Cave and Karst Science

BCRA

Volume 25 Number 1 April 1998

BRITISH CAVE RESEARCH ASSOCIATION 1973 - 1998

Oligocene-aged island remnants in Florida, USA
Caves of Jebel Hafeet, United Arab Emirates
Kirkdale Cave palaeofauna, Yorkshire, UK
Wookey Hole and Pope's Grotto
Limestone karst in Zambia
Symposium abstracts
Forum

Cave and Karst Science

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

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

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

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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 25 Number 1 April 1998

Contents

Cover photo:
Lake Inampamba, central Zambia
(see report by Thomas Kaiser et al)
The deep gorge may have formed by the collapse of a river cave guided by a major fault plane. Marks along the gorge walls indicate the extent of seasonal water table fluctuation.

Editors: Dr. D. J. Lowe — British Geological Survey, Keyworth, Nottingham, NG12 5GG.
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EDITORIAL

Dave Lowe and John Gunn

A number of changes are introduced in this Issue, which is the first of the fifth Volume of *Cave and Karst Science* to appear under our editorship. Revised information about the *British Cave Research Association* appears inside the back cover, and improved instructions for authors are provided inside the front cover. The latter includes brief guidelines relating to the use of digital media in presenting material for publication. Also included are details of the broad categories into which we subdivide contributions. Although the (flexible) working parameters that underlie the subdivision remain essentially unchanged, we have decided to abandon the terms *"Mainstream Article"* and *"Development Article"* in favour of the simpler and, hopefully, less divisive terms *"Papers"* and *"Reports"*. Definition of these two categories remains to some degree subjective but, at the broadest level, *"Papers"* are contributions seen as containing a significant proportion of scientific material and results, regardless of discipline or length, whereas *"Reports"* will essentially be either less obviously scientific (providing largely narrative details relating to subject areas of historical, current or, perhaps, future interest), or they may be interim statements, describing work that has not yet reached an appropriate conclusion. Inevitably there is scope for overlap between the two.

Also in this Issue we have introduced the policy of noting the dates when submissions were first received by the Editors and the date of acceptance for publication, following review by our referees and revision by the authors. As described in the past, it is not possible simply to publish contributions on a "first come, first served" basis, as some material is slow to review or slow to revise, while other contributions are dealt with more rapidly. Basic considerations of publication target dates, balance and available space in each Issue also affect the flow. Most authors understand the editorial problems involved and accept the delays, if any, with stoical good humour, though some delays must seem inordinately long. Thus, we feel that it is important to acknowledge first of all the time between receipt and acceptance, and secondly the time between acceptance and publication. We hope that providing this information will be a positive and beneficial step, which will not lead authors or readers to make inappropriate comparisons between the statistics for different types of material.

As noted in previous Editorials, we have been working towards the establishment of a *Cave and Karst Science* Editorial Advisory Board. This is gradually taking shape, and we expect to publish a complete list in the final Issue of this Volume. At present we are awaiting confirmation of acceptance from some of those that we have invited to join, and are seeking others to ensure as broad a coverage as possible, both geographically and by karst-related discipline.

Finally, the content of this Issue requires some comment. Several pages are devoted to abstracts from the recent *British Cave Research Association* Cave Science Symposium, held at Keele University during March this year. One of the stated aims of *Cave and Karst Science* is to support such symposia and publish material that derives from them. Publication of abstracts ensures that at least the flavour of the talks presented reaches a reasonably wide audience. Ideally, a selection of papers enlarging upon the symposium presentations should appear in the future. The Forum section is somewhat longer than usual in this Issue. This reflects first of all that we are receiving increasing numbers of potential contributions to Forum, in all areas that the section intends to cover. Secondly, we would normally have held at least a proportion of the contributions for the next Issue but, as Volume 25 Number 2 is intended to be a Thematic Issue, we cannot guarantee that space will be available for any Forum material. Some potential contributions, mainly in the form of correspondence, are being held over, possibly until Volume 25 Number 3 and, in view of this longer than average delay, the authors affected have been apprised of the situation.

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The age of the Kirkdale Cave palaeofauna

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Abstract: The Kirkdale Cave palaeofauna represents the original and classic 'warm', interglacial mammalian cave deposit in Britain. Although long considered to be 'Ipswichian' in age, no previous attempts to obtain radiometric dates have been recorded. Here we report a uranium-series disequilibrium date of 121,000 ± 4000 yr BP on a flowstone capping that overlay the original bone bed. The precision of the date exceeds that obtained at any other British Interglacial cave site, and permits tentative correlation with the high precision ice core records now available.

(Received 16 September 1997; Accepted 5 January 1998)

BACKGROUND AND HISTORICAL INTRODUCTION

"By the crust of thy Stalactite floor,
The post-Adamite ages I've reckoned,
Summed their years, days & hours & more,
And I find it comes right to the second."
Coneybeare, 1822 [see also Figure 3]

Kirkdale Cave [British National Grid Reference SE 6783 8562[a]] is an abandoned phreatic resurgence cave, 175m in length, located 58m above sea level, on the northern edge of the Vale of Pickering, north Yorkshire. The cave first came to public attention in June 1821, when it was intersected by a quarrying operation on the east bank of the Hodge Beck. Before that time, the entrance had been completely choked and presented no indications of its existence (Young, 1823; Fig.1). Fortuitously, the local surgeon, John Harrison, noticed teeth and bone in road aggregate and traced the source to the ~15-30cm-deep layer of sediment on the cave floor. Over the next four months, a diverse group of local naturalists excavated in the cave, amassing a large collection of mammalian remains of unusual aspect. The existence of hyaena, hippopotamus, 'tiger', and other decidedly atypical Yorkshire fauna marked this discovery as one of some importance, and in November 1821 William Buckland (1784-1856), the first Professor of Geology at Oxford and later Dean of Westminster, was invited to visit the cave.

Buckland was profoundly influenced by his excavations at Kirkdale, and began a series of cave visits in Britain and Germany that culminated in his *Reliquiae Diluvianae* (Buckland, 1823), a volume of seminal importance to scientific speleology, the understanding of late Quaternary extinctions, and the progress of Natural Theology. Buckland's work and philosophy have been documented in some detail by North (1942) and Boylan (1967). The very large number of specimens collected from Kirkdale Cave came to be widely dispersed amongst a dozen museums. Tragically, those in the collections of Royal College of Surgeons and the museums of Bristol and Hull were subsequently destroyed during the hostilities of the Second World War. Boylan (1981) traced some 1,250 remaining specimens and provided a thorough revision of their taxonomic representation. Most notably, Boylan resolved the apparently enigmatic concurrence of a 'warm' fauna (eg, *Hippopotamus*) with 'cold' fauna (such as the woolly rhinoceros, *Coelodonta*) by demonstrating that the latter were erroneous identifications.

The Kirkdale fauna is now considered to be a classic example of an 'Ipswichian' warm interglacial mammalian assemblage, many other examples of which are known from epigean sites and are assigned to Pollen Zone IpIIb (Stuart, 1976). These faunas are characterised by the presence of hippopotamus (*Hippopotamus*), rhinoceros (*Dicerorhinus*), hyaena (*Crocuta*), lion (*Panthera leo*) and straight-tusked elephant (*Palaeoloxodon*), and are often referred to collectively as the 'hippopotamus' fauna. Unfortunately, correlation of either the

[a] The national grid reference is reported inaccurately in Boylan, 1981.

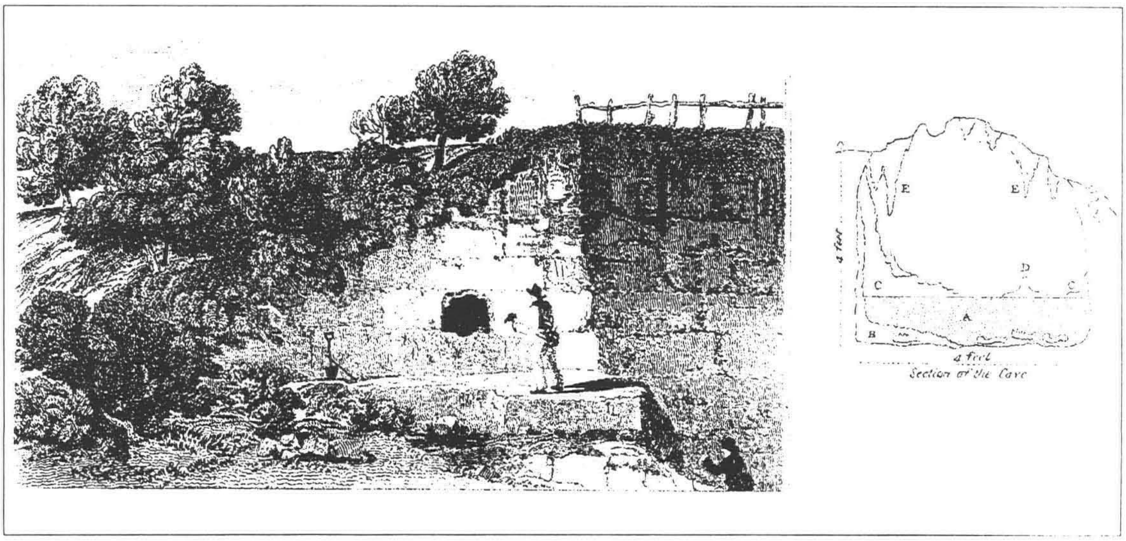

Figure 1. Kirkdale Cave and the Hodge Beck Quarry as they appeared in late 1821, at the time of Buckland's visit.
From Buckland, 1823.

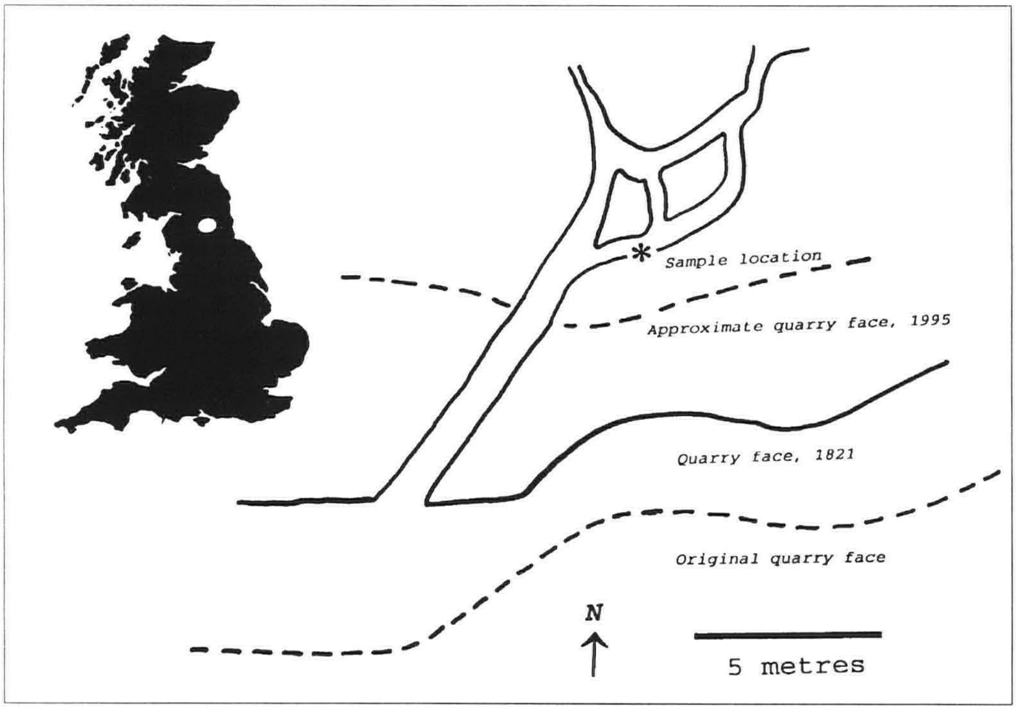

Figure 2. Survey of the entrance area of Kirkdale Cave, modified from the original in Buckland (1823).

'Ipswichian' or Zone IpIIb with the absolute time scale or the marine isotope record has been controversial (Gascoyne *et al*, 1981; Stuart 1976), with Sutcliffe (1976) arguing that Ipswichian faunas represent unresolved components from several discrete temperate intervals. The availability of high resolution records from Greenland ice cores (GRIP, 1993; Grootes *et al*, 1993) and the Lac du Bouchet (France) pollen sequence (Field *et al*, 1994), together with improved precision in the dating of cave deposits, now provides new insight into these ideas.

DISCUSSION OF THE CURRENT WORK

Despite the great historical significance of the Kirkdale fauna, the site has never been dated radiometrically. In an attempt to effect closure on the 175 year saga of Kirkdale Cave, we undertook a uranium series disequilibrium analysis of remnants of the original flowstone floor, which both capped the bone-bearing sediment, and in some cases incorporated the bones that had their upper ends, "...projecting like legs of pigeons through pie-crust..." (Buckland, 1823:12). Subsequent to Buckland's work, quarrying removed a further 15-20m of the cave. Nevertheless, during a visit in 1995, we were able to locate remnants of the original calcite floor overlying pockets of undisturbed sediment (Fig. 2). A 47g sample of yellow flowstone with clay-filled vugs was removed and assayed by standard uranium-series disequilibrium alpha counting methods (Ivanovitch and Harmon, 1992), yielding an age of 121.4 +4.8 / -4.6kyr BP. The analysis was very satisfactory, with a high uranium content complemented by low amounts of detrital thorium (Table 1), a situation unusual in a cave entrance faunal deposit.

The age of the Kirkdale Cave flowstone falls within marine isotope stage (MIS) 5e, which spans the interval 115-132kyr BP and represents the Last (or Eemian) Interglacial (*sensu* Mangerud *et al*, 1979) of continental Europe. The flowstone floor that capped the bone-bearing sediment clearly postdates the episode of hyaena occupation. However, the partial incorporation of bones implies that the flowstone was emplaced relatively quickly after the site was abandoned by these animals. Buckland's contemporary cross section of the cave stratigraphy (Fig. 1) demonstrates that in some areas flowstone actually underlay the bone deposits. It is interesting to speculate that the original Kirkdale Cave deposit may have evidenced two episodes of climatic optima within MIS 5e, producing the upper and lower flowstones respectively. Such an interpretation is consistent with a variety of recent evidence for rapid climate reversals during MIS 5e (Thouveny *et al*, 1994; Field *et al*, 1994; Hillaire-Marcel *et al*, 1996).

The date for the Kirkdale Cave flowstone floor is statistically indistinguishable fıom the age of the flowstone that caps the Lower Cave Earth of Victoria Cave, Yorkshire (Gascoyne *et al*, 1981), the remarkable dwarf deer deposit of Belle Hogue Cave, Jersey, (Lister, 1989), and the 'Sandy Cave Earth' fauna of Bacon Hole, Wales (Stringer *et al*, 1986) - all classic 'Ipswichian' hippopotamus-fauna sites. In reviewing the Bacon Hole sequence, Stringer *et al* (1986) brought attention to the apparently novel continuance of the characteristic interglacial mammals *Palaeoloxodon* and *Dicerorhinus* into the "early Devensian" (glacial), an interpretation based on the dating of the 'Upper Cave Earth', which contains these taxa together with *Microtus oeconomus*, the northern vole (a 'cold' form). However, the age of the Bacon Hole 'Upper Cave Earth', assumed by Stringer *et al* (1986) to postdate the cold 'wolverine' deposit at Stump Cross Caverns, Yorkshire (83 $\pm$ 6kyr BP; Sutcliffe *et al*, 1985), is poorly constrained radiometrically. The Bacon Hole 'Upper Cave Earth' is not dated directly, but rather by an overlying stalagmite layer, which at 81 $\pm$ 18kyr BP places its 95% confidence limits within late MIS 5e time at approximately 115kyr BP, providing only a minimum age for the underlying fauna. Certainly, it cannot be considered significantly younger than the Devensian Stump Cross fauna.

An alternative interpretation is to consider that the tenure of the Bacon Hole interglacial fauna falls entirely within MIS 5e, with the anomalous *M. oeconomus* marking one of the dramatic climatic deteriorations within later MIS 5e (GRIP members, 1993; Field *et al*,

Sample Code	Uranium content	$^{234}U/^{238}U$	$^{234}U/^{238}U$ at deposition	$^{230}Th/^{234}U$	$^{230}Th/^{232}Th$
DAM 95-34	0.675 ppm	1.448	1.63 $\pm$ 0.035	0.706	51
Calculated Age = 121,400 + 4,800 / - 4,600 yrs BP.					

Table 1. Uranium-series dating results on the Kirkdale Cave flowstone.

Figure 3. Coneybeare's satirical cartoon of Buckland in Kirkdale Cave. From Coneybeare, 1822.

1994; Thouveny, 1994; Johnsen *et al*, 1995), and the classic Zone IpIIb hippopotamus fauna correlating to the 5e5 climatic optimum. This interpretation supports arguments for the complexity of 'Ipswichian' climate change (Stringer *et al*, 1986; Gordon, *et al*, 1989), albeit spanning a much shorter time interval than these authors have supposed.

Stuart (1983) reported 14 'Ipswichian' vertebrate cave sites in Britain. All of these were originally discovered and excavated in the 19th century or first half of the 20th century, before radiometric dating techniques were developed. Several of these sites were subsequently lost to quarrying, although modern re-excavations of the remaining sites have yielded a bounty of information, the potential value of 'new' interglacial vertebrate cave sites cannot be overstated. Such discoveries, if they are to be made, will depend on the vigilance of the caving community.

ACKNOWLEDGMENTS

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Palaeoenvironmental reconstruction of an Oligocene-aged island remnant in Florida, USA

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Abstract: The oldest landforms in Florida are remnants of Oligocene-aged islands, preserved within the contemporary landscape of west-central Florida as knobby limestone hill tops, which contain the southernmost cave systems in the continental United States. Proposed mining of limestone from these island remnants would destroy valuable geological and biological information about these unique landforms, so data illustrating the palaeoenvironmental history of part of an island remnant representative of similar features in the region were collected. Thin sections prepared from 20 rock samples collected at 30cm vertical intervals from the wall of a cave in the Suwannee Limestone exhibit four microfacies, and wall and ceiling dissolutional features indicate several dissolution episodes. Processes during a sequence of marine transgression, regression and still-stand deposited and modified sediments that could correlate with (1) a low-energy open sea palaeoenvironment, (2) a high-energy shelf edge or shelf interior palaeoenvironment, and/or (3) a palaeoenvironment formed during emergence. This sequence repeats twice within the stratigraphical column, and is indicated by two distinctive zones of pelagic foraminifera deposition, and two distinctive zones of sparite pore fillings. The pelagic foraminifera correlate with the open sea palaeoenvironment, and the sparite cement probably formed in a high-energy shallow marine environment, or possibly in a fresh/saline water mixing zone. Karstification of the Suwannee Limestone was probably accelerated during the transgressive/regressive sequences, when the study area was in a mixing zone. Dissolution of the limestone bedrock was active under these conditions until the final emergence of the Florida Platform.

(Received 05 January 1998; accepted 15 April 1998)

INTRODUCTION

Strata of the Gulf Coastal Plain preserve excellent examples of Cainozoic sediments, with some sections considered the most stratigraphically complete shallow marine sequences in the world (Miller, 1986; Winston, 1993; Bryan, 1993). Unlike most Cainozoic sequences on the Gulf Coastal Plain, detailed stratigraphical evaluation of Florida Platform carbonates is not yet complete (Bryan, 1993). Of particular interest are the remains of an Oligocene island group that now stand as isolated limestone hill tops in west-central Florida.

During the mid-Oligocene high sea level still-stand (Table 1), a portion of central Florida kept pace with sea level rise and was partially emergent because of uplift. This emergent area, referred to as "Orange Island" by Vaughan (1910), was at times fringed by smaller islands. Within the contemporary landscape these exhumed Oligocene islands are the karst hills of the Brooksville Ridge section of the Ocala Uplift in Citrus and Hernando counties (Vernon, 1951; Randazzo and Jones, 1997). The Ocala Arch (Upland) is considered to be part of a relatively stable tectonic setting on the passive margin of the North American plate, but even in this setting, folding, faulting, subsidence and uplift have been recognised (Vernon, 1951; Opdyke and others, 1984). These features indicate that the Florida Platform has endured and responded to tectonic forces from the early Miocene, when uplift was initiated, through the Pliocene and into the Holocene (Vernon, 1951; Randazzo and Jones, 1997). Pleistocene seas did not inundate most of the Ocala Arch highland areas, and they remained exposed throughout the Pleistocene. Fluvial erosion and karstification extensively sculpted the highlands, producing areas of high relief (more than 70m), such as the Brooksville Ridge (Randazzo and Jones, 1997). These hills, which have remained above sea level since Miocene times, preserve Florida's oldest landforms, soils, and plant and animal communities (Arnaldi, 1994a; Randazzo and Jones, 1997). The carbonate rocks of the Brooksville Ridge also contain the southernmost cave systems in the continental United States (Brainard, 1994).

Many remnants of central Florida's Oligocene islands have been destroyed by limestone mining over the last 50 years (Arnaldi, 1994a). The best preserved remnants lie in the 17,400 hectare Withlacoochee State Forest, but the Bureau of Land Management (BLM), which owns the mineral rights in the forest, is considering opening the forest for limestone mining. A preliminary Resource Management Plan (RMP) and Environmental Impact Statement (EIS) drafted by the BLM indicates that the forest contains 13,400 hectares of high-potential

Chronostratigraphy	Description of events occurring in the Study Area
Holocene	Weathering, erosion and karstification
Pleistocene	No deposition; weathering, erosion and karstification
Pliocene	Possible siliciclastic sediment deposition
Late Miocene	Choctawhatchee Stage sea level high stand; possible deposition of the Alachua Formation after sea level regression
Mid Miocene	Alum Bluff Stage sea level high stand; possible deposition of the Hawthorn Formation
Early Miocene	Tampa Stage sea level high stand; initial development of Ocala Arch
Mid Oligocene	Middle Oligocene sea level high stand
Early Oligocene	Deposition of the Suwannee Formation

Table 1. Geological history of the study area with sea level high stand and geomorphological information included.

limestone (Shoemaker, 1994) and 400 hectares of hard limestone, prized as an ingredient in concrete. Such hard limestone is concentrated in the karst hilltops (Brainard, 1994) that are the Oligocene island remnants. The EIS admitted that, although reclamation plans are required, the associated landforms and landscape composition within the mined areas will be lost irretrievably (Arnaldi, 1994b). Hence, if the forest is opened for limestone mining, Florida's oldest landforms and the continental USA's southernmost cave systems may be destroyed, along with the geological record of these unique features. The limestones and caves in the Withlacoochee State Forest are potential sources of valuable information regarding the palaeoenvironmental, geological, and geomorphological history of the region.

Most bedrock caves within limestone form by dissolution along lines of weakness, such as joints and bedding planes, where secondary porosity is greatest (Dreybrodt, 1981a, 1981b). Variations in karst processes occur where the chemistry of the solvent varies (Bögli, 1964, 1965). For example, it is believed that parts of Carlsbad Caverns, New Mexico, formed as a result of dissolution by rising sulphuric acid solutions (Davis, 1980; Hill, 1981, 1990). In coastal areas some caves form in a "mixing zone" of fresh and saline water (Back and others, 1979). Under these conditions, the waters dissolve the carbonate bedrock more aggressively due to ionic strength variations that lead to conditions of undersaturation (Freeze and Cherry, 1979; Mylroie and Carew, 1990, 1991, 1995). The mere presence of caves in coastal karst areas that have experienced cycles of transgression and regression does not alone indicate formation in a saline/freshwater mixing zone palaeoenvironment. Data from the limestone/calcareous sandstone Biscayne Aquifer of southeastern Florida (Kohout, 1960a, 1960b; Lee and Cheng, 1974; Segol and Pinder, 1976) indicate that the contemporary saltwater front undergoes transient changes in position related to seasonal recharge patterns and related water table fluctuations. Finite numerical models and field evidence indicate the necessity of also considering the process of dispersion in coastal karst (cave) development. Examining a longer period of record, Mylroie and Carew (1990, 1991, 1995) have determined that fluctuating glacioeustatic sea levels control the size, position and stability of the freshwater lens under carbonate islands, which in turn affects where and for how long portions of the island are in the zone of maximum dissolution (freshwater/marine water mixing zone).

Destruction of the knobby limestone bedrock outcrops (the remnants of the Oligocene islands) and the caves in the forest will destroy a natural archive of data regarding palaeoenvironmental conditions and post-Oligocene modifications to the island remnants. In view of the possibility of eventual limestone mining, and the potential loss of the geological record, this research set out to document geological evidence regarding the palaeoenvironmental history of an Oligocene island remnant before its destruction.

STUDY AREA

The study area lies in the Citrus Tract of the Withlacoochee State Forest in southern Citrus County, west-central Florida (Fig.1). The Brooksville Ridge section of the Ocala Arch, where the study site lies, is dominated by sinkholes, dry karst valleys and interfluvial hills. There are no surface streams within a 30km radius of the site, and drainage is typically through sinkholes and by direct infiltration into Oligocene Suwannee Limestone, which rests unconformably on Eocene Ocala Limestone (Krause, 1979; Randazzo and Jones, 1997) (Fig. 2). The Suwannee Limestone, a yellow to white fossiliferous porous crystalline limestone, is part of the artesian Floridan Aquifer, which supplies considerable groundwater to south Georgia and Florida.

In this area Pleistocene marine quartz sands of varying thickness overlie the Suwannee Limestone. The clay-rich, Miocene Hawthorn (marine) and Alachua (terrestrial) formations (Fig.2), which overlie the Suwannee Limestone unconformably in parts of west-central Florida, have been removed by erosion in the study area (Scott, 1981), although Vernon (1951) postulates that this area was never covered by younger sediments. The unconformities that exist above and below the Suwannee Limestone represent significant erosion surfaces, probably formed during emergent periods before and after deposition (Vernon, 1951; Randazzo and Jones, 1997). Surface elevation within the study area ranges from 6m at the bottom of deep sinkholes to 45m above

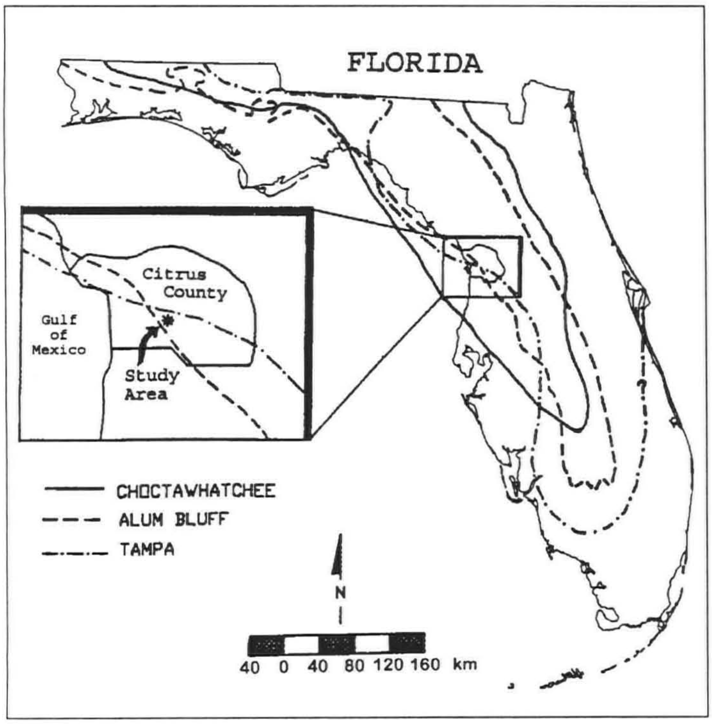

Figure 1. Location map of the study area with Miocene sea level high stands included. The Choctawhatchee Stage corresponds with the Upper Miocene, the Alum Bluff Stage with the Middle Miocene and the Tampa Stage with the Lower Miocene (Randazzo and Jones, 1997).

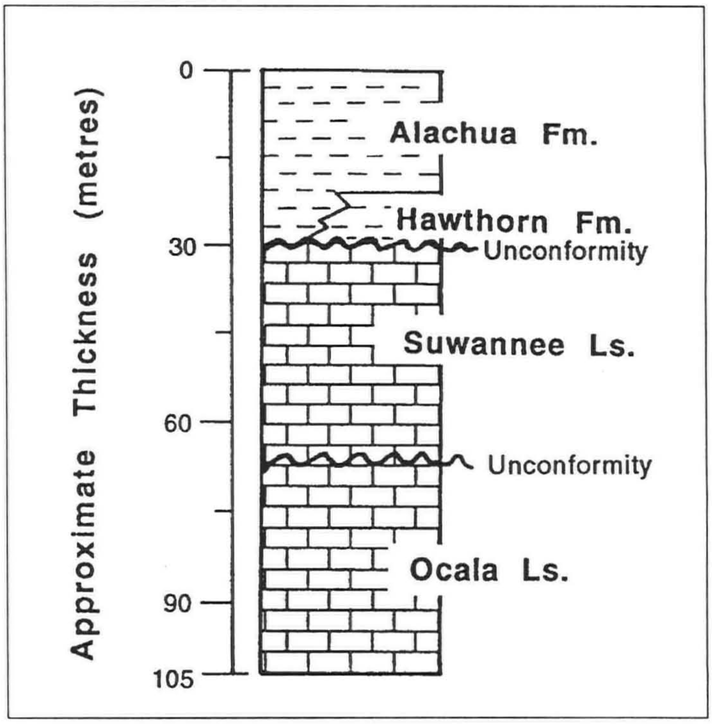

Figure 2. Partial geologic column for Citrus County Florida which includes the Ocala Limestone (Eocene), Suwannee Limestone (Oligocene), Hawthorn Formation (Miocene), and Alachua Formation (Miocene to Pleistocene) (Source: Vernon, 1951).

mean sea level (msl) on Oligocene island remnant hill tops. The relief is caused by sinkhole collapse and karst valley incision. Some of the deeper sinkholes intersect the modern water table at an elevation of about 7m above msl.

Six caves explored and mapped within the study area were probably once part of an interconnected cave system, but erosion, sinkhole collapse and deposition have cut the system into six segments (Brinkmann and Reeder, 1994). The caves occur at elevations between 24 and 27m above msl on the slopes of one of the residual limestone hills. One such cave, Vandal Cave, with three entrances and a surveyed length of 18m (Fig.3), was utilised in this study. Entrances one and three lie at the termini of northwest - southeast trending collapse features; entrance two formed when the cave roof collapsed, creating a karst window. Entrances one and two open into a room approximately 9 by 3m, the southern end of which has a domed ceiling, and ends at passages trending east and south. The east-trending passage leads to the surface collapse at entrance three, and the south-trending passage ends at a narrow, 4m-long, east-west passage. Cave orientation is controlled by northwest-southeast trending joints, which parallel major joint features in peninsula Florida (Vernon, 1951). Vandal Cave's walls display cuspate, oyster-shell-shaped dissolution depressions (scallops), formed by flowing groundwater (Curl, 1966; White, 1988). Such features can form in active dissolution zones caused by the mixing of waters of different chemistry (White, 1988), but scallops cannot be used as sole indicators of a mixing zone environment. The cave also contains many closely spaced dissolutional remnants (pendants) hanging from the ceiling. These can form under similar conditions.

METHODS

Twenty rock samples were collected at 30cm intervals from a 1m-wide, 5.8m-high section of the northeast wall in Vandal Cave (Fig. 3). The possible depositional environment and dissolution history of the limestone were determined using the Glagolev-Chayes method of quantitative mineralogical analysis (Glagolev, 1934). Approximately 300 points were counted for each thin section. The limestone was also classified using Folk's (1962) scheme, augmented by Sweeting's (1972) variations. Dissolution features on the cave walls were documented and compared to descriptions in White (1988).

RESULTS

Four microfacies are present within this section of the Suwannee Limestone (Table 2 and Fig. 4). The vertical variation of sparite, micrite, fossils, pellets and porosity are presented in Table 2 and graphed in Fig. 5. The majority of the lithological sequence consists of biomicrite and biopelmicrite. Biosparite and biopelsparite form thin (0.3-0.6m) layers separating the thicker micritic beds. These results have both similarities with and differences from other segments of the Suwannee Limestone examined by Randazzo (1972) and Goetz (1973). Randazzo (1972) studied a stratigraphical section at a lower elevation, about 20km south of Vandal Cave, which contained four microfacies: sandy pelmicrite, sandy intrasparite, biosparite and biopelsparite. Sandy pelmicrite and sandy intrasparite (indicative of high-energy environments during deposition) were not found in Vandal Cave. Biomicrite and biopelmicrite (low-energy environment facies not found in Randazzo's (1972) cross section), are found in Vandal Cave. In studies of the Suwannee Limestone at the Brooksville and McDonald quarries, at a lower elevation and approximately 15km south of the study site, Goetz (1973) identified four limestone microfacies: silty microsparite, microsparite, biomicrosparite and sandy, clayey microsparite. In contrast to the samples collected from Vandal Cave, all the quarry samples were identified as types of sparite. The palaeoenvironments associated with the stratigraphical units of the Suwannee Limestone that comprise the Oligocene island remnant containing Vandal Cave are classified as follows:

Biomicrite. Six samples (numbers 5, 9, 10, 11, 12 and 13) were identified as biomicrite. Five are from a 1.3m-thick sequence in the middle of the section and one lies approximately 1m above this zone (Fig. 4). Fossil foraminifera are the main allochemical component, and rounded pellets, of probable faecal origin, are also common in these samples. Micrite is more common than sparite, with the samples

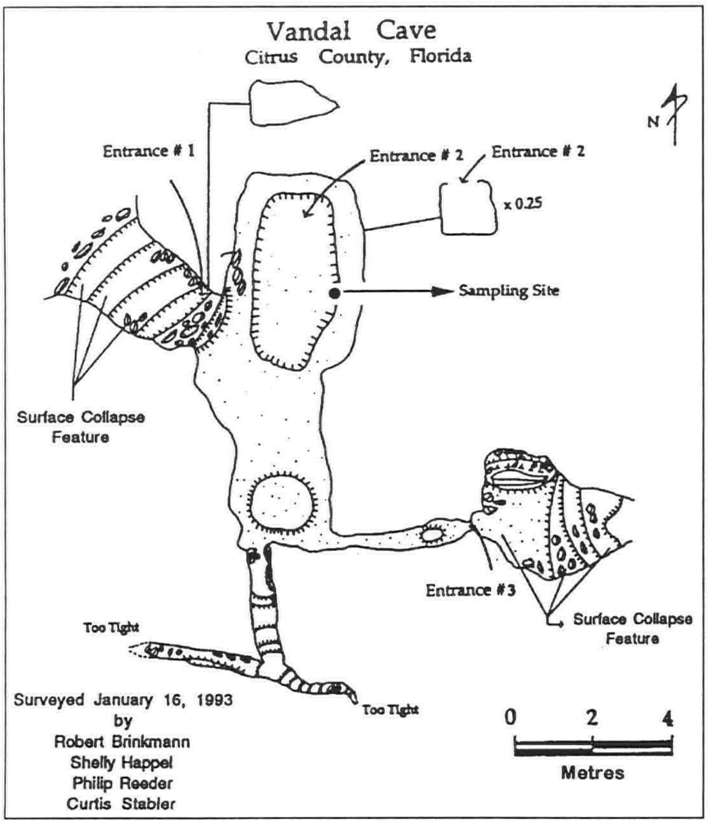

Figure 3. Diagram of Vandal Cave showing the location of the sampling site (Brinkmann and Reeder, 1994).

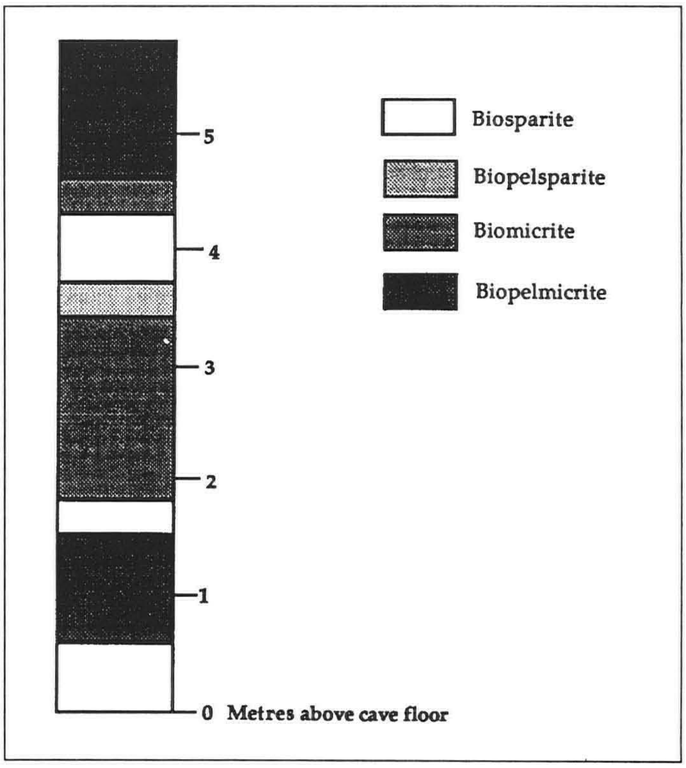

Figure 4. Stratigraphical cross section showing biosparite, biopelsparite, biomicrite, and biopelmicrite facies present in the section of Suwannee Limestone sampled from the wall of Vandal Cave, with thickness indicated in metres.

Sample	Depth	Fossils	Pellets	Micrite	Sparite	Sand	Porosity	Sparite/ micrite	Facies
1	5.8	6	32	29	23	0	10	0.82	BPM
2	5.5	5	31	31	31	0	8	1.0	BPM
3	5.2	2	31	33	31	0	4	0.93	BPM
4	4.9	2	20	41	33	0	11	0.79	BPM
5	4.6	11	30	40	16	0	3	0.41	BM
6	4.3	14	35	5	38	0	8	8.33	BS
7	4.0	5	11	20	62	0	7	3.17	BS
8	3.7	6	20	23	50	0	10	2.15	BPS
9	3.4	46	7	34	11	0	13	0.33	BM
10	3.0	56	8	26	6	0	9	0.22	BM
11	2.7	59	9	27	4	0	13	0.14	BM
12	2.4	53	5	27	13	0	8	0.48	BM
13	2.1	47	3	35	9	0	3	0.26	BM
14	1.8	3	8	14	73	1	20	5.25	BS
15	1.5	4	35	45	14	0	13	0.32	BPM
16	1.2	8	35	32	18	0	23	0.57	BPM
17	0.9	11	51	29	6	0	27	0.19	BPM
18	0.6	42	28	8	18	2	19	2.12	BS
19	0.3	47	29	6	12	0	18	2.00	BS
20	0.0	47	20	5	27	0	15	5.20	BS

Table 2. Results of point counting and porosity estimates, and sparite/micrite ratios and facies classification. Percentages have been rounded off to the nearest whole percent. Depth is in metres above the cave floor.

Note: BM = Biomicrite; BS = Biosparite; BPM = Biopelmicrite; BPS = Biopelsparite

containing the lowest percentages of sparite in the sample suite. Porosity is low, ranging from 3 to 13% (Table 2 and Fig. 5). The porosity is mainly intergranular, but vugs are also present.

Biopelmicrite. The most common facies, biopelmicrite is identified in seven samples (numbers 1, 2, 3, 4, 15, 16, and 17) (Table 2 and Fig. 5). This facies is found near the base and at the top of the cave section (Fig. 4). Rounded faecal pellets are the most common allochemical components, with some foraminifera fragments also present. Micrite is common, ranging from 29-45%, and sparite (6-33%) occurs as pore filling. Porosity varies considerably, from 4 to 27% (Table 2 and Fig. 5). Intergranular porosity dominates, though individual vugs are common in the more porous samples.

Biosparite. This occurs near the base and at the top of the stratigraphical column (sample numbers 6, 7, 14, 18, 19, and 20), and as thin (0.6m) layers between other facies (Fig.4). This facies also contains fossil foraminifera and rounded pellets, but it differs from the biomicrite because of the high percentage of sparite, which appears as vein or pore fillings in this section. The porosity of the biosparite facies ranges from 7 to 20%, principally as vugs, though intergranular pores occur. The secondary porosity values were once much greater, but sparry calcite filled many of the pores and veins. Micrite, though present, is not a large component of the samples (Table 2 and Fig. 5).

Biopelsparite. The least common facies (Fig.4), biopelsparite is represented by one sample from the middle of the section (number 8). Sparite is its most common component, although micrite is present. Rounded faecal pellets outnumber the fossils present (Table 2 and Fig. 5). The porosity is 10%. and the pores are principally vugs, although intergranular pores occur.

PALAEOENVIRONMENTAL INTERPRETATIONS

Thin section data were used to interpret the palaeoenvironments for this section of the Suwannee Limestone. Micrite is indicative of a low-energy marine phreatic environment, which allowed deposition of lime mud without winnowing (Carozzi, 1989). In contrast, sparite is indicative of high-energy marine environments (where micritic muds are winnowed from between allochemical grains) or, possibly, freshwater phreatic environments (Carozzi, 1989). The ratio between sparite and micrite in each sample (Table 2) can be used to interpret palaeoenvironmental conditions (Carozzi, 1989). Randazzo's (1972) petrographical research on the Suwannee Limestone indicated three low-energy palaeo-morphological zones: (1) near shore environment; (2) a shallow sub-tidal environment; and (3) an intertidal environment. These microfacies were interpreted as having formed as the result of sea level changes. Randazzo (1972) demonstrated that the variable environments in which the Suwannee Limestone was deposited were part of a transgressive/regressive sequence forming the different microfacies.

The microfacies represented at Vandal Cave differ from those in Randazzo's (1972) stratigraphical column. Table 2 lists the sparite/micrite ratios for the samples. Numbers much greater than 1 indicate a high-energy environment, numbers much less than 1 a low-energy environment, and values around 1, an environment of intermediate energy. This section of the Suwannee Limestone is dominated by micrite lime muds that formed in a low-energy environment (13 out of 20 samples). There are a number of different low energy environments in which micrite is stable, including (1) lagoonal, (2) intertidal and (3) open sea (Carozzi, 1989).

Allochemical constituents may also be indicative of the sample suite's depositional environment. The presence or absence of sands can provide indications of the morphological zones where sediments were deposited. Detrital sands are absent in sediments in the eastern Gulf of Mexico west of Florida (Shephard, 1932; Blake and Doyle, 1983; Sussko and Davis, 1992). Lynch (1954) noted that the continental shelf off Florida's west coast is physiographically similar to peninsular Florida, where continental sediments transported to the Gulf during Miocene uplift were not transported far from Miocene shorelines (Sussko and Davis, 1992). Where present, the continental sediments thin out rapidly beyond the shelf, and merge into the lime muds of the open sea (Stephenson, 1926; Blake and Doyle, 1983; Hine and Mullins, 1983; Sussko and Davis, 1992). Few sand grains occur in the samples collected from Vandal Cave, and this lack indicates probable offshore deposition in the open sea or the seaward ramp of the continental shelf. Deposition of abundant calcareous pelagic foraminifera tests in some zones is characteristic of offshore geosynclinal belts like that proposed to exist at the seaward edge of the Gulf continental shelf (Weaver,1950; Reading, 1978). Hence, it appears that deposition occurred in an open sea low-energy environment.

Sparite occurring between layers of micrite can reflect changes in sea level (uplift) that brought the ocean floor into a high-energy shelf interior environment or into an emergent environment dominated by freshwater phreatic flow (Carozzi, 1989). A moderate negative Pearson

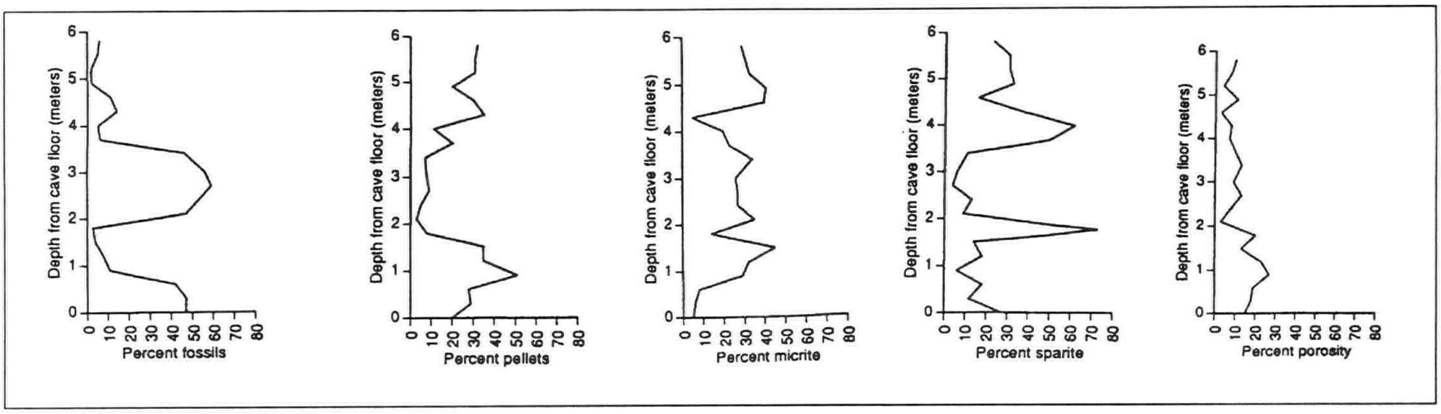

Figure 5. Graphs showing the variation of micrite, porosity, sparite, fossils, and pellets in rock samples collected from the wall of Vandal Cave, with depth from cave floor in metres.

Product-Moment correlation coefficient of -0.60 for fossils and sparite is significant at the 0.01 level, and the coefficient of determination (r^2) is 0.36, which means that 36% of the variation in fossils can be explained by the presence of sparite. This can indicate a change in environmental energy from low in the open sea environment, where micritic carbonate mud and fossils were deposited, to high at the shelf interior, where mud, along with small fossils and fossil fragments were winnowed, and spar became a pore filling cement. It is also possible that sparite pore filling cement was introduced in a saturated freshwater phreatic zone after fossils and micrite were less abundant, and pore space was increased. This scenario is less probable, because available pore space would already have been filled with sparite in the shelf interior environment. It is also possible that the pore filling cement was introduced in a mixing zone environment, where fresh/salt water mixed at the seaward limit of the Miocene Continental Facies.

The high sparite/micrite ratios in samples 6, 7, 8, 14, 18, 19 and 20 probably indicate sparite formation in a high-energy shallow marine environment, though formation in a mixing zone is also possible. Based upon evidence compiled thus far, determination of the precise the environment of sparite introduction is not possible. The two peaks in percent sparite in Fig.5 correspond to fossil lows, perhaps indicating a transgressive-regressive sequence in which the palaeoenvironment was shifting between open sea, shelf edge, shelf interior, emergent, and vice versa. A moderate negative Pearson Product-Moment correlation coefficient of -0.54 for fossils and pellets is significant at the 0.01 level and r^2 is 0.29, indicating that 29% of the variation in fossils in the sample is explained by the presence of pellets. This may indicate deposition and subsequent modification in palaeo-environments of different energy. The pellets (interpreted to be mollusc faeces) may have been deposited in a higher energy shelf edge environment, where pellets replaced fossils that had been deposited in a lower energy environment. Multiple coefficients of determination analysis using fossils as the dependent variable and sparite and pellets as the independent variables, yields an r^2 value of 0.65, indicating that 65% of the variation in fossils can be explained by the presence of sparite and pellets.

These results differ from those of Randazzo (1972) and Goetz (1973) in that the portion of the Suwannee Limestone examined did not form predominantly in a lagoon or shelf interior environment. The data indicate that the part of the Suwannee Limestone from which the twenty samples were collected formed, or was modified, in (1) a low energy offshore sub-tidal environment that favoured deposition of micrite carbonate mud and pelagic foraminifera, (2) a shelf-edge environment, where foraminifera were replaced by pellets, and (3) a high-energy shelf interior or, possibly, a mixing zone, where sparite cement became a pore filling.

PALAEOENVIRONMENTAL IMPLICATIONS FOR KARSTIFICATION

Sea level fluctuated during the Oligocene (mid-Oligocene highstand) and uplift, diagenesis, and lithification occurred within the Suwannee Limestone. The Florida Platform more or less kept pace with sea level rise, and part of the platform was emergent (Bryan, 1993). When uplift exceeded the rate of sea level rise, the study area's palaeoenvironment shifted from open sea, to shelf edge, to shelf interior, to emergent. When sea level rise exceeded uplift, the seas deepened and the study area returned to shelf interior, shelf edge or open sea, depending upon the rate of sea level rise compared to rate of uplift. Uplift continued into the Miocene, when additional parts of the Florida Platform became emergent, supporting formation of the Miocene Continental Facies (the Ocala Uplift of Central Florida). Sandy Miocene limestones and the Suwannee Limestone were removed by erosion along the axis and west flank of the Ocala Uplift, exposing the Eocene Ocala Limestone east of the study area (Lynch, 1954; Miller, 1986). The study area's residual karst hill is a remnant of an Oligocene island that existed off the west coast limit of the Miocene Continental Facies.

During periods of uplift, before the island remnant became isolated from the Miocene Continental Facies by valley incision and infilling with sea water, joints formed in the Suwannee Limestone (Krause, 1979; Puri and Vernon, 1964). The highly fractured and channelled limestone was filled inland with freshwater to a considerable height above sea level (Price, 1954; Bryan, 1993). The seaward slope of the piezometric surface and the resultant pressure-head formed freshwater springs offshore (Price, 1954; Randazzo and Cook, 1987). Groundwater flowed along dissolutionally enlarged joints which were zones of greater secondary permeability. Primary permeability in limestone is generally very low, although young coastal limestones at or near sea level can have high porosity values (Mylroie and Carew, 1990, 1991, 1995). In karst aquifers groundwater usually flows along lines of structural weakness enhanced by dissolution. Karstification of the area's rocks allowed marine waters in the Gulf of Mexico, which were high in calcium and magnesium ions (Garrels and Thompson, 1962), to merge with freshwater from oceanic springs, creating an offshore zone where waters of different ionic strengths mixed. The mixing of saline and freshwater formed a zone of calcite undersaturated groundwater, and these more aggressive solutions dissolved more carbonate minerals, thereby accelerating the rate of cave formation (Bögli, 1964, 1965, 1980; Buhman and Dreybrodt, 1985). Research by Mylroie and Carew (1990, 1991, 1995) indicates that position and nature of the freshwater lens is directly related to the development of dissolution caves in carbonate islands. Lens position is controlled by sea level, and during periods of glacioeustatic sea level still-stands, like those that occurred in the Miocene (Fig.1) (Brinkmann and Reeder, 1994), caves formed and were modified in the freshwater/saline mixing zone. In this zone, dissolution can lead to rapid cave formation, even if the cave remains in the zone for only a short time. Uplift and glacioeustatic sea level fluctuations caused these zones to become emergent at times, and hence drained of sea water. Three sea level high stands were noted to have occurred in the Miocene. These were the Early Miocene Tampa Stage, the Mid Miocene Alum Bluff Stage (which led to deposition of the Hawthorn Formation), and the Late Miocene Choctawhatchee Stage, which led to the deposition of the Alachua clay deposits.

Sparite was present in all collected Suwannee Limestone samples, but two zones of increased sparite concentrations were noted. These zones can correlate with either a high-energy shelf interior palaeoenvironment that existed during uplift, a mixing zone environment, or an emergent palaeoenvironment that existed when uplift exceeded sea level rise. During emergent episodes, landward portions of the shelf filled with freshwater to create a freshwater lens under the land and a seaward sloping hydrological gradient, where groundwater flowed through the already existing joint system. Hence, parts of the Suwannee Limestone were subjected to freshwater phreatic conditions. Because numerous transgressive-regressive sequences occurred during the Oligocene (Vaughan, 1910; Randazzo and Jones, 1997) and Miocene (Puri and Vernon, 1964; Brinkmann and Reeder, 1994) the study area experienced a variety of environments including (1) marine phreatic (when micritization and possibly sparite deposition occurred), (2) freshwater vadose, (3) freshwater phreatic, and (4) mixed freshwater/marine, where freshwater derived from the uplifted area mixed with saline water from the Gulf of Mexico. As noted, mixing of waters of different ionic strengths accelerates dissolution, and it was probably during these periods that removal of carbonate minerals and the rate of karstification were at their maximum.

The passages of Vandal Cave exhibit an obvious circular pattern (phreatic tube), indicating passage formation in the phreatic zone. Furthermore, large scallops exist in the cave walls, with the largest measuring 1.6m wide, 1.5m high and 0.32m deep. This feature, coupled with the presence of smaller dissolution features on the walls and pendants on the cave ceiling, seem to indicate cave formation in an environment conducive to dissolution, such as a mixing zone.

SUMMARY AND CONCLUSIONS

Palaeoenvironmental conditions on the limestone residual side slope where deposition, diagenesis, lithification, and karstification occurred, and Vandal Cave formed, have varied since the Oligocene. Analyses indicate that four limestone microfacies exist on the island remnant's side slope. Post-depositional environmental conditions changed because uplift of the Florida Platform periodically exceeded sea level rise. When this occurred, the sea became shallower, and the regime shifted from open sea low-energy conditions to higher energy shelf edge and interior conditions. Continued uplift placed the study area in the low-energy intertidal zone, and eventually the area became emergent. Evidence of these palaeoenvironmental conditions exists within the stratigraphical column. The two distinct zones in which sparite dominates and the two zones in which pelagic foraminifera dominate are indicative of the palaeoenvironmental extremes that existed in the study area. The pelagic foraminifera were deposited, along with lime muds, in an open sea, low-energy environment and sparite pore filling was most likely formed in a high-energy marine environment. The presence of two cycles of facies indicates that the study area was within each palaeoenvironment at least twice. During emergence, fluvial processes created and incised valleys on the Miocene Continental Facies. Sea level rise during the Choctawhatchee sea level stage (late Miocene) flooded these valleys with sea water and the karst ridge tops of the contemporary landscape were islands off the coast (Brinkmann and Reeder, 1994).

This scenario of inundation, emergence, inundation, and emergence (contemporary) also influenced karstification. During uplift, the rocks and sediments of the Suwannee Limestone passed through a zone where freshwater derived from the Ocala Uplift mixed with the saline waters of the Gulf of Mexico, creating a zone of enhanced dissolution. This accelerated karstification, and interconnected cave passages developed, becoming routes of preferential groundwater flow. These lines of weakness within the bedrock allowed overlying soils and sediments to pipe into the cave system, leading to sinkhole collapse. During periods when the cave system was in the mixing zone, the rate of cave formation was probably accelerated. The net result was development of the southernmost cave system in continental USA.

This study attempted to establish links between (1) regressive-transgressive and glacioeustatic sea level sequences, (2) palaeoenvironments of deposition, diagenesis, and lithification, (3) the alteration of carbonate bedrock in different morphologic zones, and (4) the karstification of the area landscape. The results suggest that these linkages have tentatively been established, and that valuable knowledge of the geological interrelationships responsible for karstification within west-central Florida's Oligocene island remnants has been gained. The data compiled also provide palaeoenvironmental information about Oligocene island remnants that are Florida's oldest landforms. Because limestone mining may eventually destroy these island remnants, the information gathered during this study provides an important palaeoenvironmental, geological, geographical and geomorphological dataset for an area that may eventually be destroyed forever.

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Limestone caves in Jebel Hafeet, United Arab Emirates

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Abstract: The bare limestone anticline of Jebel Hafeet rises 900m above the desert plains. Karst landforms are sparse. One cave near the summit is 96m deep; it is between 5 and 16 million years old, is now almost totally dry and contains some isolated fauna. Foot caves around the base of the mountain are partly cut in cemented bahada sediments.

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JEBEL HAFEET

The mountain of Jebel Hafeet (sometimes transliterated as Jabal Hafit) is an isolated limestone ridge in the interior desert of the United Arab Emirates, 100km south of Dubai, and the same distance east of Abu Dhabi (Fig. 1). At its northern tip stands the oasis city of Al Ain, and its southern end is over the border into Oman. The single ridge is only 12km long, but it rises to a height of 1240m, making it the highest ground in the Emirate of Abu Dhabi. It stands 900m above the dunefields of the surrounding desert, and is a most impressive landmark.

Limestone geology

Jebel Hafeet is a steep and slightly overfolded anticline of Eocene limestones, stripped of its cover rocks and only slightly eroded by wadi incision. At the summit of the mountain, the sequence of strong, massive and nodular limestones is hundreds of metres thick. In cave exposures, the buff limestone is seen to be laced with thin veins of calcite and red clay, which frame the nodular structures; the red clay is weathered away in surface outcrops, where the rounded nodular forms become more conspicuous. Concentric banding within the nodules is seen in some cave walls. Some beds are spectacularly fossiliferous, notably with echinoids, gastropods and sharks' teeth; bedding is not conspicuous.

North of the Hafeet summit, interbedded marls become increasingly thick, and break the limestones into separate and thinner units beneath the city of Al Ain. The alternation of strong limestones and weak marls has been etched into the jagged and precipitous scarps along the northwest flank of the mountain (Plate 1). Oligocene limestone forms the low hogsback ridges that extend northwards to the edge of the city on each side of the anticline (Fig. 2); this limestone thins southwards and has never been present over the summit of Jebel Hafeet. Pliocene and younger sands and gravels form the surrounding plain floors; they extend into bahadas of coalesced alluvial fans, which overlap the limestones at the foot of the mountain.

Miocene folding created the Jebel Hafeet anticline, with its axis aligned nearly north-south and plunging to the north. The western limb dips at about 40°, but the eastern limb steepens to just beyond the vertical and is broken by a reverse fault (Fig. 3). The crest of the Hafeet ridge is formed in nearly horizontal limestones along the axis of the fold. Normal faults and major joints, mostly dipping at 80-85°, have formed in conjugate sets aligned roughly to the northwest and northeast.

Environment and karst

The modern climate of the Emirates is barely conducive to karst development. Annual rainfall at Al Ain is about 100mm, much of it falling in isolated thunderstorms when runoff is very fast on the bare limestone. Temperatures regularly exceed 40°C in the shade, and are uncomfortably high under the burning sun. The ground is normally dust-dry. Natural vegetation on the mountain is limited to scattered shrubs down dry wadi thalwegs; elsewhere, patchy lichens struggle to survive.

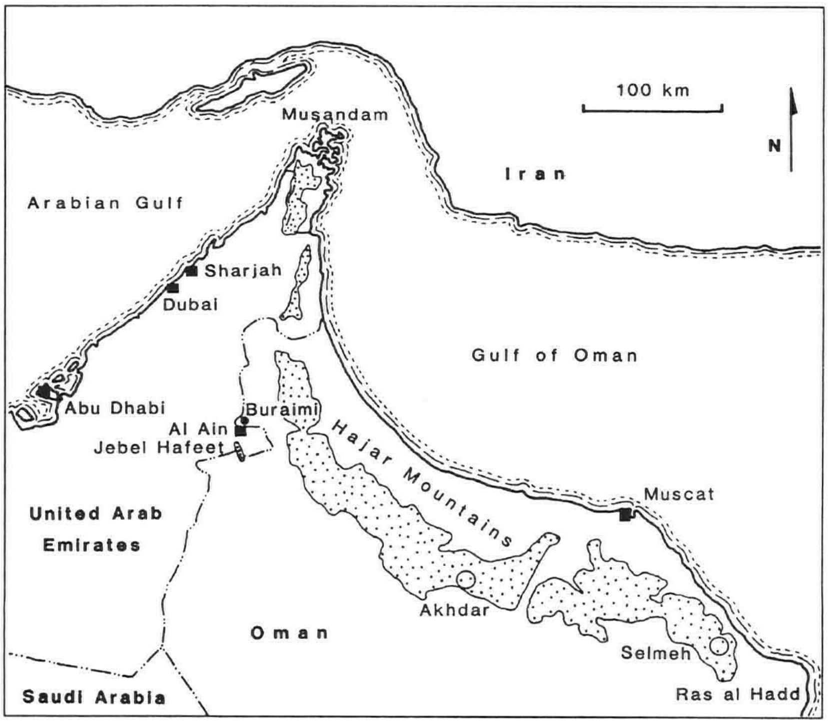

Figure 1. Outline map of Jebel Hafeet and the Hajar Mountains, with the major karst sites of Oman and the Arab Emirates. The stippled areas are the main mountain blocks, much of which have limestone at outcrop.

Plate 1. Steep limestone escarpments along the northwestern edge of Jebel Hafeet; the main mountain ridge rises beyond, and the entrance to Magharet Qasir Hafeet is just beyond the skyline in the mid-left of the view.
(Photos are by Tony Waltham, unless otherwise credited).

Karst landforms appear to be very restricted in both scale and abundance. The wadis are dry because there is no rain. There are no signs of active underground drainage, though immature fissure systems in the heavily fractured limestone do appear to absorb the sporadic rainfall input. There is no impermeable cap to gather any meagre surface flows. Microkarren are etched into most surfaces on bare, undisturbed rock; the presence of these to the exclusion of any larger karren forms is the almost ubiquitous sign of minimal dissolution in desert environments.

Jebel Hafeet is a parallel outlier of the Hajar Mountains, which wrap round the southern side of the Gulf of Oman between the headlands of Musandam and Ras al Hadd; the Hajar therefore extend through both Oman and the United Arab Emirates. Most sectors of these mountains are anticlinal, with thick limestone sequences forming white escarpments around cores of dark ophiolite, though the ophiolite is not exposed in Jebel Hafeet.

Throughout the Hajar Mountains, karst morphology is limited in extent, though there are large areas that have not been searched for caves. There are no recorded caves elsewhere in the Emirates, but Oman does have its caves. Near the eastern end of the Hajar, the spectacular Selmeh cave system (Thomas and Robinson, 1997) and the huge chamber of Majlis al Jinn both lie under the Selmeh Plateau, in the same Tertiary limestones as those in Jebel Hafeet. Closer to the Emirates, Kahf Hoti and the other caves of Jabal Akhdar (Waltham et al, 1985) are formed in older, Cretaceous, limestones.

MAGHARET QASIR HAFEET

Magharet Qasir Hafeet is a cave system just to the west of the summit ridge of Jebel Hafeet. It lies within a narrow rocky spur left between two wadis, both of which descend steeply to the west (Fig. 2). Its entrance was exposed in a shallow trench cut into the limestone to take the foundations for a new guest house in the grounds of a royal palace. A narrow vertical fissure had been blocked and covered by natural limestone debris; clearance to foundation level revealed an elliptical shaft just large enough to descend.

All the accessible cave was subsequently explored by Olivia Pozzan, Bill Algaier, Brian Goggin and a few other ex-patriate westerners; they found more than 450m of passages, reaching to a depth of 96m (Fig. 4). Exploration was a slow process as the main route on was not always obvious, and some narrow inclined rifts do not make for rapid progress underground. At the request of the land owner, the cave was surveyed by Tony Waltham and Tim Fogg in December 1997; it provides no threat to the stability of the buildings above it.

The cave morphology

The narrow entrance rift drops 9m into Top Passage, the higher of two almost horizontal phreatic tunnels, both of which are choked just short of their exits onto the hillside to the south. Northwards, the Rift Below narrows, but Top Passage descends to the spacious, rounded Main Shaft, which drops 22m into a rift passage. A traverse from the foot of Main Shaft is followed by an inclined descent in a phreatic fissure (Plate 2) to Coral Passage, a second inclined fissure aligned to the southwest, which offers uncomfortable progress as it is narrow and has coralloid speleothem on its walls (Plate 3). Further fissure traverses and a long climb descend to a wider chamber, with the stalactite curtains of the Calcite Waterfall at its far end.

In the floor of this chamber, Rift Pitch is a broken, awkward, oblique descent of 26m in a narrow fissure. From the group of rift chambers at its foot, a traverse to the southwest leads to climbs up terraced flowstone and a short descent into the Crystal Ballroom. Though only 15m long and 4m wide, this is the finest chamber in the cave, with its walls liberally decorated with flowstone, stalagmites, stalactites, crystals and coralloid coatings. A long sloping climb up flowstone reaches the Red Room, smaller than the Ballroom, but with its upper alcoves cut into ancient flowstone with spectacular red and white vertical banding. From a ledge in the far end of the Red Room, a narrow tube descends into fissures that double back beneath themselves into a vertical labyrinth of small rifts and tubes, mostly within a single fissure; all narrow in or are choked with sediment.

Magharet Qasir Hafeet contains a considerable variety of calcite deposits. Thick banded flowstone is abundant in the large rift chambers; it is exposed most clearly in the Red Room (Plate 4), but eroded remnants of the material occur in other chambers, and it also forms the roof in some of the high fissures. A later generation of flowstone forms steeply sloping floors in the lower chambers of the cave, and dripstone of similar age is on a modest scale. Notably common in the cave are coralloid speleothems; some of it formed in pools of water, but some appears to have been deposited by thin films of surface water in open passages. Aragonite occurs in some small crystalline forms, and as a few layered flowstones in both the shallow and deeper parts of the cave.

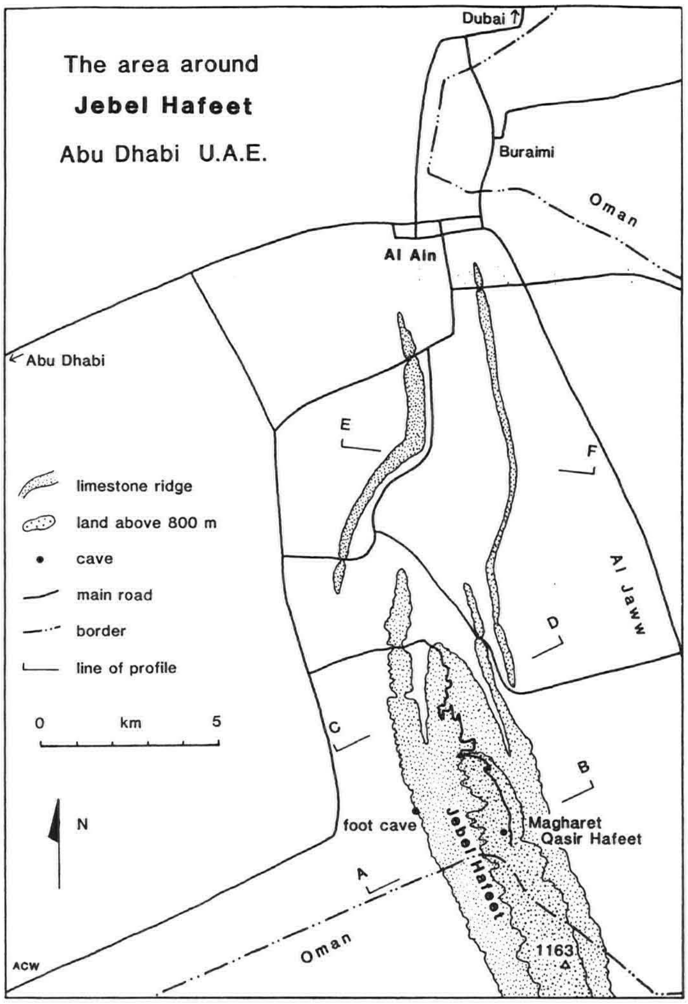

Figure 2. Location map for Magharet Qasir Hafeet, Jebel Hafeet and Al Ain (the positions of the borders are only approximate).

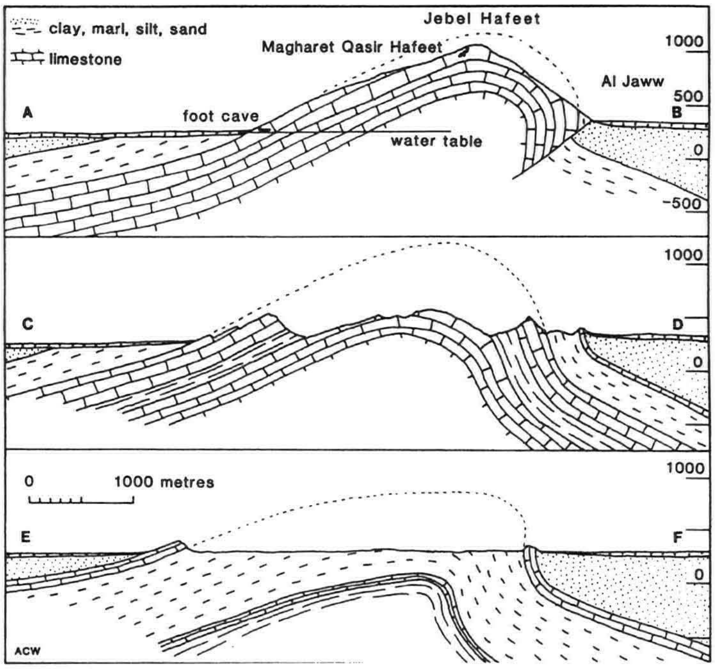

Figure 3. Geological profiles through Jebel Hafeet, on the profile lines marked on Figure 2. The thick limestone in profile AB is the Eocene unit that thins and splits northwards; it is contemporary with the two thick limestones in profile CD, and the upper of these forms the unexposed lower limestone in profile EF. The upper limestone in profile EF is the Oligocene unit that thins southwards, appears as the thin bed on the right of profile CD, and is absent in profile AB.

There are no other caves of significant extent known high on Jebel Hafeet, but the wild mountain terrain has not been examined systematically. Isolated phreatic rifts and bulbous dissolution chambers within the limestone are exposed at various sites and elevations in the cuttings along the new road that climbs to the top of Jebel Hafeet; none is known to extend for more than a few tens of metres (Plate 5). Many more cave openings have been reported on construction sites where the surface cover of limestone rubble has been cleared away, but Magharet Qasir Hafeet was the only one that was not immediately capped or plugged.

Origin and development of the cave

Nearly all the passages in Magharet Qasir Hafeet have been formed along the major conjugate joints and faults; these provided the open pathways for the initial flow of groundwater through the limestone, and only a few sections of passage have developed away from them. Rounded walls and domed roofs throughout the cave indicate that almost its entire development was under phreatic conditions.

This means that the cave is very old. The water table is now about 800m below the cave entrance, not far below the surface level of the surrounding plains; it is well defined in the permeable gravels of the plains, and is likely to continue, as a conceptual surface with a slightly more irregular profile, into the fissure systems of the limestone mountains. When the cave was enlarged beyond its inception stage, it was probably in the active zone of karstic dissolution immediately below the contemporary water table, which was close to local base level and any surrounding plain. Since then, local base level has declined by surface lowering of the adjacent plain, with or without tectonic uplift of the mountain ridge; total relative movement has been about 800m.

In the desert environments and foothill terrains of the Arabian peninsula, the mean rate of surface lowering may be estimated at about 50mm per 1000 years. Estimates of surface lowering are gained from various sites in comparable environments where some dateable feature, such as an igneous rock, can be related to surface palaeomorphology. Derived values for lowering of lowland and foothill deserts range between 15 and 80mm per 1000 years; a value of 50mm makes some allowance for more rapid erosion during wetter climates in the past, but is only a best estimate. If surface lowering were the sole factor responsible for base level decline, the fall of 800m would have taken about 16 million years.

Erosion rates would have been much higher than 50mm per 1000 years in an uplifting mountain terrain, and could match tectonic uplift rates. If these achieved the rate of 190mm per 1000 years that has been measured in the comparable mountain chain fringe environment of Mulu (Farrant et al, 1995), the age of the cave would be less than 5 million years. In Miocene times, an active plate boundary was responsible for the fold ranges of both the Zagros and Hajar Mountains, on either side of the Gulf of Oman. Uplift has continued since then, and the youthful mountains would have created an erosional environment that is more active than the almost flat modern deserts. The implication for the age of the cave is that 16 million years is probably a maximum figure, and the age could be as low as about 5 million.

It is possible that the cave was developed in the confined phreas of an interstratal environment, though no direct evidence for this has been identified. Some waters drawn from shallow boreholes close to the base of Jebel Hafeet have slightly elevated temperatures due to geothermal warming, and this does imply that there is deep artesian circulation through the synclines of limestone. If the cave did develop in either a perched phreas or deep within an artesian structure, evidence for the age of the cave would have to be reassessed.

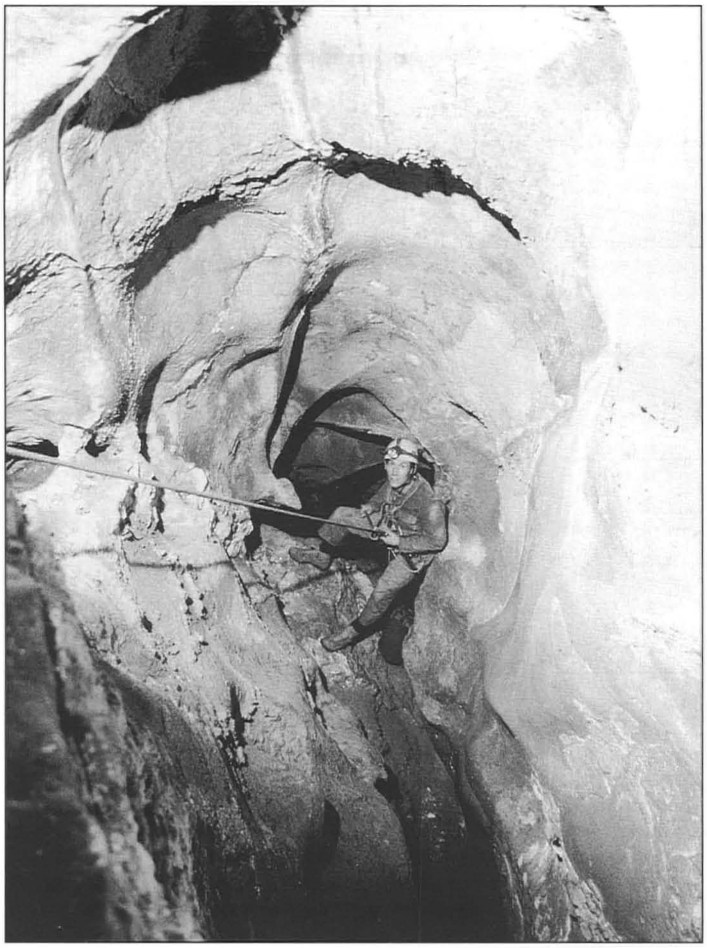

Plate 2. The phreatic tube that is formed down the end of the inclined rift below the Ledge.

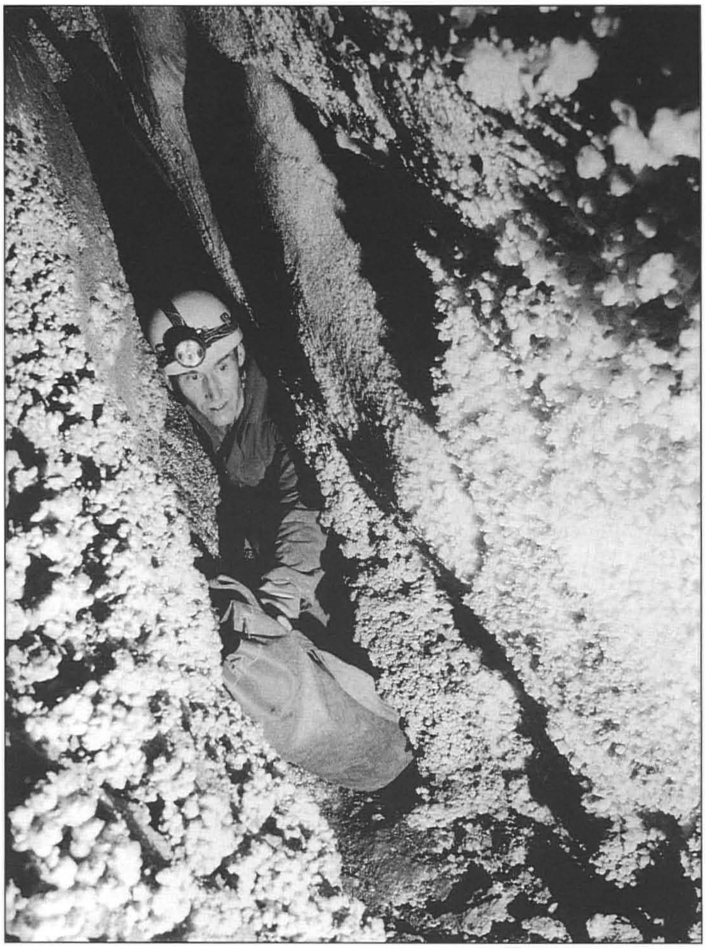

Plate 3. Coralloid speleothems coating the inclined fissure that is Coral Passage.

The largest and most mature passages in Magharet Qasir Hafeet are in the almost horizontal galleries near the entrance (Plate 6), and in the lower chambers of the Crystal Ballroom and the Red Room. This pattern may indicate that cave development was largely in two phases, the first when the water table stood at about the 1050m level, and the second when it had been lowered to about the 1000m level. Subsequently the cave was completely drained; bygone phases of percolation water were responsible for the cave's carbonate deposits, but the cave is now almost completely dry.

The modern cave environment

There are signs of only minimal water entry during rare modern storm events; tiny amounts of water observed on some of the formations may be condensation from the micro-environment created by the observers themselves. The present regional water table in the limestone is at a level close to that of the gravel plains both east and west of Jebel Hafeet; this is about 700m below the deepest parts of Magharet Qasir Hafeet. Fissures within the limestone appear to be able to carry any occasional drainage from the mountain down to the flooded zone of the aquifer, but no known cave passages reach to the greater depths.

Air circulation in the cave is not good. Below the 975m level, the air is static and stale. This suggests that the rock fissures that must exist through to the southern wadi are sealed by calcite or mud deposits. Above the 975m level, the air is fresher. Air blows out of the entrance in the late afternoons, but there is usually no significant air movement in the mornings. The air appears to be circulated and exchanged by natural cave breathing. In the heat of the day the ground warming causes thermal expansion of the cave air, creating the outward draught through the entrance in the afternoon. Ground cooling through the night probably creates an inward draught in the early hours of the morning; this then stops as the new day warms up, before the reverse draught is started in the afternoon.

The stale air in the cave's lower chambers is probably slightly depleted in oxygen and enriched in carbon dioxide, though the levels of the gas anomalies provide no hazard to occasional cave visitors. Radon detectors were placed in Magharet Qasir Hafeet during the survey, and revealed concentrations of 7368 and 9420 Bq/m^3 at the foot and the top of the Rift Pitch respectively. These radon levels are high, but not unusually so when compared with levels recorded in various British caves (Friend, 1996). They are what would be expected in a poorly ventilated cave within a massif with geothermally warmed water actively circulating through its base; high levels of radioactivity have been found in some of the warm waters at the foot of Jebel Hafeet.

Cave biology

During explorations of the cave, various living animals and organic remains have been observed, though there has not been any systematic search for micro-organisms.

Spiders' webs were established in the roof domes of Top Passage, and spiders 5mm long have been observed on them. The webs were found in December 1997, and it is likely that the spiders have entered the cave since the entrance shaft was opened; they now trap small insects that enter the cave, possibly aided by the inward draught at night time.

The remains of a beetle were found below the Main Shaft, but it probably entered the cave accidentally. Groups of bones of small mammals were found in shallow depressions in the areas of soft floor sediment in the Red Room. They were probably washed in by a pulse

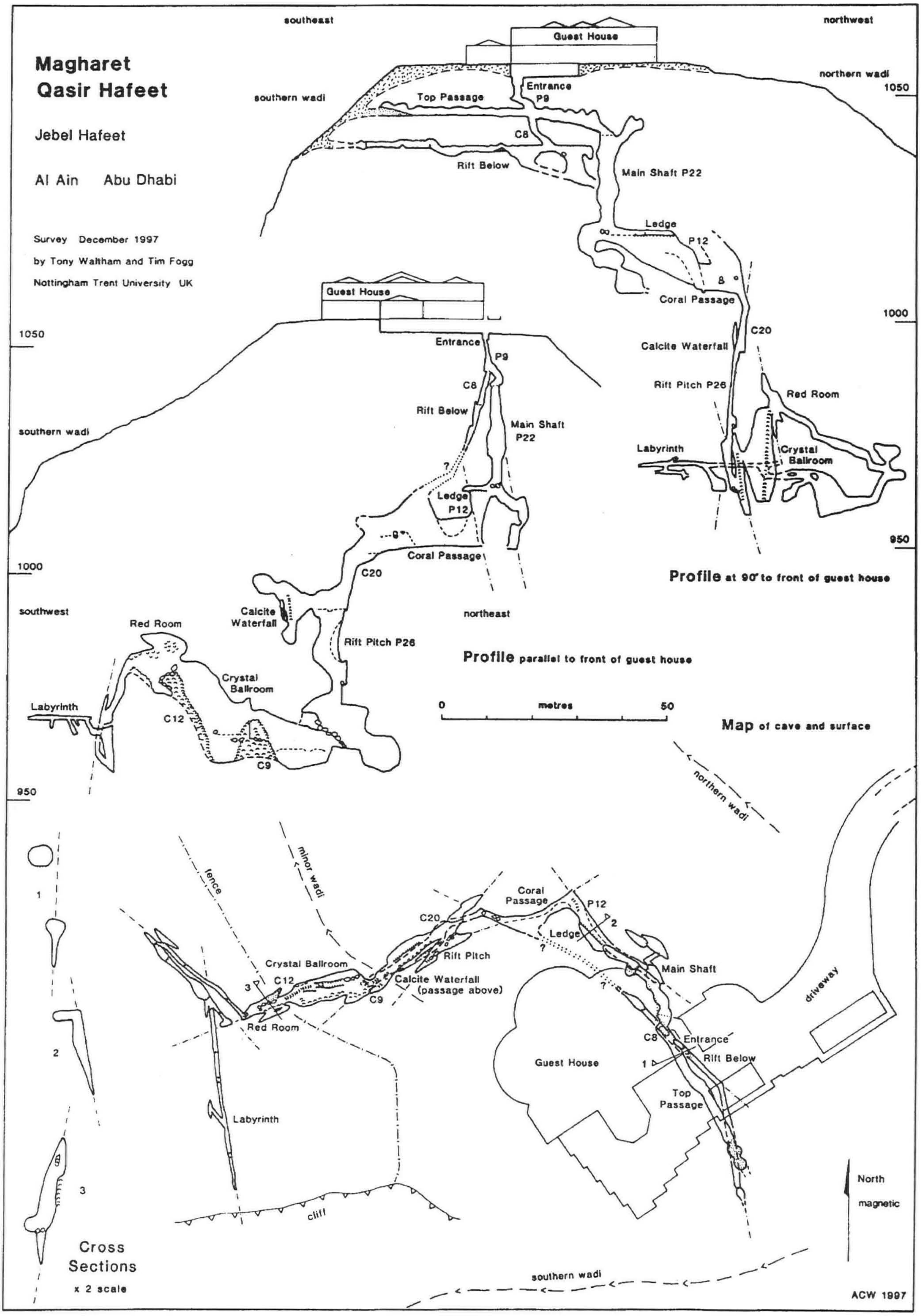

Figure 4. Survey of Magharet Qasir Hafeet.

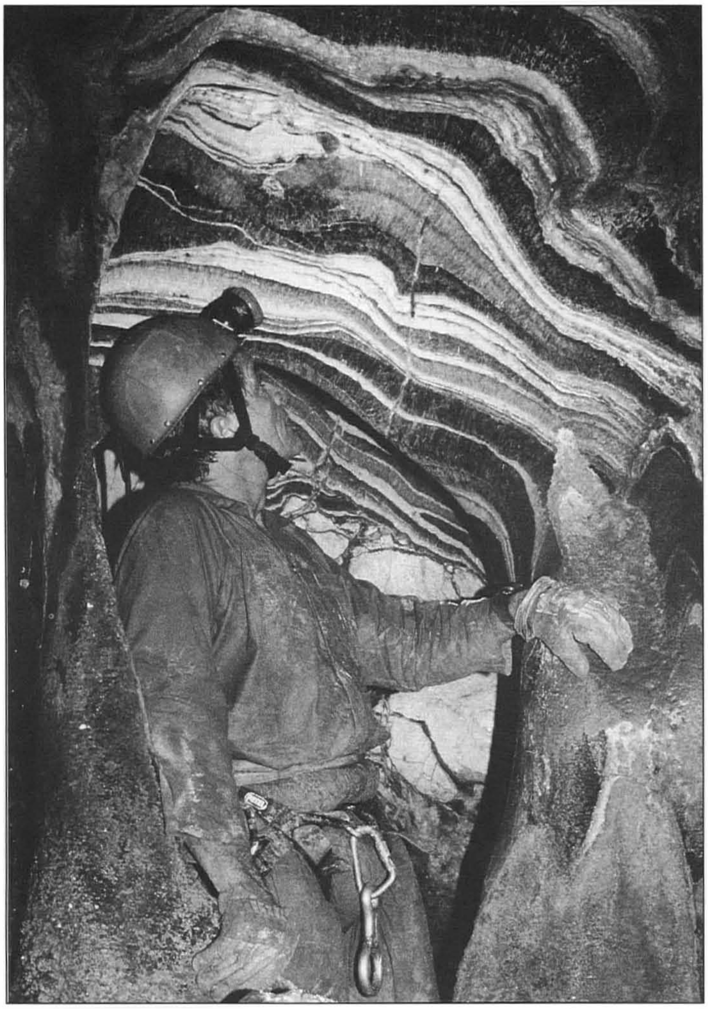

Plate 4. *An alcove high in the Red Room, cut into the thick banded flowstone that is a feature of the very old chambers in Magharet Qasir Hafeet (photo by Olivia Pozzan).*

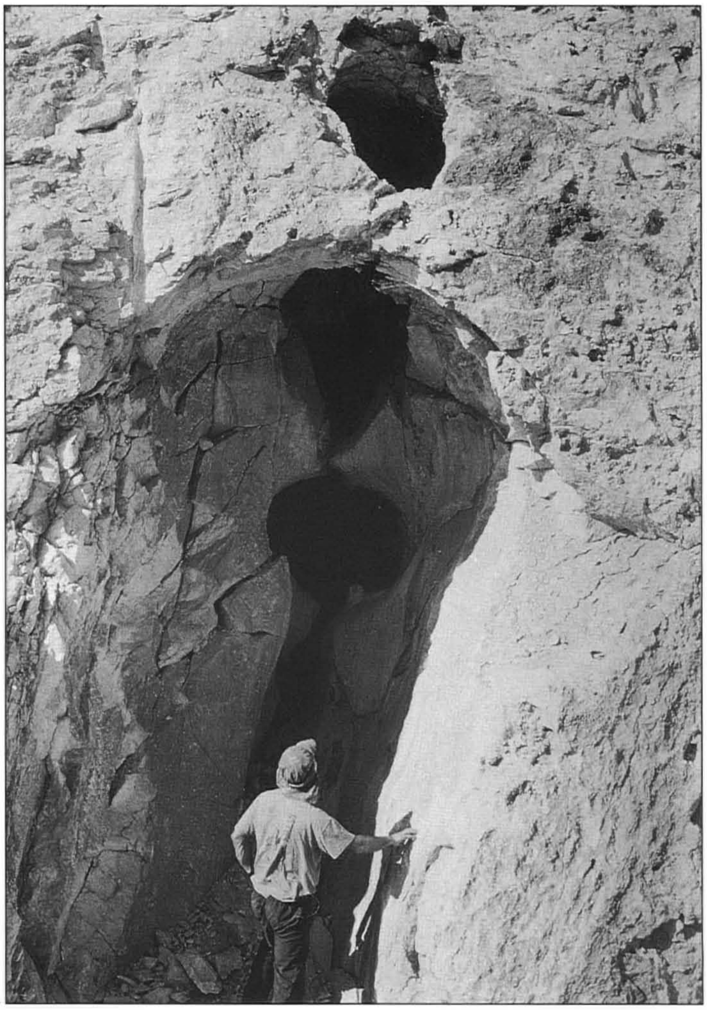

Plate 5. *Ancient phreatic tubes and chambers cut on an inclined fissure, and exposed in one of the new road cuttings on Jebel Hafeet.*

sediment in the Red Room. They were probably washed in by a pulse of flood water through rock fissures from the floor of one of the wadis that are almost above. Also in the lower part of the cave, two slender plant stems 400mm long were found bent round a cobble on the cave floor, and root material was found in a sandbank. Inwashed seeds could germinate in the damp sands, but it is likely that all the plant material was washed in from the outside in the state that it is now.

The south end of the Labyrinth passages contain a number of dismembered ant bodies, and a small population of white insects was observed living in fissures in the cave walls. Each of the latter was about 10mm in total length; with prominent antennae on its head, and a thorax and segmented abdomen. Their lack of body pigmentation, negative reaction to light, and prominent antennae all suggest that they are part of a population with a long history of cave habitation; they appear to be true troglobites, which may be of a species unique to the isolated site. However the insects were seen only in the part of the lower cave that is the closest to daylight, where it is not far in from the cliff face in the southern wadi. They may therefore indicate a relatively recent invasion from the surface, and the ants may have arrived with them; alternatively the ants could represent a food source to which the troglobites were attracted from deeper inside the cave.

FOOT CAVES

Many cave entrances are known around the foot of the steep limestone ramparts of Jebel Hafeet. Some of them have been explored by local adventurers, but none has been surveyed. Many cave entrances were revealed when surface sediments were stripped away in massive operations to construct levees around the base of the mountain; these

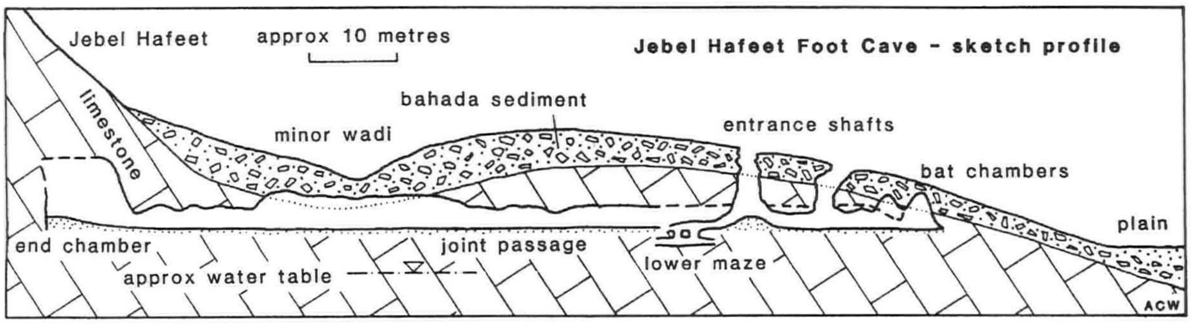

Figure 5. Sketch profile of the foot cave on the western side of Jebel Hafeet, showing its development in both the bedrock limestone and the cemented bahada sediment. The cave is developed largely on two parallel joints, so that the long joint passage lies parallel to and behind the rift from the entrances to the bat chambers; there is some development on dipping bedding planes, but it is obscured behind the main joint passage in this projection.

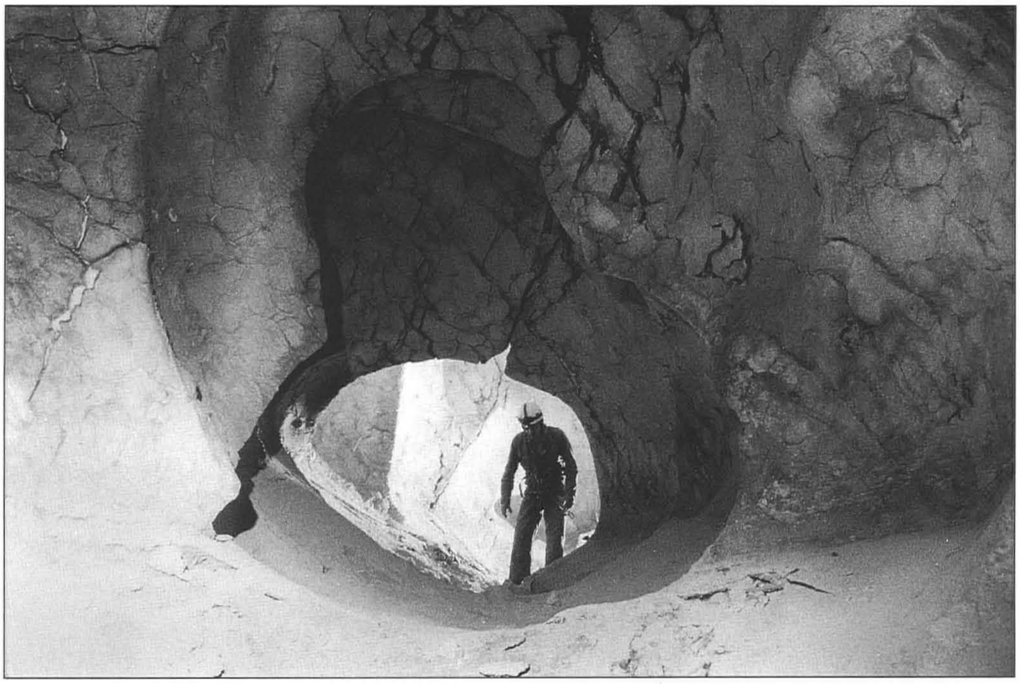

Plate 6. Rounded phreatic roof domes along the very old Top Passage in Magharet Qasir Hafeet.

are intended to capture some of the overland flow during rare storm events - in an environment where water is a very precious resource. Sadly, the entrances that were exposed behind the levees were sealed with concrete before the caves were investigated.

Most of the base of Jebel Hafeet is fringed by a classic bahada - a footslope apron composed of coalesced alluvial fans of debris washed down the many gullies in the steep mountain slopes (Plate 7). Much of this bahada debris has been recemented; it appears as a typical desert calcrete, but some profiles show that it is totally cemented, right down to the rockhead. Beneath the cemented debris, rockhead is the massive limestone in a gently sloping pediment entrenched by buried gullies.

The reported caves are complex mazes of mainly small passages. They are typical foot caves with phreatic spongework in clearly defined horizontal zones which cut across the dipping beds. This morphology suggests that the caves were created just below the water table where the limestone has been subject to dissolutional attack by groundwater in the adjacent plains gravels, which are contiguous with the bahada material. The one observed but unnamed cave (located on Fig. 2) contains a maze of passages at a level close to the adjacent plain. Development along a major joint means that it is longer than most, but it is aligned obliquely to the immediate mountain slope, so that it does not penetrate far from the plain; it passes under a low shoulder in the bahada and then under a minor wadi. In the style of most foot caves, all passages end in phreatic chambers and domes, and there are no signs that they continue further into or up the mountain. There are some zones of spongework developed on inclined bedding plaes, but they extend over only small vertical ranges. This foot cave contains large colonies of small bats, roosting in its roof domes.

A remarkable feature of the observed foot cave is that it is partly developed in the cemented bahada sediments (Fig. 5). This sediment is so perfectly cemented that the walls of phreatic domes in the cave are cut cleanly through the rock/sediment interface, the rockhead; there are no steps or ledges, and certainly no cave inception horizons at the boundary. The entrances of the cave are domes breached by surface erosion; they descend through the rockhead (Plate 8), and the boundary is also exposed in the roof of many of the cave chambers.

Some of the foot caves are on multiple levels, and rifts descend to the water table where flooded passages at still lower levels await exploration. The limestone is an aquifer that extends beneath the plains between the limestone mountains. Though it does yield water to deep

Plate 7. The western foot of Jebel Hafeet. The bahada of cemented sediment forms the slope reaching from the car up to the foot of the bare limestone crags. The person on the bahada to the right is standing at the entrance to the long foot cave.

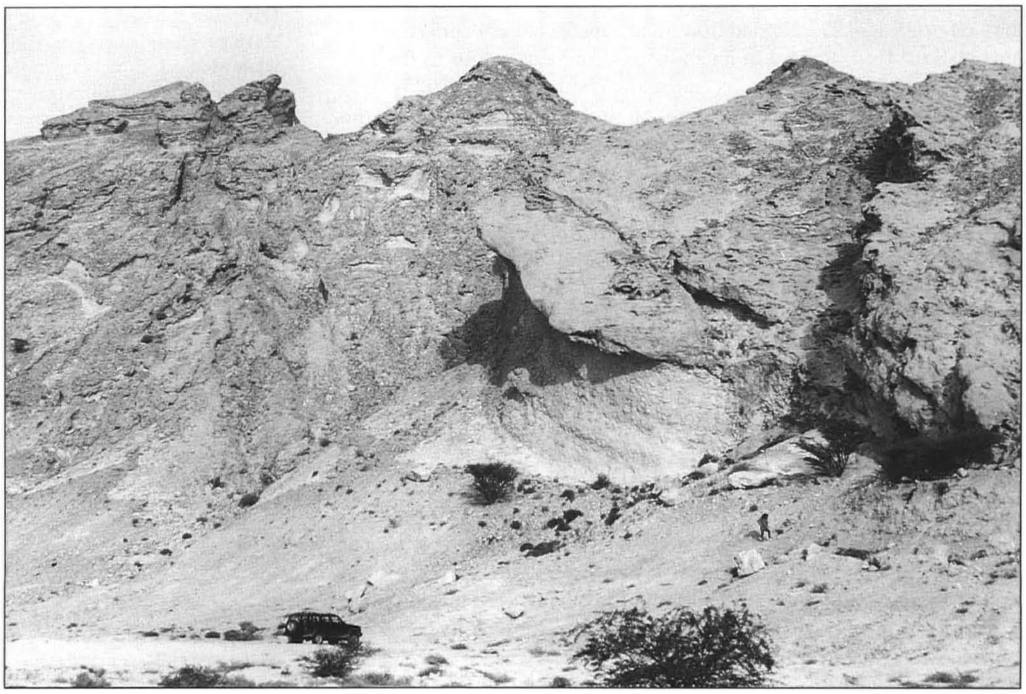

Plate 8. One of the shaft entrances to the long foot cave, shown in Figure 5. Limestone blocks within the cemented bahada sediment are cut through by the shaft walls, which are smooth, rounded phreatic domes formed from beneath, before recent collapse of the thin roof that had remained over the cave. The contact with the underlying bedrock limestone is lost in the shadow, only just out of sight.

boreholes, it is not as productive as the shallow gravel aquifers. The Buraimi oasis, beside which stands the city of Al Ain, is fed by water from the gravels; locally high yields occur because the regional groundwater flow, westwards from the Hajar Mountains, is constrained where it has to pass through a gap in the limestone ridge that rises into Jebel Hafeet. The largely buried ridge acts as a hydrological barrier due to its content of interbedded marls and its deep core of ophiolite. Aquifer yields demonstrate that there is an enlarged fissure system within the limestone, but the foot caves appear to represent a locally enhanced zone of dissolution. Their progressive abandonment is a function of regional surface lowering, but their seuence of development subsequent to the cementation of the bahada sediments must relate to climatic changes, probably largely within the Pleistocene.

EVOLUTION OF THE KARST

Karstic evolution on Jebel Hafeet commenced when meteoric groundwater regained access to the limestones after uplift of the mountain ranges and subsequent stripping of much of the cover rocks. The age of the main cave excavation can only be roughly estimated from regional erosion rates with respect to its position. Dating of subsequent events is not yet possible, but the thick banded flowstones, and some stream entrenchment, are likely to have coincided with the wetter climates of the region which are inferred from hippopotamus fossils in Neogene sediments within the Emirates - between 11 and 4 million years ago. The banded flowstone appears closely comparable to that in Kahf Hoti, formed in a similar environment not far to the east, but that material also remains undated (Waltham et al, 1985). It is likely that the major or only locus of limestone dissolution in this environment has always been just below the water table close to the contemporary plain level; if this is so, the phreatic remnants exposed in he road up Jebel Hafeet may represent a long time scale of perhaps intermittent cave development. There is no clear evidence of earlier phases of deep artesian karst development, but it is likely that the caves' inception stage was in such an environment.

From about 2 million years ago, the region had periods of wetter climate that coincided with the Pleistocene Ice Ages in higher latitudes; a last climatic oscillation was timed at about 7000 to 8000 years ago, when the Neolithic cultures flourished in the region. During these times, percolation water would again have invaded the cave, creating the dripstone and pool coralloid speleothems. Deposition of carbonates in the ancient passages of Magharet Qasir Hafeet was probably contemporary with the erosion just below the water table that formed the foot caves around the base of Jebel Hafeet. Pleistocene events appear to have been cyclic, because the foot caves were formed partly by erosion of bahada sediments that had already been totally cemented, and they have since been partially drained. Gravels and bahada sediments cemented by carbonate are widely observed in the region, and the sequence of carbonate deposition and dissolution at the foot of the limestone mountains is more complex than can yet be ascertaind from the cave geomorphology.

There is much still to know about karst and cave development in the Gulf region, but the caves of Jebel Hafeet do appear to follow the pattern that has already been recognised in the nearby caves of northern Oman - of ancient cave development followed by flowstone deposition and then almost complete abandonment.

ACCESS TO THE CAVES

There is no access to Magharet Qasir Hafeet. Its entrance is through a manhole in the basement of a private house on private ground. Only for geomorphological or biological study that is directly related to the local area is there any chance that access permission would even be considered. The caves at the foot of Jebel Hafeet lie on open ground, and are accessible to those who can find their entrances.

ACKNOWLEDGEMENTS

This paper is based on a report prepared for the owner of the land in which Magharet Qasir Hafeet lies. His financial and logistical support is gratefully acknowledged, as is his permission to publish this paper. We also thank Olivia Pozzan and Bill Algaier for enthusiastic and energetic assistance in the cave. We acknowledge an unpublished 1979 report by Hunting Mineral Surveys, from which some of the geological data have been derived, and thank Denys Brunsden, Trevor Ford and Dave Lowe for their helpful comments.

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The speleological potential of limestone karst in Zambia (Central Africa) - a reconnaissance survey

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Abstract: During a season of biological and palaeontological fieldwork, a German-Zambian expedition conducted a reconnaissance survey of the carbonate areas in Zambia. Carbonates suitable for karstification are exposed in an area of about 13,400km^2. Most of these are meta-carbonates belonging to the Late Precambrian Katanga System. Systematic survey for palaeokarst features was carried out in the Lusaka and Kabwe Districts, in the Central Province, the Copperbelt, and in the North-Western, Central and Eastern Provinces. Karst features are distributed widely throughout the areas surveyed; however, most of the extensive outcrops are situated in flat terrain with high groundwater tables. Some are overlain by thick lateritic soil cover. This is the case in the Lusaka dolomite, the Mpongwe carbonate block, and in the Mwinilunga District in the far north of the country. A few substantial caves are developed near Lusaka (Kapongo Cave, Chipongwe Cave and Leopard's Hill Cave, and Mpongwe (Copperbelt). The karst plateau of Mpongwe appears to be part of a stable peneplain with superficial drainage. Phreatic voids must, however, be developed extensively, as evidenced by the communicating water tables of two significant lake structures (Lake Kashiba and Lake Inampamba). A superficially developed cave system was documented at St. Anthony's Mission near Mpongwe. This system gives evidence of an initial stage of superficial karstification due to seasonal flooding of the area. Despite the fact that, according to this survey, carbonate rocks are widely distributed, the speleological potential of Zambia must be regarded as fairly low.

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INTRODUCTION

Little is known about limestone karst in Zambia. During a season of biological and paleontological fieldwork, two of the authors (Kaiser and Seiffert) spent a few weeks in Zambia, conducting a reconnaissance survey of the country's carbonate areas. As a by-product of this research, various observations on surface and underground karst phenomena were recorded, and these now allow a rough assessment of the speleological potential in some of the more important carbonate areas of this central African country. Though the authors hope to encourage further speleological research in this friendly country, there are obvious limitations to what can be achieved.

THE LIMESTONE AREAS OF ZAMBIA

Carbonate rocks are distributed widely in Zambia, where they are exposed across an area of about 13,400km^2. Most are Precambrian meta-carbonates belonging to the Late Precambrian Katanga System. Within this System, the Lower Kundulungu Series contain meta-carbonates, which occupy areas in the northwestern and central parts of the country. Carbonates of the Upper Roan Series are exposed in the Ndola District. Jurassic carbonatites and Neogene travertine deposits are subordinate in terms of their areas of distribution.

Area 1 (Lusaka)

The city of Lusaka lies within the biggest connected carbonate area in the country (1,600km^2; Fig. 1). The so-called Lusaka Dolomite consists of various types of Katanga meta-carbonates (Thompson, 1961; Cairney, 1967; Smith, 1963; Simpson, 1962; Simpson et al, 1963; Brown, 1967; Vrana, 1974). Very few limestone kopjes [= small hills] to the southwest of the city, provide the only exposures in an almost entirely flat landscape. One of these kopjes, at Twin Rivers Farm, was the subject of archaeological studies (Oakley, 1954). Some of the rare surface karst phenomena of the area, such as small rockholes and dissolution flutes, are developed on top of the boulders that form the summit of this hill (Plate 1). The underground karst of this huge area is almost entirely buried under lateritic soil covers. Three substantial caves are known: Kapongo Cave, Chipongwe Cave and Leopard's Hill Cave.

Kapongo Cave

This system of relict voids, formerly known as "Freeman's Guano Cave" (Brown, 1961), lies in elevated terrain close to the Kafue River gorge. The cave has been subject to archaeological and palaeoenvironmental studies (Oakley, 1954; Cooke, 1950). The exceptionally elevated terrain, appears promising for extensive speleological development. Unfortunately the cave has formed within a tiny patch of dolomite, isolated by quartzite veins (Smith, 1963). However, this investigation showed that the quartzite is also heavily karstified, as revealed in several fissures and pits close to the main entrance.

Quarry of the Chilanga Cement PLC

The only industrial quarry in the area, operated by Chilanga Cement PLC at Chilanga, is pump drained. Its section provides a good insight into the morphology of the uppermost 15m of the karstified bedrock. Exposed bedrock is severely jointed, and breccia-filled fault lines are evident, but they do not contain voids. Karstification appears to be restricted to a horizon of 2 to 4m below the land surface, where deeply dissected rock pinnacles are preserved. The undisturbed soil cover covers the dissected bedrock surface entirely without penetration by protruding pinnacles. Beneath this horizon the bedrock is compact. A

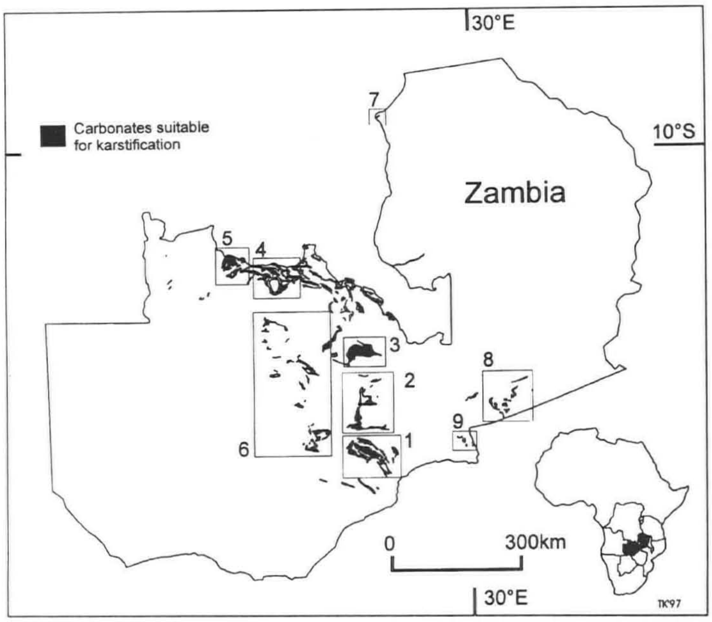


Figure 1. The carbonate areas of Zambia.
Compiled after Thieme and Johnson, 1981; Klinck, 1977; Garlick, 1947; Thompson, 1961; Cairney, 1967; Smith, 1963; Simpson, 1962; Simpson et al, 1963; Brown, 1967; Vrana, 1974.

few narrow fissures that reach below this horizon are filled with soft laterite. Although quarry base level is already lower than the hydraulic head in the area, no phreatic voids are exposed.

Chipongwe Cave

The entrance of Chipongwe Cave lies in entirely flat terrain, about 20km south of Lusaka. The cave is a fossil system, which contains a shallow lake. Brief descriptions are given by Strachan (1954) and Hansford (1969), and detailed maps are being produced (Truluck, in prep.). Archaeological, including hominid skeletal, material is described and discussed by Clark (1955, 1957), Toerien (1955) and others. The fauna has been studied by Ansell (1967, 1969) and Arnold (1983).

Leopard's Hill Area

Meta-carbonates cropping out in the Leopard's Hill area belong to the Katanga "System" (Cairney, 1967). The only cave known in this vast area is Leopard's Hill Cave, a relict system situated some 60km east of Lusaka (Burgess, 1987; Cairney, 1967; Simpson, 1962). Quaternary fossils from cave deposits are mentioned by Cooke (1950), and radiocarbon dates for occupation levels are given by Miller (1971). A detailed map of the system is in preparation (Truluck, pers. comm.). The inselberg containing the cave is the only elevated point in an otherwise flat landscape. It is covered with dense woodland vegetation, hardly providing access to exposed bedrock. Though the flanks of the Leopard's Hill may still provide access to other relict systems, the potential must be estimated as low.

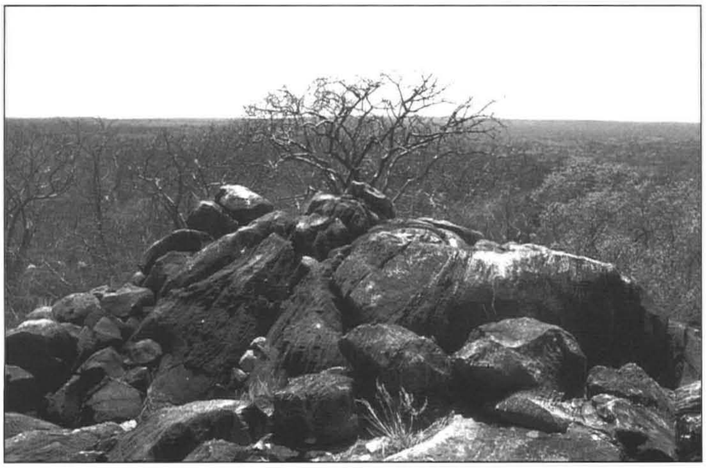


Plate 1. Summit area of Twin River kopje, a limestone inselberg, south of the city of Lusaka.

Urban area of Lusaka

Limestone is mined manually in various superficial quarries immediately to the south and southwest of the city centre. After removal of soil infill from grike hollows, access is gained to the uppermost level of a deeply dissected limestone bedrock surface, cut into pinnacles and ridges.

Sinkholes

Sinkholes [= dolines] of various dimensions are reported from different localities within the city area (O'Brien, 1953, 1954; Bailey 1953), and an impressive example was examined on the farm of Mark Jellis. However, none of the reported sinkholes is known to provide access to horizontal cave passages.

Area 2 (Kabwe District, Central Province)

The only reported karst features in this area (Fig.1) is Broken Hill Cave, a palaeokarst system exposed by opencast mining in 1921. Upper Pleistocene deposits yielded mammalian and hominid remains (Oakley, 1957; Wells, 1957; White, 1909; Cook 1950; and others).This isolated system lay within a huge area (about 1,100km^2) of exposed carbonates with no other reported karst features. The hill in which the cave was found has since been completely removed for its limestone.

Area 3, Mpongwe (Copperbelt, Central Province)

An extended outcrop area of upper Roan dolomitic meta-carbonates and argillites is found in the vicinity of Mpongwe, a small town in the southern Ndola district (Garlick, 1947). The total carbonate outcrop covers an area of almost 1,200km^2. With the exception of two anomalous lake structures, Lake Inampamba and Lake Kashiba (Bell-Cross, 1959; Hobson, 1996), no karst features have been described from this area. Various Roan carbonate bands crop out close to the city of Ndola. These bands contain two lake structures, Lake Ishiku and Lake Chilengwa, which have been described briefly by Bell-Cross (1959).

St. Anthonys Mission

Lake Kashiba lies at the northern border of the Mpongwe limestone area, a few kilometres north of St. Anthony's Mission. The lake, which has been briefly described by Bell-Cross (1959) is the most significant karst feature in the area (Plate 2). An extensive cave system was recorded near the Bilima River, some kilometres south of St. Anthony's Mission (Plates 3 and 4). The development of this shallow, superficial, system is probably closely related to seasonal high water tables, which change the area into a swamp.

Lake Inampamba occupies the central section of a deep gorge that has developed along a joint plane in the Mpongwe carbonate plateau. The estimated length of the gorge is 800m, and it has almost vertical walls (Plate 5). Though the lake is perennial, its level has clearly fluctuated in the past, as evidenced by distinct water marks in the gorge walls (Fig.6), and the fluctuation range appears remarkable. However, no serious diving has yet been undertaken to investigate the assumed unique phreatic system below.

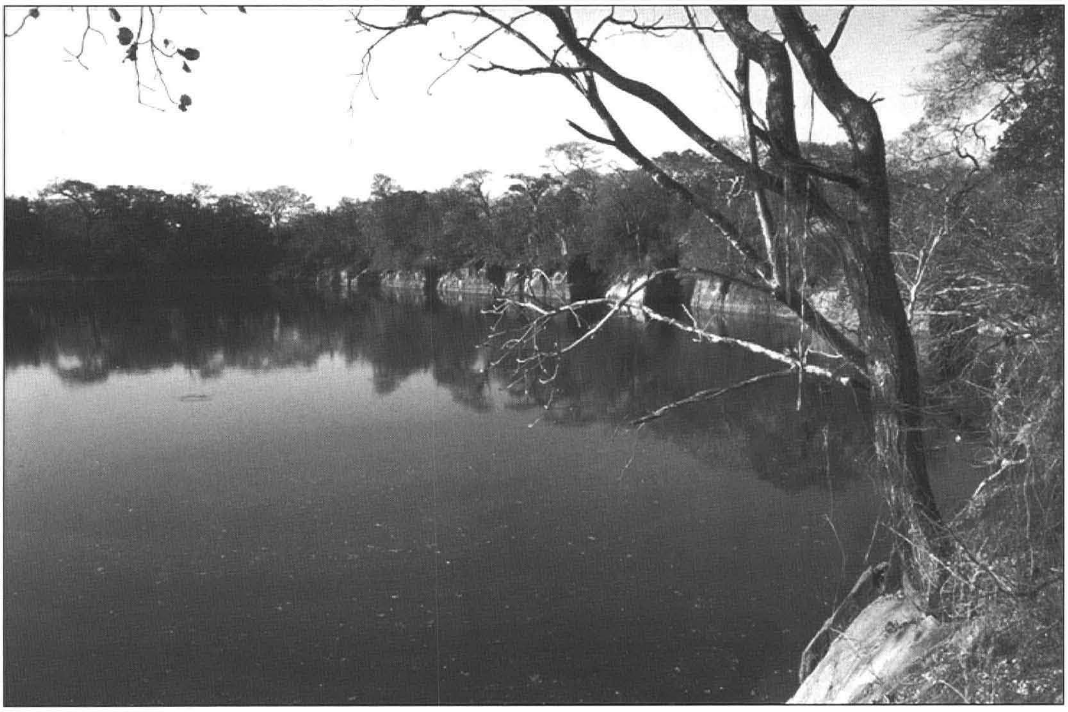


Plate 2. Lake Kashiba, filling the hollow of an impressive collapse structure.

Linsai Area

Not far from Chibili Village, close to the southern margin of the Mpongwe carbonate block, shallow outcrops of bare karst form a significant landmark. Numerous shallow pits and potholes are developed along fault planes, forming shallow fissure caves. Short horizontal passages, open to daylight, may be developed at the bottom of the pits. The floors of the potholes are filled with rubble, covered with dark humus soil, and a polygonal cracking pattern of the soil infills indicates flooding during the rainy season. Surface karst features include small rockholes, dissolution flutes, shallow dissolution pans and rectangular joint and fissure patterns. A few rock overhangs are developed in the area, but their height of 1m or less makes them unsuitable as rock shelters. A few 6 to 8m-deep pit structures have been used as natural wells by locals. The most significant of these is Mukalowatampa, a pothole with an almost circular opening. A narrow passage at the bottom of the structure leads into a low chamber, containing a small perennial pool.

Area 4 (Solwezi District, North-Western Province)

2,700km^2 of carbonates are exposed in this area. Between the villages of Chisasa and Lumwana, a northward trending track leads to an area formed by flat lying Kundulungu carbonates (Fig.1). The landscape topography is gently undulating but generally flat, and sand forms the predominating superficial deposit. There are almost no surface karst phenomena developed in the exposed carbonates, which form a patchy network of bare karst surfaces, covering hardly more than a few km^2. A slightly elevated marble outcrop in the centre of this shallow plateau contains a cave, locally known as Shankenge Cave, which is a shallow rock shelter, opening at its back into an insignificant chamber.

Area 5, Sailunga (Mwinilunga District, North-Western Province)

This area lies between the towns of Mwinilunga and Solwezi, in the far northwest of the country (Fig.1). Its geology is dominated by prominent dome-like structures, which marginally expose narrow bands of Roan dolomites, totalling less then 500km^2. Several pieces of

Plate 3. One of the many entrances of Bilima Cave (St. Anthony Mission).

Plate 4. Branching galleries in Bilima Cave. The voids are about 1.2m high.

oral information led to the decision to undertake a reconnaissance expedition to the area around the village of Sailunga, where a systematic search for karst features yielded no significant results. However, various dolomite occurrences that are not indicated on the local geological maps (Klinck, 1977) were detected in this rugged area. The existence of at least one substantial cave was reported independently by European travellers and inhabitants of the area, but an exhaustive investigation eventually revealed that this site is actually a system of fissures reached by daylight. Most of the voids are of obviously vadose origin. The area between the Great North Road in the north and the Kabompo River in the south has a gently undulating topography, without significant drainage incision, and the dolomites cropping out form gentle humps, without vegetation. Most of these areas are swamps in the rainy season, and the current groundwater table is less then 5m below the surface in the dry season.

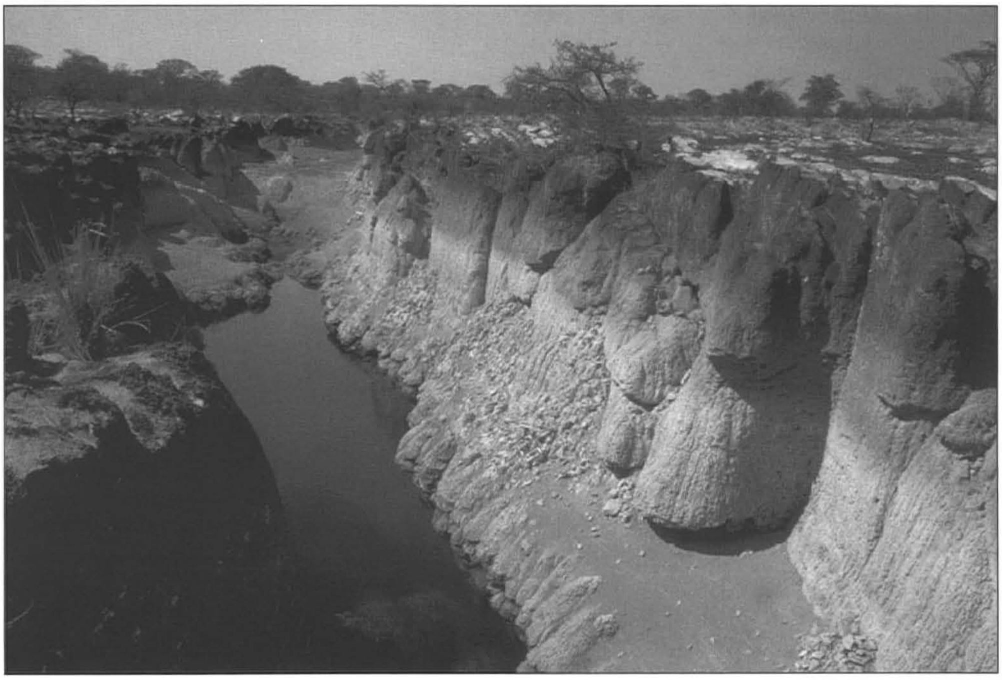
Area 6 (North-Western Province, Central Province)

Large areas of central Zambia are occupied by the lower Kundulungu "Series", including meta-carbonates, which are exposed across an area of 1,100km^2 (Fig.1, Area 6). An isolated patch of dolomitic meta-carbonate near the city of Mumbwa contains the Mumbwa Cave, a system of vadose fissures and rock shelters, developed in a group of free-standing, isolated rock towers located within a dry valley. Deposits in the rock shelters have been the subject of archaeological and paleontological studies (Dart, 1931; Wells, 1939; Jones, 1941; Clark, 1942; Cooke, 1950; and others). Word-of-mouth evidence points to the existence of one or two other caves or rock shelters in the Mumbwa area. The authors, however, have no evidence of the existence of karst features in the extensive area in the central part of the country, where patchy outcrops of lower Kundulungu carbonates are widespread in mostly flat terrain. These outcrops may be worth a systematic survey in the future.

Area 7 (Kilwa Island, Luapula District, Northern Province)

Kilwa Island is the biggest island in Lake Mweru in the far northeast of Zambia (Fig.1). The island exposes Katanga rocks, and carbonates of the lower Kundulungu "Series" are exposed as a band in the northwestern corner of the island. The Membo and Nsalu caves in this area have yielded archaeological material (Clark, 1950; Cooke, 1950; Chaplin, 1954; Derricourt, 1980).

Plate 5. Lake Inampamba (here viewed from the south) lies in a deeply incised gorge that may have developed along a major fault plane. Marks along the gorge walls indicate the extent of seasonal water table fluctuations.



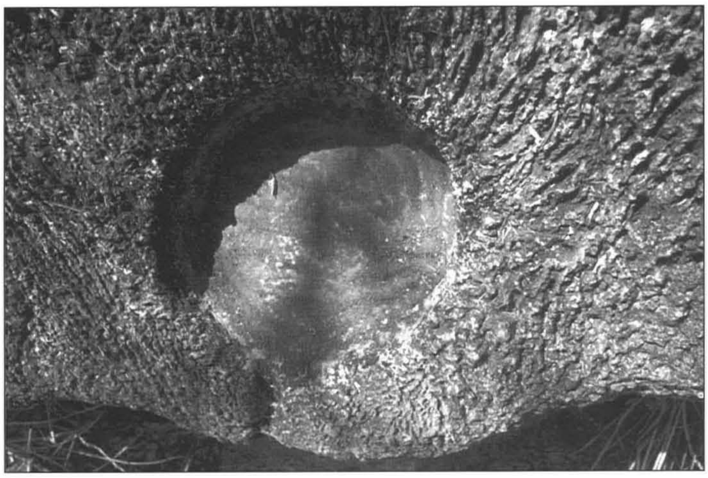


Plate 6. Solution pan on the eastern ridge of the Inampamba gorge.

Area 8 (Petauke, Eastern Province)

Carbonates may be exposed some 80km west of the town of Petauke (Fig.1). With one exception all carbonate patches marked on the maps are situated in flat terrain, and obscured by lateritic soil cover. The more elevated areas are inselbergs that expose granite rather then carbonates. Expectations of karst development in this area, must be very limited.

Area 9 (Rufunsa River Valley, Feira District, Lusaka Province)

Carbonatites near Rufunsa (Bailey, 1960), in the southeastern part of the country, could provide speleological potential (Fig.1). Oral evidence, however (Mike Bingham, pers. comm.), suggests that this territory is a seasonal swamp without any karstification.

CONCLUSIONS AND ASSESSMENT OF POTENTIAL

Area 1 (Lusaka)

Superficial karst is restricted to the horizon underlying the lateritic soil cover. It is bound to the current topography and thus is younger then the modern relief. Most of this karst is not therefore of phreatic origin, and does not represent a fossil karst horizon. The karstified uppermost portion of bedrock was probably never exposed to atmospheric conditions, but developed under this soil cover during a period of stable conditions in superficially drained flat terrain. The covered karst of the Lusaka dolomites is dominated by closed depressions, perforating a simple alluviated plain and thus is attributed to the initial stage of a new cycle of karstification. A phreatic karst horizon seems to be in its initial stage, as indicated by boreholes in Lusaka, that have revealed open voids at various depths below the water table (Simpson et al, 1963). The occasional development of fissures of several metres depth is evident from the discovery of Iron Age burials, filling a fissure exposed by the old Shimabala quarry (Anderson, 1961; Crawford, 1967; Fagan, 1968).

Area 3 (Copperbelt)

The limestone plateaux of the Ndola District appear to be part of a stable peneplain with partly superficial drainage. Phreatic voids, however, must be developed extensively, as evidenced by communicating water tables between lakes Kashiba and Inampamba, which are several kilometres apart. The potential for the discovery of air filled cavities in the vicinity of Lake Inampamba can be estimated as only low to medium, reflecting the current limited access to cave systems, which are assumed to be all within the phreatic horizon. The potential for discovery of water filled cavities is much more encouraging. The investigation found no evidence of previous serious diving attempts in Lake Inampamba. The Linsai area in the south of the Mpongwe carbonate block and the Bilima River area in the north are typical of huge parts of the carbonate landscapes in the Ndola district. Due to the high groundwater table and the superficial drainage of the area, the speleological potential of the Mpongwe area is estimated to be low.

Area 4 (Solwezi District)

The swampy environment encountered during the investigation, and the flat topography of the area, offer little promise for the discovery of substantial caves on the Zambian side of the border area. However, this seems not to apply in extensive carbonate areas just over the border into Zaire, where multiple cave occurrences are reported. However, there are stories of a cave, close to the border, on the Zambian side, where water-filled passages "containing fishes" are reported.

Area 5 (Mwinilunga District)

The area is characterised by a flat topography and high ground water tables. The recorded carbonate outcrops are of limited extent. Thus, potential for discovery of substantial underground karst features cannot be denied entirely, but the shallow hydraulic head suggests that expectations should be limited.

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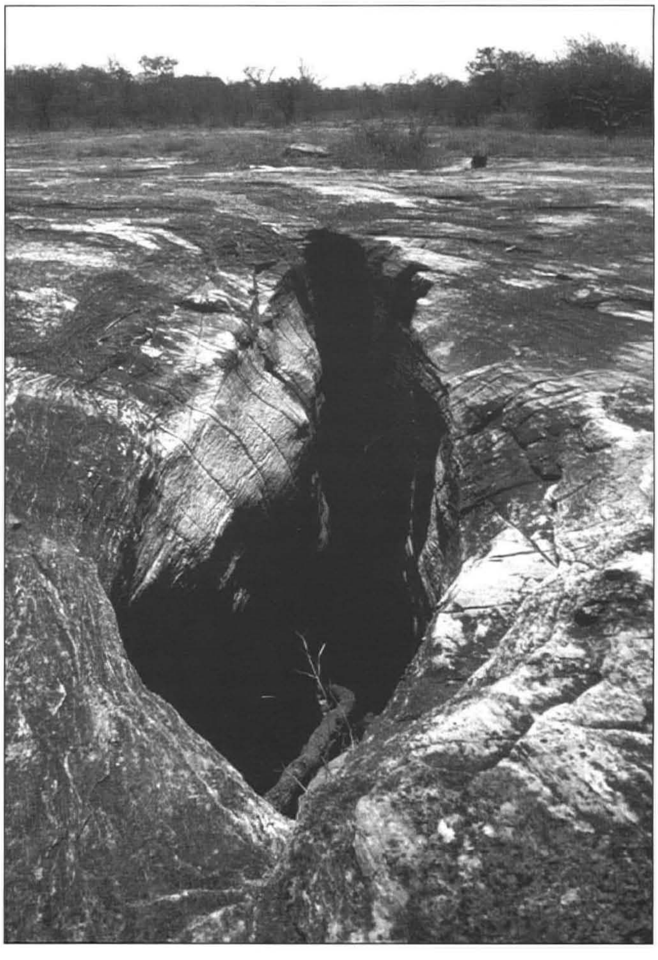

Plate 7. The limestone plateau of the Linsai Area (Mpongwe), with pothole.

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Wookey Hole in Somerset and Pope's Grotto at Twickenham, England

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Abstract: Among the minerals used to decorate Alexander Pope's artificial Grotto at Twickenham between 1740 and 1744 were stalactites and a *"petrifaction"* from Wookey Hole. Stalagmites were cut from the First Chamber of the cave to present to Pope and one of these may be this same petrifaction. The latter is known to have been placed in a part of the Grotto that was buried when Pope's house above it was destroyed in 1807. The probable site in Wookey Hole from which the stalagmites were removed is identified, and the man who took them is named as John Taylor of Wells.

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INTRODUCTION

The ornamental Grotto at Twickenham near London, made in the 18th century by the poet Alexander Pope (1688-1744) (Fig. 1), is well known by repute. He wrote about it in 1740 in his *"Verses on a Grotto by the River Thames at Twickenham, composed of marbles, spars, and minerals"*[1], and it is recorded that one or more of the specimens used in decorating the Grotto came from Wookey Hole in Somerset.

Soon after moving into his house in 1719, Pope had a tunnel made under the main road to link the house with his land on the other side. The tunnel continued through the basement level of the house and emerged in his smaller garden by the Thames. To make *"an ornament from an inconvenience"*, as Dr Johnson said of it[2], the walls and roof were decorated with ornamental stones in the style of the garden grottoes then becoming fashionable. Almost twenty years later, in 1739, he decided to be more ambitious in the decoration of his Grotto and various minerals, including stalactites, were used in the wider passage at the east end. Those particular stalactites are known to have been sent to him from Cornwall, and it was only later when he extended the Grotto into the basement rooms on either side, that a *"fine and very uncommon Petrifaction from Okey-Hole"* was used. That is how a gift received from a Mr Bruce was described[3]. At about the same time, a Mr Taylor of Wells removed some petrifactions from the cave for presentation to Pope. It cannot be assumed that these specimens are the same, though they very well may be.

This paper seeks to establish what these petrifactions were, from where in Wookey Hole they came, how and when they got to Twickenham, and where in the Grotto they were used. Moore[4] raised some of these questions in 1965, but was unable to answer them, being unfamiliar with much of the literature. There is little information to go on. The existing Grotto contains no recognisable vestiges of cave deposits; the original record of the Wookey Hole petrifaction in the Grotto consist of only fourteen words; and the reports of its removal from Wookey Hole, often based on hearsay, conflict. Nevertheless, by concentrating on the nearly contemporary accounts, together with a detailed examination of the cave and the Grotto, some conclusions have been reached that are reasonably certain, while others are less definite.

POPE'S GROTTO

In order to discuss the possible places within the Grotto where the Wookey Hole specimen(s) may have been used, and hence the date of their receipt, it is necessary to summarise the sequence and history of its construction and decoration.

Pope leased a house at Twickenham (by the side of the Thames 17km west of London) in 1719, together with two hectares of land, most of it on the other side of the main London to Hampton Court road, which passed his house[5]. He lived there for the rest of his life.

The construction and decoration of the Grotto falls into three distinct phases. Usually only two phases are identified[6], but for the purpose of this study it is helpful to subdivide the second one:

a) Phase I - 1720-1725. The tunnel under the road and house was made and decorated.
b) Phase II - 1739-1740. The expanded part of the tunnel beneath the house was lined with mineral specimens, including stalactites, given to Pope by his friends. A rustic stone wall and entrance arch had been built in 1733 (Fig. 2).
c) Phase III - 1741-1744. Three basement rooms of the house, on either side of the central tunnel, were incorporated into the Grotto, and adorned with more specimens.

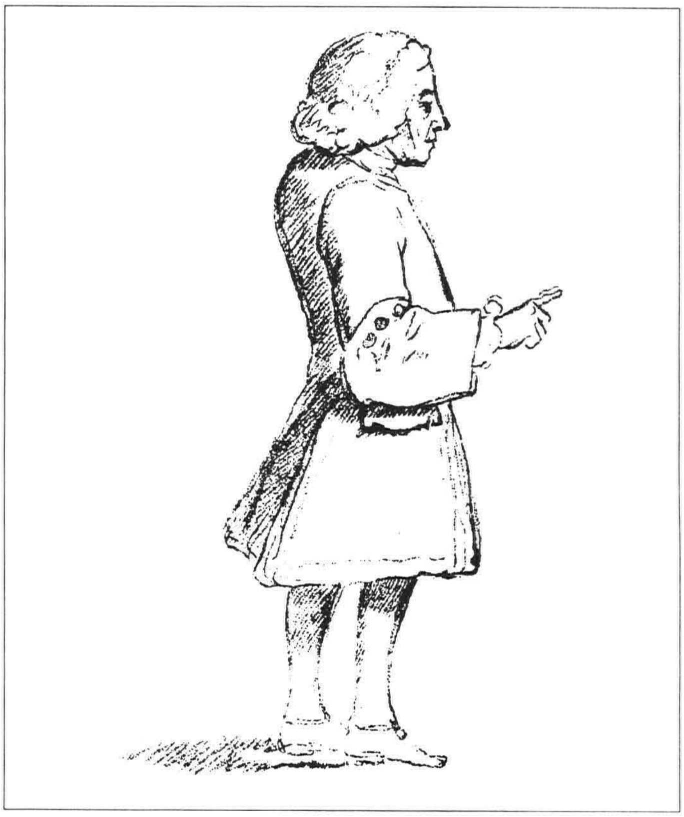


Figure 1. Alexander Pope, from a drawing by William Hoare, published 1797.

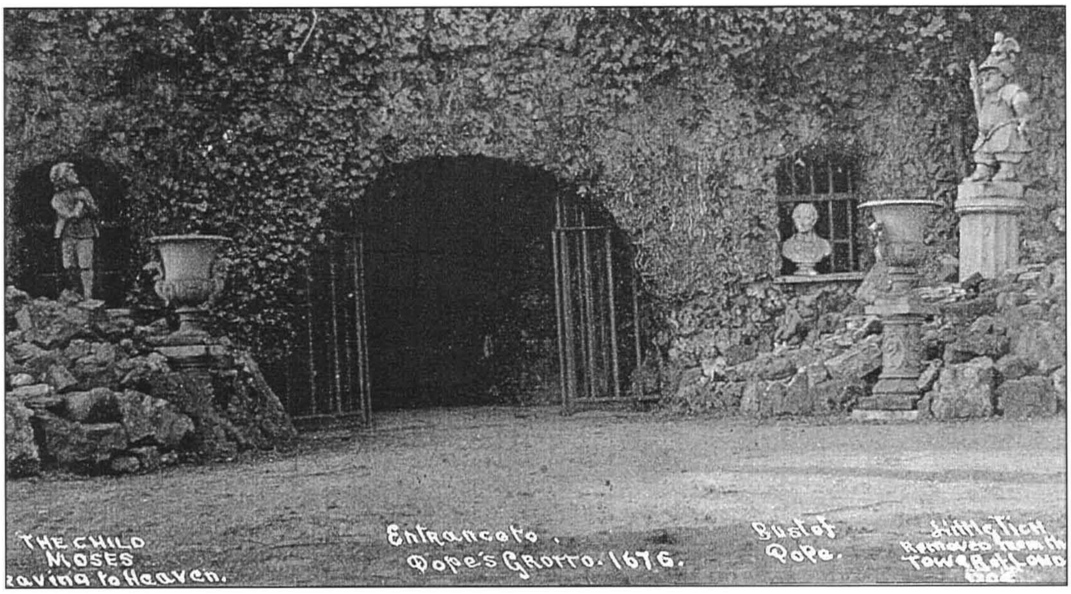


Figure 2. The rustic stone wall supporting the portico at the eastern entrance to Pope's Grotto, a little after 1900. It is much the same today though obscured by buildings.

After Pope's death in 1744, the house and Grotto had several owners until, in 1807, they were bought by Sophia Charlotte, Baroness Howe (1762-1835), daughter of Admiral Howe. She already owned and lived in a property nearby, and she had Pope's house destroyed[7], though the Grotto survived. The neo-Tudor house now on the site was built in 1842[8]. It was for many years from 1919 a convent school, and is now an independent school for boys. The Grotto is protected (Grade 2*) and is currently the subject of restoration proposals.

Phase I - 1720-1725
The Grotto was begun as an under-road tunnel, for which Pope obtained a licence on 13 October 1720[9]. It extended beneath the house itself and was 17m long. The tunnel walls were decorated with flint, chippings of white marble, and glass furnace slag[10]. In addition, the broader part beneath the house had shells, minerals and pieces of mirror glass.

Phase II - 1739-1740
The next phase of Grottofying occurred mostly in 1740. Pope had come to the West Country in November 1739, to drink the curative waters of Bristol and Bath[11]. He stayed with his friend Ralph Allen (1694-1764) of Bath, known for having devised a system of cross-country mail routes when he was deputy postmaster there, and for developing the Bath stone mines at Combe Down[12]. At Allen's house Pope came to know Dr William Oliver (he of Bath Oliver biscuits), whose brother, the Reverend William Borlase (1695-1772), was an antiquary and mineral collector in Cornwall. The letters exchanged between these three show that Borlase sent Pope many consignments of *"Minerals and Spars"* from Penzance. A sketch plan of his Grotto, sent by Pope to Borlase on 14 January 1740[13] (Fig. 3), shows that the basement rooms had not yet been Grottofyed[15], and this was still the case in the sketch of 29 December 1740 (Fig. 4)[16]. Thus it was the eastern central chamber in which the new materials were being used. Pope later had Borlase's name written here in gold letters on marble[17], and it is still known as the Borlase Room.

It was Pope's intention to use only *"the Several Productions of Nature, which are properly to be found under ground"*[18], with *"all the Minerals in their several natural Strata. I suppose the Stallactites will be pendulous from the Roof"*[19]. In March he wrote *"the Stalactites are appropriated to the roof"*[20], and by June *"The little well* [see Fig. 3] *is very light, ornamented with Stalactites above... with a perpetual drip of water into it from pipes above among the Icicles"*[14]. These must be what Serle describes as *"other Petrifactions, which form two fine Rocks with Water distilling from them"*[21]. The stalactites referred to must have come from Borlase, or their placing would not have been discussed with him in this way. On 3 October 1740 Pope wrote *"my Grotto is now finished"*[22].

Phase III - 1741-1744
So ended the second phase. But in 1741 Pope was again *"going to be fully imployed in Grottofying"*[23] and the later plans (Figs. 5 and 6) show that three basement rooms alongside the already existing Grotto had been decorated as well, some time between the end of 1740 and Pope's death on 30 May 1744.

It was probably during the summer of 1741 that the two eastern side chambers were adorned[26]. The third one - the inner one on the north side - may have been completed later. Less is known of the sources of the materials used in Phase III than is for Phase II. Absence of continuing correspondence with Borlase suggests that they did not come from Cornwall. A specimen from the Giant's Causeway in Ireland was provided by Sir Hans Sloane, the President of the Royal Society[27]; Richard Owen Cambridge, the poet, sent various stones from Gloucestershire[28]; and there were pieces of silver ore from Mexico and gold ore from Peru[29]. Pope seems to have diversified his sources, and his friends, at this stage.

The only reference to Wookey Hole in the Grotto literature, as distinct from that of the cave itself, is in a book written just after Pope's death by John Serle, his gardener and man-servant . In *"An accompt of the materials which compose the grotto"* is listed:

> Numb. X. A fine and very uncommon Petrifaction from *Okey-Hole Somersetshire*, from Mr *Bruce.*[3]

The identity of Mr Bruce is discussed later. The fact that Serle is the only contemporary source of information about the later Grotto extensions as well as of the Wookey Hole specimen(s), together with the absence of any mention of the latter in the quite detailed correspondence of 1740, suggests that the Wookey Hole item was most probably received after 1740. This is consistent with the fact that the contents of the Borlase Room seem to have been largely or wholly supplied by Borlase.

The Grotto today

There are some significant differences between the Grotto as it is today and as it was on the plan of 1785. Most notably, some parts of it have been blocked off, and the shape of two of the chambers has been modified.

Comparison of a recent sketch plan (Fig. 7) with the plans of 1745 and 1785 (Figs 5 and 6) shows that the north-south corridor and the second northern chamber are shut off or destroyed and the walls closing the previous access to them have been decorated in consistent style. The shapes of the two remaining side chambers seem to have been altered, too, which must have meant more new wall surface

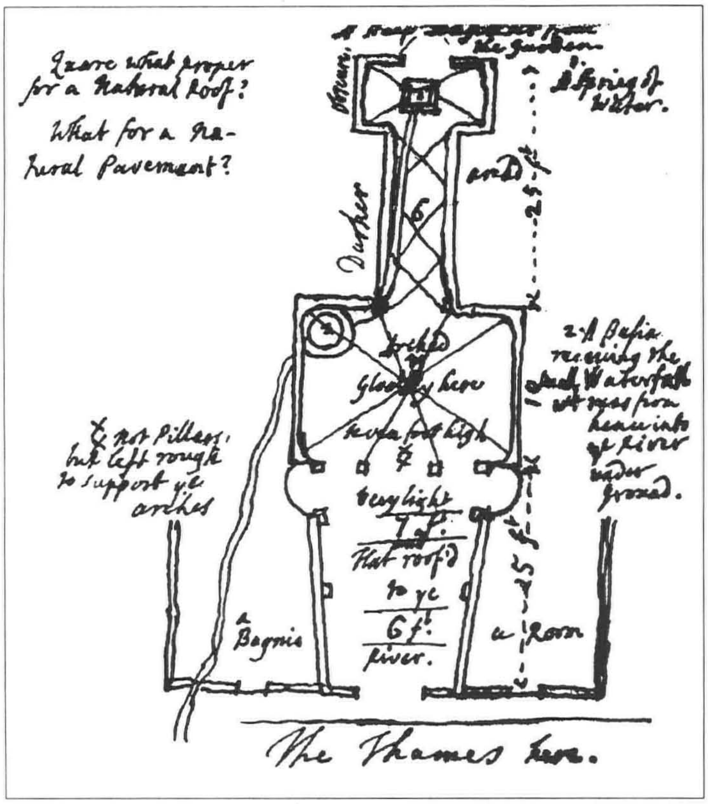


Figure 3. Pope's plan of his Grotto drawn on a letter dated 14 January 1740[13]. West is at the top of the picture; at the bottom, the river Thames is drawn too close to the Grotto entrance. The Borlase Room is the enlarged part of the tunnel in the centre. In its top left-hand corner the concentric circles labelled "2" denote what was then a little well[14] fed by a stream. It was above this well that Pope put stalactites given him by Borlase. The side rooms have not yet been grottofyed.

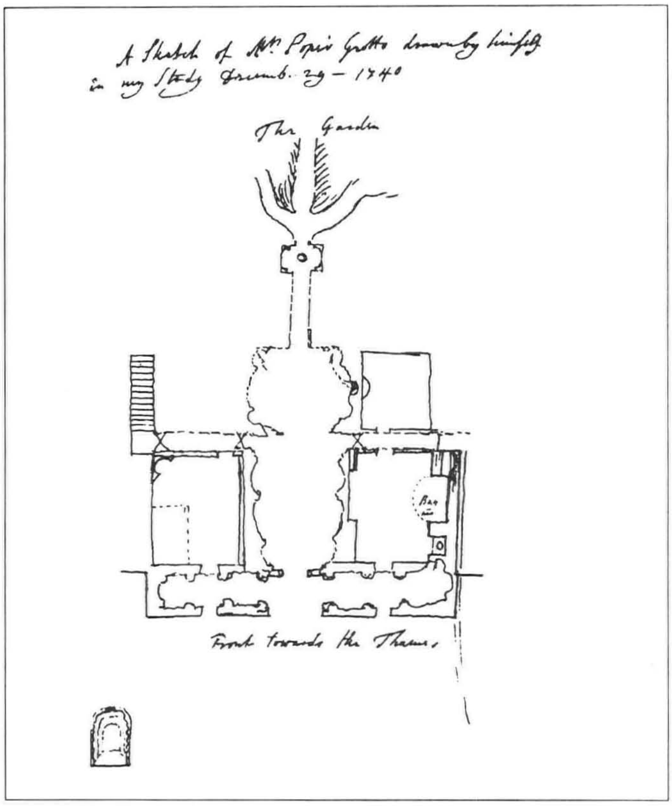


Figure 4. Pope's plan of his Grotto drawn on 29 December 1740[16]. Construction of the wall seen in Figure 2 has made a passage in front of the original Grotto. The side rooms have been modified but are still not grottofyed. A central cross-passage has been added, with doors, connecting with stairs up to the house at the southern end. The northern passage opens into a third side room.

whose ornamentation is therefore subsequent to Pope's time. Whether the 'lost' chamber and passages still exist or have been destroyed is not known. The most probable time for major changes is 1807, when the house above was destroyed[7]. The Grotto would have been liable to other dilapidations (and maybe delapidifications), especially between 1807 and 1842 when the present house was built[8].

At the present day most of the walls and roofs are covered with stone fragments: flint, much black glass slag, some quartz and other crystals, orange glass slag, a little thin glass, etc., all cemented in place or held by iron cramps. The only items projecting downwards from the roof are a few large lumps of slag and some of flint. Much of the tunnel roof over a length of 5m is wholly or partly bare, with the brick arch showing. Certainly there are now no vestiges of broken stalactites in the roofs or elsewhere, not even where they are known to have once been, above the site of the *"little well"*. Hodgkinson's statement about 1956 that the stalactites *"..can still be seen..."*[30] and Jones's 1974 remark that *"...one is shown the stumps..."*[31] seem to be in error.

Site of the Wookey Hole Specimen(s) in the Grotto

The petrifaction given to Pope by *"Mr Bruce"* was placed at the southern end of the cross-passage, for it is shown there as number *"10"* in Serle's plan of 1745 (Fig. 5). This cross-passage led to the house and the position indicated for it suggests that it was beyond the doors in Pope's own drawing of December 1740 (Fig. 4) and at the foot of the stairs - a suitable place for a *"fine and very uncommon Petrifaction"*. There is no reason to think that it was *"...a piece of petrified wood..."* as stated by Bracher[32], who may have been confused by the word petrifaction.

Now it is not known whether this gift from Mr Bruce was the only one from Wookey Hole or whether the stalagmites that it will be seen were removed from there by *"Mr Taylor"* to present to Pope were different. If they were not the same, then it is necessary to deduce where they might have been placed.

It is most unlikely that they would have been in the central Borlase Room or the rest of the central tunnel, most of whose contents are known to have been provided by Borlase or others. So any of the three side chambers are possible sites. If they were in either of the two surviving (eastern) rooms they must have been either destroyed in the vulnerable period 1807 to 1842 or removed in the course of sealing the former openings or when the walls were being relined. It is tempting to think that any other Wookey Hole specimens may also have been placed in the lost cross-passage or the third side chamber and that eventual rediscovery of these places may reveal them; but there is no direct evidence pointing to that.

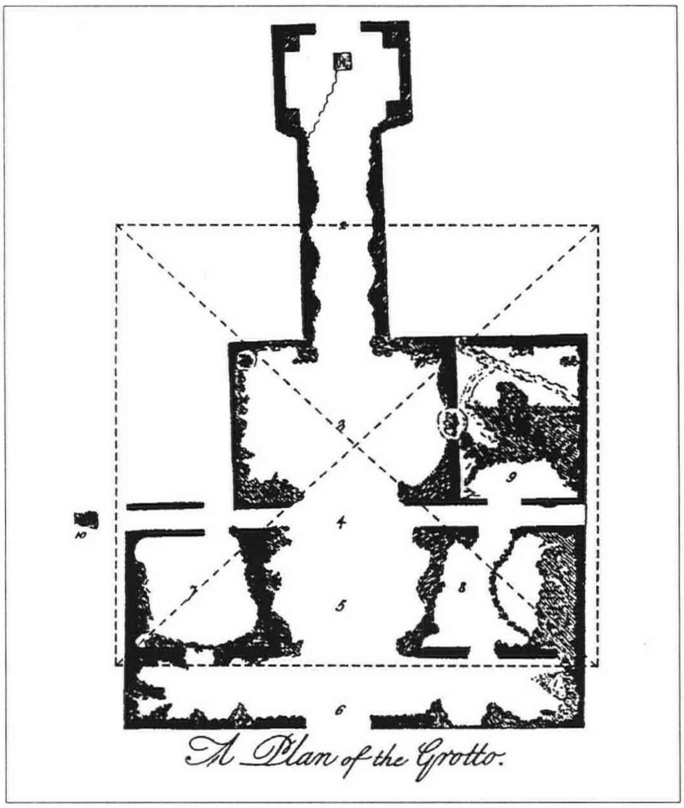
The location would have depended to some extent on whether the specimens were stalactites, stalagmites or other *"petrifactions"*. It will be shown that they were in fact stalagmites, unsuitable for hanging from a roof (unless in error) and more appropriate for corners or for flanking a statue; or indeed to stand at the foot of a flight of stairs, as Bruce's gift is known to have done. So perhaps they are one and the same after all.

Excavation may one day provide a solution, but such a rather special item is liable to have been removed before the passage was filled.

WOOKEY HOLE

Eighteenth Century

The earliest specific reference to the removal of specimens from Wookey Hole for use in Pope's Grotto occurs in a publication of 1759.



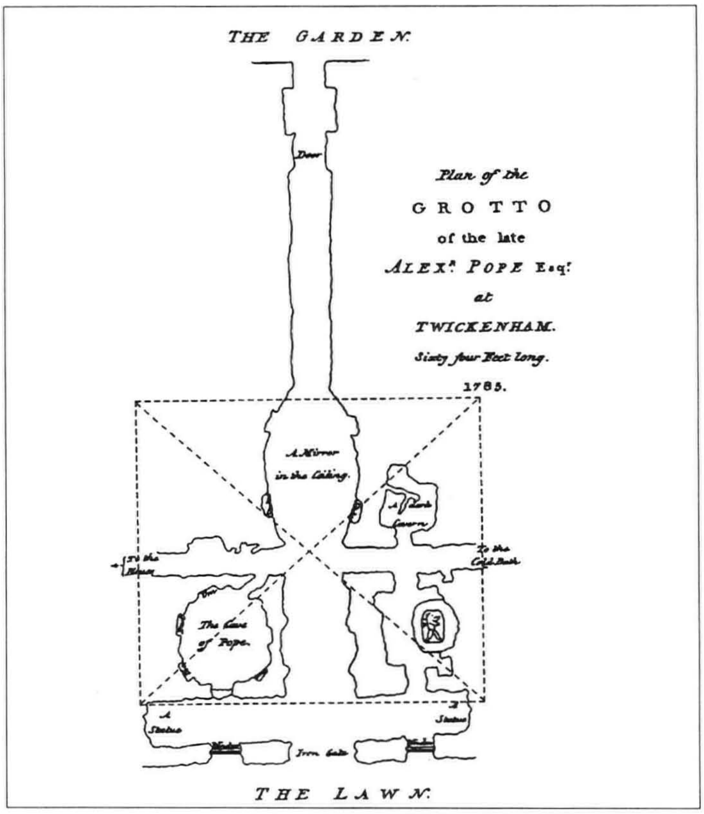


Figure 5. The plan of the Grotto drawn by John Serle in 1745[24]. The irregular wall shapes of the side rooms show that they have all been grottofyed. The numbers relate to the list of specimens in the text of Serle's book and No. "10" in the left-hand (south) margin denotes the position of the "fine and very uncommon Petrifaction form Okey-Hole"[3].

Figure 6. The plan of the Grotto made in 1785 by Samuel Lewis[25]. The differences between this plan and that in Figure 5 may be more in the drawing than in the Grotto.

When Richard Pococke had visited the cave on 22 October 1750, his diary[32A] made no mention of it. But Benjamin Martin[33], describing the First Chamber (Fig. 8) in 1795, wrote:

> *"From all Parts of the Roof there is a constant Dripping of a clean Water, which however contain a great Quantity of lapidescent Particles, since from these Drippings arise several stony Cones, which about 20 Years ago we observed added greatly to the Pleasure of such a gloomy View. The Bottom of this first Vault on which you walk is extremely rough, slippery, and rocky, abounding with irregular Basons of Water; but there are now none of those Cones, which about ten or twelve Years ago were cut away, and presented to Mr. Pope for his artificial Grotto, greatly to the Disadvantage of this natural Grotto, their native and proper Place."*

The *"stony Cones"* that were *"cut away"* had been seen to *"arise"*, so they were stalagmites. It is also to be noted that it was *"Cones"* in the plural that were presented to Pope, rather than the single *"uncommon Petrifaction"* of Serle's list. The location in the cave is quite clearly the First Chamber, the one with the stalagmite known as the Witch in it, and this is supported by the records of other 18th century visitors who will be mentioned later. The probable site from which they were taken in this First Chamber is also discussed later.

The 1759 account had evidently been written at least two years earlier, for a shortened version of it was included in a didactic book of 1757 that he had written for children[35]. The explicit reference to Pope has been left out but there remains *"... there are none of those cones, however, that were there formerly, which then added greatly to the pleasure of that gloomy grotto."*

Martin (Fig. 9) wrote as if he had himself seen these stalagmites when they were present as well as later noting their absence, so this is a direct observation - the only one in the literature, and the one most deserving of belief where later records conflict. He was known to be interested in such things himself, for he made a collection of *"fossils and curiosities"* that was auctioned after his death[36]. The term *"fossils"* at that time included minerals and stones of unusual shape. His statement that stalagmites had been cut away *"about ten or twelve Years ago"*, in a text probably written just before the 1757 publication, is consistent with their going to Pope's Grotto between 1741 and 1744 (fifteen to twelve years before).

Another near contemporary account of the removal is that by a Swedish visitor, Bengt Fernner (1724-1802). He was in the area studying mining and smelting, and visited Wookey Hole on 2 February 1760. His diary[37] records:

> *"... Mr Taylor has taken all the crystals with which the famous poet Pope has ornamented the grotto in his garden at Twickenham."*

This adds nothing to Martin's account, except for mentioning Mr Taylor, who is identified later. Fernner met Taylor so there is no reason to doubt his statement.

Still in the 18th century, but some 65 years after the event, is the record of John Skinner[38], the Somerset priest and archaeologist whose 110-volume manuscript journal is in the British Library. Arriving in Wells for his ordination, he went into the cave on 21 September 1797:

> *"we... entered the gloomy region under the direction of a guide who supplied us with candles, and passing for a few yards along a sloping passage fifteen or sixteen feet high, found ourselves in a very lofty apartment, whose unequal roof was ornamented by a variety of pointed rocks and projecting petrefactions. Some of these cones, we learnt, were cut off and presented to Mr Pope, whilst he was engaged in forming his grotto at Twickenham"*

Already the story was becoming modified; the stalagmites had become stalactites hanging from the roof, though Martin's word *"cones"* was still used and they had again been *"cut off"* not broken.

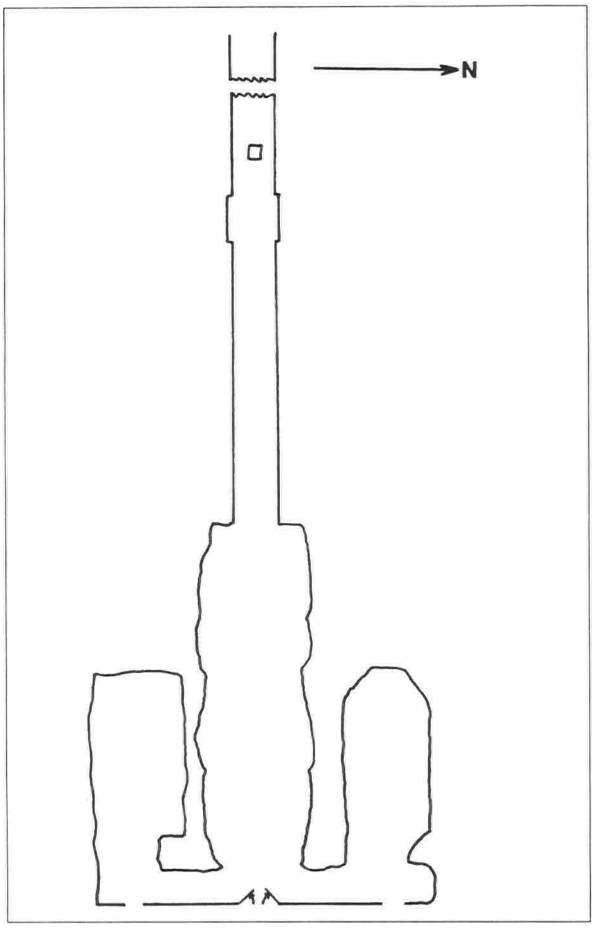


Figure 7. A sketch plan of the Grotto made by the author on 20 November 1996, showing the loss of the central cross-passage and one side room, and the blocking of four wall openings.

Almost certainly, as a Somerset man, Skinner would have possessed and read Martin's 1759 book. He illustrated his journal with drawings, including five made inside Wookey Hole, but these do not add any information. Nor do the earlier ones of Bernard Lens (1682-1740) whose pictures of 1719[39] might have been expected to show stalagmites where none now survive. He was more concerned, though, with views of rocks and the underground river.

The removal of the formations for Pope continued to be noted in later publications, so it remained well known but without any new data appearing. A version of Martin's original 1759 description was reprinted in 1779[40] and this was itself quoted over a century later[41]. In 1797 a Devon historian[42] writing about Kent's Cavern referred to *"the sort of dripstone, of which Mr Pope robbed Wokey to decorate his grotto at Twickenham"*; and the story was repeated again in 1847[43].

Twentieth Century

Twentieth century writing on the subject is of two sorts. While the Martin 1759 description has been reprinted frequently in Balch's books on Wookey Hole, guidebooks from 1928 have produced a new and quite different story which remains current today.

Balch's reprinting of the Martin account was in 1914[44] as part of a literature survey in his large book on the cave. He later repeated it, with minor changes, in the three editions of his more popular book [45,46,47]. The significance of this constant reprinting is that it made the original near-contemporary report easily accessible to modern readers. Unfortunately Balch attributed the wrong date (1757) to his 1759 quotation and does not identify the author, which makes the original difficult to trace[48].

A similar mistake had been printed eight years earlier by Tyte[49], but as he just associates the 1757 date with information from the 1759 book, without the page numbers and other information given by Balch, it seems that he obtained his information from the latter. Certainly they knew each other; Tyte attended Balch's lectures and Balch provided photographs to illustrate Tyte's article[49].

It was also in the 20th century, alongside Balch's reprints of the contemporary account, that a new story was produced. In 1928, just after the cave was first opened to modern style tourism, a guidebook[50] asserted that the specimens used by Pope were stalactites from the roof of the 23m-high Second Chamber, rather than stalagmites from the First Chamber. Doubtless the stumps visible there in the roof inspired the new story, but it is hard to see how the specimens were supposed to have been caught before shattering on the floor. The same tale was repeated and elaborated in another guidebook between 1935 and 1937[51].

Then in 1948 appeared the statement that is commonly repeated today:

> *"[In the Second Chamber] I consider it just plain vandalism that Pope, the poet, in 1702 was given permission by the Church Authorities to remove large quantities of stalactites from the cave to furnish his artificial Grotto at Twickenham. Musketeers were brought to Wookey Hole to shoot down pendant and curtain. One was almost pleased, an odd term to me, when in 1944 a Nazi bomb fell on and entirely destroyed Pope's Grotto, and that today nothing but dust and debris remains."*[52]

Figure 8. The parts of Wookey Hole known in the 18th century, redrawn from a survey made in 1912 by Balch and Troup[34].

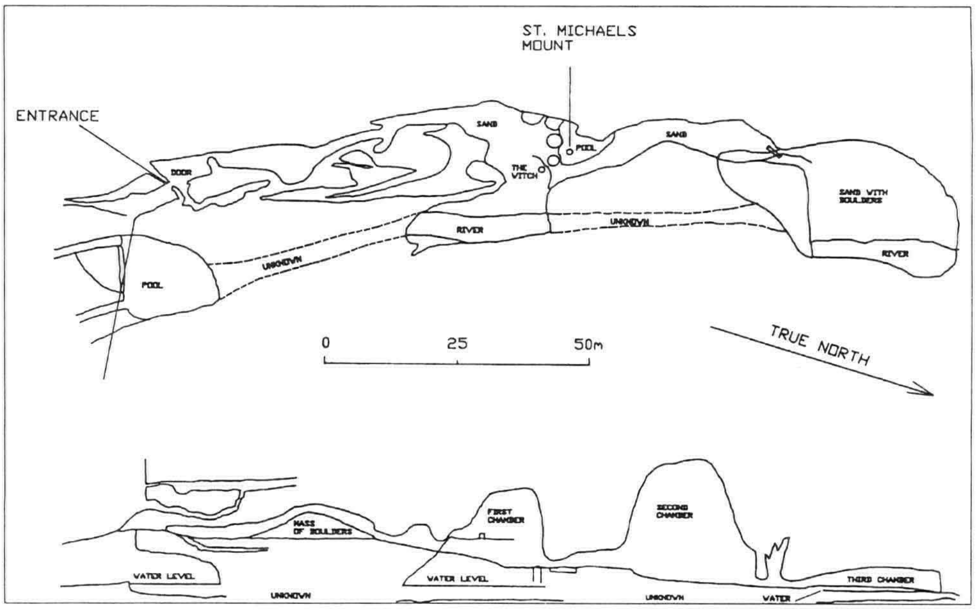


Figure 9. Benjamin Martin (1704-1782)[35A].

Almost all the *"facts"* here are wrong. The year 1702, when the removal of stalactites was said to have been authorised, was 17 years before Pope moved to Twickenham and 37 years before he was actively seeking mineral specimens. He was 14 years old at the time. Neither the Grotto nor the house above it was destroyed by bombing. So it is not surprising that the story of *"pendant and curtain"* being shot down by musketeers in the second chamber has been shown to be wrong too.

However, the cave guides have, until recently, perpetuated this colourful tale, and it is repeated in Jones's standard book on garden grottoes[31]. A temporary guide was once heard to tell visitors that the stalactites were removed *"for Alexander, the great pope"*[53].

Where in Wookey Hole did Pope's Petrifaction(s) originate?

The Wookey Hole petrifaction received by Pope from Mr Bruce, and the crystals obtained there for him by Mr Taylor are not necessarily the same. The conclusions reached here are not affected by whether they are nor not. What is clear is that they came from the First Chamber (the *"Witch's Kitchen"*). All the 18th century descriptions, including reports of three separate visits, agree on that. It can also be accepted that the specimens were stalagmites - "[there]... *arise several stony Cones"* in the only contemporary account -; it was not until 38 years later that Skinner in 1797 said, from hearsay, that they had been taken from the roof. Stalagmites, too, would have been easier to *"cut away"*. What is not immediately clear is just where in the First Chamber the specimens came from. Much of the floor there is now hidden by concrete and it was already sand-covered by 1912[34]. However Parker's plan of 1865[54], the earliest known, does not show any stalagmites in this area, and there are no stalactites or heavy drips above.

There are two areas in the First Chamber (Fig. 10) where stalagmites have been removed and where the bases are now regrowing with clear white calcite, suggesting that the former stalagmites there would have been among the whitest and most desirable in the cave. One group of about eight stumps, some 2 to 3cm in diameter, are behind and around the *"St Michael's Mount"* pool and close to the two large flowstone mounds (Fig. 10). The other group, consisting of six flat stalagmite bases between 5 and 7cm in diameter, are on the flowstone slope below the Witch (Fig. 11). All have been cut almost flush with the surrounding floor, and all are now regrowing with glistening white calcite. Any stalagmites removed from the first group could not have exceeded 50cm in height because of the low cave roof; the height of the others was not limited in this way, but is of course unknown. Nevertheless stalagmites of similar base diameter are commonly cylindrical and between 20cm and 1m in height. Some of the undamaged ones elsewhere in Wookey Hole are of this magnitude, and so were ones in Balch Cave a few kilometres away, before they were broken.

Serle's description of the Wookey Hole petrifaction as *"fine and very uncommon"* may have been exaggeration by someone unfamiliar with limestone caves, but it does imply that it was particularly impressive. So does its positioning at the foot of the stairs leading from Pope's house to his Grotto. A large stalagmite would fit this description.

It must be remembered that the specimens given to Pope would not have been the only ones removed from the cave, and indeed there are remains of broken stalactites as well as stalagmites. The fact that the vestiges of a whole group of six stalagmites consist of very similar stumps carefully cut very close to the ground does suggest that they were taken at the same time. But there were other collectors at that period - one has only to look at some of the specimens given to the Natural History Museum in London - and also other grotto builders, such as Thomas Goldney in Clifton (Bristol) who used stalactites in his grotto in the 1740s and 1750s[55]. The author of a book published in 1804[56] recalls that he had taken some stalactites from the cave.

MR TAYLOR AND MR BRUCE

Two names have been recorded as providers of Wookey Hole specimens for Pope's Grotto - Taylor and Bruce.

It was a *"Mr Taylor"* who Ferrner in 1760 noted had *"taken all the crystals with which ... Pope has ornamented the grotto in his garden..."*[37]. He describes Taylor as an apothecary or pharmacist living in Wells[57].

Doubtless this was the John Taylor, apothecary of St Cuthbert's parish, who had been married in Wells on 13 November 1725 to Susan Creyghton, a relation of a previous bishop there. They had at least five children, four of whom died in infancy; one of them was baptised in the cathedral[58]. In 1727 they were living in High Street, and they are known to have been in Sadler Street from 1728 at least until 1736. Neither John Taylor's baptism nor his burial can be traced in the registers of St Cuthbert's parish in which he lived, or in the registers of the cathedral in which his marriage is recorded; so it must be assumed that he came to Wells from elsewhere. His description in some of these registers as *"John (junr)"* suggests that his father was called John also.

Ferrner's diary shows that Taylor was a friend of Dr Harington[59], later of Bath, and Canon Robert Wheeler of Wells Cathedral. They dined at each others' houses with *"some of the town's better people in the party"*[60]. So, at least by 1760, Taylor had the social contacts which could have made him aware of Pope's requirements for his Grotto and enabled him to furnish items for it. The exact link has not been established. Harington was not at Bath in Pope's lifetime and was anyway too young then to have been involved between Taylor and Dr William Oliver.

The Mr Bruce named by Serle[3] as having sent the *"Petrifaction from Okey-Hole"* to Pope has not been identified with certainty. Brownell[61] suggests that he might have been the Charles Lord Bruce, at whose

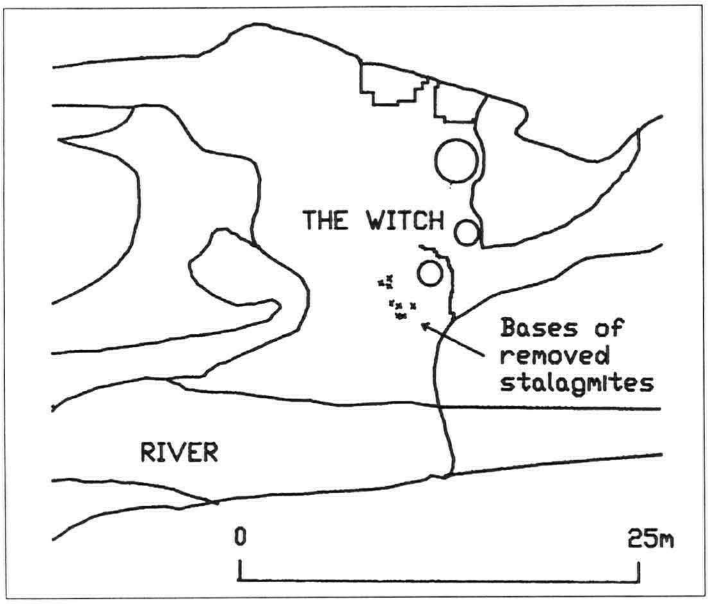


Figure 10. The First Chamber, enlarged from Figure 8, showing the areas from which stalagmites have been removed.

house at Tottenham in Wiltshire Pope had stayed on 25 July 1734[62]. This does indeed seem quite likely. Although there is no mention of Bruce in the Pope letters after 1734, he was the son-in-law of Pope's close friend Richard Boyle, 3rd Earl of Burlington, and Lord Bruce is therefore likely to have been fully aware of Pope's quest for minerals. Tottenham House is in Savernake Forest, 15km south-east of Devizes and 56km from Wells. There is no evidence that the Bruce specimen came to him from John Taylor, but Tottenham and Wells are close enough for overlapping circles of friends to have made this possible: especially with Ralph Allen at Bath between the two.

Charles Bruce (1682-1747), already Baron Bruce since 1711, became the 4th Earl of Elgin and 3rd Earl of Ailesbury in 1741[63]. The use of the word "Mr" by Serle is not necessarily inconsistent with this identification, although the Oxford English Dictionary does not recognise such a usage in written English. In the Pope household he may well have been called Mr Bruce, just as today an *"Academician Prof Dr..."* is often referred to informally as *"Mr"* in speech without disrespect.

CONCLUSIONS

The specimens taken from Wookey Hole to present to Pope for his Grotto were stalagmites and came from the First Chamber of the cave. Two groups of stumps there are now regenerating with new calcite, in an area where the deposits are white and attractive.

The *"Petrifaction from Okey-Hole"* given by Mr Bruce was placed at the foot of the stairs leading up to the house from the southern cross-passage of the Grotto.

If the specimens taken by Taylor were different, they too were probably used between 1741 and 1744 and placed in one of the side chambers of the Grotto.

No specimens are visible in the Grotto now; the cross-passage and one of the side chambers are buried; the other two side rooms have been modified since Pope's time.

"Mr Taylor" was John Taylor, apothecary of Wells and a man of some social standing.

"Mr Bruce" may have been Pope's friend Charles Lord Bruce of Tottenham in Wiltshire, who became the 4th Earl of Elgin.

ACKNOWLEDGEMENTS

I am grateful to the many people who made this study possible. The directors of Wookey Hole Caves Ltd gave permission for me to make lengthy and repeated visits to the cave and to take photographs in it. Mr N Pebenham, headmaster of St James Independent School for Boys, allowed me to examine Pope's Grotto, which is situated beneath the school. Mr Anthony Beckles Willson read this paper in draft and made helpful comments. The British Library, as always, was able to make the more difficult books available, and my colleagues Franjo Drole and Sonja Franetič in the Karst Research Institute, Postojna, prepared some of the plans and typed the text.

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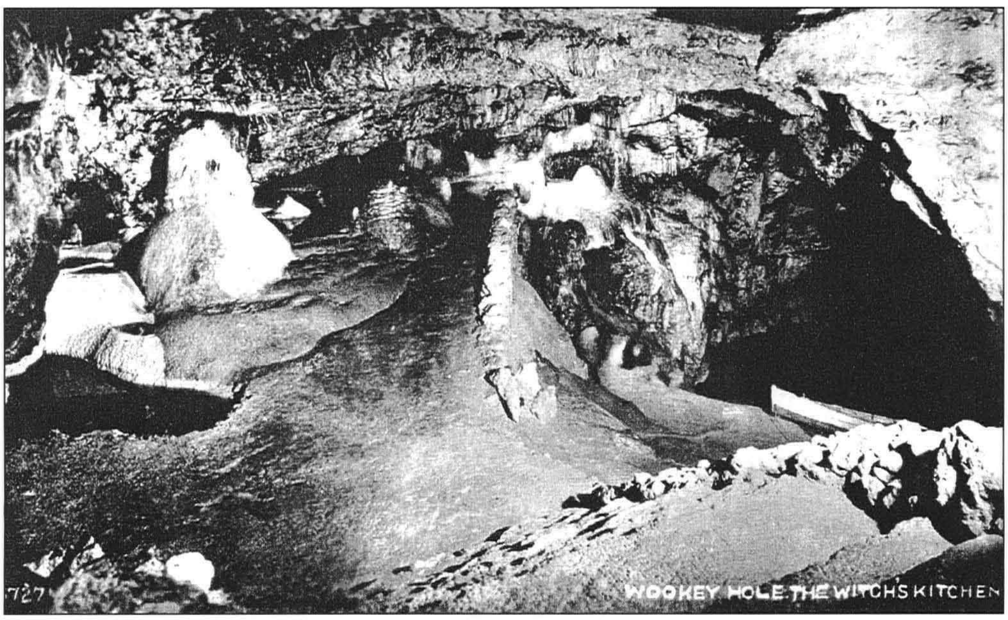

Figure 11. Looking north in the First Chamber, from a postcard photograph of about 1936. The stumps where stalagmites have been cut away are not visible in the picture, but the smaller ones are behind and to the right of the large stalagmite on the left; the larger ones are on the slight slope to the left of the boat and below the black stalagmite known as the Witch.

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"Natural History of Somersetshire" by an unnamed author (according to Green's "Bibliotheca Somersetensis", - Botanista Theophilus, M. D., - probably a pseudonym), 1757, pp.63 and 64...

What happened was this. The "Natural History of Somersetshire" is a section (pp.53-88) of a larger book but was evidently also sold separately at the time in unprinted brown paper covers. Its first page of text just has the chapter heading, "The Natural History of Somersetshire", with no mention of its author. In fact it was published as part of Martin's *The Natural History of England; or, a description of each particular county, in regard to the curious productions of nature and art* [33]. The book appeared in two volumes; published in 1759 and 1763, and the Somerset chapter is in the first volume.

Not being aware of this, Balch looked in the standard bibliography for Somerset, E. Green's *Bibliotheca Somersetensis...* (Taunton, 1902, 3 vols.). This does list the Somerset section, with its correct author and date (in Vol.1, p.340 and Vol.3., p.38) but Balch did not find the entries. Instead, he came across an entry for a different book:
Botanista, Theophilus (M. D.) Rural beauties, or the natural history of the four following western counties, viz., Cornwall, Devonshire, Dorsetshire, and Somersetshire. With additional remarks. 12 mo, 1757.

He assumed from the title that this was the book concerned without going to Bristol to see a copy, ignored the size given which might have caused him to suspect, copied this earlier date and, by omitting a comma, reversed the names of the pseudonymous author. This 1757 book is in fact the children's book[35] from which the shortened version of the cave description has already been quoted - the one in which Pope's Grotto is *not* mentioned.

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Abstracts of the 1998 BCRA Science Symposium, University of Keele on 7th March, 1998

EXTRAORDINARILY FAST STALAGMITE DEPOSITION IN POOLE'S CAVERN, BUXTON

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Abstract: Unusually fast growing, orange-capped, stalagmites have been reported at Poole's Cavern, Buxton, Derbyshire, by several authors. Their growth mechanism has been attributed to the percolation of waste from abandoned lime workings on the surface, although no samples have previously been analysed in detail. Here we demonstrate that their growth is probably through the mechanism $Ca(OH)_2 + CO_2 = CaCO_3$ with dripwater pH >10.0, rather than the conventional reaction $Ca_2^+ + 2HCO_3- = CaCO_3 + H_20 + CO_2$. The former mechanism has a faster geochemical reaction, explaining the fast growth of the stalagmites at the site (2-10mm y^{-1}). X-ray diffraction studies demonstrate that the orange colour of the stalagmites can be attributed to organic matter, derived from the overlying soil, trapped within the calcite, and not from metal ions derived from the overlying kilns. Stalagmites from Poole's Cavern contain annual laminations that can be used to calibrate luminescence records of past climate change.

Keywords: Stalagmite; Poole's Cavern; annual laminations; lime kilns; $Ca(OH)_2 + CO_2 = CaCO_3$.

THE INFLUENCE OF REGIONAL GEOLOGICAL STRUCTURE UPON THE EVOLUTION OF CAVE SYSTEMS IN THE CUILCAGH KARST

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Abstract: Cuilcagh mountain is the highest point in the uplands of southwest County Fermanagh and northwest County Cavan. On the lower slopes of north Cuilcagh mountain, the Dinantian Dartry Limestone Formation forms a plateau, where surface karst features, related to underground drainage systems, are widespread. Dye tracing experiments indicate that the known caves beneath the Cuilcagh upland karst represent only a small percentage of a large and complex karst conduit network with a long and complex evolutionary history. Factors including lithology, sedimentary features and local tectonic structural detail had great importance during the earliest phases of conduit development, termed inception (Lowe, 1992). Following inception, specific stratigraphical elements and aspects of the regional geological structure guided and focused conduit development down-dip, under deep phreatic, and probably initially confined, conditions towards the plunging axial zone of the Cuilcagh syncline, part of the major Lough Allen synclinalstructure. Evolution of the Cuilcagh karst has also been influenced by the Cuilcagh dyke, a linear igneous intrusion that cuts across the northern limb of the Cuilcagh syncline, more or less parallel to the strike. In some areas the dyke appears to have restricted development of underground drainage conduits by acting as an impermeable barrier. Elsewhere, conduit development has been enhanced, where underground flow has been directed towards and through fracture breaches along the dyke's length.

Keywords: Cuilcagh Karst; County Femanagh; County Cavan; Ireland; hydrology; lithology; stratigraphical elements; tectonic structures; Dinantian limestone.

DEPOSITS OF POORLY CONSOLIDATED PEBBLY SAND IN OGOF DWY SIR: THEIR FORM, LOCATION AND POSSIBLE PROVENANCE

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Abstract: Three adjacent areas in Ogof Dwy Sir, South Wales, contain mixed quartz pebble and sand deposits, which, although weak in comparison to the similar Millstone Grit on the surface, are strong enough to remain in place on the roof and walls. The locations are described, a possible earliest formation date for the cave passage is discussed, as is the possible period of sediment emplacement. This paper is presented by an enthusiastic amateur, and aims to bring this potentially interesting deposit to the attention of professional scientists.

Keywords: Cave development; sediments; South Wales.

CAVE STUDIES IN HELGELAND

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Abstract: Large coastal caves have been reported in Norway since at least the 12th Century, and from about 1870 the discovery of inland caves in the metamorphic limestones of the Caledonide nappes has led to an almost continuous increase in the number of recorded caves. Cave exploration in Helgeland, south of Mo I Rana, started in the late 1960s, and over 600 caves are now known. The author has started a project to study the caves in an area based on the Helgeland Nappe Complex. This is bordered to the north by the Rodingsfjell Nappe Complex at Ranafjord and to the south by the Grong - Olden Culmination. The study area will extend eastwards from the Atlantic coast via the HNC and stratigraphically lower nappes to the Caledonide thrust front in Sweden. The talk will discuss the aims of the project, the methods to be used, and the progress so far.

Keywords: Caves; Helgeland; Norway.

THE SEDIMENTS OF ILLUSION POT, KINGSDALE, NORTH YORKSHIRE: EVIDENCE FOR SUBGLACIAL UTILISATION OF A KARST CONDUIT IN THE YORKSHIRE DALES?

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Abstract: Analysis of the sedimentary fill of previously inaccessible passage in the Dale Barn Cave system has revealed evidence of a second phreatic episode in the cave's history and a reversal of flow direction through the cave. The similarity of the sedimentary succession to those described from sub-glacial eskers is noted, and the occurrence of an intermittent connection with the sub-glacial drainage system of the Chapel-le-Dale ice stream is proposed.

Keywords: Dale Barn Cave; Yorkshire; UK; Sediments; sub-glacial drainage.

THE IMPACTS OF AGRICULTURE ON NITRATE AND PHOSPHATE CONCENTRATIONS IN UK CAVE RECHARGE WATERS, WITH SPECIAL RESPECT TO THE P8 CAVE, DERBYSHIRE

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Concentrations of nitrogen and phosphorus are significantly higher in autogenic recharge to P8 than to caves beneath less-intensive land-uses. This is thought to be due to applications of phosphate and nitrate rich fertilisers, including digested sewage sludge, to the field above the cave. The soil zone buffer is ineffective, andhigh levels of nitrite indicate rapid transmission through the soil and drift cover. The rapid transmission of soil clasts, with associated 'immobilised' agrochemicals from the surface to the cave is also demonstrated by the presence of Cs-137 in inwashed autogenic sediment. The implications of these results for cave conservation and for agricultural practices in some cave SSSI are discussed.

Keywords: P8 Cave; Derbyshire; UK; nitrate; phosphate; sewage; fertilisers; Cs-137; sediments; agricultural practices.

SPELEOLOGY AND SEDIMENTATION AT MAKAPANSGAT, NORTHERN TRANSVAAL, SOUTH AFRICA

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Abstract: Re-investigation of the stratigraphical sequences within the Makapansgat Limeworks site has shown evidence for very different depositional environments than had been suggested by earlier researchers. Previously a high energy, alternating water-table environment had been postulated to explain sediment build up. However, recent research suggests that a low energy environment of periodic wetting and drying, causing characteristic mud-cracks, is a more likely evaluation. This re-evaluation has important implications for both the depositional environment and the living environment of the early hominid species *Australopithecus africanus*, the fossils of which have been discovered at the Makapansgat Limeworks site over the last 50 years.

Keywords: *Australopithecus africanus;* Makapansgat Limeworks Site; speleogenesis; stratigraphy; terra rosa; mud cracks; lime mining.

MASS-MOVEMENT CAVES - A GEOGRAPHICAL RESOURCE OF THE FUTURE

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Abstract: Mass-movement caves have traditionally been regarded as of little interest either to cavers or to geographers. Brief descriptive accounts of these caves appear from time to time in caving journals, but mostly these journals belong to small local clubs and have a limited circulation. Cave surveys are far less commonly performed, and scientific study is rare. A large number of caves have been found to the east of Bath, along the cambered valley sides of the River Avon and in its tributaries. In some caves it is possible to determine the direction of groundwater flow before cambering began. Uranium series dating of speleothems has established the minimum age of this movement. Important archaeological and Pleistocene sediment deposits have also been found. Karst researchers should consider the opportunities offered by such terrains for complementary studies.

Keywords: Cave development; speleothem dating; Bath; archaeological and Pleistocene sediments.

CAVE DEVELOPMENT IN TONGA: IS THE PRESENT THE KEY TO THE PAST?

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Abstract: The Tongan archipelago in the South Pacific Ocean comprises about 150 predominantly limestone islands, together with many smaller rocks. Initial speleological studies on the islands of Tongatapu and 'Eua suggest that dissolution at the interface between fresh and saline groundwater (halocline) has been, and remains, crucial to the inception and development of underground conduits within young carbonate rock sequences. So far as it is possible to reconstruct the earliest spelaeogenetic events in the older preserved sequences on 'Eua, it appears that the processes that acted upon young reefal and back-reef carbonates during the Eocene were effectively the same as the processes that have acted on subsequent deposits, and are still active today. Also, evidence on 'Eua indicates that some littoral cave systems, and higher level conduits that target upon them, survive gentle uplift and more extreme tectonism. This raises the possibility that some caves that can be explored today, in both tropical and extra-tropical areas, owe their origins to littoral zone cavernous porosity development processes that were penecontemporaneous with rock formation.

Keywords: Cave development; South Pacific; Tonga; halocline.

SOLUTE FLUX IN CUEVA DEL MOLINO (AGUA), MATIENZO, NORTHERN SPAIN

A Quin
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Abstract: The on-going scientific investigation of the Matienzo depression, Cantabria, Spain, has involved 'Continuous' recording (data recorded at 30-minute intervals) of the solute flux through *Cueva del Molino (Agua)* in Matienzo since October 1996. Two parameters are recorded: total hardness and calcium ion concentrations, using 'Patterson Specific Ion Probes' in conjunction with two 'Hanna' logging pH meters. The merits and drawbacks of this relatively inexpensive solution to karst water quality measurements are presented, along with the data collected to date. A brief outline of the context in which these measurements are being taken is presented.

Keywords: Cave; Matienzo; Spain; karst water quality measurements; continuous data recording; total hardness; calcium ion concentrations; solute flux.

PROGRESS IN THE LUMINESCENCE DATING OF CAVE SEDIMENTS

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Abstract: This paper represents an update on that presented at the BCRA Science Symposium of March 15th, 1997, which outlined research into the feasibility of applying luminescence dating techniques to sediments derived from caves. The research is concentrating on sediments derived from *Drotsky's, Echo* and *Sudwala* caves in southern Africa, *Kitley* and *Joint Mitnor* caves in Devon, and *Reindeer Cave*, Assynt, which reflect diverse depositional modes and palaeoenvironments. Luminescence dating encompasses thermoluminescence (TL) and optically stimulated luminescence (OSL), the latter sampling electron traps that are rapidly bleached. Perhaps the key element in applying luminescence dating to cave sediments is identification of whether total bleaching of the luminescence signal occurred prior to deposition and, where necessary, adoption of a technique that can successfully accommodate partial-

bleaching. A method of assessment utilising single aliquot OSL has identified partial-bleaching for the majority of material sampled, and adaptation of the method appears to be successful in establishing the date of its deposition.

Keywords: optically stimulated luminescence; thermoluminescence; Drotsky's, Echo and Sudwala caves; Kitley and Joint Mitnor caves; Reindeer Cave; Assynt; Africa; Devon; partial-bleaching; single aliquot OSL.

THE RECONSTRUCTION OF THE PALAEOCLIMATE OF LATE QUATERNARY WARM PERIODS THROUGH TIMS U-TH AND POLLEN ANALYSIS OF BRITISH AND IRISH SPELEOTHEMS

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Abstract: Cave speleothems offer the potential to provide an improved palaeoclimatic record, as, unlike many other terrestrial records, their cave environment protects them from destruction by surface erosion, allowing long records to be preserved. Speleothems provide a climatic signal by the timing and rate of their growth and also contain palaeoclimate records, including oxygen and carbon isotopes, organic acids and, in particular, pollen.

More conventional sources of pollen, such as lake and bog sediments, provide detailed records of climate and vegetation change in the past, but are very constrained by the fact that they can only be dated back to 40,000 years BP by the radiocarbon method. Speleothems, on the other hand, can be TIMS U-Th dated to 450,000 years with great accuracy, and when the dates obtained are combined with pollen and other proxy climatic records, it allows the terrestrial record to be extended further back in time and, possibly, correlated with the oxygen isotope record of ocean drilling and ice cores. The extraction of pollen from speleothems for palaeoclimate reconstruction is a relatively new technique in Britain (where palynological studies have tended to concentrate on sediments laid down in wetland environments), although it is a well established technique in France.

In the current study, the pollen from speleothems deposited over a large temporal (last 450,000 years) and spatial (whole of British Isles) extent is being analysed, using speleothems that have already been sampled for previous work. As speleothem deposition occurs during both interstadial and interglacial periods, pollen analysis of samples will allow a more precise determination of the climate at these times. Once suitable pollen samples have been found, they will then be analysed by TIMS U-Th dating to provide a chronology. Contemporary calibration will also be attempted through the study of recent (<100yr) speleothems from old mine sites. It is hoped that eventually a dated sequence of interglacial and interstadial periods will be established, to be used to constrain previous models of timing and nature of Quaternary warm periods, and construct detailed records for individual warm periods.

Keywords: speleothems; palaeoclimate; palynology; TIMS U-Th dating.

THE DIFFERENTIATION OF COARSE- AND FINE-GRAINED SEDIMENTS BY DEPOSITIONAL MECHANISM, CRAG CAVE, CO. KERRY, IRELAND

M Stevenson
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Abstract: The aim of this study is to investigate the depositional mechanism for both coarse- and fine-grained sediments within Crag Cave. Previous studies on the emplacement of coarse sediments in caves generally have found they are not persistent, due to restrictions caused by erosion producing boulder chokes. The depositional mechanism for fine-grained sediments is more contentious. Earlier work has suggested that fine-grained sediments are deposited in caves by vertical flow. This is in contrast to later work suggesting the sediments are emplaced along with glacial outwash.

To investigate the persistence of coarse sediments, the units were logged and sieved, to determine their persistency in the cave. Fine-grained sediments were analysed using several techniques, including filtering the drip water from straws, stalactites and cracks in the roof to determine the quantity of sediments brought into the cave by vertical flow. The geometry of the sediments was also measured, to see if there were any differences in areas of straws and stalactites, compared to areas without straws and stalactites. X-ray diffraction was then carried out on the clay from samples within the cave, and the results compared to those from samples from the surrounding area.

The results showed that the coarse sediments were laterally persistent through the cave; this suggests the boulder chokes were emplaced after the coarse sediments were deposited. There may have been earlier sediments brought into the cave that were not deposited, and later deposits may have built up on the up stream side of the boulder chokes. The results for the fine-grained sediments support the theory that they enter the cave by vertical flow. Results from the drip water analysis suggest that a large amount of fine-grained sediment is brought into the cave through this route, if the coarse sediments were deposited during the last glaciation. This is supported by the geometric results, which show a greater thickness of sediments under straws and stalactites. X-ray diffraction analysis did not produce decisive results. This may be due to the thick till overlying the cave, making it difficult to differentiate local clay from glacially derived clay.

Although the fine-grained results appeared to support the theory that deposition was by vertical emplacement, it assumes that the coarse sediments were deposited during the last glaciation. If, however, the coarse sediments were deposited in an earlier glaciation, the sediments would have had longer to accumulate, making vertical deposition insignificant. Because the fine-grained sediments can be found in areas without straws or stalactites, a secondary method of emplacement would be needed.

Keywords: Crag Cave; County Kerry; Ireland; sediments; depositional mechanisms.

THE HYDROLOGY OF SPELEOTHEM-FORMING DRIP WATERS, CRAG CAVE, KERRY, SOUTHWEST IRELAND

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Abstract: Crag Cave is developed within Carboniferous biomicritic limestone of variable dip. It is a mature system comprising low-roofed caverns, linked by partially sediment-infilled phreatic tubes. The bedrock is overlain by a clay-rich, well-consolidated, fine-grained till deposit of Munsterian age.

Daily monitoring and sampling of karst waters was performed at 14 speleothem-forming dripwater sites over a period of 21 days. Drip rates were recorded in order to investigate spatial and temporal variations in discharge during baseflow. Rainfall was monitored to ascertain the response to increased throughflow. Sites were selected to allow exploration of fast and slow dripping waters, variable hydrological routing and speleothem forms. Barometric pressure was recorded daily at surface and subsurface sites, to determine the influence of pressure gradient upon drip rate. The EC and pH of each water sample were measured to confirm postulated water routing and hydrological rainfall response.

Hydrological routing was shown to be spatially variable, dependent upon the extent of interconnectivity of conduit/fracture system pathways versus percolation flow regimes. The discharge response to rainfall events differed spatially. Some neighbouring sites showed overflow/underflow relationships at times of peak discharge. The time lag between maximum surface input and cave output varied between sites. Slower dripping sites were frequently unresponsive to rainfall events. Short time-scale variability in discharge rate was shown to be independent of baseflow drip rate (except for the slowest site), and temporal variations in rate due to increased surface input.

Barometric pressure gradient was found to have little effect on drip rate over the magnitude of variations observed. However, since the monitoring period included many rainfall events, further study during periods of prolonged baseflow is required, in order to fully understand the influence of variations in barometric pressure.

Since stalagmites grow preferentially under specific drip rate regimes, a full understanding of all factors controlling drip rate is vital, and, hence, has relevance for the geochemical investigation of stalagmites as palaeoclimatic indicators.

pH was used as an approximate indication of the amount of calcite dissolution that has occurred, and hence, to confirm postulated water routing. That is, drip waters sourced from regions of percolation flow through rock pores may have a higher pH than those derived from interconnected conduit and fracture passageways. The parameter of pH can be used to confirm the drainage of seepage waters during or after rainfall events. As well as recording storm responses, measurements of EC may record aspects of aquifer hydrology, in particular water routing.
Keywords: site description; techniques used; drip rate; drip waters; Crag Cave; County Kerry; Ireland; pH; EC.

POSTER PRESENTATIONS

SCALLOP MORPHOLOGY IN RELATION TO CAVE PASSAGE DEVELOPMENT

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Scallops are small-scale dissolutional features that appear on the walls, floors and ceilings of limestone caves. They are the key process indicators of the previous flow conditions that formed the large-scale passages that serve as scallop host beds.

Scallops develop under a variety of flow conditions by aerobic and anaerobic dissolutional processes. Detailed study of their 3-D morphology reveals that their concavities and ridges hold records of the conditions of flow influencing their development, from which temporal and spatial variations in flow conditions may be deduced.

Differences in the morphology of phreatic and vadose scallops can largely be explained by difference in the residency time of corrosive waters at the rock/fluid interface. Aggressivity of the flow may be a contributing factor to the rate of scallop development. Evidence also suggests that factors associated with the kinetics of flow (e.g. velocity and turbulence) are reflected within the configurations of scallop morphometry.

The study of scallops in relation to cave canyon morphology confirms that potential exists for the forging of relationships between scallops and their host beds. However the extent to which general relationships may be applied is restricted by the processes of diagenesis and periodic lowering of the water table.

CAVE DETECTION IN SOUTH DEVON USING GROUND PENETRATING RADAR (GPR)

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EXPERIMENTAL GROWTH AND CHEMISTRY OF SPELEOTHEMS

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Natural soda straw stalactites commonly display visible periodic bands, typically 0.05-0.5mm wide, comparable with likely linear annual extension rates of the structures. Such bands are found to represent thickenings of the walls of the structures at growth steps. In contrast, visible or UV banding, caused by variable presence of impurities, may be detectable in stalagmites. In speleothems from Grotta di Ernesto, NE Italy, soda straws display both characteristics, with inclusion-rich layers possible representing an autumn flush of humic substances from the soil zone. In this cave speleothems with visible laminae commonly display periodic banding of P (high in visible laminae), often antipathetic to Sr and/or Mg. Since P influences the growth of calcite, possible crystal surface effects on incorporation of trace elements need to be considered. Trace element geochemistry is argued to be (in favourable circumstances) an indicator of palaeohydrology of the karstic environment.

To determine the nature of calcite surface controls on trace element composition of speleothems, a programme of experimental growth of soda straws and stalagmites is underway, utilizing experimental cabinets held at constant temperature and 100% humidity. Feed solutions of $NaHCO_3$ and $CaCl_2$ are supplied by peristaltic pump and mixed immediately before passing through a soda straw stalactite, or in some cases, a glass tube, and allowed to drip onto an incipient stalagmite surface. Calcite saturation is controlled by the starting compositions of the experiments, which have PCO_2 similar to that of the atmosphere. Saturations in the experiments are up to 10 times that at equilibrium, and produce growth rates at the upper end of those found in typical caves.

Experimental runs of 6 weeks produce widths of calcite overgrowth in the range 20-100μm (less if more impurity ions are present) and provide a basis for experimental determination of partition coefficients.

DETECTION OF CAVITY SYSTEMS USING RESISTIVITY AND MICROGRAVITY

D C Walker [1], A M Binley [2], G W Stuart [1] and P J Murphy[1]
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[2] Institute of Biological and Environmental Sciences, University of Lancaster, Bailrigg, LANCASTER, LA1 4YQ, Lancashire, UK

An abstract of Dawn Walker's thesis on this topic was published in *Cave and Karst Science*, Vol.24, No.3.

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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.

Editors' note:

It has not been our normal practice to include Obituary notices within *Forum*, though recent sad events have led us to introduce the inclusion of such notices, recording the achievements of particularly well-known individuals, as a part of our Editorial content. On this occasion, we have decided that the following Obituary, received recently from South Africa, deserves to be included within *Forum,* for the very simple reason that we believe few of our readers will have linked the horrific crime, referred to by Margaret Marker in the following covering note, with a member of the karst community. We add our commiserations, and hopes for the future, to those undoubtedly already received by Lin's family.

> *"Lin Russell was married to Shaun Russell. They had two daughters, Megan aged 9 and Josie aged 6. At the time of Lin's death, the family were living in Kent, as Shaun was working at the University of Kent in Canterbury. On a July afternoon in 1996, Lin walked across fields to meet her children, who had returned in the school coach from a swimming gala. While walking home, mother and daughters were attacked and bludgeoned by an unknown assailant. Lin and Megan died, but young Josie survived, though with severe head injuries. Many in Great Britain will remember this vicious attack."*

Obituary: LIN (Linda) RUSSELL 1951 - 1996

Lin grew up and was educated in England. She read geography and geology for a joint BSc Honours degree at Exeter University, and then obtained her post-graduate Certificate of Education at the same university. In 1975 she and her husband Shaun, a botanist, emigrated to South Africa where Shaun was appointed Lecturer in Botany at the University of Fort Hare. Lin shortly took up a technical post in the Department of Geography, which she held, both as technician and temporary lecturer, until the end of 1977. She was then replaced by an African; and so moved to the Faculty of Agriculture. In 1981 she was appointed Lecturer in the Department of Geology. Lin was an excellent lecturer, and had good rapport with students, despite the years of activism and boycotts.

During 1979 she approached me about the possibility of doing a karst Master's degree by dissertation. She was awarded an MSc for a dissertation entitled *"The geomorphology of the coastal limestones of the De Hoop Nature Reserve, southern Cape"*. This was an excellent piece of work. Hers was the first MSc in Geography at the University of Fort Hare, and a first for a white candidate. She actually wrote up by correspondence while in the United States, as in 1981 Shaun was on sabbatical there. Had she been nearer to her supervisor it is likely that she would have obtained a distinction.

Almost immediately she asked about the possibility of working with me, again on a karst topic, for her doctorate. She was well aware that it was essential to gain higher qualifications in order to rise up the academic ladder. In 1988 she submitted a PhD thesis entitled: *"Karst surface landforms of the Cape Coastal Limestones"*. Graduation took place in April 1989. She had at first intended to include the Kwa Zulu limestones; but access into a semi-militarised zone and an area where 4x4 vehicles were essential precluded that part of the study, so she confined herself to the outcrops of the then Cape Province. The research involved analysis of surface landforms using air photography, ortho-photo maps and strict ground control. This was the first comprehensive account and explanation of these landforms. Her work became the definitive study on the karst of the southern Cape. Her experience of both geographical and geological techniques makes her results of particular importance. Her examiners included the late Dr Marjorie Sweeting, who felt that the work was sound. Again, hers was the first doctorate in the Department of Geography.

Her elder daughter Josie (who survived the brutal attack that killed Lin, her younger daughter and their dog) was born late in 1987, so completion of thesis writing was done with a babe at foot. She managed to produce a good thesis despite her family commitments, as by that time Shaun was employed at Rhodes University, some 80km distant. Shaun and Lin made an enormous contribution to the small community of young white liberal lecturing staff at Fort Hare University at that time. The amount of support for Shaun from South Africa during this time of bereavement is a measure of this. Shaun and Lin emigrated back to Britain, buying an old house in North Wales, but soon returned to southern Africa where Shaun was appointed to the new University of Namibia. They lived in Windhoek over the period of transition to independence, and Lin held a series of temporary jobs at the university. The housing shortage in Windhoek entailed sharing a house, which she hated. She returned to Britain ahead of Shaun, to make a home in Wales and to take on the role of mother.

Lin excelled at everything that she attempted. I think of her as an excellent geomorphologist and a knowledgeable karst scientist, with much independence of thought and ideas. This was how I knew her best. I am only sorry that her change in emphasis meant that publication of her work has been left to others. But, she was also a home-maker, a house decorator and gardener par excellence, and above all a loving and caring mother. Her untimely death is a great loss, not only to her family and friends, but also to the karst.

Margaret E Marker,
Professor Emeritus: University of Fort Hare,
Honorary Research Fellow: University of Cape Town.

GEOLOGICAL VISITORS TO INGLEBOROUGH CAVE, AS RECORDED IN THE INGLEBOROUGH CAVE VISITORS' BOOK

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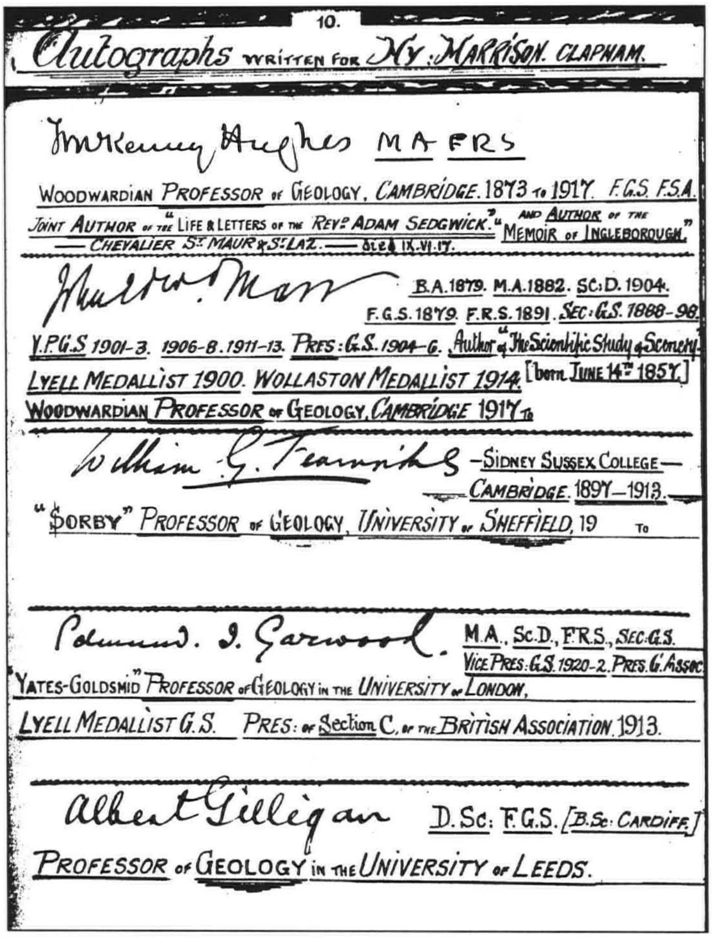
Ingleborough Cave is situated on the southern slopes of Ingleborough, about 2km north of Clapham in the English Pennines. It was discovered in September 1837, when estate workers broke through a stalagmite barrier at its entrance, exposing about ¾ kilometre of stream passage, which was immediately opened to tourists[1]. This was the first cave dig in the northern Pennines, and was the first northern cave to be surveyed. The first custodian of the Cave was Josiah Harrison, who held office until his death in 1888. He is said to have kept a visitors' book[2], but its location is unknown. Josiah Harrison's grandson, Henry Harrison, was appointed custodian of the Cave in 1888, at the young age of 22 years[3]. He kept two complementary visitors' books, both of which have survived.

The major book is 19.5 x 16.0cm, bound in red quarter leather and corners. On the outside cover "AUTOGRAPHS AND QUOTATIONS Written for H. Harrison, Clapham, Yorks" has been tooled in gold. Few of the signatures are dated. There are 24 blank sheets, followed by 70 pages autographed on one side of the paper, and a further 64 blank pages. The reason for this unused paper remains a mystery, especially as there is another, smaller and cheaper, paperback booklet, in which many of the autographs are repeated. This booklet is 17.8 x 11.2cm with 12 pages autographed on both sides of the paper. All these signatures are dated.

Harrison maintained his book until his death on 16 December 1938, after nearly half a century of service at the cave[4]. The paucity of dates makes it impossible to date the commencement of the book. The earliest date is that of Lebour on 13 June 1899, but it does not appear on the first page. This signature is on a separate piece of paper that has been glued into the book, suggesting that the album was acquired after Lebour's visit. On the other hand, Harrison may simply have mislaid the book. It is clear from the many blank spaces that the autographs were not written in chronological order.

Among more than four hundred autographs there are several of members of the Yorkshire Ramblers' Club, who were pioneering cave exploration and survey between 1892 and the Great War. After the Great War, speleological visitors included Gerard Platten, the founder and editor of the *British Caver*; Professor Leo Palmer of Hull University, who experimented with an electronic earth tester that was intended to detect caves, and Charles Hewer of the British Speleological Association. A conspicuous omission is the signature of Eli Simpson, founder, Librarian and Recorder of the British Speleological Association, who lived at Austwick, a mere 6km from the Cave. Also featured in the book are autographs of many of the well-known geologists and anthropologists of their time. For the purposes of this short note some of their signatures are transcribed below (in bold), with Harrison's comments in standard font, and my comments in italics. It is reassuring to know that the savants of yesteryear did their field work, and were not content to sit all day in their laboratories. The most notable omission from the names is that of Edouard Alfred Martel, who achieved lasting fame because of his pioneer descent of Gaping Gill on 01 August 1895. The account of that descent states quite clearly that, "Mr. Harrison has seen a good deal of M. Martel ...[5]" - and yet there is no autograph. This suggests that the album was started after 01 August 1895.

After Harrison's death in 1938, the autographs passed to the Lord of the Manor, Sydney James Farrer, who died in December 1946[6].


10.
Autographs written for Hy. Harrison. Clapham.

T McKenny Hughes M.A. F.R.S.
Woodwardian Professor of Geology, Cambridge. 1873 to 1917. F.G.S. F.S.A.
Joint Author of the Life & Letters of the Revd Adam Sedgwick." and Author of the "Memoir of Ingleborough."
— Chevalier St. Maur & St. Laz. — died IX.VI.17.

J. Marr B.A. 1879. M.A. 1882. Sc.D. 1904.
F.G.S. 1879. F.R.S. 1891. Sec: G.S. 1888-98.
V.P.G.S. 1901-3. 1906-8. 1911-13. Pres: G.S. 1904-6. Author of "The Scientific Study of Scenery"
Lyell Medallist 1900. Wollaston Medallist 1914. [born June 14th 1857.]
Woodwardian Professor of Geology, Cambridge 1917 to

William G. Fearnsides - Sidney Sussex College - Cambridge. 1897-1913.
"Sorby" Professor of Geology, University of Sheffield, 19 to

Edmund J. Garwood. M.A., Sc.D., F.R.S., Sec. G.S.
Vice Pres. G.S. 1920-2. Pres. G. Assoc.
Yates-Goldsmid Professor of Geology in the University of London,
Lyell Medallist G.S. Pres: of Section C. of the British Association. 1913.

Albert Gilligan D.Sc. F.G.S. [B.Sc. Cardiff]
Professor of Geology in the University of Leeds.

Figure 1. A collection of eminent geologists: page 10 of Henry Harrison's autograph album. This shows the original autographs, embellished with

Sometime thereafter it is said that the books were borrowed, for an exhibition, from his widow Violet M F Farrer, by Eli Simpson of the British Speleological Association. Simpson failed to return them. After his death in 1962 they were acquired by Richard Hollett & Son of Sedbergh, from whom I bought them a quarter of a century ago.

TRANSCRIPTION OF SOME AUTOGRAPHS OF GEOLOGICAL INTEREST

(in the order in which they appear)

G.A. Lebour 13 June 1899
Professor G A Lebour (Geology) was Vice-Principal of Durham University.

T.G. Bonney 9 Scroope Terrace and St. John's College Cambridge
Rev. Thomas George Bonney. LL.D. Sc.D. St. John's Coll. Camb. F.R.S., F.S.A. Professor of Geology University Coll. of London, 1876 - 1901. F.G.S. d(eaconed) 1857. p(riested) 1858 (Lond.) Assist Master Westminster Sch. S.W., 1856 - 1861. Fellow of St. John's Coll, from 1859. Hon. Canon of Manchester, 1887.

W. Horne F.G.S.
Antiquarian. W. Horne & Sons' Private Museum, Leyburn, Wensleydale.

Ernest Evans, Natural Science Master
Burnley Municipal Technical School. Author of "The Student's Hygiene"; "Botany for Beginners"; "How to Study Geology" etc.

David Woolacott D.Sc., F.G.S.
Lecturer in Geology, The Armstrong College, Newcastle-on-Tyne. Durham University.

Arthur Dwerryhouse D.Sc., F.G.S., M.R.I.A.
University Lecturer in Geology, Belfast. [Late Leeds University.]
Dwerryhouse wrote a popular book in the Romance of Reality Series, "Geology", and for some time lectured at University College, Reading.

Albert Gilligan B.Sc., F.G.S.
Assistant Lecturer and Demonstrator in Geology, Leeds University. [B.Sc. Cardiff.]
Gilligan was Head of the Geology Department at Leeds University 1922 - 1939[7].

W. Gowland F.R.S.
Professor W. Gowland died at Kensington on Sat: June 10th. 22, in his 80th. year. Past President of Mining & Metallurgy of the Royal Anthropological Society. & of the Institute of Metals. Emeritus Professor Metallurgy. Royal School of Mines. London. F.S.A. F.I.C. Chevalier of the Imperial Order of the Rising Sun, Japan.

Herbert E. Wroot
On the staff of the "Bradford Observer". Now Secretary of the Yorkshire Geological Society.
Wroot achieved fame as co-author of "Geology of Yorkshire" privately published in 1924. It is interesting that Wroot's co-author, Percy F. Kendall, who was first Professor of Geology at Leeds University[8]*, did not sign the book.*

Harold Brodrick M.A., F.G.S., Y.R.C.
Mayor of Southport, 1912 - 1913.
Brodrick & C.A. Hill of the Yorkshire Ramblers' Club surveyed as far as Giant's Hall in summer 1912, and continued further in summer 1913[9].

J. Wilfred Jackson, F.G.S.
Geological Curator Manchester Museum. Expert on Bone Classification.

T. McKenny Hughes MA FRS
Woodwardian Professor of Geology, Cambridge, 1873 to 1917. F.G.S. F.S.A. Joint author of the "Life & Letters of the Revd. Adam Sedgwick", and author of the "Memoir of Ingleborough". Chevalier St. Maur & St. Laz. Died IX VI 17.
McKenny Hughes witnessed the great flood at the Cave entrance in July 1837 i.e. before the stalagmite barrier was broken[10].

J. Edward Marr
B.A. 1879. M.A. 1882. Sc.D. 1904. F.G.S. 1879. F.R.S. 1891. Sec. G.S. 1888-98. Y.G.P.S. 1901-3, 1906-8, 1911-13. Pres. G.S. 1904-6. Author of "The Scientific Study of Scenery". Lyell Medallist 1900. Wollaston Medallist 1914. [born June 14th. 1857.]

William G. Fearnsides
Sidney Sussex College Cambridge. 1897 - 1913. "Sorby" Professor of Geology, University of Sheffield, 19 to
Fearnsides was appointed to the Chair at Sheffield in 1913[11].

Edmund J. Garwood.
M.A., Sc.D., F.R.S., Sec.G.S. Vice Pres. G.S. 1920-2. Pres. G.Assoc. "Yates-Goldsmid" Professor of Geology in the University of London. Lyell Medallist G.S. Pres. of Section C, of the British Association, 1913.

Albert Gilligan
D.Sc. F.G.S. [B.Sc. Cardiff.] Professor of Geology in the University of Leeds.
Gilligan was Head of the Geology Department at Leeds University 1922 - 1939[12]*. He obviously had been promoted before his second visit.*

Alex Macalister F.R.S.
Fellow of St. John's Coll: Camb: Professor of Anatomy, Camb: University, 1883 to Former President of Geological Society of Ireland.

W. Wickham King F.G.S.

W. Boyd Dawkins 18 Aug. 1917
Sir William Boyd Dawkins. F.R.S. Geologist & Archaeologist. Professor of Geology Victoria University of Manchester. M.A. D.Sc. F.R.S. F.G.S. F.S.A. Author of "Cave Hunting." etc. Died on Tuesday, Jany. 15th. 1929, at his home in Bowden, at the age of 91.
Dawkins was also at Ingleborough Cave in 1871[13].

T.H. Digges La Touche
B.A. F.G.S. Superintendent Geological Survey of India 1881 - 1910.

Tressilian C. Nicholas
M.A. Trinity College. O.B.E. M.C. F.G.S. Fellow and Lecturer of Trin: Coll: Cambridge. Additional demonstrator in Geology, Cam: Univ:

Herbert L. Hawkins
D.Sc. Manchester University. F.G.S. Professor of Geology. University College, Reading.

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Smith Bracewell
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BOOK REVIEWS

A Renaissance in Cave Archaeology

BONSALL, C and TOLAN-SMITH, C, (Eds.) 1997. *The Human Use of Caves.*
British Archaeological Reports, International Series 667 (1997). Oxford, Archaeopress.

DIXON, E J, (Ed.), 1997. *Geoarchaeology of Caves and Cave Sediments. Geoarchaeology* 1997, Volume 12, Number 6.

Natural caves, fissures and rock shelters have long been recognised as locations with heightened potential for the preservation of archaeological remains. Nineteenth century excavations in caves in Britain and continental Europe provided pivotal evidence for establishing human antiquity, and although many of these early excavations were poorly controlled, some of the early cave explorers, such as William Pengelly who excavated Kent's Cavern in Devon during the 1860s, were at the forefront of the development of scientific techniques of archaeological investigation. Over the last 50 years or so there has been a shift of attention away from caves, and professional archaeological interest has focused instead on stratified open sites, where clear and detailed evidence of human activity or occupation can be obtained more easily. There is also now a widespread appreciation of the difficulties in securing reliable contextual information from cave deposits, and doubt has been cast on the value of materials obtained from earlier cave excavations. Recently, however, there has been something of a revival of interest in cave archaeology, partly through the recognition that caves had a widespread ritual function (a global theme that appears in many cultures, both past and present), and partly as a result of the development of more sophisticated methods of recording, characterising and dating cave deposits.

The Human Use of Caves brings together 28 papers originally presented at an international conference held at the University of Newcastle in 1993. The papers are extremely wide ranging, both in their global geographical coverage and in their time-span, which reaches from the earliest traces of human activity in the Lower Palaeolithic right up to historical and ethnographic evidence of cave use in the present century. The range of human activities documented is similarly diverse. An introductory paper by Lawrence Straus, appropriately titled 'Convenient Cavities', provides a down-to-earth reminder of the many mundane human activities that can contribute to the accumulation of cultural materials in caves. Many archaeologists divide caves, or at least episodes of cave use, into sites where economic usage prevails and those where the cave was primarily of ritual significance. Christopher Tolan-Smith and Clive Bonsall, in summarising all of the evidence, point out that this division may be a false dichotomy that owes more to our modern rationalist perspective than to the social and ideological structures of the communities who used the caves. What emerges from the detailed analysis of the archaeological and historical evidence for cave use is that the so-called economic activities - residence, acquisition and processing of raw materials, and disposal of 'waste', are often structured in ways that point to important ritual constraints. For example, Michael Eddy's study of residential occupation of caves on the Canary Islands by the prehistoric Guanche culture shows the pervasive influence of Berber belief systems in determining the spatial arrangement of activities within the caves, and Keith Branigan's account of Romano-British cave workshops highlights the difficulties in a purely economic explanation of the choice of caves for complex craft activities.

Geoarchaeology of Caves and Cave Sediments is an edited volume of peer-reviewed papers that were presented at a symposium of the same name held at the 1996 Geological Society of America meetings in Denver, Colorado. It is commendable that the papers have been refereed, edited and published within a year of the symposium taking place. As with *The Human Use of Caves*, a wide geographical coverage is achieved and a paper by Douglas Anderson on cave archaeology in Southeast Asia plugs what is a noticeable gap in the regional portfolio presented in Tolan-Smith and Bonsall's volume. The overall focus of *Geoarchaeology of Caves and Cave Sediments* is less anthropological and more scientific, although a harmonious balance is achieved by the inclusion of papers by Joseph Kennedy and James Brady on the use of Hawaiian lava tubes as refuge caves, and by James Brady and co-authors on Mayan modification of speleothem formations in Mexico and Guatemala.

The complex nature of the depositional processes that take place in caves and rock shelters is emphasised by Rolfe Mandel and Alan Simmons in their analysis of the Aetokremnos shelter in southern Cyprus. In addition to episodes of human activity resulting in the deposition of artefacts and faunal remains in this important palaeolithic site, sedimentological analysis showed that a range of autochthonous and allochthonous processes, including rock falls, attrition of the cave walls and aeolian and colluvial inputs contributed to the accumulation of the cave sediments. Fortunately at Aetokremnos the prehistoric human activity was non-intrusive and burrowing animals (which so often disturb unconsolidated cave sediments) were absent, allowing the site stratigraphy and formational processes to be reconstructed in detail.

Other papers highlight the value of caves as receptacles for faunal remains, especially in forested and tropical areas where acid soils and high soil temperatures accelerate the deterioration of organic remains at surface sites. Faunal assemblages are important for documenting the history of natural biotas within the catchment area of a cave locality, and through the analysis of body part representation and bone modification they also provide crucial evidence about human and non-human agents of bone accumulation. In separate studies of recently investigated caves in eastern Alaska, Robert Sattler and a team led by E. James Dixon use skeletal evidence to achieve new insights into the history of vertebrate and human colonisation of the North American continent at the end of the last ice age. Human and faunal remains are also the materials of choice for radiocarbon dating deposits up to 40,000 years old, and several papers in this volume use ^{14}C dates to establish the stratigraphical sequence of late Pleistocene and Holocene cave sediments. For older deposits there are a variety of stored energy dating methods, such as electron spin resonance (ESR), thermoluminescence (TL) and optically-stimulated luminescence (OSL), that can be applied to many crystalline materials. Lau and co-authors give a detailed account of the use of ESR to date the oldest musical instrument in the world: a 75,000 year old bone flute from Divje Babe I in Slovenia.

Taken together these volumes are a testament to the heightened awareness of the archaeological potential of caves, and they provide a wide range of examples and case studies in the application of modern archaeological practice to cave deposits. These are welcome and significant contributions to the developing discipline of cave archaeology.

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GILLIESON, D, 1996. *Caves - Processes, Development, Management.* Blackwell Publishers Ltd., Oxford UK & Cambridge USA. 324pp. The Natural Environment Series -#1. Hardbound ISBN 0-631-17818-8 US$90.00; Softbound ISBN 0-631-17818-5 US$27.95.

This book comes as a welcome addition to the small, but growing, number of texts on caves and karst. It will be particularly useful with regard to the issue of karst management, to which a third of the book is devoted, and in which there is a growing international interest. It provides the most comprehensive description of karst management yet encountered in an English language text, split between two chapters: cave management, and catchment management in karst. A further, cave ecology, chapter also includes important and comprehensive discussion of management issues. The bibliography shows that examples quoted are world-wide, and various topics are tackled as logical sub-sections (about 9 per chapter) rather than as separate case studies, an approach that is potentially more educational for the target audience. The cave management section provides a good summary of the state of the art; descriptions of concepts such as VIM (Visitor Impact Management) will be especially useful to cave managers. Management of Waitomo Caves (New Zealand) is described but, surprisingly, Chris Pugsley's PhD thesis on its world-famous glow-worms is not cited, either here or in the cave ecology chapter. However, it is pleasing to see Cave Ecology included, especially as speleobiota are important cave health indicators. The catchment management chapter provides a comprehensive summary, and the author's involvement and expertise are apparent.

What is the book's target audience? Ideally readers will need some knowledge of geology, hydrology and geomorphology. A glossary is appended but is not exhaustive: some obscure but potentially important words in context (e.g. cryptogam) are missing from both glossary and index. Readers from the cave and karst world will probably appreciate the books as a whole, but karst managers might jump from Chapter 1 to the management sections -not necessarily a bad thing. For these managers, the book provides an excellent follow-on from the IUCN World Commission on Protected Areas Guidelines for Cave and Karst Protection [reviewed in this Issue], where Gillieson is one of the four editors.

Chapter 1 introduces the "Cave System and Karst" and (usefully) explains the book's organisation into three sections: contemporary processes of cave formation, past processes and their products, and cave ecosystems and their management. Chapters 2 and 3 examine "Cave Hydrology" and "Processes of Cave Development", and are of particular interest to cavers and karst geomorphologists. The text is rather traditional in places, perhaps reflecting a lack of readily available literature describing recent paradigm shifts in this field. For example the water-table concept and carbonic acid dissolution remain the cornerstones of Gillieson's description, whereas aspects such as aquifer confinement (flow nets), strong acid dissolution and inception horizons (Inception Horizon Hypothesis) might have been discussed more comprehensively. The four-state/multiphase models outlined by Derek Ford in the 1960s and 1970s, and summarised here from Ford and Williams (1989), have been extremely useful in advancing discussion and understanding of cave processes. However, as with any scientific models, these concepts, though still relevant, should be constantly re-evaluated and modified where necessary in the light of subsequent findings and hypotheses.

Since the early 1970s the number and size of cave discoveries has expanded enormously. Gillieson himself writes (page 5):

"The advent of cave diving has dramatically expanded the number and type of caves we can study, and information from these drowned conduits is causing some major revisions in thinking about caves".

This is indeed true in the type area for Derek Ford's models (the UK's Mendip Hills), where deep diving in Wookey Hole (>80m), for example, demands reinterpretation of some aspects (specifically the "fissure frequency" concept). The paradigm shift can be summed up in terms of a growing recognition that speleogenic flow patterns are potentially established during extensive periods of aquifer confinement. After this, water-tables are superimposed as aquifers are exposed following uplift and erosion, leading to fairly rapid development of vadose and some specific phreatic features. Perhaps this view, where karst is seen as a process (and has long been seen as such by "Russian" karstologists), could have been discussed more extensively. This is not to say that Gillieson does not recognise the limitations of the older views. In fact, towards the end of Chapter 3, he alludes to the paradigm shift. It is also disappointing that there is no discussion of glacial karst, in particular ice-contact caves, their morphology and the sediments that they contain. More justice could have been done to such work as that of Stein-Erik Lauritzen, at the University of Bergen, and others who have published extensively on this topic.

The remainder of the book (chapters 4, 5, 6 and 7) deals with cave formations and sediments, focusing on systematics, dating and climatology. In the main, this falls within Gillieson's own research field and the in-depth coverage is perhaps the best yet achieved in a karst text - certainly in the English language. In particular, he describes the importance of cave sediments as indicators of past surface conditions adjacent to host caves. The section on isotope climatology is locally a little muddled. For example, while the ice volume effect on variations in the $^{18}O/^{16}O$ (calcite) of marine cores is dominant, it may hardly be distinguishable in speleothem calcite due to the large temperature effects on precipitation. He presents a comprehensive record of $^{18}O/^{16}O$ (calcite) from 20 speleothems sampled in North America and Bermuda, but the details must be viewed with caution, as some of the dates have subsequently been shown not to be firm. For example, the speleothem recorded from Iowa was re-dated in 1980, to suggest that it had been deposited during the Holocene and not from 80-5ka. The discussion as a whole might usefully have included other isotope records from around the world, especially those derived by Mel Gascoyne and his colleagues.

Overall, despite the limited reservations outlined above, the book is an excellent addition to the karst literature. As an active caver as well as a karst scientist, Dave Gillieson has visited many karst regions around the world. His wide experience imparts credibility to his discussion and underlying observations. The softback version at least is very affordable, and it should be a welcome addition to the bookshelves of cavers and karst scientists alike.

Reviewed by Chas Yonge, Alberta Karst Research Institute, 1009 Larch Place, Canmore, Alberta, T1W 1S7, Canada.

KRANJC, A, (Ed.), 1997. written by Andrej Kranjc and others.
KRAS: Slovene Classical Karst.
ISBN 961-6182-42-0. Published by the Znanstvenoraziskovalni center SAZU, Založba ZRC and Inštitut za raziskovanje krasa ZRC SAZU [the Scientific Research Centre of the Slovenian Academy of Sciences and Arts and the Karst Research Institute], Slovenia, 254pp.
Available from Maja Kranjc, Karst Research Institute, Titov trg 2, p.p. 59, SI-6230 Postojna, Slovenia. Price £19-00 [including packing and postage].

There exist a relatively small number of classic "coffee table" books that deal with aspects of caves and karst, partly by written word, but most obviously by making use of combinations of informative text figures and instructive, picturesque and spectacular or awe-inspiring photographic plates. Opinions vary, but arguably the "best" among these, depending upon their particular bias, have been written and illustrated, and/or compiled, by cavers or karst scientists, with the intention of informing, as well as astonishing, serious readers or casual browsers. A few other "picture books" have been produced (one suspects more to amaze than to inform) by a variety of publishing houses, and though these books inevitably include some illustrations from the collections of those same cave explorers and karst scientists, their motives, outlook and the information presented are different. Here, from the home of the term "karst", is a "coffee-table" book that has been written and illustrated by undoubted karst experts, drawing upon their own broadly ranging experience and upon an apparent wealth of archival material. Though limited by intent and by title to that part of the Classical Karst region that today lies within the borders of Slovenia, the subject matter of this book goes beyond that of many earlier publications, and contemplates human, as well as scientific, aspects of the "Kras" phenomenon.

The book divides into two roughly equal parts though, inevitably, there is some overlap between its sections. First, various aspects of the natural history of Kras are considered, in a worthwhile Introduction and chapters that deal with geology, geomorphology, climate, hydrology, speleology, soils and vegetation, and conservation. Each chapter is illustrated profusely with appropriate coloured and (fewer) monochrome photographs, and a variety of seemingly purpose-drawn text figures, complementing an easy to follow text, with a sensible type size for this kind of publication. A small criticism of this and, perhaps more seriously, the second section, is that although most of the illustrations are accompanied by appropriate captions, some are not, and this shortfall proves quite frustrating in the face of the obvious interest provoked by the pictures. It must also be said that parts of the English text, though certainly readable and understandable, are clearly the product of literal translation, and locally require a second look to ensure understanding. As the fly-leaf provides the information that text revision was undertaken by two respected native English speakers, it would appear that their remit was not to tamper too much with the original, but simply to smooth out any major errors, ambiguities and inconsistencies. Though some readers may find some artefacts of the literal translation irritating, their presence soon ceases to be noticeable against the book's overall background impression.

The second part of the book is devoted to broadly anthropocentric aspects of the Slovenian Kras, with chapters that consider early settlement, general human geography, the ethnic origins and traditions of the Kras population, and the traditional architecture of the region. This part of the book will provide much to entertain and enlighten those whose normal reading is biased more towards the scientific side of karst studies, as well as those whose interests are more catholic. Within these sections archival illustrations are used to great effect, alongside more modern photographs and other text figures. The range of subjects covered by the plates is broad and fascinating, whether it be the many sublime views of the green and white landscape, the curious *"reviving of the dead - with wine"* or the gruesome, but undeniably down to earth, *"slaughtering a pig"*. Though the latter view will inevitably be abhorrent to some, its effect is only momentarily shocking, and there is no doubt that it provides a realistic reflection of country life (not only in the Kras) and forms but a small part of an admirable introduction to the customs and traditions of the area.

This is an outstanding "general interest" book about a karst region and its caves, which in some aspects goes well beyond general interest. Though its text is in English, its appeal should be far wider than simply to English-speaking readers. It includes a bibliography of related works in a variety of languages, few of which are in English. There is no index and, less understandably, there is no contents page to inform the reader of what is to come, but these omissions, perhaps on economic or logistical grounds, are acceptable, and thumbing through the book becomes a series of surprises and discoveries. Even the book's dust cover is immediately attractive, showing a small section of a brightly-lit drystone (limestone) wall, with inset pictures of a cave and typical karst flowers. This intriguing but reassuring picture whets the appetite for what is to come. Some of the photographs are quite literally breathtaking, and few cavers will fail to be astonished by the view of caving in 1897, contrasted with that of a modern caver following an ancient rock-cut route, that appear on page 89 of the book.

In these days when text books may cost over £100 and even "coffee table" book prices may be well into double figures (except in the remaindered book shops) the price of this volume (£19 including packing and postage) may look like a misprint. It isn't! Apparently the low price is enabled by a high level of support, including sponsorship by UNESCO and the Škocjanske jame Park, subsidising book production. For many, the book would be good value at twice this price; at £19 it is a bargain not to be missed.

Reviewed by Dave Lowe, Limestone Research Group, University of Huddersfield, Queensgate, Huddersfield, HD1 3DH, UK.

WATSON, J, HAMILTON-SMITH, E, GILLIESON, D and KIERNAN, K (Eds.), 1997. *Guidelines for Cave and Karst Protection.* IUCN, Gland, Switzerland and Cambridge, UK, 63pp. ISBN 2 8317 0388 3. Available from: IUCN, Publication Services Unit, 181a Huntingdon Road, Cambridge, CB3 0DJ, UK, or IUCN Communications Division, Rue Mauverney 28, CH-1196 Gland, Switzerland.

The Guidelines for Cave and Karst Protection is a 50 page booklet published by the International Union for Conservation of Nature and Natural Resources [IUCN] World Commission on Protected Areas. Its purpose is to *"...increase awareness of cave and karst protection issues"*. Following a brief description of the nature of caves and karst, the booklet examines karst values, uses, protection strategies and management options. The findings are distilled down into 31 guidelines.

The management strategy prescribed in the guidelines reflects the current move away from viewing caves and karst as closed systems, and turns more to focusing on the interactions between karst units and surrounding areas. Similarly, managers are encouraged to promote co-operation between agencies, and to seek interdisciplinary solutions to problems.

Perhaps the most significant aspect of the guidelines is the international nature of the contributions (with input from 38 karst experts from 18 countries). At the same time, this attempt to be all things to all people probably accounts for the rather ponderous nature of the resulting beast. A reading of the 31 resultant guidelines is a daunting prospect even to those familiar with karst jargon, and can feel akin to wading through deep, thixotropic cave mud. Repeated and heavy use of management catch phrases and buzz-words (such as "environmental controls", "non-renewable nature", "sustainability" and "karst values", with attached qualifiers of "minimal...", "significant..." and "undesirable impacts"), provides the mental equivalent of the thixotropic mud sucking the boots from the reader's feet, in a desperate struggle to make forward progress!

An improvement would have been to help readers assimilate the information by the use of diagrams to illustrate connections and interactions, and also to break-up the dense pages of narrative text. Occasional case studies, demonstrating specific problems, are used to good effect and these provide a welcome factual grounding to the otherwise largely theoretical content. The information given is broad and - in an attempt to cover all aspects of cave and karst protection - little depth is achieved in analysing specific karst management issues. Considering the aims of the publication, this broad but shallow approach is perhaps suitable, though the decision to leave out consideration of cave contents (speleothems and biota) is puzzling. Whereas land managers composing karst conservation policy statements would find plenty of ammunition within the guidelines, field operatives seeking hands-on solutions to specific problems would not find them here. After reading these guidelines, a land manager seeking to protect a karst area would be left asking the question - "OK, but what should I actually do?". For those familiar with karst there is little new in this document; for those new to karst management the central tenets of karst conservation can be found within the guidelines - by those with the time and a willingness to dig and sort.

Some more minor points: black and white photos provide welcome relief from the text, even though their quality of reproduction is less than ideal. However, a picture of a sign for Mammoth Cave National Park does little to help elucidate the text issues. Equally, it is not obvious how a photo of quarry restoration can show *"...the attention being given to maintaining water quality..."*, as its caption claims. The use of the term National Monument is something of an anachronism in the context of site designation, with an unpleasant anthropocentric ring,. Point number 15 of the Minimal Impact Caving Code, advises: *"Carry in-cave marking materials"*, which could be misconstrued by some non-caving readers. Perhaps specific reference to marker tape would have been less ambiguous.

Reviewed by Jon Rollins, Alberta Karst Research Institute, 1009 Larch Place, Canmore, Alberta, T1W 1S7, Canada.

CORRESPONDENCE

Dear Editor,

I read the "Forum" in Volume 24, Number 2 of *Cave and Karst Science* with great interest, and I have a feeling that perhaps the underlying intention of my classification of karst phenomena, proposed some years ago, was not clearly explained.

In his letter to Reno Bernasconi, Graham Mullan wrote that I had ignored the physical processes. However, I do not think that this is the case: my proposal was based primarily upon chemical processes and secondarily upon the physical ones.

As a point of clarification, allow me to present a short history of the problem. After the discovery of karst phenomena in the Classical Karst (i.e. developed upon limestone), those with an interest in this field discovered similar effects in areas of different rock types, such as sandstone and gypsum. To take into account the fact that, by virtue of its original usage, the term *karst phenomenon* was effectively a kind of "registered trade mark", intended only to describe limestone areas, other words, such as parakarst and pseudokarst, were proposed for use in areas of other rock types. Obviously the attribution of one of these terms to any given set of phenomena was totally arbitrary.

My proposal, based upon the number of phase equilibrium components, was suggested in order to introduce criteria that were less arbitrary. The latest version of the scheme, as published in 1985 in *Le Grotte d'Italia*, is summarised in the following table:

Class	Number of phase equilibrium components	Sub-class	Examples
Hyperkarst	>3	Enhanced	Hydrothermal environments; contact of calcite/dolomite
		Reduced	Dolomite
Karst	3	Karst *[sensu stricto]*	Pure limestone
		Semikarst	Marly limestone
Parakarst	2	Brady	Quartzite; tufa
		Tachy	Gypsum; halite
Hypokarst	1	-	Ice; lava flow tubes
Pseudokarst	0	Syngenetic	Gas-filled lava cavities
		Epigenetic	Tectonic, erosion caves

Some of these classes and sub-classes are based on chemical processes (Enhanced and Reduced Hyperkarst, Karst *[sensu stricto]*, Semikarst and Parakarst), others are based on physical processes (Hypokarst, Syngenetic Pseudokarst and Epigenetic Pseudokarst).

I agree with Graham Mullan that without stringent analysis of the processes involved, this classification may well be misleading, but I assume that stringent analysis must take place as the basis of any classification. I don't distinguish between different classes of diamonds (though my wife does!), but this is my own problem and is not a consequence of any classification scheme established by experts on diamonds.

With reference to the letter from Charlie Self, who objects to inclusion of quartzite and evaporite caves in the same category, may I point out that such caves fall within different sub-classes. The former lie within the Brady (= slow) Parakarst sub-class and the latter are included in Tachy (= fast) Parakarst, as a reflection of the greatly different time factors that relate to the development of erosional forms on the two rock types.

Concerning the question of how to classify a cave in a quartzitic sandstone, my answer is the same as that provided above. If the genetic process is unknown, the problem cannot be solved by the mere existence of any classification system. A classification is merely a set of shelves where things can be stored; it is not a mechanism for answering questions about where they should be stored!

Before closing this letter may I also suggest that Graham Mullan (or others with an interest in this field) contact one of the editors of the *International Journal of Speleology* (e.g. me!) to arrange a subscription (currently about US$18 per year) or to set up acceptable exchanges? Similarly, for the journal *Le Grotte d'Italia*, requests should be addressed to Professor P Forti, Ist. of Geology, Via Zamboni 67, I-40127 Bologna, Italy.

Yours sincerely,

Arrigo A Cigna
Fraz. Tuffo
1-14023 COCCONATO AT
Italy

Dear Editors,

In his recent *Cave and Karst Science* paper Robert Wray (Wray, 1997) presents a good argument that dissolution of quartzite and quartz sandstones should be considered karst processes, and that landforms produced by such processes should be considered as karst, rather than pseudokarst, features.

The introductory paragraph of Wray's paper, in discussing previous work on karst-like landforms on quartz-rich rocks, comments that such landforms were ".... dismissed as pseudokarst ....", and includes David Branagan and myself (Osborne and Branagan, 1992) among those who, ".... following conventional wisdom, have been loath to change their outlook ....". That is, to accept the role of dissolution in landform genesis on quartzose rocks.

By accusing David Branagan and myself of ".... following conventional wisdom.... " Robert Wray has missed the whole point of our little paper. The title, "? Pseudokarst in the Sydney Basin", was intended not to pronounce that the features described were pseudokarst, but to question that assumption, and throughout the paper references were made to the possibility of dissolution playing a role in the development of the features described. On page 97, in relation to St Michael's Cave, we stated that while erosion has clearly played a major role in the formation of the cave, we believe that dissolution has been involved to some extent. In the case of caves in the Royal National Park, developed in Narrabeen Group Sandstones (page 99), our comments on carbonate cement were meant to imply that dissolution of carbonate cements played a role in the development of these features. Dissolution of silica is central to our discussion of tubular features in the Blue Mountains (pp 99-101), where we stated that "A combination of solutioning and direct erosion of sand grains .... seems to be involved.". On page 101 we also referred to the landform-producing process in silica-rich rocks as "karstification".

Clearly our paper was a simple piece of largely descriptive work (reporting features that had previously been largely ignored by mainstream geology), and it lacked the detailed petrographical work of Wray (1995). However, it should be apparent that, rather than following conventional wisdom, David and I were proposing that dissolution was involved in the production of karst-like features in the siliceous rocks of the Sydney Basin, and hence were questioning the common assumption that these features should be "dismissed as pseudokarst".

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Dear Editors,

It seems that Long Churn Cave is a popular place for resistivity tomography tests. Dawn Walker's MSc thesis Abstract (Walker, 1997) reports the results of tests there, as do Mark Noel and Biwen Xu (1992), but I question whether tomography (and other techniques, such as microgravity) are as good at detecting cavities as is sometimes suggested. Experimental results over known shallow caves are certain to give a positive result, but this fact, on its own, does not verify the technique; and I question the statement in Dawn Walker's Abstract, that Long Churn Cave was an adequate "control".

Nobody doubts that resistivity tomography, microgravity, and so on, are powerful tools and that they can detect sub-surface features. But then, nobody doubts that Long Churn Cave exists either! I suggest that a better control for a 'cave detection' experiment would be to run the test over an area of rock where there were no cavities, and to verify that none were detected there. Clearly, this is somewhat difficult to do, but Walker has gone some way to demonstrating this with her statement that the technique *"...also identified a previously unmapped feature that was interpreted as an air-filled cave or fissure 40m to the south of the main passage"*. Now, if this cavity does not exist the experiment has refuted the technique; but if the cavity does exist then, instead of concluding that the technique works, we must find a new area where there are no known cavities and repeat the test. I understand that, in fact, a nearby surface feature suggests that this *"previously unmapped feature"* may well exist, but whether it is a fissure or a navigable chamber remains to be seen. A chamber (perhaps the entrance to a large new system) would be good news for cave explorers, and the common-sense conclusion would be that tomography works. But I remain sceptical as to whether this is a valid conclusion. The data inversion process caused some features to be smeared and, as Walker says, *"...in some cases anomalies from separate features were combined"*. I might be being overly pessimistic but, without a proper control, could this be interpreted as saying that the technique did not actually identify anything? (Hamlet: *"Do you see yonder cloud that's almost in shape of a camel?")*

Long Churn is clearly a tempting target for people to try out their tomography equipment, but experimenters should also be reporting results obtained over areas of limestone where there were no known caves. It would be embarrassing if every reading showed the presence of a cavity, which we then proceeded to explain away (where necessary), as being some small, sediment-filled fissures "smeared together".

REFERENCES

Noel, M and Biwen, Xu, 1992. Cave Detection using Electrical Resistivity Tomography. *Cave Science*, Vol.19, No.3, 91-94.

Walker, D C, 1997. The use of Geophysical Techniques in the Detection of Shallow Cavities in Limestone: MSc Thesis Abstract. *Cave and Karst Science*, Vol.24, No.3, 144.

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THESIS ABSTRACT

SHEARER, H., 1996

The geomorphology of solution cave sequences in the Kalk Bay Mountains, southern Cape Peninsula

Honours dissertation, prepared in partial fulfilment of the requirements for the degree of BA (Honours), Department of Environmental and Geographical Science, University of Cape Town, South Africa, 1996.

The Kalk Bay Mountains of the southern Cape Peninsula, South Africa, show marked development of pseudokarstic features such as caverns, dolines and grikes. These features have formed over at least 100 million years on supposed inert quartzitic sandstones of the Peninsula Formation of the Table Mountain Group. Pseudokarst on sandstone is relatively rare world-wide and various aspects of cave genesis are highlighted in the Cape Peninsula. Cape Peninsula pseudokarst is relict, occurs at high altitudes above the present water table and could provide clues to palaeoenvironmental conditions during the African erosion period.

The cave systems in the Kalk Bay Mountains occur in at least three levels in the thickly-bedded sandstone. These different levels are the result of differential uplift during the Miocene and Pliocene. The Cape Peninsula Mountains are tabular and blocky, as opposed to the fold mountains of the rest of the South Western Cape. Much more of the overlying sedimentary layers in the Cape Peninsula have also been removed by weathering and erosive processes. The caves can be compared to similar pseudokarst features on sandstone in areas such as Gran Sabana, Venezuela. The acidic water chemistry in Venezuela contributes to a very intensive weathering environment. Present day humid tropical conditions in Venezuela are likely to be similar to palaeoclimatic conditions in the Kalk Bay Mountains, contributing to sandstone cave genesis.

RESEARCH FUNDS AND GRANTS

THE BCRA RESEARCH FUND

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

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

The award scheme will not support the salaries of the research worker(s) or assistants, attendance at conferences in Britain or abroad, nor the purchase of personal caving clothing, equipment or vehicles. The applicant must be the principal investigator, and must be a member of the BCRA in order to qualify. Grants may be made to individuals or groups (including BCRA Special Interest Groups), who need not be employed in universities or research establishments. Information about the Fund and application forms Research Awards are available from The BCRA Administrator (address at foot of page).

GHAR PARAU FOUNDATION EXPEDITION AWARDS

An award, or awards, with a minimum of around £1000 available annually, to overseas caving expeditions originating from within the United Kingdom. Grants are normally given to those expeditions with an emphasis on a scientific approach and/or exploration in remote or little known areas. Application forms are available from the GPF Secretary, David Judson, Hurst Farm Barn, Cutler's Lane, Castlemorton, Malvern, Worcs., WR13 6LF. 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 & KARST SCIENCE - published three times annually, a scientific journal comprising original research papers, reviews and discussion forum, on all aspects of speleological investigation, geology and geomorphology related to karst and caves, archaeology, biospeleology, exploration and expedition reports.
Editors: Dr. D.J. Lowe, c/o British Geological Survey, Keyworth, Notts., NG12 5GG and Professor J. Gunn, Limestone Research Group, Dept. of Geographical and Environmental Sciences, University of Huddersfield, Huddersfield HD1 3DH.

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

CAVE STUDIES SERIES - occasional series of booklets on various speleological or karst subjects.
No. 1 *Caves & Karst of the Yorkshire Dales;* by Tony Waltham and Martin Davies, 1987. Reprinted 1991.
No. 2 *An Introduction to Cave Surveying;* by Bryan Ellis, 1988. Reprinted 1993.
No. 3 *Caves & Karst of the Peak District*; by Trevor Ford and John Gunn, 1990. Reprinted with corrections 1992.
No. 4 *An Introduction to Cave Photography;* by Sheena Stoddard, 1994.
No. 5 *An Introduction to British Limestone Karst Environments;* edited by John Gunn, 1994.
No. 6 *A Dictionary of Karst and Caves*; compiled by Dave Lowe and Tony Waltham, 1995.
No. 7 *Caves and Karst of the Brecon Beacons National Park;* by Mike Simms, 1998.

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

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

BCRA SPECIAL INTEREST GROUPS

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

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

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

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

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

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