Cave and Karst Science

The Transactions of the British Cave Research Association

BCRA

Volume 27 Number 1 April 2000

Vein cavities and early cave evolution, Derbyshire, UK
Anomalous scallop distributions, Yorkshire, UK
The age of the Dream Cave Woolly Rhino
Kent's Cavern in the 18th Century
Forum

Cave and Karst Science

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

1. 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.

2. Reports
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 appropriate expert assessment 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.

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

Manuscripts may be sent to either of the Editors: Dr D J Lowe, British Geological Survey, Keyworth, Nottingham, NG12 5GG, UK, and Professor J Gunn, Limestone Research Group, Department of Geographical and Environmental Sciences, The University of Huddersfield, Queensgate, Huddersfield, HD1 3DH, UK. Intending authors are welcome to contact the Editors, who will be pleased to advise on manuscript preparation. Enquiries by E-mail are welcomed, to: djlo@bgs.ac.uk or j.gunn@hud.ac.uk.

Notes for Contributors

These notes are intended to help authors prepare their material in the most advantageous way, so as to expedite publication and reduce both their own and editorial labour. Time and effort are saved if the rules below are followed.

Text: All material should be presented in a format as close as possible to that adopted by *Cave and Karst Science* since 1994. Text should be typed double-spaced on one side of the paper only. Subheadings within an article should follow the system used in *Cave and Karst Science*; a system of primary, secondary and, if necessary, tertiary subheadings should be indicated clearly. Initial manuscripts may be supplied as hard copy, as a suitably formatted text file on computer disk, or as an E-mail attachment (addresses above) in appropriate format. Where possible the final revised text should be submitted on computer disk or as an E-mail attachment, although paper copy remains acceptable. It is recommended that, where text includes unusual characters or equations, a hard copy highlighting non-standard features be provided as a guide for the Editors. Most modern PC-based word processing packages can be translated but, if in doubt, please consult one of the Editors. Apple Mac disks are accepted, but cannot be dealt with routinely and may cause delays.

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

References to previously published work should be given in the standard format used in *Cave and Karst Science*. In the text the statement referred to should be followed by the relevant author's name and date (and page number, if appropriate) in brackets. Thus: (Smith, 1969, p.42). All such references cited in the text should be given in full, in alphabetical order, at the end. Thus: Smith, D E, 1969. The speleogenesis of the Cavern Hole. *Bulletin of the Yorkshire Caving Association*, Vol.7, 1-63. Books should be cited by their author, date, title, publisher and where published. As there is no readily available listing of abbreviated titles, and as references to publications in languages other than English are becoming more common, periodical titles should be written in full. Failure to provide full and unambiguous reference information may lead to a delay in publication.

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

Figures: Illustrations in a number of digital graphics file formats are acceptable for eventual publication. However, as changes to figures may be requested by referees, recommended practice is to provide hard copies with the initial submission and reference hard copies and digital files with the final draft. Authors should contact the Editors to check both the desirability of this approach and suitable file formats before submitting the manuscript. Traditional hard copy line diagrams and drawings must be in black ink on either clean white paper or card, or on tracing paper or such materials as Kodatrace. Anaemic grey ink and pencil will not reproduce! Illustrations should be designed to make maximum use of page space. Maps must have bar scales only. If photo-reduction is contemplated, all letters and lines must be large and thick enough to allow for their reduction. Letters must be done by stencil, Letraset or similar methods, not hand-written. Diagrams should be numbered in sequences as figures, and referred to in the text, where necessary, by inserting (Fig.1) etc. in brackets. A full list of figure captions should be submitted on a separate sheet or on a new page following a hard page break in digital files.

Photographic plates are welcome. Photographs in various digital formats can be handled but, as only a selection of illustrations provided with a manuscript may be included in the final publication, recommended practice is to provide hard copies with the initial submission and reference hard copies and digital files with the final draft. Authors should contact the Editors to check both the desirability of this approach and suitable file formats before submitting the manuscript. Traditional hard copy photographs are equally acceptable and may be good clear black and white prints, colour prints or colour transparencies with sharp focus and not too much contrast. Prints about 15 x 10cm (6 x 4 inches) are best; if in doubt, a selection may be submitted. They should be numbered in sequence but not referred to in the text, except where essential and then only after discussion with one of the Editors. A full list of plate captions, with photographer credits where relevant, should be submitted on a separate sheet or on a new page following a hard page break in digital files.

Tables: These should not be included in the text but should be typed, or clearly hand-written, on separate sheets or on a new page following a hard page break in digital files. All tables, especially those provided in digital form, should use a simple format to allow ready translation into an appropriate publication style. They should be numbered in sequence, and a list of captions, if necessary, should be submitted on a separate sheet or on a new page following a hard page break in digital files. Authors may mark approximate locations for tables, plates and figures, in pencil in the manuscript margins, as a guide to formatting for publication.

Copyright: It is the author's responsibility to obtain written permission where necessary to reproduce all material submitted for publication. Copyright on articles published in *Cave and Karst Science* rests with the British Cave Research Association.

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

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

If any problems are perceived regarding the nature, content or format of the material, please consult either of the Editors before submitting the manuscript.

Cave and Karst Science

TRANSACTIONS OF THE BRITISH CAVE RESEARCH ASSOCIATION

Volume 27 Number 1 April 2000

Contents

Cover photo:
Titan : Peak-Speedwell cave system, Castleton, Derbyshire, UK.
This huge vein cavity is over 150m high, with a free-hanging drop of 142m from its highest point (see survey in *Caves and Caving* 85, 1999) making it by far Britain's largest natural shaft. At the top of the cavity the east-west extent is some 90 to 100m and the north-south width is some 15 to 20m. The vein cavity has developed along a minor northwest-southeast vein (see paper by Trevor Ford in this issue). Photo by Paul Deakin, FRPS.

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

Cave and Karst Science is published three times a year by the BCRA and is issued free to all paid up members of the Association.
The 2000 subscription rates to *Cave and Karst Science* are £16.00 (UK) and £18.00 (overseas) per annum (postage paid).
Details of Association membership and of annual subscriptions can be obtained from the BCRA Membership Secretary, Lynne Bailey, British Cave Research Association, Hafod Swn-Y-Dwr, The Dardy, Crickhowell, Powys, NP8 1PU, UK (email address: membership@bcra.org.uk). The Association's Registered Office address is: BCRA, The Old Methodist Chapel, Great Hucklow, BUXTON, Derbyshire, SK17 8RG, UK. (E-mail address: enquiries@bcra.org.uk).
Individual copies and back issues of *Cave and Karst Science* can be obtained from BCRA Publication Sales, at the address shown at the foot of the inner back cover.

ISSN 1356-191X

EDITORIAL

John Gunn and Dave Lowe

Since the mid – 1990s there has been a spectacular increase in the amount of information accessible via the World Wide Web, and the amount of material being added year on year seems set to continue to increase. Anyone entering the word 'cave' as a keyword on a Web search engine is likely to be overwhelmed by the number of hits. Even the word 'karst' now features in many sites, not all of which necessarily have anything to do with the subject as we know it! Caving organizations [like the BCRA], individual caving clubs, show cave operators, research groups, academic establishments (of various kinds) and different types of karst-related commercial consultancies all have their own web sites, containing variable quantities and qualities of material.

Whether this huge volume of information has actually resulted in the generation or dissemination of any <u>new</u> knowledge, and specifically whether our understanding of cave and karst science has advanced as a result, is open to debate. Indeed, we would welcome an <u>analysis</u> (as opposed to a listing/description) of web sites on cave and karst science and the type of information that they contain.

One important point to note when visiting web sites is that the vast majority of the material presented has not been subjected to any kind of independent review process. The main exception is material that has previously been published but then also made available electronically. The abstracts of papers published in *Cave and Karst Science* fall into this category, and we would like to take this opportunity to re-emphasise the importance of the persons who have helped us to maintain the quality of our journal by acting as reviewers of submitted manuscripts. Though we continue to review a small proportion of the manuscripts submitted to *Cave and Karst Science* ourselves, we could not possibly maintain standards without the freely-given assistance of many experts throughout the world. The following, some of whom provided comments on early drafts submitted several years ago, are thanked for reviewing the papers that appeared in Volume 26:

Tim Atkinson	Alexander Klimchouk
Simon Bottrell	Stein-Erik Lauritzen
Mike Edmunds	Martyn Pedley
Trevor Faulkner	Peter Rowe
Trevor Ford	Tony Waltham
David Gillieson	Chas Yonge

Many others have expressed a willingness to act as a *Cave and Karst Science* referee, and we also thank these individuals, and reassure them that they will be called into action when appropriate manuscripts are received.

Whereas it is not uncommon for authors and reviewers to disagree over particular points of interpretation and presentation, the vast majority of authors find that their paper is improved by the reviewing process. In this context, it is always gratifying when a "thank you" to the reviewer(s) appears within the Acknowledgements section of a revised manuscript. Moreover, the fact that a paper has been subject to independent review provides a good indication (although by no means a guarantee) that the factual information therein is likely to be accurate. This is an important point, because most of those who are involved in education will be aware of the ability of some students to accept any published information blindly, particularly information that is available on the World Wide Web. When visiting show caves across the world we have found a significant number that claim to be the biggest, longest, deepest or, quite simply, the best in the area, region, country – or even the world! In the past such claims would largely have been unnoticed by anyone other than the knowledgeable visitor; now they may be seen, and quoted as established fact, in undergraduate essays. Clearly it is incumbent upon those of us that are educators to engender a healthy degree of caution and scepticism in our students, but it is also important to be able to guide them to material that has already been subjected to peer review.

An additional, external, aspect relating to peer review of scientific papers is important to the authors themselves, particularly those authors who work in academic or research situations. Publication records are considered an important indicator of individual and corporate performance, by job interview boards, promotion panels, review groups and grant awarding bodies. Publications in peer-reviewed periodicals carry more weight than those that appear without review and, inevitably, even among the peer-reviewed journals, there is a semi-official scale of worthiness. In a world where new and ever more specialised scientific journals are born every week, in judging the "worthiness" of publications some organisations now rely upon the information provided by international bibliographic services such as "Ulrichs" (http://www.bowker.com/ulrichs/), which list scholarly periodicals, and give information about them, including whether or not their contents are peer reviewed. Such is the pressure on academics and other scientists to publish in journals that are listed as being peer-reviewed, that more and more authors will not even consider submitting papers to other possible outlets. It is therefore important that a journal such as *Cave and Karst Science* not only <u>is</u> peer reviewed, but is seen to be, and listed as being, peer reviewed.

As we have pointed out in the past, this leaves us in a slightly uncomfortable position, because we are committed not only to providing a high quality publication conduit for established cave and karst scientists, but also to encouraging publication by less experienced or more reticent authors. Our approach to achieving this desirable balance is relatively flexible and hinges largely upon the distinction within the journal between "Paper" and "Report" publications. In terms of subject matter and authorship there is no hard and fast line between the two. Some high quality papers have been produced by new authors whereas some submissions from well-known and experienced authors are treated as reports, and hopefully not belittled by this functional label. Our flexibility of approach lies in deciding the degree of review that is appropriate for a given manuscript. On consideration of the subject matter, the level of the treatment and our own understanding of the subject matter, we decide whether to seek review by one or two referees or whether, in the case of some reports and relatively few papers, we should carry out the review ourselves. On rare occasions this latter approach may backfire if we fail to recognise the need for expert advice on some aspect within a manuscript. In general, however, it has the great benefit of speeding up feedback and publication for authors who might otherwise be discouraged if their submission is delayed by external reviewing. It is inevitable that from time to time we will be criticised for the approach in general or for a specific case of a published Report that may appear to some to be "sub-standard". Considering the commitment mentioned at the start of this paragraph, we judge that we must be prepared to accept and, if necessary, respond to such criticism, rather than adopting a more stringent approach to the review of reports.

Moving away from the specifics of our own publication policies and returning to the question of those whose efforts have helped to maintain the standards of *Cave and Karst Science* during the past year or so, we must again make two acknowledgements in addition to thanking the reviewers mentioned above. First of all our thanks go yet again to Jean Reeve, whose desk top publishing work continues to produce output of a very high standard, despite ever greater demands from the Editors. Secondly, once again, we thank our printers, the Sherwood Press, both for the continuing high quality of their production and for their patience and flexibility in meeting our varying requirements and sometimes-erratic publication schedule.

CAVE AND KARST SCIENCE Vol. 27, No. 1, April 2000
Transactions of the British Cave Research Association

ISSN 1356-191X

Vein cavities: an early stage in the evolution of the Castleton Caves, Derbyshire, UK

Trevor D FORD
Geology Department, University of Leicester, Leicester, LE1 7RH, UK

Abstract: Recent discoveries have revealed an increasing number of large, commonly isolated, phreatic dissolution cavities in mineral veins, faults and fractures around Castleton, Derbyshire. They are suggested to be significant as an early phreatic phase of the development of the Castleton karst, having providing inception routes for movement of water through the limestone massif, thereby stimulating later phreatic and vadose development of caves along the bedding in the adjacent Carboniferous Limestone.

(Received 28 April 1999; Accepted 12 April 2000)

INTRODUCTION

Some 20 years ago attention was drawn to the significance of large caverns in mineral veins as a feature of the cave systems at Castleton in North Derbyshire, UK (Ford and Worley, 1977). This paper examines the subject in greater detail in the light of recent discoveries of more such vein cavities.

The cave systems of this northern part of the Carboniferous Limestone outcrop of the Peak District transect a gently inclined limestone massif (Figs. 1 and 2), with swallets bringing allogenic water in from Rushup Edge on the northwest, and resurgences discharging water in Castleton village some 5km to the east and 200m lower in altitude. Both input and output areas of the cave drainage system are on shales and sandstones of the Millstone Grit Group of late Carboniferous age. In mid-Carboniferous times a change from limestone formation to deltaic sand and mud sedimentation is marked by an unconformity with evidence of a palaeokarstic phase (Ford, 1984), in the form of an uneven eroded limestone surface and small caves. After burial beneath the Upper Carboniferous clastic sediments the palaeokarst was exploited by hydrothermal fluids and infilled by mineral deposits, mostly in late Carboniferous times (Ford, 1995).

Much of the Castleton cave system is a dendritic pattern of phreatic tubes with vadose trenches, generally in the uppermost 200m of the limestone beds. Some of the guiding bedding planes are characterised by thin tuff layers and there are basaltic lava horizons in part of the area. No effective base to the limestone in the Castleton area is known, as the pre-Carboniferous basement is deeply buried and was penetrated by a borehole over 1600m deep at Eyam some 10km to the southeast.

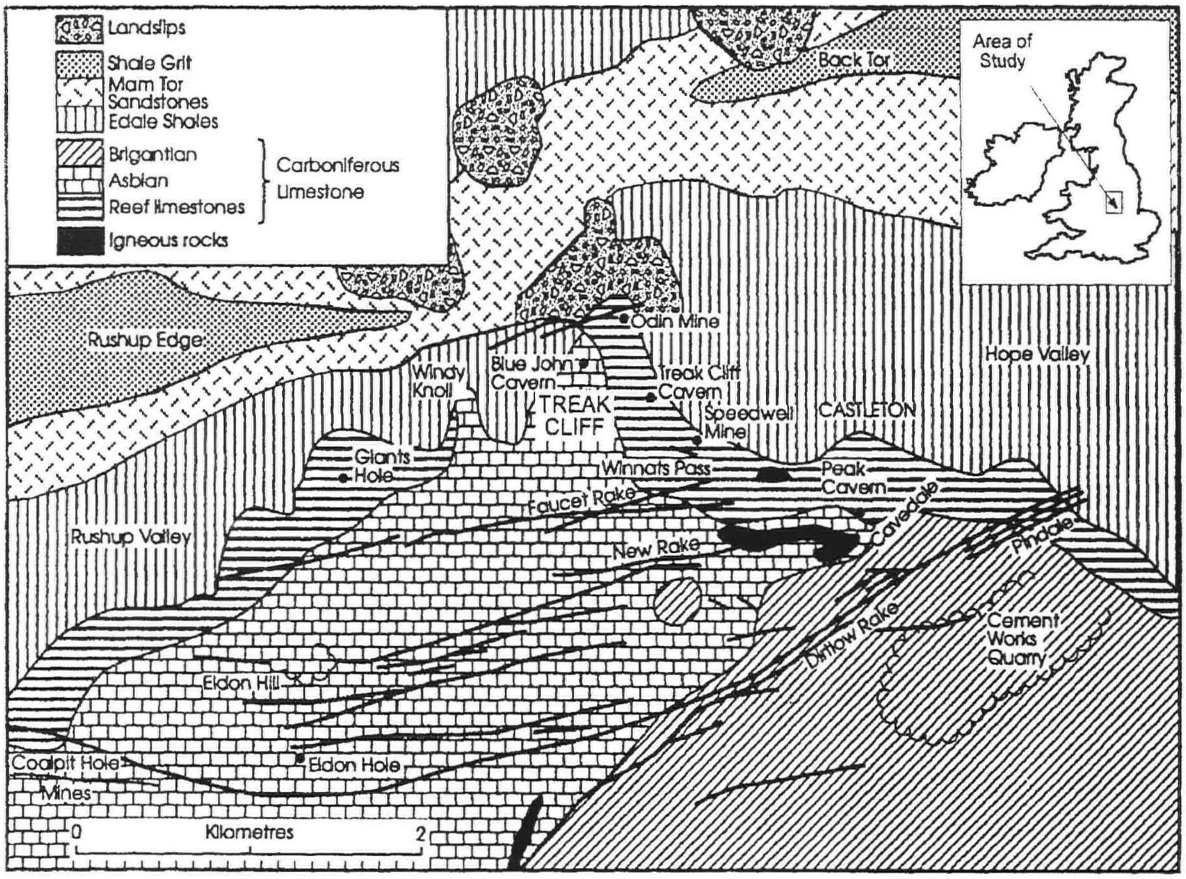


Figure 1. Sketch map of the geology of the Castleton area. The inset shows its position in the centre of Britain.

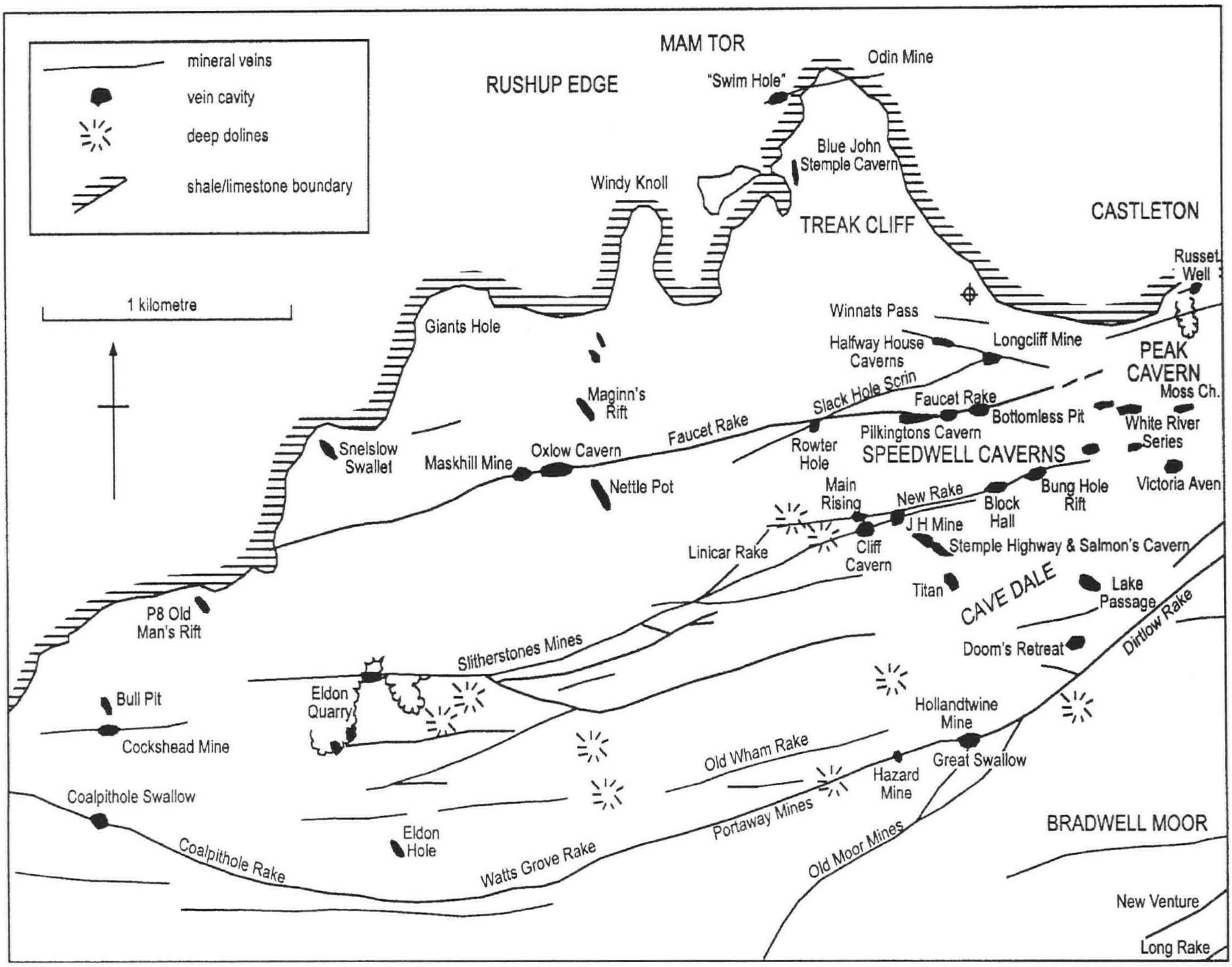


Figure 2. Sketch map of the known or probable vein cavities in relation to the mineral veins near Castleton, Derbyshire.

None of the cave systems can be followed from sink to resurgence, as in their central parts the streams disappear into deep sumps and rise again from others, commonly more than a kilometre away. The sumps are still active, and divers have explored to depths exceeding 60m. They are mostly aligned along mineral veins.

Many isolated tall phreatic caverns have been entered from the stream caves and in their brief note Ford and Worley (1977) claimed that these represented an early phase in the speleogenetic history (Ford, 1977 and 1986). Some are also of hydrological significance today (Gunn, 1985 and 1991). A review of the state of knowledge of the Peak-Speedwell cave system (Marsden, 1991) again briefly mentioned the vein cavities but did not discuss their part in the evolutionary story. It is possible that they could now be regarded as having developed from vertically-oriented inception routes.

Since the above studies several more vein cavities have been found (see many issues of *Caves and Caving* from 1991 to the present) and it seems timely to re-assess their speleogenetic significance.

VEIN AND FAULT CAVITIES

The vein cavities may be defined as generally large, more or less vertical, irregular in profile and cross-section, phreatic caverns developed along mineral veins, faults or other fractures.

There seem to be two categories of vein cavities – those clearly developed along mineral veins, and those on fractures apparently with little or no mineralisation. The former are mostly elongated in the west-east trend of the major veins, whereas some of the latter approximate to a NW-SE trend. Some of the vein fractures are locally unmineralised, whereas a few of the faults have a modicum of mineralisation in places, so that the two categories are not completely separate.

It is clear that most of the major veins (rakes in Derbyshire lead miners' jargon) are along faults, but it is rarely possible to determine the direction or amount of movement. Horizontal slickensides indicate lateral or wrench fault movement on some veins, but in gently inclined strata such movement results in only a small element of vertical displacement, which may be determined by observing the altitude of the sporadic interbedded lavas (toadstone) or ash layers (wayboards) on opposing walls. Few of the cavities studied show any marked displacement of these volcanic horizons, an exception being the Moss Chamber to Anniversary Hall section of Peak Cavern aligned along a fault with no surface expression. Minor veins (scrins, locally) commonly branch out of rakes at angles of about 30 to 45°, and their mineral content is locally reduced, to yield only a fracture with a mineral veneer on its walls. Little or no fault displacement can be detected.

Veins and faults are generally vertical or nearly so. They commonly have a slight degree of sinuosity along their length so that when wrench faulting took place, convexities in one wall could be brought in opposition to convexities on the other. Similarly, concavities may be brought into opposition. The overall effect is that veins pinch and swell along their length, and the swells were the main recipients of mineral deposition. The pinches are where mineralisation is restricted to a thin leader at best. Fault breccias are rare, though some pairs of opposing walls show intense fracturing. The mineral contents of the rakes were commonly brecciated owing to repeated movements during and after mineral deposition. Where mineral veins have been worked by opencast methods in recent years, networks of mineralised joints are seen in the walls. Between the joints there are locally abundant micro-joints, forming an incipient breccia where the clasts have not moved.

Structural and mineralisation hypotheses have generally assumed that movement and mineral deposition were more or less synchronous, as shown by brecciation of some vein fillings and by slickensided surfaces cutting through them. However, if movement preceded mineral deposition by any appreciable length of time, it would be possible for some vein cavities to have formed along fractures only to be filled or lined with mineral later. This latter relationship has not been observed during mining activities.

Some but not all vein cavities show considerable enlargement immediately below a lava or wayboard. Such volcanic horizons commonly contain dispersed pyrite, and oxidation may result in the generation of sulphuric acid. This may have caused some enlargement by meteoric dissolution but the pyrite quantities are too small to be a major genetic factor in a deep phreatic environment

The guiding factors that might lead to potential speleogenesis in the veins are (1) mineralisation generally did not fill the vein fractures, leaving randomly oriented series of crystal-lined cavities in the middle, particularly in the wider stretches; (2) the presence of mid-Carboniferous palaeokarstic features, some with mineral linings or infillings; (3) mineralised breccia with small voids between clasts in intersections of rakes with scrins; (4) localised fractured or crushed wall-rock zones; (5) systems of micro-joints; (6) zones of partial replacement of wall-rock by mineral deposits. In short, any major or minor vein or fault can have irregular zones of permeability anywhere along its length and at any depth. Unfortunately, speleogenetic development of a vein cavity means that the evidence of the guiding factors is largely removed. The cavities are, however, quite localised suggesting that a critical reaction to the factors concerned is necessary to produce the isolated caverns.

EXAMPLES OF VEIN AND FAULT CAVITIES

The following catalogue lists all of the possible vein cavities discovered to date. A few fall only marginally within the definition, and a few have been mined out to the extent that a clear assignation is not possible. The distribution is shown in Fig.2.

Coalpithole Mine

In the lowest level the water drains into an underground swallow at a little over 250m O.D. whence it flows by an unknown course to the Main Rising of Speedwell Cavern at the same altitude (see Main Rising entry below). How much of the stope immediately preceding the swallow was a natural cavern does not seem to have been recorded on any of the rare visits. Much of the 4km course between Coalpithole and Speedwell is likely to be in a series of vein cavities along the Coalpithole and New Rakes, with a cross-over between these two somewhere south or east of Eldon Hill.

Cockshead Mine

A series of stopes and caverns in a minor E-W rake descend to a depth of 50m. Details of how much is natural cavern were not recorded.

Plate 1. Eldon Hole, developed along a northwest to southeast fracture.

Jackpot (P8)

The largest chamber in the cave is the NW-SE Old Man's Rift. In spite of its name there is little evidence of the former presence of the lead miners (locally referred to as "The Old Man") and there is little sign of mineralisation. It appears to have been an early part of the speleogenesis, now used by the vadose swallet stream in its approach to the first downstream sump.

Bull Pit

This is a wide-open pothole some 30m deep, apparently the result of the collapse of a cavern beneath. It may be on a NW-SE vein though no mineralisation is visible today. No underground access is possible.

Eldon Quarry fissures

These are narrow phreatic passages, some up to 10m high, apparently aligned along north-south joints. They are filled with fluvioglacial sediments for which radiometric and palaeomagnetic dates of around 900,000 years have been obtained (Andy Farrant, British Geological Survey, pers. comm.). Their phreatic features and early Pleistocene date suggest that they may be related to the vein cavities, but a full description is still awaited.

Eldon Hole

Derbyshire's only open pothole has a NNW-SSE trend. There is some evidence of fractured limestone at each end but little sign of mineralisation. A low passage links to a second large chamber of phreatic origin with its long axis parallel to and east of the entry pot.

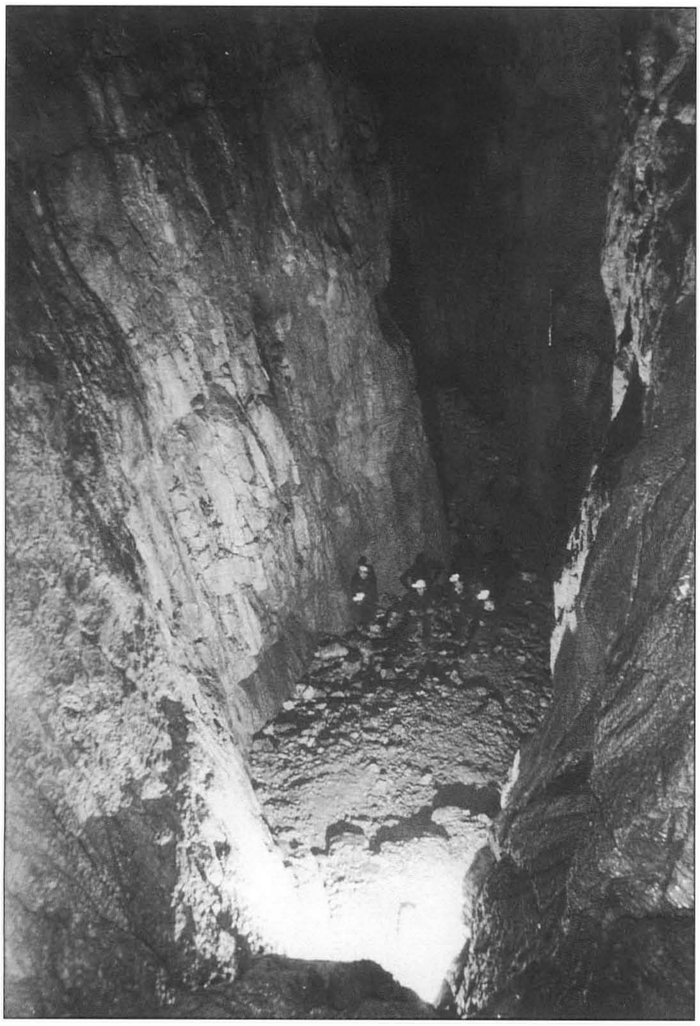


Plate 2. A typical vein cavity – Oxlow caverns West Ante-Chamber (photo by Tony Waltham).

Any mineralisation is concealed by sheets of flowstone. Historical accounts suggest that a further chamber with a stream at the bottom lies hidden beneath the boulder floor. The final depth is around 82m. The small amounts of percolating water go to Speedwell Cavern's Main Rising.

Giants Hole

This has several large rift chambers, notably Maginn's Rift and the East Canals. Maginn's Rift is well above today's water-table, with only minor joint guidance of passage direction. The East Canal is a deep phreatic cavity in a major ENE-WSW fracture. It extends deep below the water-table and takes Giants Hole drainage to Speedwell Cavern. The two cavities are in NW-SE faults, with minimal mineralisation, and each is around 30m high. The Filthy Five Pitches are along a NNW-SSE trending joint-scrin and the last part of the streamway follows the same joint set. A "rift cavern" in the entrance series appears to be along a weakly mineralised fracture. The meandering vadose trench of the Crab Walk has traces of mineralisation on an orthogonal joint set guiding its many bends. With both vein cavities and vadose trenches Giants Hole is today an important part of the underground drainage system. The water resurges in Speedwell Cavern at either or both of Main or Whirlpool risings, according to the amount of run-off and the effects of flow-switching.

Oxlow Caverns and Maskhill Mine

These associated systems are elongated along the western continuation of Faucet Rake. Whereas they are linked underground by a series of high and narrow phreatic vein cavities, their only surface expression is lead miners' shafts, leading one to wonder if the shaft sinkers had a nasty surprise when they broke through! Oxlow's East Chamber is about 40m high, with boulders concealing the floor. The West Chamber is much higher, with a series of irregular avens rising nearly 100m. Again the rock floor is concealed by boulders and miners' debris. In places the roofs rise to within about 20m of the surface, so that further erosion in the future may yield open potholes. The final depth to Pool Chamber is nearly 160m. Maskhill Mine to the west has a mine shaft opening into a series of vein chambers almost one above the other, finally entering the roof of the Far West Chamber. There is a small bedding tube inlet at floor level in Oxlow's West Chamber and an abandoned link to Giants Hole through a low phreatic tube at a slightly higher level; in turn this has a branch into a vein cavity with a sump in North Chamber. The drainage seeps away from Pool Chamber and goes to the Main and Whirlpool Risings in Speedwell Cavern.

Nettle Pot

This is aligned NW-SE along a fracture where little or no mineralisation or fault displacement can be found. The entry pothole is a narrow slot widening to an almost circular pot lower down. Below a metre-thick wayboard (the Cavedale Lava?), Nettle Pot opens out into two large elongate cavities about 50m deep, extending to a final depth of 158m. There is much broken and loose rock at each end of these lower cavities, suggestive of either fault breccia or collapse: fallen blocks litter the floor. The drainage goes to Main Rising.

Mountbatten Pot

Close to Nettle Pot, and apparently similar, but it has been dug out only to a depth of about 50m.

The Blue John Caverns

These are mostly vadose passages, but Stemple Cavern appears to be an early phreatic vein cavity, aligned north-south with minimal mineralisation.

Odin Mine

Extending 1.5km west-east beneath the shales on the south flank of Mam Tor, this includes the **Swim Hole,** *"...a self-open from which at a flood cometh a great quantity of water...",* according to an 18th century mine plan. This sounds like a classic vein cavity, but it has not been seen since mining ceased in 1869.

Rowter Hole

A series of vein cavities is penetrated at the bottom of a shaft 69m deep. It lies at the junction of Faucet Rake and Slack Hole Scrin, and reaches a final depth of 82m, close to but much higher than the Whirlpool Passage in Speedwell Cavern.

Longcliff Mine

This lies on the hillside above the Speedwell Cavern. Entered via a mine shaft, it has an almost cylindrical vein cavity about 36m high at the junction of Longcliff and Slack Hole Scrins. The name of the latter suggests that the old lead miners knew of other "self-open" caverns along its length.

Speedwell Cavern

Has several vein cavities, of which the best known is the **Bottomless Pit** cavern. Lying in Faucet Rake, here comprising about 1.5m of calcite, it is about 60m high, irregular in cross-section and not quite vertical. The only apparent inlet is choked with boulders. Its roof is somewhat over 120m below the surface. At the bottom is a lake floored by boulders that conceal and partly block a drainage outlet taking water to the Russet Well resurgence in Castleton.

The Halfway House Caverns (Speedwell Cavern)

These have only recently been explored by climbing an Old Mans' raise (Marsden, 1991). An up-and-down series of phreatic chambers developed along the northwestern end of Longcliff Rake extends beneath the Winnats Pass. With a height of around 30m the roof is still some 40m below the road in the lower part of the Pass. The floor extends downwards to an unknown depth in flooded chambers at the bottom.

Pilkington's Cavern (Speedwell Cavern)

This is in a branch inlet passage part way along the Far Canal. A series of narrow rifts modified by a vadose stream and mining activity rise to a chamber where mining has taken place in Faucet Rake.

The Assault Course (Speedwell Cavern)

Another branch inlet, associated with the lowest level of Pilkington's Cavern. Crawling up a partly blocked miniature vadose passage has recently been found to lead into another vein cavity in Faucet Rake. As yet unnamed, it has been climbed to about 60m. Lying between Pilkington's Cavern and Rowter Hole, it is not far south of the Winnats Pass and appears to have once had an inlet from there, to judge from gritstone pebbles in the Assault Course streamway. As there is a good showing of lead ore, it seems unlikely that the lead miners ever entered this cavern.

Leviathan (Speedwell Cavern)

This is a vast vein cavity, first described by James Plumptree in 1793. It lies above the Boulder Piles in the Speedwell streamway, and rises 80m in New Rake, to link with caverns and stopes in James Hall's Over Engine Mine (JH Mine) at a higher level. The lead miners have mined out the vein and so partly obscured the evidence of phreatic dissolution. The roof appears to be along a wayboard with mine workings immediately above, whereas the floor is composed of wedged boulders hanging in the roof above the Boulder Piles. A short passage links the base of Leviathan to Stemple Highway in Far Peak Extension (see below).

Bathing Pool (Speedwell Cavern)

This cavern has at least 15m below water plus about 10m above. Flowstone obscures a fracture on the far wall. The nearby Secret Sump appears to be on the same fracture, though the water levels differ between the two chambers less than 10m apart. No vein has been detected below water in either Bathing Pool or Secret Sump.

Cliff Cavern (Speedwell Cavern)

At the far western end of Speedwell Cavern is a high aven in a fracture with minimal mineralisation. Some 50m high, the top of Cliff Cavern expands into two high rift passages, Cliffhanger and Joint Effort, along a roughly west-east fracture that is probably a subsidiary vein parallel to New Rake. Both end in small sumps from which a trickle of water flows to cascade down Cliff Cavern.

Main Rising (Speedwell Cavern)

This is a deep sump, dived by John Cordingley and others over many years. An up-and-down profile first follows a minor mineral vein in a southwesterly direction and then another in a northwesterly direction. These veins appear to be scrins branching off New Rake. The farthest point reached is where the submerged passage descends to a depth of 66.5m, where a descending rift passage continues. Though not as large as some of the vein cavities, it has been developed as a phreatic system along mineralised fractures. Almost all the drainage of the area west of Castleton, as far west as Coalpithole Mines, rises here and flows down the Speedwell streamway to resurge at Russet Well at the mouth of Peak Cavern gorge. Occasionally flow-switching takes place after floods and the main discharge is via the Whirlpool Rising, which lies close to Faucet Rake (Bottrell and Gunn, 1991).

Block Hall (Speedwell Cavern)

A short way down the Bung Hole Passage, is another high vein cavity in New Rake or a closely associated scrin. The vein comprises about 60cm of calcite and was not worked by the lead miners. Its floor is just above the Bung Hole streamway and it rises about 100m to a low crawl linking it with the White River Series of Peak Cavern (see below).

Old mine workings a little farther down the Bung Hole series, now choked with debris, lie beneath a choked vein cavity descending from the floor of the White River Series of Peak Cavern, either on New Rake or a scrin branching off it.

The Rift Cavern (Speedwell Cavern)

Just a short way farther down the Bung Hole streamway, is another small vein cavity only about 15m high. Again the vein is another part of New Rake or an associated scrin, comprising about 60cm of calcite. At Rift Chamber's highest point in Egnaro Aven a crawl leads off to link with Peak Cavern. The stream flows beneath a jumble of large slabs that have split off the walls. From the downstream end of the Lower Bung Hole Streamway the water crosses beneath Peak Cavern Gorge to rise from Russet Well.

Russet Well

This is the main resurgence for the Castleton area's underground drainage. Though not on a clean-cut mineral vein, it is on a series of calcite-lined pipe vein cavities lying one above the other. Divers have reached a depth of about 30m. If drained it would fit into the category of vein cavities, though somewhat smaller than most. Its overflow spring across the gorge at Slop Moll is close to the veins in Peakshole Sough.

Peak Cavern

This system contains several vein- and fracture-guided caverns. Though the entrance chamber and the gorge are not on any obvious fracture, there are avens in the Vestibule roof elongated along a strong N-S joint. The **Great Cave** has dissolution hollows extending upwards along a major NE-SW joint of which there is little sign in the overlying Cavedale.

Roger Rain's House is on an eastward extension of New Rake, here comprising only about 40cm of calcite. The same vein is visible in Cavedale directly above. The vein cavity is about 25m high and has been modified somewhat by the small stream sinking in Cavedale.

Whether the Vestibule, Great Cave and Roger Rain's House should be regarded as vein cavities may be debatable but there is clear evidence of dissolution along fractures under phreatic conditions.

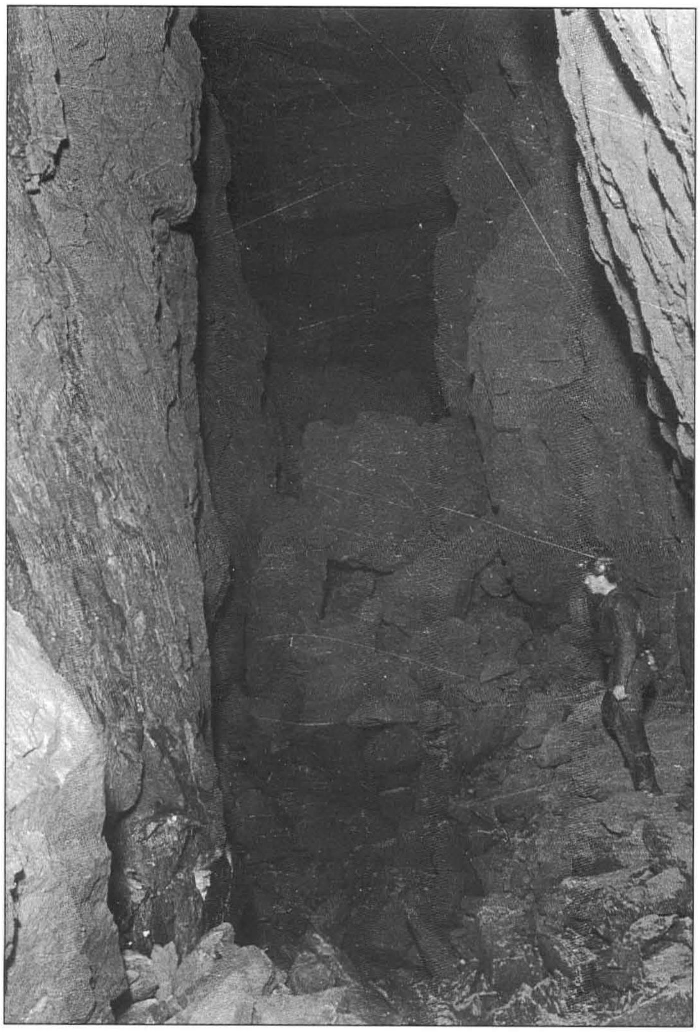


Plate 3. Boulder Hall in Peak Cavern, developed along a west-east fracture.

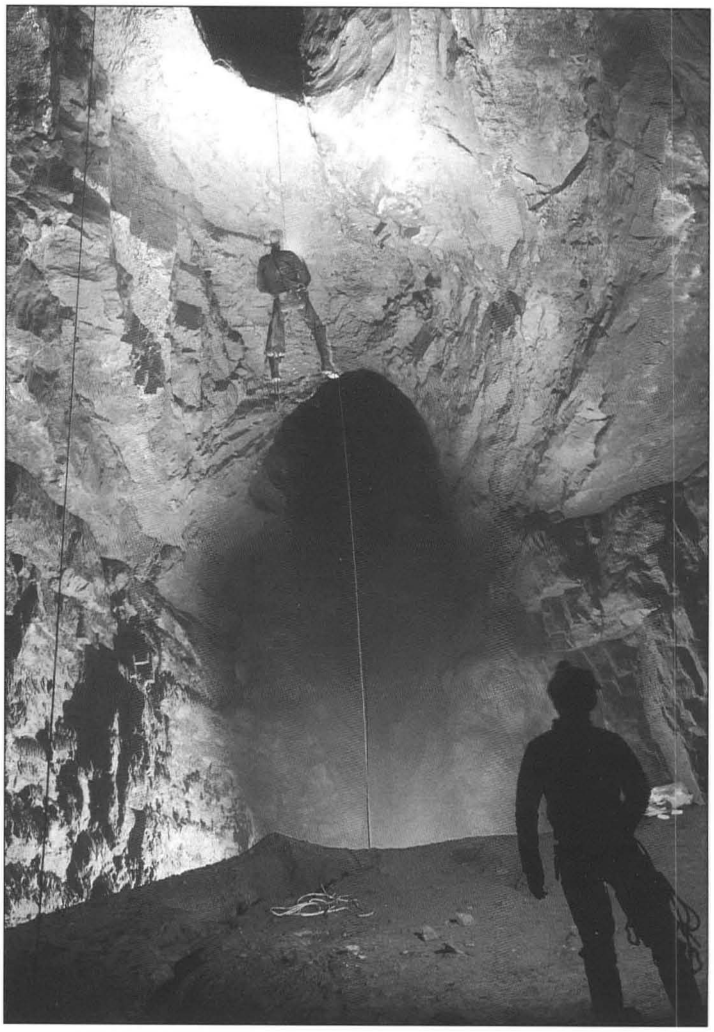


Plate 4. Salmon's Cavern at the southeast end of Stemple Highway in Far Peak, developed along a minor northwest to southeast vein (photo by Paul Deakin, FRPS).

The Five Arches (Peak Cavern)

These cavities were developed by phreatic dissolution along a series of parallel NW-SE joints, at least one of which extends up to the surface in Cavedale. No obvious mineralisation has been noted.

Victoria Aven (Peak Cavern)

This cavern is at least 100m high, developed along a NNW-SSE fracture with minimal mineralisation. The roof appears to be underneath the Cavedale Lava, and the floor is part of a tributary streamway.

Echo Rift (Peak Cavern)

Development has followed a fracture closely parallel to Victoria Aven a few metres to the west.

Cohesion Sump and Anniversary Hall (Peak Cavern)

Both are on west-east mineral veins that appear to be splays off New Rake.

Perseverence Pot (Peak Cavern)

Lying above the Mucky Ducks, this is on a NNW-SSE fracture, with much collapsed rock obscuring details, though there is mineral matter amongst the debris.

Watershed Aven (Peak Cavern)

Another small vein cavity, again with minimal mineralisation.

Disappointment Rift (Peak Cavern)

An isolated vein cavity with minimal mineralisation.

Boulder Hall (Peak Cavern)

This is aligned west-east, with considerable collapse debris beneath what appears to be a double fracture in the roof. No mineralisation is evident.

Moss Chamber and Anniversary Hall (Peak Cavern)

Both lie along an west-east fault with bedded limestone to the south and reef limestone with a wayboard to the north. Little mineralisation is visible.

Doom's Retreat (Peak Cavern)

This lies at the extreme southern end of Lake Passage, and has been reached only by divers. It appears to be a large vein cavity in Dirtlow Rake or one of its scrins, now partly filled with large collapsed boulders.

The White River Series (Peak Cavern)

An ancient high-level vadose system roughly 100m above the main Peak Cavern passages. It has a series of vertical developments including its original entrance climb, as well as the Moose Trap, an Old Mans' rift (once partly climbed from Speedwell by lead miners but the link is now blocked) and Block Hall. These vertical developments appear to be on west-east fractures associated with New Rake.

Far Peak Extension (Peak Cavern)

This was originally entered by diving, but is now accessible from Speedwell Cavern, and it has several major vein cavities.

Stemple Highway (Peak Cavern)

Development along a series of vein cavities, including **Balcombe's Way** and **Salmon Cavern**, on a NW-SE mineral vein that has no surface expression. The associated **Total Perspective Vortex** is an enlargement along a prominent wayboard. The northwestern end links to **Leviathan** in the James Hall Mine-cum-cavern complex (see under Speedwell Cavern, above). The vein cavities are at least 60m high, with a prominent wayboard at a high level. **Major Sump** at the western end of Far Peak Extension appears to be on a fracture with minimal mineralisation.

Titan (Peak Cavern)

A recently discovered vast vein cavity, close to the upstream (western) end of Peak Cavern's Far Sump. As with Stemple Highway, it is on an west-east vein with no obvious surface expression and no evidence of the miners having found a way in. Titan is a magnificent phreatic vein cavity, 160m high, with minor stream inlets along the vein, and a ruckle of large collapsed boulders at the bottom.

Somewhat separate from all the above are vein cavities beneath Bradwell Moor. **New Venture Mine** has a single vein cavity extending to a depth of 66m. At least part had a pothole opening to the surface. **Long Rake Mine** is partly in phreatic vein cavities that have been followed to a final depth of 150m. There seems not to have been any opening to the surface. The nearby **Batham Pot** is a surface depression on the same west-east mineral vein: its floor is a collapsed mass of boulders that may well lie above a vein cavity.

In addition to the known vein and fracture cavities listed above there are several deep depressions or collapse dolines that may lie above vein cavities, with or without a fill of large boulders. Two lie to the southeast of Eldon Hill Quarry, in a field sometimes used for motor cycle scrambling. They appear to lie on an west-east fracture parallel to Windle and Rush Rake (often known as Slitherstones Rake). Dye tests have shown that the drainage goes to Speedwell Cavern and Russet Well.

What appears to be a collapse doline lies on Faucet Rake, just west of the Rowter Farm road.

Two deep depressions lie close to the line of New Rake a few hundred metres to the west of Cliff Cavern, and it is tempting to wonder if they overlie similar vein cavities.

Another, less pronounced, collapse doline lies on Wham Rake, a few hundred metres west of Hazard Mine. A series of shallow channels in the drift cover converge on it, suggesting either that the drift had limited permeability or that melt-water found its way over frozen ground to sink here.

Slack Hole lies west of the upper end of Cavedale on a minor mineral vein between New and Wham Slack rakes. A dig here was unsuccessful. Small shallow depressions by the footpath in upper Cavedale lie on the same vein. Similar shallow depressions occur in the floor of the upper part of Cowlow Nick, close to Faucet Rake and the Bottomless Pit. They may conceal additional vein cavities.

As exploration continues, more vein cavities will undoubtedly be found.

OBSERVATIONS

Several features appear to be common to many of the above. The cavities are typically high and narrow, irregularly cylindrical in form, with curved or arched roofs, showing morphological details typical of phreatic dissolution. Commonly the roofs lie close to wayboards, but the latter appear to have had only minor significance in the cavity evolution. Stalactite formations are also of minor significance, as little percolation comes down from above, though scattered fallen blocks suggest that there was once much flowstone in some cavities. The floors may either go well below water-level in deep sumps or are obscured by large fallen blocks. Many of the latter have spalled off the walls, perhaps loosened by phreatic dissolution or by pressure release. Inlet and outlet passages are generally small, either unmodified phreatic tubes or shallow vadose canyons. Whereas a few have small streams cascading down them, other vein cavities have been abandoned as drainage routes. At most, they seem to have afforded the possibility of vadose streams migrating down to a lower level. On the other hand, if any cavities were accessible to free-flowing streams sediment may have been washed in, as is the case in the Eldon Hill Quarry caves, with their fills of fluvioglacial sands and silts. Some of the collapse dolines noted below might in fact be vein cavities still filled with inwashed sediment.

A few of the mineral veins seem to have a whole range of vein cavities along their length. Faucet Rake has Maskhill Mine, Oxlow Caverns, Rowter Hole, Pilkington's Cavern, the Assault Course Cavern and the Bottomless Pit along its length. New Rake has Leviathan, Block Hall, Rift Cavern and possibly some of the White River Series pots along its length. Several other cavities such as Cliff Cavern, the Bathing Pool, Stemple Highway, Salmon's Cavern, and Titan lie on associated scrin veins or fractures. Other mineral veins may well have several vein cavities but they have simply not been differentiated in either mining or modern explorers' records.

SPELEOGENESIS

It is clear that there were primary mineral-lined cavities in most, if not all, of the mineral veins. Associated with these were isolated cavities in faults and fractures, locally with fault breccias. An outline of the supposed sequence of phases is shown in Fig.3.

After an early palaeokarst phase in mid-Carboniferous times (Ford, 1995), the changing stress fields at the end of the Carboniferous resulted in movements yielding the mineral veins (Quirk, 1993). At this stage there was a 2 to 3km cover of impervious Millstone Grit and Coal Measures (each with thick shales) overlying the limestone. Tectonic "inversion" of the Carboniferous sedimentary basin at the end of Carboniferous times resulted in uplift with subsequent partial removal of the Upper Carboniferous cover.

In the ensuing Permian and Mesozoic times the limestone mass remained buried. Some strata of Triassic, Jurassic and Cretaceous age were also added to the cover, perhaps another 2km (Pearson and Russell, 2000). During mid to late Cenozoic times renewed uplift of the South Pennine region resulted in the cover of Mesozoic and remaining Upper Carboniferous strata being slowly eroded away.

The critical period for the speleogenesis of these vein cavities was when the last remnants of the cover were being removed in mid to late Cenozoic times (Fig.3). At an early stage the top beds of the limestone sequence became exposed and slow infiltration of meteoric water became possible. Until then water within the limestone would have been slow-moving and dissolution would have been limited. Apart

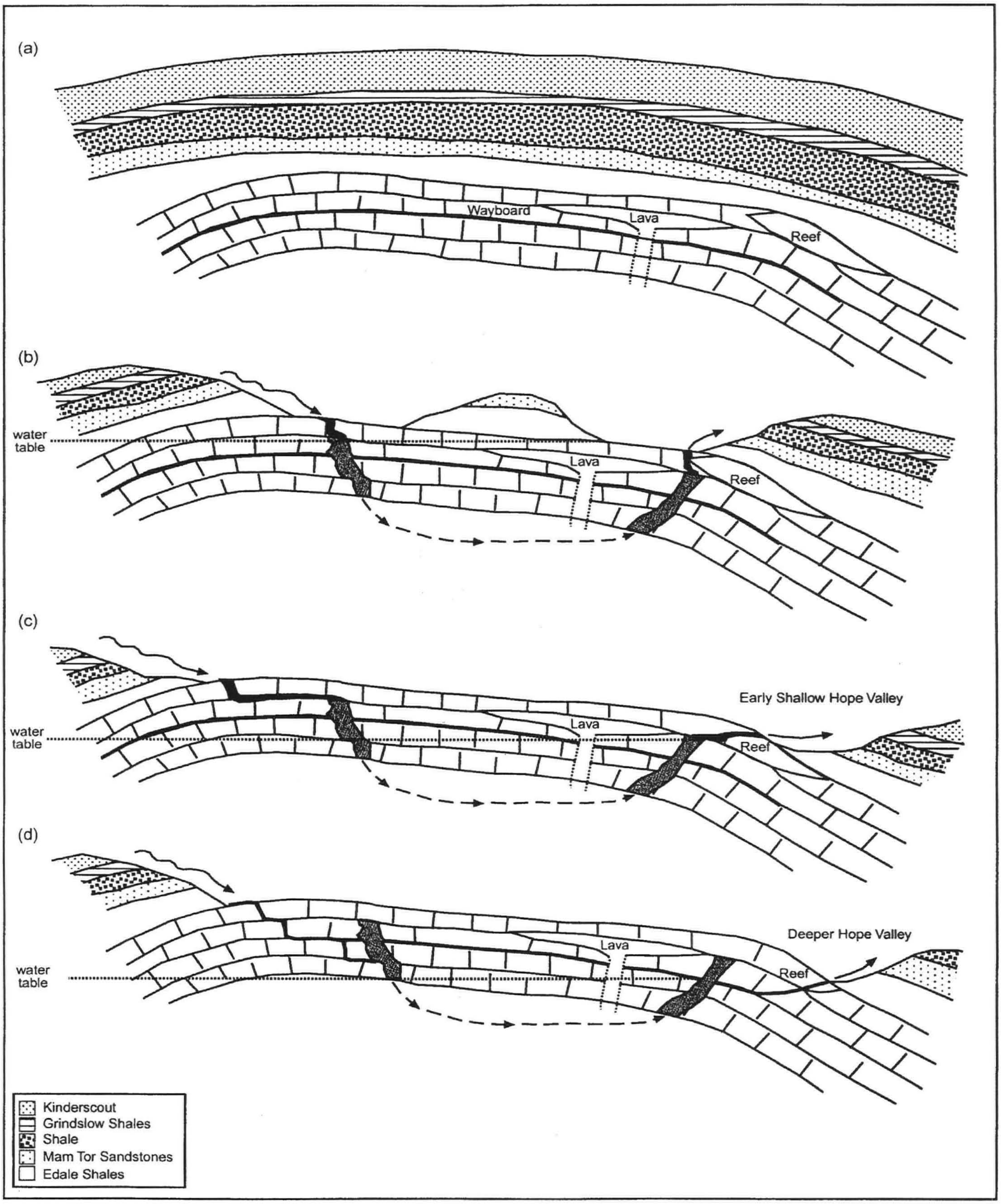


Figure 3. Diagrams to illustrate the evolution of the vein cavities around Castleton:-
(a) West-east section showing the stratigraphical and structural relationship of part of the Millstone Grit cover on top of the limestone massif at the end of the Carboniferous Period.
(b) Mid-late Cenozoic - an early stage in the erosional removal of the Millstone Grit cover to expose the limestone. A high water-table is almost coincident with the top of the limestone. Slow circulation via vein cavities in the phreatic zone dissolves out vein cavities.
(c) An early shallow Hope Valley causes the water-table to fall and vadose stream caves begin to develop with allochthonous run-off from receding Millstone Grit scarps, but with deep circulation still via vein cavities.
(d) The present-day situation, with vadose swallet caves draining via vein cavities to resurgence caves.

from mineral-lined vughs in the veins the vein-fault-fracture system formed vertically-oriented inception routes.

The limestone beds have a gentle dip to the east, anda regional The The limestone beds have a gentle dip to the east, and a regional hydraulic gradient could have existed within the buried limestone long before vein cavity formation, but fluid transfer within this closed system would have been very slow and of limited speleogenetic significance. Once the cover was breached and the limestone surface was exposed over some distance, a more local hydraulic gradient could come into effect and underground water could migrate slowly eastwards down-dip, sinking at the highest part of the massif and resurging farther east. At first the water-table was almost coincident with the top of the limestone and the whole of the vein and fracture network was in the phreatic zone. It is likely that Eldon Hill and the plateau as far as Hurdlow were the first to be revealed by stripping off the cover, followed closely by the area to the south. Circulation of water along Faucet and New rakes and their associated scrin veins and fractures would result in very slow dissolution. Thus, this preliminary phase in the establishment of a drainage network might well have lasted for at least half of Cenozoic time, say 20 million years, and possibly much longer. With no effective base to the limestone sequence the slow circulation could have gone to virtually any depth, only to rise again to the resurgence points. However, the restriction of the known vein cavities to the top 200m or so of the limestone suggests that circulating waters may have found the deeper parts of the limestone massif too tight for effective flow transmission. However, it should be noted that no evidence has been found to indicate how deep the vein cavities may extend.

Whereas some pre-conditioning of the fractures during the closed system buried stage might have had some effect, most, if not all, the vein cavity development is regarded as occurring during Cenozoic times, contemporary with the unroofing of the limestone. As the roofs of most of the vein cavities rise to within about 50-100m of the surface and exhibit dissolution hollows at the top, it is clear that the effective water-table was very near to the top of the limestone. Corrosion by slightly acidic meteoric waters would pick out any weakness in veins or fractures and slowly enlarge them, so that an undulating phreatic drainage system, unrestricted by either water-table or by an impermeable basement, could be developed in the nearly vertical planes of the rakes.

Currently, several of the vein cavities extend to, or even below, the present water-table, e.g. the Coalpithole to Main Rising drainage. Such vein cavities are still being developed and dissolution within the phreatic zone is an on-going process.

Several questions arise. *"Why are there so very few of the vein cavities open to the surface as potholes?"*. The answer could depend on several factors, the chief ones being the availability of primary crystal-lined cavities in the veins and the local density of minor fractures and/or breccia. Also surface lowering has not yet proceeded far enough to breach the tops of the cavities. *"Why are the roofs of the vein cavities characterised by dissolution hollows?"*. Upward stoping by dissolution would be limited by the altitude of the water-table. Little or no dissolution could take place above the phreatic zone, so that the cavities have "blind" tops. Another question is: *"Why are there no apparent swallets feeding the cavities, or resurgences where the circulating phreatic water rose?"*. One must bear in mind that the dissolution was a very slow process and there was no steady inflow of allochthonous streams and the outlets would be little more than seepages. Indeed, while most of the system was below the water-table there was really no need for specific inputs and outlets. With only small areas of the limestone plateau exposed, a surface drainage system on the remaining shales and sandstones of the Millstone Grit and on a former blanket of early Pleistocene drift took surplus rainfall away. Later, in the Pleistocene, glaciation trimmed off the highest beds of limestone over most of the plateau, thereby removing the evidence of former inlets or outlets. A few may still survive, filled with sediment, as in Eldon Hill Quarry and in the northwest corner of the Blue Circle cement works quarry.

When the incision of Hope Valley commenced, probably in early Pleistocene times, the remaining Millstone Grit cover would have been progressively eroded away and the hydraulic gradient would have been increased by lowering of the water-table. This would increase the possibility of underground drainage finding routes both via the vein cavities and along bedding plane inception horizons. Vein cavities would be incorporated into some stream cave systems but would be by-passed by others. With the further lowering of Hope Valley floor the underground drainage resurged by rising up a Vauclusian spring where Peak Cavern gorge is now. As the base level in or around Peak Cavern fell, the higher parts of the vein cavities were drained and abandoned. But, whereas the lower parts were still submerged, some further dissolution could take place and the development of the lower parts of vein cavities was an on-going process.

The lack of contemporary inlet and outlet passages to most vein cavities poses another problem. The likely answer is that there was slow infiltration through "tight" parts of veins or fractures, perhaps fissures no more than a few centimetres wide, which are generally ignored by cavers. A few were enlarged later and became part of the area's vadose drainage system. Similarly, bedding planes and thin wayboards are commonly tight in the walls of vein cavities, but a few were enlarged beyond the inception stage to form phreatic tubes with or without later vadose canyons.

The rest of the speleogenetic evolutionary story has been told elsewhere (Ford, 1977, 1986).

A possibility, raised by an anonymous reviewer, that the vein cavities might have resulted from uprising thermal waters, is currently discounted, as no evidence of thermal-water dissolution has yet been found.

The rest of the Peak District limestone massif has many minerals veins, but only a few "self-opens" (i.e. natural caverns) were found by the lead miners. Two such vein cavity systems are on the adjacent Bradwell Moor, namely New Venture and Long Rake Mines. Neither appears to be related to younger vadose cave networks and their position in any evolutionary sequence has not been studied. In the Eyam-Stoney Middleton area the Old Edge Rake and other semi-parallel mineral veins were known to the lead miners as "shacky", i.e. with "self-open" caverns, but they appear to have played little part in the development of the Merlin-Carlswark cave system (Beck, 1977). A few self-opens were recorded in other parts of the orefield, but none seem to have had related vadose cave systems. It is possible that the limited allochthonous catchments failed to provide enough steady infiltration of aggressive water. What may be a series of vein cavities occurs in mines around the down-faulted trough structure known as "the Gulph" at Wirksworth. Recorded by Farey (1811), most such cavities have not been entered since 19^{th} century mining days, so their significance cannot be assessed.

An initial search of speleological literature has revealed only one possible example of a comparable vein cavity phase in its speleogenetic evolution. In North Wales several large isolated caverns have been found on mineral veins or their intersections within a host rock of Carboniferous limestone (Appleton, 1989). The best known example is Powell's Lode Cavern in the Halkyn Mines. Unfortunately, these have not yet been studied as a potential early phase of speleogenetic evolution.

The numerous potholes developed on master joints splaying off the Craven Faults in the Yorkshire Dales karst are of similar speleogenetic significance, though few of them show any sign of mineral vein development.

CONCLUSIONS

Large dissolution cavities along mineral veins and fractures appear to represent an early stage of speleogenesis in the Castleton karst. They are evidence of a vertically-oriented inception route system that developed by phreatic dissolution. Very slow dissolution in slowly migrating groundwaters may have taken the great part of Cenozoic times, starting as soon as some part of the limestone surface was denuded of its Millstone Grit sandstone and shale cover. Up and down phreatic profiles evolved in the vertical rakes and faults. Dissolutional development of the vein cavity roofs could only have taken place at a time of high water-table. As water levels fell with the incision of the Hope Valley, the upper parts of vein cavities were abandoned. Overlapping chronologically, the phreatic tubes and vadose stream cave systems following bedding plane inception horizons were developed as water-tables, and hence dissolutional activity, fell within the vein cavities.

REFERENCES

Appleton, P, 1989. *Limestones and Caves of North Wales*. 217-254 in Ford, T D (editor), *Limestones and Caves of Wales*. [Cambridge University Press.]

Beck, J S, 1977. The caves of the Foolow-Eyam-Stoney Middleton area. 361-382 in Ford, T D (editor), *Limestones and Caves of the Peak District*. [Norwich: Geo-Books.]

Bottrell, S and Gunn, J, 1991. Flow switching in the Castleton karst aquifer. *Cave Science*, Vol.18, No.1, 47-49.

Farey, J, 1811. A general view of the Agriculture and Minerals of Derbyshire. *Board of Agriculture, London*. Volume 1, 532pp. [List of caverns on pp.292-4.] [Reprinted by Peak District Mines Historical Society, Matlock, 1989.]

Ford, T D, 1977. *Limestones and Caves of the Peak District*. [Norwich: Geo-Books.]

Ford, T D, 1984. Palaeokarst in Britain. *Cave Science*, Vol.11, No.4, 246-264.

Ford, T D, 1986. The evolution of the Castleton cave systems, Derbyshire. *Cave Science*, Vol.13, No.3, 131-148.

Ford, T D, 1995. Some thoughts on hydrothermal karst. *Cave and Karst Science*, Vol.22, No.3, 107-118.

Ford, T D and Worley, N E, 1977. Mineral veins and cave development. *Proceedings of the 7th International Speleological Congress (Sheffield)*, 192-193.

Gunn, J, 1985. Hydrology of the Peak-Speedwell cave system. *Caves and Caving*, No.29, 10-11.

Gunn, J, 1991. Water-tracing experiments in the Castleton karst. *Cave Science*, Vol.18, No.1, 43-46.

Marsden, A W, 1991. Aspects of the Peak-Speedwell cave system 1650-1900. *Cave Science*, Vol.18, No.1, 3-18. [This issue also contains a thematic set of papers on various aspects of the Castleton karst.]

Marsden, A W, 1991. The Halfway House Caverns, Speedwell Cavern. *Cave Science*, Vol.18, No.1, 30-34.

Pearson, M J and Russell, M A, 2000. Subsidence and erosion in the Pennine Carboniferous basin, England: lithological and thermal constraints on maturity modelling. *Journal of the Geological Society, London*, Vol.157, 471-482.

Quirk, D G, 1993. Origin of the Peak District orefield. *Bulletin of the Peak District Mines Historical Society*, Vol.12, No.1, 4-15.

CAVE AND KARST SCIENCE Vol. 27, No. 1, April 2000
Transactions of the British Cave Research Association

ISSN 1356-191X

Kent's Cavern, England, in the 18th century

Trevor R SHAW
Karst Research Institute, Titov trg 2, SI 6230 Postojna, Slovenia

Abstract: Four almost unknown records of Kent's Cavern (Torquay) from between 1750 and 1783 are discussed. A response to a questionnaire of c.1750 refers to a description once attached but now lost; bats from the cave were used in 1775 by James Cornish in his experiments on hibernation; an anonymous reviser of the 8th edition of Defoe's *Tour*... added a footnote on the cave in 1778; and Polwhele had published anonymously in 1783 almost the same description as in his book of 1797.

(Received 17 December 1999; Accepted 4 May 2000)

INTRODUCTION

The early literature of Kent's Cavern in Torquay (Devon) is probably better known than that of any other cave in England except Wookey Hole, thanks to its systematic reprinting by William Pengelly in the 19th century. Nevertheless there were four important 18th century records that Pengelly did not quote.

In a series of five long papers published between 1868 and 1884[1-5] he gathered together all he could find, from travel books, scientific papers, magazines and guidebooks - a total of 377 pages, not including the 280[2] occupied by MacEnery's account[6] of his excavations there from 1825 to 1829.

In the first of the papers[1] the earliest references known to Pengelly dated from 1797. During the next ten years his own meticulous researches, supplemented by information from other people, located also a manuscript description of the cave written in 1792, a map of 1769 on which its name appeared, and a legal document of 1659 that mentioned it. By reporting these and reprinting the relevant passages in an accessible journal, Pengelly not only drew attention to them but also made them readily available, even today.

But there are other 18th century records of the cave that even Pengelly did not find. The purpose of this paper is to introduce and reprint four items written between about 1750 and 1783. Some have remained in manuscript, some were printed but are difficult or impossible to find, and none has been discussed in mainstream karst literature.

In about 1750 Jeremiah Milles distributed a questionnaire that produced information on several caves, though the special report prepared for him on Kent's Cavern is no longer present. James Cornish used to visit the cave in the 1770s to collect bats for research, and his studies on their hibernation are summarised here. The 1778 and 1779 editions (only) of Defoe's *Tour through ... Great Britain* contained a short description of the cave, thus making it known to a wide readership. The long account by Richard Polwhele, published in his county history of 1797, has been found to exist in almost identical form in an anonymous magazine article that he wrote fourteen years earlier.

As Kent's Cavern was almost always known as Kent's Hole until the 1840s, that name will be used throughout the rest of this paper, so that the text is consistent with the quotations.

THE PREVIOUSLY KNOWN EARLY RECORDS

Before considering these 'new' 18th century accounts of the cave, it is convenient to summarise those already included in Pengelly's compilations, to provide a framework of existing knowledge as context into which the new data can be fitted.

The deed dated 22 December 1659[7] referred to:

> *"...all those closes, ffields, or pieces of ground, that is to say one piece called Middle Hill, one close called Kent's Hole, ... one close called Wildeswood, ... and the meadow called Bramble Meadow."*

So the cave, doubtless well known locally since long before, had by then given its name to a 'close' or enclosed place.
The plan of 1769[8], which Pengelly saw in a lawyer's office in Torquay, was of the manor of *"Tormoham"* [=Tor Mohun] and one of the fields there was called *"Kent's Hole Field"*.

The earliest description of the cave that Pengelly found, as distinct from its use as a place name, is in a manuscript description of Devon by John Swete[9] and was written in 1792. The passage is quite short and, because even Pengelly's reprint[10] is inexact and not very easily accessible, it is printed here:

> *"...on this estate [Torwood] in the marble rock is Kent's Hole, the largest cavern in Devon (and there are many in the rocks of Marble which as a stratum occupies nearly one third of the County) it is however nothing comparable to those in the Peak of Derby! the opening is but small and narrow, sinking into the body of the rock, the light plays only on its threshold - for the shadows quickly deepen, and the sight soon terminates in absolute darkness - an old woman attends with lighted [?? words missing] one is obliged at times to bend low to the ground, and even to creep on it - which is by no means a pleasant operation - for the floor of the Cave is not only rugged but wet and dirty - there are within some rooms high and capacious and they abound with stalactites - "*

The much better known account by Maton, describing his visit in 1794, was published in 1797 in his *Observations ... of the Western Counties of England* [11]. The guides were *"Two women, whose usual business it is"*, so it is clear that visitors to the cave were not infrequent.

Polwhele's published description of 1797[12] is quite lengthy (about 1,000 words). It is very similar to his much earlier account, to be discussed later in this paper. Not present in the early version is mention of a *"gentleman of my acquaintance, who resides in a distant county, and who lately made a tour into Devonshire"*. This cannot have been Maton, who explored the whole of the cave whereas Polwhele's friend went only *"100 yards in it, or about half the way that people sometimes go"*. Besides, the latter had only one guide, an *"old woman (77 years of age)..."*.

JEREMIAH MILLES

Milles's importance in the history of Kent's Hole is due to the interest he showed in it at such an early date and the report on it he caused to be written. Alas, as the report seems now to be lost, there are no surviving new facts about the cave resulting from his interest.

Dr Jeremiah Milles (1714-1784) (Fig.1) was Precentor of Exeter Cathedral from 1747 until he was appointed Dean there in 1762. He was interested in archaeology from an early age, being elected Fellow of the Royal Society in 1742 and becoming President of the Society of Antiquaries in 1768[14]. As soon as he left Oxford in 1733 he set off with his elder cousin, later Bishop Richard Pococke, on a series of travels in Europe. In the course of these they visited what is now Slovenia, and showed an unusual interest in the caves there[15, 16].

While he was Precentor at Exeter he accumulated information about Devon, with the intention of producing a history and description of the county. As a start, about 1750, he sent out printed questionnaires to parishes in Devon to elicit information. The returned questionnaires are now in the Bodleian Library[17]. For the parish of Tor Mohun, covering much of present-day Torquay, the answer to the question *"Any natural Caves in Limestone or other Quarries?"* was, tantalizingly, *"Kents Hole see my description"*. The once-annexed description is no longer present; nor is it in the associated *"parochial collections"* in Oxford[18], nor in Milles's many manuscript volumes in the British Library.

This Tor Mohun reply to the questionnaire was made by the Reverend James Salter, vicar of the neighbouring parish of St Marychurch, who consequently was also the author of the missing description. By 1768 Salter was no longer vicar there[19], so his undated reply cannot have been made later than 1767. It was probably much earlier, for Milles is thought to have collected most of the information by 1762[20], and there is no reason to think that a long period elapsed after the questionnaire was received in the early 1750s.

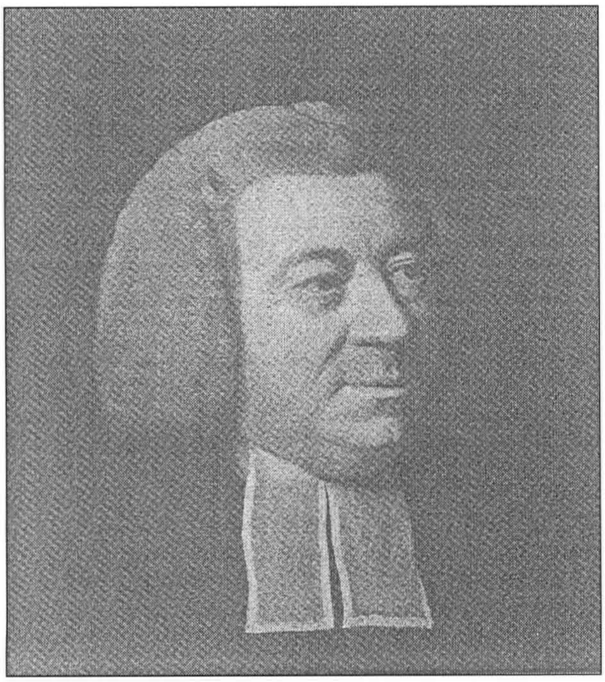


Figure 1. Jeremiah Milles in later life. An oil painting by Nathanial Dance, or a later copy of it, in the collection of the Society of Antiquaries of London and reproduced with their permission. His strange wig was apparently so notorious as to attract a humorous cartoon in The Gentleman's Magazine [13].

There is no evidence to show whether or not Milles himself visited Kent's Hole, but it is exceedingly likely that he did, for two reasons. When he was in Slovenia with Pococke in 1737 they had made a point of visiting all the caves they could hear about, even one quite small one that was not on their main route[21]. Additionally, his own manuscript of about 1755 includes a detailed description of his exploration of a narrow and difficult cave (now lost) at Dean Prior in Devon[18].

Certainly he had not forgotten Kent's Hole in 1776 when he wrote to George Catcott, the author of *A Descriptive Account of ... Penpark-Hole*[22], who had lent him an early draft of that book. In his letter dated 14 May Milles wrote, *"All Limestone Rocks have fewer or more such Cavities; but Wokey-Hole in Somersetshire, Penpark-hole near Bristol, and Kent's Hole near Torbay in Devonshire, are the most remarkable of those in the West."*[23].

JAMES CORNISH

James Cornish knew Kent's Hole in the 1770s and used to visit it to obtain bats for his studies on hibernation. He described these in letters to fellows of the Royal Society, in whose *Philosophical Transactions* they were published. His work was also mentioned in other contemporary books.

Cornish (1744-1828) (Fig.2) was a surgeon in the Devonshire town of Totnes[24]. Besides his natural history studies that concern us here, he was interested in agricultural practice, becoming in 1791 the secretary of the South Devon Division of the newly formed Devonshire Agriculture Society. He also wrote on such subjects as sheep rot, potato cultivation and land improvement.

His interest in hibernation, not only of bats and dormice but also the supposed hibernation of some birds, was at the same period as Gilbert White of Selborne was writing about it. Both were friends and correspondents of the Hon. Daines Barrington (1727-1800), antiquary, naturalist and Fellow of the Royal Society[25]. More than half the letters published as White's *Natural History ... of Selborne* in 1789[26] were originally written to Daines Barrington, who is said to have encouraged their publication as a book[25]. In one, dated 12 February 1771, White wrote:

> *"You are, I know, no great friend to migration; and the well attested accounts from various parts of the kingdom seem to justify you in your suspicions, that at least many of the swallow kind do not leave us in the winter, but lay themselves up like insects and bats in a torpid state, and slumber away the more uncomfortable months till the return of the sun and fine weather awakens them.*[27] *"*

Cornish's three letters were written in 1775. All three are in the archives of the Royal Society[28] (Figs 3 and 4) and they were all printed in the *Philosophical Transactions* for that year[29]. Convenient summaries of them exist in the manuscript record of the meetings of the Society at which they were read on the 4th and 25th May 1775[30].

Like Barrington, Cornish believed that certain birds normally thought to migrate for the winter did, in fact, hibernate. It was said that a live cuckoo had been found in a hollow tree one Christmas[31], and he himself had watched a group of martins in November[32]. Such late appearances are, in fact, not uncommon in the swallow family[33].

Figure 2. James Cornish (second from left) with his wife and family. The original portrait has not been traced.

He argued that bird hibernation was quite reasonable, by analogy with that of bats and dormice, which are of similar size. This appears in his second letter, dated 31 March 1775 and reprinted below, which also refers specifically to his obtaining the bats from Kent's Hole (Fig.4). This is followed here by a reprint of the passage in the third letter dealing with his bat experiments (Fig.5). The cave is not named explicitly again in this third letter, but it was cave bats that he was working upon, doubtless Horseshoe bats from the same source.

The principal purpose of these reprinted extracts is to provide an accurate copy of relevant parts of Cornish's letters as published in the *Philosophical Transactions*. At the same time, opportunity has been taken, by the use of square brackets, etc., to indicate where the original letters differ from the printed text. These can safely be ignored unless the reader is interested in such textual differences. Differences in punctuation have not been noted.

- words in square brackets are present in the manuscript letters only;
- words in square brackets preceded by an equals sign (=) replace (in the manuscript) the corresponding words of the printed version.

LETTER II. TO THE HON. DAINES BARRINGTON. March 31, 1775.

"... For there is certainly nothing more extraordinary in finding martins, in a state of torpidity, than dormice [=Dormice] or bats [=Batts], which are animals equal in bulk to the swallow or martin. Dormice are frequently found dead to all appearance in the winter in old hedges; and [=&] we can procure bats [=Batts] at all times, in any number, from a subterraneous [=Subterraneous] place, [=cavern] called Kents Hole, [=hole] near Torbay. Now if the examination of the intestinal tube of one of this tribe of mungrel [=mungrell] animals in a torpid state, should be thought [=considered] worth attending to, it can be done at any time. Bats, [=Batts] indeed, are sometimes seen in winter, in [a] very mild weather; [=time,] though none have yet made their appearance with us. ...[35]

LETTER III. TO THE HON. DAINES BARRINGTON. Totness, May 9, 1775.

... I have had an opportunity [=oportunity] of examining [=Inspecting] the viscera of several [of these animals [deleted]] torpid bats [=Batts]. The intestinal tube was perfectly empty, except about half an inch from the anus, where there was a little hard faeces. The gall-bladder [=gall bladder] was filled [=filld] with a pellucid, yellowish fluid. The ball [=End] of FAHRENHEIT's [=Farenheit] thermometer being laid in the body of one of them, the heat of the blood at the heart raised [=rais'd] the quicksilver [=mercury] two degrees. In [=in] three others, opened at the same time, no heat could be perceived, either by the thermometer or by the touch. These experiments being made in the beginning of April, it is [=tis] reasonable to suppose, that the bat [=Batt] which affected the thermometer, had begun to feel [=perceive] the approaching season. I think there is reason to believe, from the small quantity of faeces in the intestines, and [=&] from its being so near the anus, that those animals, when they find themselves growing torpid, take sufficient food to serve them during the winter. All [=all] the animal functions in this state are carried on exceedingly slow; but that they do go on, in some degree, is evident from their emptiness [=an illigible but different word. ?Inasity], emaciation [=poverty], and [=&] the faeces, which are found in [great] plenty underneath the place where they hang in clusters. ...[36] *"*

Figure 3. The signature of James Cornish from his letter dated 9 May 1775[28].

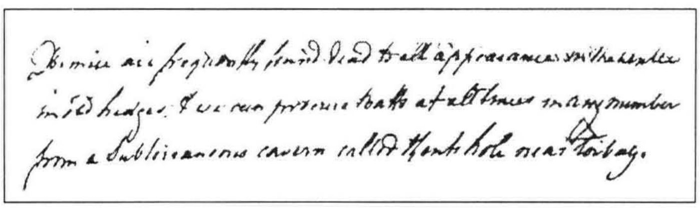
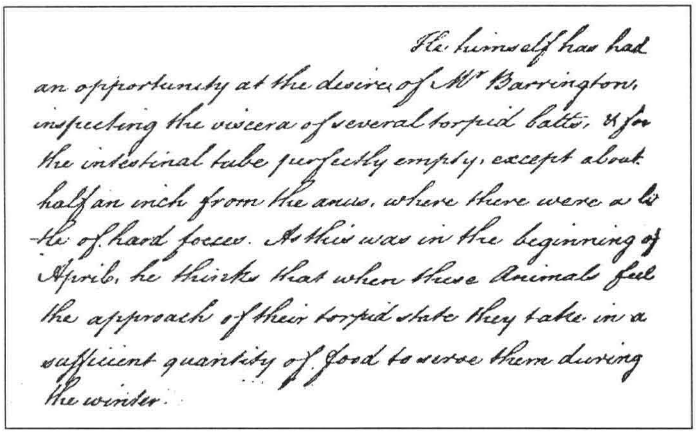


Figure 4. Cornish's statement that he "...can procure Batts at all times in any number from a Subterraneous cavern called Kents hole near Torbay", from the second page of his letter dated 31 March 1775[28].



He himself has had an opportunity at the desire of Mr Barrington, inspecting the viscera of several torpid batts, & for the intestinal tube perfectly empty, except about half an inch from the anus, where there were a lit-tle of hard faeces. As this was in the beginning of April, he thinks that when these Animals feel the approach of their torpid state they take in a sufficient quantity of food to serve them during the winter.

Figure 5. Part of the summary of Cornish's letter of 9 May, as recorded in the minutes of the meeting on 25 May at which it was read[34].

At the end of the letter Barrington added the following note concerning swallows, and also bats:

> *"N.B. I had desired him to shoot some of those which first appeared, and [=&] examine their intestines; as I also did with regard to the torpid bats [=batts].*
>
> *D. BARRINGTON.[36] "*

Cornish's conclusion that the bats *"take sufficient food to serve them during the winter"* was quantitatively confirmed, using a more bat-friendly method, 175 years later. John Hooper, working with Greater Horseshoe bats around Buckfastleigh in 1950, found that the average winter loss of body weight was 29.8% in the females and 24.5% in the males[37].

It is not known for certain how long Cornish had been studying the bats when he wrote these letters, whether it was a long-standing interest that became known to Daines Barrington or whether Barrington inspired Cornish, as a naturalist and surgeon, to undertake it. The letters tend to imply the latter. Certainly the work described in the last letter, written on 9 May, had been done that same spring, for the experiments on torpid bats were made *"in the beginning of April"*. That this was indeed the April of 1775 is shown by his apology for delaying the letter due to *"a desire to get as much information as would make my letter worth the postage"*[31] (*"... worthy your perusal"* in the printed version[29]).

Cornish continued his bat research for many years afterwards, but first should be noticed some extra publicity given to his 1775 work. In an essay *"On the bat, or rere-mouse"* in his own book *Miscellanies* of 1781, Daines Barrington wrote[38]:

> *"... I am much indebted to the communication of a most ingenious correspondent[m], who knows where to find them torpid at any time during the winter, and more particularly in a large cavern near Torbay."*

[m] Mr Cornish, Surgeon, at Totness in Devonshire

The review of this book in *The Gentleman's Magazine* [39] also refers to the cave:

> *"Most of the particulars relating to the Torpid state of this bird, or rather flying animal, were communicated by Mr. Cornish, surgeon at Totness in Devonshire, who knows where to find them torpid at any time during the Winter, and more particularly in a large cavern near Torbay."*

Later Cornish provided information to Richard Polwhele, whose *History of Devonshire* of 1797 acknowledges or quotes from his local knowledge of the Totnes area, its plants and its weather[40], as well as of bats. He had also written an unpublished history of Totnes[40A]. Clearly Cornish had continued his investigations on hibernating bats; and not just in relation to the bird problem, for he is quoted by Polwhele[41] thus:

> *"The experiments, of which I shall give you the general outline, were instituted with a view to collect materials for an history of animal heat, and with a view of ascertaining the most effectual method to recover persons in a state of suspended animation, no case in nature being perhaps so similar as that of an animal in a state of torpidity to a person apparently drowned."*

The bats now came from much nearer to hand than Torquay, from the cellars at Painsford (NGR SX 801568), a 16th century mansion about 3.5km south of Totnes. That they were Horseshoe (i.e. cave) bats is clear from their *"wrapping themselves in their wings"*. Cornish's conclusions, as published in 1797[41], are:

> *"1st. The blood is viscid and deep colored, in proportion to the time of the continuance of his torpidity. - 2d. The blood of a torpid bat has no sensible heat, at least not sufficient to affect the most exquisite thermometer - 3d. The sistole [=contraction] and diastole [=dilation] of the heart is very slow and strong, the punctum saliens [=heart beat] continuing many minutes after the animal has been laid open, and the contents of the abdomen taken out. - 4th. The intestinal tube is empty, and faeces hard, according to the length of time the animal has remained torpid. - 5th . The longer he remains torpid, the less he mutes [=discharges faeces]. - 6th . Torpid bats will awake and fly at all times, after any continuance of warm weather. - 7th. The position of the torpid bat is peculiarly adapted to produce sleep, to preserve them from cold, and from vermin; wrapping themselves in their wings, and hanging by their claws to almost imperceptible chasms in the roofs of wine-vaults, old buildings, &c. - 8th. The cause of the torpidity is in the sanguineous [=circulatory], and not in the nervous system - proved, because the torpid bat shrinks when touched, but bleeds not when cut at the extremities or integuments: this is the more remarkable, considering the third observation."*

Conclusions 2 and 4 are similar to what he had written in his 1775 letters; the others are new.

This publication of Cornish's bat work in a standard county history served to make it widely known to a readership mainly different from that of the Royal Society's *Philosophical Transactions*.

DANIEL DEFOE'S LATE EDITION

The later editions of Defoe's *A Tour thro' the whole island of Great Britain* were, like those of Camden's *Britannia*, extended, expanded and updated after his death by various writers. Much of the supplementary materials was written by Samuel Richardson the novelist, but it was after his death in 1761 that the 8th edition of the book, published in 1778, came to mention Kent's Hole for the first time. By then the supplementing was being done by *anonymous "gentlemen of eminence in the literary world"*, and a new footnote[42] reads:

> *"Not far from this bay, and in the parish of Tor, is a very remarkable place, called Kent's Hole, not mentioned, as I can find, by writers on this county, though perhaps the greatest natural curiosity therein. It consists of many caverns, into which you are let by following subterraneous passages; but it has only one outward entrance to the whole. Some of these caverns are very large, and through one of them runs a rivulet of water. The distance from the outward entrance to this rivulet is three or four hundred feet, and beyond this there are still more passages and caverns."*

It is possible that Milles was the *"gentleman of eminence"* who provided this information, based either on his own experience or on the now-lost description sent to him by James Salter. The *"rivulet of water"* presents a problem, for there are no permanent streams in the cave. Professor Straw suggests (pers. comm) that this was probably in the Bridge area at the SW end of the Long Arcade, where a strong seepage from the NW wall could have run east over the flowstone to disappear down small passages on the SE side of the Long Arcade before Pengelly's excavations altered the floors.

Rather surprisingly this reference in a standard book escaped the notice of Pengelly and his friends for many years, and he never drew attention to it in print. It was however mentioned, and part of it quoted, in a manuscript paper written by him between 1884 and 1894[43] but not published. The 1778 footnote on the cave is little known even today, for although there are many editions of Defoe's book those of 1778[42] and 1779[43A] are the only ones to contain it. The standard 20th century reprints[44, 45] are both of the 1724-26 first edition[46].

RICHARD POLWHELE

Polwhele's lengthy description of the cave in his 1797 book has already been mentioned as being printed by Pengelly in 1868[12]. There are several copying errors in Pengelly's reprint, the more important of which are pointed out below.

What Pengelly's papers never recorded was the existence of an earlier version of Polwhele's cave description, which he had published anonymously in a magazine called the *Weekly Entertainer*[47] for 5 May 1783. This publication is excessively rare and no copy of the 1783 volume has been traced. Fortunately Pengelly did come across it late in life:

> *"A dealer in second-hand books called my attention recently to a dilapidated volume, published in 1783, and containing, among its miscellaneous contents, a description of Kent's Cavern."*[48]

Pengelly included a transcript of this article in his unpublished manuscript[49], already mentioned, and this is printed for the first time below.

It might be argued that the anonymous description was not by Polwhele at all, and that he had just made use of it in his book. There are three reasons for believing that this is not so: in the 1797 book he is punctilious in acknowledging his sources, as in the case of Cornish; he is known to have been a frequent contributor to many magazines[50, 51]; and the style of the 1783 article is consistent with his other writing.

Richard Polwhele (1760-1838) had been appointed curate at Kenton in Devon in 1782 and remained there until the end of 1793 when he became curate at Exmouth, not far away[50, 51]. So he was living in Devon while working on his *History of Devonshire*, having arrived there from Oxford University only shortly before the 1783 article appeared. So, his visit to the cave must have been in 1782 or early 1783, when he was 22 or 23 years old. The portrait in Fig.6 shows him about 1778, aged 18 or so, while he was still at Oxford. In Fig.7 he is some 17 years older and publishing his Devonshire history.

Although it is very similar to the 1797 version, the full text of the 1783 article[47] is given here (as it appears in the manuscript copy made by Pengelly[49]) for three reasons:

a) the original cannot now be traced, and the transcript made by Pengelly is unique, and hence vulnerable;
b) parts of its text do not appear at all in the 1797 version; there are also some other, relatively minor, differences of the kind to be expected in a revision after 14 years;
c) even the 1797 book is not easy to find, and Pengelly's reprint of its cave description is inaccurate in places.

Again, the main purpose of this printed quotation is to provide an accurate copy of Pengelly's transcript of the article in the *Weekly Entertainer*. As with the Cornish letters, above, differences from the text of the 1797 printed book (and from Pengelly's reprinted extracts from it) are indicated by using square brackets, a different type face, or special symbols:

- words present in the 1783 article but not in the 1797 text are printed in **bold**;
- words in square brackets are present in the 1797 text only;
- words in square brackets, preceded by an equals sign, replace in 1797 the corresponding words of the 1783 text;

Figure 6. Richard Polwhele as a young man. The original painting by John Opie, made about 1778, was engraved by Audinet and published in 1826[52]. The signature is likely to be of the latter date.

Figure 7. Polwhele aged not more than 35, a portrait engraved from a miniature and published in October 1795[53].

- any changes indicated as above with asterisks before and after them denote the more important errors introduced by Pengelly in his 1868 reprint of the 1797 text.
- Underlining in the quotation below is as in Pengelly's manuscript copy of the 1783 article.

These brackets, symbols and changes of typeface necessary to distinguish between the 1783 and 1797 texts already complicate this reprint so much that the identification of the parts of the cave referred to is left until the end, where they are keyed to the reprinted text by superscript letters, thus[a,b].

<u>An Account of Kent's Hole, a Natural Grotto, in the County of Devon. Written by a Gentleman who lately visited it, and addressed to a Friend of his</u>

Sir:- <u>*Kent's Hole*</u> *[consisting of limestone, marble, and stalactites,] is situated about a mile and half from Torkey [=Torkay]. It hath two openings, about half way up a steep cliff,* ***covered with brush wood, and enamelled with a profusion of flowers, particularly the cowslip, which I believe is not considered a native of Devon.*** *The opening to the left[a] is an arch about two feet high, which lets you [=us] into the great cavern at once; [=:] but the more accessible entrance[b] is by a cleft in the rock on the right hand, which is about five feet high, three feet wide, and forty-three in length, and [=.It] leads you [=us] also into the great Cave[c] [=cave], which is ninety-three feet in depth, and about one [=an] hundred feet in width; the [=.The] extreme height may be about thirty feet, [=;] but the height is very unequal, as the floor rises in the middle to within a few feet of the roof. Two more openings front you [=us] here: that on the left[d] leads you [=us] on a level into a cave[e] fifty-two feet long and twenty-two feet broad, [=;] and then into a second[f]; [=,] fifty-four feet long, and about fifteen feet wide. Here a pool of water[g] closes the cave, [=;] and the arch bends over it. These caves are all [=also] [*=all*]* ***about*** *thirty feet high. And here, once for all, let it be understood, that from fifteen to twenty feet [,] is the height of all the caves here after [=hereafter to be] mentioned, [= -] and the extreme breadth about fifteen.*

Returning to the great Cave[c] [=cave], I entered the opening on the right, descending [=and descended] by a very rocky ["rocky" omitted*], slippery way[h], into a passage[i] one hundred and thirty six [=136] feet long, and from six to twelve feet high. I then ascended several steps of rock[j], covered with congelations, [=;] and pursued the passage (which now in several [=some] places obliged me to stoop) for forty-two feet more, [=;] when I entered a fourth cave[k], thirty-one feet long: thence [=. Thence], by a [low] [*=long*] narrow passage, forty-six feet long, I was conveyed into a fifth Cave[l] twenty-five feet long; from whence [= From this], on the right hand, branches another cavern[m], twenty-two feet long [=in length]. I then went through another passage for fifty-six feet; [=,] when, meeting [with] another ledge of rocks, I clambered over them and descended [=ascended] [*=descended*] into a vault so low[n], as to oblige me to crawl on my hands and knees for sixty feet, [=;] when I entered a seventh cavern[o] fifty feet long, [= -] with another on the right hand[p], about thirty. At the end of the largest of these caverns there is a pool of water[q], which, on account of its depth, I could not venture to measure, but I should guess it to be about twenty feet in length; [=:] and here the cave finally closes. By this measurement, leaving out the odd inches, which, on account of the irregularity [=irriguity] of the floor, may be thrown into the scale, I find the depth of this cavern to be six hundred and two [=682] feet; [=:]* ***but*** *yet I am aware, that any person who shall hereafter give himself the trouble to measure it, with the same regard to truth and accuracy as I did, may find the dimensions* ***very*** *different, on account of the darkness of the Cave [=cave], the projecting rocks; and the inequalities of height [=heighth] and breadth.*

This cavern, though ***much*** *inferior to the Derbyshire Caves [=caves] in extent and loftiness, and to Wokey in the latter respect, is yet of greater extent than Wokey, and hath four more caves. The petrefactions [=petrifactions] are very fine, [=:] and it abounds with those cones, formed of the drop-stone [=sort of dropstone], of which Mr[.] Pope robbed Wokey to decorate his grotto at Twickenham. One of these cones, near the centre of the great Cave[c] [=cave], with the stalactite[s] which formed it pendant [pendent] from the roof, would not disgrace the grotto of Antiparos. Another very large [c]one will soon block up the second passage, and close the Cave [=cave], unless another [=some] whimsical grotto[-]maker should settle near Torkey [=Torkay]. Here are several pools of very cold, pellucid water[r], [=;] but no running stream, as at Pool's Hole [=Pool's-hole] in Derbyshire, and Donald Mill Hole [=Mill-hole] in Lancashire,* ***both which I have seen.*** *The murmur of these streams, reverberated by the hollows of the cavern [=caverns there], produces a most awful effect.* ***I saw several bats in a torpid state, pendant from the roof and sides.***

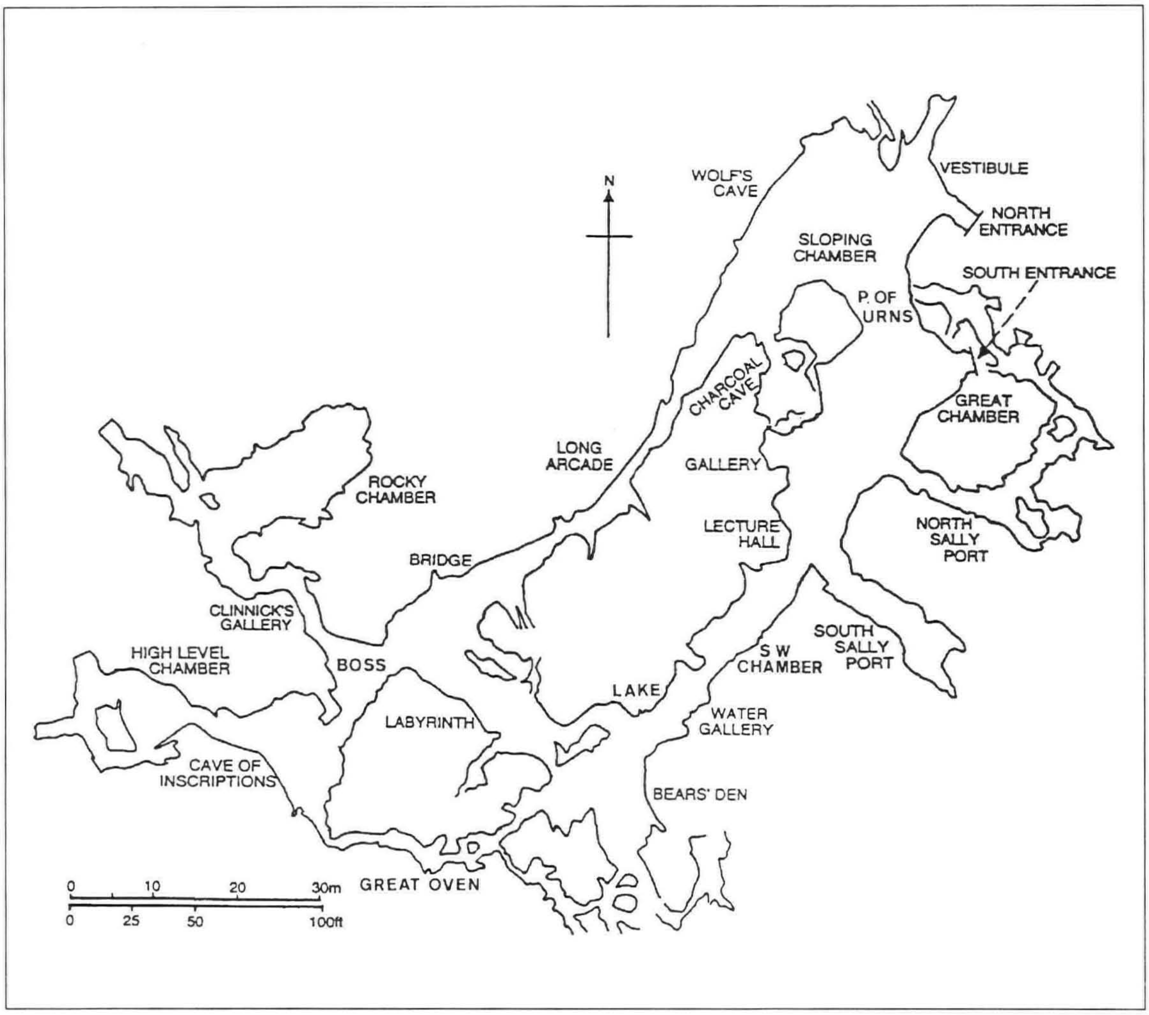
The solitary situation of this cave adds greatly to its solemnity; [=.] and I assure you, Sir, that my visit to this Cavern hath given me fresh cause to regret that a county, the second in extent in England and the most various and diversified in soil and enternal appearance hath not produced one man who would undertake to celebrate its natural productions.

[A gentleman of my acquaintance, who resides in a distant county, and who lately made a tour into Devonshire, was so obliging as to communicate to me the following remarks on Kent's-hole. I should not mention this gentleman without adding, that I consider my introduction to himself and family as one of the happiest incidents of my life. - We walked to Kent's-hole, about a mile from the Anchor inn at Torkay. An old woman (77 years of age) with candles, went with us, to be our guide in the cavern; and who, as soon as we came to the mouth of it, struck a light in a tinder-box she brought with her; and each of us entered the cave with a lighted candle in our hand. We continued in the cave half an hour, going 100 yards in it or about half the way that people sometimes go - to some water[s], which is at times five or six feet deep, though at other times very low. The congelations and incrustations of this cavern were very fine. In some parts, it was ten or twelve feet high, and in one place resembled a coved apartment[t], overlaid with curiously wrought vast stones. And in another place there was a convex stone, of a prodigious size, covered (from its color) as it were with brown sugar candy, which we had difficulty in getting by. And the variety of stones, the pearly hanging drops of water from the icicles, and petrifactions, were pleasing: and it was the next best subterraneous cavern to that stupendous one at Castleton in Derbyshire, I had ever seen."]

Professor Allan Straw of Exeter, who knows the cave intimately, has kindly provided information for the following key to modern names for parts of the cave mentioned. He points out that Polwhele describes two separate routes from the Great Cave (now the Vestibule) into the rest of the cave. In his first paragraph the left-hand opening leading from it goes to the Lecture Hall; in the second paragraph the right-hand passage from the Vestibule is longer and leads through the Long Arcade, Cave of Inscriptions, Great Oven and Bears' Den to the Lake, which closed the way until Pengelly cut the Water Gallery beneath it in the next century. The routes can be followed in Fig.8.

In the key below the names used by Polwhele (linked to his text by superscript letters) are followed by the present-day names.

Figure 8. Kent's Hole, with the modern names of places visited by Polwhele in 1782 or 1783 (cave outline after Proctor and Smart[54]).



a) opening to the left : South Entrance
b) more accessible entrance : North Entrance (Fig.9)
c) great Cave : Vestibule
d) opening ... on the left : Passage of Urns
e) cave : Great Chamber (Fig.10)
f) second [cave] : Lecture Hall
g) pool of water : there is still evidence of this on the side of South-West Chamber
h) rocky slippery way : Sloping Chamber
i) passage : Long Arcade
j) several steps of rock : Bridge
k) fourth cave : Inscribed Boss Cave
l) fifth Cave : Cave of Inscriptions
m) another cavern : lower part of High Level Chamber
n) vault so low : Great Oven
o) seventh cavern : west and NW parts of Bears' Den
p) another on the right hand : south part of Bears' Den
q) pool of water : The Lake
r) several pools of ... pellucid water : there is still much evidence of these. Before the 19th century excavations of MacEnery and Pengelly the uneven floors of flowstone caused such pools in many parts of the cave. Removal of flowstone in the course of the excavations drained these as well as opening up new passages
s) 100 yards ... to some water : the gentleman of Polwhele's acquaintance was apparently taken on the short route described in Polwhele's first paragraph, reaching the pool in South-West Chamber. His statement that some people go twice as far suggests that the longer route to the Bears' Den was also shown by the guides, perhaps for a larger fee
t) coved apartment : probably the Gallery.

Polwhele's measurements of passage lengths are reasonably accurate. Although the figure he gave for the total length of the cave (602 feet in the 1783 article as copied by Pengelly) was corrected to 682 feet in his book of 1797, the sum of the passage lengths in his text amounts to 740 feet (226m), compared with about 770 feet (235m) for the same passages in an accurate modern plan[54].

Figure 9. The North Entrance in 1832 or a few years earlier. Reproduced from a lithograph in Blewitt's Panorama of Torquay of 1832[55], the picture is probably based on an undated watercolour by Charles N. Woolnoth (T22/127 in the collection of the Torquay Natural History Society).

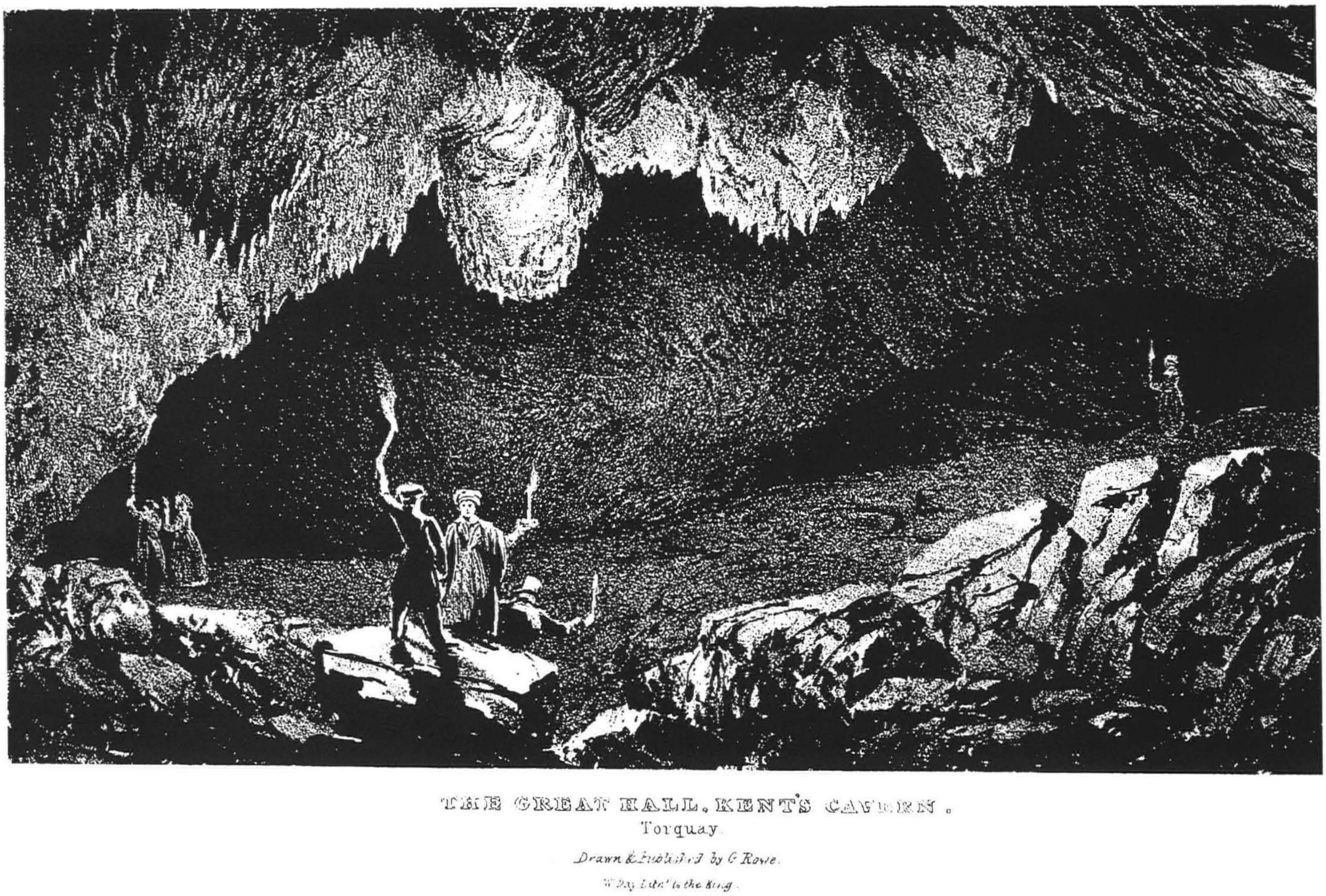


Figure 10. "The Great Hall, Kent's Cavern, Torquay." A lithograph of about 1835[56] drawn and published by George Rowe. This represents what is now called the Great Chamber, seen looking NW from the mouth of the North Sally Port. The dark opening at the extreme right leads north to the Vestibule. The hole in front of the right-hand figure is the entrance to the Gallery. The opening at the left of the picture is the Lecture Hall.

CONCLUSIONS

The significance of the 18th century material on Kent's Hole discussed in this paper amount to this:

1. A description of the cave was written some time between 1750 and 1767 (probably about 1755) and sent to Jeremiah Milles for use in his intended book on Devon. The book was never completed and the description has disappeared, but the fact that the cave was thought important enough to warrant a description at that time is of interest.
2. James Cornish brought Horseshoe bats from Kent's Hole for his experiments on the hibernation of mammals at the time when some migratory birds were also suspected of hibernating.
3. The 1778 edition of Defoe's *Tour through ... Great Britain*, containing four sentences on the cave, was the first to bring it to the attention of a wide readership, such as the Derbyshire caves and Wookey Hole had enjoyed for a century or more.
4. The first long description of the caves, known previously only from Polwhele's 1797 *History of Devonshire*, had already appeared anonymously, with a few differences, in a magazine of 1783.
5. None of these items refers to the presence of bones or of worked tools.

ACKNOWLEDGEMENTS

Above all I appreciate the help given to me by the Royal Society in London, especially its archivist Mary Sampson, who allowed me to use their archives. The President and Council gave permission for the extracts to be reproduced here.

Dr Michael Bishop, former curator of the Torquay Natural History Society Museum, provided a photocopy of Pengelly's transcript of the 1783 Polwhele article, and read through this paper in draft. Some 35 years earlier his predecessor, the late Dr F S Wallis, provided free access to the Society's manuscripts and so enabled me to discover the Pengelly transcript.

Professor Allan Straw of the University of Exeter has spent many years studying the geomorphology and sedimentology of the cave[57]. He used his knowledge of the changes made there by the extensive 19th century excavations to identify the routes described in Polwhele's article of 1783 and the openings shown in the 1835 picture of the Great Chamber (Fig.10).

Dr Juanita Burnby of Wirksworth and Major Charles O'Leary, Honorary Archivist of the Worshipful Society of Apothecaries of London, shared their experience of sources for medical biography.

The Society of Antiquaries has allowed me to reproduce their portrait of Milles for the second time in connection with his cave work, and the British Library in London remained its usual dependable self.

John Hooper made helpful comments on an early draft of the paper.

To all these I am grateful, for without them this paper would have been incomplete or even non-existent.

NOTES AND REFERENCES

1. Pengelly, W, 1868. The literature of Kent's Cavern, Torquay, prior to 1859. *Report and Transactions of the Devonshire Association for the Advancement of Science, Literature, and Art*, Vol.2, Pt.2, 469-522.
2. Pengelly, W, 1869. The literature of Kent's Cavern. Part II. *Report and Transactions of the Devonshire Association for the Advancement of Science, Literature, and Art*, Vol.3, Pt.1, 191-482.
3. Pengelly, W, 1871. The literature of Kent's Cavern. Part III. *Report and Transactions of the Devonshire Association for the Advancement of Science, Literature and Art*, Vol.4, Pt.2, 467-490.
4. Pengelly, W, 1878. The literature of Kent's Cavern. Part IV. *Report and Transactions of the Devonshire Association for the Advancement of Science, Literature, and Art*, Vol.10, 141-181.
5. Pengelly, W, 1884. The literature of Kent's Cavern. Part V. *Report and Transactions of the Devonshire Association for the Advancement of Science, Literature, and Art*, Vol.16, 189-434.
6. MacEnery, J, [c.1829-1840]. *Cavern Researches*. MS. *in* the library of the Torquay Natural History Society.
7. Pengelly, W, 1878. *op. cit.*, pp.141-142.
8. Pengelly, W, 1869. *op. cit.*, pp.191-192.
9. Swete, J, 1792. *Picturesque sketches of Devon*. MS. 564 M/F 2 *in* the Devon County Record Office. Vol.2, 1792, 217pp (pp.111-112). The whole MS.(1789-1801) was in 20 vols but vols 3, 5 and 19 were destroyed in World War II, leaving 17 (DRO 564 M/F 1-17).
10. Pengelly, W, 1871. *op. cit.*, pp.467-468.
11. Maton, W G, 1797. Observations relative chiefly to the natural history, picturesque scenery, and antiquities, of the western counties of England, made in the years 1794 and 1796. [Salisbury: J Easton.] 2 vols. (Vol.1, pp.119-121); also the cave description reprinted in Pengelly, 1868. *op. cit.* pp.470-471.
12. Polwhele, R, 1797, 1793, 1806. *The history of Devonshire*. [London: Cadell, Johnson and Dilly.] 3 vols. (Vol.1, 1797, pp.50-51) (a facsimile reprint was published in 1977 by Kohler and Coombes of Dorking); also the cave description reprinted, with some errors, in Pengelly, 1868 *op. cit.* pp.471-473.
13. Anon., 1782. Portrait of Turgott. *The Gentleman's Magazine*, Vol.52, June, 288.
14. C[ourtney], W P, 1894. Milles, Jeremiah (1714-1784). Pp.432-434 *in* National Biography, vol. 37. [London: Smith Elder.]
15. Pococke, R, 1743-1745. *A description of the East, and some other countries*. [London: printed for the author.]2 vols. (Vol.2, Pt.2, 1745, pp.257-261).
16. Milles, J, 1736-1737. Copies of letters to the Bishop of Waterford, Vol. 2. British Library Add. MS. 15774, 133ff. (ff.91a-98b).
17. Milles, J, [c. 1750-1753] Bodleian MSS. Top. Devon. b.1-2.
18. Milles, J, [c. 1750-1762] Bodleian MSS. Top. Devon. c.8-12.
19. Hennessy, [n.d.]. Devon incumbents. West Country Studies Library, Exeter, MS SX 283. 0922 WES HEN (4 vols.).
20. Typed introduction to the microfilm copies of Milles's Bodleian MSS (see 17 and 18 above) in the West Country Studies Library, Exeter.
21. Shaw, T R, 1997. Škadavnica Cave explored by English travellers in 1737. *Acta Carsologica*, Ljubljana, Vol.26. Pt.2. pp.203-224.
22. Catcott, G S, 1792. A descriptive account of a descent made into Penpark-Hole, in the parish of Westbury-upon-Trim, in the county of Gloucester, in the year 1775. [Bristol: printed by J Rudhall.] 51pp. (A second issue of this book, published in the same year, had a 5-page supplement at the end).
23. Catcott, G S, 1792. *op. cit.*, p.51.
24. James Cornish, eldest son of James and Margaret Cornish of Teignmouth, was baptised on 2 February 1743/44 (i.e. 1744 in the modern calendar) (Parish Register for West Teignmouth, MF 1 at the Devon Record Office in Exeter). The family history states that he was born in 1743 but whether its author had definite information that he had been born before 1 January or whether he had confused the old and new style calendar dates is not known (pp.3-5 in V Cornish. 1942. *A family of Devon their homes, travels and occupations*. [St. Leonards-on-Sea: King and Potts.] [viii], 56pp.). Cornish settled in Totnes as a surgeon; the family history, and his obituary, attribute to him an MD degree, which is most unlikely. Surgeons, who only separated from the Barber-Surgeons company in 1745, were not normally educated at university but learned their skills by apprenticeship. He is not recorded as being made MD at any of the normal universities - Oxford, Cambridge, Aberdeen, Edinburgh or Leiden, though it is just possible that he might have obtained one late in life from a German university. It was not uncommon for an imaginary doctorate to be used in describing a medical practitioner, especially in family histories. James seems to have described himself only as a *"surgeon"*. He is listed as such also on p.135 of Wallis, P J and R V, 1988. *Eighteenth century medics ....* Newcastle upon Tyne, Project for Historical Biobibliography, 690pp. In this book, however, his life is conflated with that of someone of the same name who lived in Bristol, so his dates are given wrongly. He died in Totnes on 10 September 1828 (*Trewman's Exeter Flying Post*, Vol.67, No.3291 of 18 September 1828. p.2, col.d).
25. M[acdonell], G P, 1885. Barrington, Daines (1727-1800). Pp. 286-288 in Dictionary of National Biography. Vol.3. [London: Smith Elder.]
26. [White, G], 1789. *The natural history and antiquities of Selborne, in the county of Southampton*. [London: B White.], v, 468, [xiii] pp. (and many later editions).
27. [White, G], 1789. op. cit., p. 138.
28. Cornish, J, 1775a. Three letters, dated 3 February, 31 March and 9 May, on the torpidity of swallows and martins. Royal Society archives, L and P. VI. 114.
29. Cornish, J, 1775b. Of the torpidity of swallows and martins. *Philosophical Transactions of the Royal Society*, Vol.65, pt. II, pp.343-352.
30. Royal Society Journal Book Copy, Vol.28, pp. 243-260. They were not all read on 25 May as stated in Ref. 29. p.343.
31. Cornish, J, 1775a, op. cit., letter dated 9 May, p. [1].
32. Cornish, J, 1775a. op. cit., letter dated 3 February, p. [1].
33. Witherby, H F, Jourdain, F C R, Ticehurst, N F, Tucker, B W, 1943-44. *The handbook of British birds*. [London: H F and G Witherby.] 5 vols. (Vol.2, p.237).
34. Royal Society Journal Book Copy, Vol.28, pp.257-259.
35. Cornish, J, 1775b. Op. cit., p.346.
36. Cornish, J, 1775b. Op. cit., pp.351-352.
37. Hooper, J H D, 1951. Bat banding in Devonshire. *Transactions of the Devonshire Association for the Advancement of Science, Literature and Art*, Vol.83, pp.272-277 (p.276).
38. Barrington, D, 1781. *Miscellanies*. [London: White and Nichols.] (p.166).
39. *The Gentleman's Magazine*, Vol.51, April, 1781, p.176.
40. Polwhele, R, 1797, 1793, 1806. op. cit. (Vol.1, 1797, pp.8, 81).
41. 40A. Cotton, W, 1850. *A graphic and historical sketch of the antiquities of Totnes*. [London: Longman, etc.], vi, [ii], 101pp.
42. Polwhele, R, 1797, 1793, 1806. op. cit. (Vol.1, 1797, p.126).
43. Defoe, D, 1778. *A tour through the island of Great Britain*. [London: W Strahan.] 8th edn. 4 vols. (Vol.1, pp.347-348).
44. Pengelly, W, 1884-94. Miscellaneous Devonshire Gleanings Part III. MS. in the library of the Torquay Natural History Society. 53ff. (ff. 13-14). This unpublished text must have been written between 1884, when the last part of The Literature of Kent's Cavern was produced, and Pengelly's death in 1894.

45. 43A. As note 42 but edition of 1779. [Dublin: Chamberlaine.] 9th edn., 4 vols (Vol.1, pp.347-348).
46. Defoe, D, 1927. *A tour through England and Wales.* [London: P Davies.] 2 vols.
47. Defoe, D, 1928. *A tour through England and Wales.* [London: J M Dent.] 2 vols. [Everymans's Library: 820, 821].
48. Defoe, D, 1724-27 [=26]. *A tour thro' the whole island of Great Britain* ... [London: G Strahan.] 3 vols.
49. [Polwhele, R], 1783. An account of Kent's Hole, a natural grotto, in the county of Devon. Written by a gentleman who lately visited it, and addressed to a friend of his. *Weekly Entertainer*, Sherborne, [1st ser], Vol.1, 5 May, pp. 422-???
50. Pengelly, W, 1884-94. op. cit., f.1.
51. Pengelly, W, 1884-94. op. cit., ff. 7-13.
52. Nichols, J B, 1858. Illustrations of the literary history of the eighteenth century.... [London: J B Nichols.] 8 vols. (Vol.8, pp.646-647).
53. C[ourtney], W P, 1896. Polwhele, Richard (1760 - 1838). 71-73 *in* Dictionary of National Biography, Vol.46. {London: Smith, Elder.]
54. Polwhele, R, 1826. Traditions and recollections. Domestic, clerical and literary ... [London; J Nichols.] 2 vols. (Vol. 1, frontis). Reproduced here from Nichols, J B, 1858, op. cit., Vol.8 opp. p.647.
55. *The European Magazine and London Review*, Vol.28, No.[5], November 1795, opp. p.329.
56. A detailed survey of the cave at a scale of 1 : 425 was published opp. p.428 of C J Proctor and P L Smart, 1989. A new survey of Kent's Cavern, Devon. *Proceedings of the University of Bristol Spelaeological Society*, Vol.18, No.3, pp.422-429.
57. Blewitt, O, 1832. The Panorama of Torquay... 2nd edn. [London: Simpkin and Marshall.] viii, [iv], 288pp. (engraved title page).
58. Cocks, J V S, 1977. *Devon Topographical Prints 1660-1870 a catalogue and guide.* [Exeter: Devon Library Services.] viii, 324pp. (pp.216, 271).
59. Straw, A, 1997. Kent's Cavern - whence and whither? *Cave and Karst Science*, Vol.24, No.1, pp.35-40.

CAVE AND KARST SCIENCE Vol. 27, No. 1, April 2000
Transactions of the British Cave Research Association

ISSN 1356-191X

The Age of the Woolly Rhino from Dream Cave, Derbyshire, UK

Donald A McFARLANE [1], Joyce LUNDBERG [2] and Derek C FORD [3]
[1] W M Keck Science Center, The Claremont Colleges, 925 North Mills Avenue, Claremont, CA 91711, USA
[2] Department of Geography and Environmental Studies, Carleton University, Carleton, Ontario, K1S 5B6, Canada
[3] Departments of Geography and Geology, McMaster University, Hamilton, Ontario L8S 4K1, Canada

Abstract: The Dream Cave woolly rhinoceros, *Coelodonta antiquitatis*, is a 'classic' specimen of a 'cold-stage' fossil fauna from central England. The find was illustrated and described by Dean William Buckland in his seminal tome *Reliquiae Diluvianae* (1823) during the first half of the 19th century, and made a significant contribution to the development of Buckland's views on the origin of extinct and extirpated fossil vertebrates. Here we present the first, albeit indirect, radiometric dates on the specimen, and argue that the animal fell into the cave just before 37,000 years before present, during the middle of Marine Isotope Stage 3 Interstadial (39-41 ka).

(Received 25 April 2000; Accepted 22 May 2000)

BACKGROUND AND HISTORICAL INTRODUCTION

Dream Cave first came to attention in December 1822, as a result of lead mining activity near the hamlet of Callow, near Wirksworth, Derbyshire. Miners sinking an exploratory shaft just north of Sprink Wood (NGR 275 530) breached a natural cave, completely (or almost completely) filled with clastic sediments. Whilst excavating this material they encountered the bones of '*ante* Diluvian' animals. William Buckland, first Professor of Geology at Oxford University, learned of the discovery through the property owner, Phillip Gell, and a mutual friend, the Reverend D Stacy. Buckland made haste to the site *"... for the purpose of examining all* [the discovery's] *circumstances..."* (Buckland, 1823, p.61). The principal discovery was of the skeletal remains of an adult woolly rhinoceros, *Coelodonta antiquitatis,* (Fig.1), together with fragmentary remains of horse, bear, and deer. Continued excavation of the fill exposed a natural fissure entrance, which forms both the original and modern entrance to the cave. Buckland figured the cave in a copperplate illustration (Fig.2), drawn by T Webster from Buckland's original notes.

Despite the prominence afforded to Dream Cave in *Reliquiae Diluvianae*, the site has not been re-examined critically in more recent times. The presence of *Coelodonta* is characteristic of a cold-stage fauna, so the site has been generally assumed to be later Devensian in age (e.g. Sutcliffe, 1983). All radiometrically-dated *Coelodonta* specimens from Britain fall in the range 35,000 – 22,350 ^{14}C years BP, but records are scarce (Table 1). Thus, a possibility that *Coelodonta* persisted through the Devensian maximum at ~ 18,000 ^{14}C years BP cannot be discounted. It might even have extended into the Younger Dryas (~ ~11,000-10,000 ^{14}C years BP: chronozones from Mangerud *et al,* 1974), which supported a fauna of reindeer (*Rangifer tarandus*) and steppe pika (*Ochotona pusilla*). The latest European continental record of *Coelodonta* is *c.*12,500 ^{14}C years BP (skeletal remains and late Magdalenian engravings; Bosinski, 1978; 1981). If the species was eliminated locally during the Devensian maximum it may have failed to recolonise Britain as the ice front retreated.

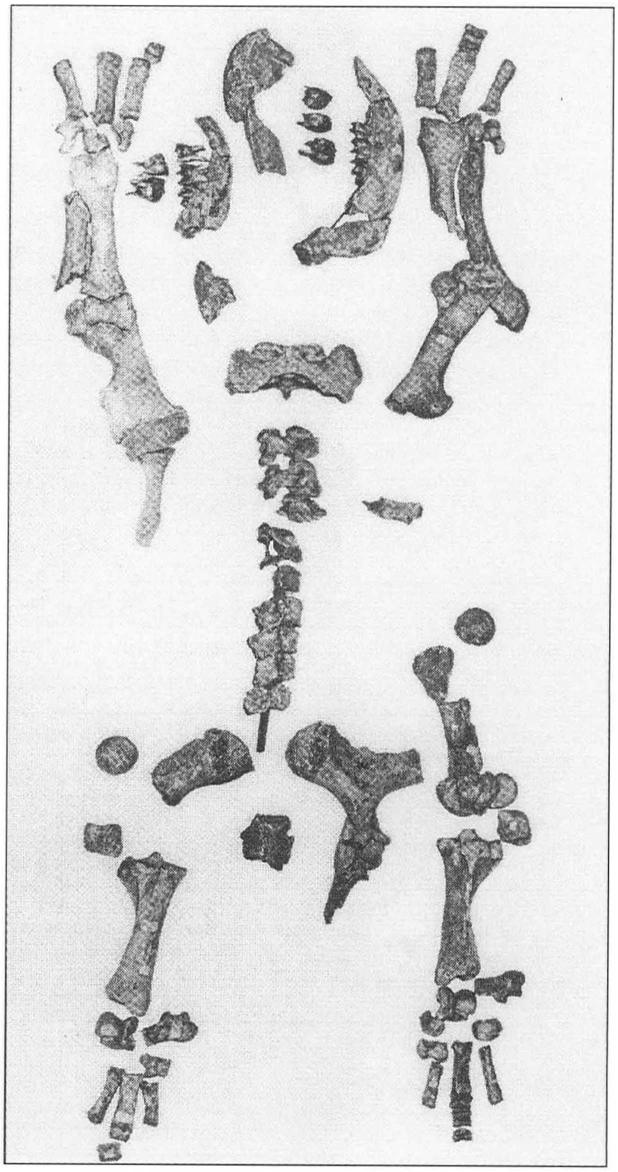


Figure 1. Buckland's Dream Cave Coelodonta specimen, courtesy of the Oxford University Museum.

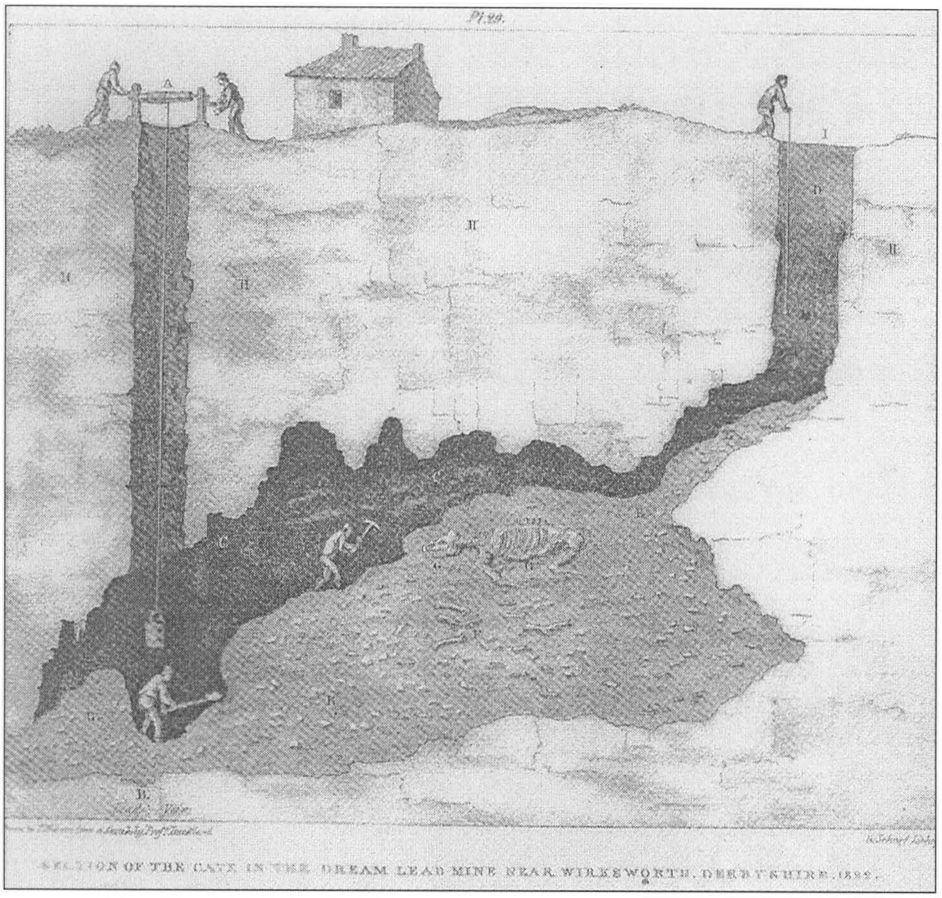


Figure 2. Copperplate illustration of Dream cave in 1822 (Buckland, 1823).

DISCUSSION OF THE CURRENT WORK

Examination of the *Coelodonta* specimen in the collections of the University Museum, Oxford University, uncovered the presence of a hitherto un-noted block of flowstone. The block carried the notation, tten in Indian Ink in Buckland's handwriting, *"from out the Dream Cave"*. As indicated by the moulds of clastic fragments and the ochre-coloured clay adhering to the lower surface, this flowstone overlay the soft sediment that preserved the bones of the woolly rhinoceros. Unfortunately none of this flowstone or equivalent material remains at the site today. The specimen consists of a layer of dense, laminated flowstone, several centimetres thick, whose underside preserves traces of a yellowish, argillaceous sediment and moulds of rounded clasts 1 to 5mm in diameter. A sketch of the sub-sample taken from Buckland's block is shown in Fig. 3.

Uranium series disequilibrium dating by thermal ionisation mass spectrometry was conducted at McMaster University. Two samples of ~1g each were taken, and laboratory preparation and dating followed standard procedures (see for example, Lauritzen and Lundberg, 1999). Isotope measurement was carried out using a VG354 thermal ionization mass spectrometer. Results are presented in Table 2. The low value for the activity ratios of $^{230}Th/^{232}Th$ suggests the presence of some detrital or non-radiogenic ^{230}Th. Correction for this would reduce the ages a little. However, the very low absolute concentrations of thorium (below 0.1 ppm) and the relatively high value of $^{234}U/^{232}Th$

22,350 620	Ogof Yr Ychen, Caldey Island.
22,500 700	Pin Hole Cave, England.
24,372 153 (weighted mean of 5)	Earls Barton, Northampton.
27,550 + 1370 / -1680	Bishopbriggs, Scotland.
28,160 435	Kent's Cavern, Devon.
29,300 480	Robin Hood's Cave, England.
29,450 350	Leadenhall Street, London.
30,729 405 (weighted mean of 2)	Ash Tree Cave, England.
32,180 580	Tornewton Cave, Somerset.
33,200 650	Pontnewydd Caves, Wales.
34,101 779 (weighted mean of 3)	Conningbrook, Kent.
34,559 573 (weighted mean of 2)	Kent's Cavern, Devon.
40,900 1800	Ash Tree Cave, England.
42,700 2200	Pin Hole Cave, England.
42,900 2400	Robin Hood's Cave, England.

Table 1. Radiometric dates on Coelodonta antiquitatis *(Gowlett, et al., 1987; Hedges et al., 1989; 1994; 1996)*

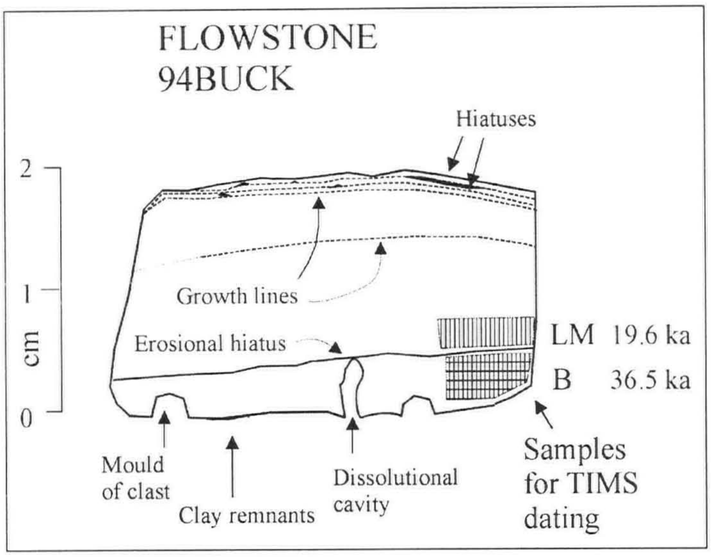


Figure 3. Diagrammatic sketch of the flowstone from Buckland's Dream Cave collection.

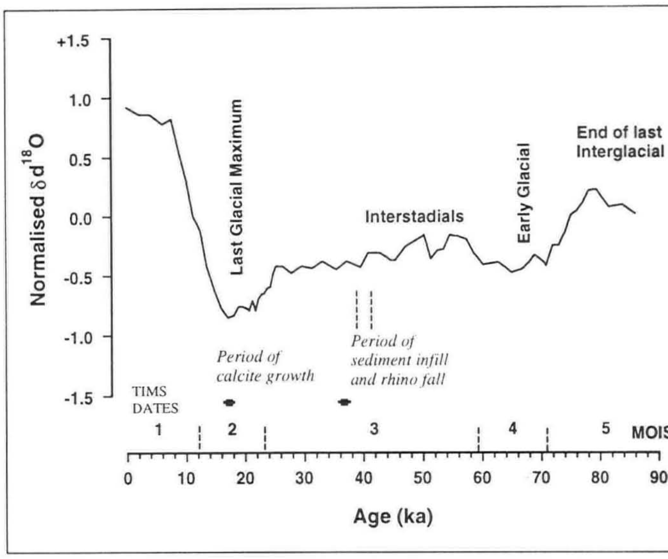


Figure 4. Marine isotope chronology of the Devensian and the Dream Cave deposits.

suggest that the detrital component is insignificant, so that use of the corrected value is probably not justified.

Sample B was cut from the basal layer, separated from the next layer, which provided sample LM, by an obvious erosional hiatus, marked by unconformable growth layers. A date of 36,451 -1262 +1277 ka on the basal sample of calcite just above the sediment fill indicates that calcite deposition began towards the end of isotope stage 3. The hiatus probably represents the Late Glacial Maximum, isotope stage 2, when conditions would have been cold and dry. A date of 19,600 -690 +695 just above the hiatus level suggests that calcite deposition resumed immediately after local deglaciation. Higher layers of the sample have not been dated; the topmost few millimetres show a distinct change in colour and several clay-lined, but not erosional, hiatuses, one of which is the top layer. Dissolutional cavities shown in the basal layer in Fig. 3 developed upwards from the base, but the hiatus level limited their penetration. This dissolutional etching probably occurred as water penetrated the sediment-calcite interface after calcite deposition had ceased.

Because its lower surface demonstrates clearly that the flowstone was deposited on top of the cave sediment, the rhino must have fallen into the cave before calcite deposition began, i.e. before 36 ka. *C. antiquitatis* is known from remains dated (stratigraphically) as 'early Devensian' (*c.*70 – 54 ka) in the Crayforth brickearths of Kent (West, *et al.*, 1964), and from Tornewton Cave, Somerset (Sutcliffe and Zeuner, 1962). So, the species undoubtedly entered Britain following the Eemian Interglacial (marine isotope stage 5). However, the steppe-tundra climate of central England during marine isotope stage 4, 'early Devensian', time was interrupted between about 43 – 41 ka by a warm interstadial, evidenced by a fossil beetle fauna (Huizjer and Isarin, 1996). It seems likely that, had the Dream Cave *Coelodonta* deposit been in place, interstadial conditions would have initiated speleothem growth and capped the deposit. The flowstone shows no evidence of deposition at this time. Therefore, it is most parsimonious to conclude that the rhino and the sediment deposit were emplaced during the sharp, cold stadial (Heinrich 4 event), which prevailed from about 41-39 ka (Fig.4). Sediment infilling must have been rapid, because the rhino was preserved intact (Appendix 1; Fig.1), which could not have occurred if the carcass had remained exposed for many seasons under such harsh conditions. An amelioration of climate at 39-36 ka followed the Heinrich H4 stadial, and the timing of this mild interstadial correlates well with the deduced date of initiation of speleothem growth over the sediment infill at Dream Cave.

ACKNOWLEDGEMENTS

Richard Gledhill and Anna Hubbard provided assistance with the fieldwork. Mr Phillip Powell of the University Museum, Oxford, kindly provided access to the specimen. Uranium series dating was performed in the McMaster University Speleothem Dating Laboratory, supported by the Natural Sciences and Engineering Research Council of Canada grant to D C Ford.

REFERENCES

Bosinski, G (Editor), 1978. Geowissenschaftliche Untersuchungen in Gönnersdorf. [Wiesbaden.]

Bosinski G, 1981. Gönnersdorf; Eiszeeitjäger am Mittelrhein. 258pp. [Koblenz: Rhenania. Steiner.]

Buckland, W. 1823. Reliquiae Diluvianae: or, observations on the organic remains contained in caves, fissures, and diluvial gravel, and on other geological phenomena, attesting to the action of a universal deluge. viii + 303 pp. [London: Murray.]

Gowlett, J A, Hedges, R E M, Law, I A and Perry, C, 1987. Radiocarbon dates from the Oxford AMS system: Archaeometry Datelist 5. *Archaeometry*, Vol.29(1),125-155

Table 2. U-series data. All errors quoted are 2Φ. All ratios are activity ratios.

Sample Lab code	mm from base	Age (years before 1997)	U conc (ppm)	Th conc (ppm)	$^{230}Th/^{234}U$	$^{234}U/^{238}U$	$^{230}Th/^{232}Th$	Initial $^{234}U/^{238}U$	$^{234}U/^{232}Th$
94 BUCK LM2	2-5	19,600 - 690 +695*	1.272 ±0.0030	0.0411 ±0.0002	0.165 ±0.005329	1.084 ±0.003407	17.67 ±0.566	1.08924 ±0.00018	107.14 ±4.84
94 BUCK B2	5-8	36,451 -1262 +1277*	1.539 ±0.0034	0.0892 ±0.0005	0.287 ±0.008459	1.196 ±0.003883	18.92 ±0.551	1.21778 ±0.00078	65.88 ±0.11

*Correction for detrital thorium using an initial 230/232 activity ratio of 1.7 gives an age of 17,895 -680 +684 and 33,726 -1232 +1246 respectively.

Hedges, R E M, Housley, R A, Law, I A and Bronk, C R, 1989. Radiocarbon dates from the Oxford AMS system: Archaeometry Datelist 9. *Archaeometry*, Vol.31(2), 207-234.

Hedges, R E M, Housley, R A, Ramsey, C R and von Klinken, G J, 1994. Radiocarbon dates from the Oxford AMS system: Archaeometry Datelist 18. *Archaeometry*, Vol.36(2), 337-344.

Hedges, R E M, Pettit, P B, Ramsey, C R and von Klinken, G J, 1996. Radiocarbon dates from the Oxford AMS system: Archaeometry Datelist 22. *Archaeometry*, Vol.38(2), 391-415.

Huijzer, A S and Isarin R F B, 1996. Reconstruction of past climates using multi-proxy evidence: example of the Weichselian pleniglacial in NW and central Europe. *Quaternary Science Reviews*, Vol.16, 513-533.

Lauritzen, S-E and Lundberg, J, 1999. Calibration of the speleothem delta function: an absolute temperature record for the Holocene in northern Norway. *The Holocene*, Vol.9, 6, 659-669.

Mangerud, J, Andersen, S T, Berglund, B E and Donner, J J, 1974. Quaternary stratigraphy of Norden: a proposal for terminology and classification. *Boreas*, Vol.3, 109-127.

Stuart, A J, 1983. Pleistocene bone caves in Britain and Ireland: a short review. *Studies in Speleology*, Vol.4(9), 9-36.

Sutcliffe, A J and Zeuner, F E, 1962. Excavations in the Torbryan Caves, Devonshire. 1. Tornewton Cave. *Proceedings of the Devon Archaeological and Exploration Society*, Vol 5, 127-145.

West, R G, Lambert, C A and Sparks, B W, 1964. Interglacial deposits at Ilford, Essex. *Philosophical Transactions of the Royal Society*, B247, 185-212.

APPENDIX I

Skull and Jaw	
	Nasal region with septum Partial maxilla 5 detached upper molariform teeth Left mandible Right mandible 1 detached lower molariform tooth
Trunk	Atlas 3rd and 4th cervical vertebrae 2 dorsal vertebrae 3 lumbar vertebrae Sacrum 1 rib fragment Partial left scapula
Limbs	Left and right humerus, ulna, radius Left and right scaphoid, lunar, cuneiform (left only), magnum(left only) and unciform carpals Left and right II, III, and IV forelimb metacarpals Left and right portions of pelvis Left and right femora and tibia Left and right patella Left and right astragalus, calcaneum, and cuboid tarsals Right navicular tarsal II, II, IV hind metatarsals

CAVE AND KARST SCIENCE Vol. 27, No. 1, April 2000
Transactions of the British Cave Research Association

ISSN 1356-191X

Anomalous scallop distributions in Joint Hole, Chapel-le-Dale, North Yorkshire, UK

Phillip J MURPHY[1], **Adrian M HALL**[2] **and John N CORDINGLEY**[3]
[1] School of Earth Sciences, University of Leeds, UK
[2] 3 Wellesley Court, Wellington Road, Ilkley, West Yorkshire, UK
[3] 29 Lynwood Close, Darwen, Lancashire, UK

Abstract: Observations and subsequent measurements made by cave divers in the Joint Hole active phreatic conduit have revealed two distinct and adjacent scallop distributions. Analysis using well established hydraulic equations show that the scallops are indicative of very different sub-critical, turbulent flow regimes. That derived for scallops observed on the floor of the passage agrees with evidence gained from previous studies of the sediment populations (Murphy, 1999). No over-printing of scallop signatures either on the roof or floor is observed, suggesting that another (as yet unknown) mechanism may give rise to the preferential enlargement of erosional features on the roof of the passage. This study illustrates the importance of direct observations and measurements made by cave divers.

(Received 5 May 2000; Accepted 5 June 2000)

THE CHAPEL-LE-DALE DRAINAGE SYSTEM

The predominantly flooded cave system behind God's Bridge risings in Chapel-le-Dale has over four kilometres of explored passage and is the second most extensive phreatic conduit system so far explored in the United Kingdom (Murphy, 1999). A full description, surveys and a summary of the known (and conjectured) hydrology of the God's Bridge catchment area are given by Monico (1995). The catchment area for this resurgence is believed to include all of Chapel-le-Dale and a large expanse of karst on the western flank of Ingleborough.

The geomorphology of the Chapel-le-Dale drainage system was reviewed by Waltham *et al.* (1997), and its place in the landscape evolution was considered by Waltham (1990). Murphy (1999) described the sediments and Murphy and Cordingley (1999) described channel karren-like features from the system.

Joint Hole consists of a main trunk passage running southwest from the junction of the Deep Route and the Shallow Route (Fig.1). It passes the artificially widened window of Joint Hole to reach a point where the main passage is lost in a confusing area of low bedding-guided passages between Meregill Skit and Chapman's Rising. The water is next seen in the immature caves associated with the God's Bridge risings. The size of the main trunk passage, five to ten metres wide by one to five metres high, indicates that the passage is of considerable age. It has been protected from draining and subsequent erosion because it lies behind a Lower Palaeozoic (Ingleton Group) metasediment inlier that forms the valley floor downstream to the southwest (Murphy, 1999).

HYDRAULIC FLOW PARAMETERS AND SCALLOP DISTRIBUTION

Scallops are asymmetrical, cuspate, oyster-shell shaped dissolution depressions in cave walls (White, 1988). They indicate the direction of flow, and the size of scallops is inversely related to the flow velocity of the water that formed them (Blumberg and Curl, 1974; Curl, 1974). Being a hydraulic phenomenon (Curl, 1966) their formation and the conduit flow conditions that give rise to them are described by fluid mechanic equations. The reader should be aware that simplifications and assumptions are inherent in the equations that follow. A full discussion of these can be found in Gale (1984). The approach of this paper follows that of Gale (1984). Previous work has shown that scallops form at a stable scallop Reynolds number (Re*) of ~2200 (Blumberg and Curl, 1974) where Re* is related to the mean boundary shear velocity $\bar{u}*$, the mean scallop wavelength $\bar{\lambda}$, fluid density ρ_f; and fluid dynamic viscosity μ by:

$$Re* = \bar{u}* \bar{\lambda} \rho_f / \mu \qquad (1)$$

Using standard UK cave diving techniques as detailed in Balcombe *et al.* (1990) scallop size data were gathered by both direct measurement in the conduit and by measurements from scaled photographs. Three sites were chosen, two on the floor of the main passage and one in the roof. Using equation (1) $\bar{\lambda}$ was calculated, and thus an estimate of $\bar{u}*$ could be made. Water temperature was assumed to be 10°C. Following the method of Curl (1974) and Gale (1984), a modified Prandtl's universal velocity distribution equation

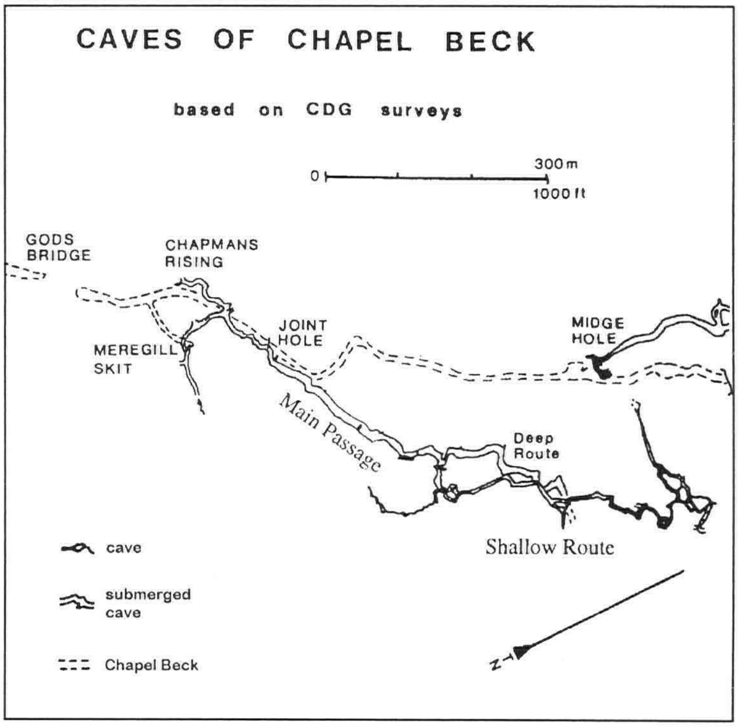


Figure 1. Plan of the Caves of Chapel Beck. Reproduced from Brook et al. (1996) with permission.

for a parallel-sided conduit was used to calculate the mean flow velocity at the time of creation of the scallops:

$$\bar{u} = \bar{u}^* \left[2.5\left\{\ln\left(d/2\bar{\lambda}\right)-1\right\}+B_L\right] \tag{2}$$

where d is the width of the parallel walled channel and B_L Prandtl's bed roughness constant. Blumberg and Curl (1974) determined, through experimental flume work on scallops, that B_L = about 9.4. Measurements made in the passage gave an average value of d = 3.8 metres. The assumption of a parallel-walled (instead of a circular) conduit is the most appropriate for the bedding-guided passage of Joint Hole.

Following the approach of Gale (1984) further hydraulic parameters can be estimated from the values obtained above and the following equations:

$$f = 8/\left(\bar{u}/\bar{u}^*\right)^2 \tag{3}$$
$$Q = \bar{u}a \tag{4}$$
$$\mathrm{Re} = \bar{u}d\rho_f/\mu \tag{5}$$
$$F = \bar{u}/\left(gd\right)^{0.5} \tag{6}$$
$$\bar{\tau} = (\bar{u}^*)^2\rho_f \tag{7}$$
$$P = \bar{u}\bar{\tau} \tag{8}$$
$$\omega_{max} \approx 0.96\bar{u}^* \tag{9}$$

where
f is the Darcy-Weisbach friction factor;
Q the discharge;
a the cross-sectional area of the conduit;
Re the conduit Reynolds number;
F the Froude number;
g the gravitational acceleration;
$\bar{\tau}$ the mean boundary shear stress;
P the power of flow per unit area of boundary;
ω_{max} the settling velocity of the coarsest material in suspension.

The results of this analysis are summarised in Table 1, where n is the number of samples, and σ the standard deviation of the sample distribution.

Table 1 shows that there are two very different populations of scallop occurring in the main passage of Joint Hole. Small scallops occur on the floor of the passage and much larger, longer wave-length scallops cover the ceiling and walls (Fig.2). This contrast in scallop size is not restricted to the main passage of Joint Hole, but can also be seen in other parts of the system. Neither Lauritzen *et al.* (1985), working on active conduits, nor Gale (1984), working on relict conduits, make reference to contrasting scallop size populations between the passage floor and other surfaces. This may in part be due to sediment cover obscuring the floor of the conduits. Goodchild and Ford (1971) used the lack of contrast between scallops on the roofs and floors of fossil conduits as evidence of the dissolutional origin of scalloping. Curl (1966) noted cases where the with normal scalloping found on the passage floor. A similar walls and ceilings of passages are covered by elongated, nearly parallel crested forms that he referred to as flutes, which contrast distribution of flutes and scallops is illustrated in Figure 1a of Blumberg and Curl (1974) but is not referred to in the text. The flutes of Curl (1966) are scallops of infinite width; this is a different use of the term flute from that of Bretz (1942), who called all scallops flutes. In the large relict conduits of Mammoth Cave, White and Deike (1989) noted large scallops or no scallops in the higher parts of passages, with a zone of small scallops near the floor. The large scallops were

Site	1	2	3
$\bar{\lambda}$ (m)	0.0514	0.050	0.207
σ (m)	0.018	0.017	0.079
n	15	20	25
a (m^2)	11.35	11.35	11.35
d (m)	3.8	3.8	3.8
$\bar{u}^*$ ($m\ s^{-1}$)	0.056	0.058	0.014
$\bar{u}$ ($m\ s^{-1}$)	0.89	0.93	0.17
f	0.032	0.031	0.05
Q ($m^3 s^{-1}$)	10.1	10.6	1.9
Re	2 587 605	2 703 902	494 261
F	0.15	0.15	0.03
$\bar{\tau}$ ($N\ m^{-2}$)	3.2	3.4	0.2
P ($W\ m^{-2}$)	2.8	3.2	0.034
ω_{max} ($m\ s^{-1}$)	0.054	0.06	0.01

Table 1. Derived parameters from scallop measurements in Joint Hole. Sites 1 and 2 are on the floor of the main conduit, Site 3 is in the roof.

interpreted as being a product of full pipe flow under phreatic conditions, and the smaller scallops on the floor as being a product of a later, higher velocity, vadose stream. This cannot be the case in Joint Hole, as the passage has an entirely phreatic history.

DISCUSSION OF RESULTS

Table 1 shows that the two floor populations of scallops are very similar, yet indicative of completely different flow regimes to that of the roof features. The conduit Reynolds and Froude numbers (Re and F) illustrate that the flow within the passage at the time of scallop formation was/is both sub-critical and turbulent. The values obtained through this study agree favourably with previous work (Gale, 1984; Lauritzen, 1985), as do those for the power of the flow (Gale, 1984).

More clearly than any of the other parameters, the calculated discharges show how different the flow regimes forming the scallop features are. The floor (roof) scallops correspond to a discharge of approximately 10 (2) cumecs, which would correspond to a major flood event. The fact that the roof features correspond to a discharge about one fifth that of the floor scallops suggests that some form of overprinting of the primary scallop populations should be observed; i.e. smaller scallops would be expected to be superimposed on the larger ones. Such a relationship is not observed, and this suggests either that more than one process is at work or that the two populations are separated in time.

COMPARISON OF RESULTS WITH SEDIMENTARY FILL ANALYSIS

The sedimentary fill of Joint Hole was described by Murphy (1999). The sediment being actively transported through the conduit at present is mainly coarse sand and fine gravel sized particles forming isolated dune and bar forms. The position of these bed-forms is seen to change only following extreme flood events. A possible explanation for the contrasting scallop populations on the conduit floor and walls/ceiling is that, under base flow conditions, the presence of sediment on the passage floor prevents scallop formation, whereas during a high discharge event the sediment will be entrained, leaving the passage floor subject to scallop forming processes. As the discharge returns to base flow conditions the sediment is redeposited, thus isolating the floor from scallop forming processes and preserving the scallops formed at a high discharge level from being 'overwritten' by scallops formed under base flow conditions.

Figure 2. The Main Passage of Joint Hole showing the contrast in scallop sizes between the floor and the roof.

Using the calculated value of ω_{max} to estimate the maximum grain size of sediment that can be moved in suspension and the particle settling velocities given by Gibbs *et al.* (1971), particles of up to 140 microns diameter may be kept in suspension by the velocities indicated by the roof scallops, whereas a maximum particle diameter of 420 microns is indicated by the floor scallops. A particle diameter of 420 microns corresponds well with the grain size of the uncemented coarse sand and fine gravel recorded in the conduit by Murphy (1999). Furthermore, Middleton (1976) suggested that values of mean boundary shear velocity in the range 0.014 – 0.20 ms^{-1} are necessary for transport of sand sized material. The values shown in Table 1 suggest that during the regimes giving rise to the floor scallops bedload transport of sand is realised, whereas the roof population gives rise to a value of $\bar{u}*$ coincident with the lower boundary for transport.

This suggests that during the periods of active scallop formation on the conduit floor the uncemented sediment in the conduit will be entrained. However, the distribution of sediment on the conduit floor is irregular and covers only an estimated 10% of the floor area, so at any given time the majority of the conduit floor is not covered. This suggests that the contrasting scallop distributions are not due to the floor being physically isolated from the scallop forming process by a layer of sediment. Scalloping of typical floor population size occurs on the upper surfaces of fallen roof slabs. These are areas where sediment is very rarely observed.

The entrainment of sediment particles at high flow velocities can result in abrasional effects overriding dissolutional effects, resulting in scallops becoming highly elongated and polished (Ford and Williams, 1991). Though features attributed to abrasion by moving sediment are recorded from the conduit (Murphy and Cordingley, 1999), these are found in areas of steeply dipping conduit floor where no evidence of scalloping is seen. The scallops on the floor are also perfectly formed, and show no evidence of abrasion.

Goodchild and Ford (1971) noted lithological control on scallop distributions where different average scallop sizes occurred on adjacent limestone layers in conduits that must have experienced the same velocities. The apparently lithologically uniform Great Scar Limestone has been shown to be lithologically varied in a number of detailed studies (e.g. Arthurton *et al.*, 1988). However, the occurrence of scalloping typical of the floor population on the upper surface of fallen roof slabs shows the contrasting populations cannot be due to lithological contrasts between the conduit floor and walls/ceiling (Fig.3).

The discharge indicated by the floor scallop populations alone would support the conclusions of Lauritzen *et al.* (1983, 1985), that scallop formation occurs during periods of flood. Perhaps the wall/ceiling scallop populations are relict features and formed under hydrological conditions very different from those of the present day.

CONCLUSIONS

Two contrasting size populations of scallops exist in the main passage of Joint Hole, with larger scallops occupy the walls and ceilings of the conduit with smaller scallops on the floor. The floor population corresponds to a higher conduit velocity than the wall/ceiling population. The conduit has been protected from draining by its position behind an inlier of Lower Palaeozoic metasediments, so has an entirely phreatic history. The position, morphology and widespread occurrence of the populations indicate the contrast is probably a hydraulic phenomenon. However, it is difficult to reconcile the differences in purely hydraulic terms, and other processes may, to a greater or lesser extent, act to accentuate differences in the populations.

This study highlights the shortcomings of trying to understand phreatic processes by studying the features of drained relict conduits and illustrates the often-complex morphology of active phreatic passages. Furthermore, it has been shown that, despite the necessary simplifications and assumptions inherent in the hydraulic equations used, the results of two distinct methods (hydraulic and sediment based), not only give rise to the same conclusions but complement each other and allow a fuller understanding of the complex processes acting in active phreatic passages.

This study shows that the contrasting scallop size distributions recorded by White and Deike (1989) in the large relict conduits of Mammoth Cave may be a phreatic feature rather than the result of an invasion by a vadose stream later in the conduits history.

REFERENCES

Arthurton, R S, Johnson, E W and Mundy, D J C, 1988. Geology of the country around Settle. Memoir of the British Geological Survey, Sheet 60.

Balcombe, F G, Cordingley, J N, Palmer, R J and Stevenson, R A (eds), 1990. Cave Diving: The Cave Diving Group Manual. [Mendip Publishing, UK.]

Bretz, J H, 1942. Vadose and phreatic features of limestone caverns. Journal of Geology, Vol.50, 675-811.

Brook, A, Brook, D B, Griffiths, J and Long, M H, 1996. Northern Caves Volume 2: The Three Peaks. [Clapham: Dalesman.]

Blumberg, P N and Curl, R L,1974. Experimental and theoretical studies of dissolution roughness. *Journal of Fluid Mechanics,* Vol.75, 735-742.

Curl, R L,1966. Scallops and flutes. *Transactions of the Cave Research Group of Great Britain.* Vol.7, No.5, 121-160.

Curl, R L, 1974. Deducing flow velocity in cave conduits from scallops. *National Speleological Society Bulletin,* Vol.36, 1-5.

Ford, D C and Williams, P W, 1991. *Karst geomorphology and hydrology.* [Chapman and Hall.]

Gale, S J, 1984. The hydraulics of conduit flow in carbonate aquifers. *Journal of Hydrology.* Vol.70, 309-327.

Gibbs, R J, Mathews, M and Link, D A, 1971. The relationship between sphere size and settling velocity. *Journal of Sedimentary Petrology.* Vol.41, 7-18.

Goodchild, M F and Ford, D C, 1971. Analysis of scallop patterns by simulation under controlled conditions. *Journal of Geology,* Vol.79, 52-62.

Lauritzen, S-E, Ive, A and Wilkinson, B, 1983. Mean annual runoff and the scallop flow regime in a subarctic environment. *Transactions of the British Cave Research Association,* Vol.10, 37-102.

Lauritzen, S-E, Abbot, J, Arnesen, R, Crossley, G, Grepperud, D, Ive, A and Johnson, S, 1985. Morphology and hydraulics of an active phreatic conduit. *Cave Science,* Vol.12, 139-146.

Middleton, G V, 1976. Hydraulic interpretation of sand size distributions. *Journal of Geology,* Vol.84, 405-426.

Monico, P J, 1995. *Northern Sump Index.* [Cave Diving Group.]

Murphy, P J, 1999. Sediment studies in Joint Hole, Chapel-le-Dale, North Yorkshire, United Kingdom. *Cave and Karst Science,* Vol.26, No.2, 87-90.

Murphy, P J and Cordingley, J N, 1999. Some observations on the occurrence of channel karren-like features in flooded karst conduits in the Yorkshire Dales. *Cave and Karst Science,* Vol.26, No.3, 129-130.

Waltham, A C, 1990. Geomorphic evolution of the Ingleborough karst. *Cave Science,* Vol.17, 9-18.

Waltham, A C, Simms, M J, Farrant, A R and Goldie, H S, 1997. Karst and Caves of Britain. *Geological Conservation Review series No 12.* [Chapman and Hall.]

White, W B, 1988. *Geomorphology and hydrology of karst terrains.* [Oxford University Press.]

White, W B and Deike, G H, 1989. Hydraulic geometry of cave passages. 223-258 *in* White, W B and White, E L. *Karst hydrology: concepts from the Mammoth Cave area.* [Van Nostrand Reinhold.]

Figure 3. Scalloping on the upper surface of a fallen roof slab. Joint Hole Main Passage.

CAVE AND KARST SCIENCE Vol. 27, No. 1, April 2000
Transactions of the British Cave Research Association

ISSN 1356-191X

Forum

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

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

CORRESPONDENCE

Comments on the Paper "On the origin of the thermal waters at Bath, United Kingdom: A sub-Severn hypothesis", by J Wilcock and D J Lowe (*Cave and Karst Science*, Vol. 26, 2)

Dear Editors

The proposal by John Wilcock and David Lowe (1999) that *"...at least part of the drainage..."* feeding Bath Hot Springs comes from limestone outcrops in the Forest of Dean and elsewhere west of the Severn is far removed from conventional hydrogeological wisdom. If it proves to be credible, the long-held belief that the Bath thermal circulation is karstic, driven by the hydrostatic pressure of high water tables on the Mendips, and could be damaged by deep quarrying there, is undermined. Bath Hot Springs rate very highly as a national asset, and the need to protect them has been a major influence on Somerset's mineral planners.

Two types of model for the thermal circulation have been considered in the literature. Both, simply stated, involve U-tubes in which the pressure difference between the limbs is sufficient to overcome the friction involved in circulation to depths of 3 to 4km, where the heat is acquired. The standard karstic model depends of the hydrostatic 'push' exerted by a high water table in the source area. In the convection cell model the flow is 'sucked' up the rising limb by the low density of hot water.

Wilcock and Lowe do not discuss the convection cell model, although it is believed by some to apply to the 27°C thermal spring at Buxton [Derbyshire, UK] (Barker *et al.*, 2000). At Bath the theoretical pressure difference between hot and cold limbs would be around 20m, a small figure compared to the potential hydrostatic head of 170m between the Mendips and Bath (Stanton, 1991). The model is somewhat idealistic; thus the rising limb must be direct enough for the water to rise rapidly from great depth without serious cooling, and it must be effectively isolated from the aquifer surrounding it, or cold water will be drawn in at many levels. Equally important, cold water in the descending limb or limbs must reach a great depth fast enough to remain cold and dense. If it warms significantly on the way down, the density difference between the limbs is reduced. Potential thermal convection cells exist wherever important vertical faults etc. cut through permeable strata, but thermal springs are rare except in regions of active or recent vulcanism where the heat source is intense, local, and at shallow depth.

The model conventionally applied to Bath Hot Springs depends on the column of water in the descending, Mendip, limb(s) being significantly taller than the rising limb, the difference between them being the hydrostatic head, defining the hydraulic gradient, that forces the circulation. Wilcock and Lowe provide no hard data on water tables in their potential source areas west of the Severn, but river level in the Wye, which controls water tables in the adjoining karst, is actually below the level of Bath Hot Springs (27-28m OD) from Chepstow to a point several kilometres upstream of Symonds Yat. Thus, the hydraulic gradient from much of the Wye karst to Bath Hot Springs is slightly uphill!

Hard data on the water tables of the northern Mendip catchments, through Gurney Slade Rising and St Dunstan's Well, appear in Stanton (1991, figure 8.7) and Harrison *et al.* (1992, map sheet 1).

The second essential feature of the conventional Bath model is that a continuous karstic conduit or conduits exists linking the source area(s) to the Hot Springs and descending to depths of 3 to 4km before rising to the springs. Wilcock and Lowe illustrate their concept by a "plumbing" diagram (Figure 5) and four "cartoons" (Figure 6), but again hard data on piezometric levels are lacking. Carboniferous strata may well be continuous from Wales to England beneath the Severn Estuary, but only between Avonmouth and the first Severn Bridge at Aust and only at shallow depth. In contrast, the karstic link between Mendip and Bath would be in Carboniferous Limestone beneath the Radstock Coal Basin (Burgess *et al.*, 1991, Figure 11.1) at sufficient depth to give groundwater the necessary heat. Uncertainty is introduced to both link concepts by the recognition that Palaeozoic strata in the Bristol-Mendip area are a pile of far-travelled thrust sheets (Williams and Chapman, 1986), but the normal stratigraphical relationships must be assumed to apply until proved otherwise.

The third essential requirement of the conventional model is that the U-tube between the source area(s) and the Hot Springs does not leak to the extent that the driving force, the hydrostatic head, is reduced or lost. This condition is fulfilled between the Mendips and bath by the 2 to 3km of Coal Measures resting on the Carboniferous Limestone and effectively confining karstic conduits in it. The Hot Springs are located at the first available leakage point, where ground level is low in the Avon valley, the limestone has risen to almost reach it, and a big vertical fault is present.

The great weakness of Wilcock and Lowe's proposal in this context is that it involves the Carboniferous Limestone that crops out at sea level alongside the Severn Estuary. The chances that their U-tube would not leak into the Severn are effectively nil. The Great Spring in the Severn Tunnel, which they describe, is a good example of such a leak, where a pre-existing possibly static karstic circulation was rejuvenated when the tunnel created a steep artificial hydraulic gradient. Water travelling from the vicinity of the Great Spring to Bath Hot Springs would have to ascend a hydraulic gradient of some 50m vertically over about 50km horizontally. Obviously this could not happen. If flow took place it would be in the opposite direction.

Wilcock and Lowe cite the Hotwells and other springs in the Avon Gorge at Bristol as another example of possible leakage from a conduit linking the Wye karst to Bath. The National Rivers Authority sampled the Avon Gorge springs at low tide in 1991-92 (Environment Agency, unpublished records). There are 7 springs, covering nearly the full stratigraphical thickness of the Carboniferous Limestone, rising on both sides of the river, all submerged at the highest tides.

Hotwells Spring is the warmest (22.5°C), but 4 others have weak thermal characteristics with temperatures 3°C to 6°C above the 10°C normal for the local groundwater. The two warmest are abnormally rich in sulphate. The cold springs are at the north end of the limestone outcrop. The warm spring outputs are interpreted (Burgess *et al.*, 1980) as a mixture of local groundwater with deep thermal water like that at Bath. The Avon Gorge thermal circulation is most simply explained as driven by high water tables in the Mendips, acquiring heat while passing at depth below the Radstock Coal Basin, and rising to emerge at the Avon valley's second potential leakage point (Bath is the other) where it mixes with local cold groundwater. Such mixing is prevented at Bath by the artesian head associated with the "recharge mound" there (Stanton, 1991, Figure 8.2).

Wilcock and Lowe remark several times that because large areas of Mendip drain to resurgences below the south scarp, little catchment area remains on the north to supply the Bath springs, and the piezometric head would be negligible. This is a misconception. Ample water tracing evidence exists to demonstrate the presence of two main groundwater provinces in the Mendip Carboniferous Limestone, one draining south and west to the Severn, the other north and east to high-level springs on the northern scarp feeding tributaries of the Bristol Avon (Harrison, et al., 1992, map sheet 1).

The mean daily yield of the north scarp springs, ignoring quarry dewatering flows, is c.570 litres/second. Compared to this the total yield of Bath Hot Springs, c.18 litres/second, is tiny. The loss of such a small proportion of the northerly flow to the distant springs at Bath, potentially 170m lower, would be undetectable. If the point(s) of capture is close to a resurgence, where there is little seasonal variation in water table level, the piezometric head is effectively constant. This is demonstrably the case in the Ninth Chamber of Wookey Hole Cave, where water is known to leak through the bed of the River Axe on its way to Glencot Spring, 1100m distant and 16m lower (Stanton, 1974).

The authors seem to consider it possible that deeply buried flows may occur "... *effectively unrelated to modern landscapes* ..." (page 75). They refer speculatively to a deeply buried flow down an eastward gradient beneath Southern England and hint (page 77) that Bath Hot Springs could be upward leakage from this flow. But modern landscapes determine the relative levels of the input and output ends of any current underground flow (excluding density effects). Modern landscapes may be unconnected to palaeogradients and palaeoflows, but they control modern hydraulic gradients and, therefore, modern flows.

Two aspects of the conventional Mendip model, the initial conduit development and the alleged vast storage requirement, have provoked much debate. Few aquifers are truly impermeable at depth, as was demonstrated when "... *brines continued to pour in ... to a depth of 8km* ..." in Germany's experimental borehole (Anon, 1996). Deep flow from the Mendips to Bath is likely to follow fortuitously open microconduits in the limestone, whether inception horizons, palaeokarst, faults, joints or whatever. At the public enquiry into a proposed expansion of Whatley Quarry, East Mendip, in 1992, the quarry consultants claimed that "no known process" could prolong the dissolution of limestone all the way to Bath, because saturation would soon occur. However, the high levels of iron and sulphate, and the absence of dissolved oxygen, that characterise the Bath thermal water, suggest a further possibility: oxidation of pyrite in veins or disseminated through the rock sequence, under certain conditions, can continue cave formation by releasing sulphuric acid. The possibility needs further research, but such a process could simplify the distance problem, explain some aspects of the water chemistry, and develop storage capacity over the 7,000 years at least (Mesolithic to present) that the Hot Springs are believed to have existed.

REFERENCES

Anon, 1996. The German deep hole. *Geoscientist,* Vol.6, No.2, 3.

Barker, J A, Downing, R A, Gray, D A, Findlay, J, Kellaway, G A, Parker, R H and Rollin, K E, 2000. Hydrogeothermal studies in the United Kingdom. *Quarterly Journal of Engineering Geology and Hydrogeology,* Vol.33, 41-58.

Burgess, W G, Edmunds, W M, Andrews, J N, Kay, R L F and Lee, D J, 1980. *The hydrogeology and hydrochemistry of the thermal waters in the Bath-Bristol Basin.* [London: Institute of Geological Sciences.]

Burgess, W G, Black, J H and Cook, A J, 1991. Regional hydrodynamic influences on the Bath-Bristol springs. 171-177 *in* Kellaway, G A (Editor), *Hot Springs of Bath.* [Bath: Bath City Council.]

Harrison, D J, Buckley, D K and Marks, R J, 1992. Limestone resources and hydrogeology of the Mendip Hills. *British Geological Survey Technical Report,* WA/92/19.

Kellaway, G A (Editor), 1991. *Hot Springs of Bath.* [Bath: Bath City Council.]

Stanton, W I, 1974. Balch was right! *Journal of the Wessex Cave Club,* Vol.13, No.155, 102-103.

Stanton, W I, 1991. Hydrogeology of the hot springs of Bath. 127-142 *in* Kellaway, G A (Editor), *Hot Springs of Bath.* [Bath: Bath City Council.]

Wilcock, J and Lowe, D J, 1999. On the origin of the thermal waters at Bath, United Kingdom: a sub-Severn hypothesis. *Cave and Karst Science,* Vol.26, No.2, 69-80.

Williams, G D and Chapman, T L, 1986. The Bristol-Mendip foreland thrust belt. *Journal of the Geological Society of London,* Vol.143, 63-73.

Dr W I Stanton
Kites Croft
Westbury-sub-Mendip
Wells
Somerset
BA5 1HU
UK.

Reply from the authors, Dr John Wilcock and Dr David Lowe

We thank Dr Stanton for his comments. A number of items in the response require no comment, as they merely provide elucidation of items within the existing (Mendip) Model. Other items, including the potential role of sulphuric acid and soluble sulphates (evaporitic rocks) in early speleogenesis, are more fully dealt with in the Inception Horizon Hypothesis itself (Lowe, 1992; Lowe and Gunn, 1997), which lies at the core of the justification for even considering a potential "Sub-Severn" Model. Worthington (1991) discussed related factors about deep, sulphate-rich, underflow in detail, and his conclusions are not at odds with those incorporated in the Inception Horizon Hypothesis. Putting these points aside, other aspects of the Inception Horizon are worthy of re-iteration, very much in simplified form, and these and other points are covered in this reply to Dr Stanton.

Initially we must re-state that neither the viability of the widely-accepted Mendip Model nor that of the proposed Sub-Severn Model is proven. Both models are hypothetical, and one or both hypotheses may be wholly or partially invalid. Additionally, both hypotheses reflect not only the (limited) hard and (rather more) circumstantial data that they reference, but also the framework of wisdom within which the authors of the models have chosen to examine and interpret the data. Indeed, the Mendip Model relies heavily upon a long accepted and rarely questioned mainstream hydrogeological paradigm, whereas the

Sub-Severn Model relies upon a more recent, more karst-centric, view that is epitomised in the as yet unproven Inception Horizon Hypothesis of cave development (Lowe, 1992; Lowe and Gunn, 1997).

Like Dr Stanton, we believe that the Bath thermal circulation is essentially karstic, and we agree that any human activity that might damage this circulation should be prevented. The viability of the Bath Hot Springs must be protected as a part of the national heritage of the United Kingdom.

In principle we agree with the model of a U-tube, where the flow is essentially driven by hydrostatic head and perhaps to a much more limited degree by the difference in densities of hot and cold waters. The flooded quarries at Chipping Sodbury, which lie on one proposed flow route, and those at Dayhouse between Tidenham and Chepstow demonstrate the existence of a "water table" that is high enough to drive the Bath thermal circulation from elsewhere than Mendip. Clearly, as Dr Stanton points out, the overall flow route cannot be "uphill", though equally obviously, geologically constrained flow segments along the regional hydraulic gradient can be (see below). So far as we know, extensive areas of the Forest of Dean and Vale of Berkeley display "water table" levels that are significantly higher than the outflows in the Wye valley to which Dr Stanton refers, and also higher than the Bath springs.

Clearly our proposed "Sub-Severn Model" depends upon allowing the possibility of a lateral view of karst drainage. We do not support the traditional view that the Carboniferous Limestone functions as a single isotropic and "sponge-like" aquifer, constrained above and below by supposedly impermeable strata. Our lateral view is of an essentially impermeable limestone mass that contains a number of vertically isolated but laterally extensive, stratigraphically-defined aquifers (inception horizons), perhaps linked locally by fractures. This viewpoint allows the drainage "system" to be considered in terms of a set of conduits or pipes - hence the "plumbing diagram" - rather than as either a semi-random net composed of a myriad of interconnected fissures or (even less realistically) an infinitely interlinked network of inter-granular voids. We are, in fact, describing true karst flow, rather than flow via fissure permeability (which could theoretically occur just as readily in the overlying Upper Carboniferous rocks) or via the primary pores and matrix, which could, and does locally, take place in the underlying Old Red Sandstone.

According to the Inception Horizon Hypothesis, which by its very name is seen to be as yet unproven, "potential voids" are imposed across the full lateral extent of susceptible horizons at a very early stage in their existence. This perhaps begins during the latter stages of diagenetic alteration or very soon afterwards. At this stage local fractures are effectively non-existent, and formational fluids are forced by overburden pressure out of the sediment/rock pile and along stratigraphy-related partings on a basin-wide scale. Modern (or even contemporary) landscapes could have had no effect upon the "input" and "output" of fluids during this inception phase. Indeed there was no "input" in the sense of Dr Stanton's argument. Nor need there have been a sub-aerial surface output, as fluids migrated along the stratigraphical "partings" until eventually emerging deep below sea-level or migrating into adjacent rock units via basin-marginal faults or lateral facies changes.

Thus, as noted, prior to significant tectonic activity the entire extent of each susceptible bed (or inception horizon) would have the potential to support fluid transfer along whatever pressure gradient was imposed upon the basin. Subsequently, following tectonism, although some of the inception horizons might be expected to have breached the contemporary land surface, it is reasonable to suppose that many, if not all, remained deeply buried, even though folded, faulted and crossed by tectonic joints. Possible combinations of processes and conditions that led to parts of the tectonised skeleton of the initial inception framework developing first into largely buried structurally aligned sub-conduit systems, later into true karst conduit systems and eventually into "surface caves" (forgive the apparent contradiction) are too many to consider here. Suffice it to say that knowledge of buried fluid movements in other contexts allows us to deduce that concentration of water movement within the structurally favourable parts of the incipient inception framework, with or without direct surface input, is perfectly feasible. Such movement, still on a regional scale, would be directed along regional hydraulic gradients whose "low points" could just as easily be contacts with porous rock units, or submarine springs, as outputs to the land surface. Along the regional hydraulic gradient the water can move "upwards", "downwards" or "sideways", as the most favourable combination of inception horizons (usually in fold cores) and linking fractures is followed. As indicated above, if a regional hydraulic gradient is intersected by the lowering land surface, its "upstream" component becomes a local hydraulic gradient, but the whole may continue to function regionally, at least until the upstream and downstream elements are totally physically divorced by continued downcutting.

Underlying data are admittedly scant. Taken at face value the apparent continuity of limestone units beneath the Severn indicates that a potential natural route along a viable hydraulic gradient could lead from high limestone terrain west of the Severn into deeply buried limestone beds closer to Bath. Theoretically, cold water derived mainly from the area around Cas Troggy and from the Tidenham Chase Syncline (and possibly still farther west and north) could pass eastwards beneath the Severn along ancient, stratigraphically-guided conduit systems as described above, regardless of whether upward leakage to more local springs takes place. In considering drainage via "pipes", as we intended to do, it would be folly to assume that all water movement along the (pre-landscape) regional hydraulic gradient "system" would cease simply because that system was intersected by the landscape, imposing a local hydraulic gradient "upstream" of the intersection. In terms of the real world, would drainage cease to follow the fall of a Victorian sewer simply because a crack caused by a 21st Century juggernaut allowed minimal upward leakage? No, the efficiency of the onward route might diminish, but it would not totally be negated. The possibility of such upward leakage is assumed within the Inception Horizon Hypothesis, and in the present context may occur in or near the beds of rivers such as the Wye, Severn, Nedd Fechan and Clydach without reducing significantly the flow in the intersected conduits.

The presence of the Severn Tunnel Great Spring and the water tracing data associated with it, provide at least partial confirmation of the former west-east passage of karst water beneath the Severn. If it can be accepted that water passed beneath the Severn prior to human intervention, there seems no reason to ignore the possibility that a component of underflow drainage, probably within stratigraphically lower inception horizons might continue to follow the overall down-dip route towards the east. Eastward of the Great Spring the proposed Sub-Severn Model suggests that the still relatively cool karst water that originates west of the Severn follows inception horizon-guided conduits within the Carboniferous Limestone beneath the Bristol Coalfield, where it is heated due to the over-riding effect of the geothermal gradient. Thus we do not disagree that eventual passage of the water to great depth beneath the Bristol Coalfield would provide a possible heating mechanism for water following the postulated route from the west. Clearly this does not differ in concept from the heating mechanism postulated within the Mendip Model.

Re-ascending on the eastern side of the Bristol-Bath Basin the still-hot water arrives - perhaps at the crest of an eroded anticline, perhaps not, but still within the Carboniferous Limestone - beneath Bath at approximately the same elevation as it entered the Basin from the west. The viability of the model then relies upon a combination of the ongoing hydrostatic potential of the remote cold water input along the regional/palaeo-hydraulic gradient and, perhaps, density difference to drive the "rising main(s)". The latter may or may not be related to upwardly sapped breccia pipes, known as vertical through structures (cf Klimchouk and Andrejchuk, 1996), that penetrate the Mesozoic rocks. Though possibly more readily acceptable for the several Hotwells springs, this mechanism could apply to at least part of the Bath output. However, as pointed out in the original paper, it appears that there is also a theoretical possibility that an additional, part fracture-related, underground drainage route could exist from the Forest of Dean Basin, under the Severn and then southwards from the Chipping Sodbury area.

Despite Dr Stanton's claim to the contrary, as we understand the situation, the evidence for the viability of the supposed hydraulic gradient and pressure head between Mendip and Bath is no less equivocal than that supporting a possible water source west of the Severn. All published results we have located of hydrological tracing on Mendip, apart from those confirming localised drainage to high-level springs at Rickford/Langford, Gurney Slade and St Dunstan's Well, confirm south or south-westward flow. This drainage emerges at the major resurgences at Cheddar, Rodney Stoke, Wookey Hole and St Andrew's Well at Wells, all on the southern flank of the Mendip Hills. Such southerly drainage is confirmed even from the upper part of the north-western flank of Mendip, closest to Bath, whence the flow is to Cheddar. Details of the supposed hydraulic gradients of the deep (under)flow assumed as part of the Mendip Model are unknown, and though appearing likely, the hydraulic continuity of the limestone in this direction has been questioned in the past.

Finally, we are in complete agreement with Dr Stanton that further research is needed into various aspects of the Bath springs drainage. We would suggest that aspects of modern knowledge of speleogenesis in buried situations (now widely studied in the context of hydrocarbon migration and storage), as well as more traditional hydrochemical and hydrogeological factors, be considered. Meanwhile, even though we cannot yet provide conclusive proof of any alternative source, we must continue to question the widely accepted conclusion that the bulk of the water emerging at the Bath springs is <u>necessarily</u> derived from the Mendip Hills.

REFERENCES

Klimchouk A and Andrejchuk, V, 1996. Breakdown development in cover beds and landscape features induced by interstratal gypsum karst. 127-144 *in* Klimchouk, A, Lowe, D, Cooper, A and Sauro, U (Eds), 1996. Gypsum Karst of the World. *International Journal of Speleology* (Theme Issue), Vol.25(3-4).

Lowe, D J, 1992. The origin of limestone caverns: an inception horizon hypothesis. Unpublished PhD thesis, Manchester Metropolitan University.

Lowe, D J and Gunn, J, 1997. Carbonate speleogenesis: an inception horizon hypothesis. *Acta Carsologica*, Vol.26/2, 457-488.

Worthington, S R H, 1991. Karst Hydrogeology of the Canadian Rocky Mountains. Unpublished PhD thesis, McMaster University.

John Wilcock
School of Computing
Staffordshire University
P.O. Box 334
Stafford
ST18 0DG
UK

David Lowe
Limestone Research Group
University of Huddersfield
Queensgate
Huddersfield
HD1 3DH
UK

Dear Editors,

Wookey Hole passage nomenclature

The paper by Chapman *et al.* on "Water Studies in Wookey Hole Cave, Somerset, UK" (*Cave and Karst Science* 26(3), December 1999) is of great interest. It is encouraging to see an increasing number of contributions from cave divers being made to these pages, as divers are uniquely able to study significant portions of cave systems to which the majority of workers are unable to gain access. Direct observation by divers of the processes involved in the development of phreatic conduits is possible, and the value of such observations should not be underestimated.

I should like to offer a few comments on the traditional system of naming discoveries at Wookey Hole, in order to clarify some information in the paper referred to above. Underwater exploration at Wookey Hole began in 1935 with a truly pioneering effort by Graham Balcombe and Penelope ("Mossy") Powell. The commonly visited part of the cave at this time consisted basically of three chambers known as the First, Second and Third Chambers, connected by relatively large dry passages. They dived upstream from the Third Chamber and entered a Fourth and Fifth (already known to cavers who had wallowed upstream in low water conditions). However, the dive took them into unexplored territory beyond this point, and they entered a further (submerged) enlargement of the passage, which they named the Sixth Chamber.

This exploration marked the start of serious cave diving at Wookey Hole and, logically, further chambers (or significant changes of passage dimensions) were also given a number. The convention has continued ever since, such that the (current) final airspace was named "Wookey 25" ("Chamber 25" or "The Lake of Gloom") by its discoverer Martyn Farr, in 1976. Unfortunately, this system is at variance with the other well known system of giving each dry section of cave a number related to how many sumps have been passed before its discovery. A good example is Swildons Hole, also in Somerset (and part of the same hydrological system as Wookey Hole). Here, "Sump 1" is passed to gain entry to a section of passage called "Swildon's 2". At the end of this is "Sump 2", leading to another above-water section known as "Swildon's 3", and so on. The final section of non-submerged passages is "Swildon's 12", which ends at "Sump 12", so far not passed.

These two systems of numbering flooded sections and dry passages or chambers have led to considerable confusion over the years and the above mentioned paper includes a few such problems. For example the authors describe water sampling in "Sump 25" when I suspect this should be described as "Wookey 25" (i.e. the 25th Chamber). In fact modern cave divers need only pass five sumps to reach "Chamber 25" (as the initial flooded section as far as Chamber 9 was helpfully bypassed by an artificial tunnel several years ago) as summarised below.

The farthest upstream dive base is now in Chamber 9 and from here a single dive surfaces in Chamber 19. The second "sump" leads to Wookey 22. Next comes a third sump emerging in the 23rd Chamber. At the end of this is a group of short muddy dives and airbells (normally treated as one sump) to emerge in "Wookey 24" - a magnificent section of streamway, with large relict phreatic passages. The 5th dive, from the end of "Wookey 24", surfaces in the 25th chamber from where the 6th dive begins: a steep descent to where the passage is usually choked by gravel at around 65m depth.

The comments above may be considered by some to be verging on the pedantic. However, given Wookey Hole's unique status in the history and development of cave diving, I feel it is very important that the record is kept accurate. It is also fascinating to note that the cave, which played a crucial role in the advancement of techniques for underwater discovery, is also still at the forefront of scientific exploration!

John Cordingley (Cave Diving Group)
29 Lynwood Close
Darwen
Lancashire
BB3 0JY
(Email: j.n.c@btinternet.com)

MEETING REVIEWS

8th INTERNATIONAL KARSTOLOGICAL SCHOOL: "Classical karst"

Background

Held in Postojna, Slovenia, from 27 to 29 June, 2000, the 8th International Karstological School ("Classical Karst") was organised by a team from the Karst Research Institute (KRI), headed by Franci Gabrovsek. Over 100 people attended during the course of the meeting, including delegates from Austria (1), the Czech Republic (4), Croatia (6), Estonia (6), Italy (14), Hungary (1), Germany (2), the Netherlands (1), Poland (3), Portugal (2), Slovenia (52), Spain (2), Switzerland (1), United Kingdom (2), USA (2) and Yugoslavia (2). This year's record attendance meant that the lecture programme could not be accommodated in the newly refurbished KRI, but instead was relocated to a senior school in Postojna.

Topic

The central theme of the School this year was collapse dolines. These features, commonly of astonishingly large size, are a relatively common part of the Slovenian Classical Karst landscape, but they are either smaller and less common in the UK – or, perhaps, largely unrecognised and undescribed.

Papers presented

20 short presentations were made during two morning sessions, some on the subject of collapse dolines, some on closely related topics and a few on unrelated topics of general interest to the audience.

Tuesday, 27th July, 2000

1. **I Gams**;
   Doline development in the global view.
2. **J. Liszowski**;
   Mechanisms and kinematics of collapse dolines formation and development: the state of the art.
3. **Pedro Robledo Ardila and Luis Pomar Goma**;
   Collapse structures genetic model of Mallorca Upper Miocene.
4. **Andrzej Tyc**;
   Remarks on collapse and collapse-like forms in carbonate karst (on the basis of Abisso Di Trebicano and Grotta Gigante in the Classical Karst and palaeokarstic features in Poland).
5. **France Šušteršič**;
   Are collapse dolines only collapse?
6. **Kortnik Jože**;
   Stability appraisel of Medvedova Konta pothole.
7. **Jiri Bruthans and Michal Filippi**;
   Thickness of gypcrete, an important factor in the morphogenesis of salt karst.
8. **Angel Gines**;
   Patterns of collapse chambers in the endokarst of Mallorca (Balearic Islands, Spain).
9. **Francesco Ferrarese**;
   Shafts and collapse dolines in the conglomerate karst of Montello Hill (Venetian fore-alps).
10. **Jack B Epstein**;
    Gypsum-karst collapse and hydrologic effects in the northern Black Hills, South Dakota, USA.
11. **Benedetta Castiglioni and Ugo Sauro**;
    Large collapse dolines in Puglia (southern Italy): the case of "Dolina Pozzatina" in the Gargano Plateau.

Wednesday, 28th July, 2000

1. **Ugo Sauro**;
   Examples of recent karst collapses in the Venetian fore-alps.
2. **Stanka Šebela and Jože Čar**
   Is Velika Jeršanova doline a collapse doline?
3. **Petr Pruner, Pavel Bosák , Martin Knez, D Otrubova, Tadej Slabe and D Vendohova**;
   Paleomagnetic research of fossil cave in the highway construction at Kozina (Slovenia).
4. **Orndorff, R C, Weary, D J and Lagueux, K M**;
   Using Geographic Information System (GIS) to determine geologic controls on the distribution of sinkholes in the Ozarks of south-central Missouri.
5. **Karl Mais**;
   Collapsed dolines in regions of the north-eastern Alps of Austria.
7. **Jelena Calic-Ljubojevic and Vladimir Ljubojevic**;
   Caves below collapse dolines - case study of the Tisova jama.
8. **Nenad Buzjak**;
   Collapsed dolines as a connection between the karst surface and underground (examples from Croatia).
9. **Francesca Andriani, Enrico Marinetti, Paolo Manca and Luca Zini**;
   Collapse and solution dolines of the Trieste karst.
10. **Pavel Bosák, Petr Pruner, Pavel Bella, Andrej Mihevc, Nadja Zupan-Hajna and Martin Knez**;
    Review of paleomagnetic data from caves in Slovakia and Slovenia.
11. **Pavel Bosák**;
    Collapse structures in the Koněprusy area, Bohemian karst, Czech Republic.
12. **Szabolcs Leel-Ossy**;
    About two crystal caves in Hungary.

Available abstracts

[Full versions of these papers will appear in Acta Carsologica in due course.]

[These are edited for English, as far as possible. The Editor apologises if any scientific content has been compromised by the editorial process]

Collapse structures in the Koněprusy area, Bohemian karst, Czech Republic

Pavel Bosák
Institute of Geology, Academy of Sciences of the Czech Republic, Rozvojová 135, CZ-165 02 Praha 6, Czech Republic

The karst developed in Lower Devonian (Pragian) skeletal limestones is characterized by numerous vertical and subvertical dissolution pipes with lithologically varied fill. Pipes (so-called karst depressions) are identifiable as "sinkhole-like" forms on the surface. Intensive exploitation of limestones in huge quarries offers clear cross-sections through these karst forms, which typically are circular to oval, with diameters ranging from 2m up to tens of metres, with some of them separated by sharp ridges and cones. Commonly the walls overhang and more rarely they contain clear examples of cave-related forms (e. g., niches, large-scale facets or phreatic half-cupolas). The depth proved by geophysical measurements and drillings is several tens of metres. The floors of most of these landforms are hidden in the depths, though some terminate in horizontal cave levels at depth. Typical examples were observed and described in the Nineteen-fifties by G J Kukla, but at present such features can be seen only rarely.

The pipes are filled with very complex sediment sequences in which collapse structures are visible. Pre-Cenomanian weathering products (varicoloured clays, sandy clays, etc.) occur in the lower parts. Cretaceous deposits are represented by the Peruc Member (Cenomanian freshwater fluvial and fluvio-lacustrine deposits), Korycany Member (Cenomanian marine sequence with glauconite) and by the Bílá Hora Formation (Lower Turonian marls, spiculites, sandstones) and locally also by the Jizera Formation (Middle Turonian sandstones). Ages are confirmed by palaeontological finds and by lithological correlations. The Cretaceous and pre-Cretaceous sediments are overlain disconformably by Tertiary sequences, and the boundary of both units is commonly marked by palaeosoil horizons. Tertiary sediments include variegated and multicoloured sands, clayey sands and sandy clays, with intercalations of grey clays resembling weathered volcanic tuff. Their Tertiary age has not yet been confirmed by paleontological evidence. The youngest fill is represented by Quaternary screes, solifluction horizons and soils.

The origin of dissolution pipes appears connected to hydrothermal activity, most probably during Palaeogene to Miocene times, when the limestone surface was still covered by a slightly eroded cover of Upper Cretaceous platform sediments. Hydrothermal karst forms developed up to the surface of the limestones as the piezometric level lay within the Cretaceous cover. After the loss of buoyant support of water, the sedimentary cover started to collapse, and internal structures within the fill indicate multi-phase collapses. Cretaceous and pre-Cretaceous deposits are commonly subvertical, with a chaotic internal texture. There are traces of younger collapses in the centre of some of pipes, and these were most probably induced by continuing karstification and suffosion at depth. Disconformably-overlying Tertiary deposits show gentler, centripetal inclination, and in places they fill depressions in the central parts of older collapsed sediment. Quaternary cover fills only very shallow structures.

Palaeomagnetic research of a fossil cave in the highway construction at Kozina (Slovenia)

Petr Pruner [1], Pavel Bosák [1] and Martin Knez [2]
[1] Institute of Geology, Academy of Sciences of the Czech Republic, Rozvojová 135, CZ-165 02 Praha 6, Czech Republic.
[2] Karst Research Institute, SAZU, Titov trg 2, SLO-6230 Postojna, Slovenia.

Highway construction between Divača and Črni Kal (SW Slovenia, Classical Karst) uncovered several fossil and unroofed caves. One of these, near Kozina, was a roofless fossil cave with remains of its collapsed roof only in the upper part. It formed a gentle depression in the field. The cave revealed a sedimentary profile more than 4m high, composed mainly of sandy light brown to ochreous sediments, but with clayey and silty intercalations. These sediments displayed depositional structures and textures, including lamination, cross-lamination, etc., and erosional surfaces divided the profile into discrete sequences.

Of a total of 38 samples taken from the profile, only one was cemented. Uncemented samples were demagnetized by an alternating (AC) field at 10 to 1,000 Oe, whereas the cemented sample was demagnetized by gradual thermal processing from 80 to 560°C in the MAVACS apparatus. Individual components of remanent magnetization after demagnetization by alternating or thermal field were detected by multi-component analysis using the Kirschvink method. Detected remanent magnetization in a natural state varies between 95 and 36,470 pT, and values of volume magnetic susceptibility are from 55 to 998.10^{-6} SI. The rocks are low or medium magnetized, and normal and inverse polarization were detected after demagnetization. Some samples showed an expressive viscose component (up to 90%); the primary component of magnetization and resultant polarity could therefore not be stated. The profile contains inverse and normal polarity magnetozones. The character of the distribution of the magnetozones is similar to that recorded at the previous Divača profile locality (a fossil cave in a road cutting at Divača). The age of the profile at Kozina is older than Bruhnes/Matuyama boundary (0.78 Ma). According to the arrangement of individual magnetozones, it could be that the sediments are older than the top of the Olduvai chron (1.77 Ma), as the magnetostratigraphic profile at Kozina is terminated by a reversed polarized magnetozone and contains two normal polarized zones.

The profile can be correlated with the Divača profile, not only from the palaeomagnetic point of view, but also lithologically. We suppose that, as in Divača, the cave is a product of the Messinian speleogenetic epoch and its fossilization was connected with rapid base level uplift after refilling of the Mediterranean basin by water. If this hypothesis is realistic, the fossilization process dates from about 5.2 Ma onwards.

Review of palaeomagnetic data from caves in Slovakia and Slovenia

Pavel Bosák [1], Petr Pruner [1], Pavel Bella [2], Andrej Mihevc [3], Nadja Zupan-Hajna [3] and Martin Knez [3]
[1] Institute of Geology, Academy of Sciences of the Czech Republic, Rozvojová 135, CZ-165 02 Praha 6, Czech Republic
[2] Administration of Slovak Show Caves, Hodžova 11, SK-031 01 Liptovský Mikuláš, Slovakia
[3] Karst Research Institute, SAZU, Titov trg 2, SLO-6230 Postojna, Slovenia

Since 1997 the Institute of Geology of the Academy of Sciences of the Czech Republic has been studying paleomagnetic properties and magnetostratigraphy of selected caves in Slovakia and in Slovenia. Although not representing an absolute (numerical) method, palaeomagnetic research appeared to be a good tool to decipher relative ages of cave fills. The Brunhes/Matuyama boundary (0.78 Ma) is a principal correlation level.

The palaeomagnetic research in Slovakia brought important results, changing recent ideas on the age of the speleogenetical process in the most important cave systems of Slovakia. Research in the *Demänovská jaskyňa Slobody* followed uranium series dating of speleothems in the whole cave system. Correlation of obtained magnetostratigraphic results, radiometric dating and river terraces of tributaries of the Váh River indicate definitively that there are no real correlations of cave levels and river terraces, as supposed earlier, or that the river terraces of the Váh have different ages to those interpreted up to now. The speleogenetic process was much older than previously supposed. Research in the *Belianská jaskyňa* revealed the most complicated magnetostratigraphic structure. Sediments here are substantially older than the Brunhes/Matuyama boundary. Sediments are clearly older than the top of the Olduvai zone (1.77 Ma). Therefore, the age of sediments is at least Early Pleistocene. The speleogenetic process had to be still older. The research in the *Domica Cave* is only just beginning.

The application of the magnetostratigraphy to cave sediments of the Classical Karst (Slovenia) represented first dating attempts in relict and palaeokarst caves. Sediments in them showed no palaeontological content and the age of sediments was beyond the range of numerical dating. Dating of sediments in *Trhlovca Cave* and *Divaška jama* indicated Brunhes/Matuyama boundary and Jaramillo zone (1.07 Ma). Newly published data from *Postojenska jama* indicate the occurrence of reverse polarized sediments, too. Dates from the *Divaška profile* and *Kozina profile* in road cuttings indicate that sediment magnetization is dominantly within a reverse polarized zone with two normal polarized zones. Magnetostratigraphy of the *Černotiče profile* is even more complicated. We correlated those profiles as being older than the top of the Olduvai zone (1.77 Ma). Magnetostratigraphic data were obtained that are older than the Brunhes/Matuyama boundary, clearly showing that the age of speleogenesis cannot be connected with Pleistocene climatic cycles but is older. Fills within palaeokarstic caves are clearly older than about 1.7 Ma. The speleogenesis of now-fossilized caves was probably connected with a very intensive palaeokarst and speleogenetic phase related to the Messinian crisis, and the fossilization itself relates to a post-Messinian sea-level rise in the Mediterranean region.

The studies were also interesting from a theoretical point of view, helping to decipher some major problems of applying magnetostratigraphy to cave fills. Sedimentary fills within all the studied profiles were separated into individual sequences and cycles, clearly divided by numerous depositional breaks. Some breaks were marked by erosion features (cut down of channels, intercalations of clays within speleothem sequences) and/or precipitation features. Some magnetostratigraphic zones start or finish at such indicators of unconformity. These features illustrate enormously complicated depositional dynamics, with numerous breaks in deposition and intervening erosional events. Parts of original profiles can be missing, and whole caves and cave systems could have been completely filled and emptied several times. Therefore, unconformities within sedimentary profiles can hide substantial periods of geological time. Depositional velocity cannot be calculated in such profiles. The time duration of individual magnetozones cannot be calculated, the geometric character of the magnetostratigraphic picture obtained cannot be compared with standard scales, and the abundance of detailed internal divisions and scarcity of fossils make the magnetostratigraphic picture's correlation with standard palaeomagnetic scales problematical.

Thickness of gypcrete: an important factor in the morphogenesis of salt karst

Jiri Bruthans and Michal Filippi
Faculty of Sciences, Charles University, Albertov 6, CZ-128 43 Praha 2, Czech Republic

The Zagros Mountains of southern Iran, near the port of Bandar Abbas, are known for the occurrence of numerous salt plugs, which occur at different altitudes and at different states of development (active, passive, decaying). Their diversity of environment is very favourable for the evaluation of the importance of morphogenetic factors. Three plugs were studied in detail: the plug on Hormoz Island (low activity); Namagdan plug on Queshm Island (passive plug); and the Khurgu (high activity). It has been demonstrated that, irrespective of the plug activity and type of environment, specific karst forms are connected to specific thicknesses of gypcrete (the term "gypcrete" as used here also includes semi-consolidated sediments covering the surface of salt plugs). We can distinguish four different classes of gypcrete thickness, each with a specific form of superficial and underground karst:

1) *Salt outcrops without sedimentary cover*
   Rock salt outcrops occur only on steep (more than 50°) or vertical slopes and also at the bottom of steep canyons and gullies, where the residuum from salt dissolution has been washed out by precipitation. In salt outcrops there is only superficial outflow. Sharp rillenkarren are typical for this environment.
2) *Thin gypcrete (thickness 0.5 to 2m)*
   Thin ferruginous gypcrete occurs on moderate to flat slopes from which thicker deposits were removed by erosion. This gypcrete is the result of current salt dissolution. The runoff is collected in small funnel-shaped dolines (diameter 2 to 8m) terminating in vertical dissolution pipes developed in rock salt. Hundreds of these dolines cover the whole area. Dolines are concentrated in flat uvala-like depressions (diameter 100 to 500m). After a short underground path, water re-emerges at the surface. The caves are short (length 10 to 300m), with a small cross-section, and generally there are also superficial bypasses several metres above the current cave level.
3) *Gypcrete of moderate thickness (5 to 30m)*
   The gypcrete thickness of more than 2m is mostly a result of previous fluvial and marine activity (terraces, subrosion). The dolines have a similar shape as in the previous case, but they are noticeably larger (diameter about 20 to 50m) and their density is considerably lower. Small blind valleys occur.
4) *Gypcrete of great thickness (more than 40m)*
   In areas formed by thick gypcrete, karst forms are generally absent. The outflow is almost completely superficial. However, scarce but huge ponors (blind valleys with catchments about 0.5 - 2km^2) occur. The largest caves in southern Iran explored to date are all connected with such huge ponors (Ghár-e Daneshyu Cave – 1,909m, Tří Nahá•• Cave – 5,010m).

There is an important difference between classes 1 and 2, and the other classes, which affect karstogenesis considerably. In the case of classes 3 and 4, the runoff is collected outside the contact with rock salt. Then the concentrated flow moves quickly into the salt environment with hardly any NaCl dissolved. On the contrary, in cases 1 and 2, the flow down the salt walls on the surface and in dissolution pipes in dolines reaches saturation with respect to NaCl very quickly.

Thin gypcrete enables the corrosion of salt and produces a dense network of smaller dolines. Massive and thick gypcrete enables water circulation only where disturbed. Places of infiltration are not so common, resulting in a more concentrated water flow from large catchment areas.

Collapse dolines as a connection between the karst surface and the underground (examples from Croatia)

Nenad Buzjak
Speleological Society Dinaridi, Marulićev trg 19/II, 10000 Zagreb, Croatia

There are many examples of collapse dolines in the Croatian karst. Some geomorphological elements and features of the collapse process were analyzed in four selected caves in different areas of the Croatian karst (Dolačina mama cave – Žumberak Mt., Tamnica cave and Mrgića pećina – Kordun and Jama na Sredi cave – Cres Island). These elements included the influence of geological conditions and the cave's stage of development, the morphology of collapse dolines and cave passages beneath them. The analysis confirms that a collapse is a significant component of cave development and that formation of collapse dolines is an important indicator of karst evolution.

Caves below collapse dolines - case study of the Tisova Jama

Jelena Calic-Ljubojevic [1,2] and Vladimir Ljubojevic [2]
[1] Geographic Institute "Jovan Cvijic" of the Serbian Academy of Sciences and Arts, Djure Jaksica 9, 11000 Belgrade, Yugoslavia
[2] Student Speleologic and Alpinistic Club (ASAK), Studentski trg 16, 11000 Belgrade, Yugoslavia

The cave Tisova Jama (-235m) lies on Beljanica Mountain (Carpatho-Balkanides, Eastern Serbia). Its entrance pit is situated at the bottom of a great collapse doline (dimensions 180 x 160m), below which there is a chamber with the greatest surface area (11,374 m^2) and volume (c.170,000m^3) so far known among Serbian caves. Such dimensions can be explained by the presence of a strong underground stream in the unreachable part of the cave. Removal of the material disrupts the stability of the underlying rock, leading to breakdown and deepening of the doline.

Gypsum-karst collapse and hydrological effects in the northern Black Hills, South Dakota, USA

Jack B Epstein
U.S. Geological Survey, National Center, MS 926a, Reston, VA 20192, USA

Gypsum and anhydrite are found in four stratigraphic units in the Black Hills of South Dakota and Wyoming, USA: in a large part of the Minnelusa Formation of Pennsylvanian and Permian age; in several horizons in the red beds of the Opeche and Spearfish formations of Permian and Triassic age; and in most of the Gypsum Spring Formation of Jurassic age. Dissolution of gypsum in the Spearfish and Gypsum Spring has resulted in collapse and formation of many dolines in several areas that are presently undergoing urban development in the northern Black Hills. Dissolution of anhydrite in the Minnelusa at depth has produced a regional collapse breccia, many dolines, extensive disruption of bedding, and breccia pipes and pinnacles, some of which extend more than 300m (1,000ft) into overlying strata. Removal of anhydrite in the Minnelusa probably began soon after the Black Hills were uplifted (early Tertiary) and continues today. Recent subsidence is evidenced by dolines more than 18m (60ft) deep opening up within the last several decades, collapse in water wells and natural springs resulting in sediment disruption and contamination, and fresh circular scarps surrounding shallow depressions. Some of the dolines in the Spearfish Formation might be too large to be accounted for by dissolution of the relatively thin gypsum beds within the lower 60m (200ft) of that formation. They were more likely produced by the removal of much thicker anhydrite layers in the Minnelusa Formation, approximately 150m (500ft) below. Much of the calcium sulphate in the lower part of the Spearfish has been dissolved, many of the beds are contorted because of expansion due to hydration of anhydrite to gypsum, and many gypsum veinlets extend down from parent gypsum beds along random fractures. Thus, a secondary porosity and permeability has developed in the lower part of the Spearfish Formation and, contrary to present hydrological interpretation, it is an aquifer, at least locally. Several sinkholes are sites of resurgent springs. These springs support fish hatcheries and are used for local agricultural water supply. As the anhydrite dissolution front in the subsurface Minnelusa moves downdip and radially away from the centre of the Black Hills uplift, these resurgent springs will dry up and new ones will form as the geomorphology of the Black Hills evolves. Abandoned sinkholes and breccia pipes, preserved in cross section on canyon walls, attest to the former position of the dissolution front. Mirror Lake, which is expanding northwestward in a down-dip direction, is a local analog of a migrating dissolution front.

Is Velika Jeršanova doline a collapse doline?

Stanka Šebela [1] and Jože Čar [2]
[1] IZRK ZRC SAZU, Titov trg 2, 6230 Postojna, Slovenia
[2] University of Ljubljana, Geology, Aškerčeva 12, Ljubljana, Slovenia

The Velika Jeršanova doline (535m a.s.l.) is situated on the surface above the Postojnska Jama cave system. Its deepening truncated the continuation of Pisani rov (535.5m a.s.l.) towards the North. Velika Jeršanova doesn't have the typical shape of a collapse doline. Considering its morphology, it is better to call it a *"collapse doline with gentle slopes"*, although its mode of formation is that of a collapse doline. The crest of the Postojna anticline runs across the northern edge of the Velika Jeršanova doline, and the strike and dip of the thin-bedded Turonian and Cenomanian rocks are rather disrupted along the fold crest, where the limestones dip at 5 to 20°. The principal tectonic structures have a Dinaric orientation.

The upper edge of the collapse doline covers an area of 325x300m, and the highest point of the edge is at an altitude of 575m, some 40m higher than the doline floor. Slope gravel covers the southwestern slope of the collapse doline, and the doline floor is covered with thick red clay sediments. The development and shape of the Velika Jeršanova doline are related directly to the formation of a collapse chamber, Velika gora, and with collapse in the passage of Čarobni vrt.

One of the factors responsible for the atypical shape of the Velika Jeršanova collapse doline is its formation in thin-bedded, clay-rich limestones, which take on a less pronounced morphology with relatively gentle slopes. The difference between a collapse doline and a *"collapse doline with gentle slopes"* relates to the degree of tectonically crushed rocks. Generally, the most intensive influence on the formation of collapse dolines is the lowering of underground water.

Using a Geographic Information System to determine geological controls on the distribution of sinkholes in the Ozarks of south-central Missouri

R C Orndorff, D J Weary and K M Lagueux
U.S. Geological Survey, 926 A National Center, Reston, VA 20192, USA
Rorndorf@usgs.gov

In an effort to understand the geological controls on the distribution and development of dolines in the Salem Plateau of the Ozarks Plateaus Province, south-central Missouri, various statistical analyses, using a Geographic Information System (GIS) platform were performed to test hypotheses related to randomness, lithostratigraphy, geological structure, topographic position, and slope. Area and point data for 2,613 dolines in two 30'x60' quadrangles were compiled on a 30m grid. To understand the relationship to lithostratigraphical units, the percent area of dolines was calculated for five units, and it was determined that the Lower Ordovician Roubidoux Formation has the highest percentage of dolines with a slightly lower percentage in the overlying Jefferson City Dolomite. A focal sum neighbour analysis was performed to see if the distribution of dolines had any clustering or linearity. A northwest trend to the alignment of sinkhole clusters occurs along a projection of the Bolivar-Mansfield fault zone in south-central Missouri. In this area the Jefferson City Dolomite has a higher percentage of dolines relative to the Roubidoux Formation. Topographically, most dolines occur on the plateau areas and on gentle slopes (less than 3 degrees). Although dolines usually develop in the Roubidoux Formation on the plateau areas, intense fracturing near regional fault zones may enhance their development in other units. A better understanding of the karst system in this area is important for land-use management including conservation of natural resources, ground-water management, and environmental protection. The study area includes potential economic lead and zinc mineralization within the Mark Twain National Forest.

Shafts and collapse dolines in the conglomerate karst of Montello Hill (Venetian fore-alps)

Francesco Ferrarese
Museo Civico di Storia Naturale, Via Piave 51, 31044 Montebelluna, Italy

The paper deals with the dolines resulting from collapse or from surface intersection of underground cavities in the Messinian age conglomerates of the neotectonic morphostructure of Montello Hill. The spatial distribution of these forms is also discussed, and compared with the degree of karst development.

Doline development processes in the global view

Ivan Gams

Across the globe, doline occurrences are at their highest density in the temperate climatic zone, where precipitation prevails over the potential evapotranspiration and, thus, doline depth development prevails over processes of slope creep. Inside this belt the doline density decreases with surface inclination. Dolines are nearly absent where the slope inclination is greater than the angle of repose, where the mass of unconsolidated material is less stable (32 to 38°) and where slope processes prevail over doline depth processes. After the first phases of doline development (subsoil doline, funnel-like doline) based on locally accelerated corrosion and drainage concentration in more fractured rock, the larger bowl-like doline form prevails, with the exceeded soil/rock interface in the "mantle" (of the geometric, upside-down cone-form) over the area of plain surface inside its upper rim. Doline development becomes the normal primary process, with collapse being a secondary process. Doline deepening diminishes as the soil in the floor of the pit becomes thinner.

As part of the work, the dissolution rates in rain and acid river water of different sizes of carbonate rock grains were simulated. Modifications of the basic postulates, based on the most dissolution being related to the soil moisture at the soil-rock interface are also dealt with.

Patterns of collapse chambers in the endokarst of Mallorca (Balearic Islands, Spain)

Angel Gines
Universidad de las Islas Baleares, Departament de Ciencies de la Terra, Edf. Guillem Colom, 07071 Palma de Mallorca, Baleares, Spain

The Majorcan endokarst is significantly characterized by a wide variety of breakdown and collapse phenomena. Several types of endokarst-collapse features occur, in the massive and micritic Jurassic limestones of the mountains and in the very porous Miocene calcarenites of the southern and eastern coast of the island.

Many well-known caves in Mallorca comprise single breakdown chambers, open to the surface due to ceiling collapse or slope recession. But many others are the result of a progressive coalescing of breakdown voids connected randomly by mechanical failure. Such strings of large rooms and vault-like passages show wandering and erratic trends, rather than the straight hydrological and tectonically guided ones that might be expected.

Some cenotes can be included in the first group, including the Cova de sa Gleda entrance pit and Cova des Serral, together with a few huge open-ceilinged breakdown domes, like Avenc de Son Pou and Cova des Drac de Santanyi. Furthermore, several large macro-chambers (difficult to recognize before surveying, due to the growth of speleothems that create partitions and smaller pseudo-chambers) also belong to this group. This is the case with Cova de Can Sion and Covota de sa Penya Rotja.

The great majority of Majorcan caverns fall within the second group, including (among many others) Cova des Pont, Cova dets Ases, Coves dels Hams, Cova des Coll, Coves de Campanet, the celebrated Coves del Drac and, last but not least, Cova de sa Campana, the deepest cave system in Mallorca (-304m).

Endokarst collapse patterns can be described, studied and eventually explained on the basis of accurate cave-surveying, because breakdown piles, sloping boulder floors, vault profiles, dome structures and coalescence areas can be detected easily when mapped. The morphometrics of specific collapse features found in caves need additional work as a fundamental contribution to the knowledge of speleogenetic processes and endokarst evolution over time.

Mechanisms and kinematics of collapse doline formation and development: the state of the art

Jerzy Liszkowski

Collapse of surficial materials into subterranean voids of any origin is the most catastrophic and hazardous type of subsidence or ground surface deformation. Strongly localized and accidental, these effects may cause buildings and other engineering structures to fail, land to be removed from use, and loss of life.

However, note that collapse is only the final, surficial expression of a long-term continuous/discontinuous subsurface process of rock and/or soil failure, which may persist for hundreds to millions of years. Also the mechanisms of void formation and development may be very different, even if we limit the discussion to natural collapses in karstic terrains, i. e., to "sinkholes" or collapse dolines.

Based on published data and the author's own experiences, the paper discusses the mechanisms of "sinkhole" formation, the modes of cavity formation and enlargement, typical strain-time curves of the whole process of rock and/or soil failure and the possibilities of their prognosis and risk evaluation. Also, the many factors that influence or determine the geometry and kinematics of void enlargement up to the final "sinkhole" formation at the Earth's topographic surface are listed and discussed.

Collapse structures genetic model of Mallorca's Upper Miocene

Pedro Robledo Ardila and Luis Pomar Goma
Universidad de las Islas Baleares, Departamento de Ciencias de la Tierra, Edf. Guillem Colom, 07071 Palma de Mallorca, Baleares, Spain

Miocene carbonates (Upper Tortonian-Lower Messinian) on Mallorca Island, are composed of reefal (Reef Complex) and shallow carbonates (Santanyí Limestones) that prograded across platforms surrounding palaeo-islands. The contact between the Reef Complex and the Santanyí Limestones is a subaerial erosion surface with palaeokarst features. The shallow-water carbonates of both the lagoonal beds of the Reef Complex and basal beds of the Santanyí Limestones, are affected by V-collapse structures, produced by roof collapse of caverns developed in the underlaying Reefal Complex. Recent work on these carbonate platforms allows proposal of a genetic model to explain the origin of these V-structures, which are related to early diagenetic processes induced by high-frequency sea-level fluctuations. These same sea-level fluctuations controlled the facies architecture of the carbonate platforms.

During sea-level lowstands cave systems developed at the water table, near the subaerial surface. During a subsequent rise of sea level, the roof of the cave collapsed as a result of increased loading due to aggradation of overlaying shallow-water carbonates. This collapse produced V-incasion structures when incompletely consolidated beds collapsed into the cavity. The cave system developed by preferential dissolution of aragonite (mainly corals) in the reef facies and coral patches existing in the outer lagoonal beds of the Reef Complex.

Examples of recent karst collapses in the Venetian fore-alps

Ugo Sauro
Universita degli studi di Padova, Dipartimento di Geografia, Via del Santo, 26, 35123 Padova, Italy

The paper deals with models of solution and collapse dolines applied to some typical morpho-structural settings of Monti Lessini and other fore-alpine mountain groups. Some recent collapses are described.

Large collapse dolines in Puglia (southern Italy): the case of "Dolina Pozzatina" in the Gargano Plateau

Benedetta Castiglioni and Ugo Sauro
Universita degli studi di Padova, Dipartimento di Geografia, Via del Santo, 26, 35123 Padova, Italy

The paper deals with the description of the largest doline of Gargano (Puglia) in southern Italy (675m long, 440m wide, 130 m deep);

aiming to suggest an interpretation of its origin and development. Surrounding karst forms and other large dolines of Puglia are also described.

Remarks on collapse and collapse-like forms in carbonate karst (on the basis of Abisso di Trebicano and Grotta Gigante in the Classical Karst, and palaeokarstic features in Poland)

Andrzej Tyc
Department of Geomorphology, University of Silesia, ul. Bedzinska 60, 41-200 Sosnowiec, Poland
e-mail: atyc@us.edu.pl

The problem of the origin of collapse and collapse-like forms is discussed, based on fundamental studies of denuded caves (by A Mihevc and co-workers) and speleo-destructive processes in caves (by F Šušteršič on the Classical Karst), as well as the author's own experience of caves in Italy and palaeokarstic sites in Poland. Examples at Trebicano Abyss and Grotta Gigante in the Trieste karst were examined to explain the transformation of big cave chambers into part of the surface morphology – collapse-like forms in shape, without participation, or with only limited participation, of cave breakdown processes. The presence of big cave chambers, as in the Grotta Gigante, in a zone influenced by epikarstic processes may testify to the possibility of the development of surface forms of similar shape to collapse dolines, but resulting from continuous destruction of speleologenetic space and denudation. In some parts of the chamber mentioned, well-defined epikarstic features occur, and they are located on phreatic forms.

The basic aim of this paper is to describe the role of denuded caves and shafts, filled with cave sediments and covered by glacial and fluvio-glacial deposits, in the development of collapse-like dolines in several areas of the Silesian-Cracow Upland in Poland. The uppermost part of the Triassic carbonate rock outcrop in this region is a good example of a polycyclic denudation surface, mostly covered by Quaternary sediments. Most attention has been paid to areas affected by mining and water exploitation, where induced collapse and collapse-like forms have been created. Processes of subrosion and suffosion, as well as rarely observed breakdown of cave fillings within the carbonate massif, are among the possible origins of collapse-like features.

Fieldwork

As in 1999 the participants were warned to be watchful for ticks. This year the horror story of infected ticks carrying Lyme Disease was reinforced by the news that they now also transmit meningitis C. Throughout the fieldwork, people could be seen scanning themselves and their neighbours for signs of ticks, and removing the offending beasts, in scenes that would have done credit to a TV coverage of chimpanzees' mutual grooming behaviour. The fieldtrips took place on the afternoons of the first and second days and for all of the third day. Most participants travelled by coach from Postojna, with a few making use of private cars.

The first afternoon's trip, extracts from which were featured on Slovenian television, was led by Professor France Šušteršič, and included visits to various enormous collapse dolines and related landforms in the general area of Cerknica, Rakov Škocjan and Planina.

On the second afternoon the field trip was led by Andrej Mihevc of the Karst Research Institute, and visited classic collapse doline sites and other features, including sections of unroofed caves, in the impressive area above Škocjanske jame.

Day 3's trip was again led by France Šušteršič and was concerned mainly with collapse dolines in "his own back yard", in the area around Laze and Logatec, north of Planinsko polje. The party was joined for part of the day by Gareth Jones, who just happened to be in Slovenia and decided to grasp the opportunity to see some classic karst sites and sights. Following lunch in Logatec, and visits to still more enormous collapse dolines, the day was rounded off in slightly more relaxed and certainly cooler fashion by a visit to the huge entrance passage/chamber of Planinska jama.

Thanks to the undoubted expertise, not to mention vitality, of the trip leaders, and the efforts they had put into preparing the routes, the sites visited during the fieldwork on all three days were both informative and impressive. The sheer size and steepness of some collapse dolines in the Classical Karst is quite breathtaking. There were also brief ventures underground on the final day. Some team members got very muddy while making a diversion to see *Proteus anguinus* in the wild, inside Vranja jama, and others suffered a variety of minor injuries as they attempted the local *"rite of passage"* [sic.], in trying to traverse the through-cave of Skednena jama without lights. Through most of the fieldwork, whether underground or on the surface, on the flat or up and down steep slopes, the party was accompanied by one well-behaved, unflaggingly energetic and undoubtedly very fit Airedale terrier. Though this Slovenian hound must have had distant forebears in Yorkshire, the UK contingent could trace no hint of an ancestral dialect in its never less than enthusiastic bark.

Assessment

Overall the event was bigger than its predecessor in 1999, but despite changes of venue and house-keeping arrangements, it was just as well organised, and most things appeared to go according to plan. The Karstological Schools' traditional cosmopolitan image remains, and might even have been widened this year. Likewise it was good to see a cross-section of attendees that included some young children, as well as students, an age-spectrum of academics and professional researchers, and those who were simply interested enough to be there. For those, like me, brought up in a world where the mysteries of the karst are of no interest at all to "the man in the street", it was a pleasant surprise to see the media interest in a karst symposium and its associated fieldwork. The same tendency was apparent in the Karstological School reception, held at the Karst Research Institute and attended by the Mayor of Postojna. This was a great opportunity to relax, unwind, chat to people from far away places, imbibe red and/ or white wine (or non-alcoholic drinks), and gorge on a staggering selection of breads, acres of ham and cheese, and a sufficiency of puddings.

Just as last year, may I stress that the International Karstological School is an ideal, as well as economical, opportunity to learn about karst and to learn about karst people. I'm already looking forward to the next one I'm able to attend.

Acknowledgements

My thanks to the Limestone Research Group for supporting travel to/ from the 8th Karstological School, to the organisers of the school for all their efforts, and for inviting me to attend. Finally, thank you to all at the Karst Research Institute and to the Family Šušteršič and their friends, for their hospitality.

Report by Dr D J Lowe, Limestone Research Group, University of Huddersfield, Queensgate, Huddersfield, HD1 3DH, United Kingdom.

FOREST 2000: FOREST OF DEAN CAVING SYMPOSIUM III

Introduction

Held at English Bicknor, Gloucestershire, over the weekend of 16 to 18 June, Forest 2000 was the third in an irregular series of such events, and it was well worth the long wait since the second symposium in 1996. During the weekend delegates were entertained by a lively series of lectures and presentations – some in the main hall, some in an adjacent marquee – by a bewildering choice of underground and surface field trips, by diversions such as rope testing, and by extras such as the local brew, Free Miners ale. The weather was superb by any standards, but especially by the standards of Summer 2000. Not even the failure of the "breakfast wagon" to turn up on Saturday, or the queues when a replacement did appear on Sunday, could quench the prevailing atmosphere of camaraderie and expectation. Only the "disappearance" of an expensive piece of audio-visual kit as the event drew to a close on Sunday burst the bubble. A sad reflection of the "real" world in which we live.

Many delegates arrived on the evening of Friday 16 June, and a small, tented village appeared on the far side of the English Bicknor sports field. However, the event proper got under way on Saturday morning, when (as already mentioned) the only serious glitch was a lack of a food vendor for those who were not self-catering. The main lecture hall was decked out with a number of poster exhibits and specimen displays, caving equipment was on sale in another room and BCRA publications were on offer in a third. Technology had well and truly arrived at this third symposium, and many of the better-prepared speakers were able to make use of a PC projection system, allowing some slick and highly professional presentations to be given in the main hall. Others, less well prepared or less adventurous, soldiered on with the well-tried combination of a slide carousel and OHP transparencies. This combination was the effective technological limit in the adjacent marquee, where the speakers also had to compete with the wind-driven background flapping and occasional whip-crack of the black plastic sheeting that was draped around the tent to improve the blackout. Isn't atmosphere brilliant?

The Saturday Talks...

Divided between the main hall and the marquee, the following presentations took place during the morning. Available edited abstracts are reproduced below. Hopefully, the editing will not have altered any of the original meaning. Fuller texts and illustrations will appear later in a special Symposium volume.

Nick Chidlaw: Geological setting
Paul Taylor: Hydrology
John Elliott: Wet Sink - the Re-melt Series
Paul Taylor: Big Sink
Ray Gilson: Forest Ochres
John Wilcock: Dowsing
Paul Taylor: The Bream Project
Maurice Febry: Bats
John Wilcock and David Lowe: Origin of the thermal waters of Bath
Paul Taylor: Radon in the Forest
Dave Steer: Surveying work

Geological setting

Nick Chidlaw

The area of interest is underlain by rocks of Early Carboniferous age (363 - 323 million years old), cropping out west of the River Severn and its estuary, between Mitcheldean in the northeast and Newport in the southwest. It comprises a steep-sided plateau reaching about 200m above sea level, deeply dissected by the River Wye along an impressive cliff-lined gorge. Surface streams crossing onto these rocks commonly disappear underground, to emerge elsewhere at resurgences in valley bottoms or where they come in contact with the underlying rocks. The area is remote, having few towns, and is occupied mainly by extensive plantations of woodland, particularly in the Wye valley and the Forest of Dean.

The geological structure of the Early Carboniferous rocks consists of a number of interlocking 'domes' and 'basins' elongated N-S. The rocks are horizontal in parts of their western outcrop, with the structures appearing and becoming increasingly pronounced (angles of up to c.80 degrees) eastwards. The rocks are of sedimentary origin, are over 300m thick, and are known as the 'Carboniferous Limestone'. This is a convenient label; in this area about half of these rocks are in fact composed of muddy and sandy sediments, the remainder being dolomites with subordinate limestones. Many of the beds contain a variety of shelly marine fossils, including corals, and were deposited in warm shallow tropical seas when Britain lay just south of the palaeo-Equator. Originally deposited as flat layers, these strata developed their current structure by the end of Carboniferous times, c. 290 million years ago.

The dolomites and limestones are hard, well-bedded and jointed. They are also subject to slow dissolution by natural acids, particularly in flowing water. Such a combination has enabled the development of fine, extensive and diverse 'karst' erosional and depositional landforms on and in these rocks. Many of these landforms have only been discovered in recent years, raising the importance of the Forestof Dean to be on a par with other, better-known, karst areas in Britain. Analysis of minerals, sediments and their fossil contents deposited in the dissolutional features is in its infancy, but studies to-date show karstic processes have been active here intermittently since Carboniferous times.

Hydrology (A layman's view)

Paul Taylor

An understanding of the hydrology of a caving area can provide a wealth of information to cave diggers and explorers alike. The existence of cave passages that run from the sinks to the resurgence sites can be established. Over the years the Forest of Dean has received its fair share of attention. This has come not only from the caving side but also from the miners, in their quest to reduce the flow of surface water into the mine workings. Only by dye tracing has it been possible to establish the links and show how, for example, Coldwell Swallet has a split drainage pattern, with flows to both Coldwell Resurgence and the Slaughter Rising. The evidence of a confirmed dye trace result has in many cases played a major factor in keeping the digging teams going. None more so than at Redhouse Lane Swallet and Big Sink, where significant results have been obtained against considerable odds.

This talk takes a "Birds Eye Layman's View" of each of the resurgence sites. Links are identified, drainage areas determined and a few of the author's ideas are put forward to generate some interesting questions. As the cave discoveries are made, the task of understanding the hydrology more fully can be passed over to experts, who can discuss the available evidence and formulate ideas about how the underground drainage routes and caves were formed.

Wet Sink, the Re-melt Series

John Elliott

The initial exploration of Wet Sink (Slaughter Stream Cave) produced just under 8km of cave passage. At the end of Snow Garden Passage John Elliott and Paul Taylor discovered a small chamber and choke.

Though they vowed to return one day, the area remained unvisited for a long time Fortunately Jan Karvik persuaded John to take another look. Persistence in the choke gave access to a narrow descending slot. Beyond this lay a network of rifts, tubes and walking-size passages that have been given the overall name of the Re-melt Plant. Subsequent surveying has seen the length of the Wet Sink system taken to almost 14km. Also the survey gave an indication of a potential connection with Kuwait Passage, which, if opened, will provide a significant round trip. John tells the story of the work that has gone on, shows the latest surveying of the "Northern Line" and suggests some interesting future possibilities for those prepared to make the 5-6 hour journey to the end.

Big Sink

Paul Taylor

Big Sink is one of a number of doline depressions that can be found along a line that runs from the Symonds Yat Rock area towards the east-west trending Mailscot Valley, 2km to the south. Many of these sites engulf streams of varying sizes and have, over the years, attracted the attention of cave diggers. Unfortunately some have also attracted the attention of the Forestry bulldozers and are now out of the reach of the diggers. Only at Symonds Yat Swallet was any notable downward progress made, yet even here, a major collapsed area and significant areas of infill restricted headway.

Tony Howard and John Berry took up the Big Sink challenge. In the years that followed, others from that team joined in the work as other projects were completed, and the steady task of finding a way through the boulder infill got underway. Although some horizontal development was found, the major work went into sinking a series of shafts down into the mass of rocks to try and find the way out of the bottom of the depression. Eventually, after four years of work, a breakthrough was achieved and open passage found. Not in places the largest of passages, admittedly, but it was progress. A couple of significant chambers and fine formations have since been added to the find, which has provided over 1km of cave, shown that determination pays off in the end, and given the Forest of Dean another classic cave.

The Forest ochres

Ray Gilson

State of the art instrument magnetic analysis in collaboration with Bulgarian and German laboratories is revealing precise properties of the three characteristic Clearwell ochres. Experimental work on mechanisms of their stratification provides quantitative confirmation of theoretical ideas that are being used in current archaeology research at Bristol University.

The presentation considers such questions as what exactly are the Clearwell ochres; whence did they originate; how does each differ from the others; and how do they form the patterns of coloured strata that they do? The part that they are playing in practical research at Bristol University, into why there are no British cave paintings, is also described.

Dowsing work (How do the dowsing results tie up with exploration underground?)

John Wilcock

Dowsing has been a feature of Forest of Dean caving activities for many years (including the author's work during the past ten years), and there have been related presentations at two previous Royal Forest of Dean Caving symposia. These took the form of reviews of known and postulated Forest of Dean systems over the whole of the limestone area from west of the Severn Tunnel system to north of Wigpool. Work since the FoD II Symposium has concentrated on the Miss Graces Lane, East Wood, Hewelsfield, Car Sink, Clanna Resurgence and Slade Brook areas.

How do the systems postulated by dowsing tie up with underground reality? There are four possibilities:

1. No cave found, no dowsing exploration;
2. No cave found, dowsing exploration postulates new systems;
3. Caves with no dowsing exploration over them;
4. Caves with dowsing exploration over them.

Category 1 is clearly of little interest, and there are few examples of category 3. In all category 4 cases studied dowsing reactions are claimed over the caves. The more interesting studies are those where a survey of the cave was not seen and yet dowsing produced accurate surface mappings. Of greater interest are the category 2 cases, where as yet unexplored new cave is postulated, perhaps representing ancient phreatic passages abandoned by the modern drainage, or totally flooded deep systems that even the best cave divers could not hope to penetrate.

Commencing with a brief physicist's hypothesis of how the dowsing effect may work, the presentation goes on to cover the whole of the Forest of Dean area, using large-scale maps with plots of known caves and dowsing results.

The Bream Project

Paul Taylor

Gloucestershire County Council in their wisdom decided that the B4231 road through the village of Bream near. Lydney needed to be straightened. In their rush to proceed they initially failed to realise that the area through which the road ran was in fact an extensive area of abandoned iron-ore mine workings (Oakwood Mill Deep Iron Mine).

As cavers are well aware, some of these workings come very close to the surface in various places. One part of the mine was even called the Engine Room, due to the noise of an engine on the surface travelling down into the void below. Once the close proximity of the workings had been established, the County Council realised another significant point, of which cavers are already well aware. Forest miners were very liberal in their use of pencils when it came to drawing up surveys of their workings, so it was very difficult to relate the underground to the surface. Although in the past cavers had produced an improved survey, this was not of a large enough scale to be used for civil engineering work. Cavers were given the task of producing a new high-grade survey of the parts of the mine within the area of the existing road and its proposed new route. This gave some very interesting and, for some, very worrying results.

The survey work, associated pictures and a final report provided the bases for an infilling project of part of the mine's Main Chamber, to ensure that the road, and vehicles using it, stay on the surface!

Origin of thermal waters at Bath (A Sub-Severn and Forest of Dean hypothesis)

John Wilcock and David Lowe

Possible sources of the Bath and Hotwells thermal spring waters are discussed speculatively in the light of some still-evolving modern views of cave development and groundwater movement, particularly the Inception Horizon Hypothesis of cave origin. A lateral viewpoint is adopted, that is not dominated by conventional ideas of underground drainage or by interpretations of "hard" data that provide partial support for a southerly water source, as preferred in the generally accepted "Mendip Model".

On this basis, a tentative "sub-Severn Model" for at least part of the drainage feeding the springs is considered, with possible water sources west of the Severn in South Wales (the "Severn Tunnel system") and the Tidenham Chase and Forest of Dean Basin synclines in Gloucestershire. Several indications support the potential existence of underground flows from the west, but neither this source nor the seemingly more likely source in the Mendip Hills can yet be demonstrated conclusively as contributing to the flow of the Bath Springs.

The presentation commences with an explanation of how this hypothesis came to be considered, and concludes with geological observations.

Radon in the Forest

Paul Taylor

Cornwall and parts of Scotland have long been well known for their levels of natural radon. Over the years the existence of radon in other parts of the country, especially in underground locations, has become more apparent.

The change of use of an abandoned iron-ore mine at Bream in the Forest of Dean into a Working Mine under the terms of the HSE Mines Inspectorate resulted in a radon check being carried out. When high radon levels were recorded, well above the recommended working limits, suitable fans were installed to ensure that the levels were reduced.

As a consequence Forest Enterprise, under a Duty of Care requirement, commissioned a series of tests to be carried out by cavers at a number of both mine and cave locations around the Forest of Dean area. (Independent tests had already been undertaken at the Symonds Yat "C Caves", where a significant amount of Commercial Caving Activity is carried out)

Tests were carried out over a two-day period during the Christmas Holiday. The results revealed a wide spectrum of radon levels, with the vast majority falling within the recommended guidelines. However, as was the case at Bream, lack of natural ventilation did result in significantly higher readings at some sites.

The work carried out is described, with a consideration of the the findings, the implications for cavers in the Forest area and future work that is required to improve understanding of this potential caving hazard.

Surveying work in the Forest

Dave Steer

An overview of the past, present and future of the surveying in the Forest of Dean.

A historical background on the surveying that has been done before to rundown on the current state of surveying in the Forest- from its early beginnings to one of the country's largest area surveying and mapping projects.

Why the surface survey is just as important to cavers as underground surveys.

Surveying and beyond - what the future holds for the Forest, the introduction of computers, the advantages and possibilities. A brief reasoning behind the choice of computer programs being used by the surveyors.

The Sunday Talks...

Tim Gilson: Digs roundup
Jan Karvik: Miss Graces Lane
Steve Tomalin: Hole-in-the-Hedge
Dave Hardwick: Otter Hole pollution
David Lowe: Slaughter Rising paradoxes
Dave Hardwick: Fishmongers Swallet
Dave Hardwick/Dave Appleing/Maurice Febry: Forest of Dean Conservation and Access Group
Dave Heaver: The work of English Nature

Digs roundup

Tim Gilson

The well-publicised successes of Forest digging teams only represent part of the story of digging for new discoveries in the area. Other sites have been tried and tested over the last few years, with varying degrees of success. Tim introduces these sites, explaining the locations, some stories, and some of the problems encountered.

Miss Graces Lane (Swallet)

Jan Karvik

With varying rates of progress, the 30m-deep concrete lined entrance shaft to Miss Graces Lane Cave took the digging team three years to complete. In October 1997 the shaft broke into Autumn Frenzy Chamber, giving the team many contorted routes to explore through breakdown material but, more significantly, enough free space to provide ample stacking room for any number of future digs.

No easy way on was found so all efforts and scaffolding were focused at the North end. Two years later and another 30m down, we exited into a clear rift and explored our first 15m of 'proper' passage. A few months of consolidation and further digging gave us the best type of Christmas and millennium present cave diggers can hope for - a breakthrough into Winter Storm Passage. This provides the first leg of what is turning out to be an unexpectedly complex series of passages and rifts.

The survey as completed at the end of February 2000, gives a total horizontal cave length of 340m, total length surveyed as 440m and a maximum depth of 70m. We are now embarking on a period of consolidation, before tackling some of the many promising leads.

Hole-in-the-Hedge

Steve Tomalin

The story so far of this very interesting site, ignored for well over 25 years. The dig was begun in 1993 by a small team of Gloucester Speleological Society (GSS) members. Soon other club members began to develop an interest, and for several years up to a dozen or so diggers busied away. In between the distractions of the regular BBQ and beer, the digging, pulling buckets of spoil up, and the building of the ever-enlarging scaffold platform carried on.

The dig is currently 35m deep and, although the site has yet to yield cave passage, the shaft in itself is very interesting. Several objects have been found, including a large quantity of pure/processed iron ore and slag, animal bones and pottery.

The potential of the site is that it lies some 500m in a straight line from Chunnel East passage in Wet Sink. Although the aim is not to create a second entrance to Wet Sink, the dig has the potential of some 5km+ in the direction of either the Hoarthorns Farm or Lower Lydbrook areas. These areas are indicated as possible destinations for any continuing passage from Chunnel East, on the evidence of drainage features in the old fossil system.

Otter Hole pollution

Dave Hardwick

Otter Hole has probably always had a pollution problem. Many will have heard of the mystery Otter Hole illness. In the early days of exploration it was common for cavers to complain of illness after a trip. Often this was typified by actual sickness; other cavers suffered a rash, sometimes described as like a diesel burn.

On 24 September 1977, when dye testing was being carried out, curious results were attributed to the dye being neutralised by pollution. The Hades Newsletter article (Newsletter 18) recorded "... a strong smell of fuel in the streamway..." when the detectors were installed. In more recent years it has been suggested that the smell is "getting worse".

The Royal Forest of Dean Caving Club controls access to the cave on behalf of the landowner. With the knowledge that there could be a potential health problem, the need for an assessment of the risk was identified. However, without either firm data on the extent of the original problem or on the current situation, a rational informed decision as to whether there is any risk could not be made. For this reason a recommendation was made to close the cave temporarily whilst a programme of testing was undertaken to provide the necessary information.

This paper sets out the history of the problem, the extent of sampling previously carried out, the strategy adopted for the recent analysis and the difficulties encountered in achieving this.

The Slaughter Rising paradoxes (A preliminary conceptual model)

David Lowe

The Slaughter Resurgence in the northwest of the Forest of Dean is a major, though in some ways paradoxical, rising that is fed by a web of allogenic inputs and background autogenic drainage east of the River Wye. Clearly the conduit system "behind" the Slaughter Resurgence is fundamentally important to modern underground drainage across a wide area. However, relationships between this system and the local geology, and between these aspects and four other (lesser) resurgences are less obvious. Based upon a broad overview of the geology, confirmed drainage connections and the trends of known cave passages, a conceptual model of the possible relationships between geology and underground drainage is described.

Fishmonger's Swallet

Dave Hardwick

It was whilst digging at Itton North (near Chepstow) and investigating the hydrology of that area that I realised I crossed a similar lump of limestone each day on my way to work (just north of Bristol). Investigations into this soon resulted in various leads, some referring to sinks and depressions, others to resurgences and even to previously discovered short lengths of cave. Each person spoken to however suggested I should "speak to the Fishmonger". Later I received a telephone call from Clive Grace saying "Hello!...I'm the fishmonger".

This resulted in a walk across various fields to many interesting sites, finishing with an invitation of "Would you like to take over my dig?". In introduction to the landowner, and permission was given, and the dig commenced.

This paper sets out a summary of the area, the history of the exploration, gives a description of the cave and the involvement of Channel 4's Time Team.

Forest of Dean Cave Conservation and Access Group

Dave Hardwick, Dave Appleing, Maurice Febry

At an inaugural meeting in March 1999, local cavers voted overwhelmingly in favour of the formation of a cave conservation and access group.

The group has been formed to relate to the continued conservation and access of the caves and mines of the Forest of Dean. Over the last few years the importance of the Forest of Dean as a caving area has grown rapidly, not just in the amount of cave passage found, but also in the importance of the many unique and rare geological and fossil/animal features that have been discovered.

The group has adopted the National Caving Association Conservation Policy and, using this, is formulating a conservation plan that is tailored to suit the area. In making these plans, careful consideration has been given to the landowners, environmental bodies and everyone who has an interest in the underground environment of the Forest of Dean.

The presenters will discuss how the Group was formed, its aims, roles and how it fits into the National scheme of caving bodies.

English Nature

David Heaver

David describes the general work of English Nature and in particular the role in the conservation of bats in the Forest of Dean and the role that cavers play within in this work. David explains the close working relationship that English Nature now has with cavers through the Forest of Dean Cave Conservation and Access Group and the activities undertaken.

Assessment

Can there be such a thing as *"organised chaos"* and, even if there can, could such an equivocal term be applied to Forest 2000? Rhetorical questions, of course, as each attendee will undoubtedly have a personal view. It has to be admitted that from time to time there was the vaguest hint of mild hysteria – but it was only the vaguest hint! Just like the 1994 and 1996 FoD events, Forest 2000 offered potential for all manner of minor things to go wrong, but it has to be said that most things went essentially right. The only minor glitches were either totally outside the control of the organisers or were related more to the natural exuberance and anarchistic tendencies of the participants, and would have been beyond the control of all but the most accomplished circus ring master or package tour courier. How the underground and surface fieldtrips went I don't know, but for the one that I led myself. That at least had its moments of embarrassment and comedy. What can you say when the trip leader can't find a crucial locality due to the luxuriance of the summer undergrowth? Not a lot! In contrast I have to assume that all the other trips were minor triumphs, having heard no information to the contrary.

Yet again, the organisers of Forest 2000 should be congratulated on planning and carrying off an event that was enjoyable, informative and, as with all good events, left those who attended looking forward to the next one. The venue was ideal for cavers, as well as for several generations of budding to geriatric "cave scientists", the talks were varied, interesting and full of useful information, the field trips were suited to all tastes and abilities, and the catering was simultaneously simple, tasty and satisfying.

Having been involved in cave exploration and more than a fair share of digging in the Forest of Dean for more than 30 years, I feel it's now fair to say that this area has finally come of age. It has shed its image as the ugly-duckling of UK karst areas. Both the underlying dedication and ongoing enthusiasm of the local cavers are emphasised not only by the obvious efforts so graphically described at the Symposium, but also by the work that must have gone into organising and hosting the event itself. Equally, the turnout and involvement during the weekend confirm that interest and keenness are not confined to those who live in or adjacent to the Royal Forest. Though the locals have realised it for quite some time, it now seems clear, even to those on the "outside", that the late Cecil Cullingford's gentle indictment (pointed out to me by Ian Standing of Coleford) can, forty years on, now safely be dismissed...

> *"...In general, however, the Forest of Dean*
> *has not enough caving interest to warrant a special visit."*
> [C H D Cullingford, 1951, *Exploring Caves*, p.79]

Report by Dr D J Lowe, Limestone Research Group, University of Huddersfield, Queensgate, Huddersfield, HD1 3DH, UK.

BOOK REVIEWS

Klimchouk, Alexander B, Ford, Derek C, Palmer, Arthur N and Dreybrodt, Wolfgang (editors), 2000. *Speleogenesis: Evolution of Karst Aquifers*, National Speleological Society, Huntsville, Alabama, 527pp, ISBN 1-879961-09-1, US$60.

With hundreds of large format pages of triple-column text, an abundance of maps and diagrams (generally very good and clear) and many photos (black-and-white and not very good reproduction), this has to be a major text within cave and karst literature. It does contain a huge amount of information, but it may not be all that some readers expect.

Its emphasis is on the early stages of cave evolution; the title reference to aquifers is very correct. So there is a stack of data on cave initiation, less on cave development, and nothing on cave deposits. Consequently, it's not the ultimate cave book, but it is a very significant literature landmark on the early stages of cave evolution. It is a credit to the many contributing authors and to the editors, especially the enormously energetic Alexander Klimchouk.

The book's 69 chapters fall into three basic chunks. There are 180 pages covering the initiation and controls of speleogenesis, including chapters on karst types, geological controls, inception horizons and hydrological factors. These very readable chapters are followed by mesmerising reviews of the chemistry and dynamics of cave genesis (much of these is seriously erudite and very heavy science, which few readers will be able fully to comprehend, but they do represent a very useful collection of essential cave science). Then there are 183 pages that carry over 20 case studies and a few overviews; their coverage is world-wide, some new, some old re-hashes; some are obscure, but most are significant and exciting, and these are the appeal to the non-scientific caver. The remaining 102 text pages include historical reviews (perhaps too long), consideration of passage morphology, discussion of non-carbonates, and applications.

So much for the contents, now for the pluses and minuses (at least, those in the eyes of the reviewer, and in no particular order).

The good points: overviews on Mammoth Cave and the maze caves of Dakota (partly updates of earlier material, but both are by Art Palmer, who is surely the best, most informative and most understandable of cave writers); Dave Lowe's inception horizon hypothesis in accessible print for the first time; Stein-Erik Lauritzen's very concise review of passage morphology; a useful combined bibliography of over 400 entries; welcome chapters on the Israeli salt caves, the spectacular Cheve cave in Mexico, syngenetic karst in Australia, and some of the Belize caves; together with some of the classic sites, including Castleguard, Carlsbad, Ukrainian gypsum mazes, Siebenhengste and Picos de Europa. For the record book, a mineral exploration borehole in Bulgaria found a flooded cavity 1,341m deep (and that's without reaching the floor), though the suggested cavern with 20 times the volume of Sarawak Chamber looks like over-interpretation of rather sparse borehole logs.

The bad points: the bits that seem to be missing, namely; nothing on some very major sites - notably Lechuguilla, Florida, Mulu, and any caves in the tower karst of China and/or Vietnam; almost nothing on the Yucatan caves, surely the ultimate karst aquifer with its 300+ km of active phreatic tubes (check out www.mexicocavediving.com for some idea of what's there); Huautla, Berger, Kanin could have been hoped for, all with stories to tell, but there has to be a limit ...; an element of parochialism in the references, where some authors are biased towards their own papers and thereby fail to overview their subject comprehensively; an inadequate and unfathomable index; a chapter on the Grand Canyon karst and caves that has no descriptions, maps or photos of any caves; and a chapter on water and land use too minimalist to be of use. Minor niggles - no scales on the Ukraine gypsum cave maps, and the block diagrams of Siebenhengste don't work (where a decent map and profile would have been much better), among the usual crop of confusing or amusing typos.

To be parochial for a moment, Britain's caves are poorly represented. There is no British case study, though Mendip is of course featured in chapters by the second editor, and the Dales caves appear in aspects of Dave Lowe's inception horizon chapter. The Peak District only gains mention for its mineral deposits, and South Wales has even less; who outside Britain has even heard of Draenen? But the book is international, so this is just comment and not criticism.

At $60 (which should be little over £40) this book is not cheap, but its hugeness makes it very fair value. Every cave library should have it. Caver readers will find many of the case studies both interesting and informative. Scientist readers will recognise some of the case studies, but will welcome others and will value some good review chapters that pitch from new angles. There may be niggles, and bits missing, but this is a book that will be taken from the shelf many times for many years to come.

Reviewed by Tony Waltham, Nottingham Trent University, Nottingham, NG1 4BU, UK.
(tony.waltham@ntu.ac.uk)

Drew, D and Hötzl, H (editors), 1999. ***Karst Hydrology and Human Activities.*** Published by A A Balkema of Rotterdam on behalf of the International Association of Hydrologists (IAH). Quoted price: EUR 67.50 / $79.00 / £48.00. Paperback edition: EUR 25.00 / $30.00 (Sterling price for paperback edition not quoted).

This is not a text book on karst hydrology so much as a manual on groundwater management in karst areas based on case studies from all over the world. The objective of the IAH was to contribute to a growing understanding of the special and vulnerable character of karst groundwaters by publishing examples of human impacts on karst. Unlike a number of previous books with similar titles, this one is more than just a seemingly random collection of case studies or conference papers. The editors have added useful and well-coordinated introductions to each chapter, and have obviously given thought to their selection of case studies - some of which go beyond just a description of a specific site to provide a review of a whole issue.

The book is organized into three sections. First is an overview and historical perspective of karst waters and human activities and impacts (with perhaps a little too much ancient history). Then comes the main part, with chapters on the impacts of agriculture (land clearance, irrigation and drainage, pollution), industry and urban development (a variety of nasty air, liquid and solid pollutants, and impacts from construction and tourism), extractive industries (mines and quarries) and water exploitation (e.g. over-production, ground subsidence, salt-water intrusions). Each chapter in this section has an introduction summarizing the activities involved, their impacts and possible managerial or remedial responses, followed by several integrated case studies. These case studies, ranging from short notes to quite long expositions, come from all around the world, but with a bias to European sites. A final section briefly reviews the vulnerability of karst waters and then provides a country-by-country summary of legislative responses that have been introduced. This information will obviously date fairly quickly, and is naturally dominated by the USA and Europe, where the combination of extensive karst areas and large populations has generated significant public awareness. The final chapter looks to the future, discussing risk assessment in karst, restoration, and possible future threats such as climate change, continuing urban spread, and tourism, which is bringing stress to remote karst areas.

The book assumes some reader familiarity with the basic principles of karst groundwater systems, but many of the concepts can be picked up as you read. It provides an excellent review of the various problems that can occur in karst aquifers, with some very relevant (and at times horrific) real examples.

Being a compilation of case studies and reviews by different authors the treatment and level of technicality tend to vary somewhat. The introductions to each chapter are generally excellent, as are most of the case studies, but I felt that some were a bit too brief, and a few had limited relevance.

Among the better studies, Worthington's contribution is only two pages long. It provides a succinct discussion of aquifer contamination by sewage in an area where there is a marked distinction between contaminated flow to distant springs via major conduits, which bypass non-contaminated water-wells much closer to the source that tap lower-permeability limestone between the conduits. Hötzl and Nahold present a detailed discussion of remediation of contamination by chlorinated hydrocarbons (chemicals used in dry-cleaning, degreasing and slaughterhouses). These belong to a class known as Dense Non-Aqueous Phase Liquids (DNAPL), which are a problem because they sink through the aquifer waters without mixing and tend to be trapped in depressions at the base of the system. Carrasco-Cantos and others describe how visitor numbers in a Spanish tourist cave have effected the drip-water chemistry (especially the saturation index) with a consequent danger of re-solution of speleothems. An anomalous chemistry of drip waters near the cave entrance was traced to the use of karst-well water in the gardens above. Gunn and Hobbs review the varied hydrogeological impacts of limestone quarries - both during their operation (a range of problems) and after they close (and either fill up with water or provide a tempting site for rubbish disposal).

This book is an excellent introduction to the varied problems that can occur in karst groundwaters. I recommend it to all managers of karst regions and to those responsible for assessing the environmental impact of proposed developments in karst. It would make a good textbook for courses in the hydrological side of karst management.

Reviewed by Ken Grimes, Regolith Mapping, PO Box 362, Hamilton, Vic 3300, Australia.

THESIS ABSTRACT

JOBLING, A, 2000

Resistivity tomography survey over a topographic depression, West Yorkshire.

Honours dissertation, prepared in partial fulfilment of the requirements for the degree of BSc (Honours) Geophysical Sciences, School of Earth Sciences, University of Leeds, Leeds, LS2 9JT, UK.

Three resistivity profiles were completed across a topographic depression near Garforth, West Yorkshire. The depression is roughly circular, with a radius of approximately 20m. Two profiles ran through the centre of the depression, with a third profile lying outside it. Data from these three profiles were processed, and graphs and pseudosections were compiled. The data were also inverted.

The pseudosections and inversions both showed a large, negative resistivity anomaly centred approximately beneath the surface depression. This anomaly had a resistivity difference of between 600Ωm and 700Ωm compared to that of the surrounding rock.

The most likely reason for this anomaly is dissolution of limestone causing development of a doline or sinkhole. The chance of the depression being an old coal mine or sand mine working has been dismissed due to the location of the site and the nature of the resistivity anomaly.

RESEARCH FUNDS AND GRANTS

THE BCRA RESEARCH FUND

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

a) To assist in the purchase of consumable items such as water-tracing dyes, sample holders or chemical reagents without which it would be impossible to carry out or complete a research project.
b) To provide funds for travel in association with fieldwork or to visit laboratories 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 Research Awards are available are available from the Honorary Secretary (address at foot of page).

GHAR PARAU FOUNDATION EXPEDITION AWARDS

An award, or awards, with a minimum of around £1000 available annually, to overseas caving expeditions originating from within the United Kingdom. Grants are normally given to those expeditions with an emphasis on a scientific approach and/or exploration in remote or little known areas. Application forms are available from the GPF Secretary, David Judson, Hurst Farm Barn, Cutler's Lane, Castlemorton, Malvern, Worcs., WR13 6LF, UK. Closing dates for applications: 31st August and 31st January.

THE E.K.TRATMAN AWARD

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

BRITISH CAVE RESEARCH ASSOCIATION PUBLICATIONS

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

CAVES AND CAVING - quarterly news magazine of current events in caving, with brief reports or latest explorations and expeditions, news of new techniques and equipment, Association personalia etc.
Editor: Hugh St Lawrence, 5 Mayfield Rd., Bentham, Lancaster, LA2 7LP, 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. 2 *An Introduction to Cave Surveying;* by Bryan Ellis, 1988. Reprinted 1993.
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. 6 *A Dictionary of Karst and Caves*; compiled by Dave Lowe and Tony Waltham, 1995.
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.

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 organises field meetings. Occasional publications include a *Bibliography* and *Guide to Regulations* etc.

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

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

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

Copies of BCRA publications are obtainable from: Ernie Shield, Publication Sales, Village Farm, Great Thirkleby, Thirsk, North Yorkshire, YO7 2AT, UK.
BCRA Research Fund application forms and information about BCRA Special Interest Groups can be obtained from the Honorary Secretary: John Wilcock, 22 Kingsley Close, Stafford, ST17 9BT, UK.