Asby Complex and Hutton Roof dominate in area.

Ward and Evans (1976) did not examine wooded pavements in their survey although they did look at clearings within wooded pavements around Morecambe Bay. Considerable survey work has therefore been required to locate and map wooded pavements and to assess their special interest. This survey work has revealed the full extent of wooded pavement and identified a smaller number of open sites. Over 180 new sites have been examined, the majority being in the Grange-over-Sands and Arnside-Silverdale areas around Morecambe Bay. Over 400 ha of new wooded pavement has been mapped. New open areas were also located and surveyed, the largest of these being in Eden District, Cumbria. These areas were not extensive and cover some 25 ha.

The comprehensive survey allows English Nature to update the figure given for the total extent of the British resource. The accepted figure for the extent of British pavement has been the 2150 ha identified by Ward and Evans. The new total for the extent of British pavement is therefore just under 2600 ha. This total may require some upward adjustment for a small amount of wooded pavement on the Scottish Durness Limestone.

Coastal pavements have also been examined and assessed in the Cumbria and Lancashire phase of the project. Glacial planation obviously occurred when sea levels were significantly lower than today. Although solution features are occasionally under developed the coastal pavements are still of significant interest. In some cases these pavements have been buried by coastal accretion, elsewhere they are being exhumed.

The new areas surveyed were in a similar condition to the Ward and Evans sites and we have no evidence to suggest that the damage figures put forward in 1976 should be modified.

HAS THE PROJECT BEEN A SUCCESS?

The Limestone Pavement Project in the north of England appears to have successfully halted the rate of pavement loss. It however seems unlikely that this alone will protect the pavements in the longer term.

It is clear that a demand for so called water worn limestone still remains and that damage is only occurring because of this demand. Operators are encouraged to exercise long standing planning permissions to extract pavement and a small number of people to risk prosecution and remove stone from sites protected by Orders.

No prosecutions have yet arisen from damage to sites protected by Orders. It has proved difficult to catch anybody in the act of removing pavement, and monitoring remains a thorny issue. In the only court case arising so far the offender was prosecuted under the Theft Acts (rather than the Wildlife and Countryside Act) and fined £100.

Sites with planning permission to remove surface stone are restricted to two sites in northern England which are currently active (Orton Scar, Cumbria and Winskill Stones, Yorkshire). There are however seven aggregate quarries where limestone pavement is removed as overburden and sold as rockery stone. These nine sites are certainly actively supplying large quantities of limestone pavement to the garden centres and landscape companies. The LPO protection is of little use on sites with active planning permission where there is a reasonable excuse to disturb or remove stone. Expensive revocation of planning permissions or a change in legislation would be the only options to solve the problem directly.

Although there has been a marked reduction in the amount of pavement damaged since the Order making process began, it is clear that damage to sites without planning permission (often termed illegal damage) continues. Since 1990 there has been proven damage to 13 pavement sites and reported damage to 8 other sites.

It therefore seems evident that reducing the demand for limestone pavement, through targeted publicity and education, will play an important part in the conservation process. A recently formed limestone pavement action group will coordinate publicity and education efforts and encourage local authorities and Government to revoke existing planning permissions. The groups message is that gardeners and landscapers should use alternative materials for rockeries thus preventing continued loss of these strikingly beautiful and irreplaceable landforms.

A national publicity and education campaign can address problems that local site-based protection can not. The tightening British site-based control on pavement removal in Lancashire has already forced one extractor to move to Ireland and import pavement clints by lorry.

International pavement conservation will inevitably be influenced by the 1992 European Community Council Directive (92/43) on the conservation of natural habitats and wild flora and fauna. This EC habitats and species directive identifies limestone pavement as a priority habitat. It places a duty on member states to prevent deterioration of habitats of Community importance within designated Special Areas of Conservation or SACs. The SACs will form part of a network of European sites called Natura 2000.

The list of SACs has not yet been published by the Department of the Environment but will undoubtedly contain a selection of our most important limestone pavement sites. Whilst this will strengthen the protection of the best pavements it may divert attention away from other sites which are not of European importance but are valuable and interesting and worthy of protection.

Concern has been expressed that limestone pavement SACs will be selected on the basis of their botanical interest rather than their geological or geomorphological features. An examination of the Ward and Evans (1976) botanical assessment of British pavement suggests that this concern may be unfounded, the majority of the best botanical pavements are also of geological interest.

CONCLUSIONS

Limestone pavements have already been extensively damaged in the north of England to meet the demand for decorative rockery stone. Recent efforts by English Nature, local planning authorities and the Countryside Commission in selecting pavements of special interest and making Limestone Pavement Orders has successfully reduced the scale of the damage. The survey has also accurately measured the extent of the resource. Longer term conservation of pavements can only be secured by reducing the demand for waterworn stone. The limestone pavement action group will attempt to achieve this through targeted education and publicity.

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APPENDIX 1

English Nature is the Government agency, established by the Environmental Protection Act 1990, responsible for nature conservation in England. It is financed by the Department of the Environment but is free to express independent views based on the best scientific evidence available.

The functions of the Nature Conservancy Council for England (English Nature) were laid down in Sections 132 to 134 of the 1990 Act which incorporates those functions previously discharged by the Nature Conservancy Council. It plays a central role in advising Government and others on the development and implementation of policies for or affecting nature conservation in England. It also responsible for:

1. The promotion, directly and through others, of the conservation of England's wildlife and natural features
2. The selection, establishment and management of National Nature Reserves
3. The designation and protection of Sites of Special Scientific Interest
4. The widespread provision of advice and support for education on nature conservation.

It supports these functions by a substantial programme of research and also has powers to make grants to others carrying out these related tasks.

The Countryside Commission was established in 1968 to succeed the National Parks Commission and became an independent body in 1982 The Commission acts as the Governments advisor on landscape and countryside issues.

The Countryside Commission has statutory responsibility for designating national parks and areas of outstanding natural beauty, defining heritage coasts and establishing national trails for walkers and riders. Its wider remit includes:-

1. Piloting new approaches to the care of the countryside such as countryside stewardship, community forests and the new national forest.
2. Undertaking research and providing technical advise on conservation, recreation and landscape change.
3. Giving grants to promote countryside conservation and recreation and also access projects.

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Field Tests of Limestone Dissolution Rates in Karstic Mt. Kräuterin, Austria

Dachang ZHANG[1], Hans FISCHER[1], Berthold BAUER[1], Rudolf PAVUZA[2] and Karl MAIS[2]
[1] Institute of Geography, University of Vienna, Universitätsstraße 7, A-1010, Austria
[2] Institute of Karst and Caves, Museum of Natural History, A-1010 Vienna, Austria

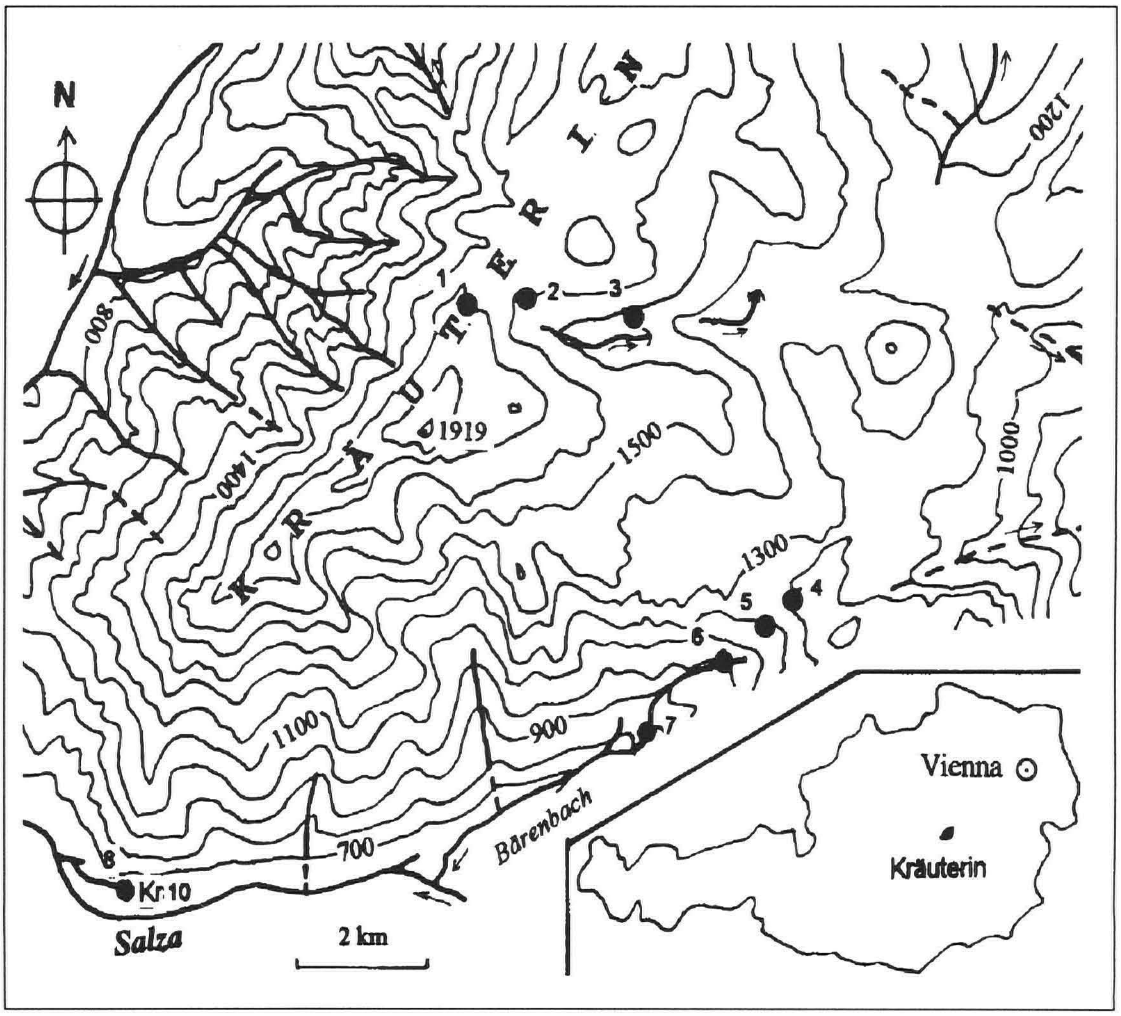
Abstract: The altitudinal zonation of limestone dissolution rates on Mt. Kräuterin, Austria was evaluated over an 18 month period using rock-tablets. The dissolution rates of the tablets ranged from 2.68-21.56 mg $.10^{-3}/cm^2/day$ in soils of grassy slopes, 7.83-36.36 mg $.10^{-3}/cm^2/day$ in soils under trees, and 5.8-13.2 mg $.10^{-3}/cm^2/day$ on bare surfaces, increasing with altitude and reaching the highest rates at the 1200 to 1300 m altitude zone, which had higher rainfall in summer. The dissolution rate of the tablet in spring water was only 5 mg $.10^{-3}/cm^2/day$. The uneven-textured tablets had higher dissolution rates than the even-textured tablets. Meteoric precipitation, atmospheric temperature and CO_2 content in soil air are important control factors, but precipitation and temperature may have stronger action on the dissolution rates in this test environment. The purpose of dissolution testing is to model quantitatively the correlation of limestone dissolution rates to environmental indices, to show whether a given aquifer is inert or active in karstification, and to estimate the intensity of karstification.

INTRODUCTION

Dissolution is the main process of karstification. Karst scientists have paid attention to the dissolution rate in different natural environments for a long time. Organised by the Commission on karst Denudation of ISU, such a joint research using tablets systematically has been done at about 60 stations in the world from 1978 to 1983 (Gams, 1985), but little attention was given to systematical measurements of altitude zoning of dissolution rates, although, such a test may give much direct information for quantitative factor-analyses. This paper describes two tests on Mt. Kräuterin in the Northern Steinmarkte, Austria from 1992 to 1993, applying the same method of using tablets.

Mt. Kräuterin, lying on the central of the East Austrian Alps (Fig. 1), consists of the Hauptdolomite and Dachsteinkalk limestone of Upper Triassic age. The Dachsteinkalk limestone, covering the upper part of the mountain, is partly thick-bedded, partly homogeneous reef-limestone. Mt. Kräuterin descends from 1919 m at its summit down to 625 m at its southern foot. The climate has chilly, heavy snowy winters and rainy summers. The temperature is about -5°C in winter and 15°C in summer. The mean precipitation is about 1400 mm. On Mt. Kräuterin the soil cover is only 8 cm to 15 cm thick. Pine trees grow up to 1500 m elevation. Mt. Kräuterin is intensively karstified, typical landforms being dolines, karren and caves. The largest cave system extends from 1665 m elevation down to 930 m level, with 8500 m of surveyed passage.

Figure 1. Location of the dissolution test points in Mt. Kräuterin, Austria.



%	Mt. Krauterin (1)	Hetzaukogel (2)	Schwarzenberg (3)	Rettenbachtal Mt. Dachstein (3)	Spital (3)
CO2	43.79	43.05			
CaO	55.91	54.7-55.0	55.79	55.05	53.73
MgO	0.35	0.13-0.32	0.27	0.40	0.83

Table 1. Geochemical comparison of Dachstein Limestones.

(1) Rock samples for tests
(2) after R. Pavuza (1982)
(3) after G. Poscher (1993)

FIELD TESTS

Rock samples

The rock samples were made of Dachstein limestone, which is widely distributed in the Alps. Table 1 shows that the rock samples are similar chemical compositions to those from other areas. Therefore, it is assumed that the samples used in the tests are representative. The first test was done from July 7, 1992 to May 19, 1993, and the second test from July 30 to October 27, 1993 at the same points. Compared with those for the first test, the rock samples used in the second test are uneven-textured. All samples were prepared as small unpolished tablets with size about 4 x 4 x 0.7 cm.

Sample setting

The tests mainly measured the dissolution rates in soils on grassy slopes, but paired tests were undertaken on forested slopes. The dissolution rates of bare limestone were also tested. The 11 test points were at 650 m, 835 m, 1000 m, 1200 m, 1300 m, 1436 m, 1600 m, and 1735 m (Fig. 1). At each point one tablet was vertically buried at 8 cm depth in the soil (-8 cm), almost on the bedrock surface, and the other one was placed horizontally on a rocky surface (0 cm). The soils at all the test points were similar, dark brown with little moisture, but the soil at Point 5 was relatively dry. In addition, one tablet was hung in the water of Spring KR10 which appears at the south foot of the Mt. Kräuterin and is characterised by stable conductivity.

Test Results

The dissolution rates were calculated by the function:

$$R = (W_2 - W_1) \times 10 / A / t \qquad (1)$$

where, R is the dissolution rate (mg .10^{-3}/ cm^2/day); (W_2-W_1) is the loss of weight of the tablet in the test period t; and A is the area of tablet surface.

Some results are unusable due to manipulation error. The result from the first test in spring water was not usable because of deposition on its surface. All usable results of the measurements are shown in Table 2.

The trends in the test results were as follows:

- The dissolution rates of the tablets in soils of grassy slopes (2.68-21.56 mg .10^{-3}/ cm^2/day) were lower than in soils under trees (7.83-36.36 mg .10^{-3}/ cm^2/day), while the rates on bare surfaces were lower still (5.8-13.2 mg .10^{-3}/ cm^2/day).
- The dissolution rates increase with altitude rising until about 1200-1300 m where the dissolution reaches its highest rate.
- The measured dissolution rate of the tablet in spring water was very low.
- The dissolution rates are lower in relatively dry soils.
- The uneven-textured tablets had higher dissolution rates than the even-textured tablets.

DISCUSSION AND CONCLUSION

The observed trends are considered to be reasonable as they occur from all the test results. Of particular interesting are the following:

Vertical difference of meteoric precipitation

On Mt. Kräuterin precipitation is the major source of water acting on the tablets. On the basis of measurements from 1992 to 1993, rainfall in summer is statistically higher in the middle altitude zone (1000-1300 m above sea level). There is a similar vertical differences of dissolution rates in summer.

Although it is difficult to measure the distribution of snow falling on the mountain in winter season, it is clear that snow covers the higher part of the mountain earlier and thicker than the lower part and vanishes later from the higher part than from the lower part. In other words, limestone outcropping on the higher part is under the action of snow water for longer time.

Rain water acts on the bare tablets for only a very short time, but moisture of fog or clouds can surround them for much longer. Thus, we might consider the action of moisture of fog or clouds. In the study mountains, the lower part, especially the middle zone, is foggy more often than the higher part.

By measuring the dissolution rates in summer and winter, it is possible to get the seasonal difference of dissolution rates:

$$Rw = R - Rs \quad \text{or} \quad Rs = R - Rw \qquad (2)$$

$$\Delta R = Rs - Rw \qquad (3)$$

Where, R is the general dissolution rate through the whole hydrological year, Rs is the dissolution rate in summer and Rw is the dissolution rate in winter.

Delannoy (1982) has measured the loss of tablet weight on mountains (1460 and 1510 m above sea level) in winter-spring and summer seasons separately. His measurement shows higher dissolution rates in the winter-spring season. Unfortunately, this paper cannot give the seasonal difference of dissolution rates in the research area, because the two tests used different rocks as samples.

Table 2. Dissolution rates (mg.10^{-3}/ cm^2/day) of Tablets in Mt. Kräuterin.

	Dissolution Rates in Soil						Solution rates on Surface	
Altitude (m)	**Trees Environments**			**Open places**			**Trees**	**Open places**
	R-I	**R-II**		**R-I**	**R-II**		**R-I**	**R-II**
1735				7.42			5.85	
1600		15.93	30.21		10.41	19.70		
1436				4.48	16.63	20.77	2.69	
1300	19.86	30.75	31.61	2.96	13.18	21.56	8.11	13.18
1200		7.83	10.75	6.70	15.19	17.45	12.05	
1000		26.06	36.36	5.97			10.15	
835				5.32		11.94	9.04	
650		8.92			2.68	5.63		11.78
Spring KR10		5.05						

1. Test time: I - July 7, 1992 to May 19, 1993, 316 days; II - July 30 to October 27, 1993, 89 days.
2. Precipitation: I - 1245.5 mm/316 days or 3.94 mm/day; II - 388.1 mm/89 days, or 4.36 mm/day.

From 1993 to 1994 we obtained two other test results from the Dachstein Plateau (west of the study area) and Lowlands (east of the study area). Plotting them with the mean rate from the study area (Figure 2) we get a rough correlation between dissolution rate (R in mg.10^{-3}/cm^2/day) on bare surfaces and effective precipitation ($P^* = P - E$) as the following, if it is expressed by a linear equation:

$$R = -2.677 + 0.01568 P^* \qquad (4)$$

where P is precipitation and E is potential evaporation loss, both in mm.

Vertical difference of temperature

On the surface, dissolution is the result of dissolved CO_2:

$$CO_2 + CaCO_3 + H_2O = Ca^{+2} + 2HCO^-_3 \qquad (5)$$

The dissolution capacity of water is positively related to the content of dissolved CO_2. Temperature controls the dissolution rate by controlling the content of dissolved CO_2 in water. A low temperature environment is helpful for dissolving more CO_2 in water. Warming water temperature makes dissolved CO_2 escape, reducing the dissolution capacity. On the basis of data (1901-1970) from 26 meteorological observatories (1973) in the central part of the Austrian Alps, a statistical correlation between the temperature (T_{atm})and altitude (H) is:

$$T_{atm} = 10.178 - 0.005155 H, \quad r^2 = 0.8742 \qquad (6)$$

Therefore, a general function can describe the correlation between the dissolution rate of limestone and altitude through the variation of temperature:

$$R_T = f[\varphi(T)] = f\{\varphi[\psi(H)]\} \qquad (7)$$

The combined effects of temperature and precipitation intensify the trend of dissolution increasing with altitude in a certain range.

Vertical differences of CO_2 in Soil Air

Due to biological action, the CO_2 content in soil air increases greatly, which may result in higher dissolution capacity of water. The CO_2 contents in soil air on Mt. Kräuterin were measured (Table 3) and found to be higher under trees than on grassy slopes and to increase with the reducing of altitude. However, the trend of dissolution rate with altitude was contrary to that of CO_2 contents in soil air.

Altitude (m)	**under trees**	**grassy slope**
1600		0.310*
1436	0.340*	0.220*
1300	0.180*-0.208+	0.120*
1200		0.140*
1000	0.229+	0.176+-0.190*
820		0.180+-0.200*
630		0.198+

Table 3. Vertical Difference of pCO_2 Contents (%) in Soil Air on Mt. Kräuterin
*+measured on Aug. 20, 1993; * measured on Aug. 19, 1994.*

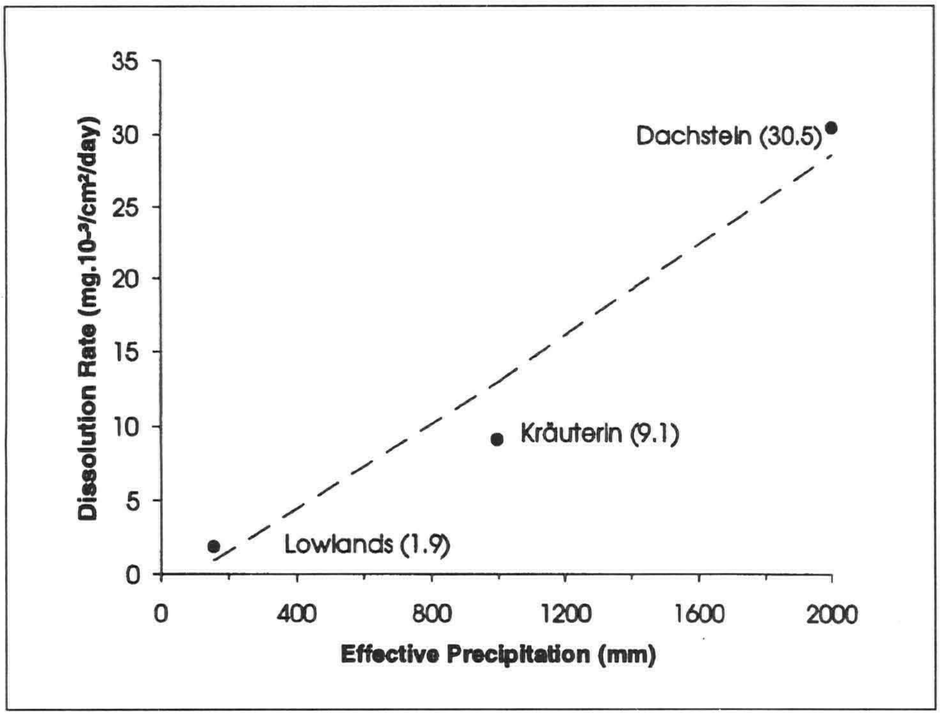


Figure 2. A rough correlation between dissolution rate on bare limestone surface and effective precipitation.

Weighting the controlling factor

The question which arises from the reverse variation trends of dissolution rate and CO_2 content in soil air in the altitude range from 650 m to 1300 m is which factor has stronger control power on dissolution of limestone. It is a well known question. The results of these tests seem to suggest that the combined action of precipitation and temperature might be stronger than biological action in the study environments. Further such a dissolution testing can be used to model quantitatively the correlation of limestone dissolution rates to environmental indices.

Determining the dissolution rate underground

The rate of limestone removal by runoff (R) is calculated by hydrochemical analysis of surface water and groundwater. This rate R is the sum of the rates on surface (Rs) and underground (Ru), including the initial content of dissolved calcite in meteoric water (Rm), or:

$$R = Rs + Ru + Rm$$

In Equation 4, the effective precipitation was regard as runoff against bare rocks. Thus, the remainders are the distribution of the sum of Ru and Rm. Applying this method to the study area, we are able to estimate the intensity of modern karstification underground. When we use the results from such a test, we must be very careful. The dissolved volume during our test is usually so small that any piece which breaks away from the rock sample can disturb the test result. For this reason, we are currently undertaking the test again, and measuring dolostone dissolution rates.

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Lakes as a speleogenetic agent in the karst of Lagoa Santa, Brazil

Augusto AULER
R. Visc Rio Velhas, 86 apt.202, Belo Horizonte - MG 30380-740, Brazil

Abstract: Study of a sample of 122 caves in the karst area of Lagoa Santa, Minas Gerais state, Brazil, showed that 50.8% were formed or modified by the slowly moving phreatic water of surface lakes. Three main types of lake were recognised. Sinkhole lakes and water table lakes have a speleogenetic role, while phyllite lakes represent perched water isolated from the limestone aquifer. Network and rectilinear caves were formed by undersaturated water that accumulates in the lakes, mostly during the wet season. The best developed caves occur in the recharge zone. The positions of ancient lake basins are indicated by today's dry relict maze caves.

INTRODUCTION

Many caves in the karst region of Lagoa Santa show features diagnostic of genesis by slow moving water dissolution. The development of these caves is associated with lakes that occur at the base of limestone cliffs. A statistical analysis of a sample of 122 caves showed that 50.8% were generated or modified by standing water.

The Lagoa Santa karst region is located in Central Brazil, in Minas Gerais state (Fig. 1). The karst is developed in a thin layer of very pure limestone, of Proterozoic age, within the Bambuí Group. The carbonate, which shows a horizontal bedding lamination, was laid down upon crystalline rocks. The most prominent joint sets are N75°-85°E and N-S (Beato et al, 1992).

Caving clubs have been active in this area for fifteen years, but little speleological work has been carried out. Piló (1986), analysing a sample of 53 caves, made a statistical study of cave distribution according to topographical location and hydrological context. The karst geomorphology has been described by Tricart (1956), Coutard et al (1978) and Kohler (1989). The Brazilian Speleological Society lists more than 300 caves in the area, mostly of small size and usually with no active drainage. This paper presents an analysis of lakes and cave morphology that supports the hypothesis that network and rectilinear caves are formed by the speleogenetic action of lake waters.

LAKE DESCRIPTIONS

The karst region of Lagoa Santa drains north-eastwards towards the Velhas River. The elevation and occurrence of karst landforms decrease in that direction, as the water table approaches the underlying crystalline rocks. Lakes occur in most hypsometric domains.

Three distinct types of lake can be recognised. The first type comprises water table lakes, corresponding to a free low gradient aquifer. These lakes are located at lower elevations, near the regional base level represented by the Velhas River. Good examples are Cerca de Achas and Maria Angélica lakes (Plate 1). Sediment typically covers the lake bottoms. The volumes of these lakes varies according to the rainfall. They are shallow (up to 10 m) and bordered by gentle limestone hills. During wet periods the lakes tend to rise, and neighbouring lakes may coalesce. These water table lakes show a gentle gradient towards the Velhas River.

The second type of lake is typical of the more intensely karstified portions of the area. They occur at the bottom of asymmetrical dolines, usually limited on one side by a vertical limestone cliff (Plate 2). The lakes are created by the obstruction of the sinkpoint of the doline by breakdown and impermeable sediment. Lake bottoms are usually floored by clay. The lakes, which occur at relatively high elevations, are fed by either surface runoff or underground streams. Lake levels vary greatly, but sometimes the levels do not follow the rainfall pattern closely. The main factor controlling the water levels appears to be the amount of sediment choking the sinkpoint, and the surface extent of the lakes may be from a few metres to 2 km, as at Sumidouro Lake.

A third type of lake is restricted to non-carbonate outcrops in the area. They occur over phyllitic rocks and are not connected directly with the limestone aquifer. These lakes have no speleogenetic importance and will not be considered further in this paper.

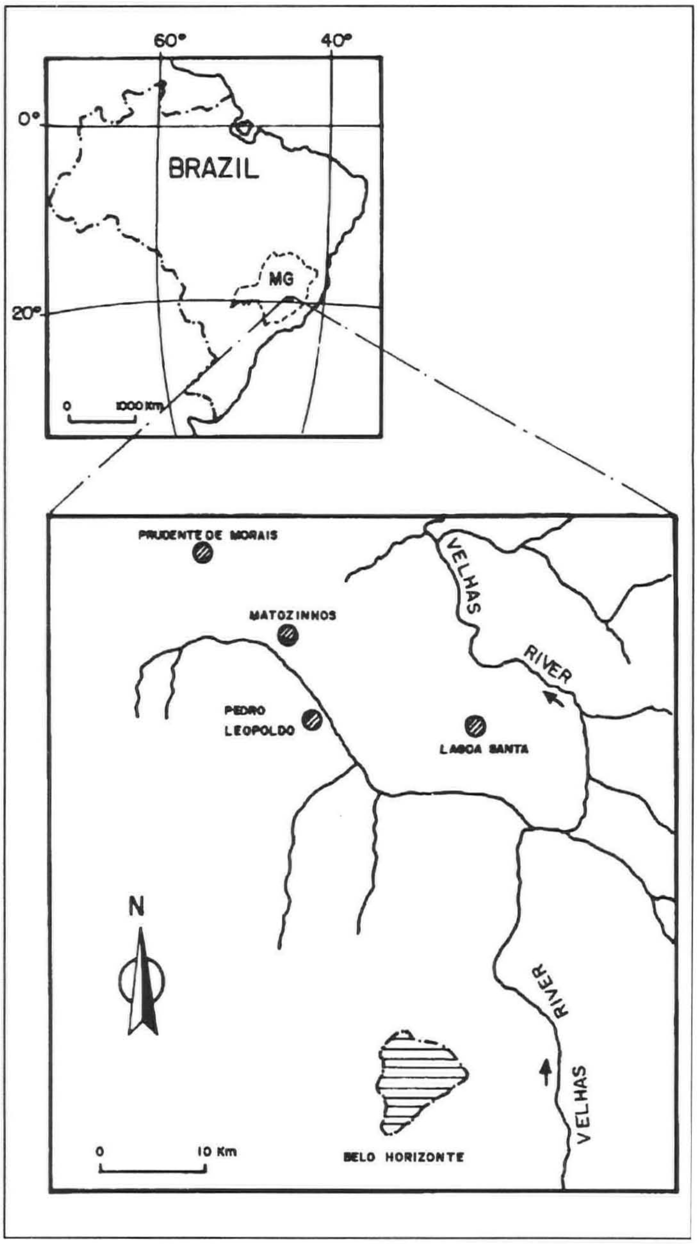

Figure 1. Location of the study area.

Type	Lithology	Aquifer	Area	Gradient	Flow	Speleogenesis	Examples
Water table	Limestone	Free	Discharge	Low	Laminar	Yes	Cerca de Achas
Sinkhole	Limestone	Free	Recharge	High/Low	Sinkpoint	Yes	Lapa Vermelha
Phyllitic	Phyllite	Perched	Recharge	-	Static	No	Lagoa Santa

Table 1. Characteristics of lake types.

Table 1 summarizes the basic characteristics of the lakes in the Lagoa Santa karst.

CAVE DESCRIPTIONS

Network Caves are common in the Lagoa Santa area. They can be large maze caves such as the 1.8 km long Lapa Vermelha I, or single rectilinear conduits. They are usually located in the sides of sinkholes. Lapa Vermelha VI is a good example of this kind of cave (Fig. 2). Phreatic forms such as wall pockets (Bretz, 1942) are widespread. Large scale scallops show no preferential flow direction. These caves typically have large size passages. Table 2 shows speleometric data about the largest network caves in the area.

Cave	Length (m)	Density m (passage)/sq.m (cave area)
Lapa Vermelha I (maze section)	1119	0.2521
Cacimbas	626	0.5400
Morro Redondo (upper section)	504	0.1689
Escrivania II	424	0.1439
Total	2673	0.2319

Table 2 Speleometric data on some selected maze caves in the area.

Single conduit caves occur at the base of limestone cliffs (Plate 3). These caves follow single joints, and in some cases are connected to each other. Some of the caves are little more than well developed dissolution pockets, with irregular ceilings. The Escrivania complex (Fig. 3) is a typical example.

Dissolutional tubes commonly occur at distinct horizontal levels along limestone cliffs, such as in the Cerca Grande Cliff. Known locally as "windows", they can be either small phreatic tubes or hundred metre long maze passages. They resemble the corrosion bevels of Ford and Williams (1989) or cliff foot caves (Jennings, 1976).

Another variety of cave associated with slow moving water is found at lower elevations, usually located in small residual limestone hills. Typically they have parallel or sub-parallel conduits connected by incidental side passages or simply by lateral enlargement. The galleries rarely exceed 100 m in length, most commonly leading to another entrance at the opposite side of the hill. The passage dimensions vary greatly, from small tubes (a few centimetres in diameter) to large compound galleries several metres wide. Cross sections are characteristically rounded or elliptical.

DISCUSSION

The speleogenetic action of flood water has been considered by Palmer (1975, 1991). Many researchers agree that, in tropical areas, aggressive static water can generate cliff foot caves (Sweeting, 1973; McDonald, 1976; Waltham, 1981). Some lakes in the Lagoa Santa karst are static swamp areas, largely unaffected by seasonal rain, while those with continuous recharge are affected by occasional flood events.

Plate 1. Cerca de Achas Lake: a low altitude water table lake.

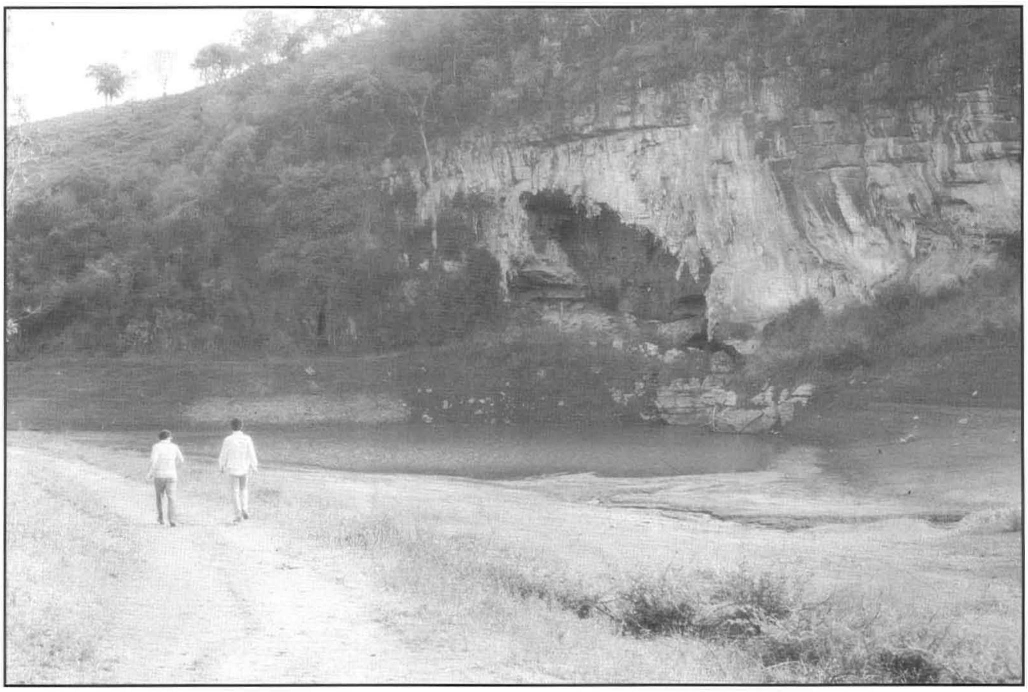

Plate 2. Sinkhole lake at the entrance to Lapa Vermelha I Cave.

Ford and Williams (1989) and Palmer (1991) point out that during floods the hydraulic gradient in constricted sections of sinking streams increases, causing rapid dissolution within fractures. The result is a network cave. However, due to the small catchment area and the autochthonous nature of the water in the Lagoa Santa karst, the flood

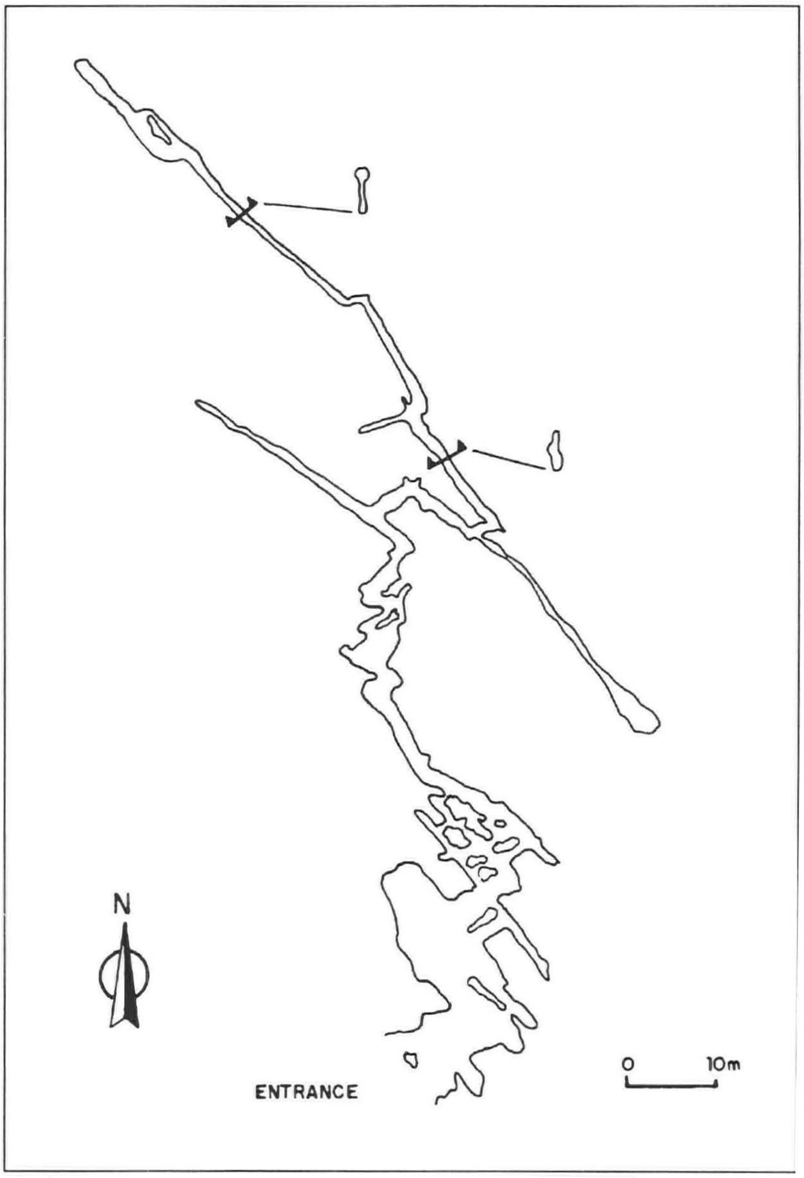

Figure 2. Map of Lapa Vermelha VI Cave. Survey by Grupo Bambuí de Pesquisas Espeleológicas.

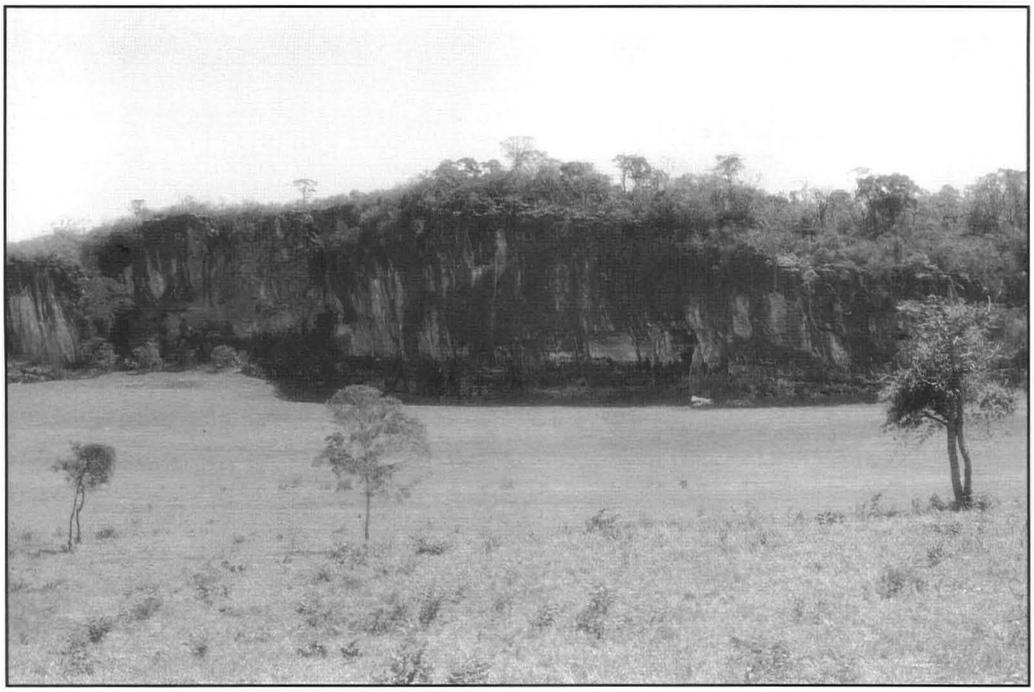

Plate 3. Escrivania cliff during the dry season.

events are not of high magnitude. Most of the network caves in the area are low gradient ones.

Kempe et al (1975) state that static water caves are formed within the upper metres of the water body. Dissolutional retreat of the cliff is initiated and enhanced by enlargement of the most favourable joints. Network and rectilinear caves in the Lagoa Santa region are stages of the same evolutionary process. Initially, small single conduit caves are formed as water acts in the front of the cliff. The joints perpendicular to the cliff will be enlarged during this first phase. Lateral dissolution will then take place in the conduits, creating a reticulate pattern that can eventually evolve into a network cave.

A well marked horizontal dissolution zone will be produced by long-term standing lake levels (Ford and Williams, 1989). The result will be horizontal levels of "windows" or corrosion notches. McDonald (1976) and Jennings (1976) suggest that these caves may have formed under a cover of CO_2-rich alluvial soil. In the Lagoa Santa karst, however, they are related to the water lines of standing lakes (front cover photo).

Analysis of scallops shows that network or parallel caves were formed by slow moving water. The assemblage of speleogens, such as wall pockets, and the irregular profile of the ceiling are related to speleogenesis under phreatic conditions. Dissolution occurs preferentially during the wet season, when undersaturated water reaches the lake (Plate 4).

Fig. 4 shows a plot of cave length against distance to the base level. The data show that the longest caves in the area lie in the recharge zone, close to the upper limits of catchments. Unsaturated water will drain towards the lakes.

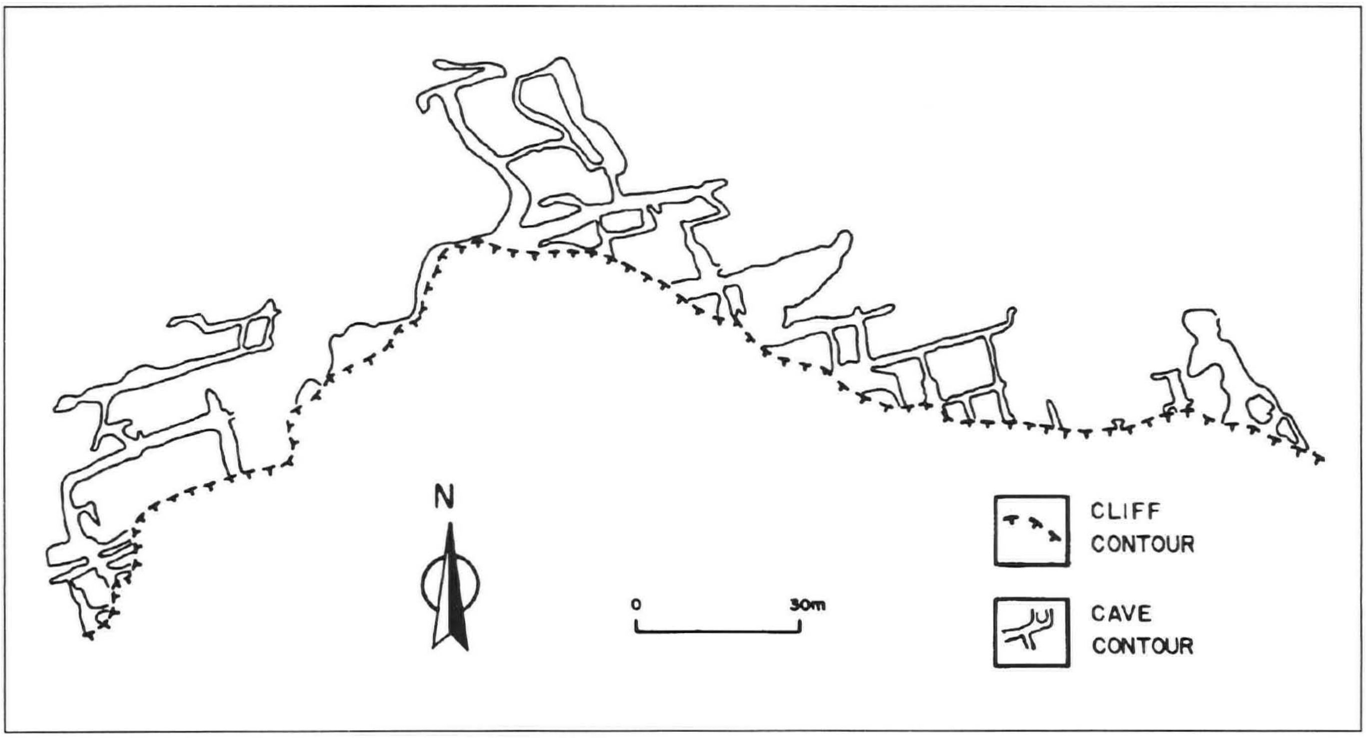

Figure 3. Map of Escrivania Complex. Survey by Grupo Bambuí de Pesquisas Espeleológicas.

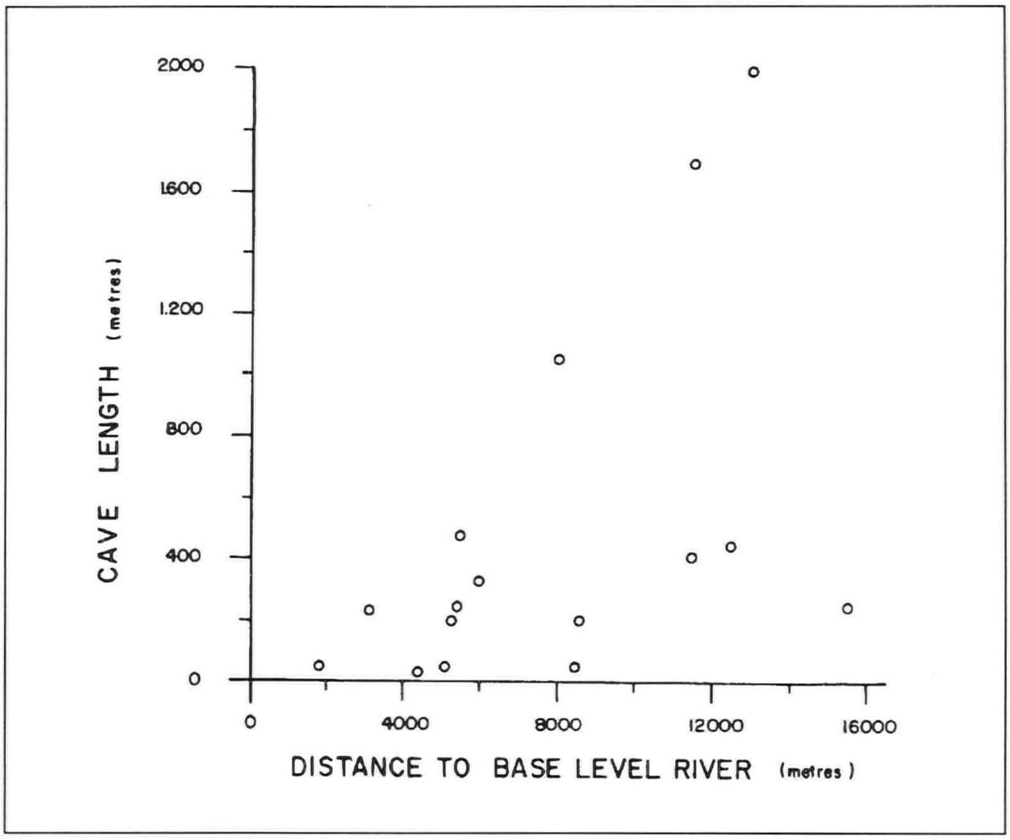

Figure 4. Graph showing a weak positive relationship between the distance from the base level (Velhas River) and cave length. Other variables such as lake basin duration and degree of sediment infilling will also influence cave length. The longest caves are found near the top of the recharge zone. The 16 sampled caves all lie in the same area and the distance from the top of the recharge zone to base level is approximately the same in each case. The distance was measured as a straight line according to the regional hydraulic gradient.

Most of the sinkhole lakes have irregular hydrological regimes. Recent observation has shown that some exist throughout the year, drying out only on rare occasions. Some last as long as a decade. Many variables appear to account for the regime of the lakes, the most obvious being the amount of clastic material available to plug the sinkpoint.

Perennial lakes are responsible for the more developed network patterns, such as the one in Lapa Vermelha I, whereas lakes that fill sporadically generate a group of single conduits, as in the Escrivania complex. The larger dry network caves represent former major lake basins. The Lapa Vermelha sinkhole illustrates this process well. Some well developed network caves occur at different levels in this doline (Fig. 5), suggesting a north-westward migration of the lake basin and therefore a changing relative lake level. Between the cave levels no substantial speleogenesis took place. Lapa Vermelha I, a maze invasion cave that drains a small lake, is the present site of speleogenesis. The longer caves are found at the base of the higher cliffs. The position of the choked sinkpoint and the flooded area will influence the pattern of the network, The longer the interaction between water and rock, the more developed the network.

The sub-parallel meandering of passages within some caves formed by water table lakes is due to the groundwater flow towards the base level. The meanders point northwest towards the Velhas River. The water flow in this type of cave, although slow, shows a well defined direction.

Plate 4. Residual hill undergoing dissolution by a surrounding lake.

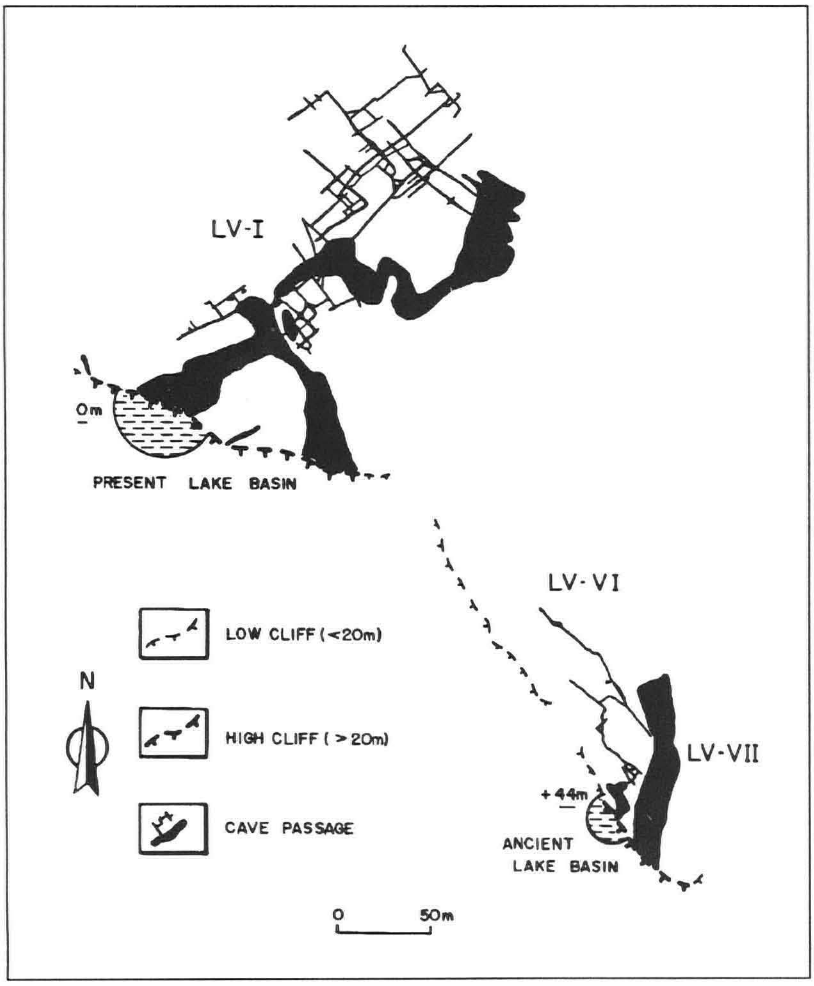

Figure 5. Map of Lapa Vermelha sinkhole showing the major caves. Lapa Vermelha I Cave is the present site of lake speleogenesis. Lapa Vermelha I and Lapa Vermelha VII have large vadose conduits, containing high-level network passages. Lapa Vermelha VI Cave, located 44 m higher than the present lake, was formed by water in an ancient lake basin. Lapa Vermelha I and VI maps courtesy of Grupo Bambuí de Pesquisas Espeleológicas. Lapa Vermelha VII Cave map adapted from Miola (1975).

CONCLUSIONS

Lakes are a characteristic feature of the Lagoa Santa karst. Sinkhole lakes are formed due to the obstruction of a sinkpoint by breakdown and impermeable sediments. Water table lakes exist at lower elevations. Rectilinear and network caves are formed on the edge of lakes by slow moving water under phreatic conditions. The topographical position in relation to the discharge zone, the flow rate and the time of interaction between water and rock determine the cave's pattern.

Dissolution takes place mainly during the wet season, when undersaturated water reaches the lakes. The best developed caves are located in the recharge zone. Well marked dissolution levels or "windows" are related to long term standing palaeo lake levels. Relict network caves can serve as good indicators of ancient lake basins.

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Geology, Palaeohydrology and Evolution of Caves in Tibet

Dian ZHANG
Department of Geography, University of the West Indies, Mona, Kingston 7, Jamaica.

Abstract: Over 500 caves on the Tibet Plateau have been visited and surveyed; all are small and short. Most are relict caves, developed in Eocene and Jurassic limestones and Triassic marbles. The geological structures of the limestones guide the orientations of cave passage development. Many phreatic caves are located high on the mountains, while the lower slopes contain vadose caves that are fewer in number and have their passages oriented down the mountain slopes. On Mt. Zebri, the elevation distribution of caves is related to the palaeo snowlines where the caves could receive meltwater. Cold and arid climates of the present day have enlarged the cave entrances, and led to deposition of frost debris at the entrances. A very small number of micro-caves are developing today on this high and cold plateau.

INTRODUCTION

The Tibetan Plateau is the highest, largest and youngest plateau in the world. Since the Eocene, the Indian Plate has collided with the Eurasian Plate, and the Neo-Tethys Ocean has disappeared (Powell, 1987; Dewey, 1988). The location of Tibet was at about 20°N at this time, and the climate was tropical or subtropical. After the collision, the northward movement of the Indian Plate compressed the Eurasian Plate and created many east-west folds. As there was little uplift an erosion surface developed over the whole region. In the Miocene, the tectonic effects created mainly block movements with small uplifts. East-west extension began 5 Ma ago. From about 2 Ma ago, contact between the rising, underthrusted, Indian Plate and the overlying Asian crust led to rapid uplift of the Plateau.

At present, cold and arid climates dominate the plateau. Karst landforms still can be found, and they are distributed over most limestone outcrops, at altitudes of 3600-6500 m. Karst dissolution caves are found in almost all limestone areas of Tibet, except in those above 5600 m; the highest cave so far discovered is at the top of Mt. Zebri, at 5600 m. All known Tibetan caves are short and small with larger entrances; they are mostly 2-20 m long, with an extreme extent of about 100 m. Most are 1-3 m in diameter, with a few larger caves of 10-18 m diameter. Almost all these caves are relict caves, not developing at present, but formed at some past time.

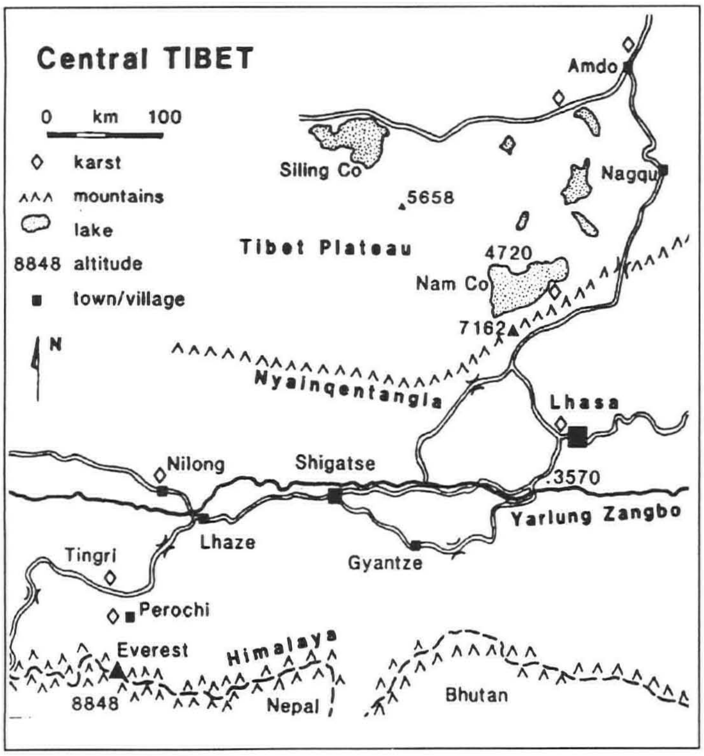

Figure 1. Location of the karst areas in Tibet (from Waltham, 1993).

This study is based on fieldwork research (Zhang, 1991) in three small karst areas, close to Lhasa, Dingri (or Tingri) and Amdo (Fig. 1).

GEOLOGY AND CAVE DEVELOPMENT

In Tibet it is difficult to compare cave development with limestone petrology, as the caves in the different limestones occur in different environments, and other influences complicate the petrological comparisons. Fewer and smaller caves occur in impure limestones high in insoluble materials. The pure limestones that crop out in the three researched karst areas exhibit few differences in relative solubility (Zhang, 1991). Rock porosity varies within the Tibetan limestones, which have values of 3.2% (Eocene biomicritic limestone at Dingri), 1.8% (Jurassic biomicritic limestone at Lhasa) and 0.8% (Triassic micritic limestone and marble at Amdo). These values show that the porosity in younger limestone is greater, but field observation shows that few cavities have originated from primary pores within the limestone. This implies that cave development depends on secondary openings that allow water to permeate the limestone. Water can pass through limestone along bedding planes, unconformities, joints and faults, which may be either original or secondary structures. It is clear that cave passages formed along such openings in the Tibetan karst. The orientations of cave passages, bedding planes and joints have been examined statistically (Fig. 2). On Mt. Zebri, Dingri, about 50% of all the caves, in a zone 2 km wide from the top of the mountain to the end of the limestone outcrop, are developed along two sets of conjugate joints. 40% of caves lie on the direction of tension joints, which is also the direction of surface slope. Less than 10% of caves occur along the direction of bedding strike (Fig. 2). Most caves in Mt. West, Lhasa, are formed on the orientation of two conjugate joint sets, one of which follows the slope of the mountain, with about 10% of them occurring in the direction of strike (Fig. 2). The pattern of cave development in Mt. North, Amdo, is complicated; most caves have developed along the alignments of various joints, with some in the directions of surface slope and strike (Fig. 2).

Statistics show that joints are more important than bedding planes in cave development in the massive limestone of Tibet. This may be a consequence of the extreme tectonic movements that have produced many joints, especially the strong north-south pressure which produced many shear joints. These are more permeable than the bedding planes as they are younger and seldom filled with other material. Joint development is related to the age of the limestones, the oldest, at Amdo, having

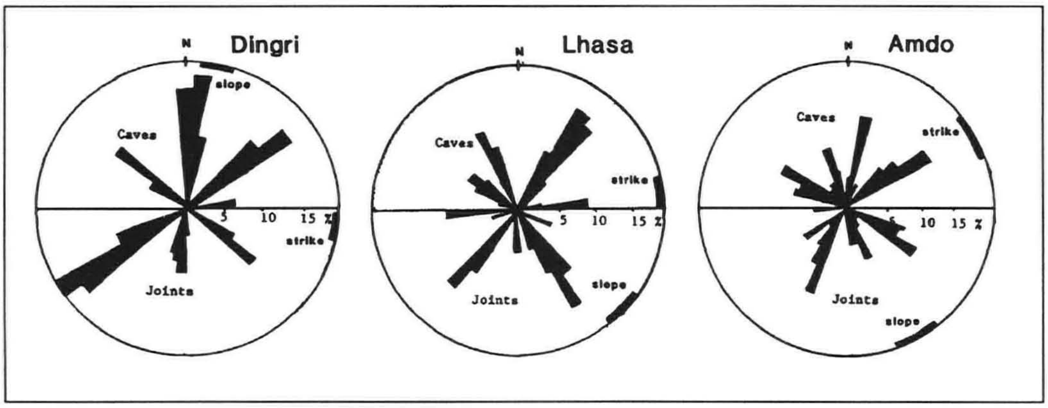

Figure 2. Relationships between cave passages, joints, surface slope and bedding strike directions in the three areas studied.

most multidirectional joints and the most complicated patterns of cave passages.

Many cave passages are developed in the direction of surface slope, especially at Dingri; this is related to the hydraulic gradient of the underground water and the degree of maturity of cave development. In the folded limestones of Tibet, the axial zones, the fault zones, unconformities and contacts with insoluble rocks are generally more karstified. An exception is the higher part of Mt. Zebri, at Dingri, which is along the axis of an anticline, but is less cavernous than other parts of the mountain; this may be due entirely to altitude and temperature effects.

PALAEOHYDROLOGY AND CAVE DEVELOPMENT

The morphology of the Tibetan relict caves is related to the palaeo water flows that created them. Many caves can be classified simply as vadose or phreatic, with reference to the palaeo conditions in which they were formed. A relict cave must have experienced two or more hydrogeological zones; if it developed by groundwater flow under both phreatic and vadose conditions, it may be classified as a compound cave. A statistical survey of caves in the three research areas (Fig. 3) revealed a number of features.

The Lhasa and Amdo karsts have relatively more phreatic caves than does the Dingri karst, which suggests that the karstified limestones in the former areas were below the water table for a longer time.

The compound caves are mostly phreatic features modified by vadose flow; the typical form is the keyhole cross-section. Some caves in the Lhasa area have experienced several stages, from phreatic to vadose then back to phreatic or water table conditions, as base levels have fluctuated. The Big Buddha Cave (Fig. 4) near Lhasa, originated as a phreatic cave, as the forms on the ceiling indicate. The cave was then modified by vadose flow as the Lhasa River entrenched and lowered the base level; stalactites and flowstone (dated from 22 Ka to >1.25 Ma) were deposited in the cave. After the Lhasa Valley was infilled with about 500 m of sediment, the cave was changed into a water table cave as the base level rose; water movement at the water table modified the cave forms, flooding the stalactites and eventually creating a new passage.

The distribution of the cave types varies with area and altitude (Fig. 3). In Mt. Zebri, near Dingri, vadose caves are more common than phreatic caves, which implies that cave development occurred mainly after formation of the mountain. The altitudinal distribution of these caves shows two peaks (Fig. 3A): one is at the contact of the limestone and shales at about 4800 m. (the valley floor is at 4200 m), and the other is at 5000-5200 m, just at the lower limits of the mid and late Pleistocene snow-lines, where some dead cirques are still preserved. In Mt. West, at Lhasa, the phreatic caves predominate, but there are more vadose caves at lower elevations. Phreatic caves also predominate in Mt. North, at Amdo, with no local contrasts in the phreatic/vadose cave ratio. The numbers and hydrogeological types of the caves in these areas appear to be related to the geomorphological and climatic changes. Hydrological analysis alone could not reveal their genesis and evolution.

In the limestone of Mt. Zebri, Dingri, many cave passages have developed in the direction of the mountain slope and fewer of the caves than in other areas are phreatic; this implies that formation of the adjacent valley and its steep hydraulic gradients preceded cave development. In contrast, the phreatic caves in the higher parts of Mt. West at Lhasa are closely guided by the conjugated joints; this may be a relic of development in cave networks, of the style normally found in karsts with low hydraulic gradients. This suggests that most phreatic caves in Mt. West formed when the River Lhasa was not deeply incised; the older vadose caves have since been eroded away.

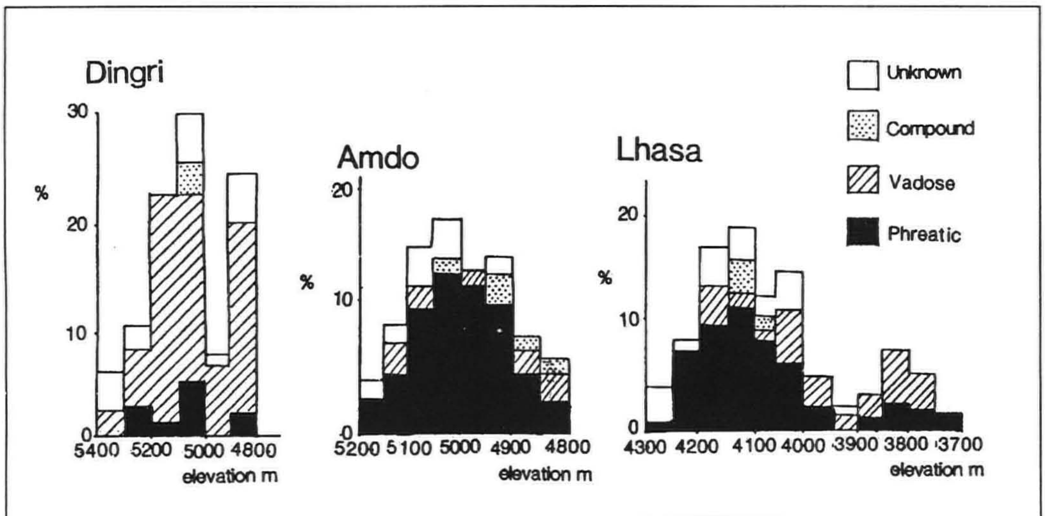

Figure 3. Distribution of types of cave at different elevations in the three karst areas.

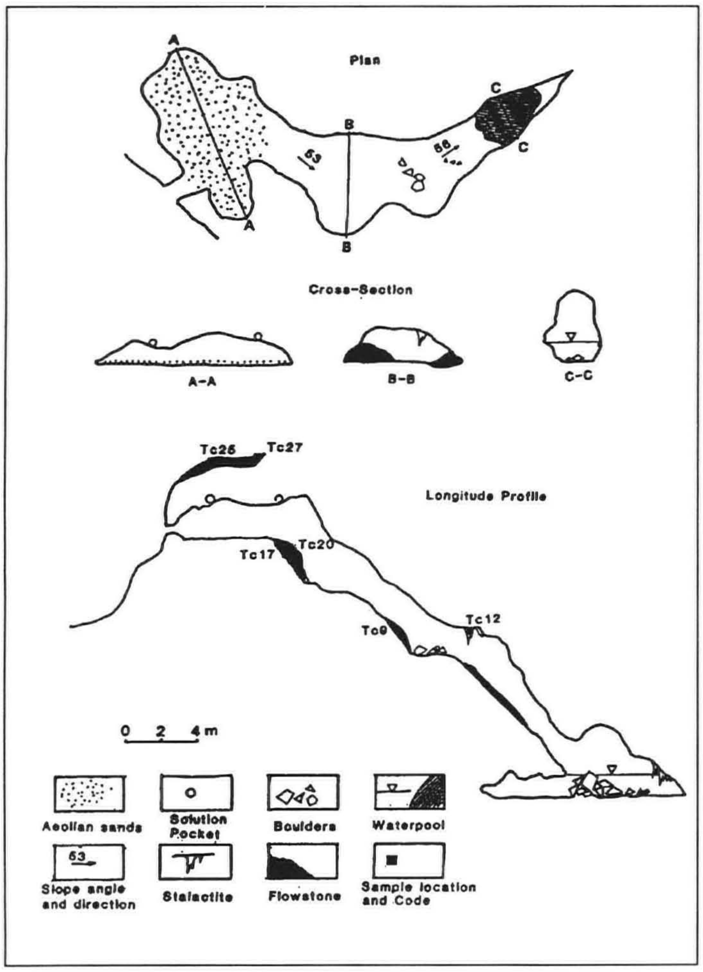

Figure 4. Map of Big Buddha Cave, Lhasa.

CAVES, CLIMATE AND GEOMORPHOLOGY

Many caves on Mt. Zebri are situated at elevations of 5000-5200 m, just within the palaeo snowline area and close to the glacial ice limit. Cave development under an ice cover on the top of the mountain would have been limited. Water entering the caves would have been glacial meltwater, as is also suggested by glacigenic sediments discovered in these caves. The outflow caves developed mainly on the lower parts of the mountains, where the groundwater met insoluble rocks. The hypothesis that meltwater created caves derives further support from the present situation, where some micro-caves are being formed by snow meltwater on the upper part of Mt. Zebri (Zhang, 1991). A second source of water might be from a thin pressure melt, or regelation, film present wherever ice and rock are in contact. This kind of water has a complex chemistry, but is probably depleted in CO_2 (Souchez and Lemmens, 1985), so that its solutional capability is lower. Most caves on Mt. Zebri should be called glaciofluvial caves.

No glaciation of Mt. West, Lhasa, occurred in the early Pleistocene. However, in the mid and late Pleistocene, the snowlines lay close to the top of the mountain. Quartz grains in cave sediments of the vadose caves of Lhasa have glacial origins (Zhang 1991). The inflow caves on this mountain are fewer than the outflow caves (Fig. 5); this may be because the upper part of the aquifer has been eroded away, or because the water input was diffuse through small cavities and fissures. The influence of glaciers on the Pleistocene vadose caves in the Lhasa area cannot be fully recognised because no typical glacial sediments have been found. However, the large number of vadose caves and the few phreatic caves in the lower parts of the mountains suggest that the Lhasa Valley was incised soon after the early Pleistocene, and the caves developed after that, when the climate was wetter and warmer than it is today.

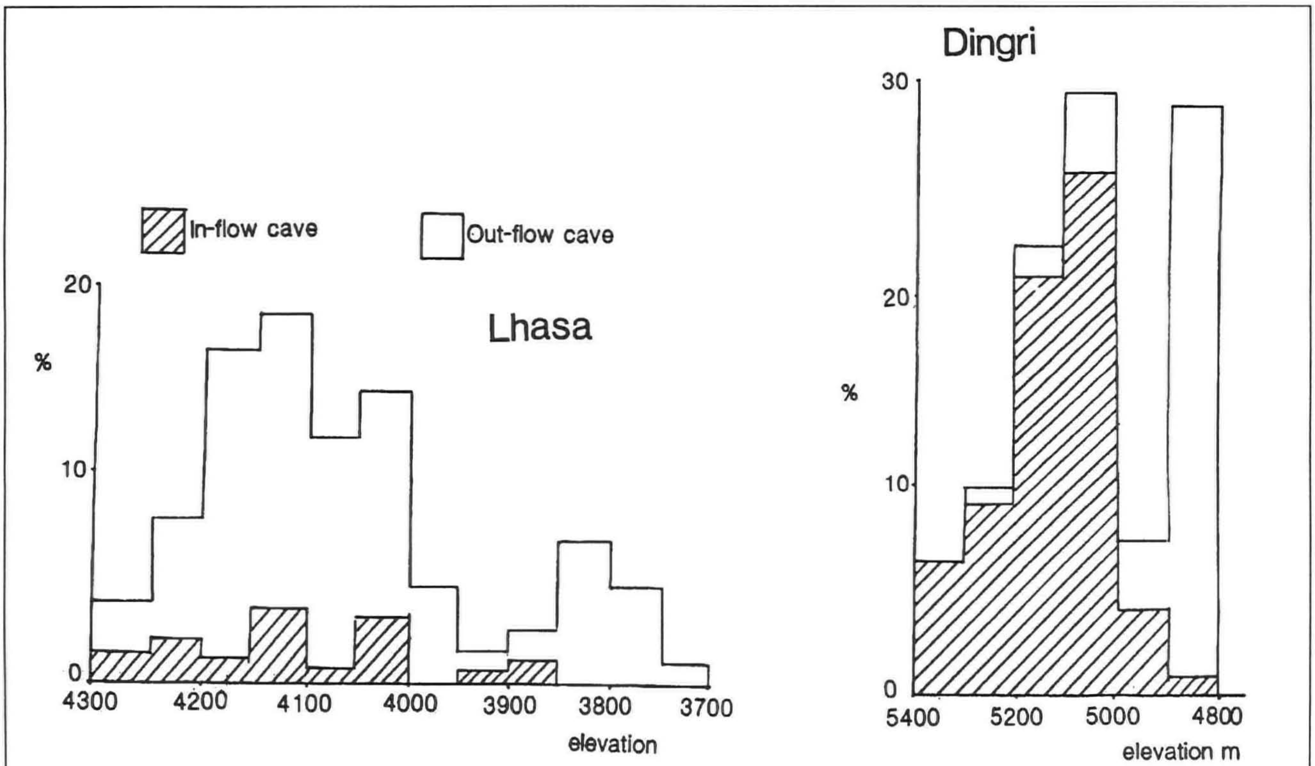

Figure 5. Distribution by altitude of inflow and outflow caves on Mt. West, Lhasa, and Mt. Zebri, Dingri.

The Amdo karst reveals a different pattern of cave evolution where phreatic caves dominate; this is related to the slow processes of surface planation on the northern Tibetan Plateau. Excavation of the valley beside the mountain was very slow, as the block movements created less relative relief and the caves reached base level slowly. Though the top of the mountain may have undergone glacial action, there is no evidence to imply that cave formation is due to glacial meltwater.

The climatic change to dry and cold conditions, when the plateau was uplifted, could have influenced the enlargement and destruction of dissolution caves by active physical weathering. In these relict caves, breakdown and scaling of the walls is common, especially at cave entrances, and limestone debris has accumulated on their floors, together with aeolian sands of limestone grains. Consequently, most caves have large entrances, which make them easier to find in the barren landscapes. The importance of frost action in the formation of the Tibetan caves has been emphasized by Waltham (1993). In some cases physical weathering has been unable to destroy and enlarge the caves where they have been reinforced by secondary carbonate, deposited in wall fissures and cementing blocks of rock. At Dingri, a cave is preserved almost as a shell where the uncemented limestone has been eroded from around the secondarily strengthened cave walls (Fig. 6).

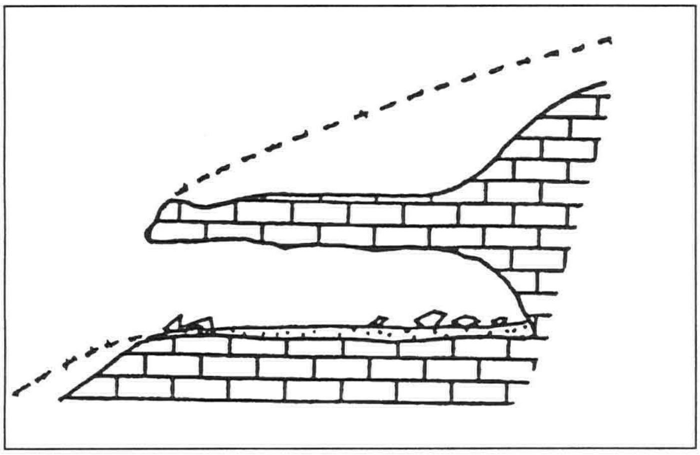

Figure 6. Long profile of a cave at Dingri, preserved due to its wallrock cementation.

CONCLUSIONS

Most caves in the Tibetan Plateau are relict features, with some exceptions at the edges of glaciers, and also where hot springs appear. Caves developed in the palaeophreatic zone are dominant in the limestones at Lhasa and Amdo; this zone probably developed during the Pliocene (Zhang, 1991). Vadose caves, which are dominant in the Dingri limestone, occurred on slopes of the rapidly uplifted mountain blocks, and are related to glacial meltwater and palaeo-snowlines. Rapid uplift of the plateau also influenced the distribution of cave elevations. The very strong physical weathering and frost action in Tibet, where the daily temperature range is greater than the annual range, enlarged the entrances of most of the caves.

ACKNOWLEDGEMENTS

I thank Professor Ian Douglas, Dr. Tony Waltham and the late Dr. Marjorie Sweeting for their encouragement and help in the Tibetan research. I also give my thanks to the people in Tibet, who helped me in many ways.

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CAVE AND KARST SCIENCE Vol. 21, No. 3, May 1995
Transactions of the British Cave Research Association

Forum

Readers are invited to offer thesis abstracts, review articles, scientific notes, comments on previously published papers and discussions of general interest for publication in the Forum of Cave and Karst Science.

THESIS ABSTRACTS

CRAVEN, S. A., 1992

Cango Cave, Oudtshoorn District of the Cape Province, South Africa: An Assessment of its Development and Management 1780-1992.

Unpubl. PhD thesis, University of Cape Town, South Africa. [Also available as Bull. South Africa Spelaeological Association, Vol. 34, 1994 (ISSN: 0560 9879)]

No detailed investigation has been previously made of the legal status, administration, history, management, finances and conservation status of a show cave in South Africa. This study, using archival sources and field work, makes a thorough assessment of Cango Cave, a well known show cave in the Swartberg foothills north of Oudtshoorn in the Cape Province of South Africa.

Repeated field trips to Cango Cave and to other caves in the area have confirmed the environmental deterioration of Cango Cave and its surroundings. This study has shown that such deterioration has been caused by human pressures on a non-renewable resource.

Reading of the extensive Government and other archives, supplemented by newspaper and other published material, has for the first time enabled the scientific, administrative and financial history of the Cave to be available in one document. Analysis of this assembled evidence, augmented by reading between the lines where the evidence is occasionally missing, has shown the reasons for the failure of successive Cave managements during the past two centuries to operate on a conservation basis. This failure to conserve Cango Cave has occurred despite the avowed policy of every political master of the Cape since 1820 that the Cave is a national asset which shall be conserved.

The thesis commences with a description of the location and topography of Cango Cave, followed by a review of cave conservation literature and a summary of the published information on the Cave. There follows a detailed account of the discovery and development of the Cave from 1780 to 1992, and an assessment of its financial status. The impact of humans on the Cave, and its conservation status, are examined in detail.

The above data are then discussed at length and the reasons for the present unsatisfactory management structure identified. Having demonstrated the past and present management failures at Cango Cave, recommendations are made for better management structures and for the necessary applied research. Such research will provide the information which is essential for the future management of Cango Cave on a conservation basis.

PERKINS, A. M., 1993

Magnetic Studies of Speleothems.

Unpubl. PhD thesis, University of East Anglia, Norwich, England, 244 pp and appendices. [Available from the British Library].

The Natural Remanent Magnetizations (NRMs) of rocks and sediments relate to past variations of the Earth's geomagnetic field (GMF). Studies of speleothems (cave deposits such as stalagmites) have shown that they often possess measurable NRMs. However, there have not been extensive studies of the magnetic minerals responsible for the NRM, nor in determining the type and origin of the NRM.

A selection of speleothems has been studied by palaeomagnetic and rock magnetic techniques to identify the magnetic minerals within them and the carriers of NRMs. Electron microscope studies of extracted magnetic phases provide suggestions as to their origin. These studies have been combined with observations of speleothem surfaces to address the question of how the NRM is acquired.

The NRMs and magnetic mineralogies of most speleothems are dominated by magnetite, with hematite and goethite present as accessories. Some samples are dominated by hematite. The bulk magnetic content of most speleothems does not vary and consequently there is only a single primary component of magnetization. However, there are exceptions. Rock magnetic data suggest that interaction between magnetic phases may be occurring and thus these data cannot be interpreted unambiguously in terms of magnetic grain size. Electron microscope studies have shown that the techniques for extracting and preparing magnetic extracts cannot by used on a quantitative basis. On a qualitative basis, however, detrital grains (<0.01 µm to >10 µm, composed of magnetite) and needle-like grains (<2 µm, possibly goethite) have been observed.

A detrital remanent magnetization contributes to the NRM of speleothems and is probably more important than previously suggested. Detrital grains are introduced into speleothems either via floodwaters or through feedwaters. It is suggested that the NRM is acquired due to grains becoming trapped in depressions in the speleothem surface. Experiments suggest that, in the near-absence of oxygen, inorganic precipitation of magnetite could occur during speleothem growth. Iron-chelating organic compounds could also introduce iron into caves. Further work is needed on de-chelation mechanisms, the transport of detrital and organic material into caves, the thermodynamic behaviour of iron at low temperatures and the oxygen content of waters in, and entering, caves.

The recent introduction of mass spectrometry for dating speleothems suggests that the reliability of speleothems as records of past behavioural features of the GMF could be assessed to a greater degree.

SEDIMENTS IN KIRKDALE CAVE, NORTH YORKSHIRE

Bud FRANK
Department of Geography, The University of Newcastle, Newcastle, NE1 7RU, UK.

Despite its speleological mundaneness Kirkdale Cave is one of the most important Quaternary sites in the British Isles. It was excavated for its palaeontological remains by Dean William Buckland in 1821 (Buckland, 1822). Buckland's interpretation of the site as a 'hyaena den' caused great controversy among his peers, as Buckland was adamant that the remains were pre-Diluvian and not deposited directly by 'The Flood' (Boylan, 1967).

The Kirkdale Cave sediment is one of only 4 confirmed Ipswichian deposits in Yorkshire (Penny, 1974). The vertebrate remains have been studied thoroughly by Boylan, whose revision of the entire faunal assemblage (Boylan, 1981) establishes the age as Ipswichian Ip IIb. To date, however, scarcely any attention has been paid to the sediments that enclose the bones. Buckland (1822) gave more space to sediment descriptions than have any modern authors.

The cave is in the Hambleton Hills, on the southern edge of the North Yorkshire Moors, some 2 km southwest of Kirkby Moorside. It has formed at the junction between the Coral Rag (above) and Malton Oolite members of the Coralline Oolite Formation (Wright, 1972). The quarry where the cave is located exposes "...6 metres of well-bedded oolitic limestone, with shell beds , and thin sandy partings..." (Wright, 1972, p.241) overlain by "...9 metres of bituminous, flaggy limestone...resting on smooth textured, massive limestone..." (Wright, 1972, p.242). The rocks are nearly flat-lying, with a dip of 2-3° towards the south.

The cave developed in the phreatic zone. The simple passage cross-section is bedding plane guided, with limited and restricted vertical development along intersecting joints, as is typical of phreatic caves (Jennings, 1985; Ford and Williams, 1989). There are no morphological signs of later erosion by vadose streams.

The remains of the original assemblage of clastic sediments, precipitates and bones comprise the interior part of an entrance-facies deposit. Buckland's (1822) description of the deposits, as he first saw them in December 1821, and his second-hand reports of what was quarried away before his arrival, are internally consistent and support the entrance-facies nature of the deposits.

By the time Buckland arrived, the main part of the entrance-facies debris cone had been quarried away. "About 30 feet of the outer extremity of the cave have now [December 1821] been removed, and the present entrance is a hole in the perpendicular face of the quarry less than 5 feet square." (Buckland, 1822, p.176). Thus, Buckland recovered only a portion of the animal remains and the bulk of the bones were "...thrown on the roads with the common lime-stone..." (Buckland, 1822, p.181). Some vertebrate specimens were recovered from the road material by local naturalists, and it was these finds that led to the discovery of the cave as the source of the bones. After Buckland's excavations additional quarrying of the limestone took place and the cave is now shorter than it was in December 1821.

The undisturbed cave deposits consisted of a simple and typical sequence of a thin flowstone on the bedrock floor, covered by about 30 cm of soil-derived sediment that was capped by another flowstone. The flowstone was not ubiquitous and the top layer was thicker, with some stalagmite development. There were vertebrate remains throughout the sequence but they were "...chiefly in the lower part of the [clastic] sediment..., and in the stalagmitic matter beneath it..." (Buckland, 1822, p.180). This strongly suggests that the floor of the cave was bare limestone, lacking clastic sediment or flowstone, before its occupation by hyaenas.

Being a typical enthusiastic field scientist of his generation, Buckland removed nearly all the deposits. Those remaining today consist of portions of the top flowstone layer and some red mud. The latter may be original in part, but will have been contaminated to some degree by present-day surface soil, brought in on the feet of curious visitors during the past 173 years.

Samples of the top flowstone and the present-day surface soil were collected for analysis. Thin sections were prepared from impregnated blocks of the samples. These show a close similarity between the surface soil and the clastic cave sediment. Both consist chiefly of quartz sand and silt within a clay matrix. The quartz grains have a size range of 0.6 mm to 0.2 mm. They are angular to subrounded and most are single crystals with straight to slightly undulose extinction. There are very small amounts of cryptocrystalline quartz.

Twombley (1965) reported beds of laminated quartz silt within the Malton Oolite, with the detrital quartz making up as much as 14% of the rock. Plate 6.4 in Twombley's thesis shows quartz grains of similar size and shape to those in the clastic cave sediment and present-day surface soil. This supports a view that the clastic sediments are derived from a surface soil that is itself an *in situ* product of the local limestone bedrock breakdown.

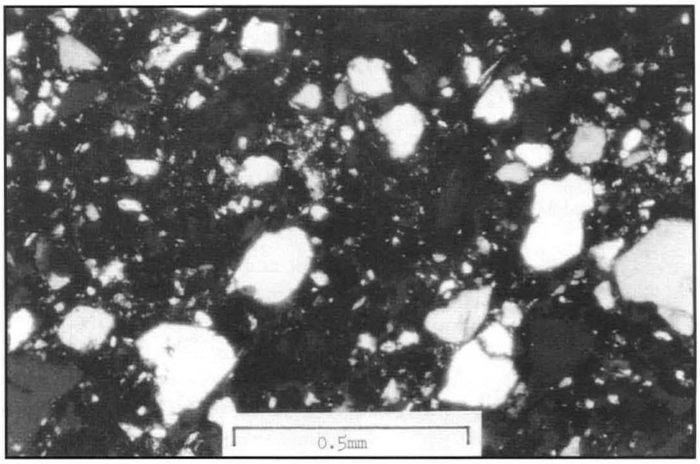

Plate 1. Photomicrograph of present-day surface soil above Kirkdale Cave, showing quartz sand and silt.

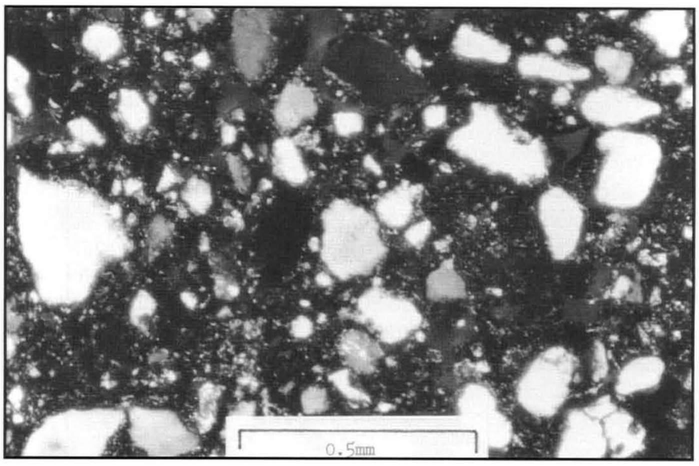

Plate 2. Photomicrograph of sediment from Kirkdale Cave, showing quartz sand and silt.

The <2m fraction of the surface soil and the cave sediment was prepared for XRD analysis using H^+ exchange resin to remove carbonates, and then smearing the clay paste onto a glass slide to provide an oriented specimen. The resulting diffractograms show kaolinite in both the surface soil and the cave sediment. The kaolinite peak is sharp and of high intensity in the cave sediment, indicating an ordered, well-crystallised mineral. In the surface soil the corresponding peak is of low intensity with a relatively broad base. According to Chamley (1989) and others, well crystallised kaolinite forms best in soils of warm climates. This complements the evidence for a warm climate provided by the faunal assemblage.

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CLINOMETER CALIBRATION CALCULATIONS

Andrew LEGG
Blackmores, Membury, Axminster, Devon, EX13 7AH.

For some time I have felt that there is a flaw in the generally accepted method for calibrating of a Suunto clinometer (Ellis, 1976, 1988). The problem is not in the procedure recommended to gain the readings, but in the method that is suggested for working out the correction needed before beginning the conversion to coordinates.

Using Ellis's method, to obtain a corrected reading, it is first necessary to work out a mean value for the error. Working with readings of +5° to -3° taken during calibration checks, the numerical mean is simply calculated as $(5 + 3) \div 2 = 4$. The positive and negative signs are ignored and, according to the method specified, 1° must be added to all clinometer readings to provide corrected figures for use in coordinate calculations.

This method is fine in the case described above, but the situation would not be the same if the readings used were -5° to +3°. The simple mean calculation used above would provide the same answer, that 1° must be added to all readings, even though it appears that more sensibly 1° should be subtracted from all readings. If the corrections were done according to the recommended method an error of 2° would carry through into the survey.

An alternative calibration method does not work out the mean value of the error, but provides the value needed for the correction directly, as follows. Reconsidering the second set of readings used above, the equation is $(-5 + 3) \div 2 = -1$. Thus a negative correction is indicated, and 1° must be subtracted from each clinometer reading. If the first set of readings is considered, $(+5 - 3) \div 2 = +1$, the results are still correct, indicating that 1° must be added to each reading.

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GHOST WIND CAVE AND THE FIRST CAVE-WIND POWER STATION IN CHINA

Dake ZHANG[1] and Dave LOWE[2]
[1] Department of Electronic Engineering, Changsha University, P R China.
[2] Limestone Research Group, University of Huddersfield, UK.

In the karstic mountains of Longshan County, western Hunan Province (Fig. 1), the Huoyan Cave Group attracts thousands of visitors every month. Among more than 200 caves in the group is Ghost Wind Cave, the site of the first cave-wind power station in China. Its entrance lies in the Huoyan Valley, about 30 m above the Pidu River, which in this area is 15 m wide and 0.3 m deep, with a discharge normally between 0.8 and 2.0 $m^3 sec^{-1}$. Wind blowing from the cave entrance causes trees to sway, even well away from the cave mouth.

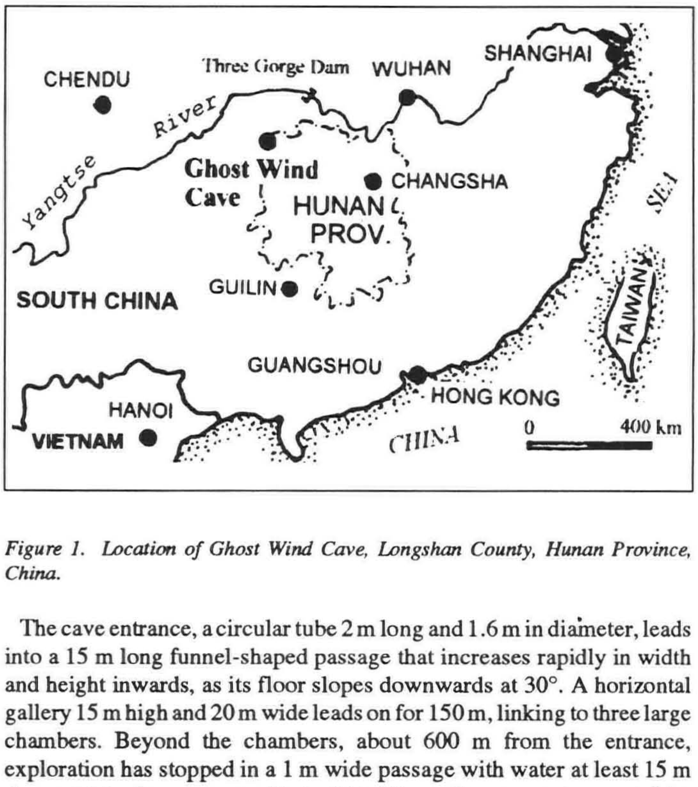

Figure 1. Location of Ghost Wind Cave, Longshan County, Hunan Province, China.

The cave entrance, a circular tube 2 m long and 1.6 m in diameter, leads into a 15 m long funnel-shaped passage that increases rapidly in width and height inwards, as its floor slopes downwards at 30°. A horizontal gallery 15 m high and 20 m wide leads on for 150 m, linking to three large chambers. Beyond the chambers, about 600 m from the entrance, exploration has stopped in a 1 m wide passage with water at least 15 m deep, assumed to connect with the Pidu River. The cave entrance and the deep water route are the only known links to the surface. Only two clusters of stalactites and stalagmites are known in the cave, but deposits of saltpetre in this and other local caves have been used by local farmers as a raw material for gunpowder production.

Cave air temperatures remain stable throughout the year, at about 18°C, but the cave's airflow regime is variable. Maximum airflow velocity is at the junction of the entrance tube and the funnel-shaped passage beyond. A 30% reduction in wind speed occurs only 1 m further into the cave (Fig. 2) and the airflow speed is zero in the chambers deeper in the cave.

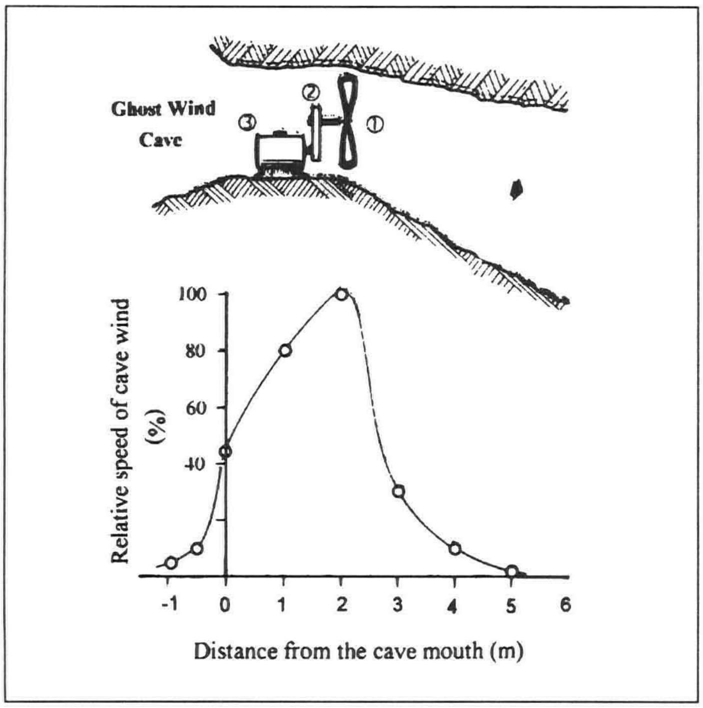

Figure 2. Sketch of the installation of the cave-wind power station in Ghost Wind Cave, and the distribution of relative wind speed in the cave mouth area. [1 = vanes; 2= transmission system; 3 = DC generator]

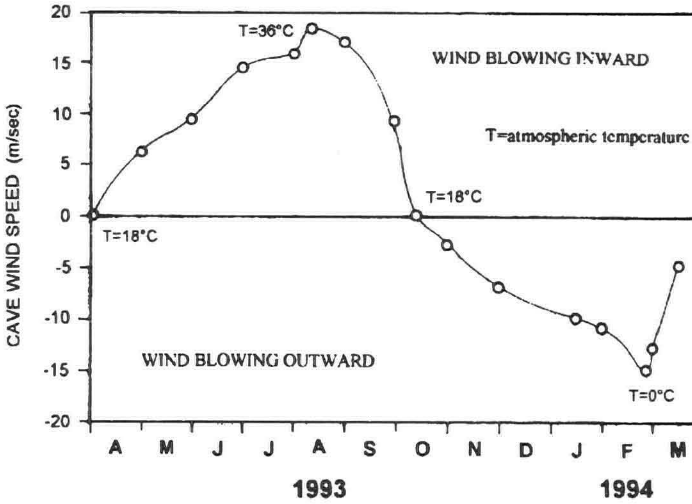

Figure 3. Monthly cave wind speed variations measured at the junction of the entrance passage with the funnel-shaped passage in Ghost Wind Cave.

There is a seasonal reversal of wind direction and a corresponding variation in wind speed in the entrance tube (Fig. 3). Under cold winter conditions the wind blows out from the cave at speeds of up to 15 m/sec. As the outside temperature increases in spring, the wind speed decreases, until it changes direction early in April, to blow into the cave. Wind speeds as high as 18 m/sec. have been recorded during August and September, after which outside temperatures start to drop and the wind speed once again begins to decrease. Around mid-October the wind again changes direction and airflow speed out of the cave increases.

A small, wind power station, designed by Deke Zhang and his colleagues, was set up at the end of the entrance tube, and has been working since Autumn 1993. The installation includes vanes 1.6 m in diameter, which rotate at up to 400 revolutions/min, connected by a transmission system (ratio 3.5:1) to a horizontally mounted DC generator (3kW). Electricity is transmitted 500m to a hotel, where it charges banks of storage batteries. A DC-AC inverter transforms the stored electricity into AC power (220V, 50Hz), to supply the needs for lighting and television in 20 rooms. Despite fluctuations in wind speed, the cave-wind power station has managed to maintain a normal power supply at the hotel since its installation.

RESEARCH FUNDS AND GRANTS

THE JEFF JEFFERSON RESEARCH FUND

The British Cave Research Association has established the Jeff Jefferson Research Fund to promote research into all aspects of speleology in Britain and abroad. Initially, a total of £500 per year will be made available. The aims of the scheme are primarily:

a) To assist in the purchase of consumable items such as water-tracing dyes, sample holders or chemical reagents without which it would be impossible to carry out or complete a research project.
b) To provide funds for travel in association with fieldwork or to visit laboratories which could provide essential facilities.
c) To provide financial support for the preparation of scientific reports. This could cover, for example, the costs of photographic processing, cartographic materials or computing time.
d) To stimulate new research which the BCRA Research Committee considers could contribute significantly to emerging areas of speleology.

The award scheme will not support the salaries of the research worker(s) or assistants, attendance at conferences in Britain or abroad, nor the purchase of personal caving clothing, equipment or vehicles. The applicant(s) must be the principal investigator(s), and must be members of the BCRA in order to qualify. Grants may be made to individuals or small groups, who need not be employed in universities or research establishments. Information and applications for Research Awards should be made on a form available from Simon Bottrell, Dept. of Earth Sciences, University of Leeds.

GHAR PARAU FOUNDATION EXPEDITION AWARDS

An award, or awards, with a minimum of around £1000 available annually, to overseas caving expeditions originating from within the United Kingdom. Grants are normally given to those expeditions with an emphasis on a scientific approach and/or exploration in remote or little known areas. Application forms are available from the GPF Secretary, David Judson, Hurst Farm Barn, Cutler's Lane, Castlemorton Common, Malvern, Worcs., WR13 6LF. Closing date 1st February.

NCA/ENGLISH SPORTS COUNCIL GRANT AID IN SUPPORT OF CAVING EXPEDITIONS ABROAD

Grants are given annually to all types of caving expeditions going overseas from the UK (including cave diving), for the purpose of furthering cave exploration, survey, photography and training. NCA delegates administration of the awards to the Ghar Parau Foundation, to prevent duplication of cost and effort, and to provide a desirable degree of independence from NCA. Application arrangements are as for Ghar Parau Foundation Expedition Awards, see above.

Expedition organisers living in Wales, Scotland or Northern Ireland, or from caving clubs based in those regions should contact their own regional Sports Council directly in the first instance. It is possible that the inauguration of the National Lottery may result in different arrangements for grant aid.

THE E.K.TRATMAN AWARD

An annual award, currently £50, made for the most stimulating contribution towards speleological literature published within the United Kingdom during the past 12 months. Suggestions are always welcome to members of the GPF Awards Committee, or its Secretary, David Judson, not later than 1st February each year.

BRITISH CAVE RESEARCH ASSOCIATION PUBLICATIONS

CAVE & KARST SCIENCE - published three times annually, a scientific journal comprising original research papers, reviews and discussion forum, on all aspects of speleological investigation, geology and geomorphology related to karst and caves, archaeology, biospeleology, exploration and expedition reports.
Editors: Dr. D.J. Lowe, c/o British Geological Survey, Keyworth, Notts NG12 5GG and Professor J. Gunn, Limestone Research Group, Dept. of Geographical and Environmental Sciences, University of Huddersfield, Huddersfield HD1 3DH.

CAVES AND CAVING - quarterly news magazine of current events in caving, with brief reports or latest explorations and expeditions, news of new techniques and equipment, Association personalia etc.
Editor: Hugh St Lawrence, 5 Mayfield Rd., Bentham, Lancaster, LA2 7LP.

CAVE STUDIES SERIES - occasional series of booklets on various speleological or karst subjects.
No. 1 Caves & Karst of the Yorkshire Dales; by Tony Waltham and Martin Davies, 1987. Reprinted 1991.
No. 2 An Introduction to Cave Surveying; by Bryan Ellis, 1988. Reprinted 1993.
No. 3 Caves & Karst of the Peak District; by Trevor Ford and John Gunn, 1990. Reprinted with corrections 1992.
No. 4 An Introduction to Cave Photography; by Sheena Stoddard, 1994.
No. 5 An Introduction to British Limestone Karst Environments; edited by John Gunn, 1994.

SPELEOHISTORY SERIES - an occasional series.
No. 1 The Ease Gill System-Forty Years of Exploration; by Jim Eyre, 1989.

CURRENT TITLES IN SPELEOLOGY - from 1994 this publication has been incorporated into the international journal Bulletin Bibliographique Speleologique/Speleological Abstracts; copies of which are available through BCRA.

Obtainable from BCRA Administrator:
B M Ellis, 20 Woodland Avenue, Westonzoyland, Bridgwater, Somerset TA7 OLQ.