Cave and Karst Science

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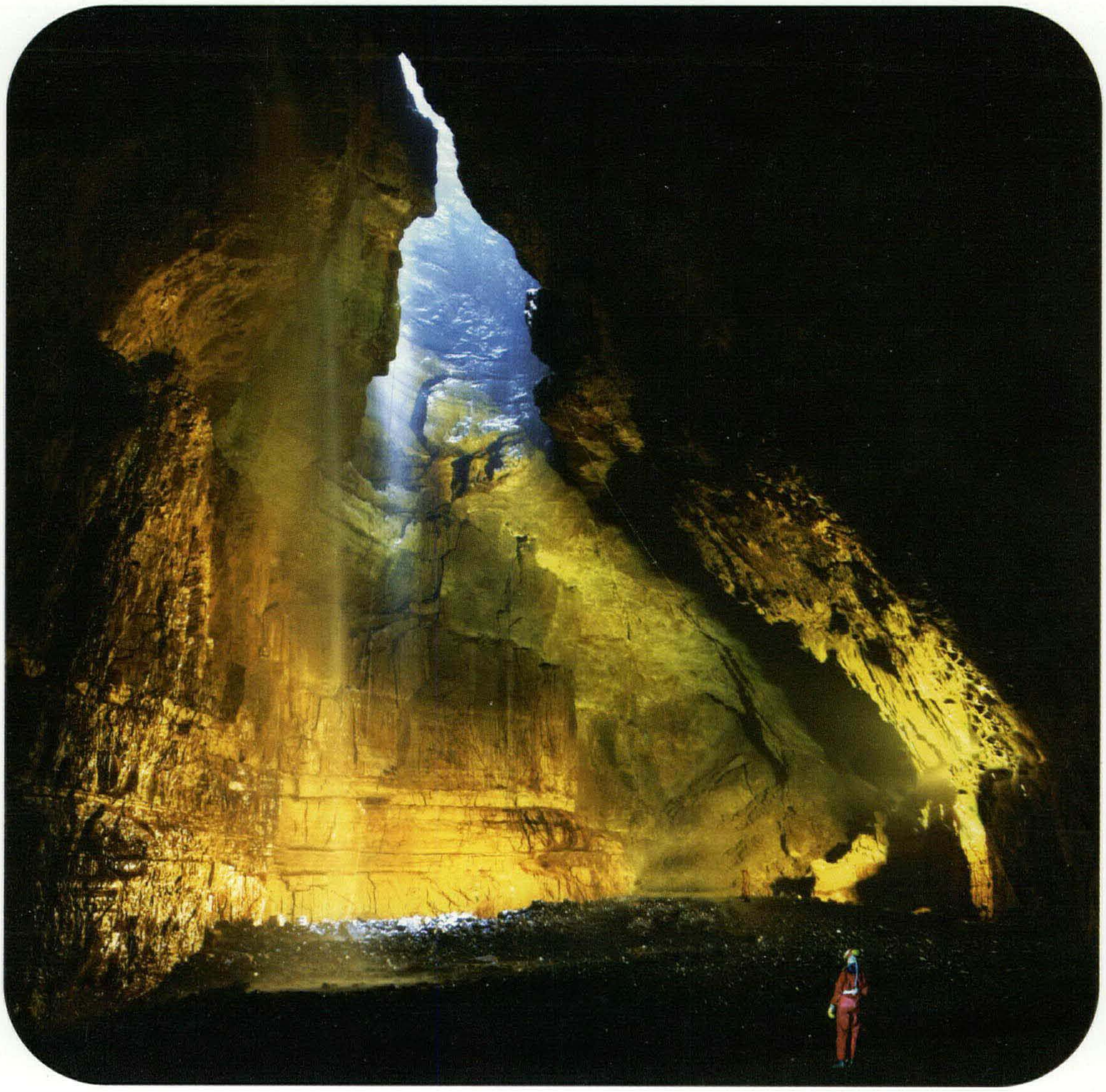

Cave and Karst Science

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

1. Papers

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. Manuscript papers should be of a high standard, and will be subject to peer review by two referees.

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

3. Forum

Personal statements, normally up to 1,000 words, on topical issues; discussion of published papers, and book reviews. Where appropriate, 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, c/o British Geological Survey, Keyworth, Nottingham, NG12 5GG, UK, and Professor J Gunn, Limestone Research Group, University of Huddersfield, Queensgate, Huddersfield, HDI 3DH. UK.
Intending authors are welcome to contact the Editors, who will be pleased to advise on manuscript preparation. Enquiries by E-mail are welcomed, to: d.lowe@bcra.org.uk or j.gunn@bcra.org.uk.

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

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Cave and Karst Science

TRANSACTIONS OF THE BRITISH CAVE RESEARCH ASSOCIATION

Volume 29, Number 3

Contents

Papers

Reports

Forum

Cover photo:

Gaping Gill Main Chamber and the base of Gaping Gill's Main and Lateral shafts, viewed from the far west slope. The depth of the Main Shaft, first descended by Edouard Alfred Martel in 1895 (see *Cave and Karst Science*, Vol.26, No.1), is the subject of ongoing discussion in this Issue's Forum.

Photographed by Jeff Cowling during the Craven Pothole Club winch meet, August 2002.

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

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EDITORIAL

David Lowe and John Gunn

Before embarking upon the Editorial proper we must record our apologies for the delays that this Issue has experienced in reaching publication. Two broad reasons underlie this greater than average delay. The first is our own ongoing and increased preoccupation with professional and related tasks, meaning (if nothing else) that we are unable to devote more than a tiny part of our time to the never-ending task of pursuing and then dealing with material suitable for publication. Secondly, however, we have suffered a number of unfortunate and unforeseen delays and misunderstandings, all beyond our control, relating to activities on both sides of the refereeing process. Hopefully, such a combination of problems will not re-occur in the future.

Regular readers will be aware that our publication policy attempts to be somewhat more progressive and flexible than that of some other scientific journals. Whereas, arguably, our lifeblood consists of papers that undergo a traditional peer review process according to appropriate criteria, we also offer space for less rigorously refereed "Report" contributions. Within this simple title we embed the scope, and the luxury of editorial discretion, to cover several aspects of a wider and more sympathetic approach to publication.

An important function of the Report is to provide a means for amateur scientists, or those who consider themselves "non-scientists", to gain experience and confidence (usually with initial advice and guidance from ourselves or from the Editorial Board), by publishing their results and ideas in a wide-circulation scientific journal. In this context we can publish material that would normally remain unpublished or, at best, be relegated to relative obscurity among the pages of more parochial club journals or newsletters. Many examples can be quoted from the past of crucial, well-observed data and related ideas and discussions being effectively hidden in this way, and subsequently being left undeveloped, unappreciated, unreferenced and, hence, leap-frogged by other scientists' work.

A second *Cave and Karst Science Repo*rt type allows publication of early or interim data and developing ideas related to ongoing research projects. We believe that such "progress reports" are potentially very important. They keep the general readership informed and can generate valuable feedback and input from workers with similar interests, suggesting ways of widening the research opportunities to maximise the returns or – more rarely perhaps – point out any possibility that the work is duplicative and potentially redundant.

The final two-pronged role of the "Report" is more controversial and some would say more "dangerous". It allows the airing of data and ideas that would normally be considered unsuitable for publication. Such work might relate to topics that do not appear at all in existing "karst" (*sensu lato*) text books, or the ideas presented might cast doubt upon, or contradict, widely accepted ideas, "flying in the face" of existing "knowledge" and "wisdom". We hope that our occasional reviewers and members of the *Cave and Karst Scienc*e Editorial Board would point out such mismatches and advise against publication as a mainstream Paper. However, we hope equally that none would be so complacent or short-sighted as to deny an author the chance to present new or more tangential ideas in the form of a Report.

Apparently, during the Nineteen-forties, the eminent, highly regarded and undoubtedly astute physicist Max Planck remarked that:

"A new scientific truth does not triumph by convincing its opponents and making them see the light, but rather because its opponents eventually die, and a new generation grows up that is familiar with it."

It is perhaps tautological to say that at any instant most of the leading experts in any research field will be at least "comfortable", if not totally *au fait*, with the accepted consensus understanding of that topic. Certainly some might see weaknesses or ambiguities in the understanding, and think laterally to find ways of testing current hypotheses, strengthening existing ideas or removing potential contradictions and shortfalls. In contrast, others, feeling more secure, will simply accept and assert that *"It's all tied up and nothing more is required"*.

This had been demonstrated *par excellence* during Max Planck's lifetime. In 1900 Lord Kelvin (the figurehead of contemporary physics) remarked that only two "clouds" remained on the horizon, preventing FULL UNDERSTANDING [our emphasis] of the laws of physics. His opinion was that the "clouds" (these being the understanding of black body radiation and of the results of the Michelson-Morley experiment) would soon be lifted, leaving no need for further physical research. In fact, Lord Kelvin's view was soon negated, and the two clouds merely ended the study of physics as he knew it. Investigation of the first "cloud" led eventually to Planck's quantum theory, and investigation of the second "cloud" led to Einstein's theories of relativity – research areas where many new questions have prompted ever more research.

In this Issue, and via the uncensored discussion board of our Forum section, just such a difference of viewpoints is continued, whole-heartedly and outspokenly. The controversy relates to an earlier *Cave and Karst Science* Report publication (Volume 28, Number 2) in which radical views relating to the origin of the words "Kras" and "Karst" (and related issues) were presented. Looking more widely than the contributions published in this Issue, and at the same time striving to retain a proper attitude of impartiality, it is fair to say that the original Report publication prompted significant interest. What's more, as is commonly the case, there seems to be no middle ground in the opinions that have reached us formally. On the one hand we have heard that the views expressed were novel, refreshing and thought provoking. On the other we have heard that the views expressed in the Report are totally irrelevant and that we failed in our editorial duties by allowing their publication. In our own defence we should say that the publication falls clearly inside the "Report" remit discussed above and that, having recognized the lateral nature of the approach and the nonconformist nature of the suggestions in the Report, we also took the trouble to highlight and explain our editorial decision.

In past issues the *Cave and Karst Science* Forum has hosted gentle and vigorous debates on a variety of topics, but even the most vigorous has not even approached the level of "feeling" that is evident in the exchanges printed in this Issue. Nevertheless, we feel that we are obliged to publish both sides of this discussion and, so long as the comments made remain "honest, legal and decent", we shall continue to do so if required, subject only to any other over-riding considerations. The authors of the contributions from both points of view have been full and frank in the criticism of their opponents. We take this opportunity to repeat and emphasise the following words from the preamble to Forum:

> *All views expressed are those of the individual authors and do not necessarily represent the views of the Association unless this is expressly stated. Contributions to the* Cave and Karst Science *Forum are not subject to the normal refereeing process, but the Editors reserve the right to revise or shorten text. Such changes will only be shown to authors if they affect scientific content. Opinions expressed by authors are their responsibility and will not be edited, although remarks that are considered derogatory or libellous will be removed, at the Editors' discretion.*

On the above basis we have taken the liberty of revising the English within each contribution, but no more stringent editorial censorship has been applied.

On a totally different note, as is customary in the final Issue of each Volume, we take this opportunity to hand out acknowledgements. Most obviously we thank the many authors who have continued to submit manuscripts for possible publication in *Cave and Karst Science*. For the next part of the publishing process many individuals have given freely of their valuable time, and given the benefit of their wide knowledge and experience, to help with the peer review of the submitted articles. In this context we thank Simon Bottrell, Colin Braithwaite, Andrew Chamberlain Helen Goldie, Chris Hunt, Clive Hunt, Alexander Klimchouk, Stein-Erik Lauritzen, Margaret Marker, Graham Proudlove, Peter Styles, Tony Waltham, Paul Wood and Chas Yonge. We also refereed some contributions, some of them jointly or in association with one or more of the referees named above. On the production side we once again thank Becky Talbot for her patience and diligence in dealing with the many aspects of desktop publishing, and we record our appreciation of the efforts of The Sherwood Press/Milford Printers in servicing our printing needs.

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Calcite moonmilk in the Humpleu Cave system (Romania): the relationship between crystal morphology and cave topoclimate

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Abstract: Calcite moonmilk is a common deposit throughout the passages of the Humpleu Cave system. The moonmilk deposits are in the form of massive flowstones, delicate draperies and patches of mould-like accumulations. Except for one sample (secondary in origin), all were precipitated directly from low-supersaturated, calcium-rich solutions. Scanning electron microscope observations reveal that the deposit consists of nanofibres, acicular microfibres, composite fibres, rhomb chains, and calcified filaments. These morphologies seem to have developed under specific topoclimatic cave conditions and at variable rates of dripping and CO_2 outgassing. Microbial activity apparently played an active role in the formation of some of the moonmilk.

INTRODUCTION

Moonmilk represents a depositional state characteristic of carbonates, sulphates, phosphates, and silicates, precipitated in a variety of cave environments. Hill and Forti (1997) indicate that it can take the form of many different speleothems (draperies, stalactites, stalagmites, helictites, flowstones, etc.). Moonmilk is usually white, yellowish-ochre to dark brown (depending on the type and quantity of impurities), soft and pasty when wet, and powdery (like talcum powder) when dry. In terms of crystallography, moonmilk deposits consist of nano- and micro-crystals exhibiting acicular, fibrous or lamellar habits.

For more information, concerning the mineralogy, morphology, and origin of moonmilk the reader is referred to: Bernasconi (1975), Onac and Ghergari (1993), Hill and Forti (1997) and Gradzinski *et al.* (1997). A study by Borsato *et al.* (2000) recently suggested the relationship between the crystal morphology of moonmilk and its depositional environment as a potential palaeoclimatic indicator. Earlier studies of moonmilk from the Humpleu Cave system were published by Onac (1992), Onac and Ghergari (1993), Ghergari *et al.* (1997) and Manolache (2001).

The aim of this study is to provide preliminary data concerning the relationships between the calcite crystal morphology of moonmilk, and cave topoclimate, using samples collected from passages with different temperature and ventilation conditions.

GEOGRAPHICAL AND GEOLOGICAL SETTINGS

The Humpleu Cave system is situated in the northwestern part of the Bihor Massif (Apuseni Mountains), in the upper part of the Firii Valley, a left-side tributary to Somesul Cald River (Fig.1, inset). The system consists of the Pestera Mare ("Big Cave") located in the Firii Valley with its entrance at an altitude of 1165m asl, and the Poienita Pothole at 1400m asl. The cave is approximately 39km in length and is formed in Lower Cretaceous miliolid-rich limestone about 350m

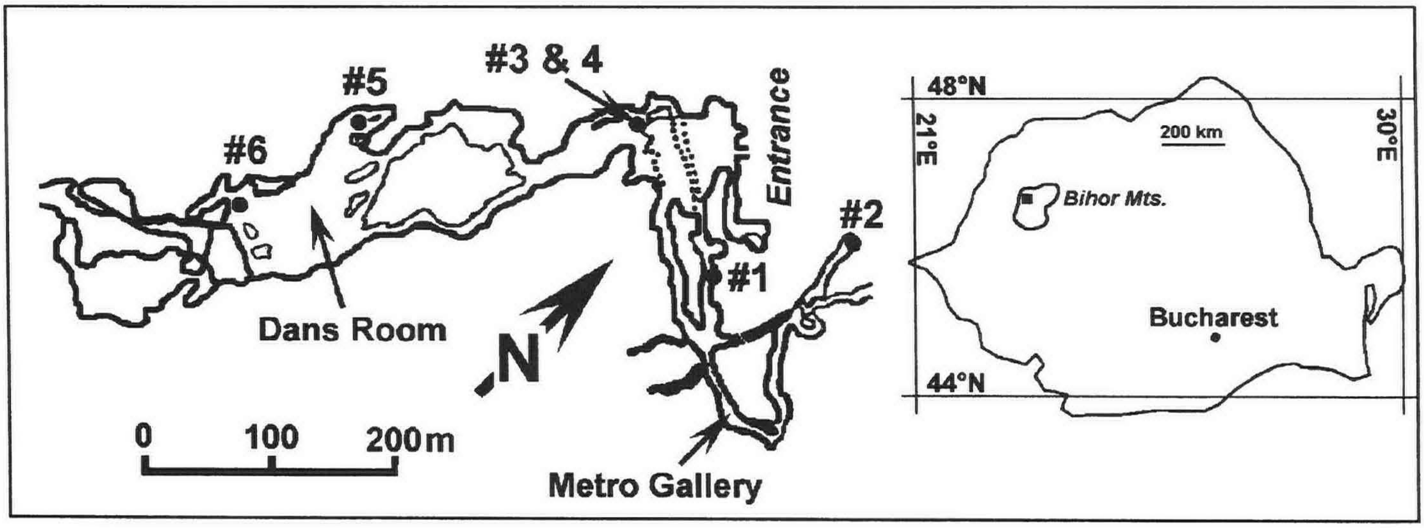

Figure 1. Simplified map of the entrance part in the Humpleu Cave system and location of the moonmilk sample sites (inset, map of Romania showing the location of Humpleu Cave).

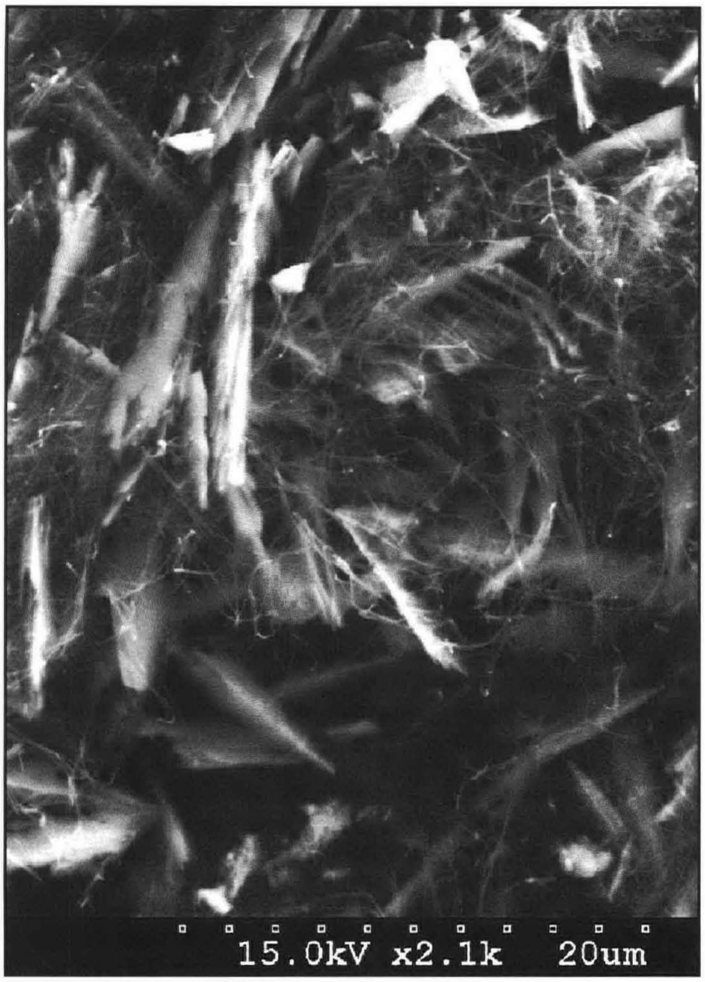

Figure 2. SEM photomicrograph of moonmilk composed of calcite nanofibres.

in thickness. This limestone unit exhibits the following sequence: micrites, calcarenites, pelsparites, and intrabiopelsparite (Mantea, 1985).

At present the climate around the cave is cold and humid with a mean annual temperature of 4°C, predominantly influenced by west to northwest oceanic air masses. Mean annual precipitation ranges between 1300 and 1400mm. The tree-line is at an altitude of ~1600m asl (Bleahu and Bordea (1981), and the region around the cave is characterized by coniferous forests and dark brown to black soils. Soil P_{CO_2}, measured with a Draeger gas detector at four separate locations above the cave, has a mean value of 0.54%.

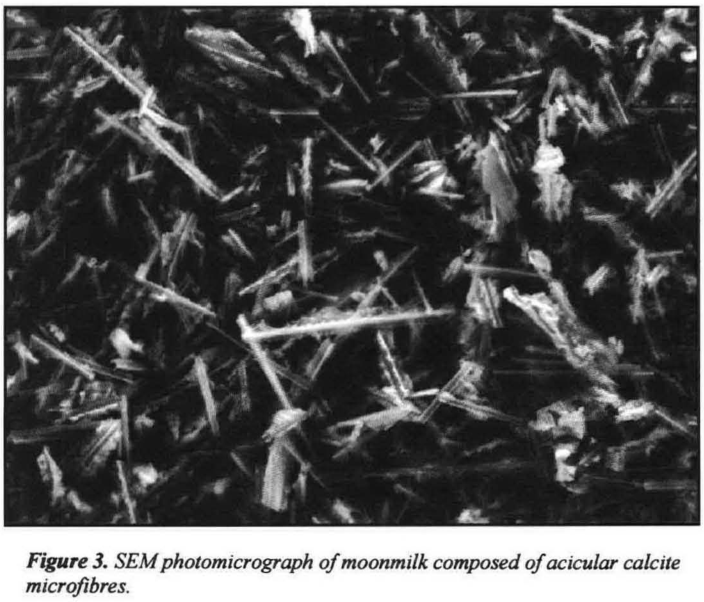

Figure 3. SEM photomicrograph of moonmilk composed of acicular calcite microfibres.

CAVE DESCRIPTION AND SAMPLES LOCATION

The Humpleu Cave system is developed on three levels. Lowermost is the active level, then an intermediate relict level (less developed), and an upper relict level consisting of large halls and passages (e.g., Giants Hall: 500 x 120 x 30m, and the Gabor Halasi Hall: 310 x 105 x 35m) (Ghergari *et al.*, 1997; Papiu, 2001). Thermocirculation (i.e. ventilation) is uni-directional (a chimney effect). In winter the air enters through the Poienita Pothole and exits through the Big Cave whereas in summer this process is reversed. Temperature values throughout the cave are between 6 and 8.6°C and the relative humidity (RH) lies between 90 and 100% (Popa, pers. comm.). All analysed samples were collected within the intermediate and upper levels, in passages showing various ventilation regimes.

Six samples were collected in the following settings:

- yellowish-ochre moonmilk (Sample 1) was collected from a drapery in the middle part of the Metrou Gallery. At this location the ventilation is low (under 0.5m/s), the temperature is 8.6°C, and the RH = 100% (Fig.1.1).
- white moonmilk (Sample 2) was collected from a mould-like deposit located beneath a limestone breakdown block in the final chamber of the Metrou Gallery. Ventilation was imperceptible near this site, T = 7.5°C and RH = 100% (Fig.1.2).
- Samples 3 and 4 were collected from a large moonmilk flowstone deposit near the entrance of the Metrou Gallery (Fig.1.3 and Fig.1.4). Sample 3 consists of a highly hydrated white moonmilk from the inner part of the deposit.
- Sample 4 is brownish-ochre moonmilk from the surface of the deposit. At this site the ventilation is moderate, whereas the measured temperature and relative humidity were 8.0°C and 99%, respectively.
- Sample 5 was collected from a moonmilk drapery in a side passage within Dans Room (Fig.1.5). At this location, ventilation is moderate, temperature is constant at 8.2°C, and RH = 92 to 99%.
- Sample 6 was collected from beneath thick fractured calcite crusts covering the floor of a gallery lying above the river passage at the southern end of Dans Room (Fig.1.6). The moonmilk resembles that in Sample 2. However, ventilation is imperceptible at the site, and the temperature and the relative humidity are higher than at Sample Site 5 (8.3°C; 100%).

The moonmilk speleothems from which samples 1, 4, and 5 were collected have formed from percolating waters with discharges ranging from 0.01 and 4ml/min. Water samples from these active depositional sites were all saturated with respect to calcite. The calculated saturation index (SI_{cal}) values ranged between 0.12 and 0.17.

ANALYTICAL METHODS

All moonmilk samples collected were studied by means of a scanning electron microscope (SEM) (Stereoscan 250 MK3-Cambridge) equipped with energy-dispersive spectrometer, and X-ray powder diffraction (XRD) using a standard Philips PW1800 diffractometer fitted with a curved graphite diffracted-beam monochromator. Operating conditions for the XRD were 45kV and 40mA, Cu*Kα* radiation using quartz as an internal standard. All samples were scanned continually from 3 to 75° 2θ with a step interval of 0.025° 2θ. Inductively Coupled Plasma-Atomic Emission Spectrometry (ICP-AES) analyses were also undertaken using a Jobin Yvon Sequential Spectrometer (JY 24). Detection limits for measured elements with this instrument are less than 0.005 wt.% in the sample and analytical errors were below 5%.

RESULTS AND DISCUSSIONS

XRD patterns from all moonmilk samples revealed their calcitic composition. After subtraction of the characteristic calcite lines in samples 1, 4 and 5, the remaining reflections conform closely to phyllosilicates and quartz. This finding is supported by ICP-AES analysis, which indicates large amounts of iron and aluminium in sample 4 (Fe_2O_3 = 3.19%; Al_2O_3 = 8.69%). In samples 1 and 5 these elements are less prominent (Al_2O_3 is 1.08%, and 2.68%, respectively) but are higher than those in samples 3 and 6 (mean value 0.34%). All samples are yellowish-ochre to brown, suggesting rather high amounts of colloidal clay minerals in the percolating water. Clay minerals within the speleothems may explain the high water content in these deposits.

SEM analysis of the crystalline phases of the moonmilk precipitated in different ventilation conditions, revealed varied morphologies. According to Folk (1965), Jones and Kahle (1993), and Verrecchia and Verrecchia (1994) crystals with a length:width ratio greater than 6:1 are fibres. Given the size of the calcite crystals in our samples and adopting the Borsato *et al.* (2000) classification, we will refer to nanofibres (50-100nm wide and less than 10 µm long), acicular microfibres (<2 µm wide, >10 µm length), calcite filaments, and aggregates (composite fibers, and rhomb chains).

Nanofibers have formed in samples 1, 4, and 5 (Fig.2) under conditions of moderate ventilation, high relative humidity and temperature (> 7.5°C), and at low water discharges. The Ca^{2+} concentrations in all these samples lie between 47 and 62 mg/l.

A special discussion is needed for Sample 5, a moonmilk drapery composed of distinct layers of calcite. Several of these layers consist of calcite nanofibres, whereas in others the crystals are acicular microfibres (Fig.3), composite fibres (Fig.4) or rhomb chains (Fig.5). This situation is partially due to humidity fluctuations (associated with seasonal changes in the airflow circulation) and to variations of the drip rate, which in turn influence (lower) the Ca^{2+} concentration. When these circumstances are combined with airflow above 0.5 m/s, low drip rate, and low supersaturation, nanofibres will precipitated preferentially. At very low airflow (< 0.5 m/s), high SI_{cal}, and RH, acicular microfibres and/or composite fibres and rhomb chains will be deposited.

Given the particular locations of samples 2 and 6, it is assumed that the water from which the contorted microfibre crystals grew was of capillary origin. The supersaturation, high humidity and absence of ventilation led to the appearance of this specific calcite crystal morphology.

The SEM images of Sample 6 revealed calcified filaments that may be an indication of biological activity (Fig.6). EDS analysis confirmed the presence of Ca in these filaments. It is important to emphasize that the temperature of the microenvironment near the sampling site was above 8°C. This value is in agreement with the experimental work of Bertouille (1972), who found that proliferation of bacteria only occurs when the temperature is higher than 8°C.

Sample 3 has a secondary origin (weathering of calcite crusts or limestone bedrock), a fact indicated by the morphology of the calcite crystals: large subhedral prisms that exhibit corrosion features along their edges. All of the other moonmilk samples were precipitated directly from low supersaturated solutions (primary or neoformation moonmilk).

CONCLUSIONS

Taking into account the temperature, the relative humidity, the ventilation, the drip rate, and the SI_{cal} of each sampling site micro-environment, along with the morphology of the calcite crystals, we conclude that acicular microfibres, composite fibers and rhomb chains appear when the RH is >92%. When conditions are such that the RH is slightly greater than 92% and the evaporation rate is very low, the saturation index is enhanced and the result is the precipitation of primary moonmilk. However, when conditions allow the RH to be very high (99-100%), low drip rates and moderate ventilation favour the deposition of calcite nanofibres. In addition, knowing that the origin of some moonmilk in this cave was biologically-mediated (Manolache, 2001), and since calcified filaments were found in samples 2 and 6, microbial activity played an active role in the formation of at least a part of the moonmilk speleothems.

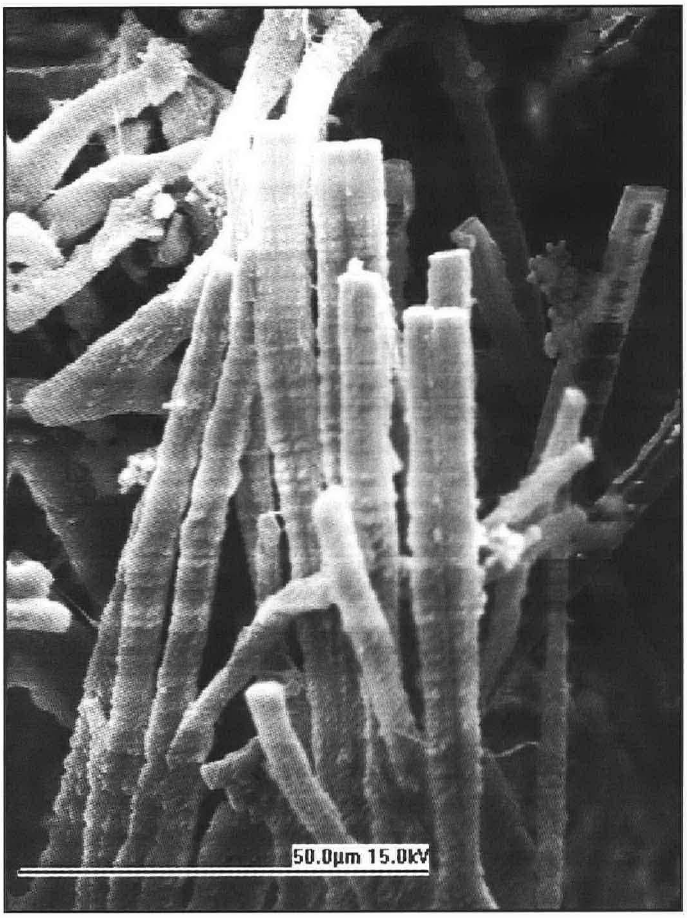

Figure 4. *SEM photomicrograph of composite fibres.*

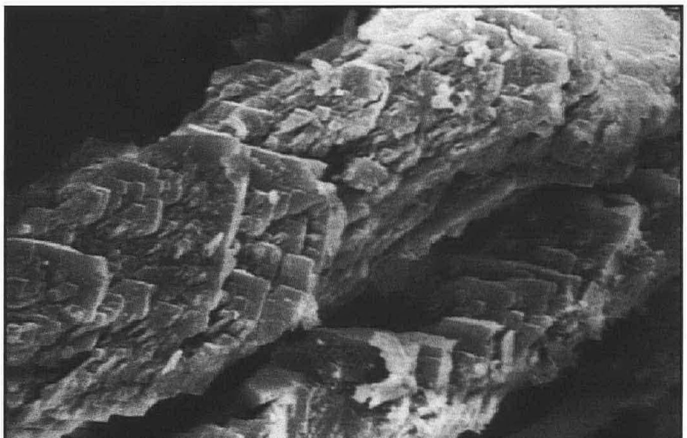

Figure 5. *Detailed SEM photomicrograph of moonmilk composed of calcite rhomb chains.*

ACKNOWLEDGEMENTS

The field trip for this work and the costs for part of the analyses were supported from a CNCSIS grant 38/41 to B P Onac. Philipp Haeuselmann helped with sample collection. This manuscript was improved by comments from an anonymous reviewer, to whom the author is grateful.

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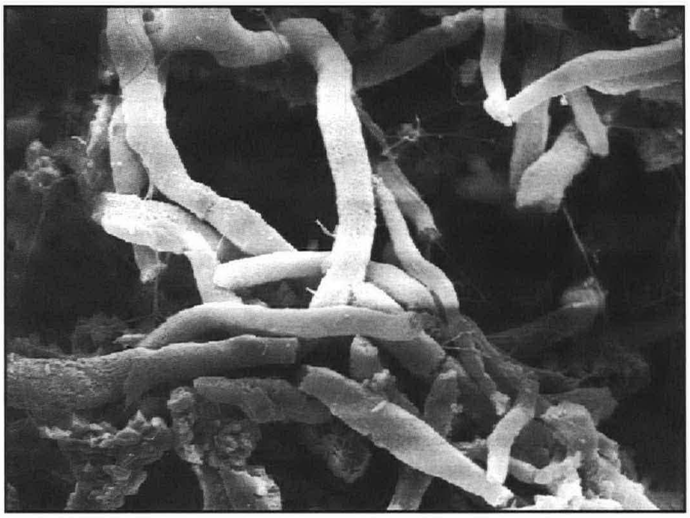

Figure.6. *SEM photomicrographs of calcified filaments.*

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The geological setting, hydrology and ecology of Roosky Turlough, Ely, Co. Fermanagh, Northern Ireland

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INTRODUCTION

Turloughs (from the Irish *tuar lough* - dry lake) are ephemeral lakes whose presence or absence is controlled by fluctuations in ground water levels. They are well known from the southwest and central Irish Republic, and are particularly well developed in northern Co. Clare, east Co. Galway and Co. Roscommon (Praeger, 1932; Sweeting, 1953; Drew and Daly, 1993). Fogg and Kelly (1995) identified three small loughs at Ely, Co. Fermanagh, that can be defined as turloughs, the only examples recorded in Northern Ireland to date. Roosky Lough is the southernmost, Green Lough lies to the north, with Fardrum Lough between the two (Fig.1). They are among the most northerly of these lake types in Ireland and represent 3 out of only 4 turloughs recognised within the United Kingdom, the other being Pant y Llyn in South Wales (Hardwick and Gunn, 1995). The lakes flood in winter, or after periods of prolonged rainfall, and dry out, partially or completely, in periods of low rainfall and/or high evaporation/transpiration, especially during summer and early autumn. The conservation importance of the turloughs is reflected in their being designated an Area of Special Scientific Interest (ASSI) under Northern Ireland's conservation legislation and being selected as candidate Special Areas of Conservation (SAC) under the European Community's Habitats Directive.

DESCRIPTION

Green Lough has no obvious point recharge or discharge features and it is assumed that the lough level reacts to variations in the piezometric surface within the Ballyshannon Limestone. The approximate maximum area of the turlough is 3,600m^2.

Fardrum Lough at approximately 20,000m^2 is the largest of the three loughs and is, at least partly, fed by a surface stream flowing from the west (Fig.1). An artificial surface outlet has been constructed into a quarry to the south, but the presence of springs and remnant cave passage in the quarry suggests that water originally drained from Fardrum Lough via a subterranean route, prior to the quarrying and outflow development.

Roosky Lough is the best preserved and most complex of the group (Figs 1 and 2, Plates 1 and 2). The western margin of the depression is formed by a steep northnortheast-trending vegetated slope, parallel to the trend of the Ballyshannon Limestone. Gradients to the northnorthwest, southsoutheast and east are more gentle and are interpreted as dip slopes. The depression has dense thorn bushes at its western and northern margins but is open to the east with a few isolated thorn bushes. A limestone drystone wall trending west–east

Plate 1. Roosky Lough in dry conditions (Summer 1995). Photo looking northeast from near the southern margin of the maximum extent of the turlough. The drystone wall coated with Cinclidotus fontinaloides and Fontinalis antipyretica, the sink and the channel leading from spring 3 to the sink are clearly visible. The marshy area associated with spring 3 in summer is visible behind the figure.

Plate 2. Roosky Lough in wet conditions (Winter 2002/2003). Looking southeast from the turlough edge at spring 2.

has been built across the centre of the turlough area. The turlough is fed by three discrete springs, two of which lie within the maximum observed turlough area, and one of which lies outside. The springs associated with the turlough area are here referred to as (anti-clockwise from spring 1):

- Spring 1: Located approximately 40m northnorthwest of the wall crossing the centre of the turlough;
- Spring 2: Located in the northwestern corner of the turlough area, approximately 0.5m above the maximum observed extent of the turlough;
- Spring 3: Situated approximately 25m southwest of the sinkhole area in the turlough. There is always a marshy area associated with this site.

Water drains from the turlough via a discrete sink area, located immediately south of the wall crossing the middle of the turlough (Plate 1). There is a marked closed depression associated with the sink site. Shallow watercourses (<0.5m) carry water due south from spring 1 and east from spring 3 to the sink. Water flows from spring 2 into the area of spring 3. In dry summer conditions none of the springs were observed to be active and only a limited wet marshy area was seen to be associated with spring 3. The shallow watercourses from springs 1 and 3 to the sink are indistinct in summer when the grass on the turlough floor is actively growing. Spring 2 has never been seen to be active in summer. In winter, the influence of increased precipitation and reduced evapotranspiration presumably raises the piezometric surface within the Ballyshannon Limestone Formation. In heavy rainfall conditions spring 2 becomes active and water can be seen upwelling from spring 1. An examination of the site during a dry spell some two weeks after the turlough had been at its maximum extent showed that spring 2 was inactive, but that there was active flow from springs 1 and 3. The flooded area was of only limited extent. These observations suggest that spring 3 becomes active first in rising water conditions, followed by spring 1 and then 2, with flow ceasing in a reverse order during falling water conditions.

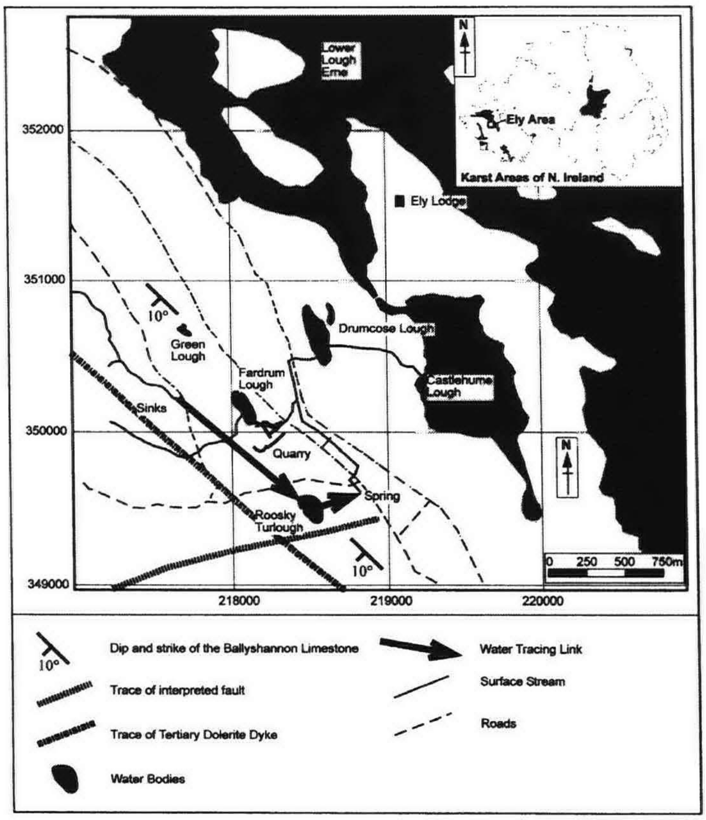

Figure 1. Topography, geology and hydrology of the Ely area.

WATER TRACING

An attempt was made to determine whether sinks located in Concaroe Townland drained to Roosky Lough and to determine if water rising at a spring in Roosky Townland to the northeast of Roosky Lough is draining from the turlough. The tracing agent used was Leucophor STA, a non-toxic, non-visible chemical that is used at extremely low concentrations. Detection is by adsorption of the Leucophor onto white unbleached cotton wool ball detectors that are placed in potential springs. Positive detectors fluoresce when exposed to UV light. Detectors were placed in the springs for at least two days before a trace was undertaken. After introduction of the tracing agent detectors were changed daily for seven days and then weekly until a positive result was obtained. Following a positive result, detectors were changed weekly until all springs were negative, before a subsequent trace was undertaken.

An initial tracing experiment was undertaken to identify the spring or springs to which Roosky Lough drains. At Roosky, 1L of Leucophor STA was introduced when the turlough was at approximately half its maximum areal extent and spring 2 was active. Detectors were placed in all identified springs within 3km of the turlough. The only positive response was from a significant spring 260m northeast of, and 15m lower than, the turlough.

Subsequent tracing was undertaken to determine if any point sources could be identified feeding the springs supplying water to the turlough at Roosky. Specifically, this was directed to determine if a significant surface stream sinking at Concaroe Townland, approximately 1.2km to the northwest and approximately 30m higher than Roosky Lough, drained to Roosky and/or a spring to the northeast of Roosky Lough. At Concaroe, 1L of Leucophor STA was introduced when water was sinking at these sites. Detectors were placed in Green Lough, Fardrum Lough, the stream entering

Plate 3. Active spring 2, Roosky Lough, high water conditions (Winter 2002/2003).

Roosky Lough from Spring 3, Roosky Lough and the spring identified as the main drainage from Roosky. A positive response was obtained from Spring 3 and the spring for the turlough, indicating that the water sinking at Concaroe enters Roosky Lough from Spring 3.

These tracing experiments indicate that the water in Roosky Lough is derived entirely or in part from underground flow sinking at Concaroe. The lake drains via an underground conduit to the spring northeast of the turlough (Plate 3). A significant strike-oriented ridge separates the sinks at Concaroe from Roosky, and a second strike-oriented ridge separates Roosky Lough from the spring to the northeast (Plate 4). Water flow in low water conditions is almost entirely underground, with significant turlough flooding and surface water flow present only in high water conditions.

GEOLOGICAL SETTING

The turloughs and their associated features are located in an area underlain by the Ballyshannon Limestone Formation, which crops out extensively on the western shore of Lower Lough Erne. The limestones are well exposed in a small quarry at Roosky, where they are composed of pale to mid grey, medium- to coarse-grained bioclastic crinoidal packstones and grainstones. The limestones dip at approximately 10° to the westsouthwest, with a number of strike-oriented limestone scarps running sub-parallel to the western shore of Lower Lough Erne. The turloughs all lie within a northnortheast trending valley developed parallel to the strike trend of the Ballyshannon Limestone Formation and are located at the low points on the dip surface of the limestone between two of these limestone scarps (Figs 1 and 3).

A large northwest-trending dolerite dyke of Tertiary age, the Cullen Hill Dyke, is located about 200 to 500m southwest of the turloughs. This intrusion consists of massive, medium- to coarse-grained, ophitic dolerite, and is partially spheroidally weathered (Legg *et al.*, 1998). Joints in the dyke strike northeast and the dyke appears to cut across other structures in the area (Legg *et al.*, 1998), suggesting that the dyke is not offset appreciably by later faulting. This indicates that the dyke forms a major vertical barrier to water movement downdip in the Ballyshannon Limestone aquifer.

The presence of the Cullen Hill Dyke, which probably forms a major hydrological barrier to down-dip drainage to the southwest, has exerted a major control on the karst drainage patterns in the Ely area. It forces drainage to follow the strike of the limestones, before breaking through and flowing against the dip of the limestones on suitably orientated structures. Water flow in the area, therefore, is interpreted as following strike-parallel conduits from the northnorthwest to the southsoutheast, the flow probably changing direction to the eastnortheast where a significant eastnortheast fracture cuts the strike-parallel ridges. It is therefore suggested that

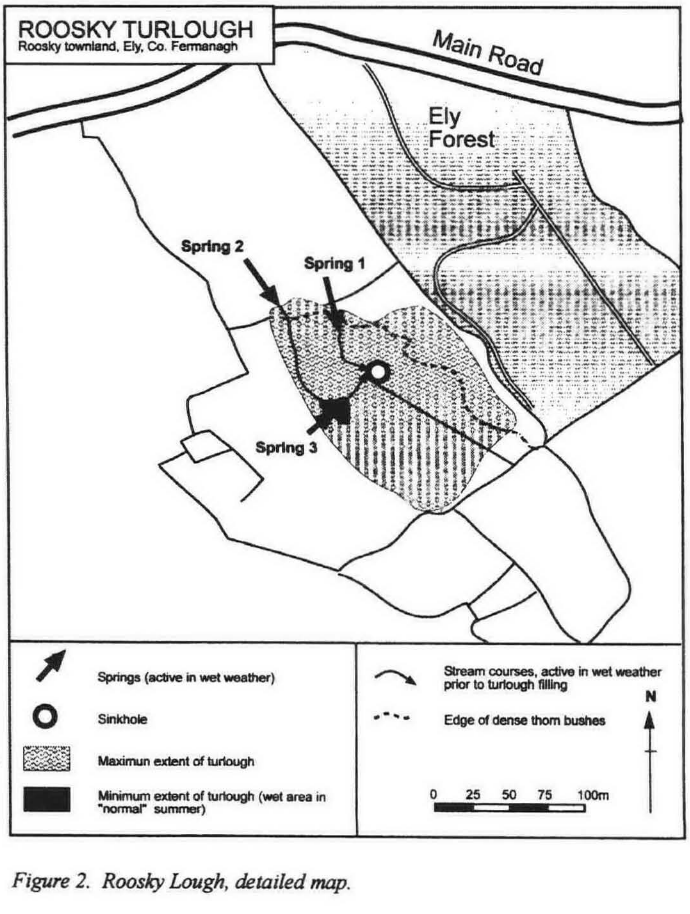

Figure 2. Roosky Lough, detailed map.

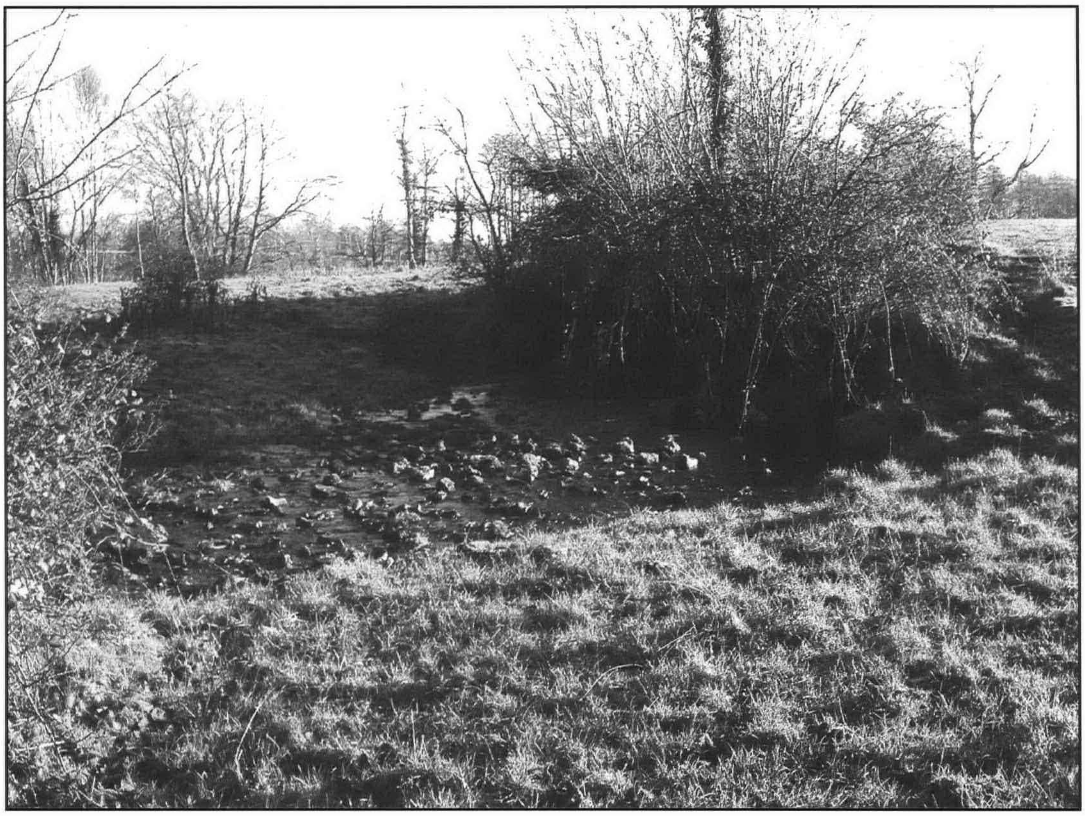

Plate 4. Spring in Roosky Townland, fed by water draining from Roosky Lough and Concaroe Sinks.

the location of the turloughs is controlled by a combination of thin shales or argillaceous limestones, which have influenced the development of the dip and scarp slopes, and by the presence of the impermeable dyke downdip of the outcrop of the Ballyshannon Limestone. Reflecting the dip and strike direction of the limestones, the presence of thin shales within the limestones and the presence of the dolerite dyke downdip, the turloughs have formed due to groundwater "trapped" in the strike parallel valleys controlled by the dip of the limestones (Fig.4).

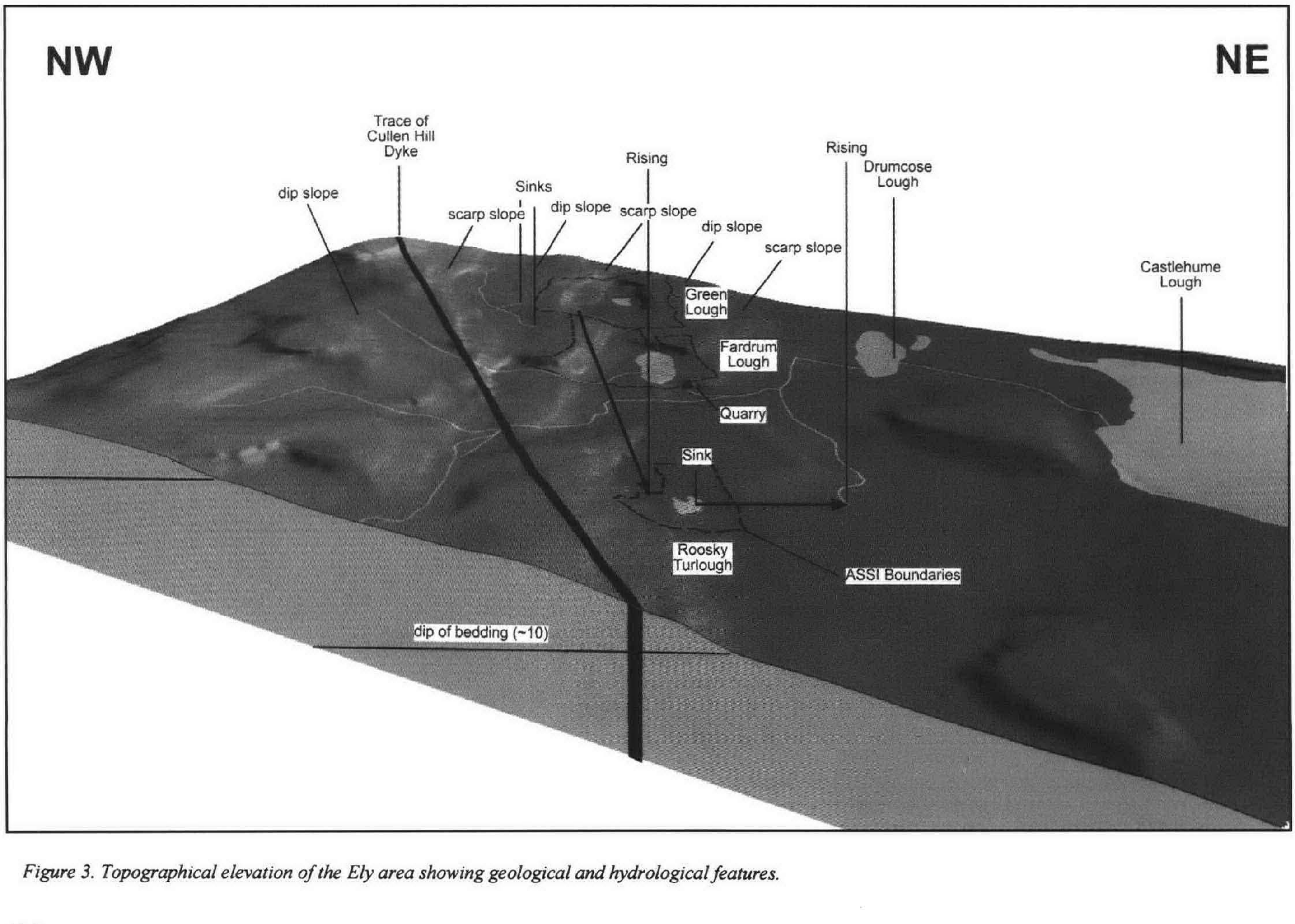

Figure 3. Topographical elevation of the Ely area showing geological and hydrological features.

ECOLOGY OF THE TURLOUGHS

Factors influencing plant communities
Plant communities within turloughs are controlled by a number of factors (Coxon, 1987) including:
1) degree of inundation (depth and duration);
2) substrate;
3) slope;
4) water chemistry, and
5) land management.

Taking these in turn:
1) Areas of permanent water are rarely present at Roosky Lough, whereas Green and Fardrum Loughs have small pools and a 2 ha lake present respectively. Between these and the maximum limit of flooding, is the inundation zone, ranging from zones of occasional flooding (the upper inundation zone) to those that are nearly permanently inundated (the lower inundation zone).
2) Substrate is generally mud, rich in peat. Limited limestone outcrop is present, particularly at Fardrum Lough. Given the generally uniform nature of the substrate, variability of community type is unlikely to be influenced by this factor.
3) Slope has a particular influence on the width of the inundation zone where this develops without management restriction. Only Roosky Lough shows an intact transition, matched by low slope angle within the basin, resulting in an extension of the various wet grassland types.
4) Chemical analysis of residual summer water at Fardrum and Green Loughs (Wolfe-Murphy *et al.*, 1992) shows high values for calcium and alkalinity, reflecting the influence of the underlying limestone. The shallow, productive nature of these water bodies was reflected in high total phosphate, whereas intensive use of adjoining land may have contributed to this status and would also be the reason for elevated ammonium and potassium values.
5) Re-seeding and associated fertiliser inputs, together with sheep and cattle grazing, have altered much of the land adjoining Fardrum and Green Loughs. Whereas some poaching by stock helps keep the inundation zone open, and hence more diverse, higher stock densities can result in substantial areas of bare mud, as at Fardrum. Reseeding at Fardrum and Green Loughs has resulted in the direct loss of adjoining semi-natural habitat, while fertiliser and other sward dressing maintains the vigour of non-native grasses (allowing them to out-compete more desirable species) and impacts on water quality and hence the turlough vegetation.

Main plant communities and species
The turloughs all exhibit distinctive vegetation communities (all species names after Stace, 1991) associated with the inundation zone. As indicated above, this zone has an upper and lower component. The upper area is characterised by species tolerant of a wet substrate and occasional immersion, together with a range more typical of wet grassland. These include Creeping Bent (*Agrostis stolonifera*), Silverweed (*Potentilla anserina*), Selfheal (*Prunella vulgaris*) and Creeping-Jenny (*Lysimachia nummularia*). The unusual looking Adder's-Tongue Fern (*Ophioglossum vulgatum*) is present in places, whereas the nationally rare Fen Violet (*Viola persicifolia*) has also been recorded at Green Lough. Two mosses that are very characteristic of turloughs (Praeger, 1932) are present, namely *Cinclidotus fontinaloides* and *Fontinalis antipyretica*. The former generally occurs at higher levels than the latter, where present. Indeed the recognition of an upper and a lower inundation zone has been based on the relative position of these mosses and associated species (Coxon, 1987).

The lower zone is typified by species including Marsh Pennywort (*Hydrocotyle vulgaris*), Water Mint (*Mentha aquatica*), Common Marsh-bedstraw (*Galium palustre*), Great Yellow-cress (*Rorippa amphibia*) and Water Forget-me-not (*Myosotis scorpioides*), together with the aquatic moss *Fontinalis antipyretica* and the brown moss *Calliergon giganteum*. Permanently wet basins within the turloughs support vegetation typical of lakes (aquatic communities) and lake

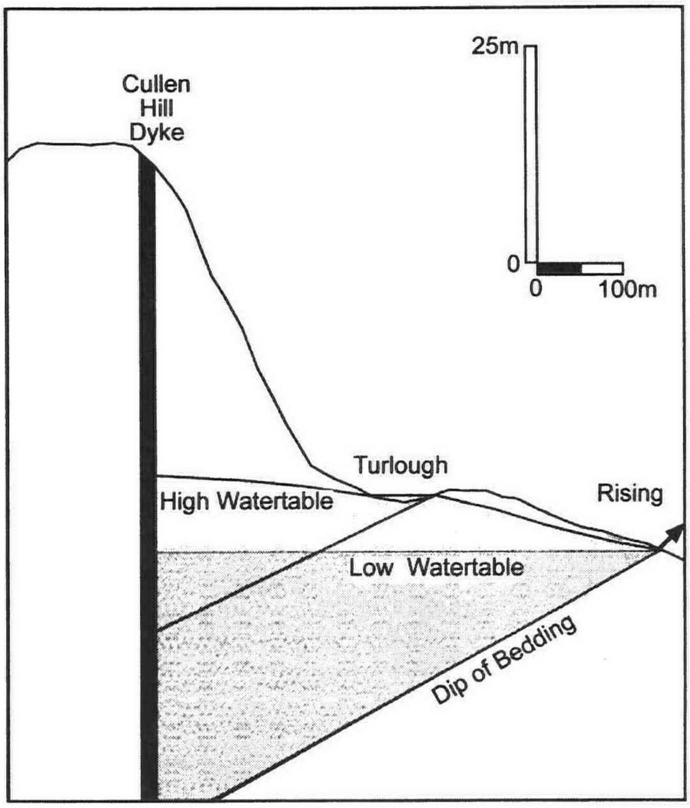

Figure 4. Schematic cross-section of the Roosky Lough area.

shores (swamp communities). Swamp communities occur between the shallow areas of permanent water and the lower inundation zone, where the substrate is always very wet. Typical species include Bogbean (*Menyanthes trifoliata)*, Amphibious Bistort (*Persicaria amphibia)*, Fine-leaved Water-Dropwort (*Oenanthe aquatica)*, Bottle Sedge (*Carex rostrata)*, Water Horsetail (*Equisetum fluviatile)*, some of which form very extensive swards. More rare and unusual species recorded include Least Bur-reed (*Sparganium natans)*, Tufted-sedge (*Carex elata)* and Water Dock (*Rumex hydrolapathum)*.

The more common aquatic species include White Water-Lily (*Nymphaea alba)*, Common Water-starwort (*Callitriche stagnalis)*, Ivy-leaved Duckweed (*Lemna trisulca)*, Mare's-tail (*Hippurus vulgaris)*, Pond Water-Crowfoot (*Ranunculus peltatus)* and the pondweeds, Broad-leaved Pondweed (*Potamogeton natans)* and Small Pondweed (*P. berchtoldii)*.

There are some obvious species absent from the Ely Lodge turloughs, when compared with the better known and larger sites in the Republic of Ireland, including the classic turlough shrub Shrubby Cinquefoil (*Potentilla fruticosa)*. Broadly, the inundation communities described here match well those elsewhere in Ireland. There is a close descriptive match with the Ranunculo - Potentillum anserinae community described by O'Connell *et al.* (1984).

Invertebrate interest
The turloughs support a range of water beetles, with the species *Rhantus frontalis* being typical of such ephemeral water bodies. Green Lough supports a very rich ground beetle fauna including the carabids *Blethisa multipunctata* and *Pelophila borealis*. One particularly notable species is the rove beetle *Philonthus corvinus*, which is rare across the whole of its range. In total, these wetlands have contributed nine records of beetles new to County Fermanagh.

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EDITORS' NOTE

Subsequent to the studies described in the above paper, the Environment and Heritage Service commissioned the Limestone Research Group, University of Huddersfield, to undertake additional studies with particular reference to possible impacts on the three turloughs from quarrying. Work between September and December 2002 has shown that the turlough hydrology / hydrogeology is more complex than is suggested in the paper. However, it was considered important not to delay publication, as the paper provides the first published description of the turloughs and their ecological and geological context.

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Occurrence of cover-collapse sinkholes [cover-collapse dolines] in the May Dam reservoir area (Konya, Turkey)

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Abstract: May Dam provides a typical example of the problems that may be associated with dams constructed in karstic regions and the associated development of subsurface karstic features beneath a reservoir. Following construction of the May Dam in 1960 there were immediate leakage problems. The reservoir behind the dam is within a heavily fractured karstic region and water leakage via fractures in the limestone floor constitutes 67% of the total water entering the reservoir. Water leaks led to the washout of unconsolidated material from underlying conduits and the formation of voids in alluvial cover. Frequent fluctuations of the levels of the reservoir and the water table cause enlargement of soil voids and formation of cover-collapse sinkholes. In February 2002, when the reservoir level was at its maximum, three large collapse sinkholes formed in the reservoir floor. These sinkholes and other sinkholes that might form in the future pose a major threat to the stability of the local environment and the dam.

Key words: Cover-collapse, sinkhole, May Dam, karst, Turkey

INTRODUCTION

Dams have been constructed on numerous rivers all over the world in attempts to meet the energy, drinking water and other water resource demands of rapidly increasing populations. New examples are built every year. Where dams are constructed in karstic regions leakage and associated sinkhole formation endangers dam stability, posing great threats to the environment (Jennings, 1971; Fetzer, 1979; Jennings and Marker, 1979; Sherard, 1979; Boncompain *et al.*, 1989; Ul Hag, 1996; Al-Saigh *et al.*, 1994, Uromeihy, 2000). Such problems were observed at the May and Apa dams, constructed on rivers west of the Konya plain between 1960 and1970 to help prevent floods and to provide irrigation, drinking water and other water resources (Öncü, 1978; Özdemir, 1991). Collapse sinkholes formed behind the May Dam, leading to loss of water.

The May Dam, which lies some 35km south of Konya Province, was constructed using a homogenous soil filling technique (Fig.1). The dam was designed to pond the waters of the May River, which flows from the Erenler–Akcadağ volcanic mass. General characteristics of the dam are as shown in Table 1.

Year of completion	1960
Embankment type	Homogenous soil filling
Crest height	19.10m
Crest width	6m
Crest length	420m
Full reservoir crest elevation	1058.60m
Catchment area	1411km^2
Reservoir volume at 1058.60m	41 x 10^6 m^3
Reservoir area at 1058.60m	860 ha

***Table 1** General characteristics of the May Dam*

Construction of the May Dam began in 1957 and was completed in 1960, when water storage also began. However, the capacity of the reservoir was observed to be well below the expected value due to water loss through its limestone floor. More than half of the water that should collect behind the dam is lost by way of karstic conduits.

Water loss from the dam reflects the presence of fractures, swallow holes and caves in the limestone that floors the reservoir. Three new collapse sinkholes were formed in 2002, adding to those that existed previously. The formation of these new sinkholes has posed a major threat to the environment and to the stability of the dam, as well as causing increased water loss. However, development of the new collapse sinkholes has also provided important insight into the relationship between water leakage from the reservoir and the karstification of its floor.

This study set out to investigate the water leakage from the May Dam reservoir, to elucidate the links between groundwater level fluctuations and the formation of cover collapse sinkholes, and to draw attention to the danger of these developments to the stability of

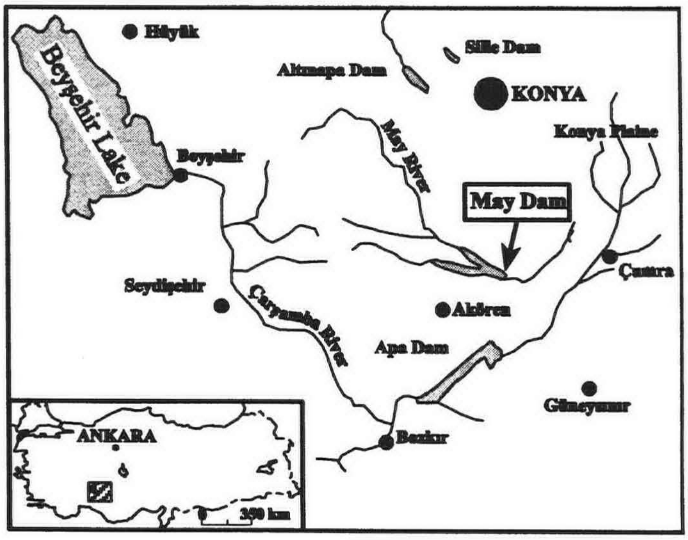

***Figure 1.** Location map of the study area.*

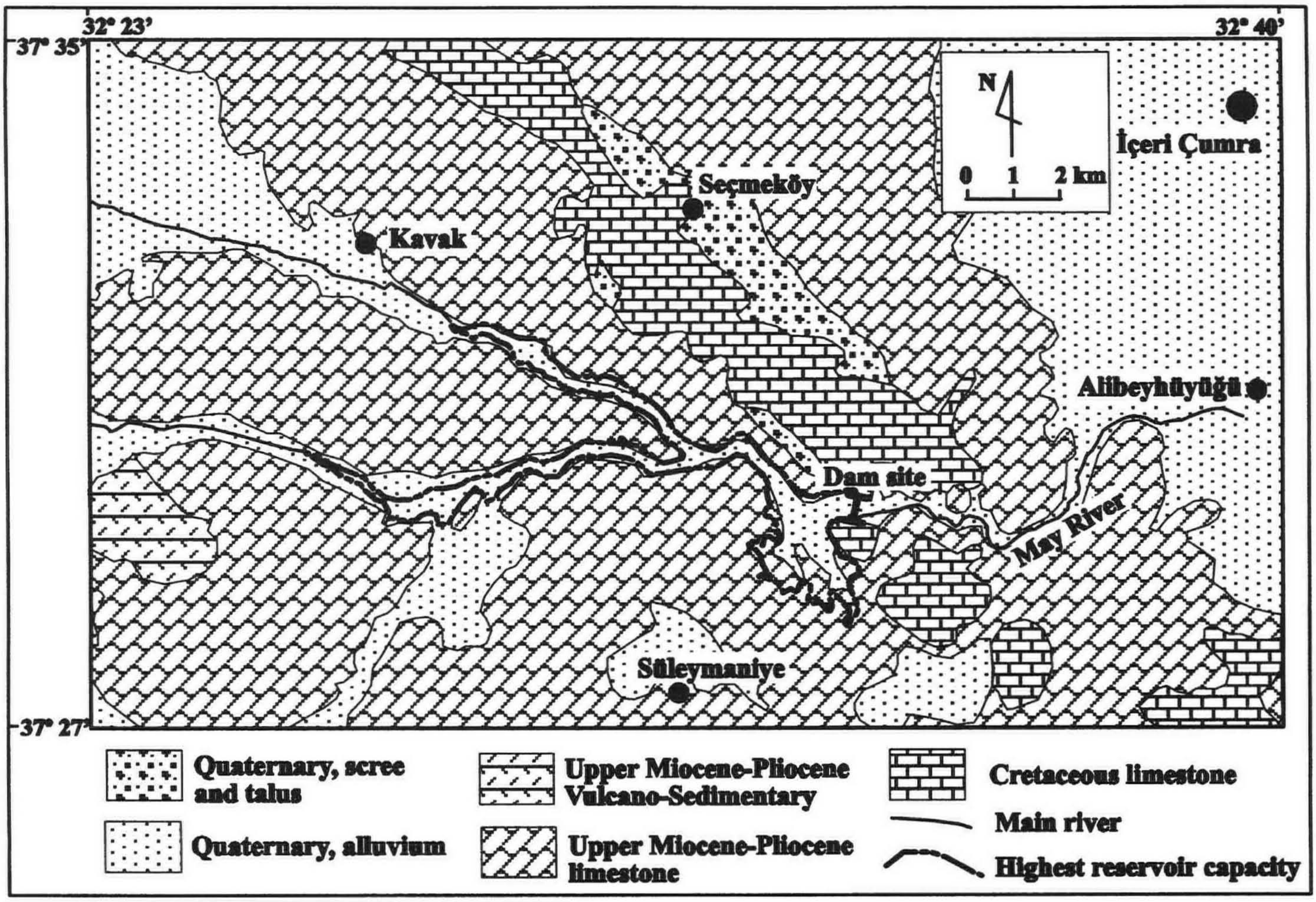

Figure 2. Geological map of the study area.

the dam. The study is based upon geological and geomorphological research, supported by data such as reservoir capacity, water inventory and drilling results obtained by the site studies of the State Hydraulic Works (DSI). The May Dam provides examples of some of the errors of engineering and site selection judgement that can relate to the construction of dams in karstic regions.

GEOLOGY

Figure 2 shows the geological situation at the site, which is dominated by limestone formations overlain by volcano-sedimentary rocks, with superficial deposits such as scree and alluvium. The older limestone that underlies the floor of the site was deposited during the Cretaceous Period. This unit of massive limestone, which also includes the Hatip ophiolite rocks (Güyer *et al*., 1998), is present east of the May reservoir and continues as isolated outcrops southeast of the dam (Fig.2). It forms an anticline extending in a northwest – southeast direction and including Abaz Mountain. The highly solid Cretaceous limestone, which has a fracture width of 1 to 7cm and joint width of 20 to 120cm (Güyer *et al*., 1998), forms steep cliffs at the top of Abaz Mountain. On the east and west slopes of the mountain scree and talus deposits have formed due to Quaternary weathering. In parts of the reservoir area the Cretaceous rocks are beneath Miocene–Pliocene limestones and, according to borehole provings, they are also present beneath the alluvial cover elsewhere at the site.

The limnic Upper Miocene-Pliocene rocks, which overlie the Cretaceous limestones unconformably, comprise limestone beds dipping at 2° to 5°, with thick travertine layers occurring locally between them. Part of the reservoir area lies on these deposits (Figs 3 and 4). Joints, bedding and fractures are apparent on 30 to 60cm-thick white–yellow limestones exposed around the reservoir. Schmidt Hammer recoil values for the limestones are between 30 and 60 (Güyer *et al*., 1998). Elsewhere this formation (known as the Dilekçi or Apa formation) includes conglomerate, sandstone, clay, marble and volcanic rocks, as well as limestone. The formation was affected by compression towards the north during the Early to Late Pliocene. Scattered sinkholes, uvalas and poljes are found upon those parts of the Miocene-Pliocene limestone sequence that are prone to karstification.

A Late Miocene to Pliocene formation comprising volcano-sedimentary rocks occupies a narrow tract west of the site, passing laterally into the limestone formation of the same age. This formed due to sequential deposition of lava and pyroclastic materials from the Erenler-Alacadağ volcanic mass (which was active in the Late Miocene-Pliocene period: Hakyemez *et al*., 1992) together with sedimentary rocks, in a former limnic environment. The tributaries of the May River, upon which the May Dam was constructed, are fed by drainage from this volcanic mass.

Alluvial deposits of Quaternary age occupy the floors of karstic features such as plains, streams and poljes. The alluvium of the May valley, especially in the reservoir area, has a varied texture, with clay, silt, sand and fine gravel The alluvial layer reaches a thickness of 20m in the reservoir site, but it is much thicker in some regions. A borehole near the newly formed sinkholes revealed an alluvium thickness of nearly 50m, probably reflecting infilling of previous subsidence or collapse.

DAM PERFORMANCE

The vision was to irrigate 5,320 ha of land using the water collected behind the May Dam (Öncü, 1978). However, it was not possible to reach even half of this objective, due to water leakage from the reservoir.

In 1960, when the dam started to collect water in its reservoir, the water level reached its maximum on 5 April. The level remained

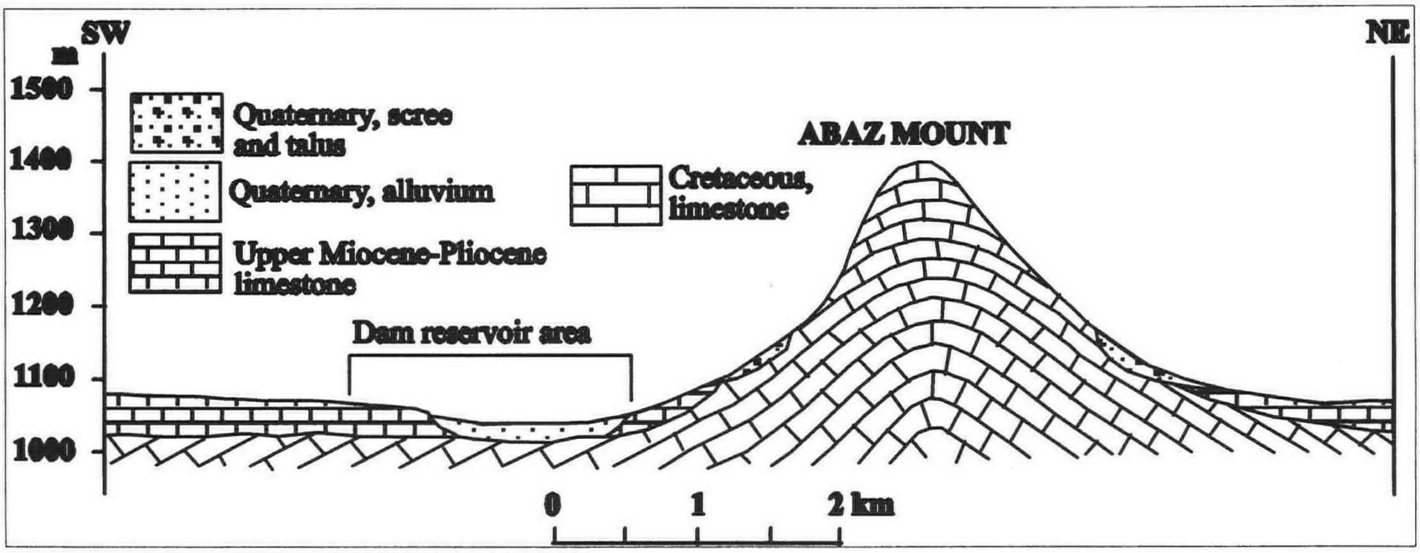

Figure 3. Geological cross-section of May Dam reservoir area.

the same during the following two days, then showed a very sharp decrease, and the water in the reservoir was completely drained out by June 1960. Investigation revealed numerous high capacity swallow holes in the reservoir area. Later survey confirmed a total of 33 swallow holes (Öncü, 1978).

The Neogene and Cretaceous limestones located on the floor of and around the May Dam are multi-fractured, layered and largely karstic. The karstic development responsible for the water leaks in the limestones of both periods, follows bedding planes and joints or fracture systems that cut the bedding planes at about 90 degrees. Such development, which takes place beneath superficial cover in the alluviated areas, is related mainly to the Cretaceous limestone (Fig.3). The fractured rocks, joint systems and bedding planes in the Cretaceous limestones resulted in major water leaks both during and after dam construction. Attempts were made to prevent reservoir leakage by closing the swallow holes and sinkholes after dam construction, but these attempts were unsuccessful. There was no decrease in the rate of water leakage, and washout of unconsolidated material from the alluvial cover continued.

It is known that branches of the May River lose water to karstic leakage before they reach the dam area. Only 14% of the total rainfall of the May River catchment reaches the dam (Özdemir, 1991). According to water balance calculation the highest and lowest amounts of water reach the May Dam in March and August, with $13.348x10^6$ m^3 and 0.148x $s10^6$ m^3 respectively. The total amount of water collected in the May Dam is 51.66 x 10^6 m^3, $34.588x10^6 m^3$ of which is lost due to karstic leakage. The lowest and the highest amount of water loss take place in September (0.0751x 10^6 m^3) and April (6.724 x 10^6 m^3). The total amount of water withdrawn from the dam for irrigation purposes is 14.005 x 10^6 m^3. In other words, only 27.1% of the total water potentially impounded in the reservoir can be used for irrigation, whereas 62.9% is lost from karstic openings such as swallow holes, joints and fractures (Özdemir, 1991).

Analyses carried out by DSI show that underground water movement is not uni-directional, and water movement is towards the south, southeast, east and northeast (Öncü, 1978). The investigations also proved that local underground water movement is quite deep, and the May Dam reservoir is not fed by underground flows. Na-24 experiments were made to determine the direction flow from the water leak sites. Water samples were collected from wells after release of Na-24 isotope into the swallow holes. The wells where Na-24 isotope was detected indicated the direction of the flow from the water leaks. Water table maps and the Na-24 experiments confirm that most water from the leakage sites follows eastern, southeastern and southern routes (Öncü, 1978; Özdemir, 1991).

There is a direct relationship between continuous variations in water levels thus causing fluctuations of the pressure within the void belts and the formation of sinkholes. Leakage that takes place through karstic openings results in a lowering of the water level in the reservoir and thus of the hydrostatic pressure in limestone. This effectively reduces the formation of sinkholes. Increase of hydrostatic pressure in some voids increases the formation potential of sinkholes.The same situation has been observed in the Lar Dam (Uromeihy, 2000). The sinkholes formed when the water level in the reservoir reached to its maximum, and the water table suddenly decreased as a result of the fact that the sinkholes that formed also function as swallow holes. Fluctuations in the level of the reservoir and water table create suitable conditions for the formation of sinkholes in the area.

SINKHOLE FORMATION

Collapse sinkholes formed due to various reasons may pose serious danger for settlements, roads, dams and people. Those in this region are known locally as *"obruk"*. These are cavern collapse type sinkholes formed inside the limestone (Erinç, 1971; Biricik, 1985; Canik and Çörekçioğlu, 1986; Erol, 1990). Jennings (1971) referred to the *obruk*, which generally contain a natural lake (for instance Kızören Obruk), as *"cenote"*. It is possible to see cavern collapse sinkholes (for instance Timraş Obruk) in the plateaus around the May Dam. These *obruks* are important to show the extent and level of karstification in the region around the dam. The sinkholes formed in the floor of the May Dam are cover-collapse sinkholes, which differ in their mode of formation.

Cover-collapse sinkhole [cover-collapse doline] is a self explanatory geomorphologic term denoting a localized depression in the surface of the ground that has been developed by the washing out and dissolution of underlying earth material (rock or soil) (Taqieddin *et al.*, 2000). Cover-collapse sinkhole development begins at the residual soil-bedrock interface above an enlargement of a conduit. Unconsolidated soil is piped down into the bedrock creating a void within the residual soil. Groundwater fluctuations may enlarge the void and, as time passes, more and more soil is lost down the drain. If the thickness of the stronger residual soil above the void is insufficient for arching to develop, the soil above will fail, resulting in a sinkhole (White, 1988, pp.26-27; Ford and Williams, 1989, pp.405-412; White and White, 1996; Nichol, 1998; Tharp, 1999; Taqieddin *et al.*, 2000; Cooley, 2002; Lolcama *et al.*, 2002; Yang and Drumm, 2002; Salvati and Sasovsky, 2002).

Three new cover-collapse sinkholes formed at the bottom of the reservoir due to water leaks and abrupt variations at the level of the water table (Fig.4). These sinkholes, which developed under thick

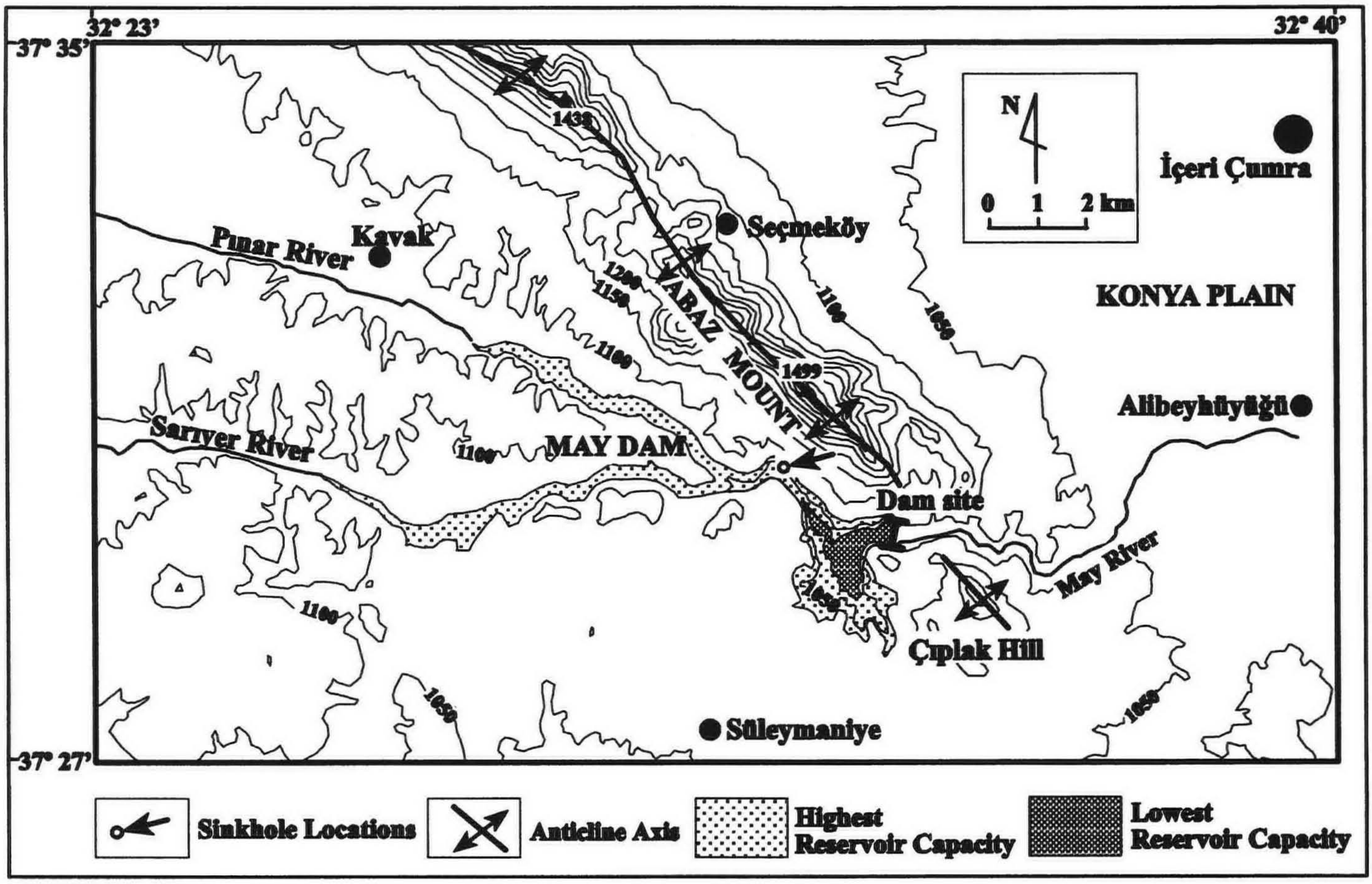

Figure 4. *Topographical map of the research area, showing location of sinkholes*

alluvial cover as a result of karstification, are cover-collapse sinkholes.

In February 2002, when the surface of the reservoir was frozen and the level of the reservoir was at its maximum, collapses occurred, accompanied by loud noise, before the eyes of the local people. The reservoir level showed a rapid decrease following this event, and the sinkholes became visible after complete escape of the waters in this area. The authorities state that the rapid shrinkage of the reservoir was due to the formation of the new sinkholes at the site. These cover-collapse sinkholes are important, because they appeared in the reservoir area and they are of a type rarely observed in Turkey.

The sinkholes are circular in plan, with an overall cylindrical shape. Soil voids became unable to carry the load on the arch as a result of leaks in the reservoir and suffusion of the alluvial cover and the collapses in February 2002 took place when the reservoir reached its maximum capacity.

The sinkholes formed on the reservoir floor are aligned in a north–south direction, and the depths and the diameters of the sinkholes decrease from north to south (Fig.5). According to coring results the thickness of the alluvium layer in the site of the biggest (northern) sinkhole is approximately 50m. Although there were no data related to the thickness of the alluvium at the sites of the other sinkholes, it is expected to be thinner, because the smallest (southern) sinkhole is close to the main bedrock area that protrudes towards the reservoir site. It can be deduced that there is a direct relationship between the thickness of the alluvial layer and size of the sinkholes.

The diameter and depth of the big sinkhole in the north are 50m and 28.5m respectively (Fig.6). There is a deep lake in the sinkhole formed by the collection of rainwater. In September 2002 the depth of this temporary lake, which starts 12.5m below the surface, was 13m at the edges and 16m at the middle (Fig.7). The depth and the diameter of the second sinkhole, 33m south of the big sinkhole, are 7.5m and 20m respectively (Fig.8). It contains a small, 1m-deep lake. The third collapse sinkhole, 70m south of the second, has a diameter of 19m and a depth of 1m (Fig.9).

External tension fractures 1m away from the edge of the big sinkhole reach widths and depths of 1m in places. It is possible that the slope profile of the big hole, which has a cylindrical shape with c.90° slopes, may be disrupted and completely filled over time. Due to the fact that the sinkhole is formed through unconsolidated material it also possible that these tension fractures will get large enough to cause collapse into the sinkhole. The middle sinkhole has the same characteristics as the big sinkhole. However the profile of its western edge is sloping due to collapse of material into it along tension fractures. It is expected that a similar phenomenon will soon take place at its southern edge. The third sinkhole is not very deep, but it is circular and cylindrical. Currently there is no distinctive tension fracture around it.

The sinkholes developed over cavities at the top of caves within the Cretaceous limestone that forms the floor of the reservoir. These cavities were washed continually by water leakage through the reservoir bed, which comprises alluvial materials such as clay, silt and fine sand. Soil voids also formed within the alluvial cover layer immediately above fissures in the limestone bed (Fig.10). The seasonal variation of the reservoir water level and fluctuations in the height of the water table caused the soil voids to grow over time. Tension fractures were formed and these reached the land surface when the voids were no longer able to support the arches, which got thinner with time. In February, when the water level reached its maximum and surface water was frozen, the soil voids were unable to carry the load upon them and cover-collapse sinkholes were formed (Fig.10). The water table showed a rapid decrease after sinkhole formation and the sinkholes also functioned as swallow holes until they were clogged by silt.

Karstic leakage causes the reservoir water level to lower, thus reducing the hydrostatic pressure in the soil. This decreases the further potential for sinkhole formation. If the underground water shows a rapid decrease the cover soil will dry up, leading to fracture

Figure 5. Newly developed cover-collapse sinkholes in the May Dam reservoir area.

Figure 6. The large collapse sinkhole and the tension fractures around it, viewed from the east.

development (Uromeihy, 2000). Termination of the rapid water level decrease behind the dam a certain time after sinkhole formation can only be explained by the clogging of sinkhole floors with sediment.

Whereas the average thickness of the alluvial cover at the reservoir site is 20m, borehole investigation showed that it reaches 50m in the area where the sinkholes have developed. This emphasizes the pre-existence of karstic drainage in the area of sinkhole formation and the presence of long-standing subsidence of the local alluvial cover.

Development of collapse sinkholes at the May Dam reservoir site is not something new. During 1960, when water collection began, the 33 swallow holes later recorded at the south of the site caused rapid drainage of the reservoir in April, when the water level was at its maximum (Öncü, 1978). The report states that these swallow holes formed due to a collapse mechanism. According to this report the swallow holes that formed in 1960 were actually cover-collapse sinkholes. Jennings (1971) stated that the May Dam did not deliver its expected benefits due to factors associated with the limestone that forms its floor. He stressed that there were problems with the dam's stability because limestone water issues were not considered during its construction. His book includes a picture of a collapse sinkhole formed in alluvium overlying the limestone floor of the May Dam. In 1960 and 2002 the soil voids enlarged as a result of leakage and suffosion in the alluvial cover, and the arches over them collapsed when the reservoir reached maximum capacity, forming the cover-collapse sinkholes. This suggests that the high hydrostatic pressure upon the voids triggers the development of such sinkholes.

One of the most important factors in the formation of these sinkholes is the presence of highly fractured Cretaceous limestones, which support karstic development. Weak resistance areas along large and small fault lines formed by Pliocene tectonism (which caused distortion of Neogene limestones and travertine layers west of Abaz Mountain) are also very important. Fault lines and fracture systems are crucial to the establishment of underground water systems and karstic waterways. Water storage in the reservoir accelerated the enlargement of the soil voids over the conduits, forming many new soil voids.

It is also noteworthy that the dam region is dominated by a continental climate regime and the temperature drops below zero during the November to April period. Hence the surface of the lake behind the dam is frozen in the winter months.

CONCLUSIONS

The May Dam was built on a karstic terrain within a heavily fractured limestone region. Water loss, amounting to 67% of the reservoir's capacity, and continuous fluctuation in the water table level result in the formation of large washout voids where alluvium covers underlying conduits. Gradual leakage from the reservoir causes washout of soil and formation of soil voids, thus creating a suitable platform for the development of cover-collapse sinkholes.

Gradual water leakage decreases the pressure on the karstic voids, decreasing the probability of further sinkhole formation. In contrast, increase in the hydrostatic pressure on the karstic voids, related the reservoir level, triggers sinkhole formation. Accordingly,

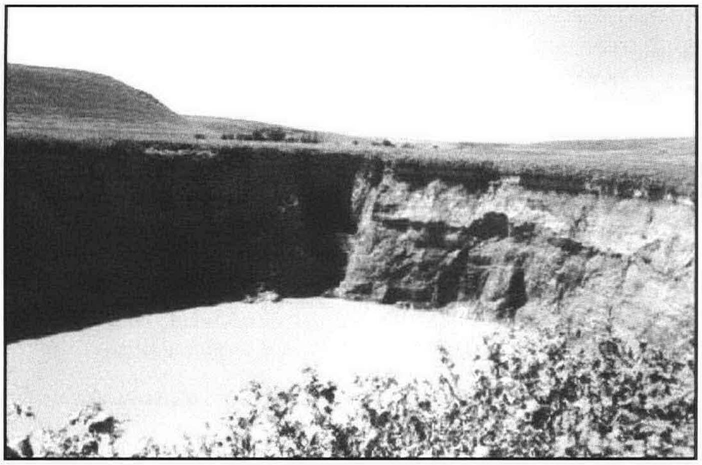

Figure 7 The large sinkhole, showing its water-filled base and slope angles of nearly 90°.

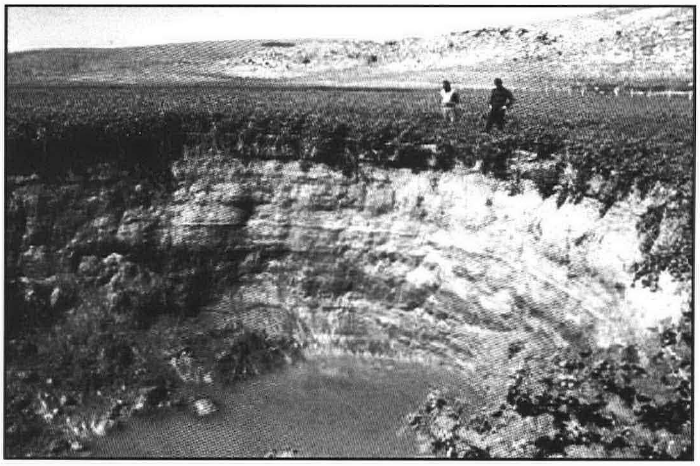

Figure 8 *The second sinkhole viewed of from the southwest. The reservoir area outside the minimum capacity area is covered by natural vegetation due to the fact that it contains no water. The photograph was taken in October 2002, 7 months after the formation of the sinkhole.*

if existing water leaks are minimized, the hydrostatic pressure applied to the karstic voids at the bottom it will enhance the chances of new sinkhole development.

Thirty-three sinkholes opened up a few months after the reservoir started to collect water and reached its maximum level in 1960. This situation was repeated 42 years later, when three more sinkholes developed in 2002. The floors of these sinkholes, which functioned as swallow holes when first formed, are clogged with silt. Those sinkholes formed up to now constitute an environmental threat. It is possible that cover-collapse sinkholes that might form in the future in the reservoir area of the May Dam represent a potential natural hazard.

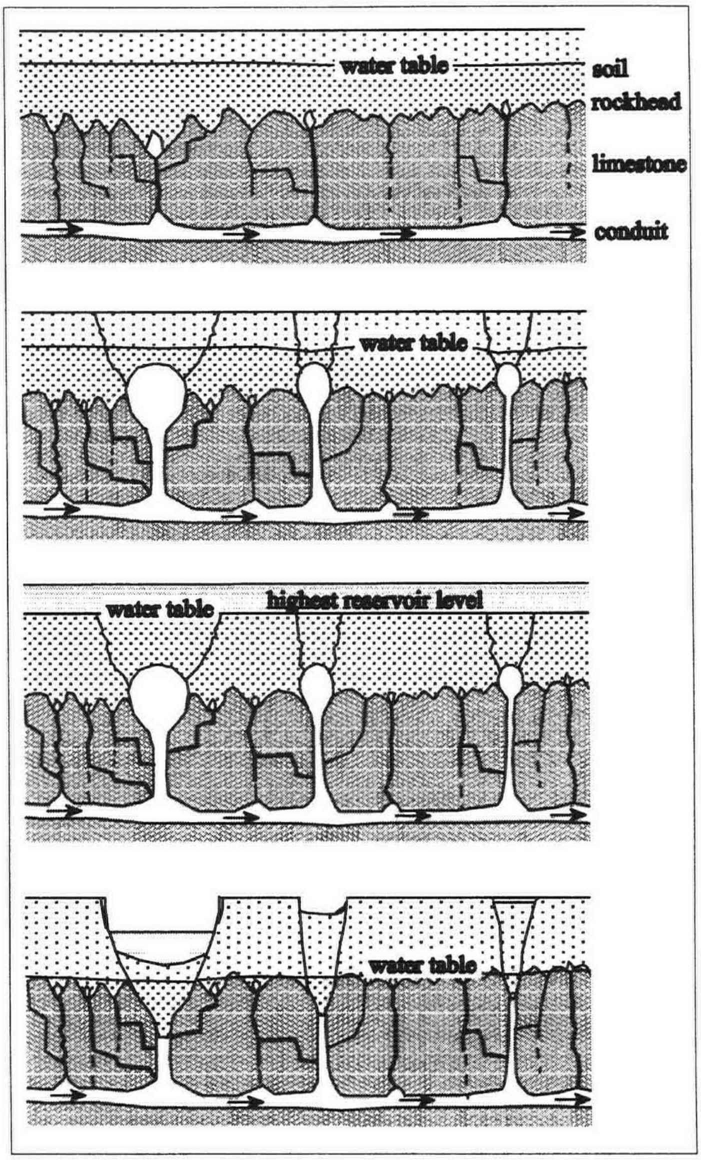

Figure 10. *Schematic view of the development phases of the May Dam reservoir cover-collapse sinkholes.*

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Figure 9. *The third and smallest sinkhole viewed from the southwest, Ahaz Mountain, which consists of Cretaceous limestone, is located in the background.*

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Energy replenishers in speleological practice: creatine and branched-chain amino acids. A scientifically controlled trial

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Key-words: creatine, branched-chain amino acids, anaerobic and aerobic effort.

Summary: A scientifically controlled trial was performed to evaluate the effects of energy replenishers with creatine and branched-chain amino acids upon caving performances. Following treatment with creatine and branched-chain amino acids or with placebos, ten healthy cavers carried out a caving trip. Subsequently the same group performed the same exercise, but with the treatments inverted. Anaerobic and aerobic effort seemed to be improved by creatine administration, with a reduction of times for individual activities and a reduction of fatigue. Whereas it is acknowledged that most of the underlying observations do not yet have statistical significance, the analysis of all the data suggests an improvement of all parameters in the treated subjects. Laboratory data relating to muscular stress indicate significant minor muscular damage in the treated subjects. This might be explained as a side effect of the creatine and branched-chain amino acids.

INTRODUCTION

Background

The background conditions of speleological practice have particular characteristics that make them very different from all other natural situations:

- physical conditions are relatively constant with respect to time, and are independent of diurnal variations. In particular, temperature is more or less constant (generally low in northern Italian caves) and there is very high humidity (between 95 and 100%);
- there are possibilities of prolonged physical activity, because of the cave environment's independence from external conditions;
- there is commonly a need for very intense physical exertion in unfavourable conditions.

Creatine

Creatine is a natural compound present in large amounts in muscular tissue. It can produce great amounts of energy rapidly and independently of sugar consumption, by stimulating use of active compounds, particularly adenosine triphosphate (ATP). Creatine has been studied from the point of view of sports medicine, and many publications have appeared on the subject.

A dietary increase of creatine could improve the muscular ATP level needed for good muscle contractions (Greenhaff, *et al.*, 1993). Five days of creatine administration before an athletic running trial showed an increased spurt ability in oxygen deficiency (anaerobic effort) in treated subjects if compared with controls (Harris, *et al.*, 1992). Creatine supplements taken before a test of exertion can improve the results during short bouts of exercise involving maximum effort (Balsom, *et al.*, 1994).

		per 100g	per pouch
Energy value	Kcal	275	22
	Kj	1152	92
Proteins	G	0.5	0.03
Carbohydrates	G	54	4.33
Lipids	G	0.5	0.03
Potassium	Mg	263	21
Magnesium	Mg	750	60
Iron	Mg	35	2.8
L-aspartic acid	Mg	950	76
L-leucine	G	6	0.48
L-isoleucine	G	3	0.24
L-valine	G	3	0.24
Creatine mono-hydrate	G	25	2
Vitamin C	Mg	375	30
Vitamin E	Mg	25	2

Table 1. *Pouch composition*

Stage		Activity
1	basal blood and urine collection, ECG, physical examination and measurements	
2	subjects enrolment, informed consent, randomization, drug/placebo pouches distribution	
3	three week treatment	
4	blood and urine collection, ECG, physical examination and measurements	
5	cave trial:	
	a	25m pitch ascent, with timing, blood pressure and respiratory and heart rate measurements at the end;
	b	50m meander, with timing, blood pressure and respiratory and heart rate measurements at the end;
	c	250ml water input + 1 Snickers;
	d	cave progression in meanders;
	e	urine collection; 250ml water input;
	f	cave progression on pitches and back;
	g	250ml water input, 1 Snickers + 1 pack of crackers;
	h	cave progression in meanders;
	i	50m meander, with timing, blood pressure and respiratory and heart rate measurements at the end (second trial);
	j	urine collection; 250ml water input, 1 Snickers;
	k	pitches back ascent;
	l	25m pitch ascent, with timing, blood pressure and respiratory and heart rate measurements at the end (second trial);
6	blood and urine collection, ECG, physical examination and measurements	
7	one month wash-out period	
8	inversion of treatments in the two groups, with repetition of the progression from point 1 to 6	
9	data analysis.	

Table 2. Study design

Branched-chain amino acids

Branched-chain amino acids have been demonstrated to be useful during physical effort and athletic training, to increase muscular mass and to reduce muscular pain after prolonged effort.

Study design

Considering the exceptional athletic efforts and unique background conditions, an evaluation of the effect of energy replenishers, including creatine and branched-chain amino acids, on caving performances could be of interest. A scientifically controlled trial on the effects of these substances on caving performances was performed in 1998.

The trial's primary goal was to evaluate the assumed increase of athletic performance after creatine administration of a group of cavers during a caving trip with mixed characteristics. A second goal was to analyze the effects of branched-chain amino acids and mineral salts taken before the exertion, for the same period of time.

SUBJECTS, MATERIALS AND METHODS

Twelve healthy and active male cavers from the Gruppo Grotte Milano and Speleo Club Orobico (Bergamo) were enrolled. They were aware of the nature of the tests and gave their informed consent, after physical and laboratory examinations proved their good health. Two of the subjects were eventually excluded from the trial due to physical exhaustion in one case and an adverse drug reaction in the other. Thus, the final group comprised ten subjects, aged from 23 to 36 years (mean 28.5, standard deviation 4.9). The study design is shown in Fig.1.

The ten subjects were split into two groups of five. The first five subjects were to take two pouches of an inert placebo (aspartame). The second five had to take two pouches of a mixture of creatine, branched-chain amino acids and mineral salts (Table 1), with a total of 4g of creatine. This was carried out according to a randomized cross-over design, for three consecutive weeks, in double-blind mode (neither the subjects nor the experimenter knew the pouch content).

After each treatment period the subjects had to perform two physical tests in a cave. They had to cover 50m along a narrow meander and make a vertical rope ascent of 25m. Both of the timed tests were repeated after prolonged effort (12 hours of progressing through the cave), to evaluate performance variations under different tiredness conditions. Blood pressure, heart and respiratory rates were recorded at the end of each test and after a minute's rest, to evaluate restoration capacity. Urine was collected at regular intervals and subsequently analyzed. During the tests water and food were administered equally to the two groups (Table 2, Table 3). After the cave test the subjects allowed a month for the substances to be washed out, and then the treatment drugs were inverted between the same groups, with the same examinations and cave tests.

Various measurements were made before and after the 21 days treatment, before and at the end of the cave test. Height, weight, body surface, lean mass (the percentage of muscle and fat assessed on the biceps of the arm), heart and respiratory rate at rest, blood pressure, electrocardiogram (ECG) with QTc determination (an indirect value of intramuscular potassium), hematocrite, plasma electrolites (Na^+, K^+, Mg^{++}), creatine phosphokinase (CPK), lactic dehydrogenase (LDH), glucose, BUN, creatinine, urines examen with density, pH and ketones. Adverse effects have also been considered.

	crackers (g 31.5) (one packet)	Snickers (one bar)		
energy value	Kcal	139	Kcal	280
proteins	g	3.2	g	4
total carbohydrates	g	21.6	g	36
sugars	g	0.9	g	29
total fat	g	4.4	g	14
saturated fat	g	1.28	g	5
cholesterol	mg	2.21	mg	10
fibre	g	0.79	g	1
sodium	mg	280	mg	150

***Table** 3: Composition of energetic input during cave assay:*

THE CAVE

The trial took place in the **Puerto Escondido** cave, in Valbrembana (LoBg3785, Bergamo, north Italy), very close to a car park, to avoid data dispersal due to unrelated exercise. Laboratory analyses were performed at S. Giovanni Bianco hospital.

The cave is predominantly vertical, with a succession of pitchs and narrow meanders. It begins with a 25m pitch, where the first timed test was performed, followed by a 20m pitch and a narrow and tiring 34m pitch/meander that leads after some squeezes to a 44m pitch. Subsequently pitch of 11m leads to a little chamber full of dripstone and with a waterfall, at a depth of 170m. The experiment continued along the ascending passages that begin after the waterfall.

After a 5m ascent, the cavers had to continue in a 50m-long narrow meander, where they were timed with a stopwatch. A telephone line was placed in the meander to allow communication from the beginning and the end of the meander, and better synchronize the time intervals. After the meander the cavers had to continue ascending a 12m pitch to "Cheope" Hall. From here they first continued in the very narrow left branch (called "boa constrictor"), and then in the right branch, with the ascent of three pitches of 30m, 21m and 11m, and then another long meander ending with a 15m ascent followed by other narrow passages to where the cave ends, with a total of about 150m of ascent. The cavers then had to return to the cave entrance.

The total depth is about 350m, of which almost 200m is up/down vertical pitches and the remainder in narrow galleries, and the plan length is about 900m. The cave is quite difficult, involving prolonged and continuous effort. The distance covered normally requires from 7 to 8 hours, of maximum physical effort without rest.

STATISTICAL METHODS

The data were imported to dBIV and analyzed using the SPSS v. 7.5.2 for Windows programme. Data relating to the cave trials were analyzed using variance analysis for cross-over design (Grizzle). The same data were analyzed globally in an ANOVA model. Hemodynamic and laboratoristic parameters have been analyzed with ANOVA for cross-over design.

RESULTS

No differences in body parameters (i.e. *weight* and *body surface*) have been observed in relation to treatment in the two groups. A statistically significant increase of *lean mass* was observed in both groups (Table 4).

No differences before and after the treatment were observed in *heart* and *respiratory rate*, nor in *arterial blood pressure* before the cave study (Table 5). After the first ascent of the 25m pitch at the start of the cave, heart rate increases were noted in the two groups, but subjects treated with creatine recovered more rapidly after a minute's rest. When the tired subjects performed the same task at the end of the journey, the treated group had a lower heart rate increase and a better recovery after a minute. In the meander a better heart rate recovery was observed in treated subjects, whether at rest or tired.

The control after a minute's rest has only introduced halfway through the experiment and was not performed on all subjects. Thus differences, even if evident, are not significant statistically. No differences of these parameters were evident in the two groups at the end of the experiment. Respiratory rate increase was less in treated subjects during maximum effort, both on the pitch and in the meander, whether fresh or tired, with analogous results in the recovery rate. Again these differences in results are not considered significant statistically. In treated subjects the blood systolic pressure decreased significantly after a 3-week treatment ($p=0.039$), but no differences were noted between the two groups during the cave trial nor at the end of the experiment.

The only difference in *time performances* was noted in tired treated subjects, who showed an insignificant reduction in the meander. Interestingly all the subjects made better time covering the meander when tired, and this probably reflects knowledge of the route. Laboratory data show no differences between samples taken at the start time and at the end of treatment, with exception of blood creatinine, which is reduced in treated patients, even if always within normal range values (Table 6).

After the cave exertion an increase of the *QTc* occurred on ECG, particularly those of treated subjects. This shows a loss of muscular potassium, which is confirmed by a decrease of serum *potassium* concentration. No modifications in the *hematocrite* occurred, and serum *sodium* showed a small decrease, with no differences between the two groups, showing no dehydration (that could have interfered

	Time	treatment	placebo	p
weight (kg):	*baseline*	70.600±8.605	70.000±7.318	NS
	before test	71.100±7.763	71.950±7.787	NS
	after test	70.270±7.741	71.000±7.192	NS
body surface (m^2):	*baseline*	1.876±0.133	1.878±0.118	NS
	before test	1.880±0.125	1.893±0.126	NS
	after test	1.871±0.124	1.880±0.118	NS
lean mass (%):	*baseline*	14.500±3.437	14.890±3.824	NS
	before test	15.780±3.632	16.000±3.994	NS
	after test	15.410±2.894	15.030±3.032	NS

Table 4. Body parameters (mean±sd)

	Time	N.	treatment	placebo	p
Heart rate (bpm):	baseline	10	66.20±12.63	61.90±15.13	NS
	before test	10	65.70±9.79	64.60±7.20	NS
	I test (pitch ascent)	10	131.33±20.90	129.11±20.36	NS
	I test (pitch ascent)+ 1'	6	99.50±18.16	117.50±13.37	NS
	II test (pitch ascent)	10	116.40±19.65	125.80±19.81	NS
	II test (pitch ascent)+ 1'	6	88.75±9.60	110.50±18.19	NS
	I test (meander)	10	119.10±15.57	118.40±12.16	NS
	I test (meander)+ 1'	6	100.75±12.12	109.83±7.25	NS
	II test (meander)	10	113.00±16.32	115.60±16.22	NS
	II test (meander)+ 1'	6	92.33±8.14	107.00±9.47	NS
	after test	10	72.50±9.05	73.20±7.80	NS
Respiratory rate	baseline	10	14.40±2.63	15.20±3.39	NS
(bpm):	before test	10	14.30±2.83	14.40±2.95	NS
	I test (pitch ascent)	10	29.80±7.69	33.40±6.40	NS
	I test (pitch ascent)+ 1'	6	25.50±9.71	24.00±2.53	NS
	II test (pitch ascent)	10	31.20±7.50	32.10±8.85	NS
	II test (pitch ascent)+ 1'	6	24.00±5.66	24.67±3.01	NS
	I test (meander)	10	31.70±9.50	35.70±8.00	NS
	I test (meander)+ 1'	6	22.00±4.32	24.33±5.13	NS
	II test (meander)	10	32.89±7.94	34.40±7.41	NS
	II test (meander)+ 1'	6	22.67±2.31	23.67±5.43	NS
	after test	10	17.40±3.78	15.60±1.58	NS
Systolic ABP	baseline	10	124.00±6.58	116.00±11.25	NS
(mmHg):	before test	10	118.20±7.81	123.90±18.13	0.039
	I test (pitch ascent)	9	167.11±19.30	174.44±21.01	NS
	I test (pitch ascent)+ 1'	6	157.00±13.88	149.67±4.97	NS
	II test (pitch ascent)	10	150.90±15.57	152.70±19.29	NS
	II test (pitch ascent)+ 1'	6	143.00±13.14	142.00±16.40	NS
	I test (meander)	10	150.40±9.80	147.70±17.93	NS
	I test (meander)+ 1'	6	137.25±9.67	133.17±11.16	NS
	II test (meander)	10	147.33±10.40	150.10±10.28	NS
	II test (meander)+ 1'	6	139.00±10.15	131.67±7.03	NS
	after test	10	107.80±10.09	112.20±10.72	NS
Diastolic ABP	baseline	10	77.50±6.35	73.00±8.88	NS
(mmHg):	before test	10	67.90±8.95	70.00±6.07	NS
	I test (pitch ascent)	9	84.67±9.08	82.11±7.47	NS
	I test (pitch ascent)+ 1'	4	75.50±5.57	78.00±13.25	NS
	II test (pitch ascent)	10	66.00±6.51	78.50±8.98	NS
	II test (pitch ascent)+ 1'	4	66.00±6.98	77.50±8.48	NS
	I test (meander)	10	74.70±9.99	74.50±10.54	NS
	I test (meander)+ 1'	4	64.75±14.68	71.67±6.89	NS
	II test (meander)	9	77.78±7.90	73.80±12.21	NS
	II test (meander)+ 1'	3	69.67±7.02	73.00±11.03	NS
	after test	10	65.00±5.94	67.90±9.79	NS

Table 5. *Vital signs (mean±sd); + 1' measurement after a rest of a minute; bpm: beats/breaths per minute; ABP: arterial blood pressure*

with performance), but intense and prolonged sweating. *Magnesium* concentrations showed small insignificant variations, and a reduction of *glucose* was noted in the two groups, indicating a high energy consumption, not influenced by the creatine. An increment of *BUN* was evident in both groups. As it has already been demonstrated that no dehydration occurred, this could be due to an increased muscular destruction, as is commonly observed during prolonged and intense effort. *Creatinine*, derived from the destruction of creatine, did not increase in any of the groups, either at basal time or after the cave exercise. This shows that the augmented absorption of creatine didn't overload body metabolism.

Different conclusions have been drawn for *LDH* and *CPK*. LDH (lactic-dehydrogenase) is a group of muscular enzymes that increase in the blood after cellular damage. After the cave exercises the LDH values were almost doubled, but the increase was more pronounced in the controls, even if not significantly (from 422 to 831 in the treated subjects as against 394 to 905 in the controls; p=0.088). CPK (creatine phosphokinase) is a muscle specific enzyme implicated in creatine employment. Mean CPK values increased greatly after the cave exercise, but less so in treated subjects, with a statistically significant difference (p=0.034). *Urine* density increased equally in the two groups, pH values decreased equally (probably because of lactic acidosis), and urinary ketones increased equally in the two groups, showing an energetic defect due to intense efforts.

Two subjects (one treated, one a control) complained of nausea at maximum effort, and one potential subject developed a skin reaction during placebo administration and was excluded from the protocol.

DISCUSSION

The final goal of the study protocol was to make a comparison between the 10 subjects when treated with creatine and branched-chain amino acids, and the same subjects without the treatment, while performing the same cave exercise.

No difference in electrolyte concentration was noted between the two groups. This was because that these substances cannot be stored, and an advantage is likely only if they are taken during exercise. Body weight and lean mass increased in the same way in both groups. These data are interesting if compared to published details describing muscular mass production with high dose creatine treatment, even in shorter times. The mixture was tolerated well, with no evidence of biological suffering.

Anaerobic (pitch ascent) and aerobic (meander) effort, under both fresh and tired conditions, seemed to be improved by creatine administration, with reduction of performance times during aerobic effort (the meander in tired conditions) and reduction of the rate of tiring (minor increase of respiratory rate and systolic blood pressure, and increasing recovering capacity of heart and respiratory rate). Most results don't achieve statistical significance, but analysis of all data shows an improvement of all parameters and biochemical results in treated subjects, suggesting that with a bigger group of subjects the results could reach statistical significance.

Glucose and ketone values show that effort was really intense, whereas other parameters indicate that neither dehydratation nor excessive potassium loss could have influenced the results.

Laboratory data concerning muscular stress (CPK and LDH) evidence minor muscular damage in treated subjects; the CPK difference is significant. This could be explained with the double effect of creatine and branched-chain amino acids.

Even if more data are needed to confirm these observations, the trends of biologicals and physical data allow the suggestion that creatine combined with branched-chain amino-acids at the dosage administered could be of beneficial during speleological activity.

		Treatment	Placebo	
	Time	mean±sd	mean±sd	p
QTc	*baseline*	0.393±0.024	0.390±0.019	NS
	before test	0.392±0.022	0.391±0.027	NS
	after test	0.439±0.037	0.425±0.031	NS
Ht (%):	*baseline*	44.06±3.67	44.33±2.28	NS
	before test	41.52±2.67	41.79±2.41	NS
	after test	40.03±2.99	40.94±2.24	NS
Na (mmol/l):	*baseline*	140.50±0.85	140.40±1.35	NS
	before test	144.26±2.93	142.62±2.29	NS
	after test	141.53±2.17	140.39±2.24	NS
K (mmol/l):	*baseline*	4.013±0.313	4.014±0.362	NS
	before test	4.411±0.352	4.310±0.252	NS
	after test	4.176±0.358	4.160±0.314	NS
Mg (mmol/l):	*baseline*	1.800±0.183	1.770±0.116	NS
	before test	1.769±0.188	1.677±0.12	NS
	after test	1.873±0.167	1.857±0.110	NS
CPK (UI/l):	*baseline*	144.4±113.4	130.6±86.4	NS
	before test	160.3±193.9	88.6±41.7	NS
	after test	1217.4±836.9	1747.8±1162.4	0.034
LDH (UI/l):	*baseline*	296.7±65.0	290.7±36.3	NS
	before test	422.0±88.8	394.7±37.1	NS
	after test	831.1±170.6	905.6±180.7	0.088
Glucose (mg/dl):	*baseline*	82.0±9.7	81.0±8.5	NS
	before test	84.9±9.8	76.4±12.4	NS
	after test	65.4±4.8	63.7±8.6	NS
BUN (mg/dl):	*baseline*	29.33±4.49	28.21±5.26	NS
	before test	27.43±3.91	28.24±5.62	NS
	after test	37.20±6.31	36.86±4.78	NS
creatinine (mg/dl):	*baseline*	1.010±0.099	0.990±0.129	NS
	before test	0.967±0.075	1.062±0.062	<0.01
	after test	0.964±0.080	1.042±0.072	NS

Table 6. *ECG and laboratory data*

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Early British reports of aquatic mollusca living in underground water pipes

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Abstract: Early records of aquatic mollusca (*Potamopyrgus antipodarum, Ancylus fluviatilis* and *Dressensia polymorpha*) found in underground water pipes in England are reviewed and discussed. It is possible that, if searched for, these species will be found in natural caves.

INTRODUCTION

Despite some recent revival of interest (Knight and Wood, 2000; Moseley, 2000) aquatic molluscs are under-recorded in British caves. I thought it worthwhile therefore to draw attention to reports of species found living in underground water supply mains when obsolete water pipes were being dug up and replaced in Manchester and London in the late 19th century. Two gastropods and one lamellibranch were found to be thriving in this seemingly at least very cave-like habitat, but only one of these has ever been recorded in caves in the British Isles.

Potamopyrgus antipodarum **(Grey, 1840)**
(Gastropoda: Hydrobiidae)
Jenkin's Spire Snail.

This small aquatic snail, previously variously called *Paludestrina jenkinsi* Smith, *Potamopyrus jenkinsii* (Smith) and *Hydrobia jenkinsii* Smith, was introduced into England sometime before 1852, and is now one of our commonest freshwater molluscs (Kerney, 1999). It is a detritus feeder, able to colonize suitable new sites rapidly due to its parthenogenic mode of reproduction. It is very catholic in its ecological requirements and can live on almost any substrate in both hard and soft waters, though it does require flowing water and is rare in still water. It is common in rivers, canals and streams, but also lives in more marginal habitats, such as springs and roadside trickles, where it may be the only mollusc present. (See Kerney, 1999.)

I have found one published record of this snail being found living in underground water pipes:

"Mr. R. Standen showed (on behalf of the Manchester Museum) *Paludestrina jenkinsi* Smith, described by Mr. Edgar A. Smith as having been found in a four-inch main water pipe in Grummont Road, Peckham, South London; the shells are beautifully clean, and apparently have thriven well in their unusual habitat." (Anon, 1907)

P. antipodarum has colonized the thresholds of some caves and mines, occurring in sites where there is some flow, such as mine drainage adits. I have found it in such habitats around Morecambe Bay, England, and on the Isle of Man (Moseley, 2002). However, at none of the sites did it penetrate very far into the dark zone, and this normally seems also to be the case elsewhere. There are reports of colonies deep in caves in County Clare, Ireland, but in this locality the animals were abnormal, being stunted with distorted shells (Chapman, 1993, p.152). Despite this evidence that the snail might not be able to thrive deep underground, the old Peckham record, quoted above, becomes important by attesting that, given suitable conditions, it can do well in absolute darkness.

Ancylus fluviatilis Muller, 1774
(Gastropoda: Ancylidae)
River or Freshwater Limpet

A native species found in rivers, streams and trickles throughout the British Isles adhering to stones in fast-flowing, hard or soft, water (Kerney, 1999). It requires clear water and avoids muddy areas.

It has not been reported from caves but in 1876, when old stone water pipes were being dug up in Manchester, they were found to be almost choked with Zebra Mussels (see below) and associated with these were living specimens of *A. fluviatilis*. Examples collected by a Mr Ray Hardy were exhibited thirty years later at a meeting of the Conchological Society:

"Exhibits. By Mr. J. Ray Hardy. *Ancylus fluviatilis*, a curious form taken from the old stone water pipes of Bath Oolite, which for so long supplied Manchester with water. When these pipes were taken up in Mosley Street, in 1876, numbers of *Ancylus* were found inside them, apparently quite healthy in their dark subterranean abode. The shells are very thick, white, and much elevated, with a solid and somewhat eroded apex, the apical hook overhanging the posterior margin. (*var. gibbosa* Bourg.)" (Anon 1906).

Standen (1909) also refers to this record, and he emphasized that the shells were very white: " ... specimens of the fresh-water limpet, which were quite white, and of which Mr. J. Ray Hardy has a fine set taken from some of these pipes ...". Reading Standen's article in context suggests that he had personally seen the specimens, and thus had been impressed by their lack of colour.

Dressensia polymorpha (Pallas, 1771)
(Llamellibranchia: Dreissenidae)
Zebra Mussel

The Zebra Mussel is another introduced exotic. It was first noted in Britain in 1824 (Standen, 1909) and spread rapidly through the interconnected canal system. It is found only in clean well-oxygenated waters in lowland areas where it attaches to stones and other hard surfaces by means of byssus threads. Like the related marine mussel, *Mytilus*, it is strongly gregarious (Kerney, 1999).

Unlike the previous two species, which have only rarely been found in water pipes, the Zebra Mussel is a well-known problem due to its frequently growing in and blocking up water and drainage pipes. In Britain, it had already become a problem by the middle of the 19th century. Dyson (1850, p.15), referring to Manchester, noted that "These shells are found in most of the large water-pipes that supply this city, from the water works at Beswick" and Jeffreys (1862, p.48) states that he was informed by Mr Norman "...that he saw immense numbers of the Dreissenae, in a living state, lining some of the iron water-pipes which had been taken up in Oxford Street, and that the colouring of the shells was as vivid as if the animal had lived in the light of day." (*D. polymorpha* is the only British example of the Family, so he must be referring to this species). Standen (1904; 1909) repeats Dyson's record, stating that the mussels were "...almost blocking old stone water-pipes carrying the Manchester water supply" and adding (1909, p.138) that "...in spite of the absolute darkness in which these shells lived and throve, they were most brilliantly coloured, with the characteristic zebra-markings standing out vividly". Finally Anon (1912) discusses a report that a 36-inch water main at Hampton-on-Thames had recently been found to be almost choked by fresh-water Mussels: "... ninety tons were taken out of a quarter of a mile of the main (and) the bore was reduced from 36 in. to 9 in."

DISCUSSION

Whereas underground water pipes, particularly those providing a stone substrate, do seem very like flooded caves, we require the discovery of healthy viable colonies in natural caves in order to admit any of these three species to the list of British stygophilic invertebrates. The records however do, at the very least, suggest that it will be worthwhile making the effort to search for them: they are most likely to occur in water-filled passages, so perhaps cave divers might spot them.

The Zebra Mussel is a widespread invasive species that can become a problem in water pipes everywhere that it has spread and which thus clearly thrives under such conditions. So, why not also in caves? It is a conspicuous animal seemingly unlikely to have been overlooked, but perhaps that is the case. Another dreissenid, the European species *Congeria kusceri* Bole, is the only incontestably stygobiotic lamellibranch that has been described.

P. antipodarum is another vigorous invasive exotic introduced to the British Isles in the 19th Century. In this case the extant records suggest that it may be extending its range into caves and ecologically might be on the verge of being a true stygophile. Most stygobiotic gastropods are hydrobids (Vandel, 1965, p.77). Possibly *P. antipodarum* is limited in its ability to colonize subterranean habitats here only by food supply: the water pipe record certainly extends its known habitat range from cave/mine thresholds and unhealthy stunted dark zone populations to what was an apparently healthy population living in total darkness.

The record of the native Freshwater Limpet is particularly interesting, and certainly raises the possibility that in this case there may be overlooked cave populations. It is rather inconspicuous and thus may need to be searched for carefully. Another member of the genus, *Ancylus sandbergeri*, is the only true cavernicolous pulmonate gastropod (Vandel, 1965, p.77).

The discovery of viable cave-dwelling populations of any of these molluscs would be of potential value in the wider context of our understanding of the initial stages of colonization and adaptation to hypogean habitats by invertebrates. To what extent for example are they "pre-adapted"? All three are closely related taxonomically to true cavernicoles, and it is tempting and plausible to speculate that each of them may be pre-adapted to survive in hypogean environments. In the case of non-natives though it is worth noting also that recent ecological studies suggest that the invasion success of many (epigean) species may depend more upon an ability to respond rapidly to natural selection than upon other factors. One piece of evidence for this is that many have colonized environments that are radically different from those they inhabit in their sources (Lee, 2002).

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Stratigraphically-guided drainage in the Slaughter catchment, Forest of Dean, UK: an interim report

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Abstract: Lying in the northwest of the Forest of Dean, UK, the Slaughter Rising is a major resurgence, fed by a web of allogenic inputs and background autogenic drainage east of the River Wye. The conduit system "behind" the Slaughter Rising is of fundamental importance to the modern underground drainage of a wide area. Relationships between this system and the local geology, and between the system and four other (lesser) resurgences are less obvious. Based upon a broad knowledge of the geology, the confirmed drainage connections and the known cave passages, a conceptual model of one possible set of relationships between geology and underground drainage is suggested.

INTRODUCTION

Under normal conditions the Slaughter Rising, on the east bank of the River Wye south of Symonds Yat in Gloucestershire, UK (Fig.1) is not an impressive sight. Even after prolonged rainfall it does not convey the picture of a major karst resurgence. Water emerges sluggishly and apparently at random, from several "culverts" and muddy holes, before gathering in a semi-derelict, part masonry-lined basin and passing through a large-diameter culvert to spill into the nearby river. As its appearance fails to impress, only consideration of the known extent of its catchment area (Fig.2) indicates the local importance of the Slaughter Rising.

Within the Slaughter catchment and in adjacent areas there are four smaller but nonetheless significant resurgences (Fig.2). Coldwell Rising and Hadnock Quarry Rising are also very close to the Wye, Whippington Brook Rising (or Oldstone Well) lies a short distance up a side valley, and Brooks Head Grove Rising lies well away from the river, but still directs resurgent water to it.

Dye tracing confirms that drainage entering numerous swallets emerges at the Slaughter Rising. Many short cave fragments have been explored from these sinks. Exploration in caves beneath Wet Sink (Joyford), Redhouse Swallet and Big Sink (Fig.2) confirms that large cave passages exist within long systems with complex multi-level structures and equally complex development histories.

GEOLOGICAL OVERVIEW

The stratigraphy and broad structure are discussed in detail by Lowe (1993). A carbonate-dominated sequence comprising Lower Limestone Shale, Lower Dolomite, Crease Limestone and Whitehead Limestone sits conformably on Devonian rocks and is overlain conformably by the Drybrook Sandstone. Much accessible cave passage here and elsewhere in the area, together with ancient cavities that guided iron-ore emplacement (Lowe, 1993), lies within the Crease Limestone, but caves within each of the other carbonate units are also known. Particular development foci occur at the boundaries between the Whitehead and Crease limestones and between the Crease Limestone and the Lower Dolomite, horizons that are especially favourable to bedding-related cave development. Some passages and shafts penetrate beds away from these contacts, and some of these are guided by tectonic fractures rather than by stratigraphical elements. Elsewhere in the Forest of Dean small caves and surface shafts penetrate limestone beds within the Lower Limestone Shales. However, in the Slaughter area these beds act at least partly as aquicludes with respect to drainage that penetrates the overlying rocks, exercising significant influence upon rising location.

The Slaughter catchment is effectively separated from the main Forest of Dean Basin (Lowe, 1993) by an anticline known as the Ridge, and lies within the northwestward plunging northwest – southeast trending Worcester Syncline (Fig.2). The syncline's axial trace passes through (or very close to) the Slaughter. A roughly northeast – southwest reach of the River Wye has incised through the fold south of Symonds Yat and then westwards, so that the youngest rocks <u>at river level</u> occur close to the Slaughter Rising, with progressively older rocks at river level both up and down stream. The Devonian basement is at river level close to Symonds Yat and Hadnock Quarry (just beyond the limits of Fig.2).

LOCATIONS OF THE RISING

Several elements of each rising's setting must be considered, notably horizontal and vertical positions relative to the Wye, relationship to the Worcester Syncline axis, and position relative to the stratigraphy.

Slaughter Rising
The Rising is near the eastern (Gloucestershire) bank of the Wye (Fig.2), at about 33m above Ordnance Datum (OD) (Fig.3). The stratal dip is virtually horizontal at nearby exposures, indicating that the site is on or very close to the Worcester Syncline axis. Poor exposure and intense dolomitization render its precise stratigraphical level uncertain but, on geometrical grounds, the Rising must be at, or very close to, the Crease Limestone/Lower Dolomite boundary (Fig.4).

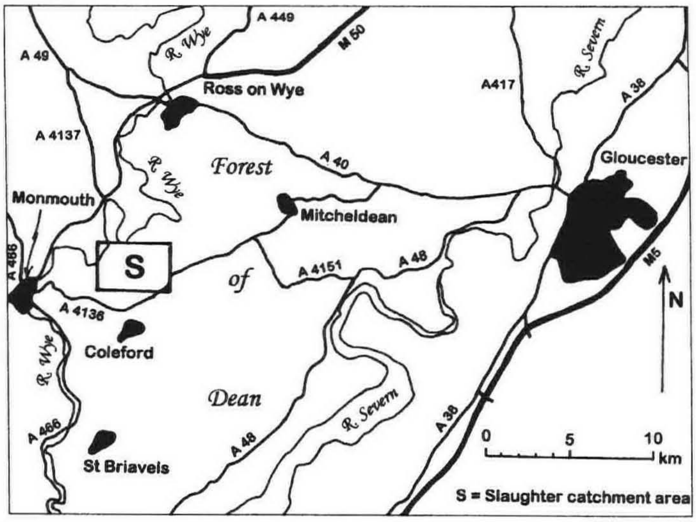

Figure 1: Location of the Slaughter catchment area in the Forest of Dean (see also Fig.2).

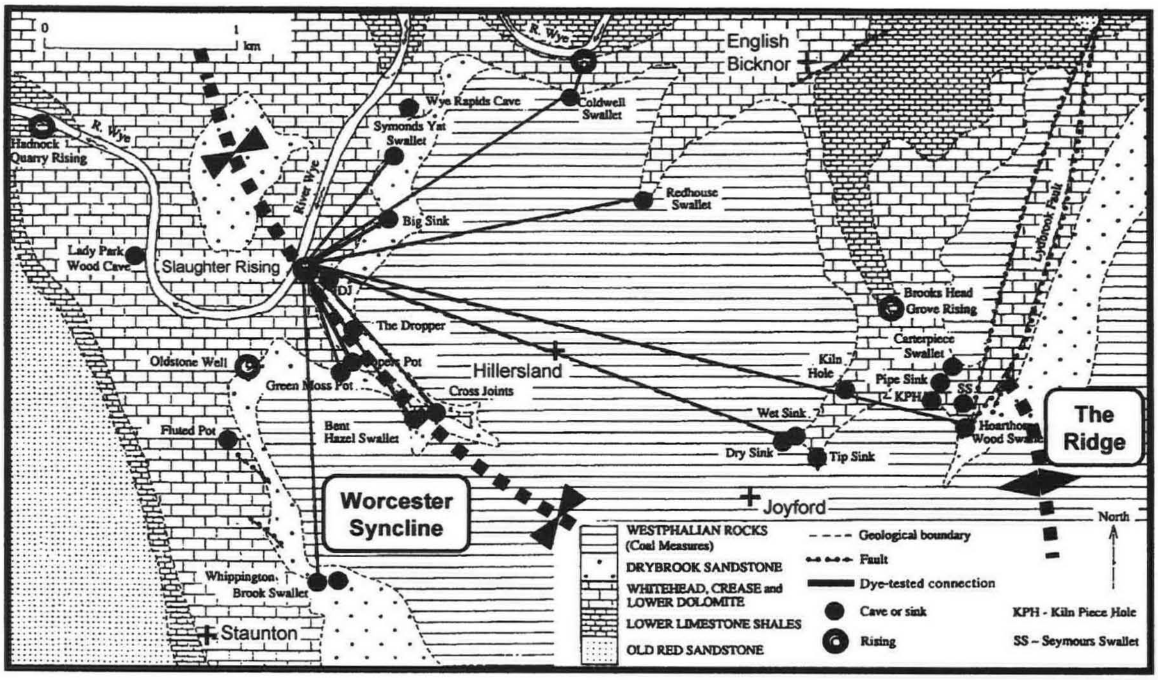

Figure 2: Generalized geology and locations within the Slaughter area.

Coldwell Rising
Coldwell Rising is close to the Gloucestershire (locally southern) bank of the Wye upstream of the Slaughter (Fig.2), on a narrow "flood plain" just above river level at c.37m OD (Fig.3). It is on the northerly limb of the syncline but, due to alluvial cover, there is no clear and unambiguous exposure at the site. Stratal geometry suggests a position at the Lower Dolomite/Lower Limestone Shale boundary or, possibly, confined in a limestone bed by shales within but near the top of the Lower Limestone Shale (Fig.4).

Hadnock Quarry Rising
Also on the Gloucestershire bank of the Wye, but downstream of the Slaughter. Water emerges from the river bank, above normal river level, at c.24m OD (Fig.3). Exposures in the track cutting above and in the nearby quarry indicate that the spring occupies a position analogous to that of Coldwell Rising, lying at the top of, or just within, the Lower Limestone Shale succession, on the southwestern limb of the Worcester Syncline (Fig.4).

Whippington Brook Rising or Oldstone Well
This small rising lies within the side of the Whippington Valley about 300m south of the Wye's Gloucestershire bank, at c. 49m OD (Figs 2 and 3). Moderately good exposure in the valley sides indicates that the rising emerges from the Whitehead Limestone/ Crease Limestone boundary (Fig.4), fairly close to the flattish axial area of the Worcester Syncline, or just on its southwestern limb.

Brooks Head Grove Rising
Unlike the other risings, Brooks Head Grove lies a long way from the Wye (Fig.2). Its altitude (Fig.3) of c.116m OD is significantly higher than the level of the Wye and the other risings. Exposure in the Brooks Head Grove valley floor is poor, but published geological maps indicate that the rising is at or adjacent to the Lower Dolomite/ Lower Limestone Shale boundary (Fig.4). Thus, its stratigraphical position is analogous to that of Coldwell and Hadnock Quarry risings but, being updip of them on the northeastern limb of the Worcester syncline, it is widely separated from them horizontally and vertically. Figure 5 is an attempt to represent vertical and perspective aspects of the spatial and stratigraphical relationships of the risings and the River Wye.

UNDERGROUND DRAINAGE

Despite numerous water tracing experiments spanning many years, there are few positive results to the smaller risings. Thus, comments about their feeders are based on negative and circumstantial evidence.

Slaughter Rising
Water sinking at many named swallets has been traced to the Slaughter Rising (Fig.2). It is virtually certain that input from many smaller, unnamed, swallets between the named sinks is also funneled towards the Slaughter Rising. As the Rising lies on the axis of the Worcester Syncline some of the drainage web lies on the fold's southwestern limb and some on the northeastern limb (Fig.2). Additional autogenic input to this drainage system across the entire catchment is assumed.

Evidence including volumetric assessments of total input and visible output, together with historical observations (discussed by Lowe, 1993) indicates that only a small part of the sinking water emerges at the visible rising at the Slaughter (see below).

Coldwell Rising
Coldwell Swallet (Fig.2) in the north of the catchment is unusual in feeding drainage to two widely separated risings. In normal (relatively low) flow conditions water sinking at the end of the short Coldwell Swallet cave follows a probably fracture-guided route, to pass from near the base of the Crease Limestone, down to Coldwell Rising, near the Lower Dolomite/Lower Limestone Shale boundary. In higher flow conditions when the capacity of this route is overtopped, or when it is wholly or partially obstructed, water takes a higher exit from the Coldwell Swallet cave. It follows a basically bedding-guided route, locally offset by faulting, near the base of the Crease Limestone, to reappear at more or less the same horizon at the Slaughter Rising. To date no other allogenic inputs have been traced to Coldwell Rising. By default it is deduced that the background drainage to the rising, which flows persistently regardless of the visible input at Coldwell Swallet, comprises autogenic water from the adjacent area. Ancillary evidence could probably be provided by detailed flow monitoring and water analyses.

Hadnock Quarry Rising
This is perhaps the least known of the five risings. To date there are no positive water traces are recorded, but this could represent sampling bias, as there are few obvious swallets in the rising's immediate hinterland. Nevertheless small swallets exist between the rising and Staunton (Fig.2), and part of this drainage could emerge at Hadnock Quarry. Again flow monitoring and chemical data might confirm whether the drainage includes allogenic water or whether, as generally assumed, the rising emits only autogenic water. Such percolation water would be gathered on the southwestern limb of the Worcester Syncline or (see below) farther towards the east, where the Lower Dolomite/Lower Limestone Shale boundary also appears at outcrop.

Whippington Brook Rising or Oldstone Well
The rising is virtually perennial, but in dry conditions the flow of clear water becomes minimal to non-existant. There have been positive dye traces, probably via fissures in the Whitehead Limestone, from small swallets in the spur directly above the spring, but no traces from more distant sinks. There must also be an autogenic water component from the immediate area. Being close to the axis of the Worcester Syncline the local dip in very gentle, with a fold plunge related component towards the Wye. Probably a favourable horizon at Whitehead Limestone/Crease Limestone boundary originally gathered water from both limbs of the syncline and directed it down-plunge towards the Wye. However, the position of the Whippington Brook valley, incised below rising level west of the current spring site, leaves little "room" for modern gravitational flow at this horizon from the fold's southwestern limb.

Brooks Head Grove Rising
The source of the water emerging at Brooks Head Grove is unconfirmed. There have been no positive dye traces, even from nearby sinks, though there is strong possibility that part of the output originates from a local but poorly-defined sink area at Carterpiece Swallet, which "doubles" as a cow-wallow. However, the flow is virtually perennial, and probably now derives mainly from autogenic input that is arrested and directed along or just within the top of the Lower Limestone Shale. The favoured horizon has been intersected by the possibly periglacial downcutting of a surface valley, so it is possible that autogenic water formerly moved further down dip and down the fold plunge towards the Wye rather than emerging at high level.

INTERIM MODEL

The current interim model of drainage relationships within the Slaughter catchment and adjacent areas is still evolving, and hinges upon ideas developed and described by Lowe (1993). The model is conceptualized in Figure 6, and can be broken down as follows:

- Allogenic drainage from the Drybrook Sandstone and/or Upper Coal Measures enters the top of the carbonate sequence and penetrates mainly vertically and locally horizontally along favoured horizons. Particularly favourable horizons are encountered at the base of the Whitehead Limestone and, more importantly, at the base of the Crease Limestone, where local main drains have developed. These direct drainage into the axis of the Worcester Syncline and then down plunge towards the Slaughter Rising in a postulated but unexplored major conduit at the same stratigraphical level. A component of autogenic water follows the same general route. Symonds Yat Swallet provides a fine example of stepped joint/bedding penetration.
- Only part of the water known (by dye trace) to feed the Slaughter Rising emerges. It is assumed that this component is upward leakage on fractures and that most of the main flow continues down dip. Some then emerges through fissures into the bed of the Wye. Depending on surface flow conditions, water may continue down-dip beyond the river and, conversely, river water might be swallowed during exceptionally dry seasons.
- The situation at Whippinton Brook Rising is similar, except that the drainage is gathered within the remnants of a system of bedding-guided routes related to the Whitehead Limestone/ Crease Limestone boundary. Flow is limited, probably local, and stage dependent, as most of the potential input flow drops below this stratigraphical level via tectonic fractures and through ancient dissolutional chambers enlarged within the thickness of the Crease Limestone. Streamway fragments at the Whitehead/Crease boundary are preserved in Symonds Yat and Cross Joints swallets, where good examples of dissolutional chambers are also found.
- Flow to Coldwell and Hadnock Quarry risings is probably mostly far-travelled autogenic water. This moves mainly down dip from the areas where the top of the Lower Limestone Shale and base of the Lower Dolomite are at outcrop, but may include fissure-guided leakage from higher beds. Flow is largely directed either above a shale aquiclude near the boundary or is confined within a single favourable bed within and close to the top of the Lower Limestone Shale. At and below river level the entire favourable horizon is effectively saturated and the two risings mark the lowest visible positions where the incising river has cut the bed on each limb of the Worcester Syncline. By analogy with the case of the Slaughter Rising, it seems probable that some drainage moves slowly down dip/down plunge beneath and beyond the Wye. Part of the flow at Coldwell Rising is confirmed as allogenic input from Coldwell Swallet.
- Brooks Head Grove Rising is effectively a late developer, and has formed where water travelling within the updip sector of the favourable horizon described above was intersected by a relatively recent (?periglacial) valley, which remains dry above the spring head. The fact that the water is not swallowed again downstream adds strength to the view that other limestone beds within the Lower Limestone Shale are less favourable than that from which the flow is captured.
- Whereas the above points relate flow to systems that are dominated by bedding-guided conduits/passages developed at three main stratigraphical levels, it is tacit that sub-vertical links, via fissures also exist, potentially allowing upward or downward migration of either flood or underflow water between the specified development horizons. Additional bedding-guided segments related to different stratigraphical elements certainly exist within the Whitehead Limestone and, possibly, within the Lower Dolomite. However, re-examination of the local geology suggests that major drains in caves such as Wet Sink and Redhouse Swallet are at the Crease Limestone/ Lower Dolomite Boundary, not within the Lower Dolomite as previously suggested (Lowe, 1993).

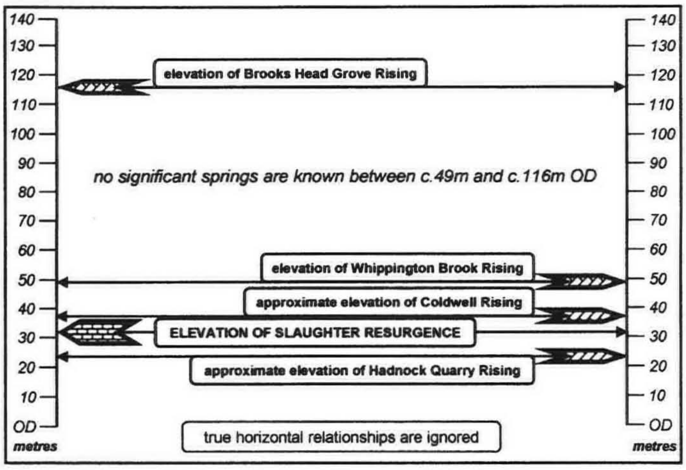

Figure 3: Approximate elevations of risings in the Slaughter area relative to Ordnance Datum (OD).

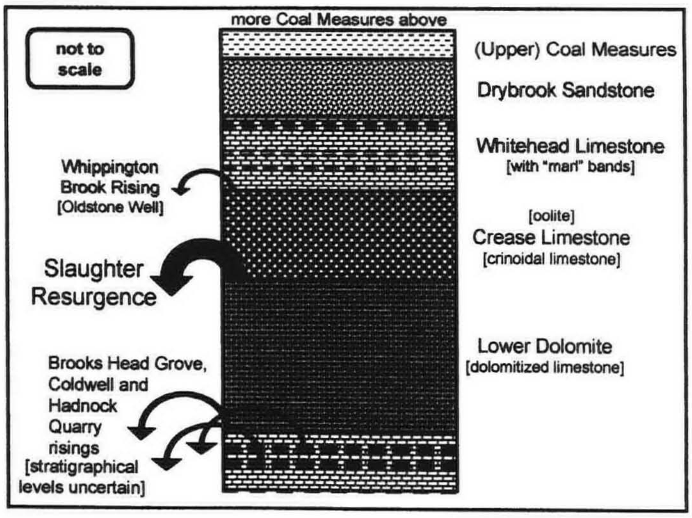

Figure 4: Schematic view of how risings in the Slaughter area relate to stratigraphy.

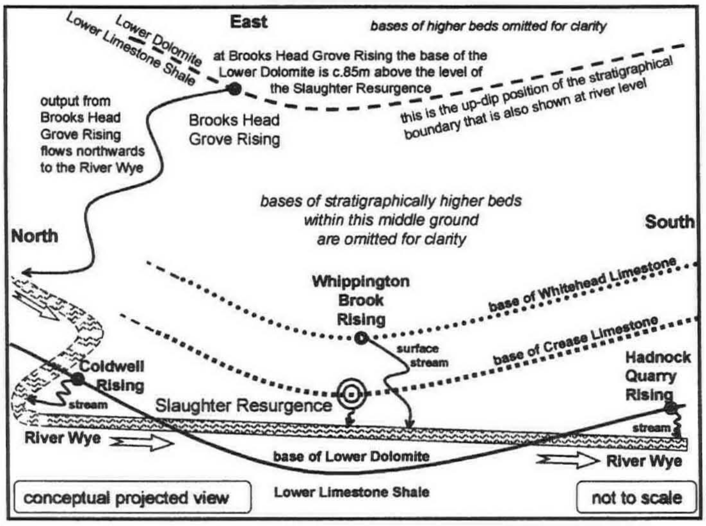

Figure 5: Schematic view of how risings relate to individual horizons close to river level and more remotely to the projected position of the Lower Dolomite/Lower Limestone Shale boundary in the east of the Slaughter area.

REMAINING PROBLEMS

Three "boxes" labelled "B", "B" and "L" towards the left-hand side of Figure 6 are intended to cover the remote possibilities of part of the flow from Hoarthorns Wood Swallet (Fig.2) does not follow the confirmed connection to the Slaughter Rising. Local "folklore" suggests that water from Hoarthorns Wood emerges at Lydbrook Spring ("L"), having passed along the Lydbrook Fault. This is highly unlikely considering the nature of the spring's output and its geological relationships. Another possibility is that some drainage moves southward along the Lydbrook Fault, to penetrate the Ridge Anticline and pass into the main Forest of Dean Basin ("B"). This, based upon a reported trace in 1914, when dye was observed in Cannop Colliery (Lowe, 1993) is not impossible, but now very difficult to test. Another possible drainage route into the Main Basin ("B") is by confined but bedding-related conduit flow overtopping the Ridge Anticline. The heights of the aquifer rocks beneath the Ridge and how these relate to input levels at Hoarthorns are currently unknown. Thus, though such a route is a theoretical possibility if all conditions were favourable, it currently appears to be special pleading that is not required if the 1914 trace result is apocryphal.

CONCLUSIONS

The complex drainage situation in the Slaughter Rising catchment and adjacent areas is conceptualized as being a dominated by a flow system related largely to bedding-guided cave passages at the Crease Limestone/Lower Dolomite boundary, within the confines of the plunging Worcester Syncline.

An element of overflow drainage, mainly autogenic but with a small local allogenic component, moves within those fragments of a higher system, guided by the Whitehead Limestone/Crease Limestone boundary, that are not by-passed by water passing downwards to the Slaughter system. This water emerges at Oldstone Well.

Drainage that might be considered as underflow, mainly comprising autogenic water, occupies all available voids across a single folded horizon at or close to the top of the Lower Limestone Shale. The virtual semi-basin thus formed loses excess water where the aquifer horizon is cut by the Wye on each limb of the Worcester Syncline, at Coldwell and Hadnock Quarry risings.

Brooks Head Grove Rising is a relatively recent feature, formed where flow in the same horizon that feeds Coldwell and Hadnock Quarry risings was truncated by the downcutting of a (?periglacial) surface valley.

ACKNOWLEDGEMENTS

This short report is an updated precis of information presented at the *BCRA Cave and Karst Science Symposium* in March 2000 and, in modified form, at *"Forest 2000"* in June 2000. My thanks to all those cavers formerly active and still active in the Forest of Dean, for freely providing the information (additional to my own observations) that makes this synthesis possible.

REFERENCES

Many additional background references can be found in the following paper, which is referred to above:

Lowe, D J, 1993. The Forest of Dean Caves and Karst: Inception Horizons and Iron-ore Deposits. *Cave Science*, Vol.20(2), 31-43.

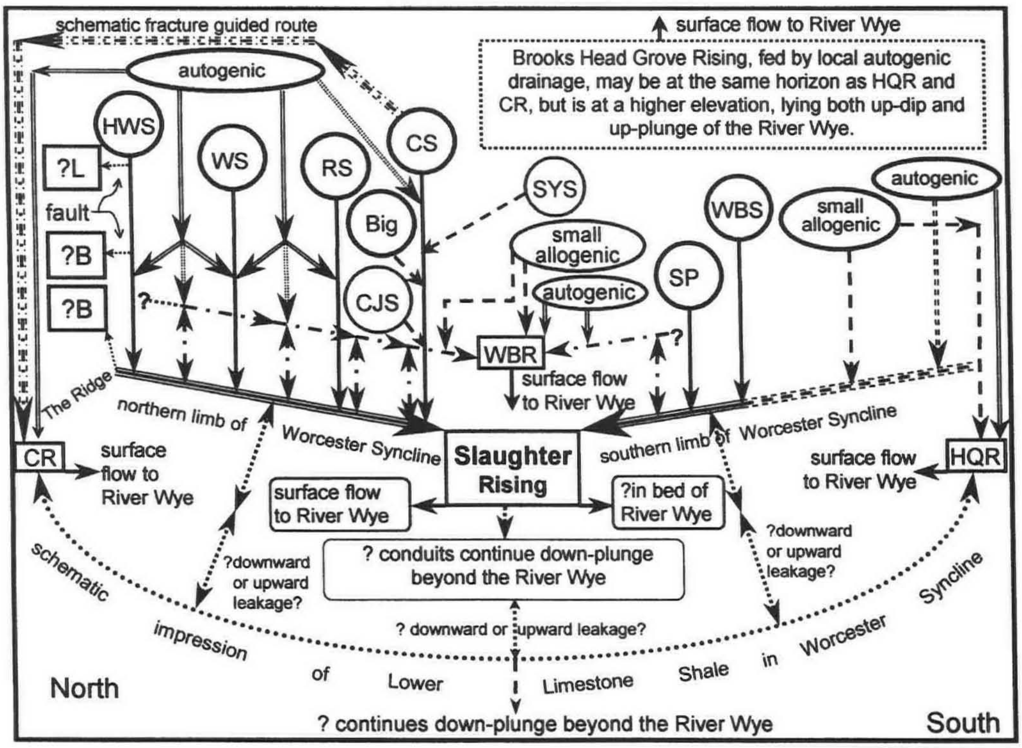

Figure 6: Interim conceptual model of drainage system components in the Slaughter area. [B = Main Basin; Big = Big Sink; CJS = Cross Joints Swallet; CR = Coldwell Rising; CS = Coldwell Swallet; HQR = Hadnock Quarry Rising; HWS = Hoarthorns Wood Swallet; L = Lydbrook Spring; RS = Redhouse Swallet; SP = Sopers Pot; SYS = Symonds Yat Swallet; WBR = Whippington Brook Rising; WBS = Whippington Brook Swallet; WS = Wet Sink]

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Ghar Alisadr, Hamadan, Iran: first results on dating calcite shelfstones

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Keywords: Speleothem, palaeoclimate, karst

Abstract: Several fossil calcite shelfstones above the present water-table in Ghar Alisadr (Alisadr cave), Iran, indicate a more humid climatic episode. Climatic conditions must have at least provided 600mm/yr palaeo-recharge, which is twice the amount the region receives today. The location of the calcite shelfstones above the water-table can be explained, if the aquifer has a fairly low transmissivity, which is untypical for mature karst aquifers. The cave-bearing limestone layer therefore seems to be thin and is partially blocked towards the resurgences, otherwise an increase of more than two metrss in water-table cannot be satisfactorily explained.

INTRODUCTION

Palaeoclimate reconstructions have received much attention over the last decades. For the Arabian-Middle East Region, however, only a few investigations have been carried out, mainly based on data from palaeo-lakes, marine sediment cores and speleothems. Data from the dry Iranian regions are almost non-existent. This paper aims to fill this gap with speleothem data from the Zagros Mountains in Iran.

Quaternary lake sediments from the Arabian Peninsula (Rub'al Khali desert, Saudi Arabia), an extremely arid area today, indicate two phases of more humid climatic conditions. The calcareous and fossiliferous marls and clays of the lake beds have been radiocarbon dated and reveal humid conditions between 37,000-17,000 ^{14}C years BP and between 9,000-6,000 ^{14}C years BP (McClure, 1976). Lake sediments from a buried lake in the eastern Sahara (Oyo Depression, NW~Sudan) reveal laminated carbonate sediments deposited in a stratified lake. The lake sediments were deposited between 9,000 and 6,000 ^{14}C years BP, in a humid savanna-type climate with approximately 400mm annual precipitation. Today, the region lies in the core of the arid Saharan desert zone (Ritchie *et al.*, 1985). Two palaeo-lakes in the Sahara and the Sahel have been cored (Gasse *et*

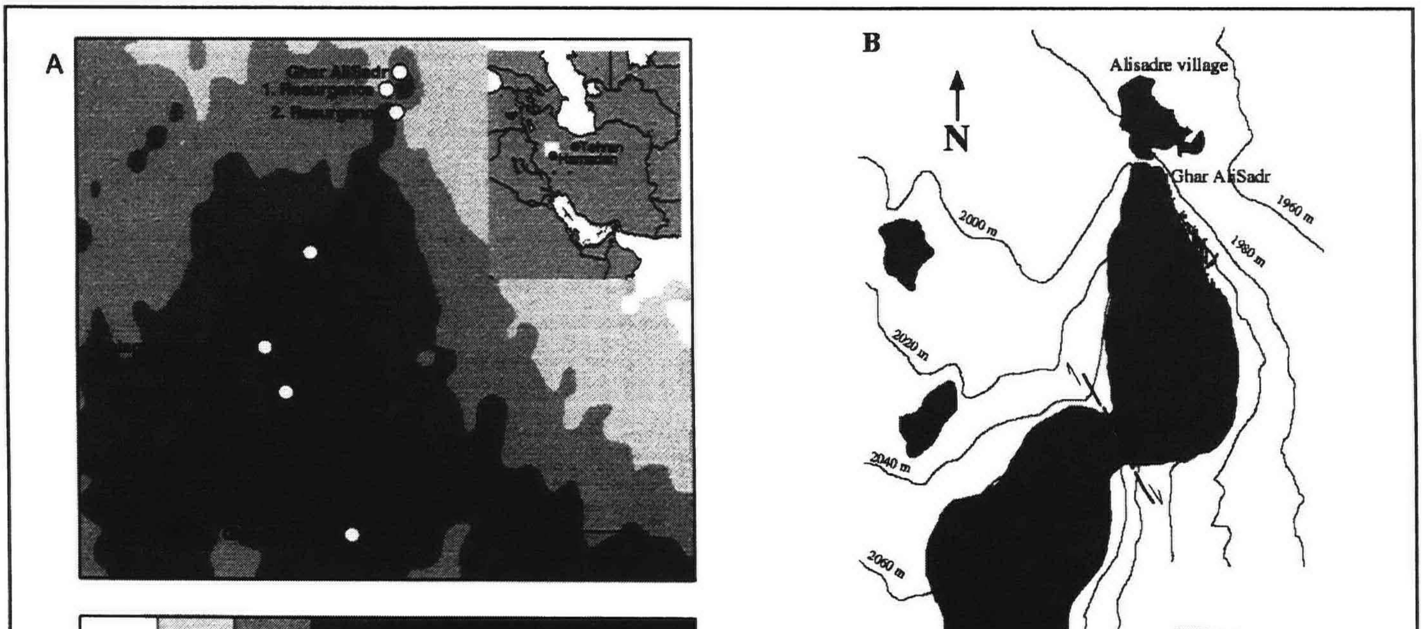

Figure 1.
(A) Topography of the Alisadr region, showing cave locations at the base of ridges. Also shown are major resurgences, with the Gorgoloh resurgence, a CO_2-rich resurgence.
(B) Geological sketch map of the limestone ridges of Alisadr and Tehalehkand. The limestone outcrops are limited to the ridges, and the large shear zone to the south of Alisadr Ridge separates the two neighbouring ridges with different anticlinal axes. Superimposed onto the map of the ridge is the plan of Alisadr Cave, with around 11km of passages explored.

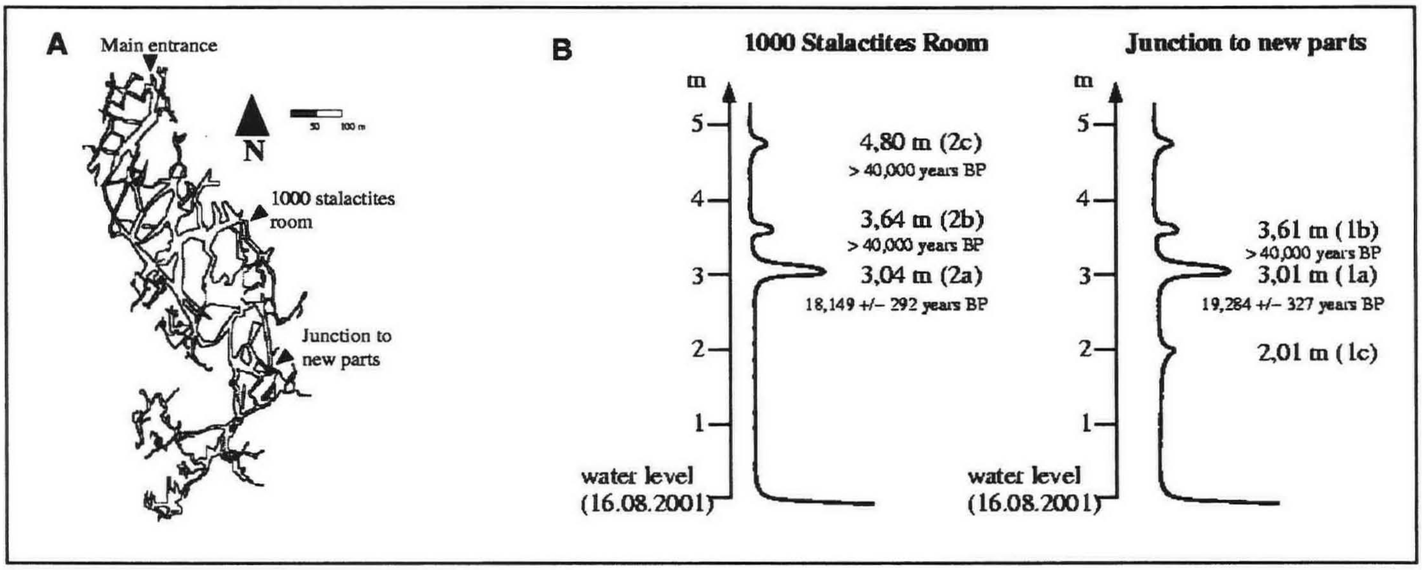

Figure 2.
(A) Plan view of Ghar Alisadr, with both sampling sites marked.
(B) Sketch of the two sampling sites. Shown are the current location of the water-table, the location of the calcite shelfstones above the current water-table, their names and calendar dates, where available.

al., 1990), and the oxygen isotope record of these lake cores also reveals a dry glacial phase, followed by the more humid period around 9,300-7,500 ^{14}C years BP.

Marine sediment core MD76135 recovered offshore in the northern Arabian Sea has been used to infer the oxygen isotope and pollen records back to the last interglacial (VanCampo *et al.*, 1982). Results indicate a wet, humid climate during interglacial periods, and generally arid climatic conditions during glacial phases. Between 10,000 and 8,000 ^{14}C years BP, a humidity peak has been established. From a similar region, marine core 74KL was sampled (Sirocko *et al.*, 1993) and the oxygen isotope record again supported the humid period around 9,900-8,600 years BP.

Groundwater from the Al Khwad Fan (northern Oman) has been analysed by Weyhenmeyer *et al.* (2000). The aquifer contains stratified groundwater levels, with the oldest one in 300m depth correlated to the last glacial maximum. Measurements of noble gases (Ne, Ar, Kr, Xe) reveal a temperature drop towards the last glacial maximum of around 6.5 +/- 0.6 °C. The analysis of stable isotope data ($\delta^{18}O$ and $\delta^{2}H$) indicates a change in moisture source from the Late Pleistocene to today. Whereas at present moisture is carried by the winter NW Mediterranean winds, during the Late Pleistocene water vapour originated from the summer SW Indian Ocean Monsoon.

A high-precision stable oxygen and carbon record from speleothems of Soreq Cave (Israel) was obtained by Bar-Matthews *et al.* (1999). Relating the oxygen isotope record to the palaeo-rainfall, a distinct wet period was localised around 8,500 to 7,000 years before present, corresponding to low $\delta^{18}O$ values. In contrast, high $\delta^{18}O$ values around the last glacial maximum indicate dry climate conditions in the Eastern Mediterranean. The wet period during the mid to late Holocene corresponds to the sapropel layer S1 in the Eastern Mediterranean Sea, which is related to a period of increased precipitation (Bar-Matthews *et al.*, 2000). Speleothem samples from Hoti Cave (Oman) were analysed by Burns *et al.* (2001) and Neff *et al.* (2001). Uranium-Thorium dating revealed several distinct growth periods, mostly during the interglacial phases (78-82 ka BP; 117-130 ka BP; 180-210 ka BP), but also during the early to mid Holocene (10,000-6,000 years BP). In between, the speleothems ceased to grow, probably due to a lack of precipitation. During the growth phases, the oxygen isotope record reveals large negative values around -0.4% to -0.6%, compared to values around -0.2% today. Hence, the source of precipitation during the growth phases was probably different than today.

From the above references, there is a general consensus of a humid period in Arabia, the Eastern Mediterranean, and parts of Africa and Asia, which occurred between 10,000-7,000 years BP. Also, most records taken in the marine climate regions (offshore cores, speleothems) indicate a relatively dry glacial phase, and wet interglacials. Only the lake sediment record for continental Arabia (McClure, 1976) establishes a wetter period also around the last glacial maximum.

GEOLOGICAL SETTING

Ghar Alisadr (Alisadr Cave) is located in the Alisadr (35°18' N, 48°18' E, 1980m asl), 60km NNW of the provincial city of Hamadan in the Zagros Mountains, Iran (Fig.1A). Alisadr Ridge is part of the western structural units of Iran, the Sanandaj-Sirjan Formation. This Formation is of Jurassic origin, with alternating bands of schists and sandstones along the base, a blackish-grey band of clay-like limestone interspersed with thin schist-layers, and a lighter crystallised limestone on top, which is a result of the high-temperature, high-pressure metamorphism related to the volcanic activity in the west of the Alisadr Ridge (Dumas *et al.*, 1993, Torabi, 2000). The limestones are impure with many insolubles, which possibly intensify the acidity of the percolating water.

The Alisadr Ridge itself is the outcrop of a large anticline, with its principal axis oriented in a N-S direction (Fig.1B). The dip of the layers in the vicinity of and within Alisadr Cave is 40-45 degrees, and the length of the Alisadr Ridge is around 2km. The ridge peaks at 2180m, whereas the cave entrance is at an altitude of 1980m in the north of the Alisadr Ridge. To the south, the limestone outcrop continues for about 30km with the Tehalehkand and Sarighayeh Ridges. However, the anticlinal axis in these southern parts is oriented in a N115E direction. Hence, the Alisadr Ridge has been sheared off from the main ridge along a large shear zone between Mt. Alisadr and Mt. Tehalehkand, and the northern part has rotated anticlockwise about 25 degrees (Torabi, 2000).

The Alisadr region is characterised by a semi-arid climate, with an annual rainfall of around 400mm/yr (Torabi, 2000). The precipitation falls mainly as snow in the winter months. Due to the semi-arid environment, recharge into the karst aquifer will be at least 30% lower. The surface of Alisadr Ridge comprises barren limestone, which with 2-3 fractures per metre has a high density of prominent fractures (Torabi, 2000). Also, several funnel-like sinkholes have been observed, which facilitate the rapid infiltration of surficial water.

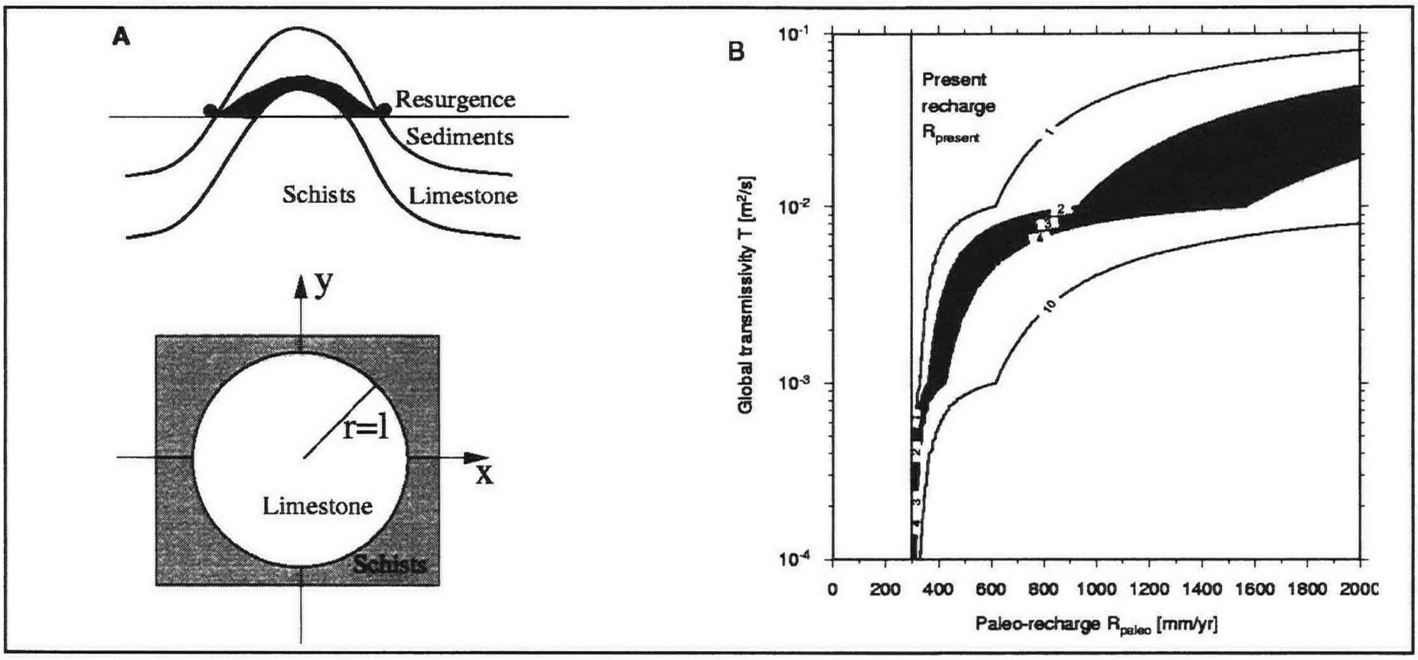

Figure 3.
(A) Schematic cross section through Alisadr Ridge with the permeable limestone, the impermeable schists and the resurgences along the bottom of the ridge. The shaded area depicts the water-table. Also shown is a plan view of the adopted geometrical model.
(B) Hydraulic head difference (in m) as a function of precipitation at the last glacial maximum and global aquifer transmissivity.

Alisadr Cave is developed along the stagnant karst water-table. The cave has been surveyed to a length of more than 11km, with no major leads open (Laumanns *et al.*, 2001). More than 4km of the cave passages expose the water-table, with large lakes of crystal-clear water reaching depths of around 15m. The temperature of the water is around 12 degrees, and with a pH-value of 7 the water is almost saturated with calcite. The level of the water-table does fluctuate annually around 0.5-1m, with a maximum in late spring to early summer. The reservoir is recharged by both diffuse surficial infiltration along joints and fractures, which are channelled into blind avens guiding the diffuse recharge down to the lakes, and a small episodic stream entering the cave at the natural sinkhole entrance. The artifical entrance, which is the main touristic entrance of Alisadr Cave, is a large gallery (5 to 10m) leading down to the water level, which is around 12m below the entrance. The nowadays dry gallery has been interpreted as an ancient Vauclusian spring (Dumas *et al.*, 1993, Torabi, 2000). The water reappears at two springs located along the base of Alisadr Ridge. Comparing the elevations of the resurgences with the elevation of the water-table in the cave (Aug. 2001), indicates a head difference between cave and resurgence of only a few metres.

Passage enlargement in Alisadr Cave is guided by three main directions: N-S, NE-SW, and NW-SE-oriented fractures (Fig.2A). The passage evolution has been described as phreatic (Dumas *et al.*, 1993, Torabi, 2000), with an almost flat ceiling throughout the water-filled passages, numerous ceiling pockets, and an intense corrosion along the cave walls. This kind of ramiform cave pattern (Ford and Williams, 1989, Palmer, 2000) originates in a maze-like widening of fissures and bedding planes in an early phase, and subsequent widening of the cave at and just below the stagnant water-table, creating a broad corrosion bevel.

Interestingly, the cave does not cross the anticlinal axis, as all passages leading towards the central axis of the ridge are filled with sediments. The same holds for passages close to the edge of the ridge. One possible explanation can be that the cave-bearing limestone layer is thin and the water-table along the centre of the ridge reaches the limestone-schist boundary, where increasing impurities inhibit the dissolution of limestone. In fact, walls in the southernmost chamber of the cave indicate limestone layers heavily interspersed with schists.

SAMPLE SITES AND DATING

Throughout the entire cave, a sequence of up to nine fossil calcite shelfstones (Hill *et al.*, 1997) can be found, which are located approx. 3-4m above the current water-table. These shelfstones may indicate a phase in which the water-table in the cave was much higher, probably due to a wetter climate. Hence, the sequence would then represent the fluctuating water-table due to climate forcing. An alternative explanation could explain the sequence of shelfstones with a steadily falling water-table, which stagnated due to temporal damming of the cave outlets during phases in which the shelfstones where deposited. We focus on the first explanation and try to establish a dated sequence of the shelfstones and a hydrological model explaining the climate-driven water-table fluctuations.

Fieldwork was carried out in December 2000 and August 2001, during which samples of the calcite shelfstones were collected from two locations, the 1000-stalactites room in the middle section of the cave, and from the junction to the new parts in the southern part of the cave (Fig.2A). The height above water-table of the calcite shelfstones was recorded with a laser distance meter, and the corresponding rims at both locations have the same height above the water-table (Fig.2B). This indicates that no major tectonic movement has taken place after the formation of the calcite shelfstones.

In a first attempt to answer the question of the origin of the shelfstones, we have dated three samples of the shelfstones in the 1000-stalactites room (Erl-4439, Erl-4440, Erl-5134) and two samples of the shelfstones from the area junction to new parts (Erl-5132, Erl-5133) with the radiocarbon method, using the AMS technique. The samples 1a and 2a from the main calcite shelfstone revealed calendar ages (recalibrated from the original ^{14}C-ages with CALIB-4 from Stuiver et al. (1998)) of 18,149+/-292 years BP and 19,284 +/-327 years BP. If correct, these ages are close to the last glacial maximum. The other samples 1b, 2b, and 2c are too old to be dated with the radiocarbon method, hence only a minimum age of 40,000 years BP could be estimated.

The unknown amount of dead carbon built into the calcite shelfstones, which can be anything between 5-35% (Genty *et al.*, 2001), imposes a large uncertainty on the two established ^{14}C-dates. Hence, the real age of the main calcite shelfstone (samples 1a and

Sample No.	Lab code	^{14}C-age	Calibrated age
1a	Erl-5132	15174 +/- 99	19284 +/- 327
1b	Erl-5133	> 42000	-
2a	Erl-4439	16163 +/- 112	18149 +/- 292
2b	Erl-4440	> 42000	-
2c	Erl-5134	> 42000	-

***Table 1.**: ^{14}C-ages and converted ages, based on the CALIB4 program from Stuiver et al. (1998).*

2a) might be as young as 10,000 years BP, if we assume a large contamination with dead carbon.

We conclude that the region around Alisadr Cave must have received more precipitation, possibly between 10,000 years BP and the last glacial maximum, and that climatic conditions around that time where more humid.

HYDROLOGICAL MODEL

The isolated location of the Alisadr Ridge with its impermeable base of schists and sandstones make it possible to propose a simple hydrological model for the region, which is essentially similar to the island recharge problem in hydrology (Wang *et al.*, 1982). Here, an aquifer is recharged by precipitation, and the water-table intersects the edge of the ridge, where resurgences are located (Fig.3A). Solving the problem as steady-state, confined aquifer problem in two dimensions, the governing differential equation is

$$\frac{d^2h}{dx^2}+\frac{d^2h}{dy^2}=-\frac{R}{T} \tag{1}$$

with h the hydraulic head [m], x and y the coordinates [m], R the recharge rate [m/s], and T the aquifer transmissivity [m^2/s]. Choosing an axisymmetric coordinate system with $r^2=x^2+y^2$, the centre of the ridge is $r=0$ and the edge of the ridge is $r=l$ (Fig.3A). Appropriate boundary conditions then are:

$$\frac{dh}{dr}(r=0)=0$$
$$h(r=l)=0 \tag{2}$$

Integrating (1) twice with respect to x and y and applying the boundary conditions (2) yields

$$h(r)=\frac{R}{4T}\left(l^2-r^2\right) \tag{3}$$

The difference between the hydraulic heads at present, $h_{present}$, and some time in the past, h_{paleo}, is given as $\Delta h = h_{paleo}-h_{present}$. Using (3), and introducing the recharge rates $R_{present}$ and R_{paleo}, we find:

$$R_{paleo}=R_{present}+\frac{4T\Delta h}{\left(l^2-r^2\right)} \tag{4}$$

We now assume that the sample sites are located in the centre of the aquifer at $r=0$, that the radius of the ridge is l=2000m, and that the hydraulic head difference can be taken as the difference between the present water-table in Ghar Alisadr and the height of the calcite shelfstones, Δh ≈2-4 m. With these parameter values, we can estimate the palaeo-recharge rate as a function of the aquifer transmissivity and the hydraulic head difference.

In Fig.3B, the hydraulic head difference Δh is shown as a function of palaeo-recharge R_{paleo}, assuming a present-day recharge of $R_{present}$=300mm/yr, and the aquifer transmissivity T. The permitted values of head difference Δh are indicated by the shaded area. Two important conclusions can be derived from the result shown: Firstly, if the global transmissivity of the aquifer is above 0.1m^2/s, the water-table will not rise significantly, even if the palaeo-recharge rate was around 2000mm/yr. Hence we define T=0.1m^2/s as an upper bound for the global aquifer transmissivity. Secondly, for transmissivities around 0.01m^2/s, a wetter climate with palaeo-recharge rates above 600mm/yr will raise the water-table by 2-4m, but the upper amount of additional recharge is poorly constrained.

Next, we need to examine the global transmissivity more closely. A karst aquifer is extremely heterogeneous, as fractures and bedding planes have been enlarged by chemical dissolution (Groves *et al.*, 1994; Clemens *et al.*, 1997; Siemers *et al.*, 1998; Gabrovsek *et al.*, 2000; Kaufmann *et al.*, 1999; Kaufmann *et al.*, 2000). Hence we have rapid flow in the enlarged fracture system, with conductivities K_f around 10-1000m/s, and slow water movement in the finer less enlarged fractures and the rock matrix, with conductivities K_m around 10^{-7}m/s. The fracture conductivity corresponds to an average fracture diameter in the order of 2-20cm. The conductivities are related to transmissivities through the relation $T=bK$, with b the aquifer thickness. We assume an aquifer thickness in the order of 10m. We also assume that around 10% of the karstified area is enlarged (β=0.1), which is a fairly high value, but not unrealistic for Alisadr Cave. This high porosity has been estimated from a comparison of surveyed cave area to the ridge area hosting the cave. We note that lower values will not alter our conclusions significantly. We then apply common mixing laws for the transmissivities (both simple volumetric mixing or Hashin-Shtrikman-mixing yield similar results), and with the above assumptions we find a global transmissivity of around 1-1000m^2/s. This theoretically derived transmissivity is at least two orders of magnitude larger than the permitted value derived from the palaeo-recharge estimate above. Hence we can only reconcile both estimates by arguing that in between the cave and the resurgences we have non-karstified layers, which inhibit rapid flow towards the resurgences. Two processes might be considered for the non-karstified layers in Alisadr Ridge: Either the enlarged fractures close to the edge of the ridge are blocked by residual material such as clays and sands, and karstification is inhibited here. Or along the edge of Alisadr Ridge the limestone gives way to more insoluble marl and schist layers.

DISCUSSION

The main calcite shelfstones in Alisadr Cave were formed sometime between 10 ka BP and the last glacial maximum (18-20 ka BP). The height of the calcite shelfstones above the present water-table and its age indicate a more humid climate in the Alisadr Region during that time. If the dead carbon contamination in the samples is as high as 35%, the formation of the main calcite shelfstones coincides with the well-established wetter period during the early Holocene around 10,000 years BP (e.g. Bar-Matthews *et al.*, 1999; Neff *et al.*, 2001). Less contamination by dead carbon will shift the pluvial period towards the last glacial maximum. In a next step, we will extent our sampling in the Alisadr Cave as well as sampling neighbouring caves, and employ the U/Th-method to obtain a better understanding of the formation of the shelfstone deposits.

From the palaeoclimate reconstruction, we have derived hydraulic properties of the Alisadr karst aquifer. In order to explain the significant rise in the water-table between the present and the more pluvial period, we need a relatively low global aquifer transmissivity, which is unrealistic for a pure limestone aquifer. Instead, we propose that the aquifer is blocked along the edges of the Alisadr Ridge, either by residual material released during the dissolution of calcite in fractures or by a more insoluble layer with lower transmissivities close to the resurgences.

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CORRESPONDENCE

Dear Mr Editor,

GAPING GILL: DEPTH OF MAIN SHAFT

Mr Forder's recent letter, in which he queried my quoted 112m (=365 feet) depth of Gaping Gill, prompted me to look at various authorities for the depth of Gaping Gill to the floor of the Main Chamber:

If the historical record is correct, flood-borne boulders appear to have raised the floor of the Main Chamber during the past century.

Year	Source	Measured from			Comments
		moor level	shaft edge	unstated	
1872	Hughes		360 feet		Plumbed (Jib Tunnel)
1888	Balderston	380 feet	365 feet		Plumbed
1892	Speight	385 feet	356 feet		Plumbed
1895	Speight	385 feet	356 feet		Plumbed
1895	(Harrison)		330 feet		
1895	Martel		100m		Descended
1896	Calvert	373 feet	340 feet		Descended & surveyed
1904	Puttrell			360 feet	Descended
1924	Kendall & Wroot	365 feet	340 feet		
1937	Simpson	365 feet	340 feet		Descended & surveyed
1946	Hamer			365 feet	
1947	Thornber			340 feet	
1949	Mitchell	345 feet			Descended
1951	Simpson		340 feet		Descended & surveyed
1953	Thornber			340 feet	
1959	Thornber			340 feet	
1965	Thornber			340 feet	
1966	Grainger	350 feet	330 feet		Descended & surveyed
1981	Brook & Brook			340 feet 100m	
1997	Waltham et al.			110m	
2002	Forder		308 feet 94m		Descended

On the other hand, cave surveying is not an exact science. Either way the lesson to be learned is very important. Explorers must err on the side of caution and ensure that they have more than enough tackle to descend in safety. Martel learned that the hard way!

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Yours sincerely,

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✉

The true depth of Gaping Gill

Dear Editors,

John Forder's letter (*Cave and Karst Science, 29(2), p.96*) raises a very important point about the frequently misquoted depth of Gaping Gill. Non-caving writers have most often referred to Gaping Gill having a depth of "365 feet". This figure presumably originates from as early as 1895, being an approximation (in the Imperial units used by the English at the time) of "110m". This figure can be obtained by subtracting the altitudes of the Main Chamber floor (300m) from the altitude of the moor top (410m), as shown on Martel's original elevation. The latter drawing is reproduced as plate 8 in Howard Beck's history of Gaping Gill (Beck, 1984), which is widely available. The altitude of the shaft top (400m) is also given on this drawing and thus Martel's measurement of the depth of the shaft itself was exactly 100m. Perhaps early writers, mindful of the lucrative late 19th Century tourist industry, chose to publish the more impressive-sounding depth from moor level rather than the true depth of Main Shaft. Presumably this has been perpetuated by subsequent generations of writers, many of whom would not have referred to Martel's original and commendably accurate drawing.

Three years ago members of the Craven Pothole Club did some surveying in Main Chamber during a winch meet, principally to establish the elevation of the site where human bones had been found the previous year (Cordingley, 1999). During this work I took the opportunity to measure the depth of the shaft directly (Cordingley, 2000a). Two 50m-long "Fibron" (non-stretch) surveying tapes were carefully connected together (to avoid introducing an error) using electrical zip ties (I am indebted both to R Duffy and P Monico for the loan of these tapes). As it is impossible to arrange a truly vertical hang in Main Shaft the tape was lowered down Lateral Shaft, accessed via the Jib Tunnel entrance. The top of the tape was suspended from the large old cemented-in bolt in the right (west) wall of the shaft (Cordingley, 2000b). This is situated a short distance out beyond the lip of the drop, so it is necessary to use SRT equipment to reach the bolt safely. Whilst I was thus positioned, the CPC President Dick Espiner descended Main Shaft via the winch and recorded the distance to the floor as 98.10m. Note, the tape was read to the nearest 50mm, which was compatible with the method used during the rest of the Main Chamber survey.)

The survey out of Jib Tunnel and round to the lip of Main Shaft is not completed. Thus it is not yet possible to confirm that the elevation of the lip of Main Shaft is identical with the elevation of the bolt chosen as the permanent station at the head of Lateral Shaft. However, it is believed to be very similar. In view of the facts that:

- we cannot identify the precise point from which Martel measured his depth
- there is a possibility of changes in the level of the main Chamber floor sediments throughout the 105 years that have elapsed since
- the Main Shaft is slightly off vertical,

it seems reasonable to assume that the 2000 measurement is in agreement with Martel's quoted depth from 1895.

Both these measurements indicate a slightly greater depth than that given by John Forder when he measured his caving rope. However, this is probably explained by the tendency of SRT rope to stretch a little under its own weight in the shaft, leading to a slightly reduced distance between the two knots used to mark the rope if it was not hanging vertically when John measured it after his trip.

Incidentally I also remember R R ("Dick") Glover mentioning in the 1970s that he had previously measured the depth of Gaping Gill with a 100m tape. I can't recall any specific depth being stated at the time, but Dick was the sort of person who would probably have published a good description somewhere. A search of the likely caving literature (perhaps late CRG or early BCRA?) might provide another reliable depth measurement taken at a time intermediate between the Martel measurement and ours described in the sources quoted below.

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⊠

How the Dravids(ians) and "Pre-Slovenes" lived together in the caves of Kras and drank Teran thousands of years ago – not to mention other curiosities.

(Comments on the article "Kras – Karst – *Karaśattu*: whence the name?" by C A Hromník, in *Cave and Karst Science*, Vol.28, No.2, pp.79-88).

These are the facts that I remembered the first time that I read the extensive paper "Kras – Karst – Karaśattu: whence the name?" by C A Hromník, in the highly respected journal *Cave and Karst Science*. The author explained various names from Kras (Kras, Timava, Reka), as well as other Slovene words and terms (kal, jerovica, reka, skala, teran) on the basis of the Dravid or Tamil languages respectively. When these words were created there were, as yet, no dictionaries or television. Therefore the author also explained how it came about that the forefathers of the Slovenes came into contact with the Dravids. Whatever the case, the author did not doubt that the Slovenes (or Slavs) were living in the area now known as Slovenia from the earliest times.

At first I was a little taken aback. In support of his statement Hromník cited 161 references and remarks from professional literature. Among these, the most commonly cited were some of my own humble works, in which I discussed the name of Kras. For this reason I must put on record my opinion about Hromník's statements. I asked myself whether ultimately he was right. Because I am not familiar with either linguistics or ethnogenesis, I asked for the help of two colleagues, Dr Marko Snoj from the Institute of Slovene language ZRC SAZU, a specialist in etymology, and Dr Andrej Pleterski from the Archaeological Institute ZRC SAZU, a specialist in ethnogenesis and mythology.

Hromník's statements relate mainly to language and to words. Thus, it is appropriate that the judgement of the linguist and etymologist **Marko Snoj** is presented first.

Recently, Cyril A. Hromník, a South African author of Slovakian origin, published an article in the periodical *Cave and Karst Science*, Vol.28/2, pp.79–88. He hypothesised that in prehistoric times people of Dravidian (i.e. southern Indian) origin lived in the caves of Slovenia. There is no historical background whatsoever to support this hypothesis. The author merely compares various Slovene, German, Latin and Greek words with apparently similar modern Dravidian words. He explains the names of the Slovene region Kras (*and Kranjska*) as deriving from the Tamil word *kara* "to hide"and the German equivalent *Karst* as deriving from the Tamil phrase *kara-aśattu*, where *aśattu* means "a person, who hides down below". He takes the Slovene place name *Kal* as being related to the Tamil kal "a stone", without considering the fact that in Slovenian the very same word means "pool" or "puddle". He considers that the name of the famous Slovene, Croatian, and North Italian wine *Teran* derives from the Tamil *teral* "pure toddy, clear juice", although it is well-known that the name originates from the Italian < Latin *terra*, meaning "soil", "ground" or "region". Hromník declares that the latter Latin word is a loan-word, taken from the Tamil *jér-tarai* "ploughing soil". He also considers that the Greek *troglodýtes* "cave dweller" derives from the Tamil *tura-kollai-ditar*, "one who is well established in forest region to renounce". And so on.

A basic principle of science is that a hypothesis has the right to exist if it is supported by arguments that are appropriate to the position of the scientific discourse. Usually the arguments include methodologically correctly interpreted facts. That is, the scientific truth is confirmed or rejected according to appropriate scientific method. If Hromník's arguments are intended to be etymological interpretations of words and names, he should have treated them according to appropriate etymological method. Whatever the case, the method should not involve **word resemblance** and **dexterity of guessing**, but should involve comparative methodology and the consideration of recognized sound and other evolutionary laws. Linguistics is an exact science, its needs cannot be satisfied by approximations.

Hromník developed his hypothesis on the basis of word resemblance only, without considering the laws of language evolution. Therefore he appears unable to understand which form of the name, Slovene *Kras*, Italian *Carso,* or German *Karst*, is the original. In Linguistics the answer to this puzzle was reached more then a hundred years ago. The original was the Latinised form *Carsus*, from the accusative form of which (Carsum) the modern Italian *Carso* developed as an inherited name. From the same accusative form the pre-Slovenian form **Kars(u)* was taken, and this changed via liquid metathesis into the modern form *(Kras)* at the beginning of the 9th century at the latest. That was the time when each pre-Slovenian *'r'* or *'l'* occurring between a vowel and a consonant changed its position before the vowel. The same process gave birth to the Slovene word *kralj* "king", after the name of the Franconian sovereign *Karl* (Charles) the Great (died 814). The German form *Karst* was taken from the Italian one. Its final *'t'* is secondary, following the German phonetic tendency that the words ending in *'s'* are extended by *'t'*, e.g., the German *Axt* ("axe") compared to the English *ax(e)*. A similar but more limited process is known from the Slovene language too, for example *jest* ("I") from the original *jaz*, pronounced *jes*. From the considerations above it follows that all the names mentioned originated from the Latinised *Carsus*, which has the root **kars-*. The variants *Kras, Carso* and *Karst* must have evolved from the same origin. It is methodologically unsound to deduce that the first two from one source and the German one from another. According to Ptolemy's written record, it seems that the root **kars-* developed by letter omission (syncope) from **karus-*. This name is supposed to contain the pre-Latin word **kar* "stone, rock". Today nothing more can be said about the origin of the name Carsus without considering improbable speculations. Whatever the case the name could not have been imported from the modern Tamil word *kara* "to hide" or the phrase *kara-aśattu*, which existed a few thousand kilometres and two thousand years apart, respectively. Formal resemblance, imperfect as it is in this case, cannot be a criterion in modern science. The fact that both a butterfly and a bird have wings does not permit supposition of the genetic affinity of both organs. According to interpretation of paleontological evidence, birds' wings have evolved from the same organ as did the human arms, that is from the front legs of reptiles, which obviously have nothing in common with insects' wings.

It appears that Hromník does not recognize the fact that most words in nearly any language are indigenous, coined by ancestors and passed on from generation to generation. Prehistoric loan words, some borrowed from the substratum, some borrowed from a neighbouring language, are rare. This is the origin of the principle that etymological analysis of any word must first consider all the possibilities of the given language. Only if the word cannot be explained etymologically within the indigenous system should its source be sought in the substratum or in neighbouring languages.

Nothing could be more natural than that the river flowing into Škocjanske jame cave be called the *Reka*, i.e. "River". In Slovenia and elsewhere there are many such examples, and the dialectal pronunciation of the name is nearly everywhere the same as that of the appellative. Hromník's suggestion that the name *Reka* originates from the Dravidian words ari ("gnaw it away") and kam ("water") is unacceptable. It is on the same scientific level as if would be trying to explain the name of the Japanese volcano *Fujiyama* as being derived from the Croatian or Serbian *puši* ("he smokes") and *jama* ("cave"). Hromník also asserts that the Slavic word *reka* ("river") has not been explained etymologically. This is simply not true. An appropriate explanation, taking into account the Indo-European root meaning "to flow", can be found in every modern etymological dictionary.

The next example is Hromník's deduction of the origin of the Greek word *troglodýtes* from the Tamil phrase *tura-kollai-ditar* "one who is well established in forest region to renounce". Hromník's argument is that the Greek word does not resemble the word *spélaion*, meaning "cave" or "cavern". But this argument is null and void, since the Greek *troglodýtes* is a compound, from the Greek words *trógle* (which also means "cave" or "cavern") and a derivative of the verb *dýomai* ("I go underground"). The suffix -tes is used in Greek to form agent nouns, for example *athletés* ("athlete") from *âthlos* ("competition" or "fight"). This explanation agrees with every sound in the Greek compound word *troglodýtes*, explaining its meaning without any overlap, in contrast with Hromník's assumption. At the same time it agrees with the perception that most words originate in the language in which they exist.

Any attempt to disprove every detail of Hromník's confusion would require an account longer than his paper. This would not be sensible, so I will conclude with the only possible comment. The etymological deductions and explanations from Hromník's paper are far from being correct methodologically, therefore they are evidently wrong.

The hypothesis that prehistoric Dravidian inhabitants occupied Slovenian karst caves is consequently nonsense. Each science has its own methods concerning how to detect scientific truth. It also has the scientists who master the methods, and it has the periodicals where the results are published. On the fringes of every science there are also dilettantes, individuals who do not care about scientific method and who set up nothing but unprovable suppositions. They try to avoid competent reviewers in every possible way. Reading Hromník's article, my opinion is that the author is an etymological dilettante. Moreover I am surprised by the unaccountable action of the Editor of a periodical with such a high karstological reputation. If following normal editorial procedures the Editor should have refused Hromník's text, since it does not deal with a karstological topic. Or, failing that, prior to its acceptance, Hromník's paper should have been given to a specialist etymologist, who would have rejected it due to the incorrectness of the methodology. Publishing papers from other special fields of science without previous adequate review encourages dilettantes, it creates unnecessary doubts among the readership and, in any case, it discredits the reputation of the periodical."

(Marko Snoj)

The opinion of Dr **Andrej Pleterski** is:

"It is obvious that Hromník's starting point is a primary core, from where everything originated. Regarding the fact that mythology is older than the Indo-Europeans and that its origins are without doubt in the Palaeolithic, mythological parallels can be found in whichever part of the World. Beside this, the author did not differentiate between the Dravidians (old aboriginals) and the younger Arian-Indo-Europeans. Bobofi, Trimurti, etc., which are interlaced with Dravidian words, belong to the younger stratum. In short, Hromník does not take into account historical processes and the changes that go with them. Instead he uses a process of arbitrary combination that, inevitably, always gives him the desired result."

(Andrej Pleterski)

May I add some comments too? Some of Hromník's arguments intended to prove the Dravidian origin of the name *Kras* are mistakes, or are misunderstandings or are misinterpretations of published data. Hence, they are groundless:

- Jesenko (p.80 in Hromník's paper) did not forge the regional name Kras in 1874. Jesenko simply recommended use of the word *kras* (written with a small initial) as a common term for *karst* in the Slovene language, based upon the regional name *Kras*.
- Hromník's deductions also included Hacquet's record of *"karoš"* (p.80). This is partly my fault. I did not examine Hacquet's work myself, but cited it, unread, from work by other authors. In reality, instead of the name *Karosch* (in the Gothic alphabet), *Krast* (in the Latin alphabet) was written in Hacquet's Oryctographia Carniolica. This is explained by Hacquet himself in the "Verbesserungen" of the fourth volume (p.83) – just as a printing error.
- According to Hromník the name *Mons Gaberk* is a composition of the Dravidian *kara* and the German *Berg* - if we ignore the few thousand missing years. I am afraid that the author clearly does not know the Slovene name of the tree *Gaber* (beech tree, *Ostrya carpinifolia*).
- A similar example is the river *Albia* (p.82) or *White river* of Hromník. On old maps, by mistake, the cartographers draw the river Unica running towards the South instead towards the North (and underground towards the springs of the Ljubljanica river). The Unica is drawn flowing on the surface towards the Postojna basin (river Pivka) and further southwards to join the Reka river. The German name for the village of Planina (at Planinsko polje) was Alben (Alpen, Alp), or summer pasture. There is no need to look for a connection between the Latin "albia" (white) and a contrast with with the underground, which is "black", or to link it to Indian mythology. The name has no mythical or mystical origin, but simply means "a pasture".
- Similar points can be made about the name of the saint, St. Kancijan, who gave the name to the village Škocjan. Hromník wrote (p.82) "... (the name *Kancijan*) fails to appear even in the most exhaustive list of Christian saints ..." and therefore "It is highly doubtful that the Catholic Church ever beatified Slovene Kancijan" (p.83). It is enough to look into the modest "Life of Saints" published by Mohorjeva družba at Celje (1929). Of course Kancijan was not Slovene. Brothers Kancijan and Kancij, together with their sister Kancianila, were members of the Roman family of Ancius, and martyrs under the emperor Dioklecianus. They tried to escape but were caught and beheaded at Grado. The conclusions that the name is of Dravidian origin and that Kancijan was the water deity of Slovenes, cannot be taken seriously.
- M Snoj has already written about the word *reka* (river). I would just like to add that such names are not unique to the Kras. In the Atlas of Slovenia there are at least 13 streams called Reka.

Everybody makes mistakes, and the ones mentioned here might not be crucial. However, some questions are left open by the author himself. Maybe he does not see them as fundamental, but they are:

- On p.84 he wrote: "Dravidian hermits, who in the Bronze Age or in subsequent times, dwelt with their Sloven brothers, in the karstic caves of Central Europe, ...". This raises the questions:

1. How can it be that there is no material (archaeological) proof of Dravidian settlers (hermits) in Central Europe, especially in Slovenia?
2. Why is there no mention in contemporary Roman sources of Dravidian hermits or merchants living or visiting the area of modern Slovenia? In Roman times Kras was not just a part of a Roman province, but it was part of the Roman Empire itself, of the "Regio X – Venetia et Histria".
3. It is proved without doubt from historical and archaeological sources that the first Slavic tribes (ancestors of the Slovenes) began to settle the area of modern Slovenia in the 6th century AD. How could they live together with Hromník's Dravidian hermits from the Bronze Age, taking into account the gap of thousands of years – not just one millennium but more?

We do not deny Hromník's ideas *a priori* or in an attempt to show superiority. Before his ideas could become an acceptable theory (remembering also that there can be a great distance between theory and facts), he should use appropriate scientific methods, he should correct and harmonize inaccurate citations, and provide the answers to open questions. I fear that the idyllic picture of Dravidian hermits drinking wine with their Slovene brothers, sitting at sunset under the porch of their caves and praising god *Kañč iyan*, is liked only by Slovene "autochthonists" [Editor's note: "Autochthonist" is a type of nationalist, a person who believes that Slovenes have inhabited the region since ancient times]. We are sorry to say that from the promising title of Hromník's paper, "Whence the name?", nothing remains.

Andrej Kranjc
Andrej Pleterski
Marko Snoj

✉

Karst: Methodology of Academic Mediocrity (MAM) sheds little light on the dark karstic underground.

A response to the critique by Andrej Kranjc, Marko Snoj and Andrej Pleterski, 2002. Kako so pred tisočletji Dravidi in "Praslovenci" živeli skupaj v jamah na Krasu in gojili teran ter še o marsicem drugem. *Acta Carsologica*, 31(3), 2001, pp.183–186; and [after editing of the English translation] in this issue of *Cave and Karst Science* as: How the Dravids(ians) and "Pre-Slovenes" lived together in the caves of Kras and drank Teran thousands of years ago – not to mention other curiosities. (Comments on the article "Kras – Karst – *Karaśattu*: whence the name?" by C A Hromník, in *Cave and Karst Science*, Vol.28, No.2, pp.79–88).

The main finding in my article "Karst, Kras or Karasattu: whence the name?" (*Cave and Karst Science*, Vol.28, No.2, 2001, pp.79-88) is that the name Karst/Kras, as reflected in the oldest Roman form *Carusadus*, is of Dravidian origin and refers in the first place to the cave-dwelling Troglodytes and only secondarily to the caves themselves. This derivation and meaning of the key term is supported by numerous related terms of similar origin, all of which combine to create a historically credible picture of the Karst/Kras in the Bronze Age and Classical times. By Roman times the names and words were preserved but their primary meanings had already been forgotten, mainly because of the reduced commercial contacts with Dravidian India.

Andrej Kranjc, to whom I am obliged for sending me most of his and other research materials, initiated the critique of my article, but immediately disqualifies himself from the task by declaring that he is "*...not familiar either with linguistics or with ethnogenesis,*". I would add "*...not to mention ancient history*". Thus he passed the burden on to the shoulders of a linguist and etymologist, Marko Snoj, and a specialist in "ethnogenesis and mythology", Andrej Pleterski.

As Andrej Pleterski makes no relevant, specific or logically understandable comment on my article, for me to comment on his incoherent remarks would be to waste space in this journal. I know nothing about his "*Bobofi*", and he obviously knows nothing about the Dravidians when he calls them "*old aboriginals.*" Dravidians are old, but by no means aboriginals. Perhaps he does not mean it, because "*dravidsko – staroselsko*", used by him in *Acta Carsologica* (31(3), 2003), can hardly mean the same[1].

Methodology is the key word in Marko Snoj's critique, and the pathetic results of the methodology that he embraces do not seem to matter. Allegedly, linguistics solved the problem of Kras and Karst "*a hundred years ago*". Apparently "the original is a Latinised form of *Carsus*". But *carsus* means nothing in Latin, it is a puzzling name and no more. The same applies to the ethnic name Carni. That is why Dr Andrej Kranjc wrote 8+ articles on the subject, trying to discover what is hiding behind the enigmatic name. All of these, of course, should have been "rejected" by specialists of Snoj's type and calibre. These articles should also have been censored by the editors of karstological journals, because they are "...not dealing with the karstological topic".

Can one be more blinkered than is implied in this statement, and the methodology he calls for can only be characterised as the **'Methodology of Academic Mediocrity' (MAM)**. It is a stagnant methodology, which any curious and serious researcher should steer away from as soon as s/he gets out from the claws of the ageing and comfortable professor supervising his dissertation. Pathetically, "*Today* [i.e. 100 years later] *nothing more can be said about the origin of the name Carsus...*", concludes an exponent of the MAM. Marko Snoj begins with the name Carsus and ends with the name Carsus, without adding one iota to our understanding of this pivotal name in karstology. As if nobody could ever go beyond his unproductive methodology. His little toying with would-be linguistic fragments and pretended regular changes may confuse some uninformed undergraduates, and readers in Marxist sociology. Had Ptolemy or Columbus used the same MAM methodology, we would still be falling over the edge of the Flat Earth. Thinking scholar wants to know what was it that the Romans actually "Latinised" into *Carsus*. Academic mediocrity knows not that curiosity, wide knowledge of evidence and real phenomena, imagination, logic and intellectual courage are the essential ingredients of scientific research. His reference to science is farcical. The Methodology of Academic Mediocrity, based on a few outdated formulae, is a suitable entertainment delivered by ageing lecturers to the naïve and inevitably bored undergraduates, but it has not made any real contribution to our understanding of the distant past, be it karstic or cultural, and it is definitely NOT "an exact science." It is a poor guesswork and a snobbish pretence. The only valid rule about its "*recognised sound and other evolutional laws*" is that they are never reliably applicable to the unknown historico-linguistic problems and situations – chiefly because (unlike chemistry) languages are not made of 120+ known basic elements, each with a specific number of atoms. Words are like individual people, each with their own history.

MAM has produced such trivia as the cited derivation of the Slovene word *kralj* for 'king' from the name of the Frankish king "Karl (Charles) the Great." All Sloveni (Slavic) languages know the name Karol, Karel, Karl, etc, and they never confuse it with *kralj, král, kráľ, król, korol,* etc., which they must have known since the Bronze Age, as it is of Dravidian origin, and means 'Victorious by Nature', in other words, '*Vítaz*'. It is quite possible that the Frankish name Karl (Charles) derived from the Sloveni *korol, kráľ,* considering the fact that Franks' ancestry originated from the Sloveni (Slovak) Pannonia and farther east. Using the would-be 'law', that "*loanwords are rare*" (half of English is loan-words) and myopic research is better than unhindered but historically justified and territorially broad research, leads to the discoveries typified by the name *Teran* for the North Italian and Karst land wine. This is allegedly derived from "Latin *terra* 'soil, ground, region', "which is thus nonsensically branded as "earth or soil wine'; as if only this wine grew out of the earth or soil. And I wonder why did the Italians drop one *r* from their word *terra*? Too drunken?

In the same vein, arbitrarily declaring the derivation of the name *Reka* from the Dravidian *arika* (*ari-ka-m*) for 'gnawing river' i.e., 'karstic river', which is a *par excellence* description of its main and rare characteristic, as "unacceptable" without giving any reason or historical evidence is totally unscientific and really unacceptable. Checking my 1:350 000 map of Slovenia for rivers with the name "Reka," I found only three. One of them, the *reka Reka*, goes underground at Škocjanske jame. Another runs into the *Sava reka* near Litija. Both of them are karstic, i.e. sink to the underground. The third name, *Kocevska Reka*, designates the town on a small sinking river, but I am not sure if it is called *reka Reka* or *Kocevska reka*. Kranjc reports that he counted 13 rivers called *Reka* in Slovenia and he kindly sent me 1:25,000-scale maps (for which I am very grateful) showing the locations of seven rivers called *Reka*. All of these (altogether 9) rivers that I have thus far studied, sink underground and, beyond any doubt, confirm my derivation of the Slovene hydronym Reka or Rekka (Latin *Recca*) from the Tamil *Ari-kam*, meaning 'Gnawing river' or 'Karstifying river'. This confirms the scientific soundness and the forte of my methodology of investigation, as opposed to the scientifically useless MAM pushed on to me by Marko Snoj.

The word *reka, rieka, řeka, reka (река), rzeka*, etc. for 'river', as opposed to the hydronym Reka, Rekka, Recca, occurs in all Sloveni (Slavic) languages, but hardly ever as a hydronym. I am well aware that the word *reka*, etc., is listed in every etymological dictionary, but it is always without an historically or logically acceptable explanation. Guesswork along the lines: "Indo-European root meaning 'to flow'" is a fiction, served to and occasionally swallowed by some folk with a mediocre education. The Czech etymological dictionary (Holub and Lyer, 1967) is more candid when it suggests that the word "may have something to do with Latin *rigare* 'to irrigate'. However, this suggestion implies that all Sloveni (Slavic nations) knew irrigation before they came to know rivers, which is absurd. Nevertheless, this etymology, puerile as it is, meets the rigours of the Methodology of Academic Mediocrity. It reminds me of the Slovak word *miškár* for a 'castrator of animals', which MAM derives from the Czech *jeptiška*, for a 'nun'. MAM is a total spoof. This critic, Marko Snoj, has shown not a sign of scientific curiosity, in other words, he is scientifically dead.

Not at all surprisingly, Snoj avoids addressing the question of the Romanized name *Carusadus*. His sarcastic remark, suggesting that articles by "dilettantes" (with which sobriquet he tries to brand my thoroughly and widely researched article) "...discredit the reputation of the periodical" in which they appear, represents an old and typical MAM tactic of defamation. I can only outline the choice before the *Cave and Karst Science* editor:

1. Publish only those articles that are censored and certified by the puerile methodology of academic mediocrity (MAM) – and watch your readers yawning or, worse, cancelling their subscriptions;
2. Publish bold and broadly researched articles on unsolved problems, articles that try to look beyond the known though unsatisfactory obvia, whose authors have the courage to probe the darker caverns of the unknown, even at the risk of committing an error here and there. After all, science is nothing more than a continuous correcting of earlier errors.

Judging by the comments I have received, my article enhanced the reading attractiveness of the *Cave and Karst Science* journal. Here is a sample. A prominent Italian karstologist writes: "*When I have received the last issue of Cave and Karst Science I was curious*

Page and column/ Paragraph/line	Printed error	Correct version
79/1/2b	oronym	Hydronym
79a/3/10t	Sloven	Sloveni (Slovene)
80a/3/6t	*troglodytes"*	*tróglodýtai"* ("τρωγλοδύται")
80a/3/5b	*tróglodýtés*	*tróglodýtes*
80a/3/1b	*tróglodýtés*	*tróglodýtes*
80b/2/6t	*Tróglodýtés*	*Tróglodýtaι*
80b/4/7b	Sloven	Slovene
80b/4/2b	'prikradnu'sa	prikradnuť sa
81a/2/7t	Preöov	Prešov
81a/2/10t	Coprniöka	Coprniška
81a/2/6b	Cerkniöko	Cerkniško
81b/3/3t	*smů la*	*Smůla*
82a/2/10t	Κάρυοι	Κάυαροι
82a/3/3t	Καρουαάγκασ όροσ	Καρουαίγκας όρος
82a/3/11t	vangku	*vangku*
82a/3/10b	ουάγκασ	ουάγκας
82a/3/9b	Καρουάγκασ	Καρουάγκας
82b/1/9t	*_eka*	*řeka*
82b/2/13b	äkocjanska	Škocjanska
83a/4/8t	μητέρα θαλάττησ	μητέρα τής θαλάττης
83a/4/8-9t	meetera Thalattes	meetera tes Thalattes
83a/4/9t	θαλάττησ as θαλάσση	θαλάττης as θάλάσση
83a/4/6-7b	*Kun,da mátar tal,l,á*	*Kunda mátar tallá*
83a/4/2b	*Kun,da*	*Kunda*
83b/4/7t	Διομήδονc … τό Τίμανον	Διομήδουc … τό Τίμαυον
84a/23b	Adriatic	Adriatic.* The story of Adria and Adriatic harks back to the Indian mountain goddess Parvatí, who was "Adrijá" i.e., 'Mountain-Born'. (Stutley 1977, *A Dictionary of Hinduism*, p.3.)
84b/1/1t	unexplained.	unexplained.[151]
85a/footnote[1]	Supplement to footnote 1: Sloveni (Slovenis) is the oldest form of the name, which was born in the forests of the upper Carpathian Basin, where it still survives in the name Slovensko (for the country) and Slovenky (for its women). Modern variants of this name are: Slovaci/Slovaks for the people of Slovakia; Slovene/Slovenes for the people of Slovenia. As the modern ethnic differentiation is in the context of ancient times and Bronze Age impossible, I should have used the name Sloveni (instead of Sloven or Slovens) both for the Slovaks and for the other ethnic groups belonging to the Sloveni (Slavic) linguistic family, with an explanatory name, when necessary, in brackets, e.g. Sloveni(s) (Slovak(s)), Sloveni(s) (Slovene), Sloveni(s) (Slav(-ic or -s)). In each case, please replace Sloven and Slovens with Sloveni or Slovenis.	
85a/footnote[3]	kraš ka	kraška
85a/footnote[4]	Χαρονσά	Χαρουσά
85a/footnote[5]	klasièni	klasični
85a/footnote[7]	154	152
85a/footnote[8]	*hÓr*	*hôr*
85a/footnote[11]	zř etelem	zřetelem
85a/footnote[13]	kraöka	*kraška*
85a/footnote[15]	p.56	p.256
85a/footnote[17]	kraöka	kraška
85b/footnote[18]	*kaluř* meaning	*kaluři*, meaning
85b/footnote[18]	*kalu ž a*; Czech *kalu ž e*	*kaluža*; Czech *kaluže*
85b/footnote[23]	*kraš ka*	*kraška*
85b/footnote[32]	AbÓmes	Abîmes
86a/footnote[47]	*slovensk_ch nárečí*	*slovenských nárečí*
86a/footnote[50]	klasièni	klasični
86b/footnote[61]	k^niglichen	*königlichen*
86b/footnote[61]	Slovensk_	*Slovenský*
86b/footnote[68]	kraš ka	kraška
86b/footnote[70]	*Savici pod kožo*	Savici pod kožo
86b/footnote[84]	litaku	*litaku*
87a/footnote[89]	Kranjc	Kranjc,
87a/footnote[91]	596	594
87a/footnote[100]	Preèkali	prečkali
87a/footnote[101]	Š kocian. [Sež ana	Škocian. [Sežana
87a/footnote[102]	klasič ni	klasični
87b/footnote[109]	Naše jame (Ljubljana)	Naše jame (Ljubljana)
87b/footnote[113]	Š uš terš ič kraš ka	Šušteršič kraška
87b/footnote[113]	Supplement to footnote 113: Vergilius (70-19 BC) is said to have made the exit of the Timava river from the underground famous by calling it "Fontes Timavi." Kelsall, C. 1830. *Esquisse de mes travaux, de mes voyages, et de mes opinions*. Londres: ??, vol. VII, p. 23. Quoted in: Shaw, T.R. 2000. *Foreign Travellers in the Slovene Karst 1537-1900*. Ljubljana: Založba ZRC (ZRC SAZU), p. 98-99.	
88a/footnote[134]	San?gam	*Sańgam*
88a/footnote[142]	KrižŽko	Križko
88a/footnote[151]	*Struèný ..... èeského*	*Stručný ..... českého*
88b/footnote[152]	Slawski … *Slownik praslowiański … Wroccaw*	Sławski … *Słownik prasłowiański … Wrocław*
88b/footnote[158]	Slawski … *Slownik praslowiański*	Sławski … *Słownik prasłowiański*

Table 1. *Corrections to misprints that appeared in the original article. Note that in the table, 1t = 1st line from top, 1b = 1st line from bottom, etc.*

to read the paper by Hromnik after having read your editorial. Well, I think that such a paper is one of the most interesting, well written and constructed of the journal (and) ... has a very good standard. It would have been very difficult to discuss the point of "kras" in a better way. I understand your hesitation because none of you is expert of languages; an etymologist would have probably introduced a different view but the chance to be right in opposition to Hromnik is quite small or perhaps negligible. Hromnik had the enormous advantage to be expert in both fields, speleology and etymology and he was absolutely successful in his work." (Arigo Cigna, 6 March 2002). A leading South African speleologist writes: *"A nice job – well done!"* (Dr Stephen Craven, 27 March 2002).

Unlike the MAM linguist, a more open-minded karstologist, Andrej Kranjc, did not fail to question the origin and meaning of the toponym *Carusadus*, and in all of his 'uncensored' articles on the subject, he repeatedly postulates that the name derives from the proto-Indo-European *"kar(r)a/ga(r)a*. But, limited by his knowledge of history and Onomastics, he concludes that the region of hollowed bedrock, which the Karst certainly is, is paradixically called the 'Rock' in Slovenia. Fortunately, it was the Romans, not the Slovene, who would have committed this geonymic blunder. I know many and much more rocky countries that know the Dravidian word for 'stone' *kal* or *kar* (in compound words), yet none of them has coined the name *Karst* or *Kras*. By the laws and methodology of academic mediocrity (MAM) they should all have done so. Clearly, ancient Dravidian and Sloveni troglodytes knew better. I am also well aware of the Slovene word *kal* for 'a pan of water, pool, puddle', and its meaning and derivation from the Dravidian *kaluři* for 'a pan of water, puddle, dirty water', is explained in footnote 18 of my article. A location *Pri-kaluži*, ca. 3.7 km SE of Kozina in Slovenia, illustrates the point.

And who were these *Troglodytes*? Snoj sees them as Greek (although Homer and Herodotus never heard of them in Greece) *trógle-dýomai-tés,* allegedly meaning 'cave-I go underground-he (agent)'. But *trógle* τρώγλη is obviously not of Greek origin. It refers to the forest and desert life of recluses who consumed *trogália* τρώγάλια i.e., 'fruits eaten at desert'. When imported to Greece, its primary though not original (Dravidian) meaning as understood by ancient Greeks, was not "cave, cavern" but 'a hole formed by gnawing action', which refers to the Ethiopian hermits who, being Dravidian *tura-kollai-ditar,* 'the forest or desert dwelling recluses', gnawed their living holes and shrines in the living rock (viz. Lalibela, Adadi Mariyam, etc.). Thence, the contracted form *trógle* which in modern Greek means 'a hole formed by gnawing, a mouse hole'. *Dýomai* δῦομαι? means 'to sink' (like the sun) not "I go underground" as claimed by Snoj. Greek suffix-*es* ες?, not the agent noun-forming singular suffix *-tés*, appears in Herodot's Garamantes Γαράμαντες or Aithiopes Αἰτίοπες, while Dravidian plural suffix *-ar* in *Turakollaiditar*, most likely reduced by Ethiopians into *Trogloditar,* is translated as *-ai* in Herodot's *Troglodytai* τρωγλοδῦται. Romanization, not Hellenisation, of the name produced the form Troglodytes, not Troglodytés. Snoj's attempt at Greek etymology has obviously failed. MAM hardly ever fails to fail.

Amongst the points that Kranjc thinks I have misunderstood or misinterpreted, and which allegedly make my Dravidian derivation "groundless," are the following:

- I did not ever accuse Jesenko of "forging" the regional name *Kras*. I said he "coined" it ("*skoval*"); the rest I leave to Kranjc to straighten up. It bears not at all on my derivation of Karasattu.

- Being a Sloveni (Slovak) not a Sloveni (Slovene) I indeed did not know that the beech tree is called *gaber* (certainly not *Gaber*) in Slovene, but, should Valvasor's (1689) Latin oronym "*Mons Gaberk*" mean 'Beech Mountain', as argued by Kranjc, I wonder what might be the meaning of its final *-k*? And why is it applied to a mining hill in Slovakia, where beech tree is called *buk*, and *buk* does not grow on the given hill? And, should Kranjc be able to overcome this difficulties, why did not the Romans call this mountain *Mons Fagus* since, in Kranjc's chronology, Romans must have known this mountain at least 600 years before his Slovene ancestors ever came into existence? I also wonder why Ivan Gams, France Habe, Aci Leben, Du-an Novak, France Osole, Franc Šušteršič, some or all of whom are Slovene-speaking, did not see it fit to mention that *Mons Gaberk* is Beech Mountain and that Sloveni (Slovene) named it so. Instead, they, just as Valvasor and after him Schmidl (1858), saw it as a descriptive name for the "terraced mountain Karst," which "in Italian is Carso, Monti del Carso; in Slovenian: Gaberk"[2]. Historical etymology is a bit more than rattling a few simple formulae from an apparently pseudo-scientific methodology.

- I had not seen the *Life of Saints* [Kranjc's bibliography] published by Mohorjeva tiskarna in Celje when I was writing my article, but my source, cited in my article, refers to it (*Živlenjepisi svetnikov* [sic]). However, from what I then had at hand, my impression was that, most probably, the booklet is too "modest" to be taken seriously, especially when compared with the voluminous compilations of saints by the Catholic Church, which are cited in my article. Since then, Dr. Kranjc has kindly sent me the relevant pages of *Živlenje svetnikov*, and it leaves me convinced that this work, based as it is on "old sayings or old proverbs" ("*poročila*") and tales interlaced with popular legends, must be read in that light. In these tales, Jesus Christ himself talked to the holy triad of Kancij, Kancian, and Kancianila[3]. It reminds me of the tale about "Jakci, Jakci Drakci, Jakci Drakci Drakci Drone and Pipi, Pipi Lipi, Pipi Lipi Limpi Pone." Had there ever been a "Kancijan," whether saint or not, most likely he would have been Slovene in pre-Christian times. That possibility is sufficiently explored in my article. Had he been Roman, from "a Roman family of Ancius" in the reign of Diocletian (AD 284-305), as asserted by Kranjc, he would have been Ancian. But among the 15 water-related names of localities in Slovenia, none is called Ancian; all refer to Kancijan (i.e. Škocjan) and never to Cancian. Perhaps Kranjc will show me the better sources of Mohorjeva's *Živlenje svetnikov.* I would be happy to correct my mistake had I erred. At the same time I wish Kranjc would show me my "wrong citations," other than the one for which he accepted the responsibility.

- In historical geography we know of several rivers called *Albia*, *Albus*, etc., mostly meaning 'White'. If in the Slovene case *Albia flu* should derive from Alben (Alpen, Alp), meaning 'summer pasture', why should it have been applied to the river that is now called Unica (Unec on map), which flows north rather than south? Germans applied the name Alben/Alpen to a village (now Planina) at the source of the short sinking river Unica or Unec, which makes sense, not to the river. As I said in my article, the possible confusion of old cartographers about its direction is irrelevant to the question about the meaning of its name. However, the name Unec/Unica tells us clearly, that the ancient Dravidian-speaking troglodytes knew which way the given river was flowing and what was its name. This is confirmed by the surviving name Unec (applicable to its upper course where it was but a small stream Unec = *potok Unec*; see village Unec nearby) and Unica (lower course called *reka Unica*). The hydronyms Unec and Unica are based on the Dravidian root *uń* , which means 'to swallow', and these hydronyms securely predict that, north of Planina, this river will be 'swallowed' by two "swallow holes," or *doline*[4]. This indeed happens just north of the town of Laze. I have not seen the *Un doline* at Laze with my eyes, but I do hope that Kranjc will be able to admit that my methodology has been fully vindicated, and he has been duped by the MAM pseudo-experts.

- Kranjc laments the absence of "any material (archaeological) proof of Dravidian settlers (hermits) in Central Europe, in Slovenia specially." Lots of Dravidian archaeological material has been found and identified in Central Europe by, among others, Gordon Childe, under the name "Orientals". They were responsible for much of the early Central European mining and metallurgy. Unfortunately, archaeologists are unable to sort out these small onomastic problems of ancient history. Kranjc cannot be blamed for failing to understand it, but then, he should not use misunderstood records in arguments against me.

- Romans had not yet occupied *Venetia et Istria* when Dravidian *Turakollaiditar* or *Trogloditar* shared the *Karasattu* caves with their Sloveni (Slovene) counterparts. Kranjc's 6th century AD Sloveni occupation of Slovenia is a fiction that sprang from Niederle's fairy tales about the "Slavs," who allegedly until then shared the Pripjat swamps with the mosquitoes and then, suddenly, without a single battle with the earlier inhabitants, occupied the greater half of Europe. Nothing in this tale is "proved without doubt." It is a confused tale of a little Czech Germanophile, swallowed by many uncritical MAM academics, and nothing else[5]. It should be called Unec.

Kranjc's parody in the last paragraph, though gratuitous, has been approved by the Methodology of Academic Mediocrity (see signatures at the end), so it must be published and, presumably, will enhance the reputation of this journal. It does not deserve my comment.

My article deals with ancient history of the Slovene Karasattu/ Karst/Kras, as reflected in the historical Onomastics. The logical consistency and the historical feasibility of the story of the ancient Karst/Kras, as it emerges from my interpretation of the known historical and onomastic data, is so strong that it outweighs any statistically based phonological or other rule that MAM can throw in, as these are never based on sound and comprehensive data. Weighing the evidence is always more reliable and effective than counting. My critics' weakness in history, chronology and ancient geography is only too apparent. Pomposity of expression and offensive, denigrating tone are not a suitable compensation for this weakness. May I remind them that each word has its individual history and the task of the historian and linguist is to find it – not to postulate it. Otherwise, the function of the nuns' loose habits would not be to protect their chastity, but to hide the castrating knives, and beware of those! – especially if you depend on the MAM.

CORRIGENDA TO MY ARTICLE.

Because of a rather high number of diacritical markings in my article, the editor experienced considerable difficulty translating my article from my computer programme to his or, as he put it, "because our 'technology' could not cope." As a result, several small but not insignificant misprints occurred in the printed version. I take this opportunity to correct them. (See Table 1.)

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21 February 2003

Footnotes to my response:

[1] Kranjc, Andrej, Snoj, Marko and Pleterski, Andrej, 2001. Kako so pred tisočletji Dravidi in »Praslovenci« živeli skupaj v jamah na Krasu in gojili teran ter še o marsičem drugem. *Acta Carsologica*, Vol.31(3), 185.

[2] Valvasor, J W, 1689. *Die Ehre des Hertzgothums Crain*. Laybach. Cit. in: Gams, Ivan (Ed.), Habe, France, Leben, Aci, Novak, Du·an, Osole, France and Šušteršič, France, 1973. *Slovenska kraška terminologija - Slovene Karst terminology*. Ljubljana: Zveza geografskich institucij Jugoslavije, 46, 48.

[3] *Življenje svetnikov. Drugi del: April, maj, junij*. Compiled by Družba sv. Mohorja v Celju. Celje: Mohorjeva tiskarna, 1929, 362-365.

[4] *The Lifco Tamil-Tamil-English Dictionary*. 1978. Tirucci: Ti Viddil Plavar Kambeni, 109.

[5] See: Hromnik, Cyril, Andrew, 1998. *Sloveni a Slovensko: Velebníci Vlasatého Boha na Horizonte Histórie (ca. 3200 pr. Kr. – 907 po Kr.)*. MS 2000, unfortunately, still in a computer-script.

THESIS ABSTRACT

David A. Gibson , 2003

Channel Characterisation and System Design for Sub-Surface Communications

PhD Thesis, Institute of Integrated Information Systems,
School of Electronic & Electrical Engineering, University of Leeds,
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Sub-surface or through-the-earth communication using electromagnetic fields - and specifically magnetic induction equipment - plays a key role in search and rescue systems used in the mining industry and, increasingly, by cavers and potholers. Similar equipment is used for radio-location, sub-surface surveying and geophysical measurements.

The use of fast desktop computers allows a mathematical model of the propagation to be investigated in detail, demonstrating the preferred orientation of the antennas and the existence of an optimum frequency that is dependent on depth and other parameters. Computer simulations demonstrate a reduction in accuracy of radiolocation at skin depth distances, and methods of correcting this inaccuracy are introduced.

The transmitter and receiver antennas for portable induction loop systems are usually air-cored loops or magnetic-cored solenoids, tuned to resonance. However, the preferred antenna often depends on the intended use of the communication system, with untuned antennas having an advantage in some situations. The use of toroid (anapole) structures and rotating magnets as transmitters is discussed briefly. A figure of merit - the specific aperture - is introduced as an aid to antenna design.

Internal (amplifier) noise can be reduced by noise-matching, although special account has to be taken of the inductive antenna. Internal noise is often swamped by external (atmospheric) noise, for which several mitigation strategies are discussed. Differing up-link and down-link noise performance may dictate different antennas. External noise is frequently characterised by the atmospheric noise temperature ratio, but data derived using the standard electric field antenna cannot be applied to a study of magnetic noise.

The design of a wide-band low-frequency channel sounder is described, with which it is intended to perform a detailed channel evaluation using a binary sounding sequence. A simple method of calculating the inverse of such a sequence is introduced, for which cross-correlation with the inverse sequence at the receiver results in a system identification signal that is used to maintain synchronism with the transmitter. The extreme wideband nature of the system results in a low efficiency, which is countered by using signal-averaging techniques at the receiver. Preliminary results are reported, in which the sounder was used to capture background noise.

Keywords: atmospheric noise, cave radio, channel sounding, electromagnetic theory, inverse sequence, mine rescue, noise-matching, noise temperature, propagation, radiolocation, sequence design, specific aperture, sub-surface communication.

Yongli Gao, 2002

Karst feature distribution in southeastern Minnesota:

Extending GIS-based database for spatial analysis and resource management.

PhD dissertation, University of Minnesota, USA.

The karst lands of southeastern Minnesota present ongoing challenges to environmental planners and researchers and have been the focus of a series of research projects and studies by researchers for over 30 years. As GIS, GPS, and web tools became more accessible to resource managers in the 1990s, the need for a statewide, web-accessible, and GIS-compatible karst feature inventory and database has become increasingly evident. A GIS-based database management system was developed to manage and analyze karst feature inventories at both county and statewide scales.

The conceptual model of the karst feature database includes three interactive modules: spatial operation, spatial analysis, and hydrogeological modules. All three modules manipulate data from the central database, verify and update attribute values of karst feature data, and put some of the results back to the database. A working database is developed to include many mapped karst features in Minnesota. Standardized metadata and management tools were developed for this database that will be beneficial for management and future study of karst features in Minnesota.

Nearest neighbour analysis was extended to include different orders of nearest neighbour analysis, different scales of concentrated zones of sinkholes, and directions to nearest sinkholes. The statistical results, along with the sinkhole density distribution, indicate that sinkholes tend to form in highly concentrated zones instead of as scattered individuals. The pattern changes from clustered to random to regular as the scale of the analysis decreases from 10 – 100km^2 to 5 – 30km^2 to 2 – 10km^2. Hypotheses that may explain this phenomenon are: 1) areas in the highly concentrated zones of sinkholes have similar geologic and topographical settings that favor sinkhole formation; 2) existing sinkholes change the hydraulic gradient in the surrounding area and increase the dissolution and erosional processes that eventually form more new sinkholes.

Decision-tree and cartographic models were developed to create sinkhole probability maps in southeastern Minnesota. The decision-tree model is implemented in GIS to create a preliminary sinkhole probability map in Goodhue, Wabasha, Olmsted, Fillmore, and Mower counties.

Claire Hunter, April 2003

Electrical imaging and characterisation of gypsum dissolution related depressions at High Common Farm, Ripon, North Yorkshire.

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The aims of this project were to image and characterise topographic depressions at High Common Farm, Ripon, North Yorkshire [430800 472800]. The outcome of the project was an overview of the history of subsidence and the likelihood of future subsidence. Electromagnetic and electrical resistivity tomography surveys were conducted to determine these outcomes.

The field site has been active before and after the last glaciation and is currently in an active period of subsidence. Subsidence is occurring due to the dissolution of gypsum by groundwater and subsequent collapse into caves and cavities left in the gypsiferous layers.

Future subsidence at the field site is certain, particularly in the main survey field in a band of rocks with conductivity 16-26 mS/m that stretches from the southeast to the northwest. This area contains all of the major depressions and is likely to represent a system of caves in the gypsum layer 5m below the surface, with a diameter of 8m and extending to a depth exceeding 15m.

In addition, glacial infill of pre-glacial depressions was mapped in a number of locations, predominantly in the west survey field. This confirms the field was active before the last glaciation.

REVIEW

U.S. Geological Survey Karst Interest Group Proceedings, Shepherdstown, West Virginia
August 20-22, 2002

Eve L. Kuniansky (editor)
U.S. Geological Survey - Water-Resources Investigations Report 02-4174, Atlanta, Georgia, August 2002.

The Karst Interest Group (KIG) was formed in 2000 as the result of the November 1999 National Groundwater Meeting of the U.S. Geological Survey, Water Resources Division. The purpose of the KIG is to "bring together U.S. Geological Survey scientists with other Department of Interior scientists, land managers and University researchers interested in karst hydrology."

Representatives from several federal and state agencies participated in the workshop last August and included the U.S.G.S., National Park Service, U.S. Environmental Protection Agency, Western Kentucky University, Karst Dynamics Laboratory, New Jersey Geological Survey, Maryland Geological Survey, and the Northwest Florida Water Management District. Sixteen contributions are included in the proceedings volume along with a fieldtrip guide that contains stop descriptions of several karst features in the northern Shenandoah Valley of West Virginia and Virginia.

Beck discussed obscure or gray area publications and the need to conduct thorough research of gray areas to avoid rework in ones own research. Bailey presented a progress report of the first two years of the National Cave and Karst Research Institute. Kerbo discussed the National Parks Service role in management of cave and karst resources.

To gain greater insight of the interactions between surface water and the Upper Floridan aquifer, Katz used naturally occurring isotope and chemical tracers to develop groundwater and geochemical models. Field summarized the Efficient Hydrological Tracer Test Design (EHTD) methodology. This method could be used to predict toxic substance arrival times in drinking water supplies in response to terrorist attacks. Mathes, Stoeckel, and Hyer of the USGS provided an update regarding the tracking of bacteria in groundwater in the karst areas of Berkeley County, West Virginia.

Through the use of continuous hydrochemical and flow data, Groves et al. reported on investigations being conducted in the Mineral King valley of California and Guilin, China to quantitatively evaluate the magnitude and rate of changes of carbonate chemistry from limestone/dolomite karst flow systems under a variety of climatic conditions. Their mission is to improve understanding of the association between atmospheric carbon dioxide and dissolved aqueous carbon as the result of carbonate dissolution with a global monitoring network.

Kozar presented a summary of investigations conducted by the U.S. Geological Survey in the karst of Berkeley and Jefferson Counties in West Virginia. An update was provided on the National Karst Map Project. Epstein et al. They stated that "the resultant goal is for the U.S.G.S to produce a national karst map in digital form, derived primarily from maps prepared by the individual states, and to link that map on a web based network to State and local scale maps and related data."

Harrison, Newell, and Necdet reported on karst processes acting along an active fault in Cyprus. A three dimensional geologic model was developed by Murray and Hudson for a karst region along the Buffalo National River in northern Arkansas. The model was developed to help protect the water quality in the Buffalo River hydrologic system. Brezinski and Reger presented preliminary findings of a study conducted in the karst of Frederick Valley in Maryland. The scope was to determine the relative susceptibility of rock units to karst feature distribution.

Long and Putnam presented the results of an approximate 6-year study along a losing segment of Spring Creek near the Black Hills of South Dakota. Results demonstrated a hydraulic connection between the sinking stream segment and a nearby well through the use of stable isotope sampling and linear systems analysis. Katz, Chelette, and Pratt quantified the surface/groundwater mix at Wakulla Springs and River Sink in the Woodville Plain of Florida. In the karst of northern Utah, Spangler provided convincing evidence that dye tracing continued to be the most effective tool to define source protection areas for springs and wells.

Copies of the 2002 Proceedings volume can be obtained online at http://water.usgs.gov/ogw/karst/kig2002/. Additionally, the 2001 Proceedings can be obtained online at http://water.usgs.gov/ogw/karst/kigconference/proceedings.htm

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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. A total of £2000 per year is currently 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 that 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 that 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 for Research Awards are available from the Research Fund Administrator (address at foot of page or e-mail research-fund@bcra.org.uk).

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 pure exploration in remote or little known areas. Application forms are available from the GPF Secretary, David Judson, Hurst Barn, Castlemorton, Malvern, Worcestershire, WR13 6LS, e-mail: d.judson@bcra.org.uk. Closing dates for applications are: 31August and 31 January.

The E K Tratman Award

An annual award is 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 (see above for contact details), not later than 31 January each year.

BRITISH CAVE RESEARCH ASSOCIATION PUBLICATIONS

Cave and Karst Science – published three times annually, a scientific journal comprising original research papers, reports, 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, Nottingham, NG12 5GG, UK, (e-mail d.lowe@bcra.org.uk) and Professor J Gunn, Limestone Research Group, University of Huddersfield, Queensgate, Huddersfield, HDI 3DH, UK (e-mail j.gunn@bcra.org.uk).

Speleology - published three times annually and replacing BCRA's bulletin *'Caves & Caving'*. A magazine promoting the scientific study of caves, caving technology, and the activity of cave exploration. The magazine also acts as a forum for BCRA's special interest groups and includes book reviews and reports of caving events.
Editor: David Gibson, 12 Well house Drive, Leeds, LS8 4BX, (e-mail: speleology@bcra.org.uk).

Cave Studies Series - occasional series of booklets on various speleological or karst subjects.

No. 1 *Caves and Karst of the Yorkshire Dales*; by Tony Waltham and Martin Davies, 1987. Reprinted 1991.
No. 3 *Caves and 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. 7 *Caves and Karst of the Brecon Beacons National Park*; by Mike Simms, 1998.
No. 8 *Walks around the Caves and Karst of the Mendip Hills*; by Andy Farrant, 1999.
No. 9 *Sediments in Caves*; by Trevor Ford, 2001
No. 10 *Dictionary of Karst and Caves*; by D J Lowe and A C Waltham, 2002.
No. 11 *Cave Surveying*; by A J Day, 2002.

Speleohistory Series – an occasional series.

No.1 The Ease Gill System – Forty Years of Exploration; by Jim Eyre, 1989.

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 organizes field meetings. Occasional publications include a Bibliography and Guide to Regulations, etc.

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

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 organizes seminars and field meetings.

Copies of BCRA Publications are obtainable from: Ernie Shield, Publication Sales, Village Farm, Great Thirkleby, Thirsk, North Yorkshire, Y07 2AT, UK.

BCRA Research Fund application forms and information about BCRA Special Interest Groups can be obtained from the BCRA Honorary Secretary: John Wilcock, 22 Kingsley Close, Stafford, STI7 9BT, UK.