

Cave and Karst Science

The Transactions of the British Cave Research Association



BCRA

Volume 23

Number 3

December 1996



"Hidden" shafts in the Venetian Pre-Alps, Italy
Karstification of the Garron area, Co. Antrim
Mineralogy of Speleothems from Romania
CO₂ in Cango Cave, South Africa
Symposium abstracts
Forum

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.

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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.

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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.

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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.

Figures: 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

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Speleological expeditions have a moral 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.

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

Cave and Karst Science

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Cover photo:

Entrance rift to Black Burn Cave, Co. Antrim.

Photo by Tim Fogg (see article by Kelly, Fogg and Enlander)

The fracture-guided entrance rift to Black Burn Cave shows vertical passage development along a joint.

Note also the prominent bands of insoluble flints within the Ulster White Limestone Formation, a highly indurated Cretaceous chalk.

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.

Cave and Karst Science is published three times a year by the British Cave Research Association and is issued free to all paid up members of the Association.

The 1996 subscription rate to Cave and Karst Science is £16.00 per annum (postage paid).

Individual copies, back issues and details of annual subscriptions to Cave and Karst Science, and of Association membership, can be obtained from the BCRA General Administrator, 20 Woodland Avenue, Westonzoyland, Bridgwater TA7 OLG.

The Association's permanent address is: BCM BCRA, London WC1N 3XX.

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ISSN 1356-191X

EDITORIAL

David Lowe and John Gunn

In *Cave and Karst Science* Volume 23, No.2 we raised the issue of possible futures for the publication of information related to the study of caves and karst. We neither intended to provide a strategy nor promised to implement (or even pursue) any strategies that were suggested in the editorial or were raised by others. Nonetheless, we are pleased to report that a variety of responses, most of which are sensible, positive and constructive, has already been received. We will allow a little longer for late responses to arrive, and then produce a digest of comments and ideas in a later issue.

In this Editorial we want to broaden the discussion and to consider the wider question of the dissemination of information and why we do it! Is it enough to publish details and discussions of scientific investigations, expedition work and technical innovations in *Cave and Karst Science*, or in a variety of other refereed or non-refereed journals? Or should this type of information be disseminated in other ways? Clearly, there are other media that can be exploited, but are they exploited in the best possible ways, and do enough of the potential contributors and potential audience take full advantage of the available opportunities, whether these be local, national or international?

In Britain more than 20 years ago, those with an active interest in the scientific side of cave exploration [speleology in the strict sense] could attend regional meetings or special science symposia organized by the Cave Research Group of Great Britain (CRG). For a price that seems trivial by today's standards, CRG members and (one assumes) non-members could attend these (usually small) gatherings and listen to ground-breaking reports, presented first hand by the likes of Derek Ford or Alfred Bögli, two among many "big names" of cave research whose ideas were at the forefront of western karst innovation at that time. The emphasis at the CRG meetings (which rarely attracted more than 50 or 60 delegates) and symposia was variable, including those that were most definitely scientific, but also dealing with aspects of technology (such as cave surveying) and local discoveries and exploration.

During this same phase the other "national" caving body, the British Speleological Association (BSA) also organized meetings, the most notable of which were the annual September Conferences. These latter events could attract audiences of 200 to 300, and they included scientific as well as more general interest topics. During their last few years they included, specifically, the "Simpson Lecture", presented each year by a different well-known worker, and later published in the BSA Proceedings.

With the amalgamation of the CRG and the BSA to form the BCRA, a new annual "Conference" emerged, that was initially strongly biased towards cave science and technology. Over the years this emphasis has become less apparent, and though Conference still includes a scientific element, its overall image has evolved. It now provides an annual focal point and forum, at which all aspects of cave exploration, whether sporting, scientific or an amalgam of these, can be brought to the surface. Some people love the blend of talks, displays, videos and miscellaneous activities, and the freedom to "mix and match", that is presented; some do not enjoy it at all and never attend, while others are, inevitably, ambivalent. Like it or loathe it, however, it seems to work, getting a significant number of people together and providing a mix of information and entertainment, in an atmosphere that is almost always convivial.

But where does this leave the "speleologists" or those with a passing interest in, and a desire to learn about, the scientific side of caves and karst? Those whose passion lies in "sporting" caving can simply go caving; those with a need for grandeur can join, or organize, expeditions. They can even enjoy annual transfusions of "other peoples' experiences" at the Conference. But how do you pass on, or find out about, information relating to the more esoteric aspects of speleology?

A common trend amongst the more "professional" speleologists in Britain has been to air their ideas at meetings organized by a variety of specialized learned societies at home or overseas. It has to be admitted though that, until recently, cave-related research was often seen by those in the academic "mainstream" of the UK, as being second class science, if not totally irrelevant. This narrow-minded and short-sighted view has now ameliorated somewhat, following international recognition of the importance of caves as repositories of valuable information, relevant to many areas of pure and applied science and technology. However, it remains difficult to present and publish "pure" speleological ideas.

For “amateur” speleologists, and indeed for many who are professionally employed, the most important opportunities for the exchange of ideas and information are provided by the four-yearly International Speleological Congress events, the latest of which will take place in Switzerland in 1997. These international “happenings”, and their fringe events, have attracted scientists and non-scientists, and, like some BCRA Conferences, they have provided something for everyone. Other, more specific, conferences, symposia and “karst schools” take place relatively frequently in countries such as the Czech Republic, France, Slovenia, the USA, and even in the UK. For those with specific interests and a generous source of funds, they provide an efficient way to keep up with scientific developments and co-workers.

Back on a national level, however, as the BCRA Conference has moved away from being a dominantly scientific talking shop, other events have appeared to fill the perceived vacuum. Some of these, such as Cave Science Symposia and a variety of Study Weekends, have been organized by, or on behalf of, the BCRA. Similar events have been run by BCRA Special Interest Groups, mainly for their own members. Others, such as the recent and highly successful Forest of Dean gatherings, have been run outside the BCRA, with or without its blessing or support. Though, inevitably, some of these events have dealt with narrow fields of interest, many have presented information in a way that is useful to scientists but also quite within the grasp of the proverbial and politically correct “interested lay-person”.

As editors of *Cave and Karst Science* we are aware that we have obligations that go beyond the relatively simple function of providing an outlet for “hard” science, though this has been, and currently remains, the mainstay of the publication. We would like to see more contributions from newcomers to cave science, and from those who as yet have only “dabbled”. The major barrier to achieving this ambition is simply that, since taking over, we have received no more than a handful of suitable contributions, and we seem unable to convince potential new authors that *Cave and Karst Science* is worth a try. Obviously, as responsible editors, we cannot guarantee that all material submitted will be acceptable for instant publication. As far as possible, however, if a first submission is unsuitable but shows potential, we will suggest ways in which the author can develop the work (or ideas), or improve the manuscript. *Cave and Karst Science* is not unique in operating a policy that “the editors’ decision is final”!

We see a possible answer to this “confidence gap” experienced by some potential contributors lying not directly with the publication, but with the types of event alluded to above. Cave Science Symposia and Study Weekends, though perhaps sounding “off-putting” to some, should provide the opportunity for people to present ideas, listen to ideas and discuss ideas, both formally within the programme and informally among the attendees. In the past these events have demonstrated that they interest a wide spectrum of people, drawing academics and non academics alike. Most notably they have drawn significant numbers of those who had not (and still have not!) considered publishing their ideas in *Cave and Karst Science*.

Many motives can be imagined for organizing and supporting this type of event but, looked at from our viewpoint, one (admittedly idealistic) concept seems paramount – they should not be the province solely of high-powered academics seeking to make or enlarge a reputation. Instead their content and environment should welcome all those with the desire to find out about caves and karst. All attendees should feel relaxed and not feel out of place, speakers should be approachable and not aloof or patronizing, and the less-experienced should go away feeling encouraged rather than deflated or overpowered. It has seemed inevitable that some symposia have taken place in universities and colleges, as these offer the accommodation and facilities that are needed for providing presentations in relative comfort. Other events have taken place in village halls and even in caving hostels, and have proved no less stimulating and enjoyable.

What we would say to everybody is don’t be put off attending these functions simply because they are called Symposia, Study Weekends or whatever, or because the venue is inside a university. If you are interested in at least some of what’s on offer, come along. You won’t like it all, you won’t understand it all (nobody does!), but you’ll learn something and you’ll get to meet and talk to some potentially interesting people, and they’ll get to talk to you. The next BCRA Cave Science Symposium is once again in a university, and takes place at Huddersfield on Saturday 15 March. The abstracts are published in this edition so you have some idea of what to expect. Why not come along and meet the editors of *Cave and Karst Science* - or even buy them a beer – and talk about the paper you plan to write or have written!

Carbon dioxide variations in Congo Cave, South Africa

Stephen A. CRAVEN

7 Amhurst Avenue, Newlands 7700, South Africa

Abstract: Congo Cave, a leading South African show cave, has deteriorated during the latter part of this century. Little pure and applied research has been carried out in the cave; and there has been no previous atmospheric monitoring. A limited set of measurements confirms an expected increase in the partial pressure of carbon dioxide during the day, and decrease during the night when the cave is closed. The relevance of these observations to conservation of the speleothems in the cave is considered.

INTRODUCTION

Congo Cave is located in the Swartberg foothills, about 27km north of Oudtshoorn in the (new) Western Cape Province. The cave can be conveniently divided into three sections (Fig. 1):

- 1) Congo I - the first 750 m is a show cave and has been known since 1897. The proximal part, as far as the Drum Room has been open to visitors for two centuries.
- 2) Congo II - the intermediate part of the cave is 300m long and has never been open to tourists. Although Congo II was not discovered until 1972, there has always been unimpeded movement of air between Congo I and II.
- 3) Congo III - the terminal part of the cave which is 1500m long. This was discovered in 1975 by lowering a sump. This water appears effectively to seal Congo III from the proximal part of the cave, and is lowered only very occasionally to facilitate access.

Although Congo I forms a leading South African show cave no attempt has been made to restrict visitor numbers despite considerable evidence of deterioration of the cave environment (Craven, 1994). Since Congo is a low-energy cave, the effect of large numbers of visitors can be expected to increase the humidity, temperature and pCO_2 . On busy days the cave can receive over 3000 visitors. Although a raised pCO_2 may be deleterious to the speleothems in the cave, and therefore to its appeal to tourists, no

previous attempt has been made to monitor the show cave atmosphere. This paper presents preliminary results from monitoring atmospheric pCO_2 over two busy weekends in 1995. The results are discussed in the context of the need to conserve the cave environment, not only for its scientific content, but also because it is the dominant tourist attraction in the Oudtshoorn district. This is very much a preliminary report based on two opportunities, which arose at short notice, to measure CO_2 in Congo I and Congo II. Its shortcomings include lack of direct measurements of barometric pressure, windspeed, temperature and humidity. Nevertheless it is presented in the hope that it will stimulate further work and debate on the subject, and that the observations will provide a baseline for future research.

METHODS

April is a busy time at Congo Cave. During Easter, 13 - 16 April, 1995 there were up to 2000 visitors daily, to which were added the patrons attending evening performances of a Passion Play in Van Zyl's Hall (Table 1). Each performance was attended by 1200 paying patrons and about 200 actors, technicians and others. Therefore about 1400 people can be expected to have been in Van Zyl's Hall for three hours per performance. On 14 April 1995 there were 1133 visitors before the cave was closed to tourists at 17.00 hours. Thereafter the pCO_2 was estimated every 30 minutes during the two evening performances, and again the following morning after the cave had been closed for the night. The site chosen was against the north wall of Van Zyl's Hall, well away from the entrance passages. A control measurement was made in the Banqueting

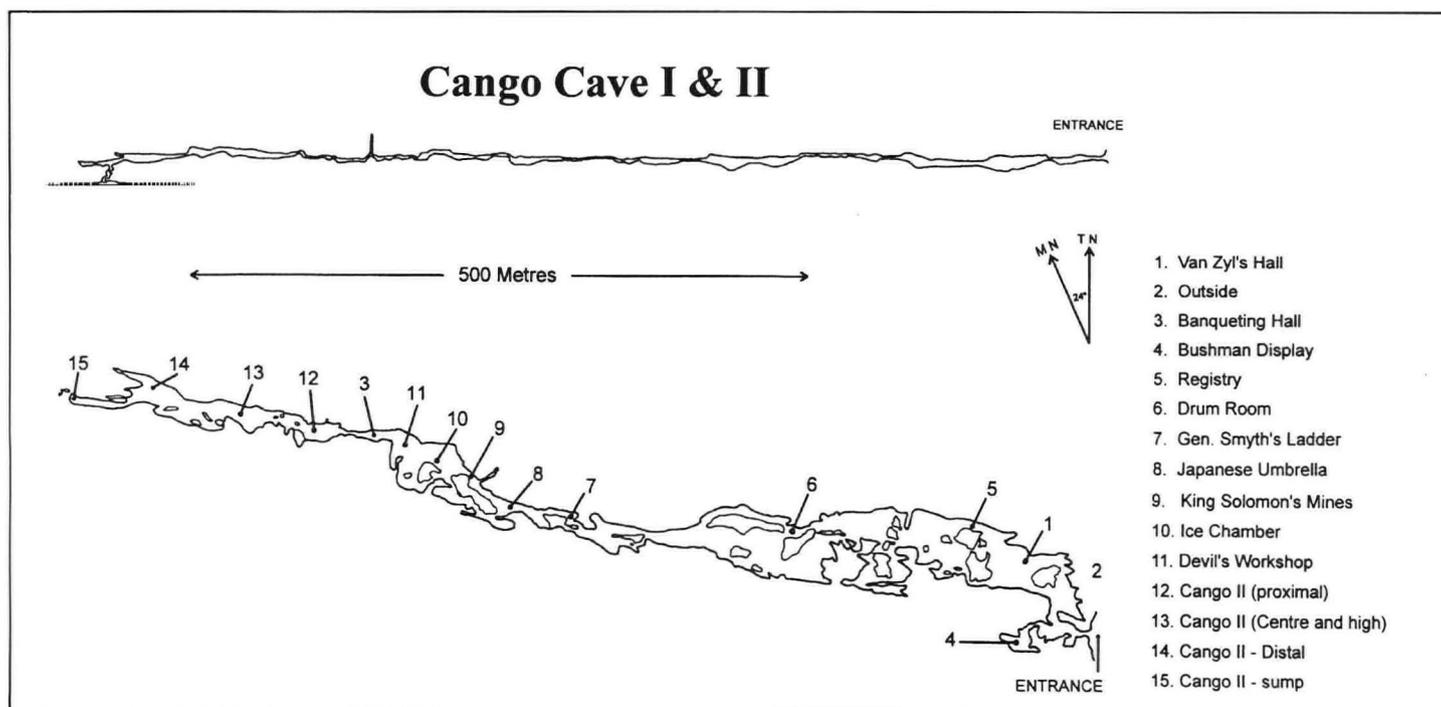


Figure 1. Survey of Congo I and II indicating the sampling sites.

Date	No. of (evening) performances
April 12	1
13	2
14	2
15	2
16	2

Table 1. Easter 1995 Congo Cave Passion Play Performances.

Hall at the far end of the show cave. Two weeks later another opportunity arose to estimate pCO₂ at a number of sites throughout Congo I and II (Fig. 1.)

The concentration of CO₂ was measured about 1m above the cave floor using Dräger Tubes CH 23501 (0.1% - 6%). The tube readings were multiplied by the correction factor: 1013/ actual atmospheric pressure (hPa). As no barometer was available, the barometric pressures and dry bulb temperatures for Oudtshoorn were obtained from the Weather Bureau in Pretoria, and the barometric pressure at the cave was calculated according to the formula (Preston-Whyte and Tyson, 1988):

$$P_1 = e^{\left(\ln P_0 - \left[\frac{\delta Z}{(29.27 \times \delta T)} \right] \right)}$$

where:

P₁ = barometric pressure at the cave entrance (hPa)

P₀ = barometric pressure at the weather station (hPa)

δZ = altitude difference between the cave and the weather station
[= 334 m.]

δT = the mean of the temperatures at the weather station and at the cave entrance in °K

This assumes that the barometric pressure is constant throughout the cave, an assumption which may not be correct.

RESULTS

These results (Table 2) show that on 14, 29 and 30 April 1995 the numbers of visitors were sufficient to raise significantly the pCO₂ in the proximal part of the show cave, and that the show cave recovered to some extent during the night when closed. They also show that there is an even higher pCO₂ in the more distal parts of the cave, including those which seldom receive visitors.

There has been only one previous, isolated, attempt to estimate pCO₂ in Congo Cave (Maxwell, 1980). During a 4 day sojourn in Congo III between 4 - 7 April 1980 by six members of the South African Speleological Association (Cape Section), random pCO₂ measurements were made using Dräger tubes. Corrected readings varied between 1.25 and 1.74 per cent with an average of 1.48 per cent. Measurements were repeated at only one observation site, the base camp, where the concentrations increased from 1.35 per cent on day 1 to 1.74 per cent on day 3.

DISCUSSION

James (1977) outlined several possible sources of carbon dioxide in caves:

1. Volcanic gases: As Congo Cave is not in a volcanic area, such gases will not be present.

- Burning of hydrocarbons: Before electrification of Congo Cave in 1928, the sources of illumination were candles, flares, flaming torches, acetylene and paraffin lamps, all of which would have increased the CO₂ in the cave. However, mains electricity was provided in the 1960s, so there is now no hydrocarbon pollution from lighting sources.
- Evolution of CO₂ from cave waters: The only running water in Congo Cave is the small stream between Congo II and Congo III. The contribution of water-borne CO₂ to the cave atmosphere can therefore be expected to be negligible.
- Diffusion of gaseous CO₂ through the soil and rock: Atmospheric CO₂ also finds its way into Congo Cave via the tourist entrance, through which there is often a considerable draught which blows in and out at different times. The low outside atmospheric CO₂ (0.033 per cent) is augmented by that produced by the micro-organisms in the overlying soil, and enters the cave through cracks in the rock. The pCO₂ in soil may be as much as 100 times that in the atmosphere, and will correspondingly increase the dissolved CO₂ which finds its way into a cave. However, the xerophytic vegetation overlying Congo Cave may or may not be a significant source of CO₂ (Sweeting, 1973).
- Production of CO₂ by micro-organisms: Micro-organisms require a source of organic matter from which to produce CO₂. There appears to be minimal, if any, organic matter in the stream between Congo II and III. Unpreventable sources of organic matter in the rest of the cave are similarly minimal and include desquamated skin cells from, and lint from the clothes of, humans. Preventable sources include dumped food particles, tobacco and sawdust which, if not removed promptly, will tend to increase the pCO₂ in the cave. Micro-organisms therefore have the potential to increase the pCO₂ in Congo. At one time there were huge amounts of bat guano in Congo I, but most of this had been removed by 1948. The micro-organisms in this guano can be expected to have contributed to the cave atmospheric CO₂ which, in former times, may well have been considerably higher than today.
- Respiration of animals, including humans: Not unexpectedly, these preliminary observations confirm that CO₂ exhaled by the human visitors to Congo I markedly increases the pCO₂ in the cave atmosphere (Table 2). The cave recovers partially during the night when it is closed to visitors. Visitor numbers are undoubtedly the major variable now controlling CO₂ levels in Congo I.

Congo Cave is a low-energy cave in that there is very little natural energy which can dissipate the energy brought in by the visitors (CO₂, water vapour and heat) and by the heat from the electric lights (Heaton, 1986). There is effectively only one entrance; and the only natural ventilation in the cave is that induced by changes in outside temperature and barometric pressure. The dissolution and precipitation of calcium carbonate is controlled by the relative amounts of CO₂ in the percolation water and in the cave atmosphere. Ground water in contact with limestone may contain more than 200 mg/l calcium carbonate. If this water percolates into a cave where the pCO₂ is lower than that in the overlying soil, the solution becomes unstable. The calcium carbonate may precipitate as calcite (speleothem) and the CO₂ enters the cave atmosphere (Martini, 1995). If the cave pCO₂ is higher than that in the overlying soil, dissolution occurs.

The pCO₂ is not the only parameter which controls speleothem formation. The relative humidity and temperature also affect the formation and destruction of speleothems to a much lesser extent; but the literature, on this topic is scant (Picknett et al, 1976; Ford and Williams, 1989). Other things being equal, low humidity can be expected to increase the rate of evaporation of the super-saturated solution of calcium carbonate, and therefore to encourage the deposition of calcite. Temperature can be expected to have a double effect. High temperature will increase the rate of evaporation of the water, and therefore encourage precipitation of calcite. The solubility of CO₂ in water is inversely proportional to the temperature. Therefore high temperature will decrease the solubility of the CO₂ and assist the precipitation process.

Table 2. $p\text{CO}_2$ estimations in Cango Cave, April 1995.

Date	Time	Place	$p\text{CO}_2$	Corrected Vol. %
14	(1133 tourist tickets sold before 1700 hours)			
	1700	Van Zyl's Hall	0.4	0.43
	1730	Van Zyl's Hall	0.4	0.43
	1800	Van Zyl's Hall	0.4	0.43
	1830	Van Zyl's Hall	0.4	0.43
	1900	Van Zyl's Hall	0.45	0.48
	1930	Van Zyl's Hall	0.5	0.54
	2000	Van Zyl's Hall	0.5	0.54
	2030	Van Zyl's Hall	0.5	0.54
	2100	Van Zyl's Hall	0.5	0.54
	2130	Van Zyl's Hall	0.5	0.54
	2130	Van Zyl's Hall	0.5	0.54
	2200	Van Zyl's Hall	0.55	0.59
	2230	Van Zyl's Hall	0.55	0.59
	2300	Van Zyl's Hall	0.55	0.22
	2330	Van Zyl's Hall	0.55	0.11
	2400	Van Zyl's Hall	0.55	0.54
15	0905	Van Zyl's Hall	0.2	0.59
	1020	Banqueting Hall	2.25	0.59
29	0855	Bushman display	0.1	0.22
	1005	Van Zyl's Hall	0.1	0.11
	1005	Van Zyl's Hall	0.1	0.11
	1120	Registry - new calcite	0.1	0.43
	1215	Drum Room	0.4	1.61
	1305	Gen. Smyth's ladder	0.5	0.11
	1345	Japanese umbrella	1.5	0.11
	1405	King Solomon's Mines	1.75	0.54
	1515	Van Zyl's Hall	0.1	1.88
	(1009 tickets sold by 15 15 hours)			
	0845	Van Zyl's Hall	0.075	0.08
	1025	Ice Chamber	2.5	2.65
	1042	Devil's Workshop	2.5	2.69
	1104	Banqueting Hall	2.5	2.69
	1124	Banqueting Hall sm. chamber	2.5	2.16
	1155	Cango II (proximal)	2.5	2.42
	1310	Cango II (centre and high)	2.0	0.11
	1425	Cango II (distal)	2.5	2.69
	1442	Cango II (sump)	0.25	2.69
	1541	Cango II (proximal)	2.5	2.69
	1644	Van Zyl's Hall	0.1	2.69
	('about' 1000 tickets sold by 1600 hours)			



Plate 1. New calcite deposition in Cango I (scale: whistle = 18mm).
(Photo: D. Hilton)

It is clear that Cango I has deteriorated markedly, since the majority of the speleothems have a dull, matt and crumbling appearance suggesting that they are being destroyed, or “dead”. Part of this deterioration can be attributed to apatite which was formed by the decay of bat guano (Martini, 1996). Nevertheless, the early visitors to Cango I during the last century commented on the brilliance of the speleothems. In 1823 a visitor compared the stalactites to icicles, and reported that the rimstone pools were full of fresh water (Thompson, 1827). The speleothems in Cango II and III shine and glisten indicating that they are still being formed, or “alive”. It thus appears that during the last century Cango I was very similar in appearance to Cango II and III today.

As noted above, the formation and destruction of speleothems are reversible processes which depend largely on the $p\text{CO}_2$ of the cave atmosphere and the overlying soil, and on the rain water which finds its way into the cave. Variables of lesser importance are the temperature and relative humidity inside the cave. If these parameters are favourable, the speleothems may slowly regrow. This phenomenon can be seen in Cango I on the south wall of the Registry immediately beyond Van Zyl’s Hall (Plate 1). There, in 1928, a vertical groove was cut in the limestone to accommodate an electrical cable, which was removed in the early 1960s when the cave was rewired. Since then, significant quantities of calcite have been deposited in that groove. If the microclimate within the groove could be reproduced and maintained throughout Cango I, the speleothems could be expected slowly to recover.

The original, natural, $p\text{CO}_2$ in Cango Cave before human visits cannot ever be known. It may be that the comparatively, low basal $p\text{CO}_2$ in Van Zyl’s Hall has been caused by the cave winds dissipating the gas either to the outside and/or into the distal reaches of the cave. A possible additional or alternative cause may have been the removal of the guano which was present until 1948. The high $p\text{CO}_2$ in Cango III is natural because there may be free movement of air through an above-water passage which has not yet been explored. The lower $p\text{CO}_2$ at the sump, which is the lowest part of Cango II where could be expected to accumulate, deserves further comment. This lower than expected measurement suggests that the CO_2 may be removed by the stream either in solution and /or by convection current.

The $p\text{CO}_2$ changes recorded in Cango Cave are not merely an exercise in academic speleology. For two centuries, Cango Cave has attracted to Oudtshoorn visitors who come to see the spectacular speleothems. The other tourist attractions in the district are largely dependent on Cango Cave in the sense that they are not peculiar to Oudtshoorn. If Cango Cave is allowed to deteriorate further to a condition where it no longer attracts visitors, Oudtshoorn will become an insignificant economic backwater of Southern Africa. The Oudtshoorn Municipality, which is responsible for the control and management of Cango Cave commissioned a scientific survey of the cave. It is to be hoped that the contractors will, inter alia, make a thorough investigation of the meteorology of the cave and will establish the cause(s) of the deterioration of the speleothems, which may well be multifactorial. A management plan could then be prepared with a long-term view to restoring Cango I to its former glory without restricting access to tourists.

ACKNOWLEDGEMENTS

I am grateful to the promoters of the Passion Play for permission to estimate $p\text{CO}_2$ during two performances; to the National Monuments Council for transport and for purchasing the Dräger tubes; to Messrs. Dräger (Cape Town) for the loan of an Accuro pump and tube cutter; to Prof. M.E. Marker for reading the manuscript and commenting thereon, to Dr. B. C. Hewitson for showing me how to correct the Dräger tube readings and to Miss G. van Heerden for the map.

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Holocene and Tertiary karstification in the Ulster White Limestone Formation (Cretaceous) of the Garron area, County Antrim, Northern Ireland

John G. KELLY¹, Tim FOGG² and Ian ENLANDER³

¹ CSA (NI), 45a Adelaide Park, Belfast, BT9 7FZ

² Newtate, Florencecourt, Co. Fermanagh, BT92 1FW

³ Environment and Heritage Service, Commonwealth House, 35 Castle Street, Belfast, BT1 1GU

Abstract: White Cretaceous limestones (the Ulster White Limestone Formation) crop out in a narrow band along the coast of County Antrim, Northern Ireland. In the Garron Point area, an active Holocene karst system, the Black Burn/Foaran Spring system, has been explored. Several other Holocene karst features have been located within the area, where evidence for karstification of the white limestones during or before late Tertiary times also exists.

INTRODUCTION

The Ulster White Limestone Formation, a highly indurated Cretaceous chalk, crops out as a narrow band between upland areas capped by the Antrim Tertiary Basalt sequence and the Irish Sea coastline along the east and northern coasts of County Antrim, Northern Ireland. In the Garron Point-Tievebulliagh area the Hibernian Greensands are absent and the limestones are underlain by "Lower Lias Clays" and overlain disconformably by the Antrim Basalt Formation sequence (Fig. 1).

An active river cave system, associated with Black Burn, was discovered at Carrivereagh, Carnlough, County Antrim in 1984. This is the only major cave system in the Ulster White Limestone Formation and is the only explored, extensive, active cave system developed in Cretaceous limestones in Ireland. It is probably the longest accessible karst drainage system developed in Cretaceous carbonates currently known in the United Kingdom.

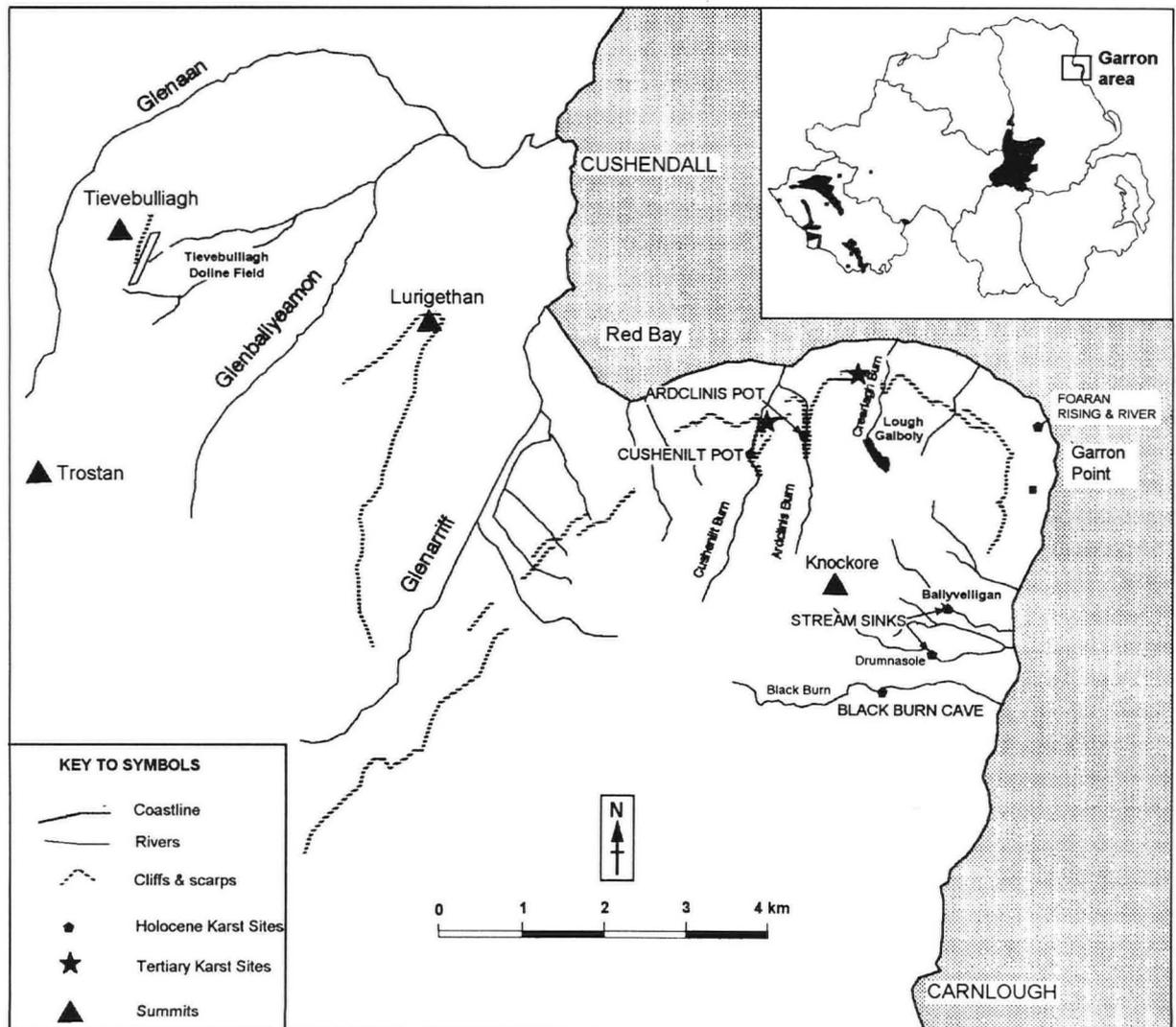


Figure 1. Location map of the Garron-Tievebulliagh area, showing locations of Holocene karst and Tertiary palaeokarst sites.

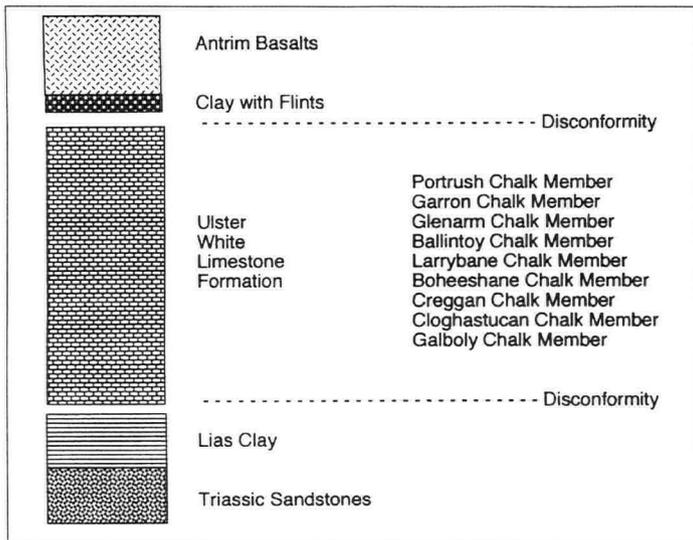


Figure 2. Lithostratigraphy of the Garron Point area (after Fletcher, 1977).

GEOLOGY

Approximately 57m total thickness of the Ulster White Limestone Formation are exposed between Carnlough and Garron Point (Fletcher, 1977). The formation overlies calcareous, bioclastic clays of the “Lower Lias” with disconformity, and is in turn overlain disconformably by the Clay with Flints and the Antrim Basalt Formation. Fletcher (1977) divided the Ulster White Limestone Formation into the several members that are summarised in Fig. 2.

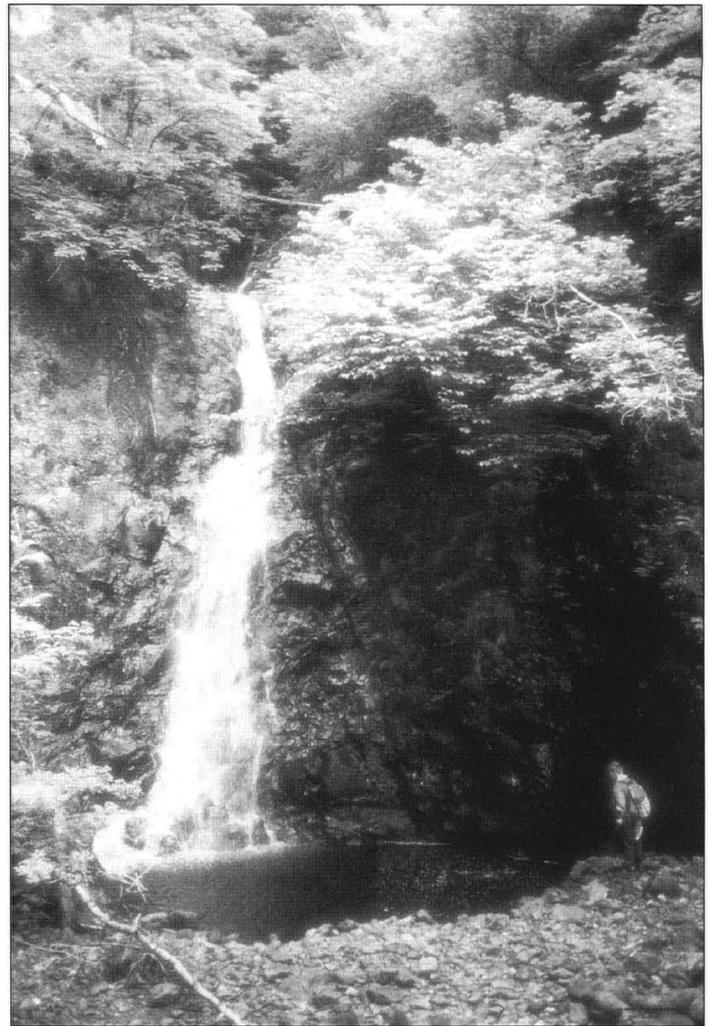
In the Garron area, the Ulster White Limestone is an indurated, pure, coccolith-foraminiferal micrite with well-developed bands of flint nodules. Porosities and primary permeabilities are very low (Bennett and Harrison, 1980, record porosities less than 5%), and fluid movement through the formation is largely along fissures of various types, which guide a secondary permeability.

Stream sinks occur at or near the contact between the Ulster White Limestone Formation and the overlying rocks. In many localities, however, the limestone is exposed only in cliffs and its outcrop has no horizontal extent, or extensive Pleistocene deposits cover stream beds, preventing sink development. The resurgence level is at the contact between the base of the Ulster White Limestone Formation and the underlying “Lias Clay”.

HOLOCENE KARSTIFICATION

Introduction

Karst features within the Ulster White Limestone have been known for some time. Exploration of a number of minor surface sites was undertaken in the 1970s (O’Hagan, pers. comm.), and significant water-filled cavities have been intersected by drilling (P. Bennett, pers. comm.). Caves have been revealed by quarrying, but most such sites have been destroyed or infilled during quarrying operations (Fogg, 1991). In 1984 an active river cave was discovered at Black Burn (Campbell, 1984). Fogg and Kelly (1995) re-examined the Black Burn site and a number of minor sites in the Garron Point-Tievebulliagh area. The Black Burn system (and associated sites) and other localities in the Garron Point-Tievebulliagh area are described here.



Basalt scarp with waterfall draining the Garron upland, and sink pool at its base. Picture taken in normal water conditions. In flood the stream continues, to sink at the open entrances to Black Burn Cave.

THE BLACK BURN CAVE - FOARAN RIVER SYSTEM

Introduction

Several streams drain the east-facing scarp of the Garron Plateau and some of these sink into the Ulster White Limestone. The most significant, speleologically, is Black Burn, which has an active associated cave system. Two other rivers to the north of Black Burn are known to sink into the White Limestone, at or adjacent to the Basalt/White Limestone contact. Black Burn Cave is 3.4km from, and 125m above, the Foaran Rising, the resurgence for the water sinking at Black Burn.

Hydrology

Three streams draining the eastern edge of the Garron Plateau sink at or near the contact between Antrim Basalts and the Ulster White Limestone. The largest sink lies in the bed of Black Burn. Two additional sites are located to the north, in Drumnasole and Ballyvelligan townlands. The former is similar to the Black Burn sink, the stream sinking in a boulder-strewn pool at the base of a waterfall at the edge of the basalts (D2882E 2197N). At the second site the stream sinks gradually over c.200m of stream bed, after passing the Basalt/White Limestone contact (D289E 222N). The only major resurgence in the area is the Foaran Rising. Simple water tracing experiments were conducted, with 0.5 litre of Leucophor

STA being introduced into the sinks at Black Burn and Ballyvelligan. Cottonwool detectors were placed in the Foaran Rising for each trace and were collected approximately one week after the tracer was introduced. Water from both sinks was recorded as rising at the Foaran Rising. The stream sinking at Drumnasole probably also emerges at the Foaran Rising.

Black Burn Cave

An entrance to Black Burn Cave was discovered by a party of canoeists in 1984. The cave was explored initially, for approximately 150m to a sump, by Maurice Neill and the Reverend George Pitt of the Reyfad Group in July 1984. In September 1984, Mark Campbell, Tim Fogg and Pam Fogg returned with diving gear to attempt to pass this sump. Water levels had fallen and a short duck was encountered at the former sump position. This was quickly passed, but a sump proper was encountered after a further 40m. Beyond this sump, a main stream passage was reached and four more sumps were passed, with a further 300m of passage explored. This remains the farthest point explored in the cave (Campbell, 1984).

In August 1994 the cave was visited by Tim Fogg and John Kelly, who discovered the old entrances hopelessly blocked by flood debris. They located a new entrance and explored a new shaft into the previously known cave. The cave was surveyed to the area of the erstwhile duck, which was completely dry due to low water conditions. It was also noted that a sizeable inlet enters the system via an aven at this point, and that boulders entering via this inlet had choked the passage, making it impassable. This point is underneath the stream bed adjacent to the waterfall at the basalt/white limestone contact.

Entrances

In normal conditions the stream sinks at the base of a 25m-high basalt waterfall, presumably the contact between the Antrim Basalts and the Portrush Chalk Member. The entrances to Black Burn Cave lie 110m east of the waterfall on the southern side of a deep narrow (6m x 2m) limestone gorge. With increasing water level, the stream flows from the pool at the base of the waterfall to sink at these entrances, while during floods the cave system is too immature to allow all the water to sink at this site and Black Burn carries a stream to the coast.

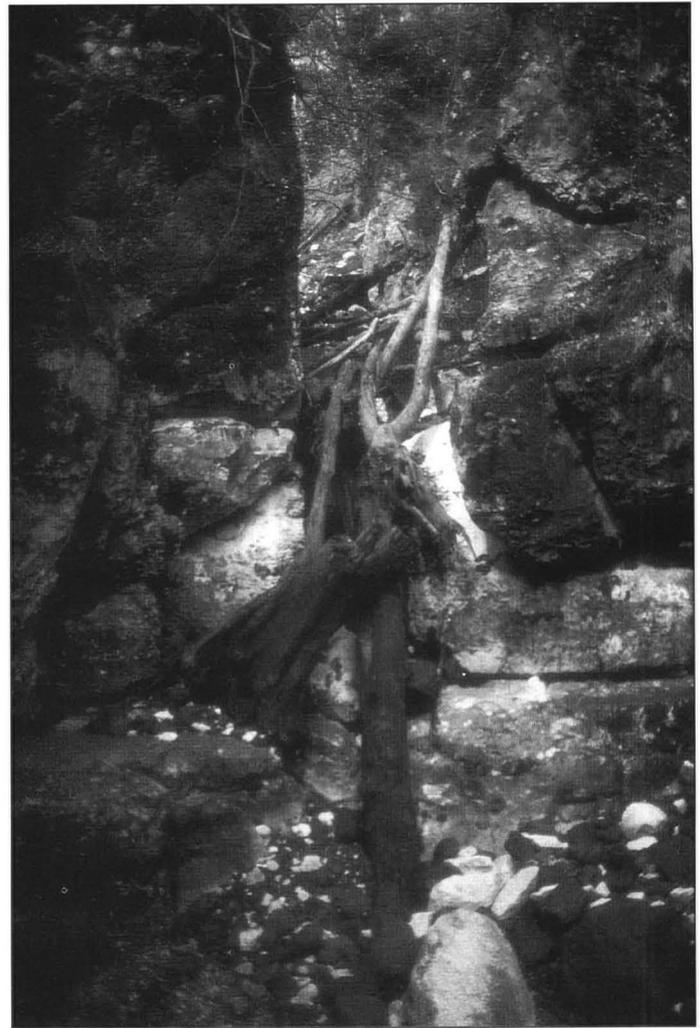
To date the cave has been entered via three entrances, although some of these are frequently blocked by flood debris, requiring digging. Flood debris (large tree trunks) is frequently seen wedged in the gorge some 3m above the entrances, indicating that they are under up to 3m of water during flood conditions.

Cave description

The passages in Black Burn Cave are guided by the major joint sets and alternate between sections of vadose and perched phreatic passage. In addition to the entrance series, there are several avens that lie on the guiding joints and bring trickle inlets and coarse clastic sediments into the main conduit.

A series of joints is seen in the north and south cliff sides at a narrowing of the gorge 80m downstream from the waterfall and low water river sink. There is a 3m vertical drop in the stream bed at this point. Access to the cave is via a number of the enlarged joints in this area. Upstream of the 3m waterfall, an enlarged joint leads to a 4m climb down into a chamber. The joint is known to continue south but is currently choked.

Downstream of the 3m waterfall is another prominent joint, through which access to the cave was possible after digging in 1994. This joint, initially horizontal and restricted (1.5m high by 40cm wide), develops after a short distance into a series of short vertical rifts dropping a total of 12m into a chamber. The chamber roof holds three other prominent avens,



Narrow limestone gorge (and flood debris) at the entrances to Black Burn Cave. Looking upstream from just below the entrance (on left).

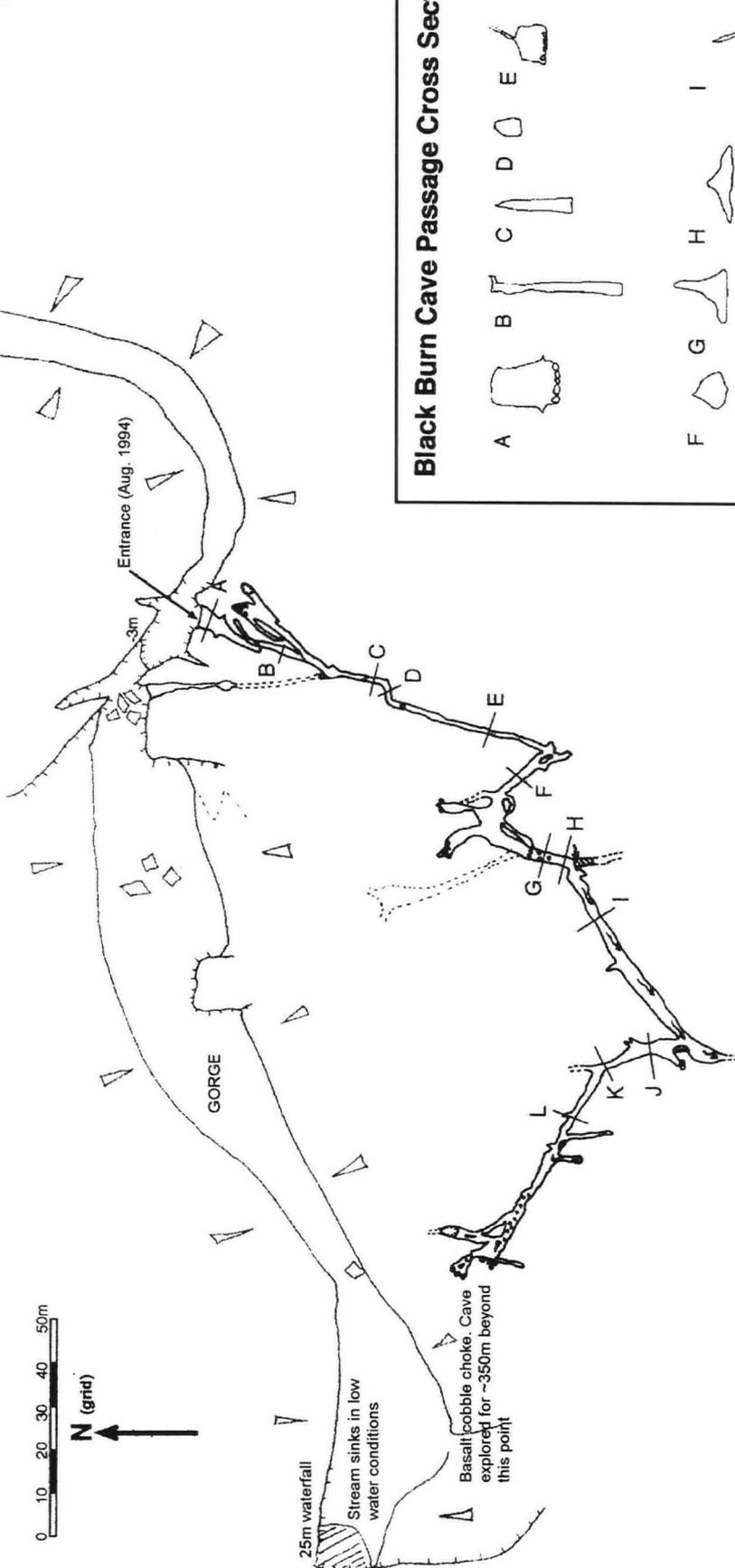
the most southerly of which leads back up to the choked joint above the 3m waterfall. In this entrance series of shafts, there are a number of large limestone collapse boulders and smaller basalt cobbles.

From the entrance climbs, the passage follows a southerly trending joint and the vadose nature of the passage changes to phreatic for 15m, to where the joint guidance changes from south-southwest to the southeast. Here the passage is a fine phreatic tube with well-developed scalloping and a small (15cm wide x 10cm deep) vadose trench. This leads to an aven chamber after 10m. It is possible to climb up from this chamber into a series of passages heading north towards the gorge.

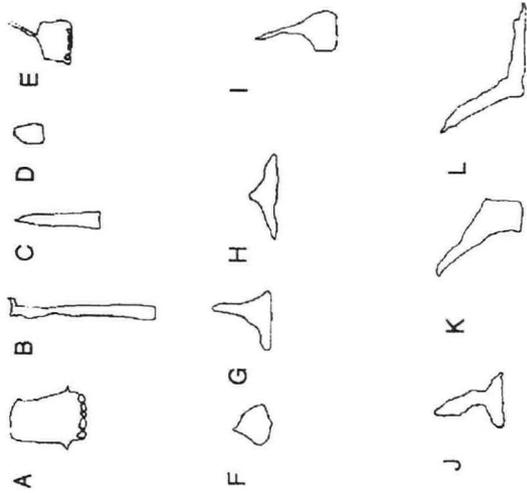
From this chamber a vadose passage with a notch at stream level follows a southerly trending joint to a point where a small inlet feeds into the main conduit. In very dry conditions this is the first flowing water encountered in the cave. The stream leaves the main conduit 20m downstream at another change in joint guidance. The passage is widened into a notch at floor level, particularly where basalt cobbles form the passage floor.

The passage now trends northwestwards, maintaining proportions of 4m high by 1m wide, until another aven chamber is encountered. This is the current limit of the survey, the aven being partially filled with basalt boulders that have prevented a continuation of the survey. The location of this point is close to the base of the basalt waterfall on the surface. Bad air, due to decomposition of vegetation trapped in the choke, was reported here in 1996 (Cockfield, pers. comm.)

Black Burn Cave
 Carrivereagh, Carrlough, Co. Antrim
 GR D2462E 2117N
 Surveyed to BCHA 5b by T. Fogg and J. Kelly, Aug. '94



Black Burn Cave Passage Cross Sections



Projected elevation on 180°

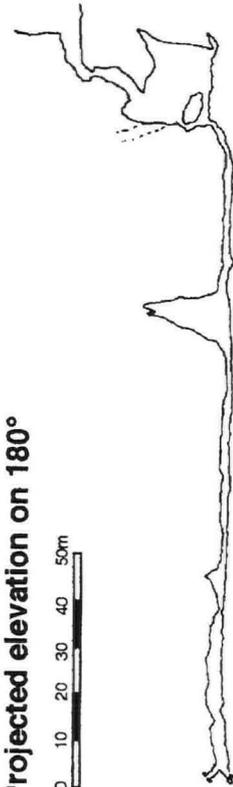


Figure 3. Survey of Black Burn Cave, Carrivereagh, Carrlough, County Antrim, Northern Ireland. Surveyed to BCHA Grade 5c by T. Fogg and J. Kelly, 1994.

Phreatic tube in Black Burn Cave, developed on a joint and showing a marked dissolution notch, due to the passage floor being armoured by basalt cobbles.



Campbell (1984) reports that, beyond the boulder blockage, the general direction of the unsurveyed passage is northwest and similar in character to the surveyed cave. After the first sump, the passage entered from Black Burn enters a larger main stream passage. In this passage, vadose sections between the sumps reach a maximum of 6m by 2m, significantly larger than in the surveyed section of cave. There is also a significant loss of height in this section, including a 4m waterfall. Exploration was halted at the fourth sump (sump 5 in all) in the main stream passage.

Foaran Rising

Foaran Rising is the source of the Foaran River, probably the shortest river in Northern Ireland, at approximately 70m from source to high water mark. It is located at 5.57m amsl at D3006E 2436N, near Garron Point, where the stream resurges from a pool some 2m by 3m at the base of a 3m-high white limestone scarp. There is evidence for listric slippage of the limestone on the "Lias Clay" at this locality. The stream bed is composed of fossiliferous "Lias Clay" and the rising is impenetrable. During high rainfall conditions the rising responds rapidly. Water turbidity increases in flood conditions, indicating that flow-through times from the sinks feeding it are likely to be much shorter than one week.

BIOSPELEOLOGY

The northeast Antrim karst area lies some 150km from the main karstified Carboniferous limestones of northwest and central Ireland. It was hoped that this isolation might have allowed a unique fauna to develop in the Antrim area. Troglonenes are carried into Black Burn Cave by the stream, bringing organic material into the system to provide nutrients for populations within the cave. The cave regularly floods completely and the habitat is very dynamic. This, in conjunction with the short time period since the last glaciation (c12,000 BP), may have prevented cavernicolous faunas developing at this locality.

Biospeleological observations and collections were initiated in the Black Burn Cave system as part of the Earth Science Conservation Review. A small faunal collection was made, and identification of the specimens was undertaken by Dr. R. Anderson of the Department of Agriculture.

A ground beetle, *Trechus fulvus*, was collected from basalt boulders on the stream bed 20m from the entrance. This species is recorded very sparingly from the upper shore and above on rocky coastlines around Ireland (Johnson and Halbert, 1902). Records are mostly of single specimens taken under boulders or at the mouths of rivers. The genus is, however, possibly partly subterranean (Dr. R Anderson, pers. comm.) and has been recorded from three caves in County Clare (Hazelton et al, 1974). It is therefore thought to maintain cavernicolous populations in Ireland (Chapman, 1993).

A collembolan, *Anurida thalassophila*, was collected from a static pool 15m from the entrance. This species is found in coastal areas of Ireland and is probably largely subterranean, as it is blind (Dr. R Anderson, pers. comm.). This collembolan was previously unrecorded from Irish caves.

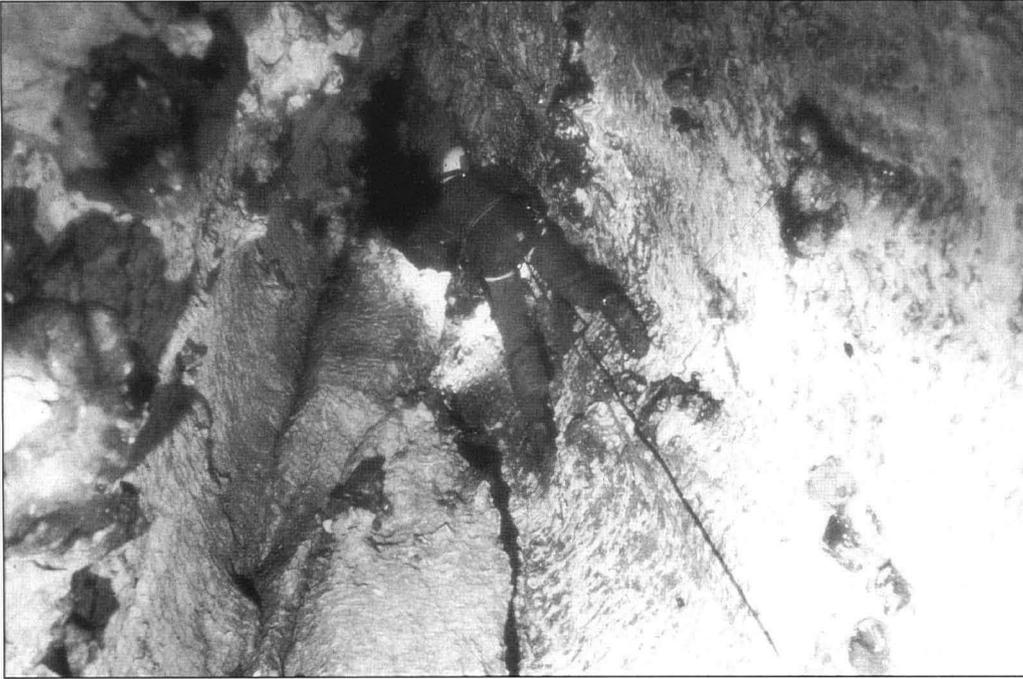
A crane fly, *Thaumastoptera calceata*, was collected 30m from the entrance. This common species is found around boggy springs and is almost certainly a troglonene.

In a static pool 80m from the entrance, a large population of flat worms was observed grazing on the clastic sediments on the bottom of the pool and on the underside of the surface tension film. Specimens were collected and identified as *Phagocata vitta*, which is commonly found in spring waters in Ireland.

During the early exploration of the cave a number of individual pallid Brown Trout, *Salmo trutta*, were observed in the cave and, during a recent visit to the site, a dead specimen was found in a dried-out pool 20m from the entrance. These fish probably enter the cave by accident.

ADDITIONAL SITES IN THE GARRON POINT-TIEVEBULLIAGH AREA

There are many sites with minor karstic features, some of which are of speleological interest. These are summarised here, with brief descriptions and interpretations. The list is not intended to be exhaustive, and it is probable that many other sites are present.



1. Red Hall Estate. D 450E 954N.

One major gorge feature with rising at Chalk/"Lias Clay" contact. A number of sinks occur to the south of the gorge and are presumably linked.

2. North of Ballycarry Village, southwest of Red Hall.

A major sink, which is apparently substantial enough to allow access, has been reported in this area (I. Enlander, pers. comm.).

3. Tievebulliagh area D193E 263N

A series of solution dolines and sinks is located to the south of the escarpment line at the basalt/Chalk contact.

4. Carrivemurphy Pot:- D267E 244N.

First descended by Kevin O'Hagan, this lies approximately 10m above the stream bed in a small scarp on the western side of Cushenilt Burn. It is 16m deep with a ledge at 7m. The shaft splits at the bottom into two shallow pots choked with gravel. There are some speleothem deposits developed to the left of the entrance. The site appears to be an abandoned sink, truncated by valley deepening and retreat of the waterfall at the head of the valley.

5. Shaft on bank of the Ardclinis Burn

This is a 22m deep shaft choked with gravel approximately 6m above the stream bed in the valley side. As in the case of Carrivemurphy Pot, this site appears to have been abandoned following valley deepening and retreat.

6. Glenballyeamon and Glenarriff.

There are a number of immature sinks and small remnant caves in these areas (K. O'Hagan, pers. comm.).

TERTIARY PALAEOKARSTS

Introduction

Considerable evidence (summarised by Smith and McAlister, 1987) exists for a period of emersion and erosion of the Ulster White Limestone Formation, prior to the eruption of the Antrim Basalts. A distinctive layer of "clay with flints" is interbedded between the Ulster White Limestone Formation and the Antrim Basalts. This is composed of flints, commonly rotten in character, interbedded with red lateritic muds and silts, which are commonly coarsely laminated. This lithology is interpreted as comprising resistant flints, which have been weathered from the Chalk during

emergence, in a matrix of lateritic muds and silts derived from Tertiary soils and/or volcanic ash from the initial Tertiary basaltic eruptions on the Antrim Plateau.

Such an emersion period with widespread exposed carbonates would be expected to produce karst features within the carbonates, although the extensive areal extent of the Antrim Basalts means that any such features are only likely to be exposed in coastal cliffs and quarries that expose the basalt/limestone contact.

Fissures filled with Tertiary sediments have been reported from Magheramorne Quarry near Larne (Savage, 1957) although it could not be proved conclusively that these fissures were Tertiary in origin. During investigations of the potential catchment for the Black Burn Cave system, a number of palaeokarstic features, of definite Tertiary age, were examined at several localities. A preliminary list and description of the features examined is given here, although it should be stressed that this is merely a record of chance discoveries and that there may be a much wider range of such features along the Antrim coast.

Doline

A coastal scarp in the Lower Basalts and Ulster White Limestone Formation exposes a large cone-shaped depression in the upper surface of the Ulster White Limestone at D280E 250N. The depression is approximately 10m deep and is infilled by horizontally bedded lateritic deposits containing flint cobble horizons. This depression is interpreted as a doline, on the upper surface of the Ulster White Limestone Formation, that has been infilled by laterite and derived flints prior to being buried beneath the Lower Basalts.

Cave

At D2677E 2459N, on the eastern side of Cushenilt Burn (a steep-sided narrow valley on the northwestern margin of the Garron Plateau), a cavity infilled by red lateritic muds and silts with flint nodules was recognised on the vertical southeastern side of the valley. The valley is formed along the line of a fault with a southeasterly downthrow of approximately 25m. The infill sediments are generally massive, but show some poorly developed horizontal lamination in places. The cavity is approximately 3m high by 1.5m high and has the characteristic shape of a phreatic tube.

Tertiary palaeo-cave passage infilled with flints, clays and lateritic muds, exposed in the valley side at Cushenilt Burn.



This feature is interpreted as a phreatic cave that developed before the initial Tertiary volcanism, as part of a palaeokarst system within the Ulster White Limestone. It has subsequently been infilled by laterites and flints weathered from the chalk, and the palaeokarst has then been buried under the basalts.

DISCUSSION

Few cave systems developed in Cretaceous carbonates are recorded in Britain and Ireland, and at present Black Burn Cave is the longest and deepest explored cave system known from carbonates of this age. Beachy Head Cave, Sussex (Reeve, 1981), is the second longest at 353m.

Lowe (1992) reviewed the question of cave development within Cretaceous chalks and suggests that similarities could exist between the speleogenesis of Black Burn Cave, Beachy Head Cave and other dissolutional cave systems within chalk rocks. These potential similarities hinge upon the existence within the rock successions of horizons that favour inception of dissolutional voids. The earliest phases of cave development are guided by these "inception horizons", which allow establishment of a secondary (cavernous) permeability in rocks that though initially porous and homogeneous display only a limited permeability. Once the processes associated with void inception have opened incipient drains along these more susceptible horizons, the processes more normally associated with cave development begin to operate.

Lowe (1992) pointed out that the apparent complexity of Black Burn Cave, with several vertical drops and sumped sections, was strongly suggestive of a situation where a single inception horizon has been translocated by minor faults, so that the earliest underground drainage utilised a combination of routes along the actual horizon and along fractures that linked the horizon at different levels. Within the entrance pitches of Black Burn Cave, however, no offset of flint bands is seen across the fractures on which the vertical cave is developed. The total

depth of the cave from the main sink at the basalt/white limestone contact to Foaran Rising, at the white limestone/"Lias Clay" contact can be explained adequately by the regional dip, and no significant faulting needs to be invoked.

It is therefore probable that a number of inception horizons at different levels are involved, with short vertical sections formed on major joints linking horizontal sections developed within a number of more favourable horizons within the limestone. The contact between the white limestone and the "Lias Clay" may be particularly significant in this respect. It is important to note that in this type of situation the primary porosity of the chalk (whether this be the <5% characteristic of the Ulster White Limestone or the 15 - 45% more typical of the chalks of southeast England) has no bearing upon the initial progress of speleogenesis. It has commonly been assumed that caves will not form in chalks because their porosity favours establishment of diffuse rather than conduit flow, but this view may be misguided (Lowe, 1992). Despite the relatively high porosities of all chalks, their primary permeability is low, and it is the dissolutional widening of fissures and favourable bedding planes that allows development of a significant secondary permeability.

It is possible that Black Burn Cave is the only major active cave developed within the Cretaceous white limestones of County Antrim, although the presence of karst features in other parts of the Antrim Plateau suggests that other systems may be present.

ACKNOWLEDGEMENTS

This paper is based on part of the Earth Science Conservation Review (Karst Geomorphology of Northern Ireland). Funding towards this publication was received from the Environment and Heritage Service, an Executive Agency within the Department of the Environment (Northern Ireland). Much useful information on a number of minor sites and early exploration was kindly provided by Mr. Kevin O'Hagan. Faunal identifications and helpful comments on the biospeleology of Black Burn Cave were provided by Dr. Roy Anderson of the Department of Agriculture. Mr. Mark Kelly conducted the field work for the water tracing experiments.



Doline developed on the upper surface of the Ulster White Limestone Formation, now exposed in a coastal cliff section at Garron Point. The doline is filled with bedded clays and flints (derived by Tertiary weathering of the white limestones), Tertiary soils and volcanic ashes.

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“Hidden” shafts at the base of the epikarstic zone: a case study from the Sette Comuni plateau, Venetian Pre-Alps, Italy

Alexander B KLIMCHOUK¹, Ugo SAURO² and Marco LAZZAROTTO²

¹ Institute of Geological Sciences, National Academy of Sciences, PO Box 224/8, Kiev-30, 252030 Ukraine

² Department of Geography, Padova University, Via del Santo 26, 35123 Padova, Italy

Abstract: The epikarstic zone differs structurally from the underlying bulk rock mass, reflecting the higher degree of fissuring and diffuse karstification due to relaxation, weathering and active dissolution that encompass this uppermost layer. Hydraulic conductivity contrasts between this zone and the bulk rock mass below cause some groundwater storage in the epikarstic zone and flow concentration at its base. These hydrological features favour the development of shafts at the base of the epikarstic zone, and during the early stages of their development these shafts have no open entrances to the surface. The nature of the epikarstic zone is well illustrated on the Sette Comuni Plateau, where its thickness and properties depend mainly upon lithology and initial structural partings within the uppermost (exposed) rock unit. Observations in open-pit quarries indicate the presence of many shafts, with blind terminations at their tops, that have developed downward from the base of the epikarstic zone. The appearance of an eventual karst landscape depends strongly upon the relationship between the denudation surface and these “hidden” shafts at the base of the epikarstic zone.

INTRODUCTION

The specific hydrological role of epikarst and related morphogenetic mechanisms are pre-conditioned by the contrast in joint density and hydraulic conductivity between the uppermost layer of the karst rock and its bulk mass at depth (for details see the recent review in Klimchouk, 1995). This contrast forms due to weathering processes affecting the uppermost layer. The layer can be developed as a zone several metres thick that is highly fissured and diffusely karstified, as compared to the underlying bulk mass of the rock, and is distinguished as the epikarstic zone. Because of its high and relatively uniform hydraulic conductivity, the epikarstic zone receives diffuse recharge from the surface. As a general rule, the joint density and diffuse karstification diminish rapidly with depth, so that permeability also decreases rapidly in this direction.

Beneath the epikarstic zone a rock mass is much less uniformly fractured; it is divided by major joints and faults into large blocks, so that infiltration into the top of the epikarstic zone is much easier than drainage out of it (Williams, 1983). Considerable distinction in the structure and permeability between the epikarstic zone and underlying block zone brings about an important percolation threshold, and causes a temporary aquifer to form within the epikarstic zone. This aquifer is perched above the vadose zone (at the top of the block zone) and leaks into it along major tectonic joints and faults that possess high hydraulic conductivity. Two major features of epikarst hydrology are storage and flow concentration at the base of epikarstic zone.

Flow concentration causes speleogenetic development to occur at the base of epikarstic zone. A model for this development was suggested initially to explain the formation of “hidden” shafts and shafts without entrance catchments in the Kyrktau Plateau of Central Asia (Klimchouk et al, 1979 and 1983), and developed later to describe a more universal mechanism of speleogenesis in the upper part of the vadose zone (Fig.1; Klimchouk, 1987, 1989, 1995). The stage of “hidden speleogenesis” is characterised by the development of shafts at a certain depth below the surface, at the base of the epikarstic zone (stages A and B on Fig.1). The fact that shafts without open entrances are known in some karst massifs, accessible through occasional over-widened fissures in karren fields, was rather strong evidence in support of the suggested model, although such examples are relatively scarce due to the access difficulties peculiar to shafts at this stage of “hidden speleogenesis”. However, speleological explorations provide many examples of shafts in the upper part of the vadose zone, accessible from the bottom or from side “windows”, that extend upward and have blind terminations somewhere near the surface.

Maucci (1975) and Rossi and Sauro (1977) made early attempts to explain their genesis, implying bedding plane circulation and local perching of water at the top of the vadose zone. Shafts without entrance catchments are more common (stage C on Fig.1), positioned in the landscape in such a way that they receive no surface run-off at all. For such cases the assumption is commonly made that catchments did exist in the past, then were scoured and removed by various processes.

Recent study of epikarst in limestone quarries on the Sette Comuni Plateau (Altipiano di Asiago) has provided much excellent evidence of speleogenesis at the base of the epikarstic zone.

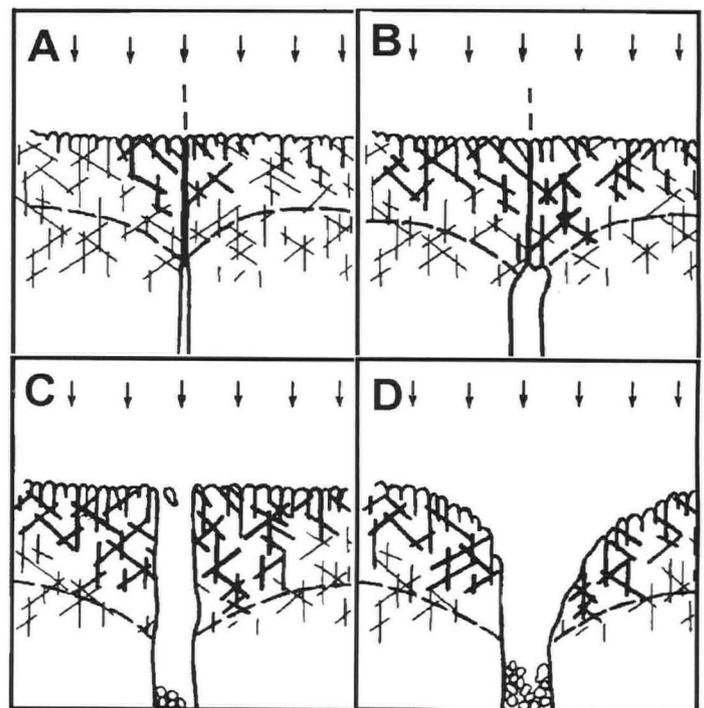


Figure 1. Model of the development of shafts at the base of the epikarstic zone and associated landforms at the surface (modified from Klimchouk et al, 1979). A = initial stage; B = “hidden” shaft stage; C = collapse stage; D = doline stage.

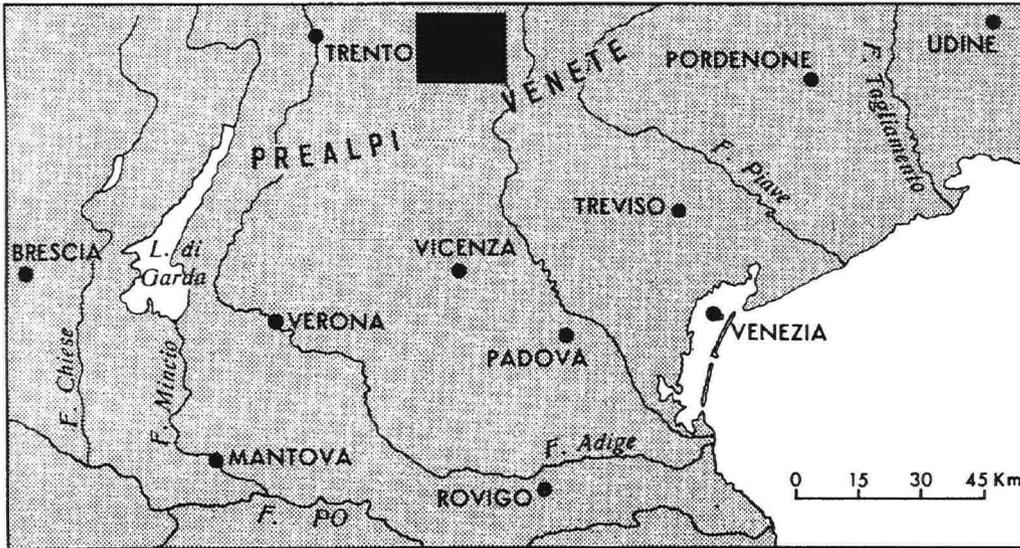


Figure 2. Location of the Sette Comuni Plateau.

GEOLOGICAL AND GEOMORPHOLOGICAL SETTINGS OF THE STUDY AREA

The Sette Comuni Plateau is the widest mountain group in the Venetian Fore-Alps, a belt of karst morpho-units in the Southern Alps (Fig.2). The main plateau surface extends for more than 600km² at elevations ranging between 1000 and 2300m a.s.l. The southern plateau, marked by dry valleys and ridges, the central basin (basin of Asiago), influenced by periglacial processes, and the northern plateau, sculpted into a glaciokarstic relief, present well-defined morphological styles (Sauro, 1993).

From the morpho-tectonic point of view, the Sette Comuni Plateau is a large tectonic wedge, delimited by a thrust on its southern side and by a backthrust on its northern side. The plateau structure corresponds with the nearly tabular form of thick upper Triassic and lower Jurassic carbonate rock units. The lowermost formation at outcrop is the 600 to 800m-thick Dolomia Principale (equivalent to the German "Hauptdolomit") of the Upper Trias (Barbieri, 1993). Above this lies the Calcarei Grigi di Noriglio Formation of the Lias (Lower Jurassic), with a thickness of about 300 to 600m. These latter limestones differ from the underlying formation in their more distinct stratification and an abundance of fossils. Overlying these is the Rosso Ammonitico of the Dogger and Malm, 20 to 35m thick and composed mainly of nodular micritic limestones rich in ammonites. It is divided into lower (massive) and upper (thickly-bedded) units by a closely stratified and densely fractured intermediate unit (the "Fogaro") 2 to 4m thick (Fig.3). Above the Rosso Ammonitico is the Biancone, a chalk-like limestone, 200 to 300m in thickness, comprising whitish, closely stratified and densely fractured marly limestones, with conchoidal fractures.

Various geomorphological styles are distinguished throughout the plateau, providing expression of the prevailing influence of different processes during recent morpho-dynamic phases (Sauro, 1993). Within the Sette Comuni Plateau landscape, the Dolomia Principale and Calcarei Grigi di Noriglio are at outcrop in the northern plateau, which represents structural and sub-structural surfaces moulded by karst and glacial erosion. The Calcarei Grigi di Noriglio of the southern plateau are exposed in surfaces of periglacial and karst origin. The Rosso Ammonitico crops out mostly in the southern plateau and in the southern part of the northern plateau. It gives rise to structural and sub-structural surfaces that are intensely karstified locally, to form limestone pavements and "rock cities", the typical surface expressions of epikarst. The Biancone, at outcrop in the central basin of Asiago, is characterized by a highly dissected relief with rounded ridges and small V-shaped dry valleys.

The southern plateau of the Sette Comuni Mountain Group exhibits relatively few surface karst landforms; in particular, there are only a few dolines. On the other hand, numerous mainly vertical shafts open up on

the plateau. The apparent contrast between the development of the underground drainage network and the scarcity of surface forms can be explained by the relative immaturity of the karst landscape. The highest density of dolines and shafts is found near the stratigraphical or tectonic limits between the Biancone and Rosso Ammonitico and between the Rosso Ammonitico and Calcarei Grigi.

QUARRYING AND LITHOSTRATIGRAPHY OF THE EXPOSED UNITS

Numerous large quarries on the central and southern plateau have been opened, mostly during the last 20 years, to provide solid blocks of the lower Biancone and Rosso Ammonitico (Barbieri and Ginevra, 1993). The quarries allow observation both of the geological characteristics of the limestone sequence and of the features of the epikarstic zone at the transition from the Calcarei Grigi to the Rosso Ammonitico and the transition from the Rosso Ammonitico to the Biancone.

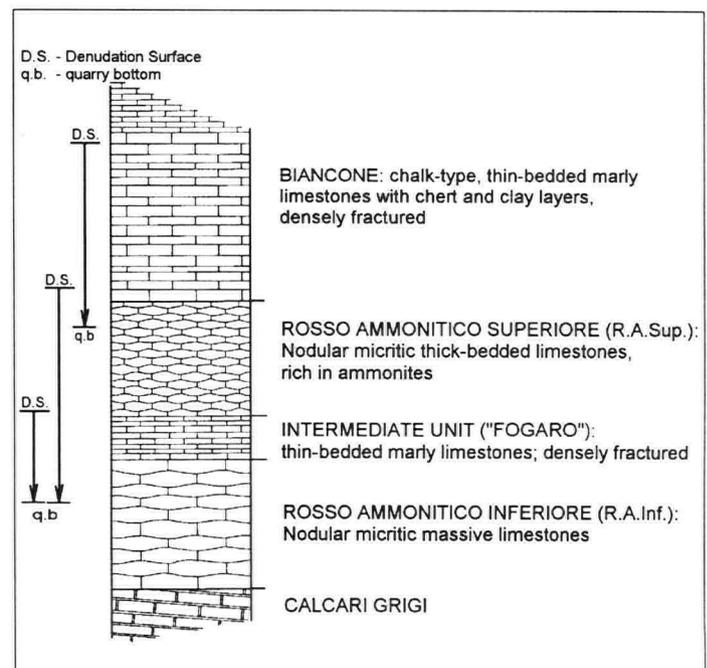


Figure 3. Lithostratigraphy of the formations exposed in the Sette Comuni Plateau (modified from Barbieri and Ginevra, 1993).

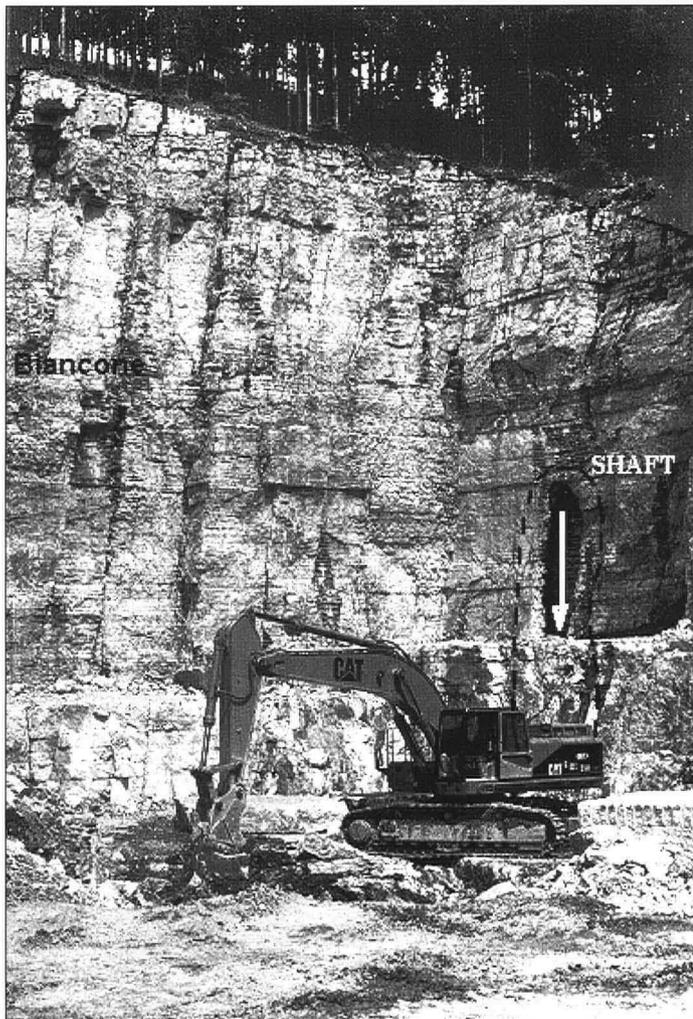


Plate 1. Col dei Remi di Sotto quarry, the Sette Comuni Plateau. The Biancone is exposed in the walls, and the Rosso Ammonitico Superiore at the quarry floor. The shaft is opened up by the wall and extends down into the Rosso Ammonitico Superiore.

The following units (listed in descending order) are cut by quarries and crop out at the denudation surface (Fig.3):

- the middle Biancone: a pure fine-grained white limestone, more densely stratified and fractured; the fracturing is due both to tectonic stresses and to weathering processes; some clay beds are also present;
- the lower Biancone: a pure fine-grained white limestone 20 to 30m in thickness; individual beds are 20 to 100cm thick, with sparse fractures;
- the upper Rosso Ammonitico (R.A.Sup.): a nodular micritic limestone about 10m thick, with individual beds from 10 to 30cm in thickness;
- the intermediate Rosso Ammonitico ("Fogaro"): 1 to 10m thick, made up of densely stratified and fractured limestones (beds from about 5 to 15cm in thickness), with interbedded clay and cherty beds;
- the lower Rosso Ammonitico (R.A.Inf.): a nodular micritic limestone, 5 to 15m in thickness; the component beds are massive, 30 to 150cm thick, with sparse fractures.

Depending upon the position of the denudation surface, the epikarstic zone encompasses one of these units or parts of different ones.

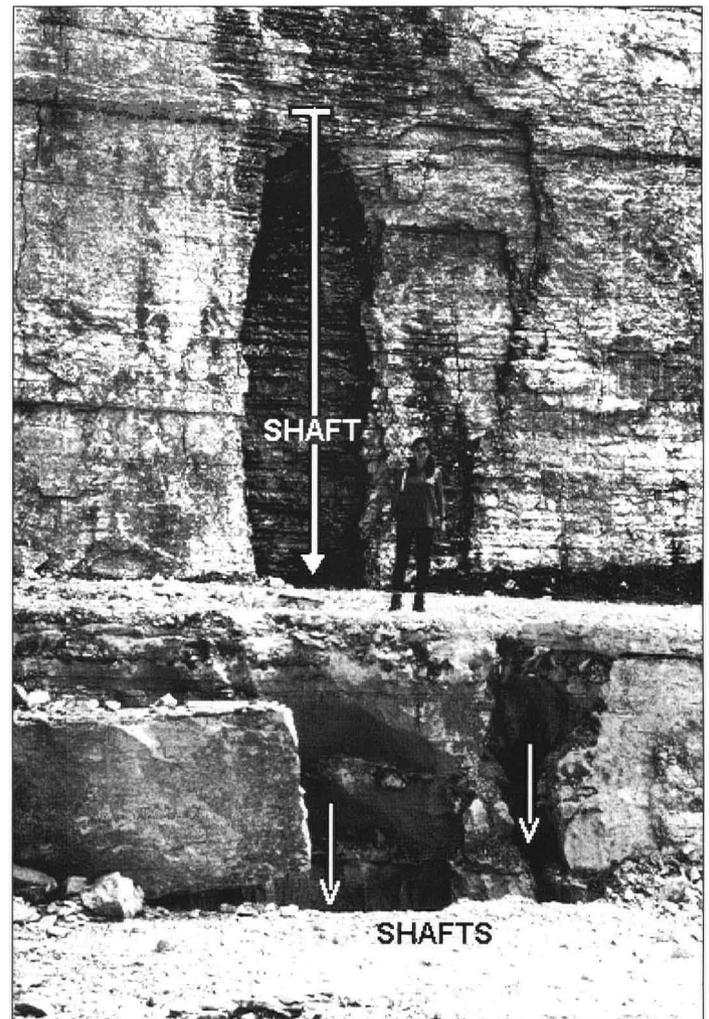


Plate 2. The shaft opened up in the wall begins in the Biancone and extends down into the R.A.Sup. The shafts on the quarry floor are cut by the quarry level at the top of the Rosso Ammonitico Superiore.

THE EPIKARSTIC ZONE AND "HIDDEN" SHAFTS AT ITS BASE

The thickness and the structure of the epikarstic zone vary according to the morphological position of individual sites, but the most striking variations are determined by lithological and structural peculiarities of the exposed and immediately underlying rock units. The lower limit of the zone is marked by more or less distinct decrease in fissuring density and in fissure widths. Within the zone dispersed karstification is expressed mainly by solution-widening of numerous fissures. At the base of the epikarstic zone flow becomes increasingly concentrated, and receives its morphogenetic expression in the formation of shafts. Numerous well-developed shafts with no upward connection to the surface have been found in all the quarries inspected. Some of the most representative situations are described below.

Col del Remi di Sotto quarry

The quarry is positioned on the ridge slope developed within the Biancone limestones, which here are 10 to 25m thick (Plate 1). The epikarstic zone encompasses almost the full present thickness of the Biancone. The main quarry levels are cut along the contact between the Biancone and the underlying upper Rosso Ammonitico, or 2 to 5m beneath it. Numerous shafts with cut heads are opened to these levels

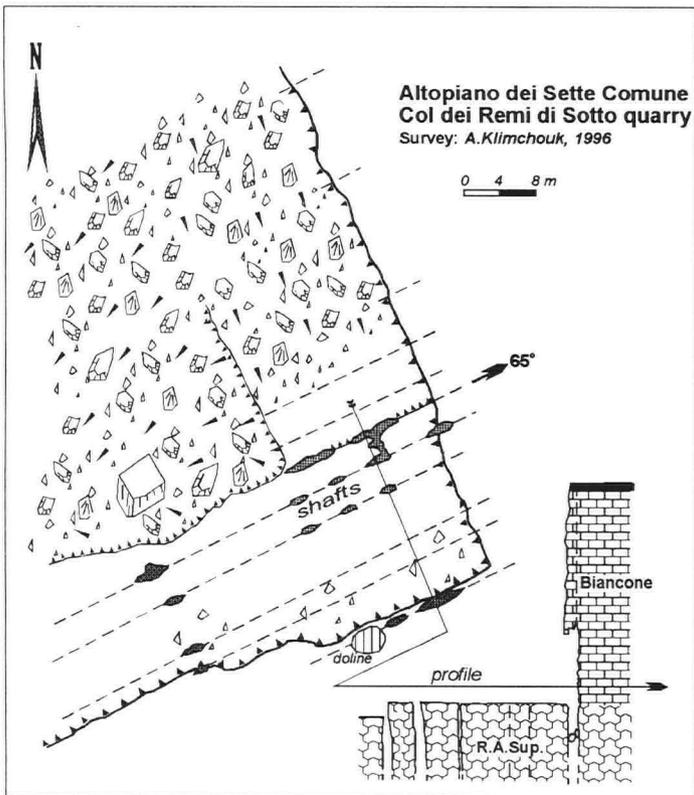


Figure 4. Plan and profile showing shafts at the base of the epikarstic zone in the Col dei Remi di Sotto quarry.

(Fig. 4), extending down to the Rosso Ammonitico, at depths ranging from several to about 20m, depending upon the degree of blockage by quarried material. Their typical cross-sectional dimensions are 2 to 5m along the long axis and 1 to 2m along the short axis. Shafts are developed along vertical tectonic fissures striking at 65-245° and are arranged in an orthogonal pattern in plan view.

Some shafts are exposed in the quarry walls (Plates 1 and 2), showing that their blind heads begin in the base of the Biancone, 10 to 20m below the surface. Blind terminations are of gothic-arch shape and the controlling tectonic fissure is always recognisable on the ceiling. Water percolation has been observed at the heads of some shafts, even when there had been no precipitation for at least three days before the inspection. Thin calcite flowstone displaying re-dissolution features occurs at the shaft heads. The shaft walls show well-developed dissolutorial relief with vertical grooves, sharp edges between them and insoluble (chert) nodules protruding from the walls.

Pozzette Col d'Asiago quarry

As with the site described above, this quarry lies on the gentle slope developed within the Biancone limestones, which here are 15 to 25m thick (Plate 4). The quarry levels expose the surface of the underlying upper Rosso Ammonitico, or cut some metres down into it. Shafts with cut heads are abundant on the quarry levels; those opened up at the base of walls show the position of blind heads at the lower part of the Biancone, some 10 to 20m below the surface (Plates 3 to 5). Characteristics of the shafts are basically the same as those in the previous quarry.

Kaberlaba quarry, face 1

The quarry is located on a gentle slope. The upper Rosso Ammonitico is exposed up to the natural surface and has a local thickness of 10 to 15m. It is underlain by the "Fogaro" unit, here 3 to 4m thick, that is closely stratified and fractured. Below this lies the lower Rosso Ammonitico, which is also cut by the quarry (Plate 6). The epikarstic zone encompasses most of the thickness of the upper Rosso Ammonitico and ceases several

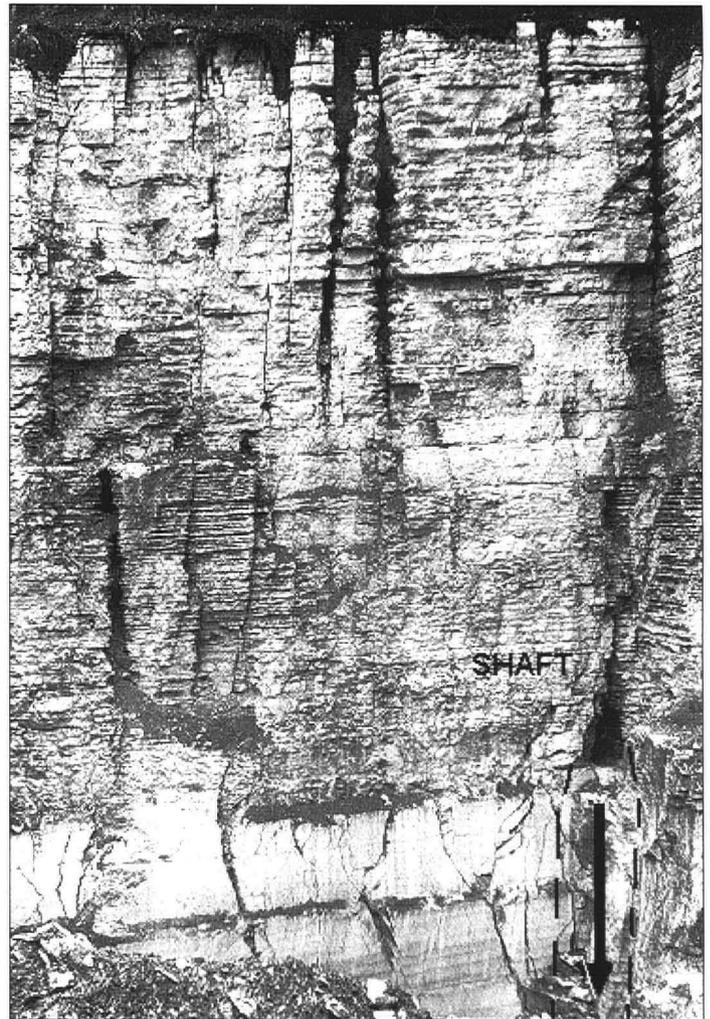


Plate 3. Pozzo col d'Asiago quarry, the Sette Comuni Plateau. The Biancone is exposed in the walls, and the Rosso Ammonitico Superiore on the quarry floor. The shafts begin in the lower part of the Biancone and extend down into the Rosso Ammonitico Superiore.

metres above its lower contact. It is remarkable that numerous shafts, marking the transition from diffuse to concentrated flow, begin within the "Fogaro", despite the fact that the "Fogaro" is much more densely fractured than the overlying unit. In other words, once focussed at the base of the epikarstic zone, the flow remains focussed, even if it enters a unit of high and diffuse initial permeability, causing a pronounced speleogenetic effect. In the shafts here considerable water percolation has been observed, despite a lack of precipitation in the days before the inspection.

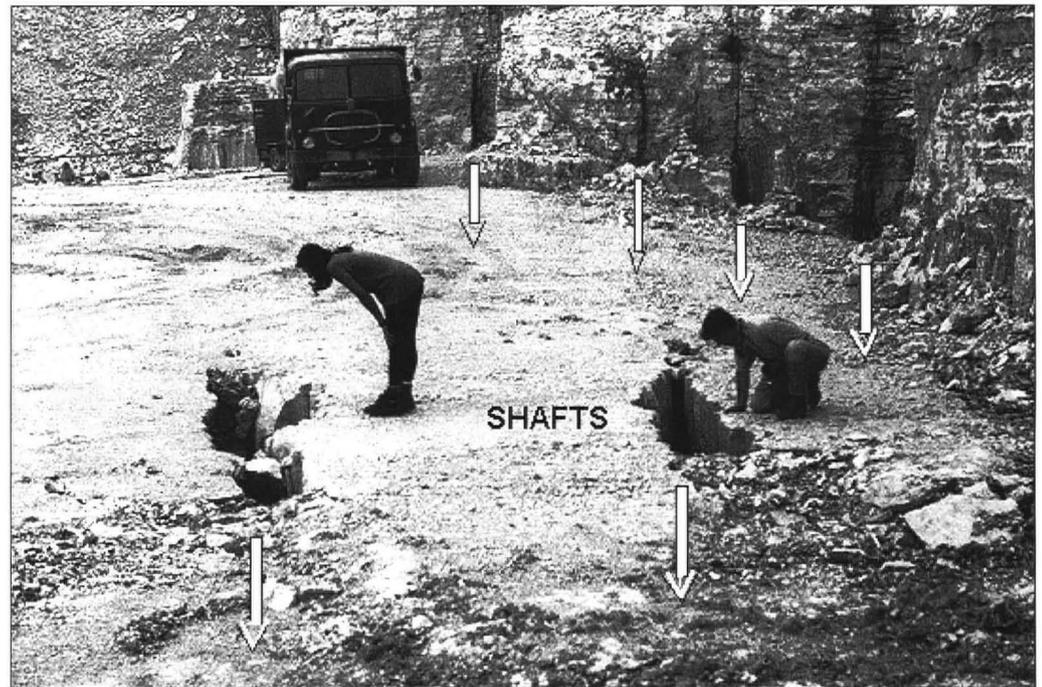
Kaberlaba quarry, face 2

In this case the top of the "Fogaro" unit, 3 to 4m in thickness, is exposed at the denudation surface and the bed is underlain by massive limestones of the lower Rosso Ammonitico. Because of the high initial fracture density of the "Fogaro", the epikarstic zone is developed only within these marly limestones, being limited downwards by the top of the massive lower Rosso Ammonitico (Plates 7 and 8). Shafts have formed, beginning immediately beneath the "Fogaro". It can be seen clearly on Plate 8 that minor subsidence takes place above such shafts, giving rise to initial dolines on the surface.

ANALOGIES WITH THE ALTI LESSINI MOUNTAINS

Geomorphological studies of the Alti Lessini Mountains, another karst massif of the Venetian Pre-Alps that displays lithological and structural conditions similar to those of Sette Comuni Plateau, allow interpretation

Plate 4. Shafts with cut heads are intersected by the main level of the quarry cut at the top of the Rosso Ammonitico Superiore.



of surface karst features in the context of the epikarst concept and relationships with shaft development. Most of the dolines here develop when and where the denudation surface (ridges, slopes, valley bottoms) approaches the stratigraphical transition from the Biancone to the Rosso Ammonitico during its progressive lowering. Examination of the different development stages of dolines and of their morpho-structural positions suggests that these forms develop as hydrogeological structures, before they become morphological features. The typical morphological positions of the dolines of Alti Lessini are: a) valley slopes, b) structural surface, c) fault line depression, d) valley bottom (Sauro, 1973, 1974, 1995). It seems certain that these types of doline are the external expression of the evolution of important drainage structures (shafts) at the base of the epikarst, linked to the transition between a dispersed circulation within the epikarstic zone developed in the Biancone and a more focussed circulation in the Rosso Ammonitico (Fig.5).

Also in the Alti Lessini, most of the cave entrances occupy the same morpho-structural position as the dolines (Sauro, 1973). The only difference is that the shaft entrances open to the denudation surface some metres lower, as related to the lithostratigraphic level. Speleological observations

indicate that many karst shafts extend upwards, having an ogival cross-section corresponding to a pointed arch (Maucci, 1975; Rossi and Sauro, 1977). At their tops water seepage occurs, supplied from the overlying epikarst zone. Dolines develop when these hypogean forms intersect or are intersected by the denudation surface; this commonly occurs due to collapse.

DISCUSSION AND CONCLUSIONS

The above examples demonstrate that the thickness and form of the epikarstic zone depend mainly upon the initial discontinuity structure within the exposed and immediately underlying rock units. When a densely stratified and fractured unit (as compared to the underlying rocks) is exposed at the surface, the epikarstic zone tends to encompass its entire thickness; its lower limit is commonly underlined by, and coincides with, the contact between units. This is the case when typical features of an "idealised" epikarst are inherited largely from the initial permeability contrast between units. The thickness of the zone can vary considerably in this case, for example from 3 to 4m in the Kaberlaba face 2 (the

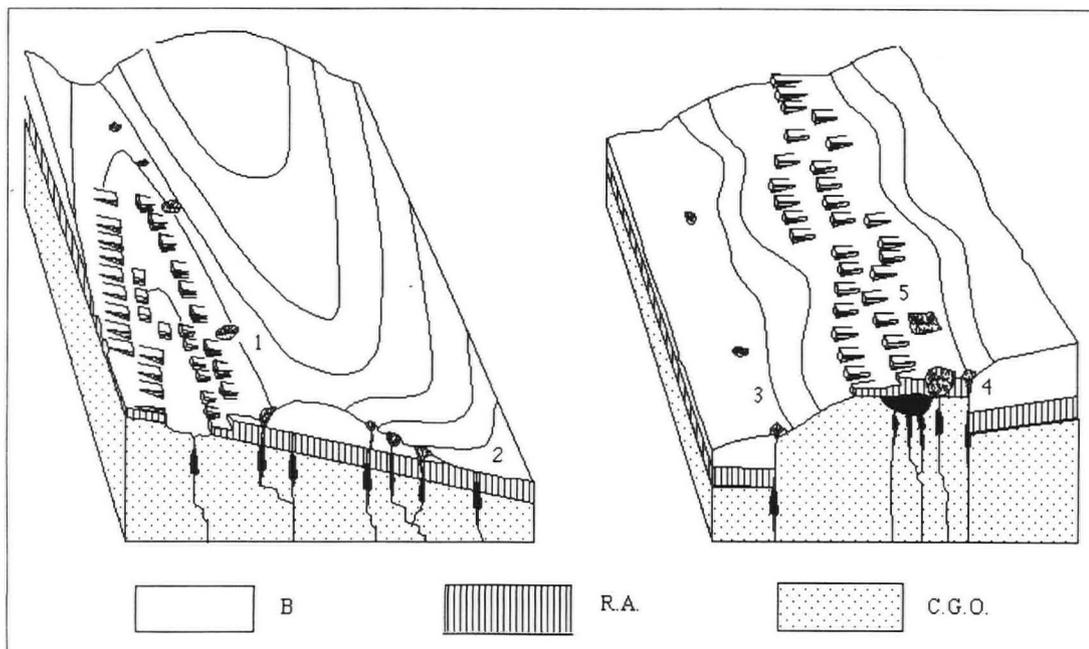


Figure 5. Typical morpho-structural positions of dolines and shafts in the Alti Lessini Mountains. Formations: B = the Biancone; R.A. = the Rosso Ammonitico; C.G.O. = the Calcari Gialli Oolitici.



Plate 5. The blind head of a shaft opened up at the base of the wall, Pozzette Col d'Asiago quarry.

“Fogaro” at the top) up to 15 to 20m in the Col del Remi di Sotto and Pozzette col d'Asiago quarries (the Biancone at the top).

In cases where a relatively thick and massive limestone is exposed at the denudation surface, the epikarstic zone develops within it to some depth with a less distinct lower limit. Even if a unit of high and diffuse initial permeability lies somewhere beneath this limit, flow maintains its focussed character formed at the base of the epikarst (Kaberlaba face 1). In all cases, the general hydrological function of the epikarstic zone remains the same: retention and focussing of initially dispersed flow. The focussing of flow at the base of the epikarstic zone causes speleogenetic development, manifested as the formation of shafts along major tectonic fissures.

Observations in quarries have revealed that “hidden” shafts (those having no natural upward connection to the surface) are abundant on the Sette Comuni Plateau. All their characteristics fit well with the previously suggested model of speleogenesis at the base of the epikarstic zone, and strongly support its validity. The fact that unambiguous field evidence has been obtained from karst areas of very different geological/climatic contexts (from the Kyrktau Plateau in the semi-arid Tjan-Shan Mountains

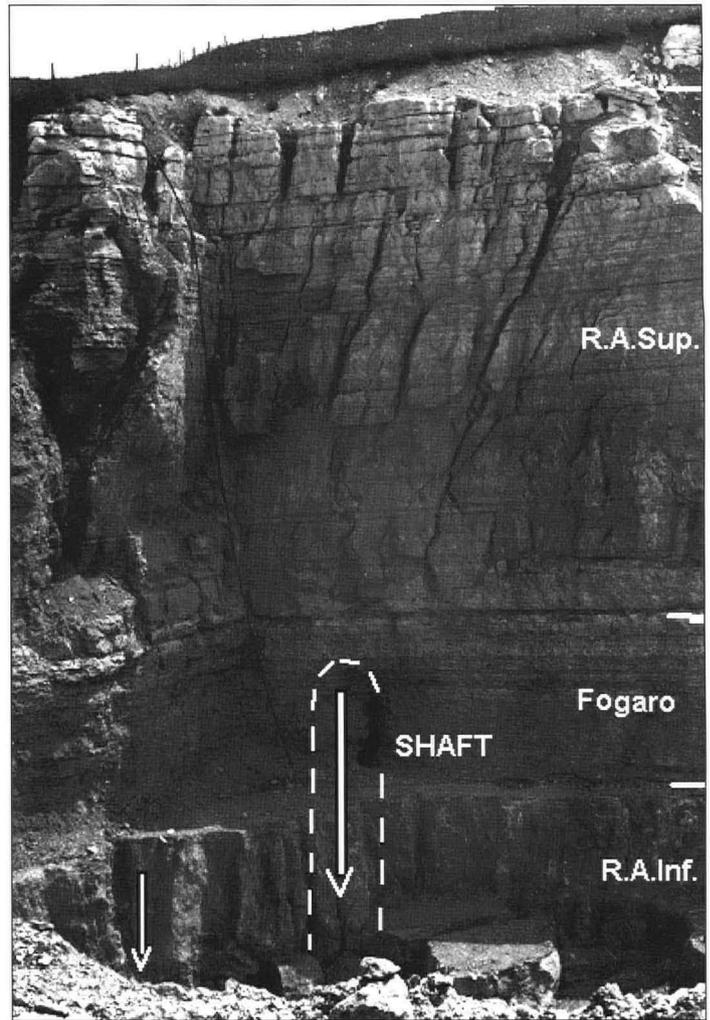


Plate 6. Kaberlaba quarry, face 1, the Sette Comuni Plateau. The Rosso Ammonitico Superiore is exposed in the upper part of the walls, the Fogaro unit and the Rosso Ammonitico Inferiore in the middle part and at the base. Epikarst is developed in the Rosso Ammonitico Superiore, shafts begin in the Fogaro and extend down into the Rosso Ammonitico Inferiore.

of Central Asia to the Sette Comuni Plateau in the humid Southern Alps) suggests a broadly universal applicability for the model. The presence of well-expressed dissolutional sculpting of shaft walls, as well as of calcite flowstone with re-dissolution features, indicates that present shaft flow at the base of the epikarstic zone remains, at least under prevailing flow regimes, aggressive with respect to limestone, and is capable to further dissolution.

In general terms the epikarst concept suggests that surface karst forms reflect, through specific mechanisms of epikarstic morphogenesis, the permeability structure of the vadose zone (Williams, 1983; Klimchouk, 1987, 1995). The model of epikarst morphogenesis described treats the development of karren fields (“rock cities”), hidden shafts, collapses and dolines as successive stages of the epikarstic morphogenetic process (Klimchouk, 1995). On the Sette Comuni Plateau, the abundance of “hidden” shafts and shafts “recently” opened to the surface, the widespread occurrence of karren fields and “rock cities”, together with the scarcity of dolines, indicate that the karst landscape is relatively immature.

ACKNOWLEDGEMENTS

This article is a slightly modified version of a similar paper that was delivered at the 4th International Karstological School, “Classical Karst”, at Postojna, Slovenia, in June 1996. The organisers and attendees of the School are thanked for providing the opportunity and an audience for presentation of these ideas. The authors gratefully acknowledge the constructive comments of Professor Dr France Šušteršič, who reviewed the paper, and the assistance of the Editor, Dr D J Lowe, in finalizing the article.

Plate 7. Kaberlaba quarry, face 2, the Sette Comuni Plateau. The Fogaro unit underlies the surface and is exposed in the walls, with the Rosso Ammonitico Inferiore at the base. The epikarstic zone encompasses the Fogaro. Shafts begin from the bottom of Fogaro and develop in the Rosso Ammonitico Inferiore.



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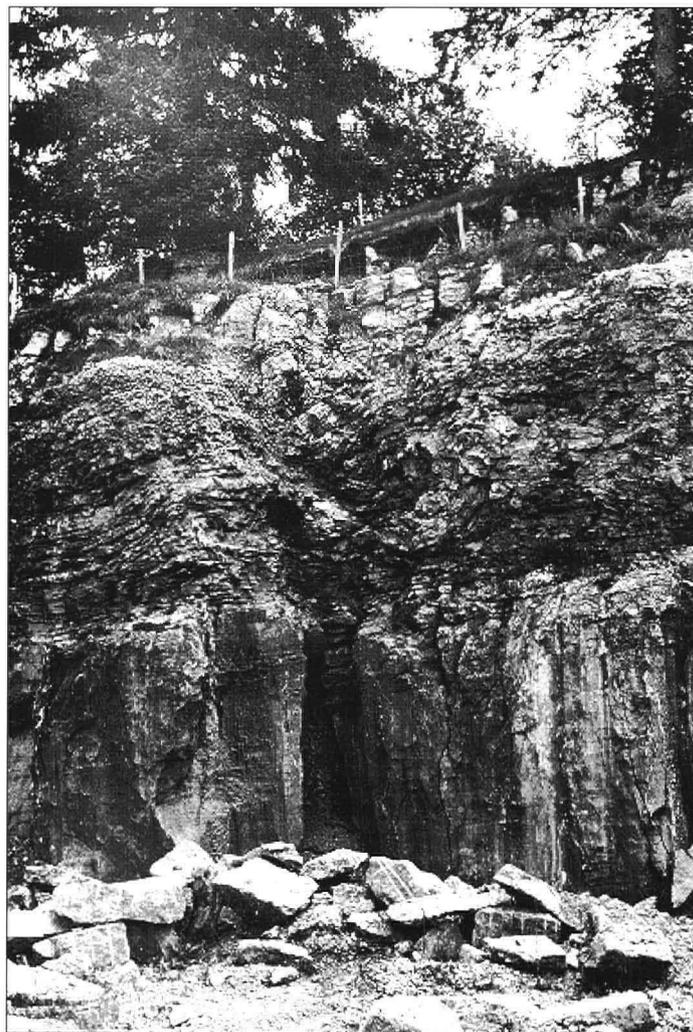


Plate 8. Kaberlaba quarry, face 2. A shaft at the base of the Fogaro caused subsidence of the overlying rocks and initiated a small doline at the surface.

Mineralogy of speleothems from caves in the Padurea Craiului Mountains (Romania), and their palaeoclimatic significance

Bogdan Petroniu ONAC

Department of Mineralogy, Babes-Bolyai University, Kogalniceanu, 1.3400 Cluj, Romania.

E-mail: bonac@bioge.ubbcluj.ro

Abstract: A short introduction to the geological and speleological settings of the Padurea Craiului Mountains (King's Forest Mountains) of Romania is provided. Against this brief background the results of recent mineralogical, crystallographical and geochronological studies in this area are presented and discussed. Details of minerals known from underground localities, here and elsewhere in the world, are set out as an appendix. The value of cave speleothem dates in providing an indication landscape evolution rates is also considered.

High up in the North in the land called Svithjod, there stands a rock. It is a hundred miles high and a hundred miles wide. Once every thousand years a little bird comes to this rock to sharpen its beak. When the rock has thus been worn away, then a single day of eternity will have gone by.

(from *The History of Mankind*, Hendrik van Loon)

INTRODUCTION

The Padurea Craiului Mountains (hereafter PCM) lie in north-western Romania. As part of the Apuseni Mountains they cover about 750 km², extending far towards the west, almost reaching Oradea (Fig. 1). They are bounded by the Neogene Vad Basin (of the Crisul Repede River) to the north, by the Neogene Beius Basin (of the Crisul Negru River) to the south, and they border on the volcanic Vladeasa massifs in the east, with the Iada Valley acting as a demarcation line between the two massifs.

The PCM form a geologically well-defined unit that, morphologically speaking, boasts two distinct main subunits, conventionally separated by the Vârciorog-Dobresti alignment: the PCM in the east and the hills of the Padurea Craiului (Vârciorog, Tasad, Valani) in the west. The salient morphological and hydrogeological elements of the PCM are represented by a broad development of Mesozoic carbonate rocks whose outcrop covers 330 km².

Although the average altitude is only 505 m, the PCM are well-defined in terms of relief, owing to the low altitudes that characterise the depressions surrounding them to the north and south.

The great variety of rocks making up the geological structure, and their mosaic-like disposition (a result of advanced tectonic processes that have affected the massif) are expressed morphologically by a chaotic relief that lacks any generally unique feature. A massive, upstanding relief, including sandstones, conglomerates and eruptive rocks, alternates with a lower relief of karst capture depressions and the flat relief characteristic of karst plateaus that are strewn with sinkholes.

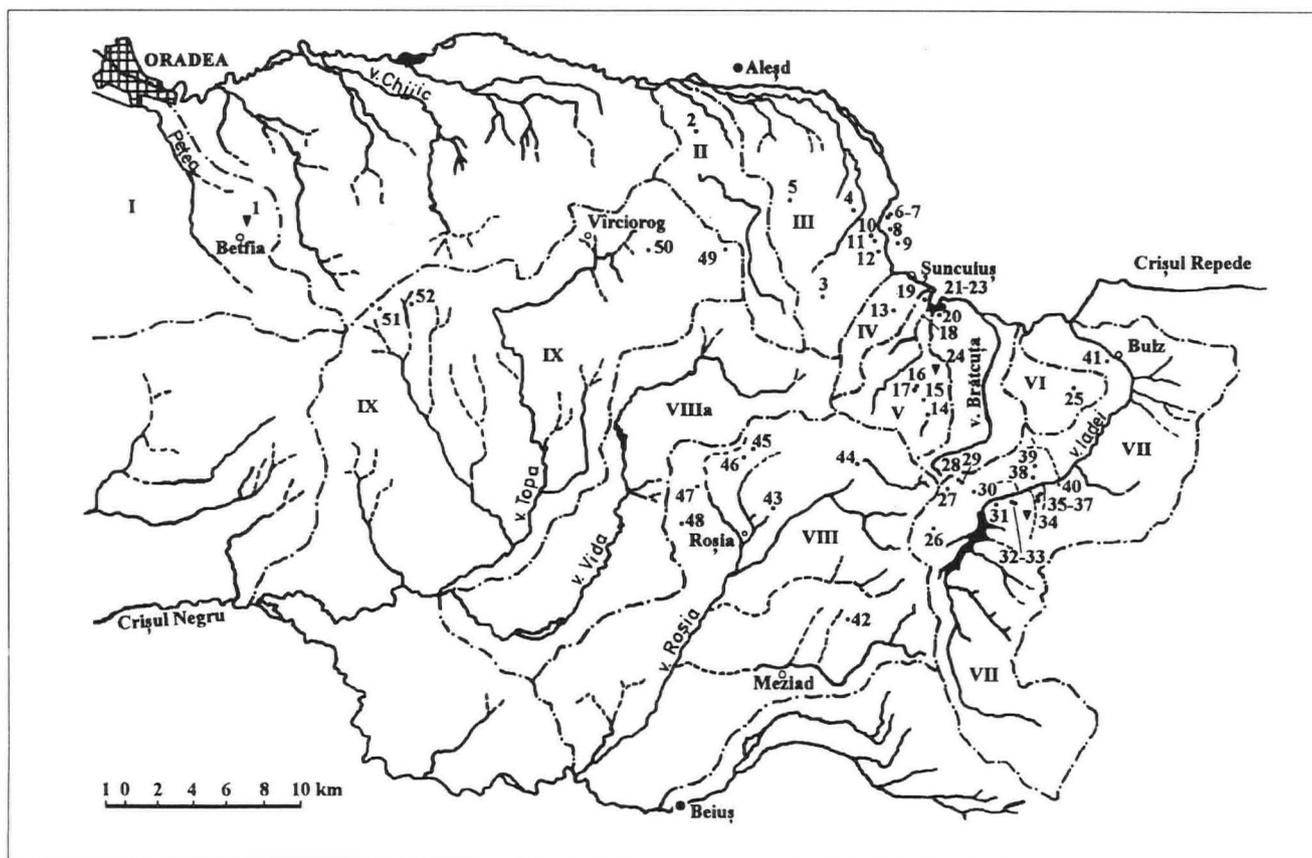


Figure 1. Map of the Padurea Craiului Mountains with the location of the studied caves and potholes. After Rusu (1988).

A substantial part of the population is engaged in exploiting bauxite deposits (which are scattered throughout the massif), refractory clay deposits (situated east and south of Suncuius) and the limestone and clay used as raw materials at the cement factory in Alesd.

THE GEOLOGY OF THE PADUREA CRAIULUI MOUNTAINS

The PCM are formed mostly of deposits belonging to the Bihor Autochton. Small areas of deposits ascribed to the Codru Nappes, as well as eruptive rocks of the Vladeasa banatitic massif, can also be found on the southern and south-eastern sides (Ianovici et al, 1976).

The sedimentary formations of the Bihor Autochton trace out a vast monocline with a crystalline basement in the east and south-east, covered, towards the north-west, by younger and younger formations, to Eo-Cretaceous deposits in the Baile 1 Mai ("May Day") area. Towards the north-east and south-west the geological structure of the PCM is buried beneath the Neogene deposits of the Vad and Beius depressions.

Three thick carbonate sequences of special karstological importance are distinguished within the sedimentary succession of the Bihor Autochton:

- a Triassic carbonate sequence includes up to 1,500m of Anisian limestones and dolomites and Ladinian limestones, and is underlain by Permo-Werfenian rocks;
- a Jurassic carbonate sequence, averages 150 to 200m in thickness and is formed of Middle and Upper Jurassic limestones, separated from the Triassic carbonates by a Lower Jurassic detrital formation;
- a Cretaceous carbonate sequence overlies the Jurassic carbonates discordantly. It includes two packages of Lower Neocomian to Aptian limestones and is covered by an Aptian to Albian, predominantly detrital, complex.

Around the villages of Tasad and Stracos, Valenas and Dramba (1978) and Onac and Istvan (1994) described interesting karst features developed on Neogene (Badenian and Sarmatian) rocks.

Quaternary formations in the PCM are represented by periglacial (Bleahu, 1964) and deluvial-karst deposits, alluvial and proluvial deposits.

THE KARST OF THE PADUREA CRAIULUI MOUNTAINS

The PCM boasts the largest density of exo- and endokarst features in Romania. The 1981 inventory listed 680 caves, of which 17 are longer than one kilometre (Goran, 1981). The number of caves is now far greater.

The genesis of the PCM karst is linked to the emergence of the Bihor carbonate platform, firstly in Upper Triassic times, then from the end of the Jurassic and, more particularly, during the current phase, which began during the Paleogene (Rusu, 1988). Assessment of the age of the karst features generated during the first two stages is very difficult, possible only in areas where the deposits were not subjected to subsequent erosion. The relief-boasting Anisian and Ladinian limestones and dolomites may belong to the first generation; they were subsequently covered by the detrital deposits of the Eo-Jurassic transgression. This situation is well documented in the Suncuius area, thanks to the intensive exploration and exploitation of the fireclay deposits that are characteristic of the local relief (Onac and Popescu, 1991).

The genesis of the bauxite accumulations is linked to the better known second-generation karst. Bauxite exploration revealed a rough depressionary, palaeo-relief, with numerous hollows, dissolution channels and lapies (Orascanu, 1991).

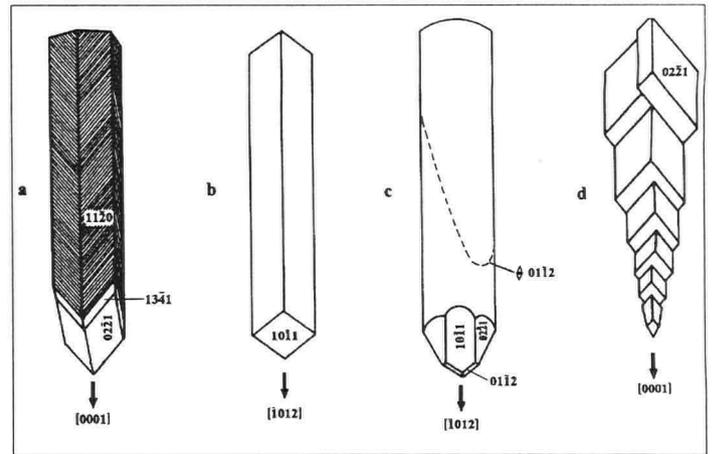


Figure 2. Crystallographic forms identified within different stalactites in Lithophagus Cave.

Undoubtedly, the genesis of most of the karst features covering the entire area of limestone and dolomites is mainly the result of a third stage. This still continues, after having reached a climax during the Pleistocene, when several periods with hydrometeorological conditions highly suitable for karst development occurred.

The speleothems for analysis were collected from 31 caves located mainly in the central and north-north-eastern part of the PCM (Fig.1).

MINERALOGY OF SPELEOTHEMS

Mineralogical and crystallographical investigations of different speleothems revealed several new aspects concerning their morphology and origin. In this paper only the most important results are presented, together with a compiled list of all minerals so far identified in speleothems (see Appendix 1).

Stalactites and stalagmites

Remarkable examples of monocrystalline and polycrystalline calcite stalactites can be seen in Lithophagus Cave. They have been ascribed to four groups, according to their internal crystallography:

- Monocrystalline stalactites* (prismatic or cylindrical) are developed either parallel to the c-axis [0001], or parallel to the edge of the $(10\bar{1}1)$ rhombohedron, which is $[10\bar{1}2]$. All cylindrical stalactites investigated terminated with first order positive $(10\bar{1}1)$ or negative $(01\bar{1}2)$, $(02\bar{2}1)$ rhombohedron faces. Prismatic stalactites grow parallel to the c-axis, so that the hexagonal prism $(11\bar{2}0)$ will develop. The negative rhombohedron $(02\bar{2}1)$ develops on the tip of the prism (Fig.2a). Elongation of the prismatic stalactites after the edge $[01\bar{1}2]$ of the $(10\bar{1}1)$ rhombohedron forms prisms with rhombic contours. On the tip of these prisms the most developed face is that belonging to the (1341) scalenohedron (Fig.2b).
- Stalactites made up by *symmetric growth* (twins) can be either deprived of clearly developed crystallographical faces, or they can be formed by symmetric growth of 2 to 3 crystals twinned after $[01\bar{1}2]$ (Fig.2c).
- Stalactites made up by *parallel growth*. The dominant crystallographical form is the negative rhombohedron, where development is along the c-axis (Fig.2d).
- Stalactites composed of aggregates with *different orientations*, may have cylindrical or oval cross-sections. These are formed by a large number of crystals showing independent centres of crystallization.

In Lithophagus Cave several **triangular monocrystalline stalagmites** were identified. Most of them are prismatic and the crystallographical form that prevails is either the di-trigonal prism(21 $\bar{3}$ 0) or a very steep form of scalenohedron(13 1 $\bar{1}$ 4 1). The decreasing diameter of the 98cm-long stalagmite from 16cm at its base to 11.5cm at the top can be explained by the presence of this steep form of scalenohedron. The angle of this face against the vertical axis is about 1.5 to 1.6°. The positive rhombohedron (10 $\bar{1}$ 1) was recognised on the top of the stalagmite.

In Ponoras Cave, soda straws and stalagmites, a few centimetres in length, made up of **goethite** were found. Most of these speleothems are red-brown to dark-brown and the material is soft enough to crumble to a smear between the fingers. The origin of goethite is ascribed to oxidation of pyrite that occurs in the black clay deposits from this cave. In Romania this kind of speleothem was described only from caves developed on marble and pyroclastic rocks (Nedopaca, 1982; Naum and Butnaru, 1967).

Rimstone dams

Beautiful examples of shallow, tightly-curved dams, made up of goethite, are found in Ponoras Cave. The same type of speleothem, but consisting of black **allophane**, was identified in Wind Cave. **Kaolinite** and **halloysite** were also found in association with allophane. The first mineral that precipitated was halloysite in an acidic environment, followed by kaolinite and allophane. The source of these minerals may be the fireclay deposits located just above the cave.

Coatings and crusts

Gypsum crusts are the most common and widespread sulphate speleothem in Wind Cave (Onac, 1991). The following types were found:

- **Granular crusts** (Fig.3a), are made of isometric, tabular and/or curved crystals. Prismatic or tabular crystals (Fig.3c) 0.5 to 6cm in length usually appear on the gypsum crusts' surface. The most developed faces are (110) and (010).
- **Fibrous crusts** (Fig.3b), are made of fine crystals (2cm in length) that grow perpendicular to the cave wall.
- **Balloon-like crusts (wasps nests)** (Fig.3d) form by direct precipitation of gypsum microcrystals at the surface of the slowly seeping solution that emerges from small cracks and pores in the cave bedrock.

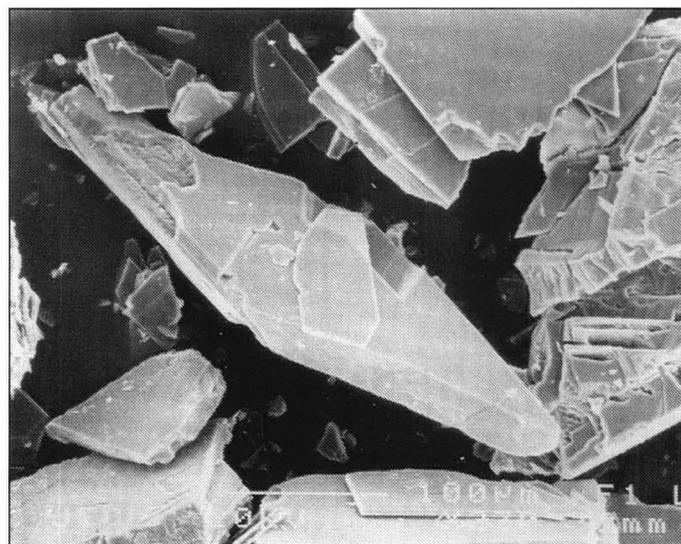


Plate 1. Pseudomorphosis of hydroxylapatite after brushite (Ciur-Izbuc Cave).

Hydroxylapatite occurs as red-brown to almost black millimetre-thick crusts in several caves from the PCM (Igrita, Stracos, Meziad, Galaseni, Bulz and Betfia) (Onac and Bengescu, 1992). The process of hydroxylapatite formation in these caves was as follows: percolating water passing through bat guano leaches away the nitrogen compounds, leaving phosphorus to combine in various proportions with calcium and hydroxyl ions available from the limestone bedrock (Hill and Forti, 1986).

Brushite was found in paragenesis with hydroxylapatite in Meziad Cave. Both minerals appear as millimetre-thick crusts covering limestone blocks partly buried in the guano. The co-existence of these two minerals gives some information about the cave genetic environment. Brushite and hydroxylapatite form in solutions with acidic and alkaline pH, respectively. Therefore, it is likely that brushite formed at low pH, and hydroxylapatite precipitated successively when the Ca/P molar ratio was favourable (Flicoteaux and Lucas, 1984). It is also possible that brushite transformed into hydroxylapatite.

In Ciur-Izbuc Cave *Ursus spelaeus* bones were found covered by two distinct, superimposed, crusts. X-ray analyses of the internal dark-brown layer indicated the presence of hydroxylapatite, but the scanning electron microscope revealed an atypical monoclinic crystal structure for this mineral. The most likely explanation for this deviant morphology is that hydroxylapatite (a mineral that crystallizes in the hexagonal system) is pseudomorphic after brushite (a mineral that crystallize in the monoclinic system) (Plate 1).

Clay minerals, **birnessite**, **romanechite**, quartz and **wad** were identified by means of X-ray and infrared analyses within some black coatings (on the walls or as stains on speleothems) from Wind Cave. Chemical analyses of the percolating water showed an extremely low manganese content (0.003mg/l), such that the source of these minerals can be explained just as being precipitated directly from the groundwater running through the cave, due to chemical or biological processes (Coman, 1979). The quartz and the clay minerals are allochthonous, being transported into the cave by the percolating water.

Fungites

This new type of calcite speleothem was discovered in Lithophagus Cave. Its shape is very similar to some tree-mushrooms (*Polyporus*). The name **fungite** is derived from the Latin name for mushrooms - fungi. It consists of a spherical disk attached to the cave wall by a very delicate foot. The edge of the disk is gently folded upward and is well-curved (Plate 2). The size of the fungite disk ranges from half a centimetre up to 5cm in diameter.

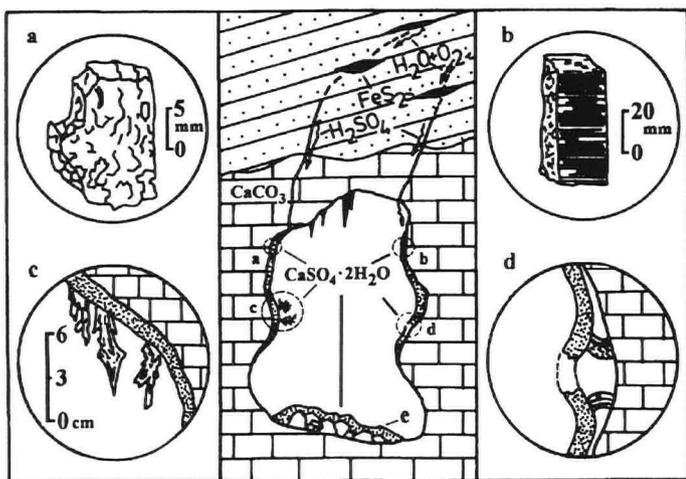


Figure 3. Types of gypsum speleothem studied in Wind Cave and their genesis.

The curved crystals belonging to this category present normal optical behaviour and the position of their indicatrix remains along the crystal. To help understand the mode of curving two composite crystals with different orientations (one was parallel to 100 and the other to 010) were studied. For each crystal the position of the indicatrix was established in 6 different points (the distance from I to VI was just 1.5cm), and the contact surface indices were deduced by reference to the crystallographical elements obtained on the basis of the cleavage plane.

The positions of the contact surfaces were designated I to VI for the main crystal (normal orientation; vertical c-axis) and I' to VI' for the other crystal (Fig.4). It was noted that normals to the contact faces could each be placed to a zone plane with index [112] for the main crystal and [111] for the other crystal. Therefore no regular laws governing twinning were found when the two composite crystals were analysed, so twins are excluded. The directions of growth in points number I, II, IV and VI, marked with squares on Fig.4, describe a zone plane. It changes from one that is close to [101], to one perpendicular to [010], close to the b-axis.

All crystal faces identified on different gypsum speleothems (anthodite and oulopholite) are shown, marked by circles of various sizes, on the stereogram (Fig.4); the larger the circle, the more common the face.

- c) *Crystal growth is interrupted at various development stages and a new, slowly deviating, crystal begins to grow.*

Fibrous anthodites showing a short curving radius were ascribed to this group. Their genesis is controlled mainly by variations in the sulphate solution supply.

Along some prismatic aggregates (at the base or on the gypsum blade sides), in both anthodites and oulopholites, narrow zones with fine- to medium-grained, closely interlocking gypsum crystals (saccharoidal texture) are to be found. Within these small crystals, light-brown liquid inclusions and celestite microcrystals (stronger relief when compared with gypsum) were noticed.

The solubility of celestite in supergene solutions behaves qualitatively somewhat like that of gypsum. In solution it exists as ions, and the quantity of celestite that can be precipitated from a particular solution depends largely upon the temperature, pressure, and salinity, as well as on the ratio of the activity of the alkaline earth to that of sulphate in solution.

As this study strongly indicates the presence of more than one type of solution during the formation of gypsum flowers, it appears likely that mixing has played a role in celestite precipitation. It is supposed that celestite microcrystals were precipitated from residual solutions at different stages.

Inclusions are trapped by the advancing growth surface and variations in either the supply, or the rates of absorption. Following the orientation of the microcrystals and inclusions, it can be stated that the calcium sulphate solution was stored and/or moved upward within the gypsum flowers along these channels with small gypsum crystals.

Kendall and Broughton (1978) found that inclusions in calcite sometimes impeded crystal growth. Discontinuities in the crystal mosaic may therefore occur at these growth surfaces. The inclusions recognized in the gypsum flowers never caused discontinuities that were large enough to define growth-layering.

Based on the crystallographical studies Huff's theory was found to be partly accurate. Deposition of gypsum flowers in a cave environment is due to capillary supply of the calcium sulphate solution producing a gypsum crystal that will grow - as he suggested - from the rock by increments to the base. On the other hand, the curving processes observed are significantly different to those that Huff (1940) claimed.

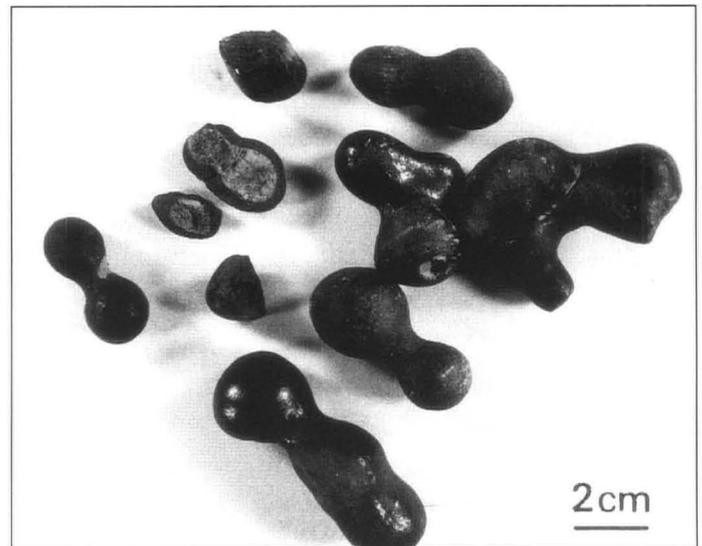


Plate 3. Vadoids made up of goethite and limonite (Stracos Cave).

Most of the anthodites are shown to be composed of groups of crystals that grew in approximately parallel orientation (following one of the mechanisms described in cases a) or b), as a result of the precipitating atomic groups forming nuclei in preferred orientations, governed presumably by different thermo-dynamic conditions.

All gypsum oulopholites follow the growth mechanism described at case a). Dislocations in the crystal lattice rarely influence the curving process. This study indicates that the mechanism by which these speleothems are curved is controlled both by flow rate and by concentration of the calcium sulphate solution. Direction of solution supply, bedrock type and topoclimatic conditions of deposition strongly influence formation of distinctive gypsum crystal aggregates (fibrous and/or prismatic), as described above. Upward movement of solutions through pores or/and capillary channels developed along gypsum crystals may occur. Seeping might also be a process that can contribute to the development of the crystal tip.

Pearls

The so-called **vadoids** (Peryt, 1983) discussed here, are concentrically-banded concretions that form in shallow pools located along the underground stream of Stracos Cave (Plate 3). These speleothems are composed of **limonite** and **goethite** bands, commonly covering fragments of detrital material that act as nuclei. Cave vadoids precipitate from iron-rich colloid solutions that were leached away by the underground stream from Permian formations at outcrop near the cave.

Spar

Truncated and excavated varieties of pool spar occur in Ponoras Cave. The first type forms under the pool-water surface up to the water/air interface, and is typical of pools with a very constant water level (Fig.5a). Development of the second type indicates that the growth rate of the crystal equals the rate of increase in the water level in the pool, or that high supersaturation caused growth layers to spread inward from the edge, thus forming hopper crystals (Fig.5b).

Also, owing to a more or less constant water level on some pools, an even "shelfstone" up to 25 cm wide develops toward the pool centre. It consists of a network of fine crystals having in the horizontal plane either a rhombohedron face (up to 1cm long) or a truncation of one of the rhombohedron faces. Due to a parallel accumulation of some primary crystals that are limited by (h0h1) rhombohedron faces, a coherent platform will appear at the water surface. Very slow CO₂ diffusion out of deeper water zones towards the surface allows the rest of the rhombohedron

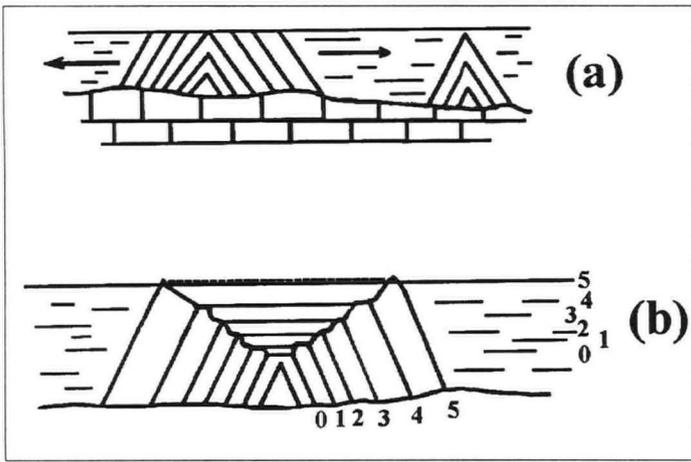


Figure 5. The genesis of truncated (a) and excavated (b) calcite crystals. After Andrieux (1965).

crystal to grow downward and either complete the crystal or contact the pool bottom. The habit of the crystals composing these "crystalline build-ups" is ruled by the presence of the following faces: $(10\bar{1}1)$, $(01\bar{1}2)$ and, especially, $(022\bar{1})$.

Crystallographical observations undertaken on 103 gypsum crystals formed within the sandy clay in Wind Cave revealed 18 different crystallographical forms. The most common are the pinacoid (010) and the prism (120). The tips of both acicular and prismatic crystals are limited by different pinacoids (001), (102), (101) and prisms (011), (122).

The Hettangian clay horizon in Ponoras Cave occurs as two different facies. The main one is represented by a stratum of black clay (0.25 to 1.1 m thick); the other is a fine-grained black clay that has been washed away by the stream and re-deposited on the cave floor. Gypsum speleothems (crystals) were identified in both types of clay, but their morphology is different in each occurrence. Gypsum crystals that grew within the black clay along the wall are randomly distributed and show prismatic habit (Fig. 6). The length of these crystals never exceeds 6cm (usually 4 to 5cm). During the growth process fine particles of clay have been enclosed in the gypsum lattice, causing a high degree of contamination. Very few crystals are clean and transparent.

The other types of gypsum crystal forms under a thin layer (2 to 4mm) of fine black clay on the cave floor. They have an acicular habit (Fig. 7), never exceed 1.2cm in length, and grow perpendicular to the clay surface, with the crystal tip pointing downwards.

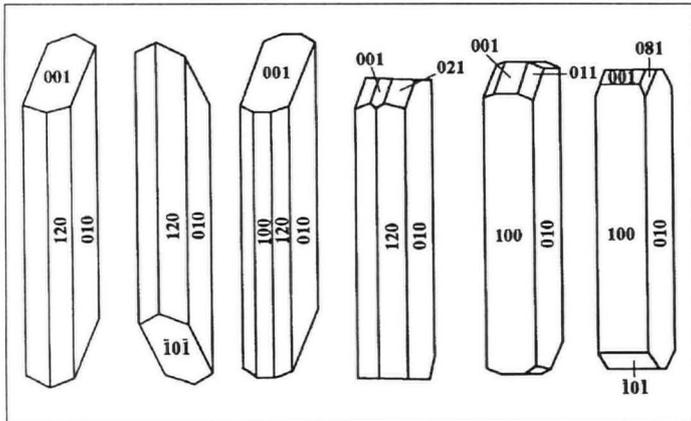


Figure 6. Prismatic gypsum crystals (Ponoras Cave).

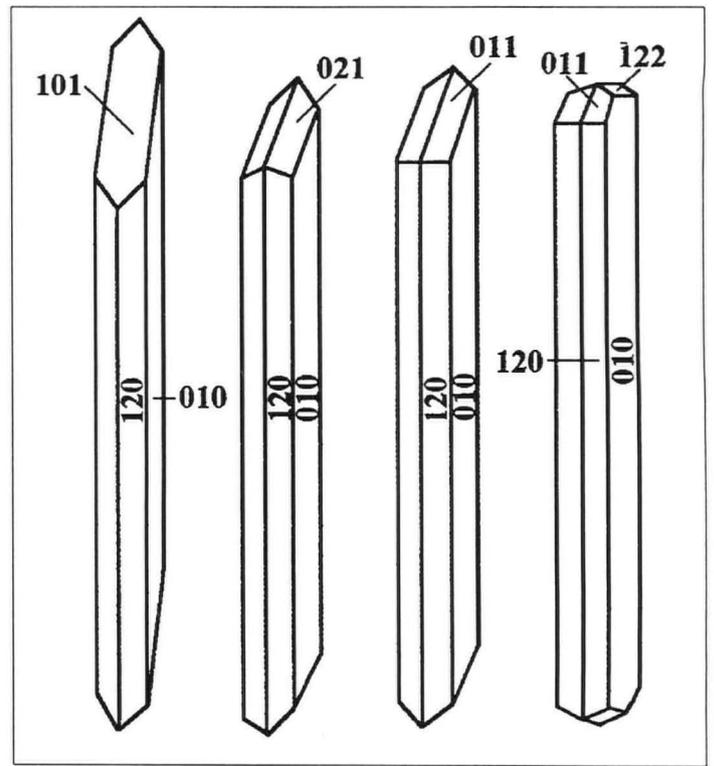


Figure 7. Acicular gypsum crystals (Ponoras Cave).

Over 200 gypsum crystals of both types were analysed, by means of a single-circle reflecting goniometer, to determine their main crystallographical forms. In addition, the persistence and frequency of all these forms, as well as the number of crystallographical forms per crystal, were established.

24 forms of pinacoid and prism were found, the most common of which were: (100), (010), (001), $(\bar{1}0\bar{1})$, $(\bar{1}02)$, $(\bar{1}03)$, $(\bar{1}01)$, and (011), (021), (081), (110), (120), $(\bar{1}22)$ respectively.

The statistical studies rely on two different groups of crystals; the first was represented by 120 crystals that grew within the black clay located along the northern wall, and the other by 91 crystals formed on the clay that accumulated on the cave floor. Statistically speaking, the pinacoid forms occur most frequently.

As shown in Figure 8, the number of crystallographical forms per crystal was plotted against the frequency of combinations. The most common combination for the prismatic gypsum crystals (Fig. 8a) is that made up of 5 to 6 forms (combinations of 3 to 4 forms are less common); 68% of the acicular crystals are built up from 3 forms (a few crystals have 4 forms and even less have 5 or 6) (Fig. 8b).

The characteristics of both types of gypsum crystal hosted by the black clay are represented in Figure 8c. The bi-modal curve suggests two generations of crystal growth under different conditions.

The presence of prismatic gypsum crystals with a higher number of crystallographic forms indicates a very slow growth rate under conditions of relatively constant solution supply. Equal values (in all directions) for the pressure inside the sediment could explain the chaotic distribution of the gypsum crystals within the clay.

Some of these gypsum crystals did not have sufficient crystal energy to push aside the clay, and so-called "eroded crystals" (Hill and Forti, 1986) were formed.

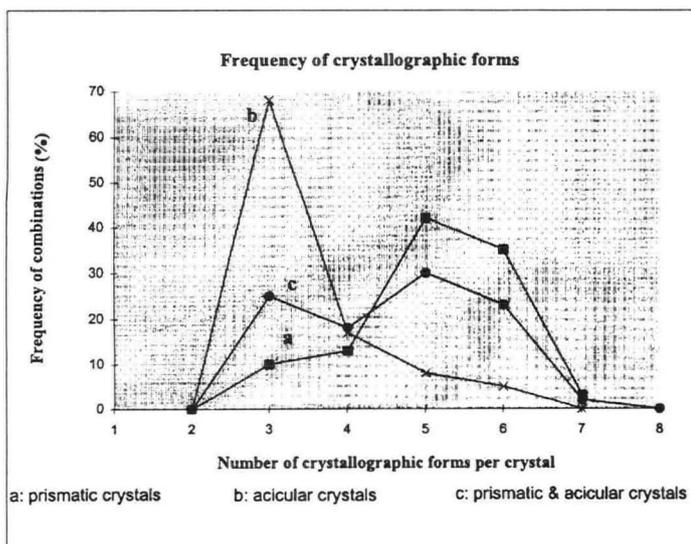


Figure 8. Frequency of crystallographic forms for gypsum crystals in Ponoras Cave.

In turn, the small number of crystallographic forms that characterize the acicular “floor gypsum crystals” is evidence of a much faster crystal evolution. Pressure perpendicular to the cave floor (inside the clay layer) seems to be higher than in any other direction, so the crystal growth followed this trend. The crystal energy was sufficiently high to raise the thin clay layer under which the crystals developed.

The study suggests that oxidation of pyrite into sulphuric acid and the reaction of the latter with the calcium ions presents in the seeping water led to the formation of the gypsum crystals in Ponoras Cave.

Moonmilk speleothems

Moonmilk samples from Wind, Osoi, Galaseni and Stracos caves were investigated by means of the scanning electron microscope. The moonmilk speleothems were found to be composed of calcite crystals with fibrous, acicular, prismatic and fibrous-lamellar morphologies. Not all the crystal morphologies were typical for calcite. In some cases calcite paramorphs after aragonite or vaterite and pseudomorphs of calcite after

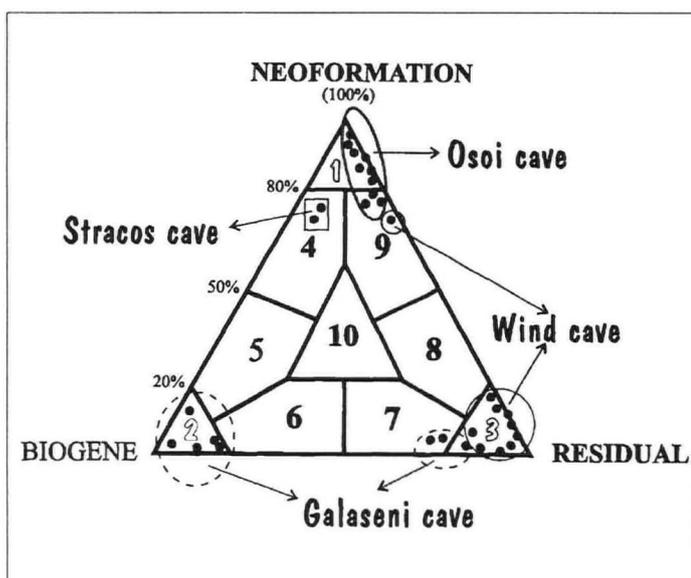


Figure 9. Ternary diagram showing the genetic types of moonmilk. Each dot represents a sample.

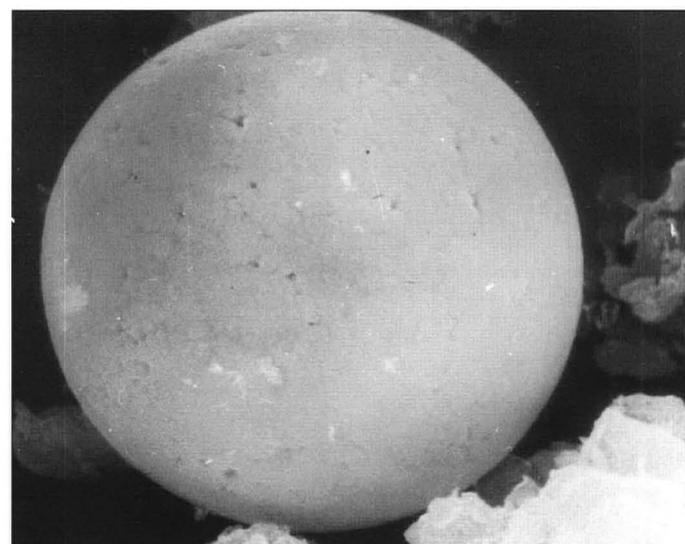


Plate 4. Scanning electron microscope picture of an uncovered sphere composed of iron and various rare earth elements (Wind Cave).

monohydrocalcite were recognized. Few samples tested by X-ray analysis confirmed the existence of monohydrocalcite in the moonmilk’s composition.

Crystals of calcite precipitated directly on some anastomosed filaments that resemble an organic structure were found in moonmilk samples from Galaseni and Stracos caves. It is believed that this moonmilk could have been produced by a biological process.

Application of the genetic ternary diagram designed by Onac and Ghergari (1993) locates the samples in fields 1, 3, 4, 7 and 9 (Fig.9).

Earthy aggregates (Terite)

Taranakite forms irregular white to yellow aggregates (nodules) within the clay deposit (its upper part covered by fresh guano) in Stracos Cave (Onac and Bengeanu, 1992). It has been identified by means of X-ray analysis. The ultimate source of the phosphorus in this cave can be related to decomposition of the bat guano. Phosphorus-rich solutions promote the alteration of calcite on the speleothem surface into phosphate minerals. In Stracos Cave reaction between aluminium clay minerals and phosphate solutions formed taranakite. Indeed, lower illite and kaolinite contents have been observed in clay at the contact with taranakite.

Black, earth-like deposits that cover gravels and boulders in the underground stream of Wind Cave are composed of **birnessite**, **romanechite**, **todorokite** and, possibly, **hollandite**. The most probable mode of origin for these manganese minerals is that they were leached into the cave from surface organic matter by streams. Soluble, reduced, manganese is transported by streams or by percolating groundwater until oxidizing cave conditions are encountered. Micro-organisms may aid in the deposition of manganese in the cave environment (Coman, 1979). Except for birnessite, which is in a fully oxidized (4+) state and precipitated as a final product, the other manganese minerals exist as intermediary products during manganese oxidation.

Further investigations on the black deposits from Wind Cave were made with a scanning electron microscope¹ (JEOL JSM 6400) equipped with a Tractor Norton TN 5600 Energy Dispersive System (EDS). Several energy dispersive secondary X-ray analyses (EDX) were also performed under the control of the Tractor Norton’s SQ program, which applies multiple least square analysis and a ZAF matrix correction procedure to calculate elemental concentration using a reference library stored on disk.

¹ The analyses were performed at the Department of Geology, Bergen University, Norway.

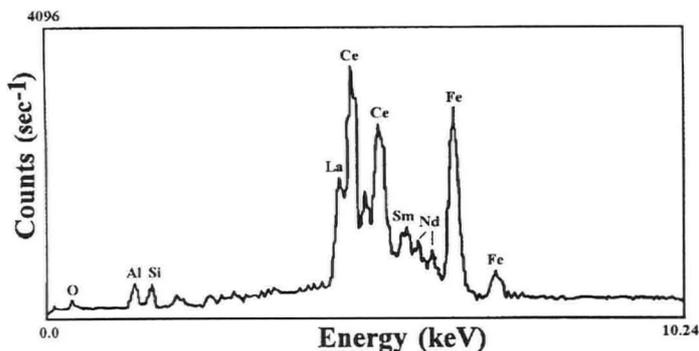


Figure 10. Microprobe analysis of the sphere shown in Plate 4.

SEM analysis showed a homogeneous mass made up of welded, botryoid-like agglomerates that proved to consist mainly of manganese and iron. Several perfectly rounded spheres with diameter ranging from 4 to 12.5µm were observed (Plate 4). The EDX spectra of the spheres showed that they are made up of iron and an association of rare-earth elements (REEs), including cerium (Ce), lanthanum (La), samarium (Sm) and neodymium (Nd) (Fig. 10). These botryoid-shaped agglomerates are covered by clusters of thin platy crystals. The diffraction pattern produced by these crystals is characteristic of phyllosilicates with pseudo-hexagonal symmetry (kaolinite).

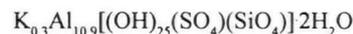
The correlation of ¹⁴³Nd/¹⁴⁴Nd ratio (measured by thermal ionization mass-spectrometer¹) for 4 different samples (black material, residual red clay from Wind Cave, bauxitic clay and rhyolite) indicate extremely close values for the first 3. This means the source of the REEs in those samples is the same. The REEs are believed to have been leached from the bauxitic clay that fills the palaeokarst formed on Ladinian limestones and then transported into the cave by the percolating waters.

All along the underground stream bed in Bolhac Cave, a layer of white, sometimes brownish-yellow, jelly-like sediment can be observed, covering both sandy alluvium and its limestone borders. The thickness of the deposit is 1 to 3cm on the river bed, while the submerged blocks are covered with only 3 to 5mm of the same material (Fig. 11).

Under polarizing light the material behaves like an isotropic, earthy-mass, due to the very small size of the granules. Transmission electron microscope analysis shows a homogenous mass (more than 90%) made up of agglomerates of tiny spheres or, rarely, ovoids.

The infrared spectrum clearly shows the presence of H²O and OH⁻. Absorption bands characteristic of SO₄²⁻, as well as of Si-O-Al and of Al-OH bands were also obtained.

Chemical analysis revealed high contents of Al₂O₃ and notable amounts of SO₃, SiO₂ and H₂O⁺ (as main components of the mineral) and K₂O, mainly as adsorbing ion. The results of the analysis of the white-yellow mineral in the Bolhac Cave plead for the existence of a new amorphous mineral, assigned to the group of hydrated aluminium sulphate-silicates, and proposed to be called *crisite* (Ghergari and Onac, 1993). The formula of the mineral is:



The origin of the *crisite* has been ascribed to the action of strongly acidic water (pH = 3.8 to 4.3), rich in aluminium and potassium (leached from the fireclay deposit), on the clay and limestone boulders of the underground cave stream.

DATING TECHNIQUES

Surface deposits are commonly altered by weathering and pedogenic processes and offer poor chances of preservation of evidence. However, caves commonly provide suitable sites for the accumulation of chemical, detrital and organic deposits. In cave environments the effects of sub-aerial weathering agencies are much reduced, and the chances of long term preservation of both sediments and fossils are greatly enhanced. Thus, caves and cave deposits are important tools for the study of past environmental changes (Lauritzen, 1993).

Uranium-series dating

The geographical position of Romania, far south of the maximum limits of the Pleistocene ice sheets, make speleothem dating especially interesting from a palaeoclimatological point of view (Lauritzen and Onac, 1995).

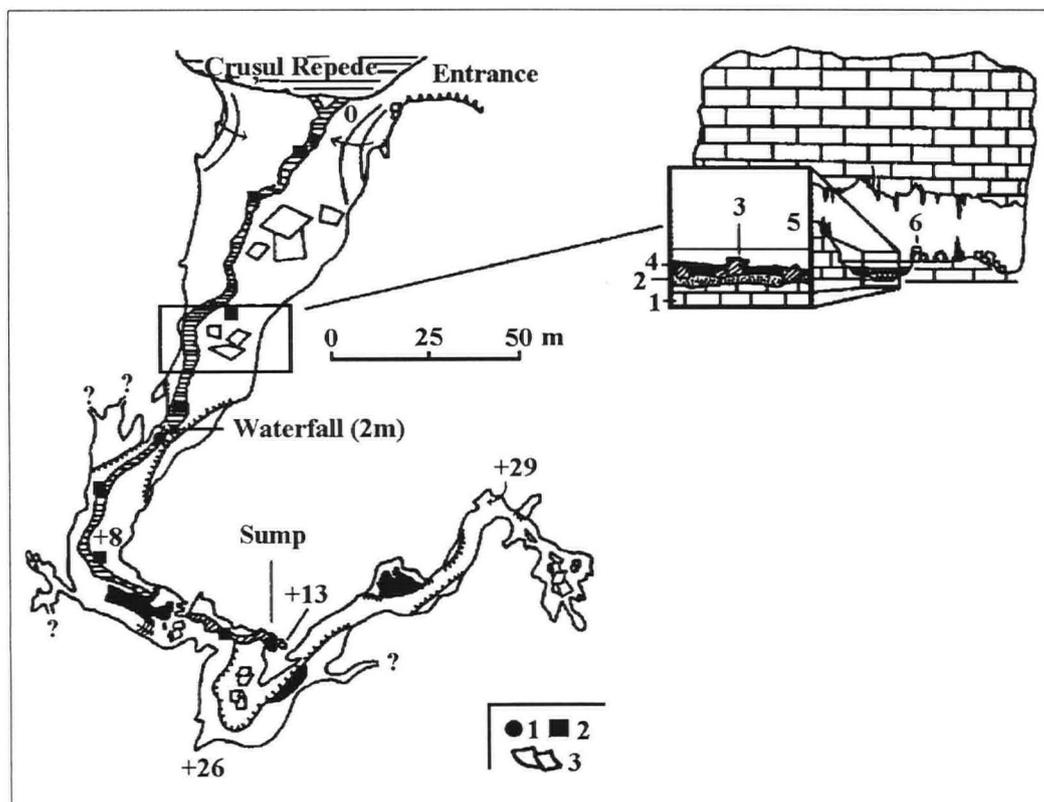


Figure 11. Map of Bolhac Cave: 1) samples of water; 2) samples of *crisite*; 3) limestone boulders.

Speleothem growth may be expected to be more continuous during glacial cycles in southern areas than in the northern latitudes, where the close proximity of glaciers interrupted speleothem deposition (Lauritzen, 1993, 1995).

Thirty-nine $^{230}\text{Th}/^{234}\text{U}$ ages for 13 different speleothems from six caves in the Padurea Craiului Mountains were performed, based on alpha particle spectroscopy at the U-series dating Laboratory at the Department of Geology, Bergen University (Norway). Both the caves and the speleothems were carefully selected in order to provide an efficient database for climatic and future geomorphological interpretations. Caves at different altitudes (between 200 and 700m asl) were sampled, in regions of well-documented morphotectonic evolution during the Tertiary and Quaternary periods. Also, speleothems from each cave were collected at various levels (where possible) or from peculiar locations (such as flowstone covering clay and detrital deposits, or stalagmites formed on top of other deposits).

The sampled caves are: Lithophagus (Fig. 1, No.33), Rotarides (Fig. 1, No.39), Ponoras (Fig. 1, No.14), Vântului (Fig. 1, No.19), Vadu-Crisului (Fig. 1, No. 12), and Galaseni (Fig. 1, No.5). The best results were obtained from samples LFG-2 and LFG-4 (Lithophagus Cave), so these will be discussed in detail in this paper.

The most distinct physical features of the LFG-2 sample were: (a) the numerous laminae, visible due to colour variations (amber, milky, clear, white), (b) the lack of single crystal cleavage, (c) a zone of closely spaced ferruginous layers underlain by small prismatic crystals orientated perpendicular to the growth layers. This clearly represents a period of suspended growth.

Fourteen sub-samples were cut on the basis of what appeared to be major growth increments. Each sub-samples was dated. All the sub-samples showed a gradual age decrease from 132ka to 55ka, except for UBL 1156 and UBL 1158, which were older with respect to the rest of the stratigraphic sequence. No explanation for the two deviant dates has yet been found. The analytical procedure followed was the same for all sub-samples cut from LFG-2.

A plot of radiometric ages against median sample height above base indicates a linear growth rate (fairly constant) of about 0.17mm/ka over the period 132 to 55ka (Fig. 12). The U/Th age data show a 21ka timespan from increment LFG-2h (7cm from base) to LFG-2c (9cm from base). These data suggest that growth has been relatively slow during this interval, but no depositional break is indicated in the morphology.

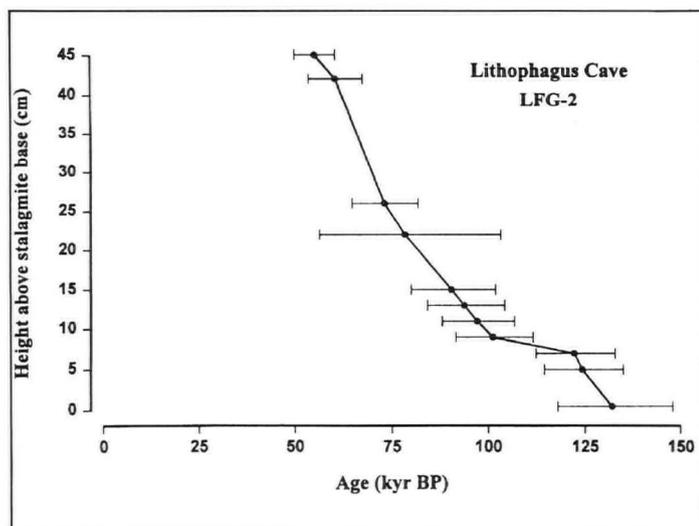


Figure 12. Plot of radiometric ages against median height above the base (stalagmite LFG-2).

LFG-4, perhaps one of the longest triangular monocrystalline stalagmites ever mentioned in the speleological literature (Knight, 1995), was sampled at 4 places along its 98cm length. The $^{230}\text{Th}/^{234}\text{U}$ ratio was in excess of equilibrium for the first three samples (at the base and respectively 47 and 74cm from the base). The absence of ^{232}Th is evidence that no detrital thorium was incorporated into the stalagmite to provide the excess ^{230}Th observed. Since the samples plot within the diagram of possible $^{230}\text{Th}/^{234}\text{U}$ and $^{234}\text{U}/^{238}\text{U}$ ratios, and there is no detectable evidence for isotopic migration that could have been caused this situation, it can safely be concluded that the age of this sample (xi) is within the interval $[350\text{ka} < x_i < 1.2 \text{Ma}]$. No ages could have been computed from the $^{230}\text{Th}/^{234}\text{U}$ ratios for these three samples. The top of the stalagmite gave a reliable age of 127ka.

The internal structure of the LFG-4 stalagmite suggests that its growth history took place under extremely stable conditions (water supply, temperature, humidity, fluid chemistry, little ventilation) until very recently, when a thin surface coating was deposited.

Collective properties of the dates

All analyses having their chemical yields below 10%, as well as those for which the $^{230}\text{Th}/^{232}\text{Th}$ ratio fell below 5%, were excluded. Although only 31 samples survived these selections, it may be worthwhile discussing the distribution of the ages in time and with respect to Pleistocene climates. This can be done by plotting the dates in a histogram, or by using a cumulative distributed error frequency approach (Gordon et al, 1989). As radiometric ages are based on exponential relationships (ie. first-order processes), the error intervals are asymmetrical and increase (exponentially) with age. Plotting age distributions in histograms with constant class size would therefore be misleading; high ages will appear with too high a precision, and younger (more precise) ages may become grouped into intervals that are too large to do justice to the resolution. Therefore, ages should be transformed into a continuous probability density function (PDF) (Gordon et al, 1989), yielding a much more realistic picture of significance levels. The cumulative growth frequency record can be used to define the timing of warm and cold periods by taking the timing of the peaks and troughs as a simple binary signal (Baker et al, 1993). This way of presenting the data (all 31 samples included) is shown in Fig. 13a (curve 1 represents data only from the Padurea Craiului Mountains caves, while curve 2 includes 65 dates from many caves outside of the studied unit).

The significance of the peaks and troughs in a PDF distribution depends strongly upon the size of the underlying sample set. Probably, a sample of about 250 to 300 dates is required for this purpose, so the following discussion must be regarded as tentative, while collection of more dates is in progress.

No detailed data are available for the Romanian Quaternary climate and there is no general agreement on the number and timings of interstadial periods in the last 150ka. However, an attempt to reconstruct the main climatic events for this period has been made by Cărciumaru (1980). He drew a climatic curve based on pollen analysis, archaeological studies and ^{14}C dates of bones. This curve does not correlate in any part with the data from the Padurea Craiului Mountains, nor with the orbitally-tuned oxygen isotope chronology. This may be a reflection of the location of his sampled sites, which were mostly high altitude caves from the Southern Carpathians, and also with a lack of reliable chronology.

Speleothem growth is a sensitive indicator of both temperature and aridity, and independent changes in either one or both of these can cause periods of enhanced or reduced growth. Thus, the current data are correlated chronostratigraphically (Lauritzen, 1995) with pollen analysis, coral growth frequency and oxygen isotope record from both ocean and ice cores (Fig. 13b, c). The following observations emerge:

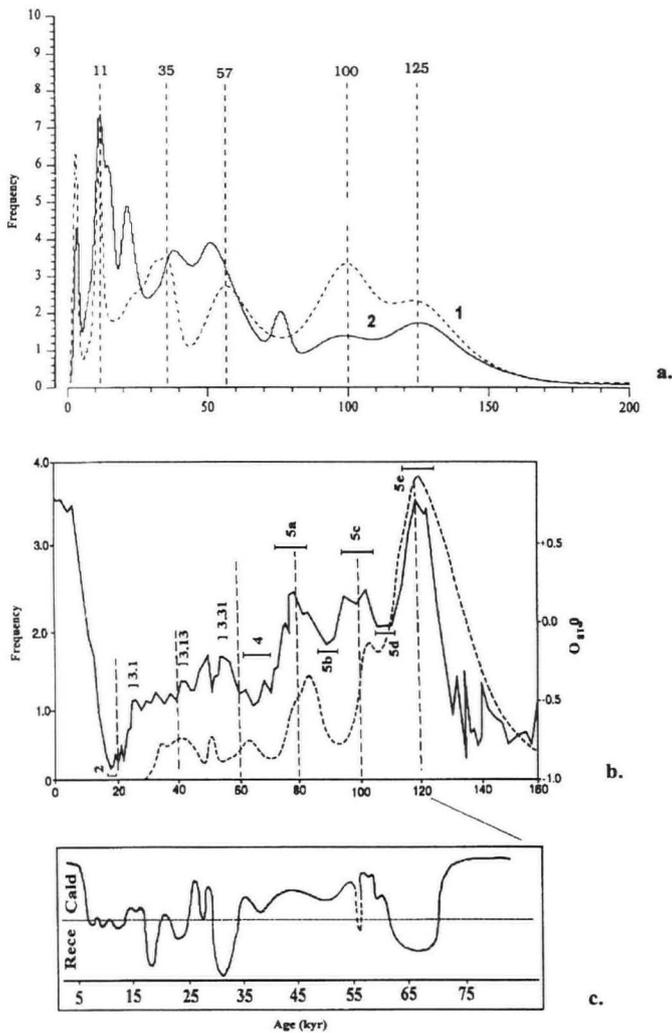


Figure 13. Comparison of palaeoclimatic records for the period 0-200 ka. a) PDF distribution of all dates available ($n = 31$). Numbers indicates the ages of various peaks in the distribution. b) Oxygen isotope record from deep sea sediments and coral growth frequency (dashed line). After Baker et al. (1993). c). The climatic curve drawn by Cărciumaru (1980).

- (i) High levels of growth frequency occur at around 3ka and represent the Holocene interglacial;
- (ii) The peak at around 11ka would probably correspond to the Younger Dryas stadial;
- (iii) The maximum from 35ka correlates with one of the events recorded in isotope stage 3, more exactly between sub-stages 3.1 and 3.13, when the climate cooled down but was still wet (Martinson et al, 1987);
- (iv) A period followed when a significantly low level of growth is recorded in the Padurea Craiului Mountains. This signal corresponds with a cold, dry period recorded in the Grand Pile pollen analysis (Guiot et al, 1989). On curve 2, drawn for all U-Th dates available for Romania, this signal is not well shown.
- (v) Evidence of an improvement in climate is given by the maximum from around 56ka, which is in good agreement with an event from sub-stage 3.31.
- (vi) The very low level of secondary carbonate growth evident in isotope stage 4 (from 65 to 75ka) indicates a severe climate. Though in the Padurea Craiului Mountains the end of isotopic sub-stage 5a cannot be recognised clearly, this event is evident on curve

2. This might suggest slightly different climatic conditions in south-eastern Romania (Dobrogea), from where one sample was dated, probably due to its location being outside the Carpathian chain.

- (vii) The two peaks around 100ka and 125ka correlate with sub-stages 5c to 5e. Favourable palaeoclimatic conditions seem to have occurred throughout this period. Neither peak is well resolved, as large counting errors associated with analyses of this age suppress their significance in the diagram.

To summarize, the dates cover a large timespan (from late Riss/Würm (Eemian), through Würm (Weichselian or Devensian), up to late Holocene, and compare well with similar records published by Gordon et al (1989) for the United Kingdom and Baker et al (1993) for NW Europe. The higher age of 142.5ka (taking into account only ages below 350ka) agrees well with high latitude data from Norway (Lauritzen, 1990) and also with the controversial Devil's Hole vein calcite in the USA (Winograd et al, 1988).

The periods of non-deposition of speleothems shown in Figure 13a agree well in age with similar periods determined for north-western Europe by different authors (Atkinson et al, 1978; Gordon et al, 1989; Lauritzen, 1990; Baker et al, 1993).

In summary the PDF curve of the whole collections of dates (Fig.13a) displays peaks and troughs that correlate broadly with known climatic variations during the same period. Due to the low number of samples ($n = 31$) none of the peaks is significant from a statistical point of view

Erosion rate based on speleothems study

The implications of carbonate speleothems in the geomorphological and palaeoenvironmental reconstruction are summarized below.

Because most common speleothems (stalactites and stalagmites) form only in air-filled cave galleries within the vadose zone, the occurrence of a speleothem in time and space also indicates the position of the

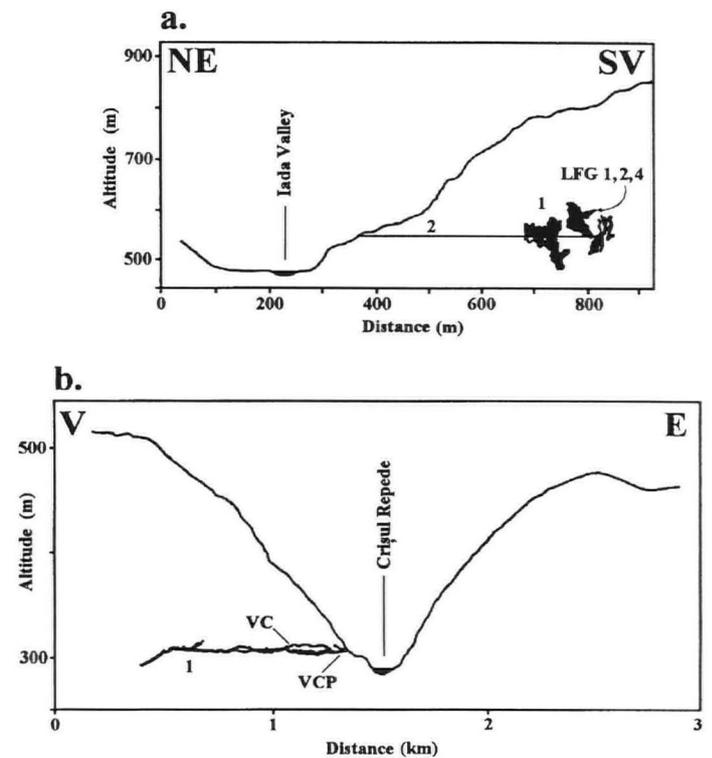


Figure 14. Erosion rate estimates in the Crisul Repede basin from speleothem position and ages in Lithophagus Cave (a) and Vadu Crisului Cave (b).

contemporary base-level of erosion. In cases where the water-table in caves is dictated by stream-levels in adjacent valleys, the oldest speleothem found at a given altitude provides a minimum age for the corresponding position of the adjacent erosional base-level, ie. the valley floor. The *minimum* age can be converted into *maximum* valley erosion rates (Ford et al., 1981; Atkinson and Rowe, 1992), equation (1):

$$R_{\max} = \Delta h/t_{\min} \quad (1)$$

This conversion has been attempted for three caves where the position of speleothems could be associated with a corresponding water-table controlled by the adjacent valley floor. The elevation (h) was 66 and 16m for Lithophagus and Vadu-Crisului caves (Fig.14). Equation (1) yields minimum average erosion rates through the last 40 to 140ka of 0.46 to 0.43m/ka. These minima are of the same order of magnitude, or slightly larger than glacial/interglacial erosion rates deduced in a similar way in glacial landscapes (Ford and Williams, 1992, pp. 112-113).

If 0.445mm/yr is considered as the average erosion rate in the Crisul Repede Basin, than the lowering of the valley from the 3rd terrace (situated between 300 and 320m in the Crisul Repede Gorge, and between 535 and 575 in the Iada Valley) (Ficheux, 1971) down to the actual river floor, was achieved during the Late Pleistocene and Holocene. This conclusion agrees with the opinions of other geomorphologists cited by Ianovici *et al* (1976).

ACKNOWLEDGEMENTS

I especially thank my supervisors, Dr Ioan Bedeleian, Dr Stein-Erik Lauritzen and Dr Lucretia Ghergari, for their encouragement received both during fieldwork and during the writing process. Discussions and support from Drs Marcian Bleahu, Iosif Viehmann, Gabriel Diaconu and Gheorghe Racovita are highly appreciated.

Chemist Monica Bengeanu (Mining Research and Design Institute, Cluj), Dr Magne Tysseland and Ing. Egil Erichsen (Bergen University) are gratefully thanked for their help in some analytical work. I had extremely useful discussions during field trips and in the office with Drs Reno Bernasconi, Paolo Forti, Jerzy Glazek, Jacques Choppy, Tim Atkinson, Carol Hill, Pompei Cocean and many others. I am indebted for the support received from Susi Kinzl and Werner Janz during my stay in Switzerland when I visited the UIS Library. Thanks are due to Dr Dave Lowe, who read the manuscript and improved the English. Dr Iosif Viehmann, Oana Moldovan, Matei Vremir, Gheorghe Fratila and Istvan Görög provided valuable assistance throughout the fieldwork. To them, and to many other speleologists, I am very grateful.

I thank my parents who encouraged (and allowed) me to develop and pursue my interests in karstology at an early age.

Lastly, thanks to my family, Silvia, Laura and Alexandru, to whom I was just a guest during the last four years.

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Speleothem from cave in Apuseni Mountains (Photo: Cristian Lascu).

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APPENDIX 1
LIST OF MINERALS FORMING DIFFERENT SPELEOTHEMS

Mineral	Chemical formula	Crystal system	Symmetry	Frequency
OXIDES and HYDROXIDES				
Akaganeite	β -FeOOH	tetragonal	C_{4h}^5	Very rare (VR)
Atacamite	$Cu_2(OH)_2Cl$	rhombic	D_{2h}^{16}	VR
Bauxite	hydroxide Al+Fe	-	-	Rare (R)
BIRNESSITE	$[Mn^{4+},(Mn^{2+},Ca,Mg,Na,K)](O,OH)_2$	rhombic	-	R
Boehmite	γ -AlOOH	rhombic	D_{2h}^{17}	VR
Brucite	$Mg(OH)_2$	trigonal	D_{3d}^3	R
<i>CHALCEDONY</i>	SiO_2	hexagonal	-	Common (C)
Calcophanite	$ZnMn_3O_7 \cdot 3H_2O$	triclinic	C_i^1	R
Cuprite	Cu_2O	cubic	O_h^4	VR
Gibbsite	γ -Al(OH) ₃	monoclinic	C_{2h}^5	R
ICE ¹	H_2O	hexagonal	C_{6v}^3	V. common (VC)
GOETHITE	α -FeOOH	rhombic	D_{2h}^{16}	R
Hematite	Fe_2O_3	trigonal	D_{3d}^6	C
Hollandit	$Ba_{<2}Mn_9O_{16}$	monoclinic	C_{4h}^5	VR
LIMONITE	aggregated hydroxide Fe	-	-	C
Lithiophorite	$(Al,Li)(OH)_2MnO_2$	hexagonal	C_{2h}^3	R
Maghemite	γ - Fe_2O_3	cubic	T^4	VR
Magnetite	$(Fe_3,Fe^{2+})Fe^3O_4$	cubic	O_h^7	VR
Manganite	γ -MnOOH	monoclinic	C_h^5	R
<i>OPAL</i>	SiO_2+H_2O	amorphous	-	C
PYROLUSITE	β - MnO_2	tetragonal	D_{4h}^{14}	C
Plattnerite	PbO_2	tetragonal	D_{4h}^{14}	VR
<i>QUARTZ</i>	SiO_2	trigonal	D_{3d}^4	VC
ROMANECHITE	$(Ba,Mn^{2+})_3(O,OH)_6Mn_8O_{16}$	rhombic	D_2^1	C
Rancieite	$(Ca,Mn)Mn_4O_9 \cdot 3H_2O$	hexagonal?	-	VR
Rutile	TiO_2	tetragonal	D_{4h}^{14}	R
Tenorite	CuO	monoclinic	C_{2h}^6	VR
TODOROKITE	$(H_2O, \dots)_{\Sigma 2} (Mn, \dots)_{\Sigma 8} (O, OH)_{16}$	monoclinic	C_{4h}^5	C
Uraninite	UO_2	cubic	O_h^5	R
WAD	aggregated oxide+hydroxide of Mn	-	-	C
Wyartite	$Ca_3U^{4+}[(UO_2)_6/(OH)_{18}/(CO_3)_2] \cdot 4H_2O$	rhombic	D_{2h}^{16}	VR
CARBONATES and HYDROCARBONATES				
<i>ANKERITE</i>	$CaFe[CO_3]_2$	trigonal	C_{3i}^2	C
ARAGONITE	$CaCO_3$	rhombic	D_{2h}^{16}	VC
Artinite	$Mg_2[(OH)_2/CO_3] \cdot 3H_2O$	monoclinic	C_{2h}^3	VR
Auricalcite	$(Zn,Cu)_5[(OH)_3/CO_3]_2$	rhombic	D_{2h}^5	VR
Azurite	$Cu_3[OH/CO_3]_2$	monoclinic	C_{2h}^5	C
Baringtonite	$MgCO_3 \cdot 2H_2O$	triclinic	-	VR
Baylissite	$K_2Mg(CO_3)_2 \cdot 4H_2O$?	-	VR
CALCITE	$CaCO_3$	trigonal	D_{3d}^6	VC
Carborborite	$Ca_2Mg[CO_3/B_2O_5] \cdot 10H_2O$	monoclinic	-	VR
Cerussite	$PbCO_3$	rhombic	D_{2h}^{16}	C
<i>DOLOMITE</i>	$CaMg[CO_3]_2$	trigonal	C_{3i}^2	C
Dypingite	$Mg_5(CO_3)_4(OH)_2 \cdot 5H_2O$?	-	VR
Giorgite	$Cu_5(CO_3)_3(OH)_4 \cdot 6H_2O$?	-	VR
<i>HUNTITE</i>	$CaMg_3[CO_3]_4$	trigonal	-	VC
Hydrocerussite	$Pb_3[(OH)/CO_3]_2$	hexagonal	-	VR
HYDROMAGNESITE	$Mg_5[OH/(CO_3)]_2 \cdot 4H_2O$	monoclinic	D_2^5	VC
Hydrozincite	$Zn_5[(OH)_3/CO_3]_2$	monoclinic	C_{2h}^3	C
Lansfordite	$MgCO_3 \cdot 5H_2O$	monoclinic	C_{2h}^2	VR
<i>MAGNESITE</i>	$MgCO_3$	trigonal	D_{3d}^6	VC
<i>MALACHITE</i>	$Cu_2[(OH)_2/CO_3]$	monoclinic	C_{2h}^5	C

MONOHYDROCALCITE	CaCO ₃ ·H ₂ O	hexagonal		VC
<i>NESQUEHONITE</i>	MgCO ₃ ·3H ₂ O	monoclinic	C ⁵ _{2h}	VC
Pyroaurite	Mg ₆ Fe ₂ [(OH) ₁₆ /CO ₃]·4H ₂ O	trigonal	D ⁵ _{3d}	VR
<i>RHODOCHROSITE</i>	MnCO ₃	trigonal	D ⁶ _{3d}	VR
Rosasite	(Zn,Cu) ₂ [(OH) ₂ /CO ₃]	monoclinic		VR
Rutherfordine	[UO ₂ /CO ₃]	rhombic	D ¹³ _{2h}	VR
Soda	Na ₂ CO ₃ ·10H ₂ O	monoclinic	C ⁶ _{2h}	R
Schrockerite	NaCa ₃ [UO ₂ F/SO ₄ (CO ₃) ₃ ·10H ₂ O	triclinic	PI	VR
Sharpite	[UO ₂ /CO ₃]·H ₂ O	rhombic		VR
<i>SIDERITE</i>	FeCO ₃	trigonal	D ⁶ _{3d}	VC
Smithsonite	ZnCO ₃	trigonal	D ⁶ _{3d}	C
Strontianite	SrCO ₃	rhombic	D ¹⁶ _{2h}	C
Termonatrite	Na ₂ CO ₃ ·H ₂ O	rhombic	D ¹ _{2h}	VR
Teschemacherite	NH ₄ HCO ₃	?		VR
Trona	Na ₃ H[CO ₃]·2H ₂ O	monoclinic	C ⁶ _{2h}	VR
<i>VATERITE</i>	CaCO ₃	hexagonal		C
Zellerite	Ca[UO ₂ /(CO ₃) ₂]·5H ₂ O	rhombic	Pmn2 ₁	VR
Witherite	BaCO ₃	rhombic	D ¹⁶ _{2h}	VR

SULPHATES and HALIDES

Aluminite	Al ₂ [(OH) ₄ /SO ₄]·7H ₂ O	monoclinic		VR
Alunite	KAl ₃ [(OH) ₆ /(SO ₄) ₂]	trigonal	C ⁵ _{3v}	R
<i>ALUNOGENE</i>	Al ₂ [SO ₄] ₃ ·18H ₂ O	triclinic		R
Anglesite	PbSO ₄	rhombic	D ¹⁶ _{2h}	R
<i>ANHYDRITE</i>	CaSO ₄	rhombic	D ¹⁷ _{2h}	C
Apjohnite	MnAl ₂ [SO ₄] ₄ ·22H ₂ O	monoclinic		VR
Arcanite	K ₂ SO ₄	rhombic	D ¹⁶ _{2h}	R
<i>ARDEALITE</i>	Ca ₂ H[PO ₄ SO ₄]·4H ₂ O	monoclinic		C
Astrakanite (Blodite)	Na ₂ Mg[SO ₄] ₂ ·4H ₂ O	monoclinic	C ⁵ _{2h}	C
<i>BARITE</i>	BaSO ₄	rhombic	D ¹⁶ _{2h}	C
Basaluminite	Al ₄ [(OH) ₁₀ /SO ₄]·5H ₂ O	hexagonal	?	VR
<i>BASSANITE</i>	CaSO ₄ ·½H ₂ O	monoclinic		R
Brochantite	Cu ₄ [(OH) ₆ /SO ₄]	monoclinic	C ⁵ _{2h}	R
Chalcanthite	Cu[SO ₄]·5H ₂ O	triclinic	C ¹ _i	C
Chalcoalumite	CuAl ₄ [(OH) ₁₂ /SO ₄]·3H ₂ O	triclinic	?	VR
Carnalite	KMgCl ₃ ·6H ₂ O	rhombic	D ⁴ _{2h}	VR
CELESTINE	SrSO ₄	rhombic	D ¹⁶ _{2h}	C
Cianotrichite	Cu ₄ Al ₂ [(OH) ₁₂ /SO ₄]·2H ₂ O	rhombic		VR
Clairite	Fe ₃ (NH ₄) ₂ (SO ₄) ₄ (OH) ₃ ·3H ₂ O	triclinic		VR
Cloromagnesite	MgCl ₂	hexagonal	D ⁵ _{3d}	R
CRISITE	K _{0.33} Al _{10.9} [(OH) ₂₅ /SO ₄ /SiO ₄]·2H ₂ O	amorphous		VR
Devilline	CaCu ₄ [(OH) ₃ /SO ₄] ₂ ·3H ₂ O	monoclinic	C ⁵ _{2h}	VR
<i>EPSOMITE</i>	Mg[SO ₄]·7H ₂ O	rhombic	D ⁴ ₂	VC
Phybropherite	Fe[OH/SO ₄]·5H ₂ O	monoclinic		VR
Guanovulite ?	K(NH ₄)(SO ₄)·2H ₂ O	rhombic		VR
GYPSUM	Ca[SO ₄]·2H ₂ O	monoclinic	C ⁶ _{2h}	VC
Glaserite (Aphthitalite)	K ₃ Na[SO ₄] ₂	trigonal	D ³ _{3d}	R
Glauberite	CaNa ₂ [SO ₄] ₂	monoclinic	C ⁶ _{2h}	VR
<i>HALITE</i>	NaCl	cubic	O ¹ _h	VC
<i>HALOTRICHITE</i>	FeAl ₂ [SO ₄] ₄ ·22H ₂ O	monoclinic	C ¹ ₂	R
Hexahydrite	Mg[SO ₄]·6H ₂ O	monoclinic	C ⁶ _{2h}	R
<i>JAROSITE</i>	KFe ₃ [(OH) ₆ /(SO ₄) ₂]	trigonal	C ⁵ _{3v}	C
<i>KALINITE</i>	KAl[SO ₄] ₂ ·11H ₂ O?	monoclinic	?	C
Kieserite	Mg[SO ₄]·H ₂ O	monoclinic	C ⁶ _{2h}	R
Lecontite	(NH ₄)Na[SO ₄]·2H ₂ O	rhombic	D ⁴ ₂	R
Lonecreekite	FeNH ₄ (SO ₄) ₂ ·12H ₂ O	cubic		VR
Melanterite	Fe[SO ₄]·7H ₂ O	monoclinic	C ⁵ _{2h}	C
Metavoltine	α-K ₅ Fe ₃ [OH/(SO ₄) ₃] ₂ ·8H ₂ O	hexagonal		VR
<i>MIRABILITE</i>	Na ₂ [SO ₄]·10H ₂ O	monoclinic	C ⁵ _{2h}	VC
Misenite	K ₈ H ₆ [SO ₄] ₂	monoclinic		VR
Natrojarosite	NaFe ₃ [(OH) ₆ /(SO ₄) ₂]	trigonal	C ⁵ _{3v}	VR
Nickelalumite ?	(Ni,Cu)Al ₄ [(SO ₄ (NO ₃))(OH) ₁₂ ·3H ₂ O	monoclinic		VR
<i>PICKERINGITE</i>	MgAl ₂ [SO ₄] ₄ ·22H ₂ O	monoclinic	C ¹ ₂	C
Pisanite	(Fe,Cu)[SO ₄]·7H ₂ O	monoclinic	C ⁵ _{2h}	VR
Posnjakite	Cu ₄ [(OH) ₆ /SO ₄]·H ₂ O	monoclinic		VR
Sabieite	FeNH ₄ (SO ₄) ₂	trigonal		VR
Spangolite	Cu ₆ Al[(OH) ₁₂ /Cl/SO ₄]·3H ₂ O	trigonal	C ³ _{3v}	VR

Sylvite	KCl	cubic	O_h^5	C
Singenite	$K_2Ca[SO_4]_2 \cdot H_2O$	monoclinic	C_{2h}^2	VR
Tamarugite	$NaAl[SO_4]_2 \cdot 6H_2O$	monoclinic	C_{2h}^2	VR
Taylorite	$(K,NH_4)_2[SO_4]$	rhombic		VR
<i>THENARDITE</i> (< 197°C)	$\alpha-Na_2[SO_4]$	rhombic	D_{2h}^{24}	C
Tschermigite	$(NH_4)Al[SO_4]_2 \cdot 12H_2O$	cubic	T_h^6	VR
Voltaite	$K_2Fe_5Fe_4^{3+}[SO_4]_{12} \cdot 18H_2O$	cubic		VR
Woodhouseite	$CaAl_3[(OH)_6/SO_4PO_4]$	trigonal		VR

NITRATES

Darapskite	$Na_3[SO_4/NO_3] \cdot H_2O$	monoclinic	C_{2h}^2	C
Sveite	$KAl_7(NO_3)_4Cl_2(OH)_{16} \cdot 8H_2O$	monoclinic		VR
Hydrombomkulite	$NiAl_4(NO_3)_2(OH)_{12} \cdot 13-14H_2O$	monoclinic		VR
Mbobomkulite	$(Ni,Cu)Al_4[(NO_3)_2SO_4](OH)_{12} \cdot 3H_2O$	monoclinic		VR
Nitratite	$NaNO_3$	trigonal	D_{3d}^6	VC
Nitrammite	NH_4NO_3	rhombic	D_{2h}^{13}	C
Nitre	KNO_3	rhombic	D_{2h}^{16}	VC
Nitrocalcite	$Ca[NO_3]_2 \cdot 4H_2O$	monoclinic		C
Nitromagnesite	$Mg[NO_3]_2 \cdot 2H_2O$	monoclinic		C

PHOSPHATES

APATITE	$Ca_5[F/(PO_4)_3]$	hexagonal	C_{6h}^2	R
Archerite	$(K,NH_4)H_2PO_4$	tetragonal		VR
Biophosphamite ?	$(NH_4)H_2PO_4$	tetragonal		VR
<i>BOBIERITE</i>	$Mg_3[PO_4]_2 \cdot 8H_2O$	monoclinic	C_{2h}^5	VR
BRUSHITE	$CaH[PO_4] \cdot 2H_2O$	monoclinic	C_{2h}^3	VC
Carbonat-Apatite	$Ca_5[F/(PO_4,CO_3OH)_3]$	hexagonal	C_{6h}^2	VR
Crandallite	$CaAl_3H[(OH)_6/(PO_4)_2]$	trigonal	C_{3v}^5	C
<i>DAHLITE</i> (var.)	$Ca_{10}(PO_4)_6(CO_3)(OH)$	hexagonal		VC
Diadochite	$Fe_4[(OH)_4/(PO_4,SO_4)_3] \cdot 13H_2O$	monoclinic		VR
Dittmarite	$(NH_4)Mg_3H_2[PO_4]_3 \cdot 8H_2O$	rhombic		VR
Evansite	$Al_3[(OH)_6/PO_4] \cdot 6H_2O$	amorphous		VR
Francoanellite	$H_6K_3Al_5(PO_4)_8 \cdot 13H_2O$	trigonal		R
Hannayite	$(NH_4)_2Mg_3H_4[PO_4]_4 \cdot 8H_2O$	triclinic	C_i^1	R
Hibbenite	$Zn_7[(OH)PO_4]_2 \cdot 6H_2O$	rhombic	?	VR
HYDROXYLAPATITE	$Ca_5[OH/(PO_4)_3]$	hexagonal	C_{6h}^2	VC
Hopeite	$Zn_3[PO_4]_2 \cdot 4H_2O$	rhombic	D_{2h}^{16}	VR
Klinostrengite	$FePO_4 \cdot 2H_2O$	monoclinic		VR
Koninckite	$FePO_4 \cdot 3H_2O$	tetragonal		VR
Leucophosphite	$K_2(Fe,Al)_2[OH/(PO_4)_2] \cdot 2H_2O$	monoclinic	C_{2h}^5	VC
Martinite (var.)	$Ca_5H_2(PO_4)_4 \cdot 1/2H_2O$	trigonal	D_{3d}^5	VR
Minyulite	$KAl_2[(OH,F)/(PO_4)_2] \cdot 4H_2O$	rhombic	C_{2v}^1	VR
Mitridatite	$Ca_3Fe_4[(OH)_6/(PO_4)_4] \cdot 2H_2O$	monoclinic		R
Monetite	$CaH[PO_4]$	triclinic	C_i^1	C
Montgomeryite	$Ca_4Al_5[(OH)_5/(PO_4)_6] \cdot 11H_2O$	monoclinic	C_{2h}^6	R
Mundrabbillaite	$(NH_4)_2Ca(HPO_4)_2 \cdot H_2O$	monoclinic		VR
Newberyte	$MgH[PO_4] \cdot 3H_2O$	rhombic	D_{2h}^{15}	C
Niahite	$(NH_4)(Mn,Mg,Ca)PO_4 \cdot H_2O$	rhombic		VR
Parahopeite	$Zn_3[PO_4]_2 \cdot 4H_2O$	triclinic	C_i^1	R
Phosphammite	$(NH_4)_2HPO_4$	monoclinic	?	VR
Pyromorphite	$Pb_3[Cl/(PO_4)_3]$	hexagonal	C_{6h}^2	VR
Purpurite	$(Mn,Fe)[PO_4]$	rhombic		VR
Sasaite	$(Al,Fe)_4(PO_4)_{11}SO_4(OH)_7 \cdot 83H_2O$	rhombic		VR
Schertelite	$(NH_4)_2MgH_2[PO_4]_2 \cdot 4H_2O$	rhombic	D_{2h}^{15}	VR
Scholzite	$CaZn_2[PO_4]_2 \cdot 2H_2O$	rhombic	D_{2h}^5	VR
Spencerite	$Zn_2[(OH)/PO_4] \cdot 1/2H_2O$	monoclinic	C_{2h}^4	VR
Stercorite	$(NH_4)NaH[PO_4] \cdot 4H_2O$	triclinic		VR
Strengite	$FePO_4 \cdot 2H_2O$	rhombic	D_{2h}^{15}	C
Struvite	$(NH_4)Mg[PO_4] \cdot 6H_2O$	rhombic	C_{2v}^7	C
TARANAKITE	$K_2Al_5H_6[PO_4]_8 \cdot 18H_2O$	trigonal	D_{3d}^6	VC
Tarbuttite	$Zn_2[OH/(PO_4)]$	triclinic	C_i^1	R
Tinticite	$Fe_3[(OH)_3/(PO_4)_2] \cdot 3H_2O$	rhombic	?	VR
Variscite	$AlPO_4 \cdot 2H_2O$	rhombic	D_{2h}^{15}	VC
<i>VIVIANITE</i>	$Fe_3[PO_4]_2 \cdot 8H_2O$	monoclinic	C_{2h}^3	VR
<i>WAVELLITE</i>	$Al_3[(OH)_3/(PO_4)_2] \cdot 5H_2O$	rhombic	D_{2h}^{16}	VR

Whitlockite	$\beta\text{-Ca}_3[\text{PO}_4]_2$	trigonal	D_{3d}^5	VC
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SILICATES

ALLOPHANE	$m\text{H}_2\text{O} \ n\text{SiO}_2 \ p\text{H}_2\text{O} \ \text{Al}:\text{Si}=1:1$	amorphous		C
BENITOITE	$\text{BaTi}[\text{Si}_3\text{O}_9]$	hexagonal	D_{3h}^2	VR
Chrysocole	$\text{Cu}_4\text{H}_4[(\text{OH})_8/\text{Si}_4\text{O}_{10}]$	monoclinic		VR
Clinochlore	$(\text{Mg},\text{Al})_3[(\text{OH})_2/\text{AlSi}_5\text{O}_{10}]\text{Mg}_3(\text{OH})_6$	monoclinic		VR
DICKITE	$\text{Al}_4[(\text{OH})_8/\text{Si}_4\text{O}_{10}]$	monoclinic	C_4^s	VR
Epidote	$\text{Ca}_2(\text{Fe},\text{Al})\text{Al}_2[\text{O}/\text{OH}/\text{SiO}_4/\text{Si}_2\text{O}_7]$	monoclinic	C_{2h}^2	VR
HALLOYSITE	$\text{Al}_4[(\text{OH})_8/\text{Si}_4\text{O}_{10}](\text{H}_2\text{O})_4$	monoclinic	C_3^s	C
Hemimorphite	$\text{Zn}_4[(\text{OH})_2/\text{Si}_2\text{O}_7] \ \text{H}_2\text{O}$	rhombic	C_{2v}^{20}	VR
Hydromuscovite	$(\text{K},\text{H}_2\text{O})\text{Al}_2[(\text{H}_2\text{O},\text{OH})_2/\text{AlSi}_3\text{O}_{10}]$	monoclinic		VR
ILLITE	$\text{K}_{1-1.5}\text{Al}_4[\text{Al}_{1-1.5}(\text{Si}_{7-6.5})\text{O}_{20}](\text{OH})_4$	monoclinic		VR
KAOLINITE	$\text{Al}_4[(\text{OH})_8/(\text{Si}_4\text{O}_{10})]$	triclinic	C_i^1	VR
Metahalloysite	$\text{Al}_4[(\text{OH})_8/\text{Si}_4\text{O}_{10}]$	monoclinic	C_s^3	VR
MONTMORILLONITE	$(\text{Al}_{1.67}\text{Mg}_{0.33})[(\text{OH})_2/\text{Si}_4\text{O}_{10}]^{0.33}\text{Na}_{0.33}(\text{H}_2\text{O})_4$	monoclinic		C
NACRITE	$\text{Al}_4[(\text{OH})_8/\text{Si}_4\text{O}_{10}]$	monoclinic	m	VR
Palygorskite	$(\text{Mg},\text{Al})_2[\text{OH}/\text{Si}_4\text{O}_{10}]2\text{H}_2\text{O}+2\text{H}_2\text{O}$	monoclinic	C_{2h}^3	C
Saponite $(\text{Mg}_{3-2.25}\text{Fe}_{0-0.75})_{\text{S}_3}[(\text{OH})_2/\text{Al}_{0.33}\text{Si}_{3.67}\text{O}_{10}]^{0.33}\cdot\frac{1}{2}\text{Ca},\text{Na}_{0.33}(\text{H}_2\text{O})_4$		monoclinic	C_s^4	VR
Sepiolite	$\text{Mg}_4[(\text{OH})_2/(\text{Si}_6\text{O}_{15})]2\text{H}_2\text{O}+4\text{H}_2\text{O}$	rhombic	D_{2h}^6	C
Shattuckite	$\text{Cu}_5[(\text{OH})_2/(\text{SiO}_3)_4]$	rhombic	D_{2h}^{15}	VR
Stilpnomelane	$(\text{K},\text{H}_2\text{O})(\text{Fe},\text{Mg},\text{Al})_{-3}[(\text{OH})_2/\text{Si}_4\text{O}_{10}]\text{X}_n(\text{H}_2\text{O})_2$	monoclinic		VR
Tremolite	$\text{Ca}_2\text{Mg}_5\text{Si}_8\text{O}_{22}(\text{OH})_2$	monoclinic		VR
Vermiculite	$\text{Mg}_{2.36}\text{Fe}_{0.48}\text{Al}_{0.16}[(\text{OH})_2/\text{Al}_{1.28}\text{Si}_{2.72}\text{O}_{10}]^{0.64}\text{Mg}_{0.32}(\text{H}_2\text{O})_4$	monoclinic		VR

OTHER MINERALS

SULPHUR	S_α	rhombic	D_{2h}^{24}	R
Bornite	Cu_5FeS_4	tetragonal	D_{2d}^4	VR
Chalcopyrite	CuFeS_2	tetragonal	D_{2d}^{12}	VR
Cinnabar	HgS	trigonal	D_3^4	VR
Galena	PbS	cubic	O_h^5	VR
Marcasite	FeS_2	rhombic	D_{2h}^{12}	VR
Metacinnabar	HgS	cubic	T_d^2	VR
Oldhamite	CaS	cubic	O_h^d	VR
PYRITE	FeS_2	cubic	O_h^6	VR
Pyrrhotine	FeS	hexagonal	D_{6h}^4	VR
Sphalerite	$\alpha\text{-ZnS}$	cubic	T_d^2	VR
Stibnite (Antimony)	Sb_2S_3	rhombic	D_{2h}^{16}	VR
Fluorite	CaF_2	cubic	O_h^5	C
Bromargyrite	AgBr	cubic	O_h^5	VR
Arseniosiderite	$\text{Ca}_3\text{Fe}_4[\text{OH}/\text{AsO}_4]_4 \cdot 4\text{H}_2\text{O}$	monoclinic		VR
Beudantite	$\text{PbFe}_3[(\text{OH})_6/\text{SO}_4\text{AsO}_4]$	trigonal	D_{3d}^5	VR
Conicalcite	$\text{CaCu}[\text{OH}/\text{AsO}_4]$	rhombic	D_2^4	VR
Mimetite	$\text{Pb}_5[\text{Cl}/(\text{AsO}_4)_3]$	monoclinic		VR
Olivenite	$\text{Cu}_2[\text{OH}/\text{AsO}_4]$	rhombic	D_{2h}^{13}	VR
Strashimirite	$\text{Cu}_4[\text{OH}/\text{AsO}_4]_2 \cdot 2\frac{1}{2}\text{H}_2\text{O}$	monoclinic	C_{2h}^1	VR
Talmessite	$\text{Ca}_2\text{Mg}[\text{AsO}_4]_2 \cdot 2\text{H}_2\text{O}$	triclinic	C_i^1	VR
Descloizite	$\text{Pb}(\text{Zn},\text{Cu})[\text{OH}/\text{VO}_4]$	rhombic	D_2^4	VR
Hewettite	$\text{CaV}_6\text{O}_{16} \cdot 9\text{H}_2\text{O}$	rhombic	C_{2h}^1	VR
Tangeite	$\text{CaCu}[\text{OH}/\text{VO}_4]$	rhombic	D_2^4	VR
Tujamunite (Tyuyamunite)	$\text{Ca}[(\text{UO}_2)_2/\text{V}_2\text{O}_8] \cdot 5\text{-}8\frac{1}{2}\text{H}_2\text{O}$	rhombic		VR
Vanadinite	$\text{Pb}_5[\text{Cl}/(\text{VO}_4)_3]$	hexagonal		VR

Abstracts of papers presented at the B.C.R.A Cave Science Symposium, University of Huddersfield, 15.3.97

ANNUAL LAMINATIONS IN SPELEOTHEMS - RECENT PALAEOCLIMATE INTERPRETATIONS AND FUTURE PROSPECTS

Andy Baker¹, William L. Barnes², Dominique Genty³ and Natalie J. Mockler^{1,2}

¹Department of Geography, University of Exeter, Amory Building, Rennes Drive, Exeter, EX4 4RJ
a.baker@exeter.ac.uk

²Department of Physics, University of Exeter, Stocker Road, Exeter, EX4 4QL

³Universite de Paris-Sud, Laboratoire d'hydrologie et de geochemie isotopique, URA 723, CNRS, Batiment 504, 91405 Orsay Cedex, France

Laminations have been observed in speleothems for many years, firstly in visible light, and more recently under ultra-violet illumination. Visible laminations were first demonstrated to be annual in some instances in the 1960s; laminations visible under UV light were first observed in the 1980s and demonstrated to be annual in the 1990s. Annual laminations provide: (1) a precise measure of growth rate of speleothem samples; (2) a floating chronology which can be constrained by radiometric dating techniques (U-Th); (3) a palaeoclimate record from variations in the width and structure of the annual laminations. Recent advances in the use of annual laminations for high resolution palaeoclimate analysis are presented: (1) Short lived growth rate bursts from stalagmites from Uamh an Tartair, Assynt; (2) Correlations between the structure of the UV laminations and drip water discharge from Lower Cave, Bristol and Brownes Folly Mine, Wiltshire; (3) Theoretical relationship between cave environmental characteristics and the deposition of visible and/or UV laminations. Potential future research prospects are discussed.

EXPOSURE TO RADON IN GILFIELD MINE

G. R. Barker-Read and R. A. Farnfield

Department of Mining and Mineral Engineering, The University of Leeds, LEEDS LS2 9JT
mingrbr@ecu-01.novell.leeds.ac.uk

Radon is a naturally-occurring radioactive gas which is commonly encountered in caves, pot-holes and abandoned mines. A study of the concentration of radon gas and its decay products in the atmosphere within Gilfield mine, a disused lead mine in North Yorkshire, has been undertaken in order to quantify the risk to the health of persons entering the mine. The measurements indicate that the principal factor controlling the concentration is the strength and direction of natural ventilation within the mine which, in turn, is determined by the temperature of the air outside of the mine. The health risk thus varies with the season.

INITIAL THOUGHTS ON CAVE INCEPTION AND DEVELOPMENT ON CUILCAGH MOUNTAIN

Les Brown, Dave Lowe and John Gunn, Limestone Research Group, The University of Huddersfield, Queensgate, HUDDERSFIELD, HD1 3DH, UK.

SAPPLB3@hud.ac.uk, D.Lowe@bgs.ac.uk, J.Gunn@hud.ac.uk

Ongoing studies of cave systems beneath Cuilcagh Mountain (County Fermanagh, Northern Ireland, and County Cavan, Eire) are attempting to relate the development history and form of the caves, and their associated complex underground drainage relationships, to aspects of the local geology. Most results to date are from the Marble Arch Cave System. They demonstrate that stratigraphical and lithological relationships within

the Carboniferous limestones of Cuilcagh, and their effects on cave development, are locally complex and laterally variable. Consideration of early observations allows recognition of the potentially widespread involvement of specific, favourable, lithological contrasts (considered as Inception Horizons) and other geological features in guiding the earliest stages of cave development and imprinting a variety of possible alternative underground drainage route combinations locally and regionally beneath the mountain.

THE DEVELOPMENT OF THE DERWENT GORGE AND ITS CAVES AT MATLOCK, DERBYSHIRE

Dr Trevor D. Ford, 21 Elizabeth Drive, Oadby, LEICESTER LE2 4RD, UK

The River Derwent is thought to have been superimposed onto a partly eroded Millstone Grit from the Mio-Pliocene Brassington Formation and thence onto the Carboniferous Limestone. As the limestone was exposed by erosion a system of phreatic caves developed in the hydrologic compartment between two impermeable lava flows. Outwash sediments filling these cave systems indicate an early Pleistocene glacial episode. Later glaciation(s) yielded firstly a high-level plateau till, and a later terrace till of probable Wolstonian age. The gorge was incised between these two glacial episodes and uniclinal shift was blocked by the upstanding reef of High Tor. The gorge is today effectively an elongate knick point in the thalweg of the River Derwent.

TUFA AND TRAVERTINE DEPOSITS OF THE GRAND CANYON, USA

Dr Trevor D. Ford, 21 Elizabeth Drive, Oadby, LEICESTER LE2 4RD, UK (with H.M. Pedley)

Although tufa is widespread in the Grand Canyon, it has only attracted passing attention in guide books, limited research on a few occurrences, and no specific investigation has been traced. The present account describes the deposits and suggests which mechanisms have been operative. The potential effects of wet climatic phases versus those caused by lava dams are also assessed.

THE USES OF HYPERTEXT MARKUP LANGUAGE (HTML) IN CAVING

Peter Grant and Wookey

Peter Grant, Greenfoot Barn, Greenfoot, Low Bentham, LANCASTER LA2 7EQ, UK

pagl@cyserv1.cybase.co.uk

Wookey, 734 Newmarket Road, CAMBRIDGE CB5 8RS, UK:
wookey@aleph1.co.uk

Recent work using HTML to describe a guide to complex cave systems will be outlined. The example used in this instance is the Easegill System in North Yorkshire. A demonstration of the guide will be given showing seamless navigation through the cave with links to Photographs, Rigging Guides, Surveys and Text. A demonstration of HTML as a caving database will also be given; in this instance a database of work carried out in Austria by the C.U.C.C. A demonstration shows the wealth of data that can be stored using this method, including related subjects, QM lists, glossary, logbooks, history list, surveys, pictures, sound, VRML etc. The finished work could be placed on the Internet and links to other related sites could be added. The data would then be accessible across all computer platforms.

CHANNEL SOUNDING THROUGH ROCK USING WIDEBAND RADIO PULSES

David Gibson, 12 Well House Drive, LEEDS LS8 4BX, UK
gibson@mcrosolv.demon.co.uk

Channel sounding is a technique for measuring the characteristics of wave propagation. This paper explains how the technique can be used to make measurements in rock. As well as providing experimental determination of the optimum range of frequencies for cave communications, the technique lends itself to geophysical investigations.

CAVES IN THE MECHARA AREA, ETHIOPIA: OLD, BUT HOW OLD?

John Gunn & Les Brown, Limestone Research Group, The University of Huddersfield, Queensgate HUDDERSFIELD, HD1 3DH
j.gunn@hud.ac.uk

During two recent expeditions to Ethiopia a complex network of previously undescribed caves has been explored near to the settlement of Mechara in eastern Harrar. The passages are all rifts but nowhere in the 8km so far explored can a solid floor be seen as a result of breakdown, dust and guano. The caves contain a number of distinct sediment sequences and give the appearance of being very old. The Anatolo Limestone in which the caves are formed is of Lower Jurassic age and at one stage it was overlain by Lower Miocene volcanic rocks deposited c. 30My ago during the formation of the Ethiopian Rift Valley. This episode was accompanied by extensive tectonism. As some passages in the caves are truncated by faulting it is suggested that a mature cave system was already in existence by the early to mid-Miocene. These caves not only survived the volcanism and tectonism which accompanied formation of the Rift Valley, but also the subsequent uplift and erosion of the volcanic plateau which formed the landscape observed today.

RAWTHEY CAVE

Philip Murphy, University of Leeds, LEEDS
p.murphy@earth.leeds.ac.uk

Rawthey Cave is a resurgence cave situated in the Rawthey Gorge ten miles North East of Sedbergh, Cumbria. The cave drains a thin band of upturned limestone intimately associated with the Dent Fault. A recent reinvestigation has resulted in the discovery of a major new section of cave illustrating its atypical geological setting and providing significant archaeological finds. Preliminary hydrological data indicates the existence of a much more extensive cave system than so far explored. The results of C14 dating of samples from the cave, at present being undertaken in the USA, are awaited.

THERE'S LIGHT ENOUGH FOR WOT I'VE GOT TO DO - LUMINESCENCE DATING OF CAVE SEDIMENTS

Dave Sainty, Department of Geography, University of Sheffield, Winter Street, SHEFFIELD S10 2TN
ggp95ds@sheffield.ac.uk

This paper will outline current research into the feasibility of applying optically stimulated luminescence dating (OSL) to cave sediments. The research project is focusing on samples of probably glacial sediments from caves in the Assynt area of north-west Scotland, of likely periglacial sediments from caves in Devon, and aeolian sediments from caves in the

Kalahari region of Africa. Each location presents sediments with contrasting climatic regime and mode of deposition and imparts unique problems that challenge successful application of OSL dating. Dating techniques currently applied to materials derived from caves concentrate on faunal/human remains, artefacts, or speleothem material. In contrast to these, OSL dates sediments directly, based on their last exposure to a light source, and correlation between these episodes and deposition offers great potential for dating specific events in cave palaeoenvironments.

ULTRASONIC CAVE MAPPING

W. I. Sellers and A. T. Chamberlain, Department of Anatomy, The University of Edinburgh, Medical School, Teviot Place, EDINBURGH EH8 9AG
bill.sellers@ed.ac.uk

Surveying the internal structure of a cave is an important part of any archaeological or palaeontological excavation. However, using standard topographical surveying techniques is extremely difficult due both to the irregular nature of the structure and to the difficult working conditions. This study uses a novel method based on ultrasound reflections to produce an accurate 3D model of Kitley Shelter Cave, an archaeological cave in Yealmpton, Devon. This model allows the easy location of finds and enables the cave system to be visualised allowing better understanding of the taphonomy of the site.

LEACHING OF SOIL AND ROCK SAMPLES FROM TWO NORTHERNEUROPEAN CAVE SITES: METHODOLOGY AND PRELIMINARY RESULTS

Anna F. Tooth, Department of Earth Sciences, University of Keele, KEELE, Staffordshire ST5 5BG
ggd14@keele.ac.uk

Leaching experiments were performed in order to investigate the potential cation contribution from soil and aquifer zones to the geochemical signal of karst water. Samples were collected from two cave sites: Grotte de Clamouse, near Aniane, southern France, and Crag Cave, Castleisland, southwest Ireland. Clamouse bedrock comprises secondary limestones and dolomites; soils reflect their parent lithologies, being red earths and dolomitic sands, respectively. At Crag, the bedrock comprises limestone with patchy dolomitization, overlain by a well-consolidated, clay-rich till deposit. Low and high water:sediment ratios were used as analogues for percolative and conduit flow through soil, respectively. Rock leaches investigated differing water/rock interaction ratios. Experimental run duration was varied in order to imitate different residence times. Leachate chemistries were compared with congruent dissolution, acid-soluble cation concentration data. For both sites, 31 day rock leachates were close to saturation for calcite, irrespective of water/rock interaction ratios. All rock leaches had lower Ca, Mg and Sr yields than karst waters and concentrations progressively decreased with shorter residence times. Leachate yields trended towards incongruent dissolution. Low water:sediment, 31 day Crag till leachates were highly undersaturated for calcite. In contrast, the equivalent Clamouse leachates were supersaturated, whilst high water:sediment leachates became progressively undersaturated with shorter experimental durations. Soil leachate yields for both sites indicate incongruent dissolution effects. Long residence time rock leaches from both sites may approximate karst water cation chemistries, if pCO₂ was slightly increased. The low carbonate Crag till contributes little to karst water cation chemistry. Clamouse soil leachate chemistries suggest that percolative flow regime solutions will yield high carbonate concentrations, whilst conduit evolved solutions will be carbonate poor.

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.

All views expressed are those of the individual authors and do not necessarily represent the views of the Association unless this is expressly stated.

A COMMENT ON TREVOR SHAW'S 1996 PAPER ON WOOKEY HOLE

The article by Trevor Shaw in *Cave and Karst Science* 23 (1), p. 17-23, is destined to become a true classic of speleological history. His identification of the cave at Cheddar-hole as Wookey Hole may not be accepted universally but I am convinced that it is correct.

However, it surprises me that there continues to be controversy about identification of the cave mentioned by Clement of Alexandria about 200 A.D., "lying below a mountain... (where) the sound of cymbals clashing... is heard". To this day, there is a well-known cave lying below a mountain in Britain where the sound of cymbals clashing (and other orchestral music) is heard with tidal movements: Otter Hole. Ore-seeking Romans were accustomed to tight orifices, and its riverside site was even more accessible to Romans than was Wookey. I don't understand why this is not accepted universally. Is there evidence that, in Roman times, mean sea level in this estuary was at a different level, or that tidal patterns were different then?

William R. Halliday
Hawaii Speleological Survey
PO Box 1526
Hilo, HI USA 96721

BOOK REVIEW

KRANJC, A., (Editor), 1995. *Acta Carsologica*, Volume 24. Proceedings of the International Symposium "Man on Karst", Postojna, September 23.25. 591pp. ISSN 0583-6050.

Acta Carsologica is one of a number of publications that deal with aspects of the Natural Sciences, the fourth class of fields covered by the activities of the Slovene Academy of Sciences and Arts. Some would say that it also functions as the official bulletin of the Karst Research Institute at Postojna. This particular volume comprises almost 600 pages, most of which reproduce a series of papers that were presented at the Symposium: "Man on Karst", held in Postojna in 1993. The Symposium, dedicated to the 70th birthday of the well-known karst scientist Professor Ivan Gams, was attended by more than 70 delegates from most of the countries in Europe.

English-speaking readers might be forgiven for expecting this massive publication, being the official dissemination of a Slovene learned society, to be written mainly in Slovene, or perhaps in the dozen or more native languages of the many contributors. Not so. Almost the entire publication appears in English, with only one or two papers in French or German, and with some of the Symposium's speeches of welcome in Slovene or French, with English translations. Whatever its language of publication, each paper is accompanied by abstracts in English and Slovene, and with a brief concluding digest of its contents, also in Slovene.

There is no possibility for mistaking *Acta Carsologica* as anything other than a serious scientific work. It has an undeniably satisfying "thud factor", as might be expected from its c.4cm thickness. Yet for all this, it is not simply a "dry as dust" repository of scientific facts and figures.

Perhaps surprisingly the volume manages to retain and project some of the vitality, as well as the obvious variety, that must have been present at the Symposium itself. That the programme was varied and entertaining cannot be doubted, including the widest spectrum of topics that could legitimately be included within its broad title. Physical factors are amply covered in numerous papers dealing with karst soils, surface and underground karst landforms, mineral and clastic deposits and aspects of underground drainage. Modern and ancient cave biology, merging into palaeontology and archaeology are included, together with papers dealing with historical aspects of karst research. Questions of planning related to conservation, land-use and habitation are discussed, together with detailed considerations of various anthropogenic effects, pollution potential and strategies for groundwater protection. Among all this are details of techniques and methodologies currently applied or potentially applicable to pure and applied aspects of karst studies.

This is not the place to attempt to consider the individual papers presented in this issue of *Acta Carsologica*, nor to attempt dissection or criticism of their contents. The overall impression is of an informative, but also entertaining, cross-section of contemporary and cosmopolitan thinking, on all manner of topics that are related directly or indirectly to the understanding and preservation of the natural karst heritage. In general the papers are easy to read, though there are local peculiarities of translation. This is only to be expected, and does not affect understanding of the contents. The quality of the text printing is high, and the same is true of most of the non-photographic figures that accompany the papers, reflecting the generally high quality of the authors' originals and the printing itself. Relatively few monochrome photographs are also included, printed within the running text on the standard paper stock, and most of these provide acceptable illustrations in context.

It is perhaps unusual for a reviewer to pick upon a single item in a multi-faceted publication that is undergoing a generalised review. However, among the many papers in this volume that might elsewhere merit individual attention is one that is at once both disturbing and yet fascinating. Written by Andrej Mihevc, one of the delegates from the Karst Research Institute at Postojna, the short and, in some ways, shocking paper deals frankly but sensitively with the subject of "*Caves as mass-graveyards in Slovenia*". Few cave explorers in Britain will be able to imagine either the activities that led to this use of caves, or the experiences of the author and other explorers that lie behind this paper. But no doubt there will be those elsewhere in the world who will have had similar encounters.

During my early caving career I remember being fascinated by the story of members of a party from the recently-formed Birmingham University Speleological Society, who stumbled across a long-dead body, in a mine near Buckden in Yorkshire. It appeared that this individual had entered the mine of his own free-will, in pursuit of scrap metal in the form of railway tracks, but had suffered some misadventure. Innocent as this death was, I was unable to imagine how the explorers must have felt when, enjoying their chosen pastime, they encountered the pitiful remains. Yet their experience pales towards insignificance in the light of the observations, and extrapolations, reported by Andrej Mihevc. Among the many and varied papers presented in this volume of *Acta Carsologica*, and maybe among the much wider extent of karst-related literature worldwide, this one stands out as one that cannot have been easy to write. It handles a subject that might easily be seen as "taboo", dealing with historical facts that many might find distasteful and would prefer to see swept under the carpet. And it handles the subject well. The author deserves congratulation.

In this day and age, many reviews, whether of fiction, theatre, films or scientific texts, tend to gloss over the positive side of the subject, almost as if excellence is only to be expected, and somehow unworthy of comment. Instead the negative side is commonly over played, with various types of “nit-picking”, much of which betrays the reviewer’s subjectivity and prejudice rather than any real fault in the original. Though some minor criticism could be directed at Acta Carsologica, none would have any significant bearing on the questions of its overall quality and scientific value. This volume can be recommended to all those with an interest in karst, as it contains something for everybody, presented in a way that is generally readable, without being overpowering. There will be few who will find the entire content of interest, but that applies to most karst related publications, whether they be popular or scientific. The Editor and members of the Editorial Board should be congratulated on producing a quality publication, which feels and looks as if it “means business”, and achieves this without recourse to gimmicks or expensive publishing techniques. I would suspect that Acta Carsologica is not considered essential reading by many English-speaking karst scientists, still less by those non-scientists who simply have a healthy interest in karst-related matters. This example volume may be atypical with regard to the number of papers presented in English, yet even in issues where papers are included in the native Slovene or other European languages, English abstracts, captions and summaries are generally provided. So, whilst perhaps not an essential subscription, Acta Carsologica is certainly worth watching, and will almost certainly repay attention by providing karst insights and viewpoints that might well be ignored or overlooked by the more traditional and wider-remit “western” geomorphological journals.

Reviewed by Dr. D. J. Lowe, British Geological Survey, Keyworth, Nottingham, NG12 5GG.

THESIS ABSTRACT

SJÖBERG, R., 1994

Bedrock caves and fractured rock surfaces in Sweden, Occurrence and origin

PhD thesis, Stockholm University

[Available from Paleogeophysics and Geodynamics, Department of Geology and Geochemistry, Stockholm University, S-106 91 Stockholm, Sweden]

Fractured bedrocks are common all over Sweden. In this thesis we deal with the special type of fracturing that appeared during or after the deglaciation. They appear in the form of fractured bedrock surfaces, with little or none displacement on each side of the fracture; fractured hills, where the width of the fractures can be in the scale of one centimetre up to several decimetres; boulder heaps (“blown up” or “blasted” hills), where the direction of the original fractures can be observed, but the blocks and boulders are separated in a scale where they are totally free. Sometimes these fractures have been opened and covered by dislocated boulders, so that large cave systems have been formed within the opened fractures and the dislocated boulders. The transition between these features is not clear. On the same site we can find transitional forms where one part of the site is a fractured hill, while further away it is developed into a boulder heap. This shows that these forms are created by the same processes.

For the first time these features have been described in one context. Their occurrence have been investigated. Some of the sites have been investigated using the Schmidt Test-hammer, and their origin has been searched for among the following caution processes: glacial tectonics, frost deformation, methane ventings, postglacial aseismic stress adjustment, hydrofracturing and seismotectonics. These different processes are discussed and evaluated.

The results reveal that during the deglaciation of the Weichselian ice-sheet a combination of a very fast isostatic uplift, and corresponding changes in stress and strain, resulted in a here well documented neoseismotectonic activity. Several bedrock features, as the above described, seem to have been formed as a function of this paleoseismicity. A possible combination with other processes cannot be excluded.

RESEARCH FUNDS AND GRANTS

THE BCRA RESEARCH FUND

The British Cave Research Association has established the BCRA 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 must be the principal investigator, and must be a member of the BCRA in order to qualify. Grants may be made to individuals or groups (including BCRA Special Interest Groups), who need not be employed in universities or research establishments. Information about the Fund and application forms Research Awards are available from The BCRA Administrator (address at foot of page).

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.

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.

No. 6 *A Dictionary of Karst and Caves*; compiled by Dave Lowe and Tony Waltham, 1995.

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.

BCRA SPECIAL INTEREST GROUPS

SPECIAL INTEREST GROUPS are organised groups within the BCRA that issue their own publications and hold symposia, field meetings etc. *Cave Radio and Electronics Group* promotes the theoretical and practical study of cave radio and the uses of electronics in cave-related projects. The Group publishes a quarterly *technical journal* (c.32pp A4) and organises twice-yearly field meetings. Occasional publications include the *Bibliography of Underground Communications* (2nd edition, 36pp A4).

Explosives Users' Group provides information to cavers using explosives for cave exploration and rescue, and liaises with relevant authorities. The Group produces a regular newsletter and organises field meetings. Occasional publications include a *Bibliography* and *Guide to Regulations* etc.

Hydrology Group organises meetings around the country for the demonstration and discussion of water-tracing techniques, and organises programmes of tracer insertion, sampling, monitoring and so on. The group publishes an occasional newsletter.

Underground Photographer Magazine. This magazine was first published in December 1995, 48pp A4 with black and white photos. Subsequent editions have colour photos and articles on cave photography topics.

Speleohistory Group publishes an occasional newsletter on matters related to historical records of caves; documentary, photographic, biographical and so on.

Cave Surveying Group is a forum for discussion of matters relating to cave surveying, including methods of data recording, data processing, survey standards, instruments, archiving policy etc. The Group publishes a quarterly newsletter, *Compass Points* (c.16pp A4), and organises seminars and field meetings.

Copies of publications, information about Special Interest Groups, the BCRA Research Fund application forms, etc. are obtainable from the BCRA Administrator: B M Ellis, 20 Woodland Avenue, Westonzoiland, Bridgwater, Somerset, TA7 0LQ.

