

# Cave and Karst Science

*The Transactions of the British Cave Research Association*

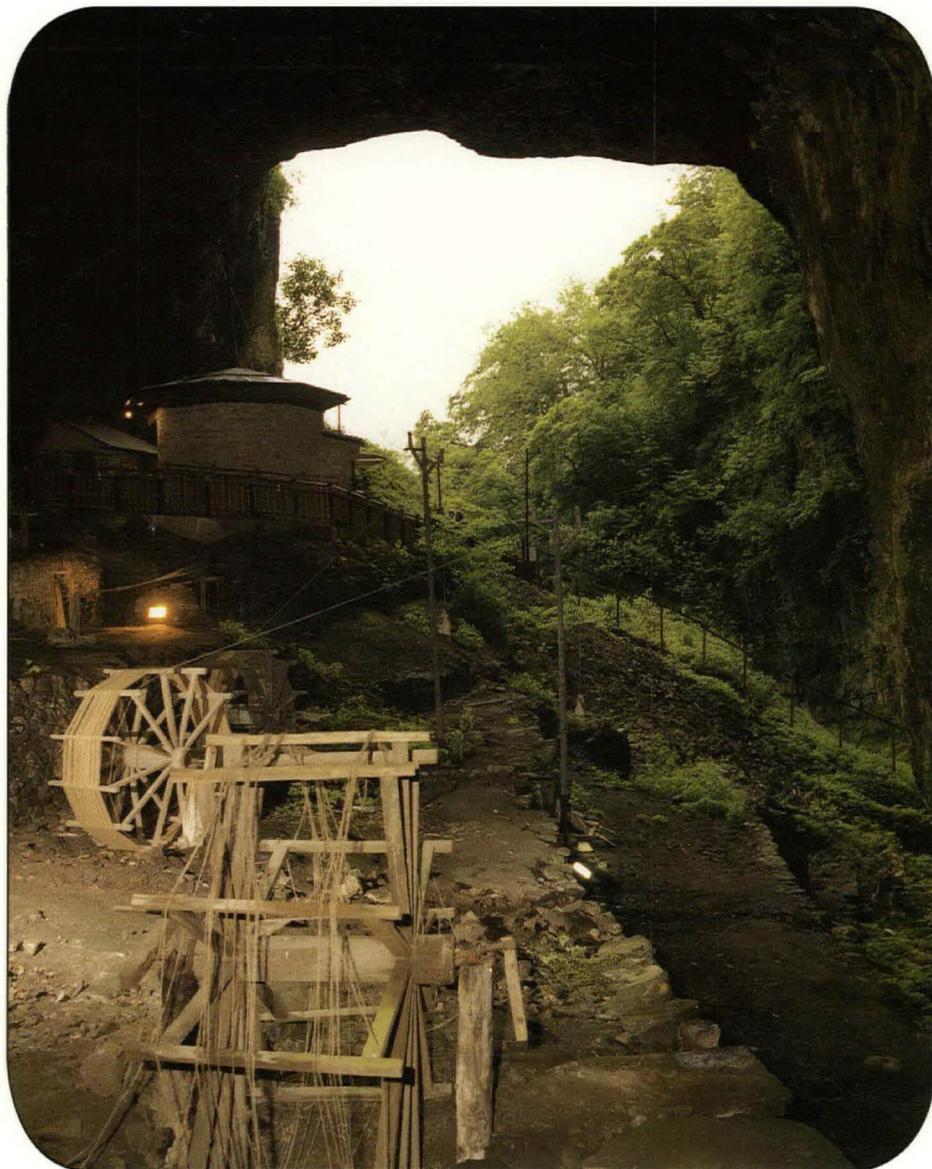


BCRA

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**Speleogenesis and mineral veins, Derbyshire, UK**  
**LIDAR survey of the Peak Cavern Vestibule**  
**Bird observations in the karsts of Belize**  
**Sarıot Polje, Central Taurus, Turkey**  
**Karst and caves in Madagascar**  
**BCRA Symposium abstracts**  
**Forum**

# Cave and Karst Science

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

## 1. Papers

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

## 2. Reports

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

## 3. Forum

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

## 4. Abstracts

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

Manuscripts may be sent to either of the Editors: Dr D J Lowe, c/o British Geological Survey, Keyworth, Nottingham, NG12 5GG, UK, and Professor J Gunn, Limestone Research Group, 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@bcra.org.uk or j.gunn@bcra.org.uk.

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

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

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

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

# Cave and Karst Science

TRANSACTIONS OF THE BRITISH CAVE RESEARCH ASSOCIATION

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### Cover photo:

The entrance of Peak Cavern ("The Devil's Arse"), Castleton, Derbyshire, is the largest cave entrance in the British Isles. A 3D digital CAD model of the entrance chamber (the Vestibule) was presented in *Cave and Karst Science* Vol.29(2), and the results of a re-survey of the Vestibule using ground LIDAR (Light Detection And Ranging) equipment is reported in the present Issue. In the foreground are the rope-walk benches, which date back over 400 years, and a rope making demonstration forms part of the present day show-cave tour. Water from the cave discharges via an underflow spring, but in times of flood the waters back up and flow down the channel at the bottom right of the photograph.

Photograph by Paul Deakin, copyright reserved.

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## EDITORIAL

### John Gunn and David Lowe

As some readers will have noted, Issue 30(2) represented a departure from our norm – there was an almost complete absence of full stops! It appears that this problem was caused by over-sensitive settings on the scanning software used by our printing company. The software decided that full stops and decimal points were specks of “dirt” and filtered them out before the printing plates were produced. The omission was not picked up on the proofs either by the Editor, who believed that the pre-approved “camera-ready” text would be reproduced faithfully, or by the printers themselves.

We apologize to all our readers and, more particularly, to the authors of the four papers that appeared in the Issue. To reprint and redistribute a full run of more than a thousand copies would involve an unreasonable expense, not least in the postage. However, the printers have agreed to produce a limited print run of corrected copies. These will enable us to re-supply the authors with acceptable off-prints of their publications, and we will then be pleased to distribute any surplus copies on request, on a “first come first served” basis.

In this last Issue of 2003 we look forward to the annual BCRA Cave Science Symposium, abstracts from which are presented in the *Forum* section. This year there is a very good mix of papers covering archaeology, ecology (bats and bugs) and a wide range of geoscience topics. Talks will describe research in the Caribbean, Ethiopia, France, Spain and Scandinavia, as well as at several sites in Britain, but overall the geographical spread of the British subject matter is less wide than in some previous symposia. The focus is distinctly northern, and it is particularly disappointing that no topics relating directly to research in South Wales or the Mendip Hills will be discussed. We hope that this merely reflects the northern venue of this year’s symposium rather than indicating any slowing down of cave and karst research in these fascinating southern areas.

Being the final Issue of the current Volume, we will again thank the various people that have helped us to keep *Cave and Karst Science* thriving this year. Most obviously of course we are indebted to the many authors, some old hands, some debutant(e)s, who continue to provide interesting material for our consideration. Some authors are prolific in their output while others are taking the first tentative steps in their publishing career, but all their “offerings” are welcomed and appreciated. We are equally indebted to the photographers who continue to provide striking and interesting illustrations for the Journal covers. Some photographs arrive routinely in support of papers and reports, but occasionally we need to solicit appropriate material from among a growing list of accomplished photographers who are prepared to allow our use of their creations. In the case of Volume 30 we thank Dean Smart, Phil Chapman and Paul Deakin for providing a fine choice of relevant images.

As in previous years we have kept up our own role in helping to review those Paper and Report contributions that fall within our individual areas of competence. Nevertheless we remain indebted to an ever-widening circle of individuals who are prepared to give of their valuable time to act as *Cave and Karst Science* referees. It should be remembered of course that not all manuscripts that undergo the refereeing process actually end up being published, while some others may undergo several potentially extended episodes of revision and reassessment before appearing in print. Thus, in context, we are particularly grateful to those among our reviewers who are called upon several times during the gestation of each Volume of our journal. This year our combined thanks go specifically to Vanessa Banks, Andrew Chamberlain, David Gillieson, Ken Grimes, Chris Hunt, Alexander Klimchouk, Stein-Erik Lauritzen, Joyce Lundberg, Giuseppe Messina, Bruce Miller, Graham Proudlove, France Šušteršič, Peter Styles, Tony Waltham, John Webb and Simon Zisman. Equally, we should not forget but cannot name individually all of those – colleagues and friends of the manuscript authors – whose contribution of early peer review and discussion (commonly acknowledged within the eventual publication) helps to raise the overall quality and interest of most of the material that reaches us.

On the technical side, we once again thank our Desk Top Publishing associate, Rebecca Talbot, for her continuing efforts on our behalf, and for her growing understanding and involvement in the material that we publish and the way that it should be treated. Every submission is, inevitably, different and, depending upon how the text and illustrations are provided, each has its own peculiarities and occasional problems. After some initial shocks and the resultant, necessarily steep, learning curves the DTP aspect of the journal is now proceeding efficiently and at a pleasingly high standard. Our printing needs continue to be met by the Sherwood Press Group, with the direct involvement of their Milford Printers and Gordon Graphics divisions. We particularly thank Steve Summers, Sales Director of the Sherwood Press, for the individual attention he dedicates to our specific requirements and for the highly efficient interface that he provides between his colleagues and ourselves.

## Faunal associations with karst landscapes: a preliminary assessment of bird observations in Belize.

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**Abstract:** The ecological significance of karstlands is a recent focus of studies by karst scientists, and there is growing recognition of the need for a holistic approach to their geo-ecology. The existence of distinctive and significant karstland vegetation communities raises the question of whether there are similar associations between karstlands and their fauna. Karst covers about 5000km<sup>2</sup>, or 22% of Belize's land area. Prior research suggests significant relationships between the karst, its vegetation and its ecology. The avifauna of Belize is diverse and bird records are readily available. Over 570 species have been reported and more than 350 species breed in the country. Over 300 bird species have been identified in the karst, with at least 250 occurring on a regular basis. The karst and the forests associated with it appear to represent an important avifaunal habitat whose conservation is warranted. Other studies in the region reinforce the suggestion that the Belize karst represents a significant bird habitat. Other karst terrains may also represent significant faunal reservoirs and the associations between karstlands and their fauna merit future attention from karst scientists.

**Key-words:** karst, birds, Belize

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### INTRODUCTION

The ecological significance of karstlands has only recently become a focus of studies by karst scientists, the majority of whom understandably devote their attention to the distinctive aspects of karst geomorphology and hydrology. At the same time, an understanding of the ecological foundation of karst landscapes is critical if the emerging central issue of their management is to be addressed successfully (Gillieson and Smith, 1989; Williams, 1993).

Research on the vegetation of karst areas has expanded in recent years (e.g. Ivimey-Cook and Proctor, 1966; Ward and Evans, 1976; Anderson and Chai, 1982; Crowther, 1982; Kapos, 1986; Proctor, 1986; Larson *et al.*, 1989; Bartlett *et al.*, 1990; Barany-Kevei, 1992, 1998), but most of these studies focus on soil-plant relationships rather than on the broader associations between karst landscapes, their geomorphology, hydrology and ecology. Nevertheless, recent studies have revealed distinctive and significant karstland vegetation communities in regions as disparate as the Burren of Ireland (Ivimey-Cook and Proctor, 1966), the Gunung Mulu National Park in Sarawak, Malaysia (Anderson and Chai, 1982), the Niagara Escarpment of North America (Larson *et al.*, 1989; Bartlett *et al.*, 1990), and the Cockpit Country of Jamaica (Kapos, 1986; Proctor, 1986), and there is a growing recognition of a need for a holistic approach to the geo-ecology of karstlands (Gillieson, 1997; Barany-Kevei, 1998).

Although the subterranean fauna associated with caves has been recognised as distinctive and worthy of intensive study (Chapman, 1993; Palmer *et al.*, 1998), there have been only limited efforts to inventory and analyse the much more diverse surface fauna of karst terrains (for two examples, see Sket, 1997 and Hutchinson, 1998). Detailed studies might well be expected to reveal a distinctive soil biota associated with karst (e.g. Schaefer, 1990), but it is less clear whether there are associations between karstlands, their commonly distinctive vegetation communities and mobile surface-dwelling animals.

In this paper, avian records for the karstlands of Belize, Central America are examined. Previous research on karstlands and their ecology in Belize (summarized in Day, 2003), together with the availability of extensive bird records (which in large part reflects the growing importance of eco-tourism) renders Belize an ideal location

for this pilot study. The selection of birds, rather than any other component of the fauna, reflects the availability of data and the author's personal interests and experience. Moreover, any association between karstlands and birds, which are highly mobile, would be suggestive of stronger correlations between karst and less mobile animals, indicating the potential for future research.

### KARST IN BELIZE

Carbonate rocks underlie over 50% of Belize's land area of approximately 23,000km<sup>2</sup>, but not all are extensively karstified. In particular, Tertiary limestones, which occur in the northern third of the country, have developed distinct karst landforms only locally, such as in the Rio Bravo area of northwestern Belize and in the Yalbac Hills of the western Cayo District (Fig.1).

Karst terrain is more distinct on the Cretaceous limestones that border and receive allogenic surface runoff from the Maya Mountains. The central Belize karst covers about 2000km<sup>2</sup> in a belt located north and west of the Maya Mountains (Day, 1993b; 1996), and a smaller area of karst is developed south of the Maya Mountains, primarily in the Toledo District (Fig.1). In sum, the principal karstlands of Belize accrue to about 5000km<sup>2</sup>, or about 22% of the country's land area (Day, 1993a).

Miller (1987, 1996) recognizes eight karst regions in Belize, but only the five in the central and southern parts of the country are extensively karstified (Table 1; Fig.1). Although these five regions represent the main karst areas from a geomorphic perspective, the karstic functional component of the remaining areas has considerable ecological significance (Day, 2003).

The prominent karst landscapes contain widespread and extensive surface landforms and cave systems. The most diagnostic surface features are enclosed depressions of variable shapes and sizes and variously termed dolines, sinkholes or cockpits. The depressions may be individually distinct and near circular but the majority exhibit indistinct, locally communal margins, and many are elongated along the axes of essentially dry surface valleys (Day, 1986b; Miller, 1987, 1996). The extensively fissured internal slopes of the depressions function as vertical and centripetal conveyors of surface water and sediments to the subsurface (Day, 1986a, 1987b).

Location	Area (km <sup>2</sup> )	Relative relief (m)	Surface features
Boundary Fault	300	350	C, P, F
Vaca Plateau	1000	400	C, F
Sibun-Manatee	550	200	F, P, T
Little Quartz Ridge	750	600	C, F
K-T Fault Ridges	300	250	C, F, T
Yalbac Hills	2000	200	F, S, E
Tertiary Plain	7000	70	S
Cayes/Barrier Reef	n.a.	150?	–

**Key:**  
C = cockpits, P = poljes, F = fluviokarst, T = towers, S = shallow depressions, E = escarpments

*Table 1. Main karst regions of Belize (modified after Miller, 1996).*

Other surface components of the karst landscape include a variety of residual hills and ridges, which are locationally and functionally linked with the neighbouring valleys and depressions. These cones or towers are locally interspersed with natural bridges, talus piles of fallen rock, and surfaces fretted by deeply dissolved crevices.

Although the hydrological focus of the karst has become increasingly subterranean, many surfaces have relict fluvial components (fluviokarst), which may be activated during extreme rainfall, including integrated dry valley networks, commonly with disjunct “hanging” tributaries and desiccated tufa-encrusted waterfalls reflecting different stages of valley abandonment. Where allogenic rivers enter the karst from adjacent non-karst landscapes there are blind valleys, sinking streams and swallow-holes (ponors). Major allogenic rivers may maintain surface courses through the karst, producing gorges or alluviated valleys or poljes.

Beneath the surface are extensive cave systems (Miller, 1996). Much of the karst surface is without permanent water, although some sinkholes contain water and locally the underground flow is exposed in karst windows, such as the inland Blue Hole (Day, 1992). More than 150km of cave passages have been surveyed in Belize. The Chiquibul Cave System alone includes 55km of surveyed passage, with a vertical depth range of 300m and trunk conduits up to 100m in width (Miller, 1996). The surveyed cave systems are but a fraction of the total cave population.

### PREVIOUS ECOLOGICAL STUDIES IN THE BELIZE KARST

A review of ecological research in the karstlands of Belize is provided by Day (2003). Studies of plants and animals date back to the colonial period of the early Twentieth century (e.g. Standley and Record, 1936). However, ecological research on the relationships between plant communities, animal populations, soils and land-use, date back essentially to the second half of the Twentieth century, following the landmark British Honduras land-use potential survey of the 1950s (Wright *et al.*, 1959).

Acknowledgement of the intrinsic significance of Belize’s biological diversity, which results from its unique combination of geography and history, has resulted from both long- and short-term research programs, many of which have been undertaken in karst areas (e.g. Furley, 1987; Zisman, 1996). Widespread recognition of the importance of Belize’s biological resources has promoted the establishment of a national conservation program (Zisman, 1996; Day, 1996) and the growth of the eco-tourism industry (Phillips, 1994; Silver and Koontz, 1997).

By surface area, more than half of the biological resource in Belize is based upon karst landscapes, which function as integrated

systems of landforms and geomorphological processes with ecological ramifications, for example in hydrological and nutrient cycling, in pedogenesis, and in habitat provision (Day, 2003). In addition to being of interest to karst science, the karstlands are eco-tourism foci, function as valuable hydrological reservoirs, and are of archaeological significance (Hartshorn *et al.*, 1984; Day, 1987a). In the light of this, it is significant that some 68 percent of the karstlands in Belize are designated as protected areas (Day, 1996).

The ecology of Belize’s karst regions has rarely been examined from a holistic perspective, and the underlying role of the karst landscape and processes in influencing biological patterns has received little attention. One critical ecological element is the spatial and temporal distribution of water. Surface drought is common, despite annual rainfall totals of 1500 to 4000mm (Walker, 1973), and aridity may be acute during the dry season (typically January to May), particularly on the rocky upper slopes of residual hills and ridges. There is little permanent surface water, and sites such as water-filled sinkholes and karst windows may have considerable biological significance. Vertical drainage through the clay-rich vertisols, as noted elsewhere, “... creates special conditions for evapotranspiration, gas exchange and root penetration.” (Gillieson, 1997, p.27).

Near-surface karst hydrology also influences nutrient cycling and pedogenesis. In general the karst soils are slightly basic, stony, clay or clay loam soils with high levels of base saturation, and ranging in colour from grey through red-brown to black. The soils reflect the topography, with marked variations in depth, texture, pH, carbonate content, organic content, colour and exchangeable cations (Furley, 1972; Furley and Newey, 1979; King *et al.*, 1986).

Overall there is a clear relationship between vegetation types and the distribution of limestone bedrock, although complications arise from the modification of vegetation by the pre-Hispanic Maya (Wright *et al.*, 1959) and by the impact of hurricanes and fires (Johnson and Chaffey, 1973). Distinctive limestone vegetation communities are recognized by Iremonger and Sayre (1993) and the association between karstlands and cedar (*Cedrela mexicana*) is a common theme of forest studies (e.g. Johnson and Chaffey, 1973). Overall, the association between karst and accentuated dry season drought leads to greater deciduousness in the vegetation (King *et al.*, 1986).

There has been very little research into the relationships between the karstlands and their fauna, but associations are suggested by the studies of Johnson and Chaffey (1973), Frost (1974), Day (1987a) and Campbell *et al.* (1994). Although there is no evidence of exclusive relationships, it is clear that karstlands harbour a wide variety of animal species. Likewise, the cave fauna is diverse and numerous (Reddell, 1981; Reddell and Veni, 1996).

## BIRDS OF BELIZE

The resident avifauna of Belize is diverse, containing species associated with peninsular Yucatan, the Central and South American mainland and the Caribbean (Miller and Miller 2000; Howell and Webb, 1995). The association with the last of these is minimal, particularly away from the coast, and the Central American Neotropical element is the most significant. Much of the avifauna is sedentary, although North American migrants comprise perhaps 20% of the total species recorded (Howell and Webb, 1995; Jones and Vallely, 2001).

General guides to the birds of Mexico and Central America include those by Edwards (1998), Howell and Webb (1995), Peterson and Chalif (1973) and Davis (1972). Birds of neighbouring Yucatan, Guatemala and Honduras are listed by Paynter (1955), Land (1970), Monroe (1968) and Ridgely and Gwynne (1989), and birds of the Caribbean are illustrated by Allen (1961), Bond (1993) and Raffaele *et al.* (1998). The first detailed studies of birds in Belize were those by Devas (1953), Burgess (1964) and Russell (1965), although an earlier, pioneering study of the birds of the Cayo District was made by Austin (1929). Important additional records were provided by Barlow *et al.* (1969, 1970, 1972), Frost (1981), Hartshorn *et al.* (1984), Wood and Leberman (1987) and Howell *et al.* (1992). Matola (1995) and Miller (1995) provide particularly useful guides. Checklists based on these sources have been prepared by Baldwin (1970), Weyer and Young (1977), Wood *et al.* (1986), Garcia *et al.* (1994), Miller (1995), Miller and Miller (2000) and Jones and Vallely (2001).

Avifaunal records for Belize are of a generally high quality, reflecting a relatively lengthy history of observation and recording in the Twentieth century (Miller and Miller, 1998), the coordinating efforts of the Belize Audubon Society, and the recent boom in bird watching as a component of eco-tourism (Silver and Koontz, 1997). Detailed records of bird sightings are maintained by the Belize Audubon Society and other NGOs, by individual eco-tourism operations, and by the Belize Government under the auspices of the Belize Biodiversity Information System (BBIS) in conjunction with the Ministry of Natural Resources' Conservation and Environmental Data System (CEDS) (Miller and Miller, 2000).

Numbers of bird species reported in Belize have risen steadily, from 465 (Russell, 1965) to over 550 (Garcia *et al.*, 1994). In the most definitive recent studies, Miller and Miller (2000) list 551 bird species as reported in Belize, including 358 residents, and Jones and Vallely (2001) list 566 species, including 346 permanent residents.

### KARST LANDSCAPE AND BIRD RECORDS

In general, the distribution of karst within Belize corresponds with that of the Southern Hardwood Forest vegetation (Wood *et al.*, 1986; Garcia *et al.*, 1994; Miller and Miller, 2000). Although Frost (1981) maintains that only 13% of Belizean bird species are forest dwellers (18% of the breeding species), Miller and Miller (2000) list 385 species that have been recorded within the Southern Hardwood Forest, including 174 species that are common, 111 that are uncommon, 60 that are rare and 40 that are very rare. Most recently, agglomerating the Southern Hardwood Forest into a broader category of Lowland Broadleaf Forest, which also includes the Tertiary karst of northern Belize, Jones and Vallely (2001) report 246 species, including 161 common, 47 uncommon, 16 rare and 22 occasional, local or marginal species.

Additionally, perhaps 25% of the karst is no longer forested but has been cleared for pasture, citrus and cacao groves, pine plantations and small-scale agriculture. In the Hummingbird karst the percentage forested declined from 55% to 46% between 1975 and 1985 (Day, 1989) and from 46% to 38% between 1985 and 1995 (L. Waight, personal communication, 1995). Such land-use changes are not necessarily deleterious to avian diversity (although clearly so to forest-dwelling species). Of the species reported in Belize over 45% may occur in disturbed habitats or open areas, including agricultural land and low second growth (Miller and Miller 2000; Jones and Vallely, 2001).

More detailed records of birds observed within the karst are provided by individual ornithological studies, by inventories of protected areas, and by records of birds observed at conservation-

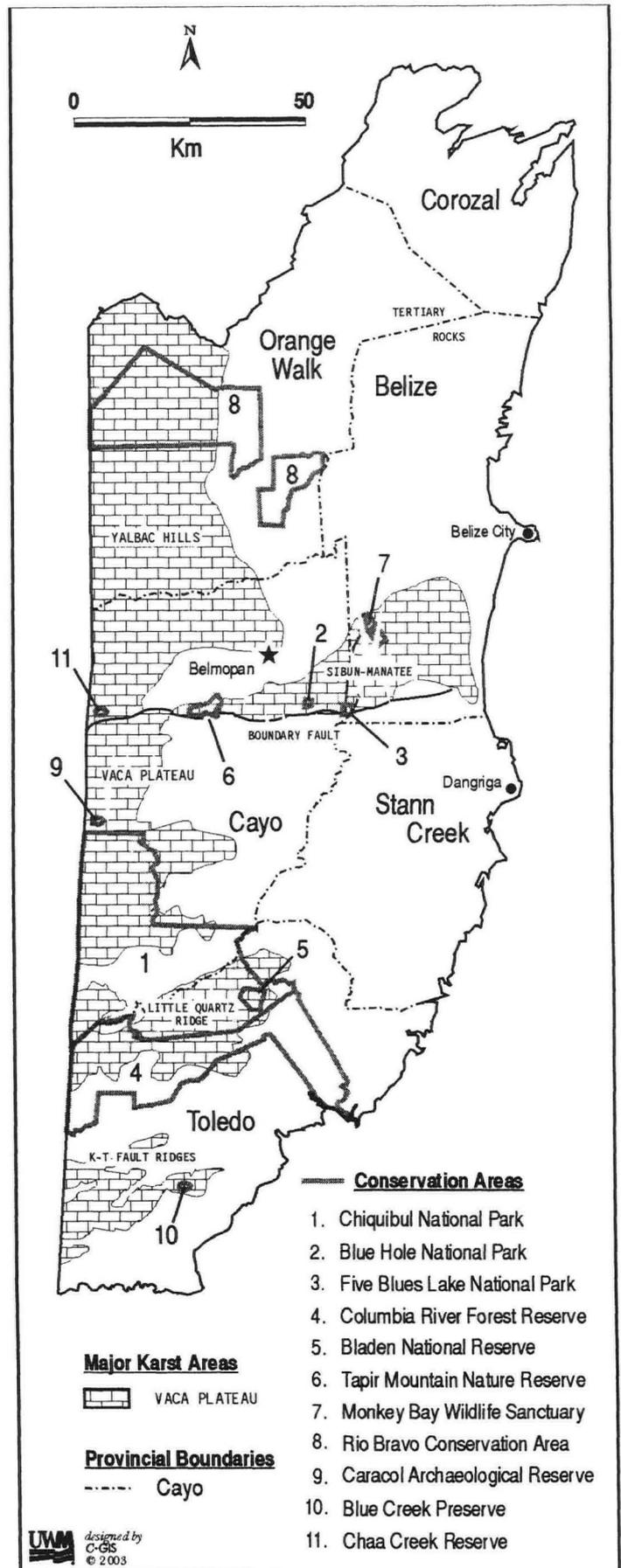


Figure 1. Karst and Conservation areas in Belize.

oriented eco-tourism sites (Table 2). Although these numbers reflect varying levels of expertise and effort, and should not be regarded as definitive, collectively they indicate that over 300 bird species have been identified in the karst landscape of Belize, with at least 250 species occurring on a repetitive basis.

Location	Species number	Comments/sources/dates
Belmopan Christmas Counts (1975–2000)	317	* 1, 2
Bladen Nature Reserve	215	* 3, 12
Blue Creek Preserve	211	4
Blue Hole National Park	146	1, 2, 5, 6
Caracol Archaeological Reserve	218	1, 7, 12
Chaa Creek Reserve	189	8, 13
Chiquibul National Park	291	* 1, 6, 12
Columbia River Forest Reserve	271	* 9, 12
Five Blues Lake National Park	217	1, 6, 10
Hummingbird Karst	226	1, 2, 6
Jaguar Creek Environmental Center	246	14
Monkey Bay Wildlife Sanctuary	222	1, 6, 11, 12
Rio Bravo Conservation and Management Area	392	* 12
Runaway Creek Nature Preserve	155	13
Slate Creek Preserve	173	* 1, 6
Tapir Mountain Nature Reserve	244	1, 6, 12
<b>Key</b>		
* Not entirely karst		
1. Belize Audubon Society records, 1975-2000.		
2. Day, 1989		
3. Brokaw and Lloyd-Evans, 1987; Iremonger and Sayre, 1994.		
4. Frost, 1974, International Zoological Expeditions records, F. Dodd, <i>pers.comm.</i> , 2000.		
5. L Waight, <i>pers.comm.</i> , 1995.		
6. Author, personal records		
7. M Meadows, <i>pers.comm.</i> , 2001		
8. M Fleming, <i>pers.comm.</i> , 2001		
9. Parker <i>et al.</i> , 1993; Wright, 1996		
10. J Dempsey, <i>pers.comm.</i> , 2000		
11. M Miller, <i>pers.comm.</i> , 2000		
12. Belize Biodiversity Information System Report 2001.		
13. Birds Without Borders-Aves Sin Fronteras, 2001.		
14. J Vermillion, <i>pers.comm.</i> , 2000.		

**Table 2.** Bird species numbers recorded in the Belize karst.

The greatest number of bird species recorded within a karst area in Belize is the nearly 400 species identified in the Rio Bravo Conservation and Management Area in northern Belize (Fig. 1, Table 2). Under the auspices of the Programme for Belize NGO and through the efforts of visitors to eco-tourism lodges, bird observation

here has been intensive and the numbers recorded may represent a potential total for other karst areas where studies have been more sporadic.

Within the central Belize karst reported bird species number between 200 and 300 species, with reports of over 200 species at several sites (Table 2). 244 species have been identified at the Tapir Mountain Nature Reserve and 226 within the karst adjacent to the Hummingbird Highway (Day, 1989). Annual Christmas bird counts around Belmopan since 1975 and other Hummingbird karst recording trips organized by the Belize Audubon Society since 1969 have tallied over 300 species within the annual count area, although this is not all karst landscape, and over 200 species within the karst itself (Day, 1989). Numbers for southern karst areas are similar, with over 200 species recorded in the Blue Creek Preserve, the Columbia River Forest Reserve and the Bladen Branch Nature Preserve (Table 2).

Via the Belize Biodiversity Information System (BBIS) database, a record is available of bird species reported for each of 55 1:50,000 topographic quadrants within Belize ([http://fwie.fw.vt.edu/wcs/B\\_distribution\\_map.htm](http://fwie.fw.vt.edu/wcs/B_distribution_map.htm)). Ranking these quadrants separately by reported bird numbers and according to their percentage karst terrain provides another tentative assessment of the relationship between birds and karst. Although many (38) of the quadrants contain no karst landscape, the Spearman's Rank Correlation (0.54, significant at the 0.05 level) results in rejection of the null hypothesis that there is no correlation between percentage karst and recorded bird numbers. Although the bird records are greatly influenced by numbers of observers and the varying accessibility of the quadrants, this again suggests that karst areas are associated with considerable avian diversity.

Although it appears that a significant percentage of Belizean bird species occur within the country's karstlands, the ecological relationships involved have not yet been specified and require further research. A functional relationship between the bird populations and the forest vegetation is not yet demonstrated, and the linkage with specific attributes of the karst ecosystem, such as nesting sites, water supply and food sources, is as yet conjectural. Additionally, none of the bird species recorded in the Belize karst appears to be restricted to the karst landscape, although some, such as the Cave Swallow (*Petrochelidon fulva*) and Vaux's Swift (*Chaetura vauxi*) may be most numerous there.

Although other Belizean birds are specific to coastal regions, wetlands and mountain areas (Wood *et al.*, 1986; Garcia *et al.*, 1998; Miller and Miller 2000), the birds of the karst are generally widespread, if not necessarily numerous, throughout the country. The primary association with the karst is with the persistence of an intact forest vegetation, which is in itself a function of the disincentives proffered by the karst to permanent human settlement. In other words, the association is an indirect, rather than direct one, with the vegetation playing the critical and intermediate role.

Comparative studies are not numerous, in part because avian research is rarely confined to or identifies a particular lithological or landscape unit. A notable exception, however, and one which reinforces the interpretation of the Belizean situation, is in the karst landscape of the Cockpit Country in Jamaica. Here, ongoing studies have revealed a distinctive and significant avifauna associated with the limestone forests (Fairbairn, 1986; Proctor, 1986). A total of 109 bird species have been recorded in the Cockpit Country, including 72 of the 121 Jamaican breeding species (C. Levy, S. Koenig, *pers. comm.*). Birds recorded in the Cockpit Country include all but one of Jamaica's 28 species of endemic birds, including the two endemic and threatened species of *Amazona* parrots (C Levy, H Davis, *pers. comm.*, 1999; Vogel, 1998). Not coincidentally, the Cockpit Country also boasts the highest rate of West Indian plant endemism per unit area, with over one hundred species occurring nowhere else (Proctor, 1986; Vogel, 1998). The limestone forest is floristically diverse (Kelly *et al.*, 1988; Proctor, 1986), and the karst also hosts significant populations of invertebrates, amphibians, reptiles and mammals (Fairbairn, 1986; Vogel, 1998).

Similar reinforcement is provided from studies of the karst forests of southern Mexico (Stattersfield *et al.*, 1998). Here it is apparent that in the case of one threatened species, Sumichrast's Wren

(*Hylorchilus sumichrasti*), "...it is the limestone outcrops rather than the primary forest understorey that are essential for the wren..." (Stattersfield *et al.*, 1998, p.655). Likewise, the karst forests of Puerto Rico have been recognized as significant habitats for migratory and endemic bird species, and are currently being considered for designation as a National Wildlife Refuge (Hunter, 1999; Lugo *et al.*, 2001).

## CONCLUSION

The associations between karstlands and their fauna are worthy of increased attention by karst scientists. In general it appears that karst terrains may represent significant faunal reservoirs, although these are not necessarily distinctive from those of adjacent non-karst regions, and further ornithological research into this topic is warranted. In the karst of Belize over 300 bird species have been recorded, more than 60% of the total species documented in the country. Although there is little evidence that any bird species are restricted to the karst, it is clear that species diversity is considerable, reflecting the varied vegetation and the range of habitats. Although some of the birds are associated with disturbed karst areas, it is clear that the forested karstlands potentially represent an important bird habitat, and their future conservation is thus rendered all the more important.

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# Speleogenesis in mineral veins in the Carboniferous Limestone around the Stanton Syncline, Derbyshire, UK.

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**Abstract:** Several old lead mines around the Stanton Syncline have “cavernous ground” recorded, particularly the dissolutionally enlarged scriin veins in Mill Close Mine. Whereas most mines are now flooded or inaccessible, available evidence suggests a sequence of at least two phases of dissolution in the phreatic zone, separated by a mineralization episode. The first phase occurred in the deep phreatic zone and was a probable precursor to hydrothermal mineral deposition under a cover of non-calcareous strata some 2km thick. The last phase recognized included much later meteoric phreatic zone dissolution, as the cover strata were progressively eroded away. Evidence relating to these phases suggests that at least two reversals of hydraulic gradient took place.

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## INTRODUCTION

The Stanton Syncline lies on the eastern flank of the Carboniferous (Peak Limestone Group) limestone outcrop in Derbyshire, United Kingdom (Fig. 1; Table 1). It forms an embayment filled with clastic Viséan and Namurian (Craven Group and Millstone Grit Group) strata, comprising the Longstone Mudstone and Edale Shale, capped by a tongue of Ashover Grit (Table 1). These strata are folded into a syncline some 6km E-W and 4km N-S, which plunges gently eastwards beneath the Derwent Valley. The synclinal flanks are formed of the higher subdivisions of the Peak Limestone Group, which dip inwards from the north, west and south, leaving the syncline open to the east but concealed beneath the alluvial deposits of the 1500m-wide flood plain of the River Derwent. The flanking limestone plateaux reach around 300m above sea level, whereas the floor of the syncline is near sea level or a little lower.

As part of the author’s study of the mineral veins and lead mines hosted in the limestones around the syncline (Ford, in press.), it

came to light that several mines had records of cavernous ground and that a hitherto unrecognized speleogenetic history could be deduced in this area. Regrettably the mining records are commonly vague about the nature and distribution of the caverns (“self-opens” in mining jargon) and very few are accessible, but sufficient information is available to demonstrate a logical speleogenetic history. There is evidence of at least two phases of phreatic zone dissolution with intervening mineralization, with some indication of reversals of hydraulic flow pattern, plus a late phase of sedimentary infill.

This contribution aims to provide an overview of the previously little known evidence of speleogenetic developments in and around the Stanton Syncline, and is an enlargement of the outline presented in the author’s earlier comments on hydrothermal karst (Ford, 1995). It is hoped that other workers will be able to find ways in to the cavernous mines concerned, and to conduct a more detailed analysis.

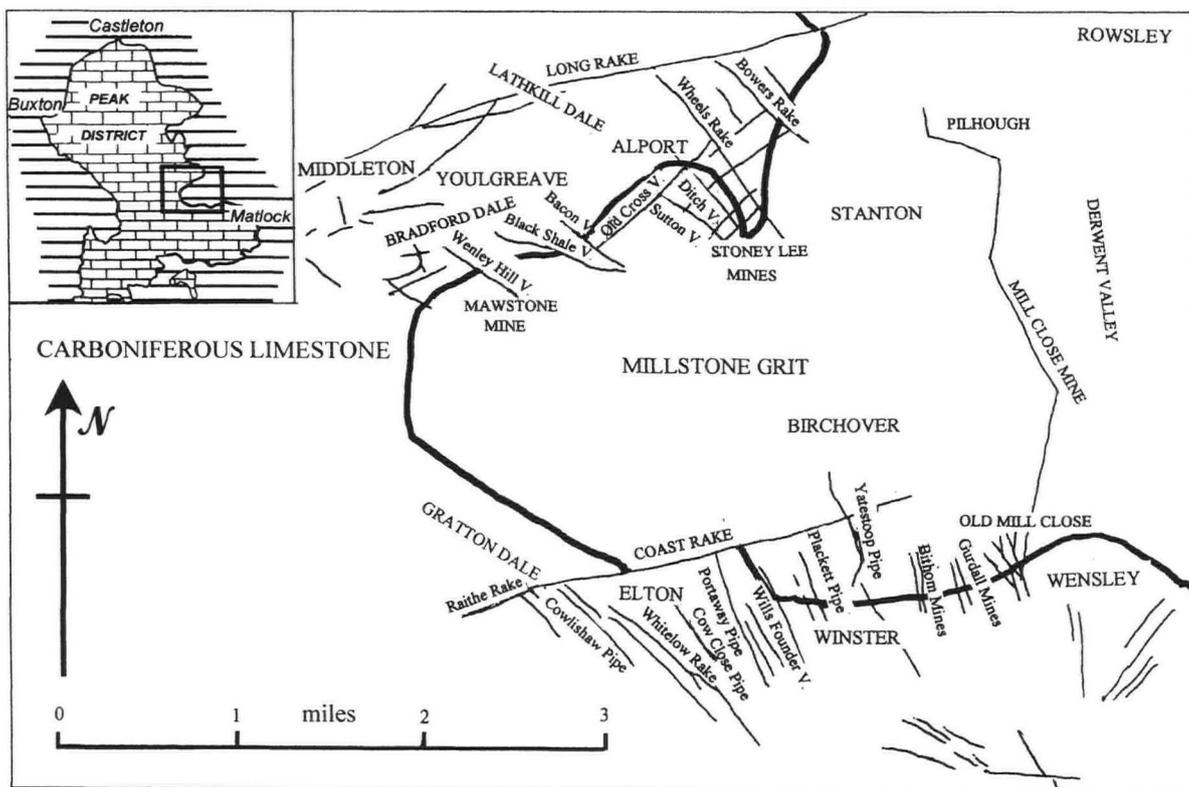


Figure 1: Sketch map of the Stanton Syncline showing the principal mineral veins (Inset shows the location of the syncline on the eastern flank of the Peak District limestone outcrop).

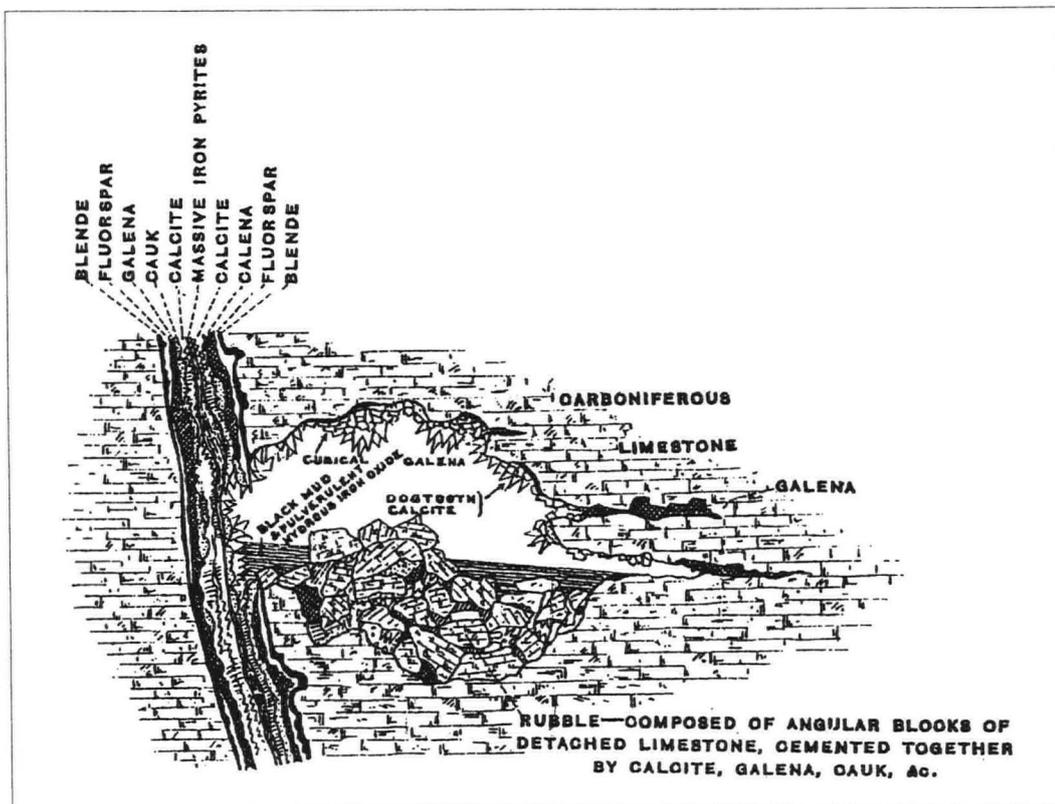


Figure 2: Sketch of a pipe cavern opening off a rake in Mill Close Mine, showing collapsed limestone blocks, mineral encrustations on the roof, and black mud containing "pulverulent iron hydroxide" (from Parsons, 1897).

### STRATIGRAPHY

Details of the strata of the Stanton Syncline have been described in the British Geological Survey Memoirs for Buxton (Sheet 111) (Aitkenhead *et al.*, 1985) and Chesterfield (Sheet 112) (Smith *et al.*, 1967), as well as in the Limestone Resources Survey Report for the Bakewell area (Bridge and Gozzard, 1981). Terminology is currently undergoing revision by the British Geological Survey, and the stratigraphical succession summarized in Table 1 assumes that the new recommendations are adopted.

The Bee Low Limestone Formation comprises mostly massive calcarenites with outcrops outside the synclinal area. They are seen only in a few of the deepest mines. The Monsal Dale Limestone Formation is also dominated by thick calcarenites but the formation tends to have more chert and have scattered shaley mudstone partings, clay wayboards (thin tuff horizons) and rare mud-mounds (locally called reefs) (Gutteridge, 1995). The Eyam Limestone Formation is mostly thin-bedded rather fine-grained limestones with numerous shaley mudstone partings, and contains numerous mud-mounds, which vary in thickness from around 10m up to 30m, e.g. High Tor at Matlock (Gutteridge, 2003). Both the Monsal Dale and Eyam Limestone formations are of a more shaley facies in the depths of the syncline (Bridge and Gozzard, 1981). Some of the mud-mounds have coarse crinoidal limestones banked against their flanks. In the inter-mound beds bedding partings and clay wayboards locally show evidence of contemporaneous karstic weathering and

palaeosols, indicating brief periods of emergence. Limestone beds become thinner and fewer upwards, as shaley mudstone partings increase in thickness, and the Eyam Limestone Formation passes upwards without any recognizable break into the Longstone Mudstone.

The Monsal Dale Limestone Formation is subdivided by basaltic lava flows and tuffs, commonly 10 to 20m thick, locally known as toadstones, which die out at flow fronts. Dust tuffs form laterally extensive clay wayboards, mostly only a few centimetres thick, in both the Monsal Dale and Eyam Limestone formations.

Both the Monsal Dale and Eyam Limestone formations forming much of the plateau south and west of the Stanton Syncline have been dolomitized (Ford, 2002a). Within the syncline only a small area north of Elton and Winster has been affected, and dolomitization extends a short distance beneath the cover of clastic strata. Elsewhere the limestones are unaffected. Dolomitization yielded porous dolostones, resting on unaltered limestones, commonly with vughs along the undulating boundary. Around Elton these vughs indicate minor cavernization along this boundary, but elsewhere dolomitization appears to have made little contribution to speleogenesis. It is clear that dolomitization preceded mineralization, as veins cut through both limestone and dolomite (Ford, 2002a).

Overlying the limestones, the Longstone Mudstone, of latest Brigantian age, is distinguishable from the still younger Edale Shale only on the basis of detailed palaeontology (Table 1). The highest rocks preserved in the area belong to the Ashover Grit (Millstone Grit Group). These deltaic sandstones display variable thickness,

Chronostratigraphy				Lithostratigraphy			Local thickness (m)
System	Subsystem	Series	Stage	Group	Formation	[?]Member	
Carboniferous	Silesian	Namurian	Kinderscoutian	Millstone Grit Group	–	Ashover Grit	variable, to 100
			Kinderscoutian and Pendleian	Craven Group	Bowland Shale Formation	Edale Shale	c.150 to 200
	Dinantian	Viséan	Brigantian			Peak Limestone Group	Eyam Limestone Formation
				–	c.15 to 30		
			Asbian	Monsal Dale Limestone Formation	Bee Low Limestone Formation	Various lava and tuff members (see text)	c.200
		c.200					

Table 1: Generalized bedrock stratigraphy of the Stanton Syncline area.

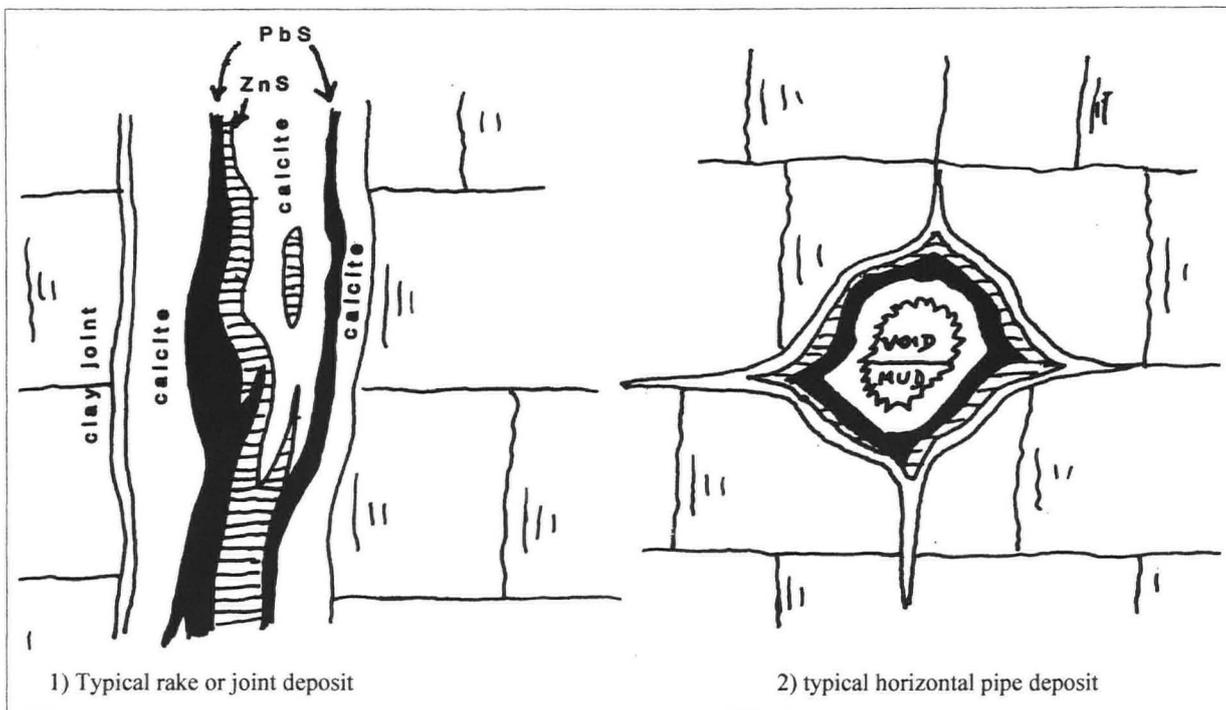


Figure 3: Diagrammatic sketch of a rake and a pipe vein in Mill Close Mine (from Foster-Smith, 1987).

partly as a result of growth faulting, i.e. contemporary submarine landslipping of the delta front into deeper water, with later infilling of the landslip scar with more sand (Chisholm, 1977). Younger Millstone Grit Group beds and Coal Measures Group strata once covered the area, but these have been removed by erosion.

### TOADSTONES

These basalt lavas and tuffs form important aquicludes, which guided mineralizing fluids in Late Carboniferous times and also guide elements of the more recent karstic drainage. The lava flows and tuffs crop out extensively on Masson Hill above Matlock (Ford, 2001). On this southern flank of the syncline the principal lava flows are the Upper and Lower Matlock lavas, with the more localized Winster Moor Lava lower in the sequence. To the north of the syncline there are two more lavas near Alport-by-Youlgreave: the Conksbury Bridge Lava above and the Lathkill Lodge Lava below. Sub-surface evidence from Mill Close Mine shows that, though there is broad contemporaneity, both groups of lavas split and die out within the Mill Close sector of the syncline, so that direct correlation is not possible (Traill, 1939, 1940; Bridge and Gozzard, 1981; Walters and Ineson, 1981). However, enough is known from old lead mine records to show that the toadstones divide the limestone into partly watertight 'compartments', both in the flanking limestone areas and beneath parts of the syncline. The lateral extent of the lavas are marked by their original flow limits, and hence there are areas where they are absent and the limestone compartments above and below are linked, permitting transmission both of mineralizing fluids and of karstic water between them.

### STRUCTURE

The Stanton Syncline forms an embayment on the eastern flank of the Peak District limestone "high". The limestone area was a massif with local sub-basins within the Pennine sedimentary basin. In Late Carboniferous times the basin underwent tectonic inversion to form the north-south Pennine Anticline, and the cover of Upper Carboniferous strata was subsequently removed by erosion.

The limestones dip into the syncline at about 5° from the north, and at 10–15° from the south. There is a gentle eastward plunge of about 3°. Detailed stratigraphical evidence suggests that the syncline was growing as a gentle downwarp during both late Viséan (Brigantian) and early Namurian times, as both the limestones and shaley mudstones show indications of being a deeper-water facies and thicken slightly into the core of the fold.

Faulting affected the area at the end of Brigantian times, as shown by the pattern of mineral veins. These fractures have strong

NW-SE and lesser NE-SW trends in the limestones on the north flank of the syncline, where they abut against the strong WSW-ENE Long Rake. On the south flank, NW-SE fractures are common around Winster and Wensley, some abutting against the WSW-ENE Coast Rake. The latter dies out eastwards beneath the clastic beds, and it was not recognized in Mill Close Mine. The "Main Joint" in the latter had an anomalous N-S trend, though in reality it was a series of NNW and NNE joints or faults, in places showing a small downthrow towards the east. There are also a few roughly N-S fractures within some of the mud-mounds of the Eyam Limestone. Miners have followed the veins beneath the overlying clastic rocks on the two flanks, but no mine workings have met beneath the syncline. Although a few of the NW-SE fractures have the hallmarks of wrench faults, such as horizontal slickensiding on the walls, only a few have any determinable displacement. Long Rake and Coast Rake have been proved as faults with downthrows of 10–40m inwards towards the synclinal axis.

As wrench movements can be demonstrated on the NW-SE fractures, it seems likely that the NE-SW fractures are pull-apart gashes normal to the former. As such, dissolutional pipe development was followed by somewhat more intensive mineralization.

None of the NW-SE and NE-SW fractures in the limestone can be shown to extend upwards into the overlying shaley mudstones and sandstones. Any late movement on these fractures was probably absorbed by deformation in the poorly exposed mudstones. The only faults recognized in the Ashover Grit are growth faults due to contemporary submarine landslips (Chisholm, 1977). These do not affect the underlying limestones.

### MINERAL DEPOSITS

Most of the mineral veins are typical fissure-fillings of galena, sphalerite, fluorite, baryte and calcite, with trace quantities of greenockite, cinnabar and phosgenite. Larger fissure veins are termed rakes and the smaller ones scrins. They are the result of Mississippi Valley Type (MVT) mineralization. It is generally accepted that the mineralizing fluids derived their ions from diagenetic alteration of the mudrocks in sedimentary basins to the east (Quirk, 1993). The hydrothermal fluids rose up-dip during tectonic inversion, i.e. there was westward fluid movement. Mixing with oxygenated and cooler waters within the limestones contributed to the precipitation of the mineral suite while the limestone was still deeply buried. Mineral deposition filled fractures, yielding fissure veins, and locally filled bedding plane voids, to yield flats. Pipes are void fillings or linings of vughs generally aligned along bedding

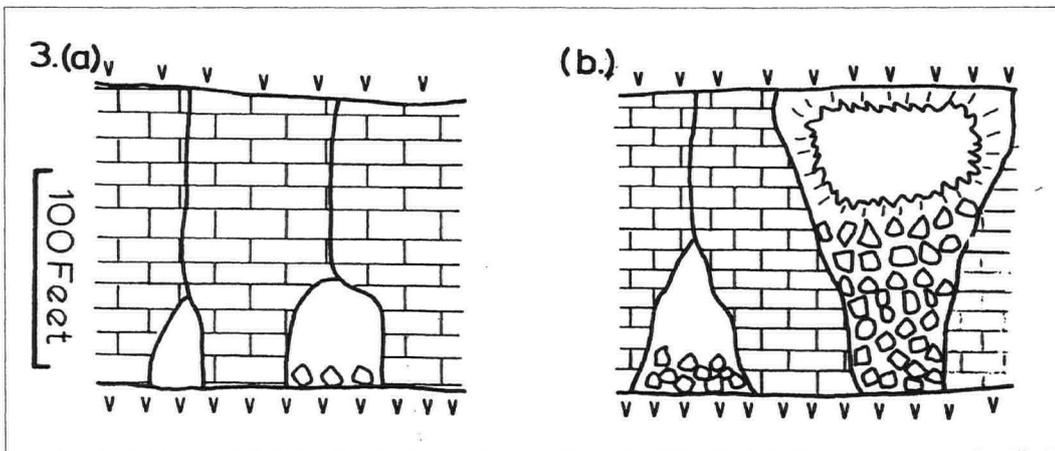


Figure 4: Evolution of a pipe cavern between two toadstone beds (redrawn after Traill, 1939).

intersections with fractures, commonly along scrins. Confusingly, the term “pipe” was also used by the lead miners in a compound sense, to denote mineralized complexes consisting of assemblages of fissure veins, flats and mineral-lined vughs, with some replacement of the limestone wall-rock by disseminated minerals. Gravel ores are detached pieces of mineral, mainly galena, lying in the floors of cavities, mixed with both residual and inwashed clastic deposits. Some of the mineral deposits are thought to be hydrothermal infillings of earlier palaeokarst (Ford, 1995; Ford in Bosak, 1989).

By far the majority of veins in the Stanton area have galena with a gangue of baryte and calcite. Fluorite is confined largely to sections of Long Rake and to the “new” Mill Close Mine (worked from 1865 to 1940), though minor quantities have been found on mine waste heaps elsewhere (Butcher, 1976). Sphalerite was common in Mill Close Mine, where its proportion increased downwards and northwards. This mine was by far the richest lead mine in the Derbyshire orefield, having produced some half million tons of galena concentrates and about a hundred thousand tons of sphalerite concentrates. The richest ore zones were in fissure veins capped either by the base of the overlying clastic rocks or by a toadstone whose impermeability channelled mineral fluid flow into the immediately underlying limestones.

### MINES AND SOUGHS

Farey (1811) provided lists of mines with brief notes on their contemporary features, but subsequent mining has had only brief coverage in Memoirs and other publications. A catalogue and short description of the old lead mines around the Stanton Syncline has recently been compiled by the author (Ford, in press). Many fissure veins were followed down-dip beneath the mudstone cover for up to 500m but none were linked between the two flanks of the syncline. Mill Close Mine was entirely beneath clastic rocks at the Derwent Valley end of the syncline, with workings more than 1600m long. The deeper part of the syncline west of Mill Close Mine has never been investigated. Only those mines with records of cavernous ground are noted below.

The lead mines were drained by several short and three long adits (soughs) (Oakman, 1980; Rieuwerts, 1987; Ford and Rieuwerts, 2000). The latter are Mill Close Sough, lying more or less beneath Mill Close Brook and draining the Old Mill Close Mine area (Warriner, 2000), Hillcarr Sough, draining the Alport-by-Youlgreave area (Rieuwerts, 1981a), and Yatestooop Sough, draining the Winstor and Elton area (Rieuwerts, 1981b) (see also Ford and Rieuwerts, 2000) (Fig.7).

Mill Close Sough was driven during the early 18th century, initially through mudstone but subsequently following its contact with the limestone, with numerous bends where the contact was faulted along mineral veins. The two great soughs of Hillcarr and Yatestooop were each about 5km long and were driven during the 18th century, almost entirely in mudstone, with branches into the limestones along the various veins (Fig.7). These two carried most of the mine drainage from the syncline. The later 19th – 20th century Mill Close Mine workings passed underneath both soughs without affecting their discharge into the River Derwent and no leakage from those soughs into the mine was recorded. Indeed both soughs

continued to discharge water even when Mill Close Mine was pumped out. A short branch driven through mudstones from the Mill Close Mine shafts to the outer section of Yatestooop Sough provided a pumpway for the later mining operations.

Since 2001 Hillcarr Sough has apparently been blocked by a roof fall, and impounded water has risen by around 20m up mine shafts along the northern flank of the Stanton Syncline. At a rough estimate, some 10km of mine workings have been flooded. Some overflow has flooded fields in lower Lathkill Dale.

### CAVERNS AND SPELEOGENESIS

Though cavernous ground was well-known to the early lead miners, it was rarely recorded and the nature of the caverns was not described until Parsons (1897) noted that many of the SW–NE scrins in Mill Close Mine had been enlarged by dissolution, leading to the development of scrin-caverns (Fig.2). These were developed along bedding/joint intersections and were characterized by their lower parts being filled with limestone blocks fallen from the roofs. The voids between fallen blocks were filled by black mud with “pulverulent iron hydroxide”, the latter presumably derived from the oxidation of pyrite disseminated through the adjacent mudstones. The remaining space above the fallen blocks was lined with galena and calcite crystals, the former in up to 10cm cubes and the latter commonly as scalenohedra up to 30cm long. Parsons provided a valuable diagram but, unfortunately, gave no location for his example within the ramifications of Mill Close Mine. Traill (1939), Varvill (1962) and Foster-Smith (1987) (Fig.3) added that fallen slabs of mineral linings were to be found locally amongst the limestone blocks, indicating post-mineralization dissolution. None of these writers gave any data on the frequency or distribution of these caverns, though they were evidently a common feature of the mine. They are not shown on the surviving mine plans and contemporary photographs show very little of speleogenetic significance.

The caverns in the enlarged scrins are herein called scrin-caverns for convenience. Both Parsons’ diagram and the later sketches suggest a joint-plus-bedding plane tubular profile typical of phreatic zone dissolutional development. Unpublished data indicate that some were developed at joint and vein intersections, presumably giving a vertical tubular form.

The whole of Mill Close Mine is beneath the mudstone cover and so its scrin-caverns were still in the phreatic zone, and have been throughout their history, until they were pumped dry during 19th and 20th century mining operations. They have been submerged again since mining ceased in 1940. Though descriptions are frustratingly vague, the scrin-caverns appear to be best developed within the Monsal Dale Limestones between the toadstones (Fig.4). Smaller scrin-caverns occur in the upper Monsal Dale and Eyam limestones above the highest toadstone, beneath the mudstone cover.

Varvill (1937), Traill (1939) and Foster-Smith (1987) gave sketch diagrams of scrin-caverns in Mill Close Mine (Figs 2, 3, 4 and 5), without the detail shown by Parsons in 1897. A cartoon diagram (Traill, 1939) of the evolution of these scrin-caverns by progressive upward dissolutional enlargement of joints in the limestones between two toadstones portrayed an early phase of speleogenesis along joints before mineralization. This could thus

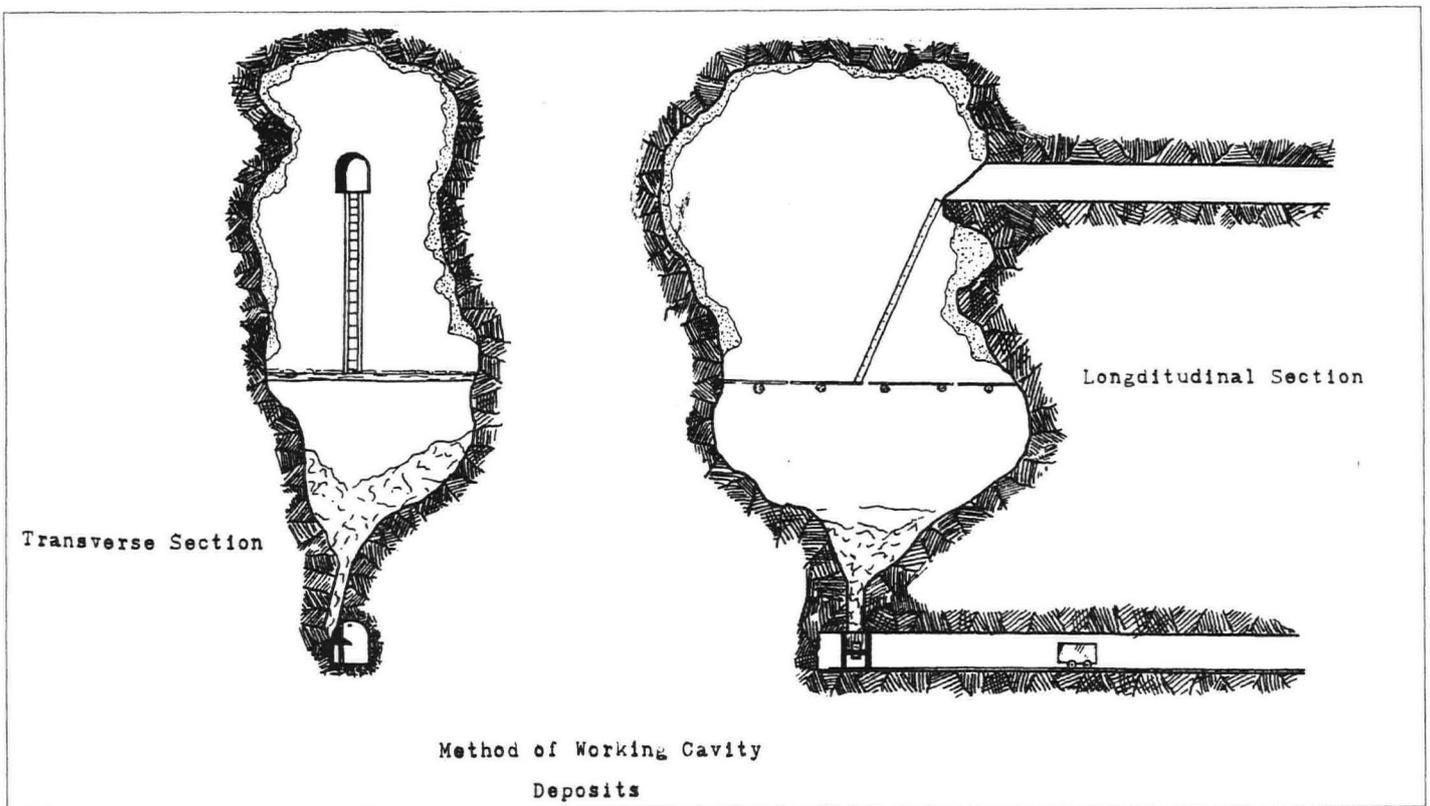


Figure 5: Method of working a scriin-cavern in Mill Close Mine (from an unpublished report).

represent phreatic zone dissolution while the limestone was still deeply buried beneath clastic cover rocks, i.e. before the Late Carboniferous.

Two further observations on Mill Close Mine are significant: one is that though the published accounts hint that the majority of the scriin-caverns were in SW scriins, there are some inferences of hydrological linkages via weaker NW scriins and via flats, all with some degree of mineral infill (Foster-Smith, 1987). At least one large cavern (30 by 12m) was met within the N-S Main Joint, again between two toadstones (Traill, 1939).

The second observation is that minerals such as cerussite and smithsonite, characteristic of oxidation, have been found at the deepest levels within the mine. They demonstrate that oxygenated meteoric waters have circulated to depths of at least 300m below shaft collar. The presence of pulverulent iron hydroxide also indicates an oxidizing phase. According to the writers cited above, such oxygenation occurred in pre-mining days, not as a result of mining, but no proof of this is available.

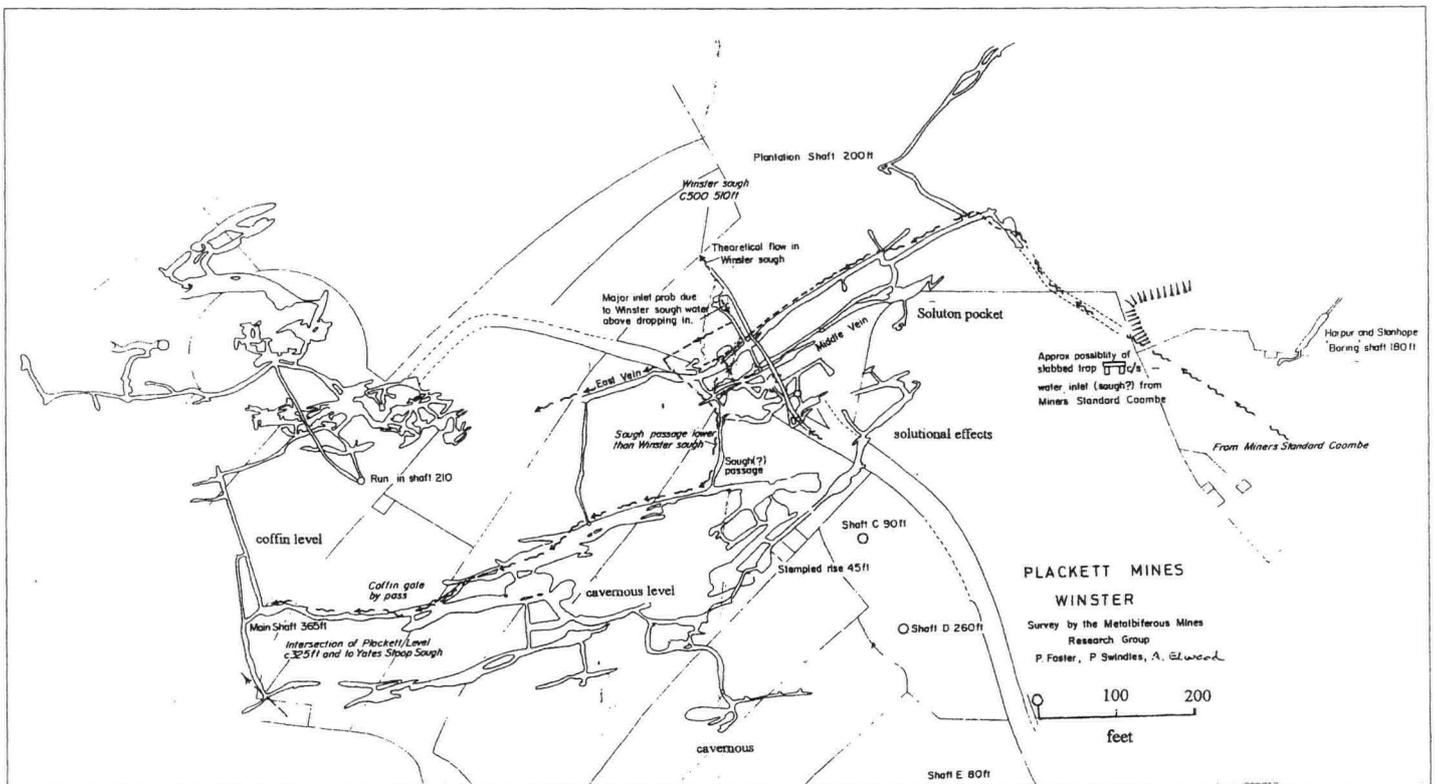
To the south Old Mill Close Mine was worked mainly in the 17th and 18th centuries and its existence was only known in the vaguest terms to those who described the later "new" Mill Close Mine. It lies within Monsal Dale and Eyam limestones beneath the southern flank of the mudstone cover west of Wensley and above the highest toadstone (Warriner, 2000; Ford, 2000a). More than 15km of workings have been surveyed. Though sometimes referred to as a "pipe" in old mining documents, the complex shows a predominance of NW-SE scriins, many with dissolutional enlargement and infill by sands and silts derived from overlying clastic rocks, possibly as inwashed pro-glacial sediments. The early miners found it advantageous to work through these fills, removing galena that had been detached by dissolution from the walls, thereby destroying most of the sedimentary evidence of speleogenetic processes. Unfortunately Warriner's account does not give distributional data for natural caverns.

Though Old Mill Close Mine is now above the water-table, much was probably under water until the driving of some short shallow soughs and the longer Mill Close Sough in the early 18th century (Rieuwerts, 1981b). The latter now takes the limited drainage from Old Mill Close, as well as from the nearby Gurdalls and Bithoms mines, lying some 300 and 500m to the west respectively (Fig.7b).

On the dip slope of the limestones east, north and west of Winster, there are several "pipes" in the compound sense. These include Yatestooop and the adjacent Horsebuttock and Orchard pipes, as well as Placket and Portaway pipes. Each trends northwards down-dip beneath the mudstones on the southern flank of the syncline, and they are at least partly within mud-mound complexes in the Eyam Limestone. Deeper workings went down into the Monsal Dale Limestone as far as the highest toadstone. Only Horsebuttock and Plackett mines have been explored in recent times, unfortunately with no observations of a speleogenetic nature being made. Very little is accessible today and there are few mine plans.

Yatestooop Pipe was "a crooked vein but very rich in lead ore"; and it had the reputation of having caverns with gravel ore. Horsebuttock Mine has been explored by Penney and Dixon (1990): their description noted caverns with sediments, which appeared to have been worked through by the miners searching for loose lumps of lead ore. Orchard Mine was said to be in a pipe (in the compound sense) 150 yards wide "with caverns in it" (Farey, 1811). Placket Mine was explored by MMRG (1974) who provided a survey and description. Whereas they recorded caverns, the survey did not show their location. However, an earlier sketch survey by Nash in the 1950s (see Worley and Nash, 1979) noted cavernous ground at several points, and these have been added to the MMRG survey herein (Fig.6). West of Winster, Portaway Pipe was shown on old maps as an area south of Coast Rake some 500m NNW-SSE and 100m wide. Long-inaccessible, it is reputed to be a complex of NNW-SSE veins and replacements at the base of dolomitized Monsal Dale Limestones, i.e. beneath a dolomite roof, with several caverns, reached by several shafts. The caverns had sediment fills that yielded manganese wad deposits at Heyspots Mine (Ford 2002b).

West of Elton village, an old lead miners' plan (c.1800) marked several small pipes cutting NW-SE across the Raithe Rake sector of Coast Rake in an area of dolomitized limestones. Where the dolomites are in contact with unaltered limestones, some 10m or so below the surface, scriin veins "bellied out" into caverns with clastic infill and gravel lead ore. So far as is known, the clastic infills were sorted through for lumps of lead ore in the caverns or the fills were raised to the surface and galena was recovered there. Though a few of these shallow mines have been explored in recent years, no detailed accounts are available.



**Figure 6:** Plan of Plackett Mine, redrawn from a Metalliferous Mines Research Group survey (MMRG, 1974), with the addition of indications of cavernous ground after Worley and Nash (1979).

These pipes all lie on the south (Winstler) flank of the syncline. Whereas several veins are referred to as “pipes” on the north (Alport and Youlgreave) flank, and old mining records occasionally referred to “opens”, as caverns were known to the lead miners, regrettably few detailed observations are available. Mining records include references to some SW–NE veins being pipes, e.g. Old Cross Vein changes its name eastwards to Oldfield Pipe. As these are now underwater and thus inaccessible, no further details are known.

Though detailed observations are sparse, it seems that most of the pipe vein complexes noted above had caverns of rift-like form developed along mineral veins both before and after mineralization, comparable to the scriin-caverns of Mill Close Mine. The fill of black mud in the latter was not recorded elsewhere: coarser clastic sediment inwash was apparently common in some Winstler pipes.

As most of the caverns noted herein are submerged or inaccessible, it is not yet possible to assign them to epigene or hypogene categories (Worthington and Ford, 1995), though it is probable that many have gone through both phases of development.

## DISCUSSION

An early stage of ground preparation by incipient dissolutional enlargement probably occurred during late Brigantian times, as connate water was expelled from the limestones towards the margins of the East Midlands basin (Downing *et al.*, 1987). It was followed by a phase of pre-mineralization phreatic dissolution beneath a considerable cover of Silesian (Upper Carboniferous) rocks, as a precursor to the dolomitization and mineralization processes. As this occurred at a depth of 1.5 to 2km beneath the Silesian cover, elevated temperatures were involved, so the phase may be regarded as hydrothermal karstification as discussed by Ford (1995). However, no morphological evidence of uprising hydrothermal corrosion has been reported and feeders into the bottom of the syncline have not been recorded. Instead, a general slow migration of aggressive hydrothermal fluids through any available bedding planes or fractures is much more likely. These formed both horizontally- and vertically-oriented inception routes, the latter providing cross-stratal links between different or displaced bedding routes (inception horizons). These early stages of cavernization are likely to have involved sulphuric acid, derived from pyritic mudstones (Worthington and Ford, 1995; Lowe and Gunn, 1997),

both those interlayered with the limestones and those in the lower parts of the late Viséan to early Namurian succession (Table 1).

The hydraulic gradient appears to have suffered reversals from eastwards to westwards. Neither the present study nor any previous researcher have invoked north–south flow patterns, so these may be discounted. During limestone burial beneath the Upper Carboniferous rocks water would have been squeezed out, giving an initial eastwards flow pattern. But, the hydrothermal fluid flow was westwards out of distant basinal sources of mineralizing ions into the rising Pennine “high”. The hydrothermal mineral fills resulted from the latter reversed flow pattern.

The long period between mineralization (c.290 million years) and the development of the late Tertiary and Quaternary erosional regime saw a reversal to eastward flow again. Leaving aside the effects of mine drainage, the Stanton Syncline is an obvious site for the accumulation of near-static water during and after the elevation of the Pennine Anticline, long before the River Derwent was incised to its present altitude (Ford, 1997). Throughout this period phreatic conditions persisted, with very slowly-moving waters enlarging inception routes. Drainage of veins and caverns did not occur until deep mining began in the 17th and 18th centuries.

Percolation from the rain falling on the adjacent limestone plateaux to north, west and south would feed to a phreatic water accumulation within the synclinal trough both via bedding planes and via mineral vein fractures. A slow eastward flow would lead to overflow rising eastwards into the River Derwent and its tributaries (or possibly even farther east into Mesozoic strata (Downing *et al.*, 1987)). The toadstones interleaved within the limestone succession formed partial aquicludes, separating the latter into compartments with cross-stratal transmission possible where lava flows terminated or were faulted.

The overlying mudstones and sandstones in the core of the syncline have too small a catchment today to provide any significant allogenic stream input directly into the limestone. However, if a wider extent in earlier (pre-Quaternary?) times is visualized, one might expect some signs of “fossil” swallets and vadose stream caves higher up on the limestone flanks of the syncline, paralleling the situation below Rushup Edge at Castleton today. However, neither swallets nor vadose stream caves have been found and such caves as are accessible in the Winstler and Old Mill Close area show no evidence of vadose development. It is, however, possible that

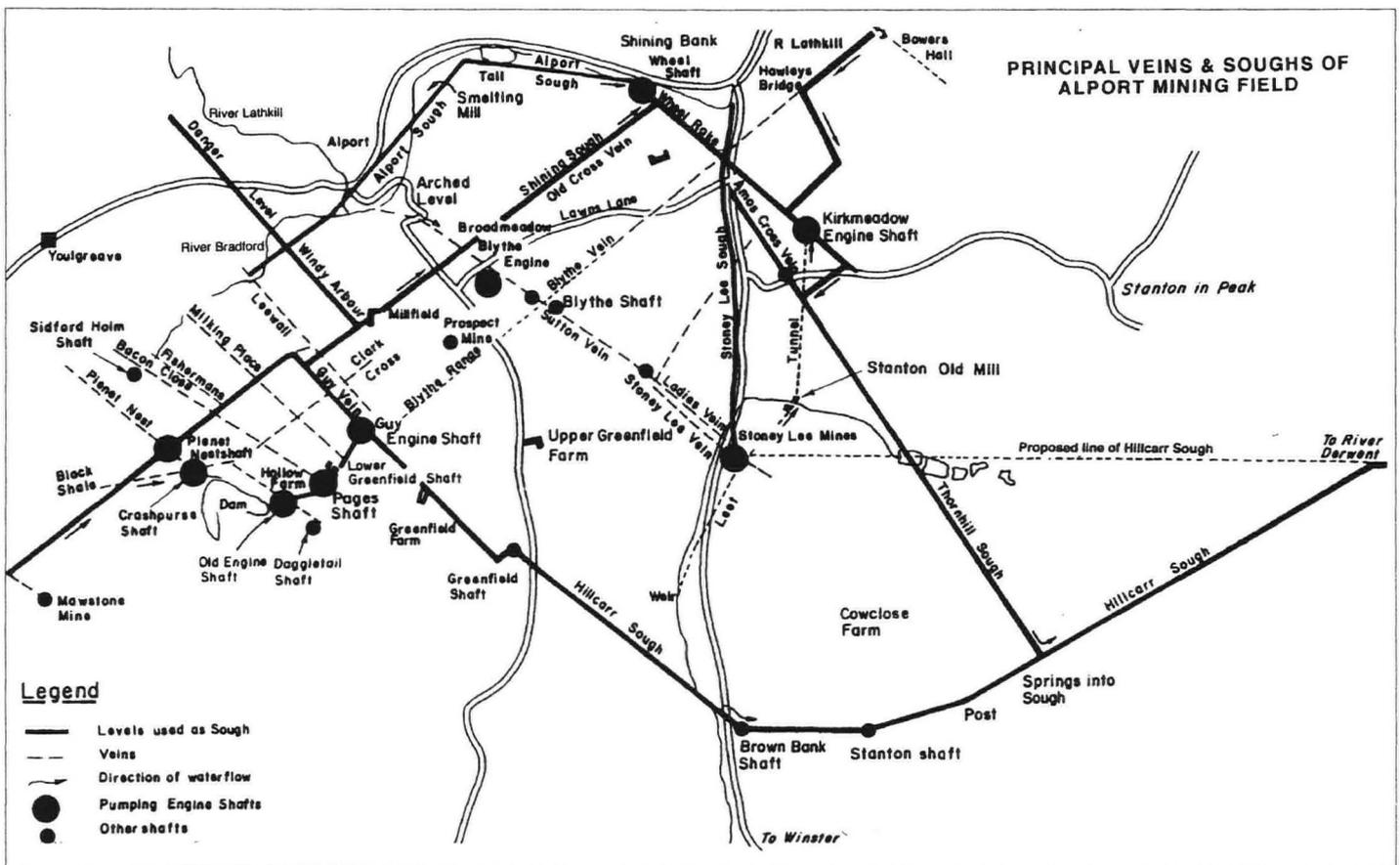


Figure 7a: Hillcarr Sough, a major drainage adit in the Stanton Syncline (from Ford and Rieuwert, 2000).

swallets and short vadose caves once existed high on the flanking hills and have been entirely eroded away by general surface lowering of the limestone plateau; and any swallet-feeder stream courses cut into the former extent of the Craven and Millstone Grit groups (Table 1) have similarly been eroded away.

Whereas Pleistocene phreatic zone dissolution is evident from the cavernous ground in Plackett, Yatestooop, Orchard, Horsebuttock, Portaway and Old Mill Close mines, it has exploited an earlier phase of pre-mineralization dissolution, as demonstrated by the scrincaverns in Mill Close Mine and the other pipe veins with the fills containing collapsed limestone blocks and mineral linings.

The pipe caverns at the dolomite/limestone contact around Elton compare with similar mineral-lined vughs in the Masson Mines of Matlock (Ford, 2001). Comparison may also be made with some baryte deposits in the Golconda Caverns (Ford and King, 1966), where slabs of baryte linings detached from cavern walls are cemented with calcite, indicating an alternating system of mineral deposition and dissolution. A sequence of events can be deduced as follows:

### Phase 1

Dinantian limestone sedimentation with mud-mounds and discontinuous lava flows and tuff sheets. Some palaeokarstic effects have been recorded on bedding planes and wayboards in Mill Close Mine, and there were widespread effects elsewhere in the Peak District indicating intermittent emergence (Walkden, 1974). Indications of contemporary (Carboniferous) cave development have been detected in the mines around the Stanton Syncline and none of the palaeokarsts has yet been shown to influence the later cavernization. Groundwater movement was very slow, but an increasing content of sulphuric acid derived from pyrite meant that it was probably aggressive. Late Dinantian tectonic stresses induced a fracture pattern in the limestones, later occupied by mineral veins – see Phase 3 below.

### Phase 2

Deposition of the late Viséan to Namurian cover of mudstone and deltaic sandstones, followed by Westphalian Coal Measures, Perno-

Triassic sandstones and mudstones and other Mesozoic strata (long since stripped off by erosion). Some minor evidence of contemporary down-warping in Viséan to Namurian times. Groundwater movement was probably directed out of the basin towards the east.

### Phase 3

Early phreatic zone dissolution evidently took place under a considerable stratigraphical cover (about 2km) and may well have been due to an aggressive precursor of the entry of mineralizing fluids in Late Carboniferous times. At some stage the fluids were magnesium-rich and caused dolomitization of some nearby limestones. The source of both magnesium-rich and mineralizing fluids is thought to be from deeply-buried mudrocks in basins to the east, where diagenesis of clay minerals released the necessary ions. The early hydrothermal fluid movement was westwards, up-dip from distant basins into the tectonically rising limestone massif. The fluids exploited both bedding planes and fractures as inception routes, gradually opening cavities in both, though no specific fluid routes can now be determined.

### Phase 4

Mineralization – generally regarded as Late Carboniferous (Late Westphalian – Plant and Jones, 1989). Following the early fluid movement of Phase 3, mineralizing fluids rose westwards up-dip into the limestone while it was still beneath a cover of some 2km of Craven Group, Millstone Grit Group and Coal Measures Group strata. Galena, sphalerite, baryte, fluorite and calcite lined fractures, forming rakes and scrins. Minerals deposited in bedding-guided cavities formed flats, and minerals lining or filling scrincaverns formed pipes.

### Phase 5

Final folding of the syncline, as a W–E trough on the flank of the N–S Pennine Anticline, during the Variscan earth movements at the end of the Carboniferous. Erosion during Permian to Triassic times was followed by re-burial during the Mesozoic Era, with a long period (approaching 290 million years) of virtually static

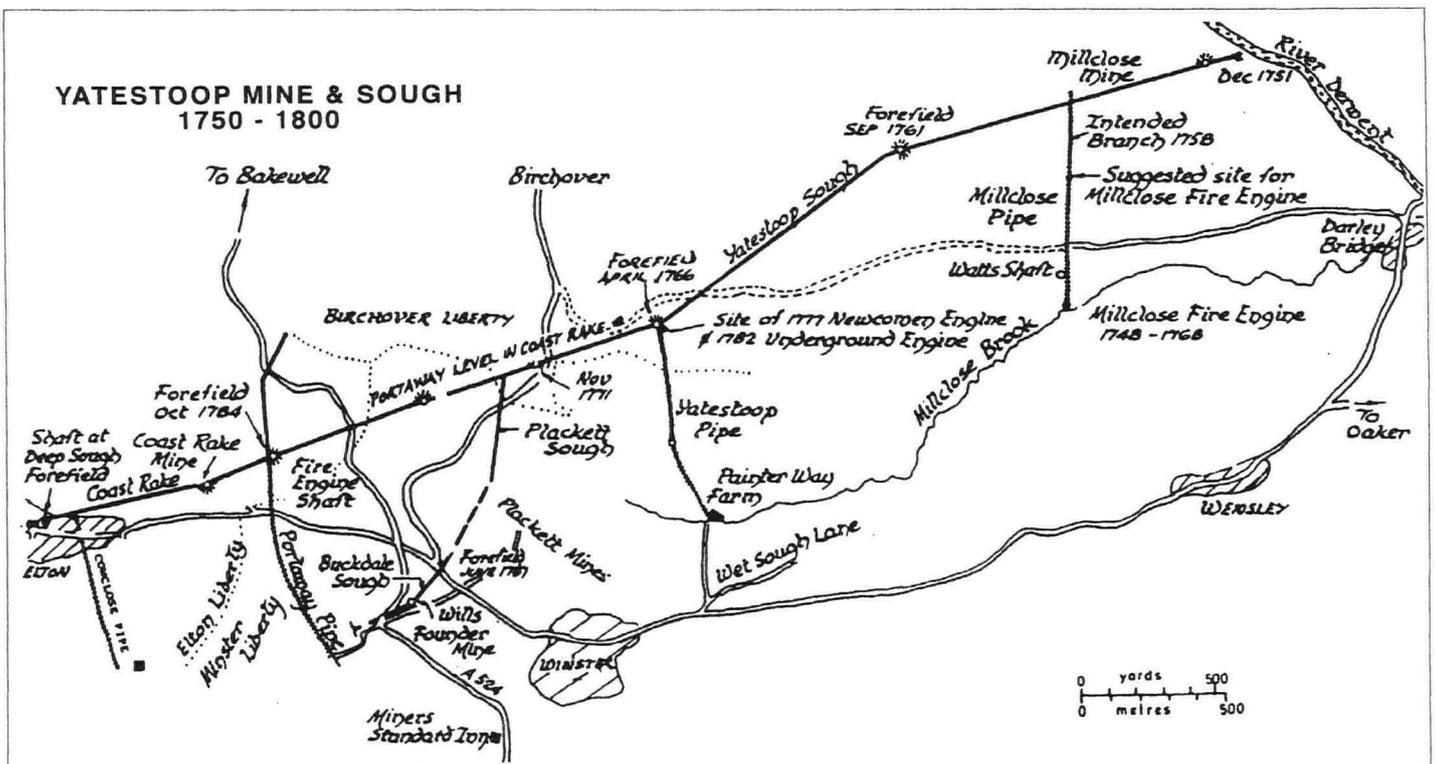


Figure 7b: Yatestoop Sough, a major drainage adit in the Stanton Syncline (from Ford and Rieuwert, 2000).

groundwater. During Tertiary times the remaining cover of Upper Carboniferous and Mesozoic strata was stripped off by erosion.

### Phase 6

Under meteoric conditions in late Tertiary to Quaternary times an increasing hydraulic gradient towards the east developed as the River Derwent was incised. Ongoing dissolution in the phreatic zone widened the pipes and also formed caverns along the fissure veins, partly guided by mudstone partings and wayboards. Parts of the mineral linings were subsequently detached, to join collapsed blocks in the bottoms of the scriin-caverns. Such dissolution was probably a long slow process, operating from Late Carboniferous times onwards but increasingly effective during the Tertiary.

### Phase 7

In early Pleistocene times the shaley mudstone and sandstone cover now seen in the synclinal core probably still extended well up onto the limestone plateau, providing a catchment for allogenic waters to drain into the limestone. However, no evidence of fossil swallets or vadose streamways has been found, and the few accessible caves show only features typical of phreatic zone dissolution. No flow-through hydrological system can be deduced, and slow dissolution in the phreatic zone continued beneath the clastic rock cover, as exemplified by the Winster pipes. A limited episode of input of sand, silt and clay filled some of these voids, yielding gravel ores. Black mud, probably mostly derived from mudstones, partially filled the scriin-caverns in Mill Close Mine. The sand and silt fills may represent outwash from an early glacial phase, and may be coeval with fills in some of the Masson Hill caverns, dated palaeomagnetically at around 780,000 years (Noel *et al.*, 1984). However, no section of undisturbed sediments suitable for dating is currently accessible in the Winster area.

### Phase 8

During later Pleistocene times the cover of mudstone and sandstone was stripped back to approximately its present position as surface streams cut down. The general lowering of the limestone plateau surface removed any potential evidence of swallets. The surface streams included ancestors of the Bradford and Lathkill rivers and Mill Close Brook, all tributaries to the Derwent. A small proportion of the limestones with phreatic caves was exposed as the mudstone margin retreated, though most are still beneath the mudstone cover.

The caverns were not drained until the lead miners' soughs lowered water levels during the 18th century.

Thus, there have been at least two reversals of groundwater movement: eastwards during basin evolution in Mid to Late Carboniferous times; westwards during mineralization, and eastwards again during the meteoric hydrological regime. Some deep circulation continues to the Present, as shown by the thermal springs at Buxton, Bakewell and Matlock (Downing *et al.*, 1987). Relatively high sulphur contents of these waters suggest that the initiation of deep conduits is still on-going (Worthington and Ford, 1995).

The post-mineralization, and present-day, phreatic zone dissolutional process requires both input and outlet systems, no matter how slow the process may be. Whereas percolation into the limestone and transmission along mineral veins provides the input, the outlet(s) are more difficult to locate. No evidence has been found for the possibility that springs rose through mudstones along the adjacent Derwent Valley. Thus, a hypothesis of long distance (at least 5km) water movement through the limestone must be invoked, towards an assumed outlet for the phreatic zone system by as yet unidentified springs, possibly in the bed of the River Derwent in the Matlock Gorge.

The artificial hydrological regime produced by the soughs and by pumping out Mill Close Mine throws some light on the problem. At the peak period of mining 7000 gallons per minute were being raised from that mine (Traill, 1939) (some reports mention up to 15000 gallons per minute, and another claims 2 million gallons per day). Inputs came from fissures close to the margins of toadstones, and from fissures in the Pilhough Fault at the northern end of the mine workings. It is possible that these inputs were fed by leakage through the alluvial sands and gravels of the Wye and lower Lathkill flood plains where they overlie limestones around the confluence of those rivers near Haddon Hall.

Pumping out Mill Close Mine did not drain the whole syncline. No effects on water-levels were recorded in the mines farther west, and both Hillcarr and Yatestoop soughs continued to flow (Fig.7). A rough calculation shows that the amount pumped out of Mill Close Mine is about 6% of the potential input of percolation water (taking the total catchment as 50km<sup>2</sup> receiving 1m rainfall annually, with 40% percolation - a potential daily input of 55,000m<sup>3</sup>). Some of the rainfall feeds direct run-off into the rivers, and the rest of the percolating rainwater discharges via the soughs.

A possibility remains that artesian water rose up into the syncline from an unknown source to effect the post-mineralization phreatic zone dissolution. The limestone plateau to the west must have received large quantities of rainfall with an unknown proportion percolating, but no routes channelling it into the bottom of the syncline can be demonstrated. A supply of artesian water from the east has no obvious catchment: the limestone inlier at Ashover is much too small. The limestone farther east is nowhere exposed and percolation water would have to pass down through thick Coal Measures Group, Millstone Grit Group and Craven Group clastic rocks, which seems highly unlikely. Indeed Downing *et al.* (1970, 1987) argue on the basis of increasing solute loads that the hydraulic gradient is down-dip towards the east and that water eventually rises through the Silesian cover into Mesozoic aquifers or even into the North Sea.

On the basis of the flotation method of separating minerals during post-mining processing, Varvill (1962) proposed that there had been secondary enrichment of galena by natural flotation. This required energetic streams coursing through vadose caves along mineral veins, with pulverized galena adhering to bubbles which were transported into the phreatic zone where they burst under pressure to release the galena. However, no real evidence for vadose streamways along veins has been found, and it is difficult to see how bubbles coated with galena were transmitted through the phreatic zone. Equally, no powdered galena deposited from such bubbles has been reported. Furthermore, Varvill proposed that the enriching waters overflowed via springs rising in the bed of the River Lathkill, and no such springs have been identified.

## CONCLUSIONS

A study of the lead mines around the Stanton Syncline has revealed the presence of caverns along mineral veins, some herein referred to as scriin-caverns. A sequence of hydrological and thus speleogenetic phases can be deduced, starting with deep-seated phreatic zone dissolution by connate waters being expelled eastwards, followed by an early phase of aggressive westward-rising mineralizing fluids in Late Carboniferous times. This led to partial collapse of cavern roofs. Mineral deposition took place in fissure veins and pipes, in the voids between collapsed blocks of scriin-caverns and as linings on the cavern roofs, also in Late Carboniferous times. Much later phreatic zone dissolution further enlarged the caverns during a phase when meteoric groundwater was moving eastwards as the cover of Silesian mudstones and sandstones was stripped back. A short-lived phase of fluvio-glacial sand and silt sedimentation during the early Pleistocene partially filled some of the caverns, enclosing detached galena as gravel ore.

At least two reversals of groundwater hydraulic gradient probably occurred as the Pennine Basin evolved into an antilinal uplift and was later exposed by erosion. Speleogenetic evolution went through an early sulphuric acid phase before entering a later carbonic acid phase.

The scriin-caverns of Mill Close Mine and the pipe vein caverns of the Winster area owe their pre-mineralization inception and post-mineralization development to dissolution along mineral veins in a similar manner to the vein cavities of the Castleton area (Ford, 2000b). However, any equivalents to the vadose stream caves of the latter area either never developed in the Stanton Syncline or have subsequently been removed by general surface lowering of the limestone.

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## Sariot Polje, Central Taurus (Turkey): a border polje developed at the contact of karstic and non-karstic lithologies

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**Abstract:** Sariot Polje, in the north of the Taurus Mountain range in Turkey, was investigated to determine its formational history. The polje group to which it belongs was established on the basis of its geomorphological and hydrological features. This polje lies in a region that is highly complex structurally and tectonically, within the Taurus Karst Belt. The Sorgun Stream flows towards the northeast along the contact between karstic and non-karstic formations in a valley that formed in the Late Miocene and was affected by tectonic movements during the Late Miocene – Early Pliocene, becoming a blind valley drained by various swallow holes. During the Early Pliocene the blind valley was converted into a polje by lateral karstic corrosion of the Jurassic – Cretaceous limestones. If examined from a geomorphological and hydrological point of view, Sariot Polje, which initially formed at the contact of Eocene karstic and non-karstic rocks, is seen to be a border polje.

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### INTRODUCTION

#### A general background to poljes and their classification

Poljes are generally described as large enclosed depressions with flat alluviated floors and karstic drainage within a karstic terrain. Although there are many common statements describing poljes and their formation, there has so far been no totally agreed consensus as to what poljes are. Taking their geomorphological description in the karstic literature into account, Gams (1978) accepts that some controversy remains over what a polje really is. According to Gams (1978) there are three criteria to be satisfied before a depression can be described as a polje:

- a flat floor on bedrock (which can also be terraced) within unconsolidated sediments such as alluvium;
- a closed basin with a steeply rising marginal slope on at least one side;
- karstic drainage.

There have been various attempts to classify poljes, which from geomorphological and hydrological viewpoints appear to be the most significant landforms of the karstic zones, especially within the Dinaric Karst (Lehmann, 1959; Gams, 1969, 1973, 1978; Ristic, 1976; Ford and Williams, 1989). However, Gams has made the greatest effort to erect a geomorphological and hydrological polje classification (Gams, 1969, 1973, 1978), but has classified poljes in different ways at different times. In his studies published in 1978 he classified poljes into five groups: 1) border polje, 2) piedmont polje, 3) peripheral polje, 4) overflow polje 5) baselevel polje. Ford and Williams (1989) claim that the poljes that Gams (1978) divided into five groups can be examined under three main headings (Fig.1). They thought that the first two types described by Gams were blind valley types, and they classified them both as border poljes. They grouped the third and fourth types together as structural poljes, and they left Gams' final type (baselevel polje) unchanged (Ford and Williams, 1989).

Gams (1978) described the border polje as a polje where the surface flow is along a contact zone, the flat floor partly cuts karstic rocks and water disappears through swallow holes. According to Ford and Williams (1989, p.431) "Border poljes are allogenic input dominated. They develop where the zone of water table fluctuation in non-karst rocks extends onto the limestone. This ensures that allogenic fluvial activity is kept at the surface and that lateral planation and alluviation dominate valley incision; otherwise blind valleys form. Floodplain deposits may partly seal the underlying limestone and encourage water to stay near the surface, although leakage may be widespread upstream of the final point of engulfment". As seen in both these groupings poljes developed at a

karstic – non-karstic contact were regarded as border poljes (Gams, 1969, 1973, 1978; Ford and Williams 1989). However in Lehmann's (1959) studies, border poljes were referred to as semi-poljes, randpoljes or marginal poljes. On the other hand Sweeting (1973) considered poljes to occupy two groups, one with impermeable beds forming the polje floor and completely surrounded by limestone (closed poljes) and the other comprising border poljes or rand poljes (open poljes). Ristic (1976) examined poljes from a hydrological point of view and classified them into four groups: a) wholly enclosed, b) open upstream, c) open downstream, d) open both upstream and downstream. Border poljes are among those that are open upstream.

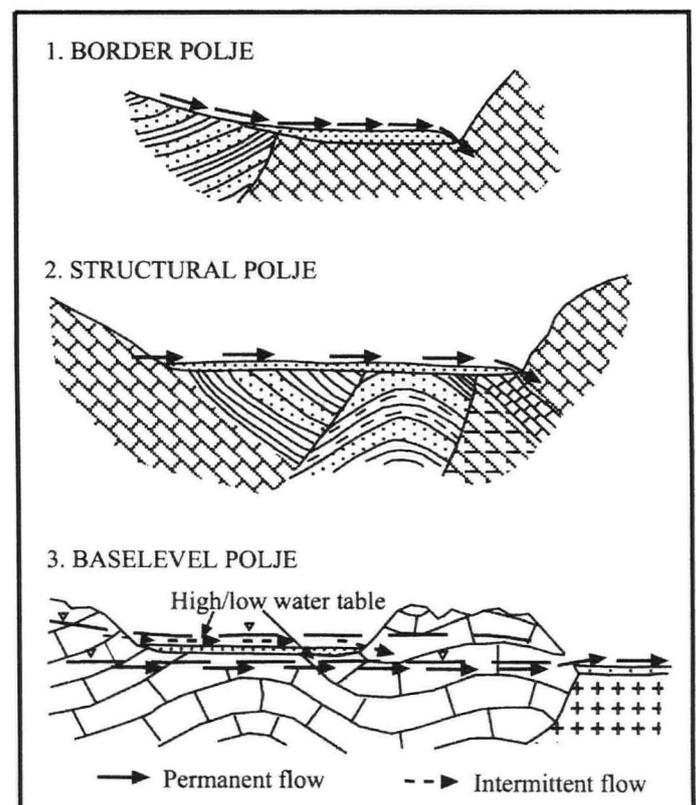


Figure 1. Basic types of polje (redrawn, after Ford and Williams, 1989, Figure 9.30).

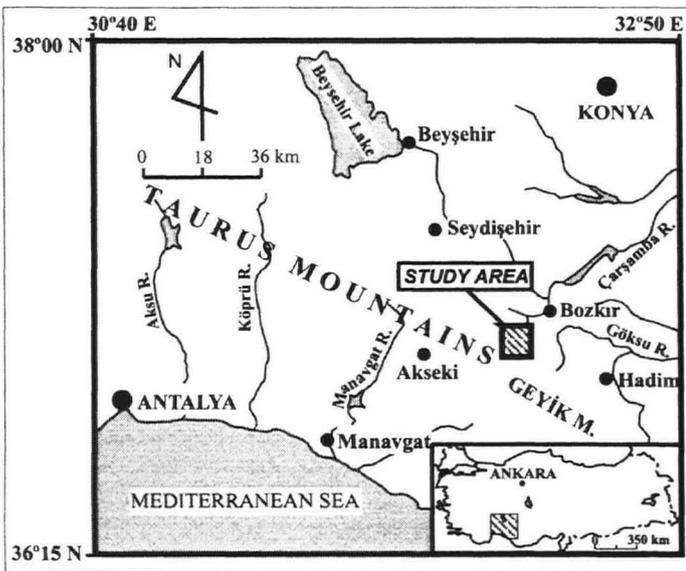


Figure 2. Location map of the study area.

### General features of Turkey's karst and poljes

Approximately one third of Turkey's total area comprises karstic terrain, and this contains many large and small poljes. Poljes, the macro structures of karst morphology, are generally widespread in the Taurus Karst Belt, developed upon the carbonate platform of the Taurus Mountains, especially in the Western and Central Taurus regions. The Taurus Mountains, which have highly complex stratigraphy, lithology and tectonic structure, are part of the Alpine – Himalayan orogenic belt. Poljes in southwestern Turkey are like those in the Dinaric Karst (White, 1988), though some researchers claim that poljes in the Dinaric Karst have their own unique characteristics.

The Taurus Mountains were greatly affected by palaeo-tectonic and neotectonic movements. In this region, well-developed karst features such as swallow holes, dolines (sinkholes), uvalas, dry valleys, poljes and caves have developed within a main fracture system and along a fault zone. This is why the tectono-karstic basins of the Western and Central Taurus Mountains contain poljes that extend along NW–SE and N–S trends. Erosional areas with non-karstic lithologies (such as metamorphic rocks, ophiolitic mélangé or Eocene flysch) lying within or around the basins have an important role in the formation of poljes and fluvio-karstic depressions, being formed by active fluvio-karstic processes (Erinç, 1971; Atalay, 1987a; 1987b; Doğan, 2002; Doğan and Nazik, 2003). Water kept at the surface by non-karstic material carried from the flysch in these areas to the polje floor causes recession in the polje slopes and facilitates lateral extension of the polje (Doğan, 1996). Nazik and Törk (2000) state that most of the poljes in the Central Taurus were tectonically controlled fluvio-karstic poljes formed during the Plio-Quaternary. According to Güldal (1976), poljes in the Western Taurus developed alongside the platforms between the Miocene molasse and Mesozoic limestones. Most of the poljes in the Central Taurus are formed at the borders between Eocene flysch formations and Jurassic – Cretaceous limestones. The north face of the Central Taurus towards Central Anatolia is a region of tectono-karstic basins or poljes. Although they are closed at the surface, the poljes are connected to the Mediterranean Sea via NE–SW trending faults (Nazik and Törk, 2000).

Some of the big poljes, located in the Western and part of the Central Taurus region (such as Elmali, Kembos, Kestel, Akseki, Suğla, Kovada poljes, etc.) are thought to be important with regard to karst geomorphology and hydrology, and have been subjected to various types of scientific research (Güldal, 1970, 1976; Güneysu, 1991; Nazik, 1992; Çelik, 1994; Doğan, 1997). However, these poljes have not yet been fitted into any geomorphological or hydrological classification.

### The aim and the study area

Sariot Polje lies 14km west of Bozkır town in southern Turkey, on the northeast side of Akdağ Mountain (2419m), part of the Geyik Mountains, which belong to the Central Taurus range overlooking Central Anatolia (Fig.2). The study area covers approximately 95km<sup>2</sup>. The polje floor at an altitude of 1707m is 3km long and 1km at its widest point.

Alagöz (1944) first mentioned Sariot Polje, but did not give detailed information. Whereas most poljes in the Taurus Karst Belt were connected to the Mediterranean Basin, Sariot Polje developed within the Konya Closed Basin in Central Anatolia. Features of the region around the polje throw light on the tectono-geomorphological development between the Central Taurus Mountains and the Central Anatolian plateaus. Although small in area, Sariot Polje is a typical example with regards to karst morphology development stage and karst hydrology. The inputs and outputs of the polje and its basin can even be determined by geomorphological methods.

This study concerns the development process and hydrological properties at the karstic – non karstic rock interface in Sariot Polje. It is expected to be the starting point for a classification of the poljes that constitute a large part of the Turkey's karstic regions and which are of great importance with regard to socio-economic activities.

### GEOLOGICAL FEATURES

Sariot Polje is in an area of highly complex tectonics and structure within the Central Taurus Mountains. Preserved rock formations were formed between Devonian and Eocene times (Fig.3). However, as mentioned above, formations related to different environments are juxtaposed tectonically (Blumenthal, 1947; Monod, 1977; Akay and Uysal, 1988; Özgül, 1997). In other words, units deposited at different times, under different conditions and in different areas are brought together by the influence of nappe tectonics. Apart from these deposits, Quaternary alluvium occurs on the valley floor.

The Devonian, Carboniferous, Triassic – Jurassic and Lutetian formations are not prone to karstification. To these must be added the Mesozoic ophiolitic mélangé. Among these non-karstic units a Lutetian formation comprising sandstone, shale and various clasts,

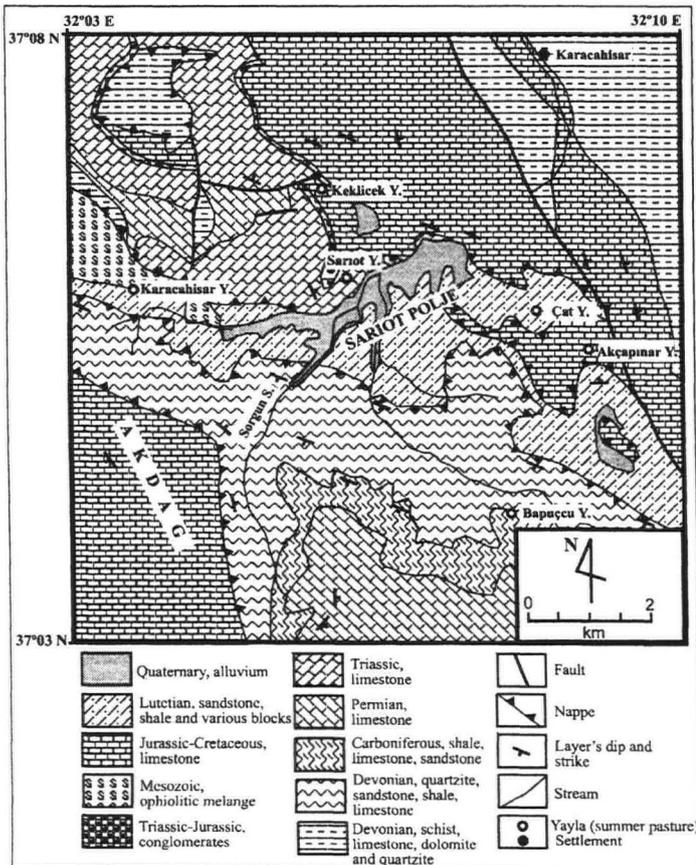


Figure 3. Geological map of the study area (derived from the Maden Tetkik ve Arama [MTA], or General Directory of Mineral Research and Exploration of Turkey).

referred to as Sobüçimen by Özgül (1997), had a very important role in the development of the polje.

Formations around the Sاریot Polje that are prone to karstification originated during three different periods. Among these, a Permian formation found at Gökbelen Hill, south of Sاریot Polje, comprises limestone with sporadic sandstone bands near its base. Another, from the Triassic Period, crops out northeast of Sاریot Polje and comprises limestone with some clay and sand. The third karstifiable formation is of Jurassic – Cretaceous age. Jurassic – Cretaceous limestones north and east of Sاریot Polje that are directly related to the polje are allochthonous, and Jurassic – Cretaceous limestones at Akdağ in the southeastern part of the area are autochthonous (Fig.3). The upper parts of both units are Cretaceous white-grey limestones containing many rudist fossils. The lower parts are blue-grey Jurassic limestones. These limestones are 550m thick in the Akdağ region, thinning to 400m in the allochthonous limestones in the east and northeastern parts of the polje.

## GEOMORPHOLOGIC DEVELOPMENT IN THE SARIOT POLJE AREA

The Sاریot Polje is a small closed basin within the Geyik Mountains, a part of the Central Taurus Mountains. The basin is surrounded by extensions of the Geyik Mountains, such as Akdağ (2419m) to the westsouthwest, Üçardıçlar Hill (2079m) to the westnorthwest, Menendi Hill (1828m) to the east, Esenek Hill (2070m) to the southeast and Gökbelen Hill (2198m) to the south (Fig.4). Although these elevations are known as mountains or hills they are all plateaus or denudational surfaces at different levels, which have undergone significant periods of erosion. Among them Akdağ, Menendi Hill and parts of Üçardıçlar, Gökbelen and Esenek hills display karstic plateau characteristics (Fig.4).

The most widespread landform around the polje is a denudational surface (Erol, 1990; 2001; Nazik, 1992; Doğan, 1997; 2002; 2003), characteristic of a high plateau above 1900m, which cuts across almost all the karstic and non-karstic, autochthonous and allochthonous formations of Devonian, Carboniferous, Triassic, Permian, Jurassic – Cretaceous and Lutetian age. According to data obtained in the study area, this surface is the first denudational surface (Mid Miocene) developed after the area became continental in the Late Eocene (Akay and Uysal, 1988; Özgül, 1997).

Development of this Mid Miocene denudational surface (2100–2300m) (Fig.4) around the Sاریot Polje ended after the development of the new base level that appeared as a result of tectonic activity (block-faulting, etc.) and epeirogenic movements in Late Tortonian times (Şengör, 1980; Koçyiğit, 1981; 1984; Akay and Uysal, 1988; Erol, 1990). According to tectonic data and regional correlations the surface is the product of prolonged erosional processes since the area became continental, and is of Mid Miocene age (Erol, 1990; 2001; Nazik, 1992; Doğan, 1997). Parts of the Mid Miocene denudational surface lying on limestone are in the form of plateaus, where karstic landforms such as karren, uvalas and dolines are common (Fig.4). Concentrations of dissolution dolines are seen especially on the Cretaceous limestone at Akdağ.

Following renewed tectonic activity during the Late Tortonian, a new geomorphological process started in accordance with the newly formed base level. These intense tectonic movements in the Upper Miocene imprinted the basis of many tectono-karstic basins, largely in the form of closed depressions whose borders are determined by fault lines in the inner and northern parts of the Western and Central Taurus Mountains, especially in the Lake District (Bircik, 1982; Koçyiğit, 1981, 1984). The Sorgun Stream was connected to the Beyşehir-Suğla closed basin at that time.

Evidence from the reshaped regional and local base levels in this period suggests that the Mid Miocene denudational surfaces were dissected, and a new denudational surface developed. The area-wide denudational surfaces evolved into trough type erosional features normally observed in newly formed tectonic depressions or valley systems (Erol, 1990). During this renewed period of uplift and erosion new denudational surfaces developed in the trough occupied by Sاریot Polje. These now lie at 1800–1900m and extend from northeast to southwest (Fig.4). The slope of this surface towards the Çarşamba River in the northeast shows that the floor of the

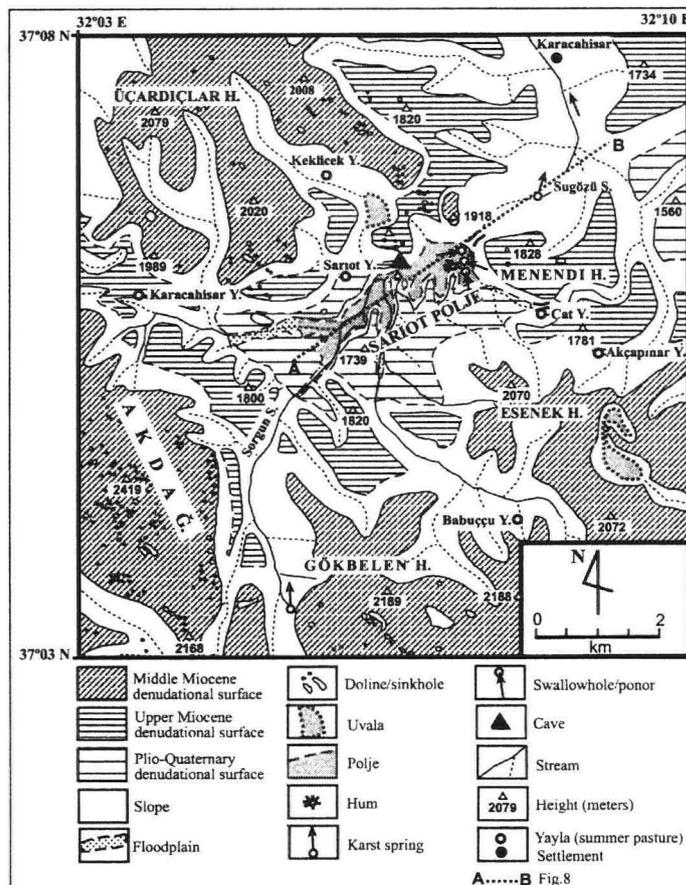


Figure 4. Geomorphological map of the study area.

Beyşehir–Suğla tectono-karstic depression acted as the erosional base level. Late Miocene deposits in the Beyşehir-Suğla depression appear to correlate with the latter denudational surface. Erol (1990) states that these surfaces relate to fault lines cutting the mountain regions, and he described them as Tortonian denudational surface troughs. Concentrations of karren and dissolution dolines are observed in regions where the Late Miocene denudational surface cuts the limestones and, especially, where Jurassic and Cretaceous limestones are present.

The last denudational surface recognized in the research area is observed in a narrow area within the Sاریot closed basin and especially around Sاریot Polje. This denudational surface was shaped with respect to a regional base level influenced by Sاریot Polje itself. Tectonic movement of the Central Taurus between the Late Miocene and Early Pliocene directly affected the Beyşehir-Suğla depression, causing a discontinuity in the Late Miocene denudational surface. The Sorgun Stream, which joins the Çarşamba branch at a confluence east of the Sاریot Polje at 1760m, could not adapt to the vertical fault movement and lowering base level caused by the Late Miocene – Pliocene tectonic movements in the Beyşehir-Suğla depression. This is why the drainage of the Sاریot Polje region is via swallow holes that formed in the Jurassic – Cretaceous limestones. The Plio-Quaternary denudational surface (Fig.4), which started to develop relative to the base level provided by Sاریot Polje, acquired its closed basin character starting in the Early Pliocene.

## SARIOT POLJE

As mentioned in the consideration of the general geomorphological development of the research area, the Sاریot Polje started to develop during the Early Pliocene. It is still in active development today. During the Late Miocene the palaeo Sorgun Stream originated at about 1900m between Akdağ and Gökbelen Hill and flowed along the contact between Jurassic – Cretaceous and Triassic limestones and Lutetian non-karstic rocks (where the present polje exists) to reach the Çarşamba River (Figs 3 and 4). During the tectonic movements of the Late Miocene – Early Pliocene the Sorgun Stream was unable to adapt its valley to the Beyşehir-Suğla depression's base level across elevation changes where faults cut across its valley.

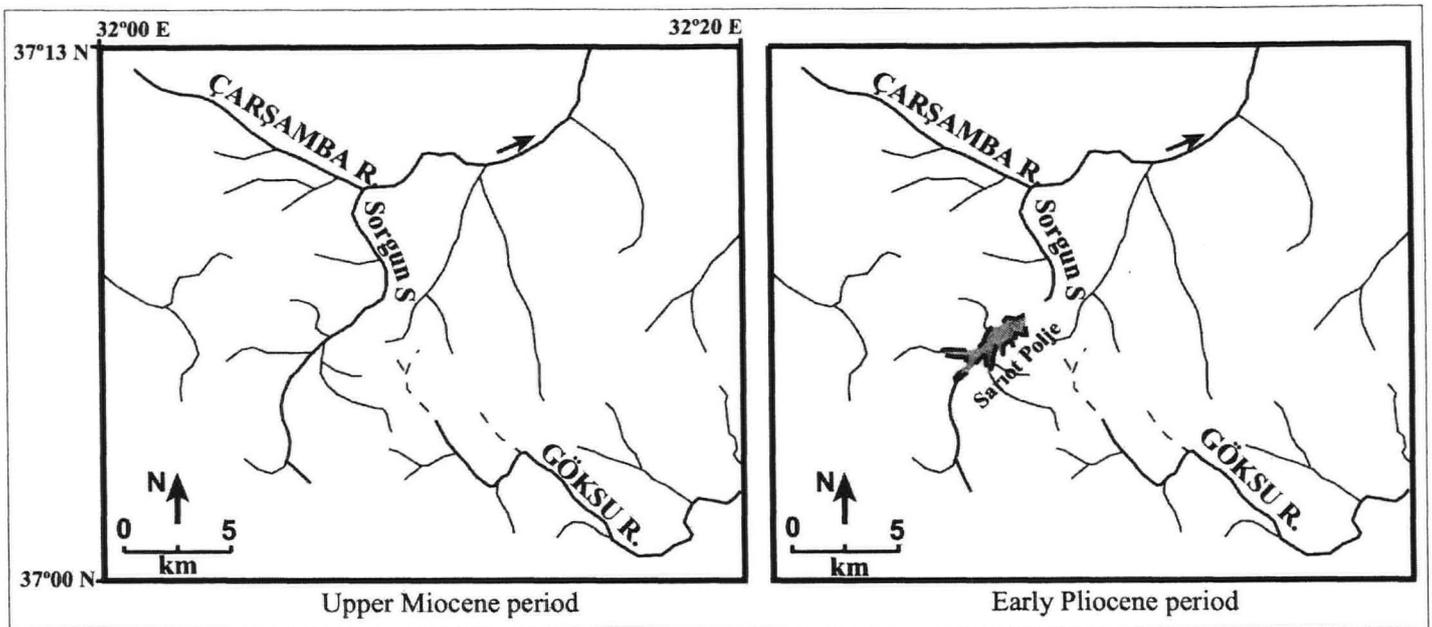


Figure 5. Drainage maps of the study area and its surroundings during the Late Miocene and Early Pliocene.

Thus karstification started on a hanging valley floor (Fig.5). Drainage of the Sorgun Stream waters by the swallow holes in the polje region caused the Sorgun valley to become a blind valley. Because the hydraulic gradient is not steep in such elongate blind valleys, there appears to be no vertical incision but only lateral planation. Such processes cause neighbouring blind valleys to merge, eventually resulting in formation of a large enclosed depression (Ford and Williams, 1989). Thus, a blind valley that formed a significant time before the initiation of lateral enlargement turns into a polje. If the present shape of the polje is examined it can be concluded that the polje formed due to karstic development, as a result of superimposition of the palaeo Sorgun Stream and its branches flowing at the karstic-non-karstic lithological contact (Fig.4). 20m erosional terrace levels observed southwest of the polje and the V-shaped hanging valley southeast of the polje verify this situation. The evidence indicates that Sarıot Polje began to form in the Early Pliocene.

Sarıot Polje's has a distinctly flat floor at 1705m, which is truncated to the north by steep plateau sides ranging from 50 to 100m in height (Fig.6), while 10 to 20m-high steps limit the polje to the south. The polje extends northeast – southwest and reaches 3km

in length, with an average width from 300–500m and a widest section of 1km (Fig.4).

Alluvial deposits, which are mainly restricted to the polje floor, reach a thickness of 5m in the western region, where the swallow holes are located. The alluvium comprises clay, silt, sand and pebble material derived from non-karstic sources. Two hums a few metres in height at the eastern end of the polje are formed of grey-blue Jurassic – Cretaceous limestone (Fig.7). Hums and a 6 to 7m-high limestone mass left from the karstic denudation at the southern border of the polje show that the polje floor formed in Jurassic – Cretaceous limestone and the limestone disappeared as a result of corrosion. The slopes to the north of the polje show that the lateral development due to corrosion is ongoing.

The main factors affecting the lateral enlargement, or in fact the overall development of the polje, are the operation of differential denudation processes on the karstic and non-karstic rocks, and the presence of a low gradient water table in the non-karstic rocks in the contact area (Fig.8). The transition zone of the water table, which extends up to the limestone within the nappe surface in the polje's development area, kept the fluvial activity at the surface. This made lateral planation and alluvial sedimentation much more effective



Figure 6. The polje is extensive and has a large flat alluviated floor. The north and east sides of the polje are surrounded by steep slopes of Jurassic – Cretaceous limestone. The "V" shaped col seen in the slope northeast of the polje is a vestige of the Sorgun Stream valley dating from the Late Miocene.

**Figure 7.** Hums that rise above the polje's flat alluvial floor provide evidence of the lateral development that allowed the polje to form.



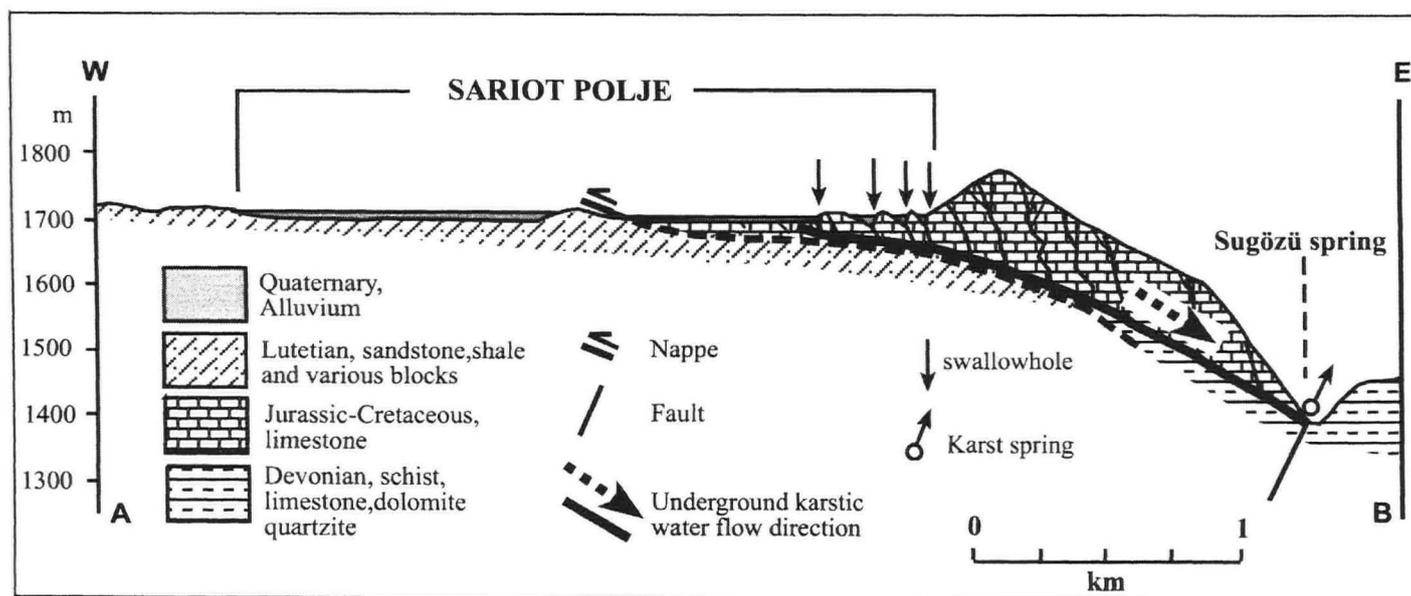
than the incision of the valley. According to Ford and Williams (1989, p.431), "Where a low gradient water table is close to the surface, lateral fluvial planation (corrosion and corrasion) and deposition processes are more important than incision, hence plains are created rather than deep valleys". Non-karstic Lutetian rocks lying on top of the Jurassic – Cretaceous limestone at the polje site form the local karstic base level, resulting in development by incision being replaced by lateral planation (Fig.8).

Swallow holes have formed either on the flat alluvial surface covering the limestones in the polje floor or at contact between the alluvial floor and the limestone. Small suffosion dolines with a depth of 1 to 5m and 2 to 10m across formed around the swallow holes as a result of alluvial material being carried underground with the sinking water (Figs 9 and 10). The sizes of the suffosion dolines change according to the year and the season. During suffosion doline development the transmissivities of the swallow holes may be reduced by build-up of sedimentary material carried away from the polje floor.

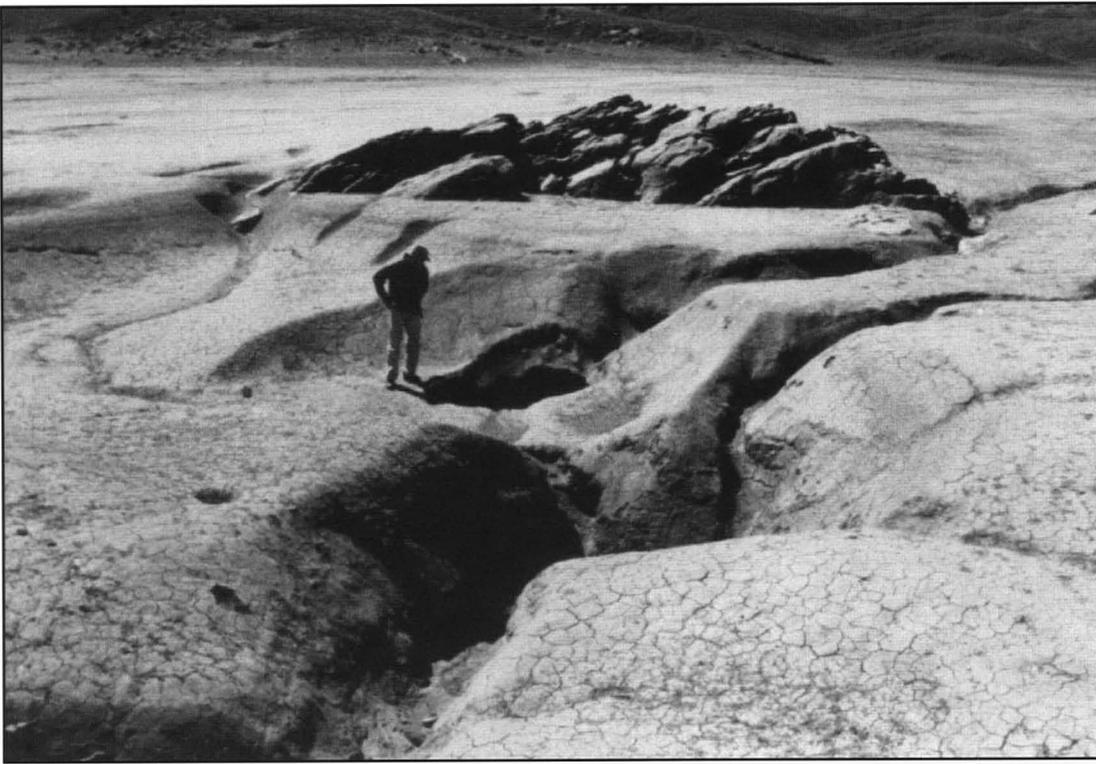
Between November and May the water input to the polje exceeds the capacity of the swallow holes. Thus, at this time of year, a 3m-deep lake generally covers the polje floor. There are several

reasons for the polje floor being water-covered. Firstly, most of the rainfall in the region occurs in winter and spring, and the water level in the non-karstic formations rises during this period. Secondly, snow precipitated at higher level melts during the spring months, augmenting the surface flow into the polje. Thirdly the swallow holes in the northeast of the polje become partly clogged by sediment transported by the increased flow. At the start of the summer months a small amount of water remains, with a small area of swampland surviving afterwards in the cave region. Traces of the lake's shoreline are visible on the southern banks of the polje (Fig.11).

No experimental work has been carried out to confirm where the water sinking through the swallow holes in the polje resurges. However, geological and geomorphological data, investigations in the surrounding area and the statements of local people appear to suggest that the water emerges at the Sugözü karst spring (Fig.8). Various strands of evidence support this hypothesis. Firstly the karst terrain to its north and east is not very large. Secondly the basement of this area and its surroundings is formed of non-karstic rocks and karstic base level is not deep. Thirdly, although the karstic aquifer behind it appears insufficient, abundant water emerges from the



**Figure 8.** Geological and geomorphological cross-section of Sarıot Polje, a border polje developed along the contact zone of karstic and non-karstic formations. Water that disappears in swallow holes in the polje floor emerges from the Sugözü Spring.



**Figure 9.** Alluvial or suffosion dolines are formed around swallow holes within thick alluvial deposits on the polje floor.

spring. Added to these considerations are the observed dip and strike of the karstic rocks. It would be natural to expect that any underground water flow will be in accordance with the surface flow at the northeast end of the polje or valley system, since the Çarşamba River valley also acts as the karstic base level for this region. Apart from that, the Sorgun Stream, which disappears at the polje, is the remains of the palaeo Sorgun Stream, and the flow of karstic water coming from Sugözü Spring is in perfect accordance with the valley of the Sorgun Stream, which continues the deepening of the valley (Fig.4). Thus, it can be asserted that the 2400m part of the Sorgun Stream to the east of the polje has continued its flow under the ground and maintained its existence, channeling its waters to the Çarşamba River, since the Early Pliocene.

## DISCUSSION AND CONCLUSION

The bedrock formations around the area surrounding Sarıot Polje are dominated by sedimentary rocks deposited in Devonian to Eocene times. These formations, which are mostly allochthonous, settled in the region in the form of nappe masses following Senonian and Lutetian earth movements. Up to now there have been rapid land denudation and sedimentation processes in the region, and landform features date back to the end of Eocene. Intense palaeotectonic and especially neotectonic movements have been the most important factors influencing geomorphological development in the region.

Mid Miocene, Late Miocene and Plio-Quaternary denudational surfaces have developed around the site of Sarıot Polje. In contrast to the Mid Miocene denudational surface, which developed in accordance with a general regional base level, the Late Miocene denudational surface in the research area formed relative to the Beyşehir-Suğla depression. The area has had a closed basin character since the Early Pliocene, as a result of tectonic movements in Late Miocene to Early Pliocene times. During the Late Miocene – Early Pliocene, part of the Sorgun Stream, which flowed to the Çarşamba River on the surface, became a blind valley. The Sarıot Polje began to form due to karstic lateral planation, starting from its original blind valley form due to the prevailing low hydraulic gradient in the Early Pliocene. Polje development is continuing today.

Cvijić (1893) claims that to be described as a polje the width of the flat floor of a karstic formation should be at least 1km. On the other hand, Gams (1978), says that this distance should not be less than 400m. The dimensions of Sarıot Polje are within these limits (average width is 400–500m, and the widest section is 1000m). However, as mentioned by Ford and Williams (1989), these criteria

are completely arbitrary. In order to describe a karstic formation as a polje one should take its geomorphological (karstic) and hydrological features into account rather than just its dimensions.

Sarıot Polje is a polje displaying various diagnostic features including karstic drainage, a large flat alluvial floor, a typical closed basin character, hum hills, a temporary lake formed during the winter and spring months and drainage swallow holes (Jennings, 1971; Gams, 1978; Bögli, 1980; White, 1988; Ford and Williams, 1989). Water that disappears via swallow holes in the polje floor re-emerges from the Sugözü (Aygır) spring, to the east.

Additionally, Sarıot Polje is a border polje, where lateral planation and alluvial sedimentation at the karstic–non-karstic rock interface has been effective as a result of the water table fluctuation extending onto the limestone and keeping allogenic fluvial activity at the surface (Gams, 1978; Ford and Williams, 1989). Sarıot Polje is among the polje group whose upper part is open, according to the Ristic (1976) classification.

Border poljes have a significant place among the several polje types present in Turkey. In Turkey, geomorphological and hydrological grouping of the poljes is very important with regard to the description and evaluation of karstic features.

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**Figure 10.** Suffosion dolines on the polje floor are up to 5m deep and 10m across.



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**Figure 11.** Traces of the shoreline of a 3m-deep ephemeral lake are visible on the southern hills of the polje.



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## Karst and caves in Madagascar: further observations.

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**Abstract:** Explorations during an extended visit to the Mahafaly, Toliara and other little-visited karst areas in Madagascar revealed new and up-dated information on some caves, including Ankikikymaty (85m deep).

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### INTRODUCTION

This short report is intended to be read as an addendum to an earlier paper by Middleton and Middleton (2002), wherein locations of the karst regions are identified on a figured map of the island and there is further background information on the Madagascan karst. The sites described below were those visited in autumn 2003. A fact that might clarify some of the confusion over Madagascan cave literature is that J Radofilao and J Dufloss are the Malagasy and French names of the same person.

### MAHAFALY

Within the Itampolo area a low terrace of Quaternary coralline calcarenite extends from the coast to the base of a prominent and continuous escarpment that rises to an altitude of 120m (Fig.1). This terrace is variously covered by dry forest and scrubs or is used for subsistence farming by villagers. The steep slope of the escarpment is very rocky and includes many small limestone cliffs etched by karren. Above the escarpment a low-relief plateau is covered in dense xerophytic forest, but there are extensive exposures of flat-lying and locally fractured limestone. This surface is pitted by many circular dissolution pockets and flat-floored kamenitzas. Both above and below the escarpment, recorded caves are mainly collapse

dolines, and no true horizontal cave passage development has yet been found.

The potential for cave discovery appears considerable, but exploration through the forest is difficult. Decary and Kiener (1970) briefly mentioned the area for its "avens". More recently, Gregg Middleton described various caves observed during a 1998 visit and, in 2000, Jean-Claude Dobrilla and Florent Colney conducted a two-man expedition (Delaty, 2000). A few caves were visited (Fig.1).

**Androypano** (at S24°39'00.7" E43°57'47.5", alt. 87m) is reached along the old road to Ejeda, onto the plateau and then after 300m a small path on the left leads into the succulent forest. Some 150m along this path, close to an impressive baobob tree, the cave is a 15m x 9m hole (Plate 1). The karren-fluted walls of the shaft descend 4 to 6m before belling out into a large chamber, with the top of a rock and sand pile just visible about 30m below. The floor drops into darkness, and the depth was estimated to be at least 50m. Many Greater Vasa Parrots (*Coracopsis vasa*) and African Black Swifts (*Apus barbatus*) nest within the hole.

**Anikotse** (S24°38'18.3" E43°56'56.9", alt.24m) is difficult to find without a local guide. A chamber reached from a roof collapse some 6m across measures roughly 30m x 15m and is up to 4m high. A hole in one corner gives access to a small water supply used by local villagers, and takes the depth to -10m.



Plate 1. Androypano.  
Itampolo area.

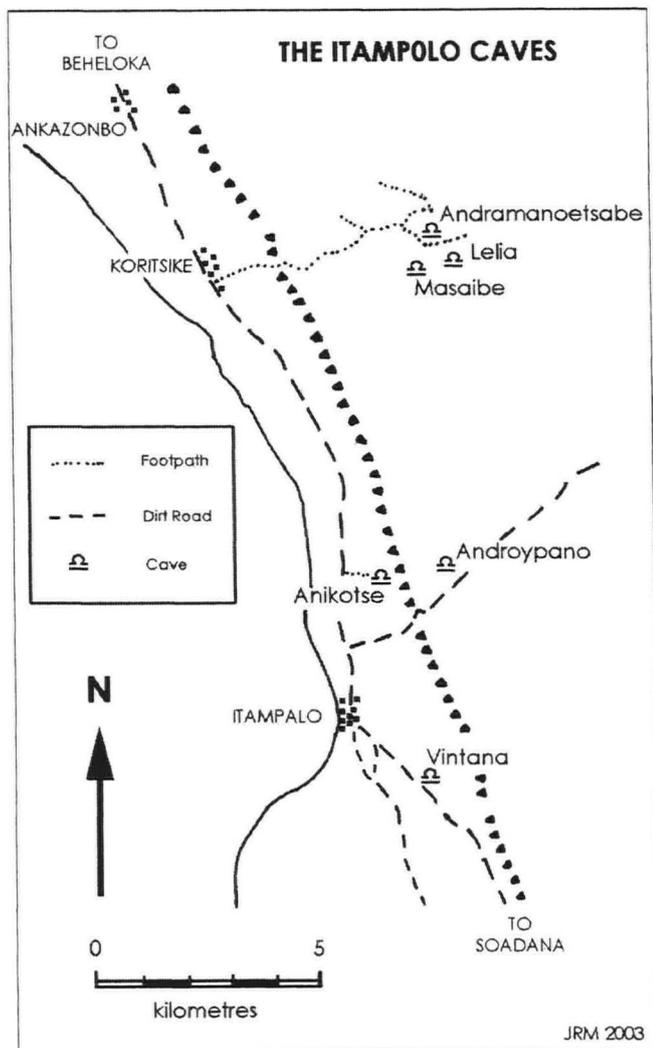


Figure 1. Features around Itampolo within the Mahafaly karst.

**Vintana** (S24°42'07.2" E43°57'51.2", alt. 12m) is a classic cenote, 2km south of Itampolo and just 50m east of the main road (but not easily seen within the thick scrub). The sinkhole measures 40m x 35m, with vertical walls dropping 5–10m to the lake surface. A large species of *Ficus* grows from the water and allows precarious access, but there is a local "fady" that bans swimming.

**Andramanoetsabe** (S24°34'31.3" E43°57'58.4", alt. 36m) lies in a large, forested depression (or valley) 3km along a track from Koritsike. It is an impressive collapse doline, about 50m by 35m across, with a well-trodden path leading down to a large and murky pool used by both humans and cattle. Above the pool, vertical walls rise at least 50m directly onto the plateau. From here, a short but difficult walk through the forest crosses to the opposite side of the valley, where **Lelia** is another equally impressive collapse doline about 70m across. Its undercut walls rise 18m above a cool, crystal clear pool apparently untouched by the villagers. **Masaibe** is a large gash in the hillside, which was seen from a distance but could not be found in the dense forest.

### TOLIARA

Flat-topped hills of Eocene limestone dominate the landscape north of the perennial Onihaly River (Fig.2). Notable caves are unknown on either the slopes or at river level, but two large risings (each of several m<sup>3</sup>/s) lie close to the villages of Ambohimavelona and Ambinanitelo. At levels of 180–300m, gently rolling plateaux (*lembalemba*) were, until less than four years ago, covered in dense xerophytic forest. This is currently being removed by an influx of new farmers from Toliara, hoping to grow maize. About 75% of the plateaux surfaces are composed of well-fractured limestone, with many minor karren features. A few large shafts are known, and clearance of the forest may reveal more.

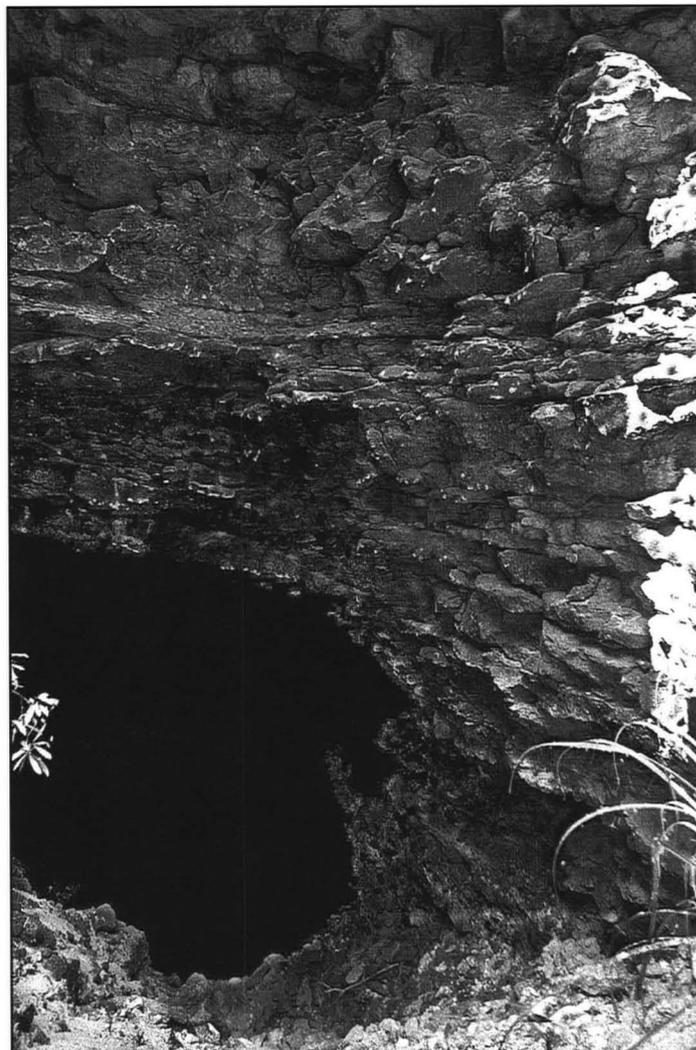


Plate 2. Ankikikymaty at -15m. The small bright white "blurs" are cobwebs.

**Ankikiky Velo** (S23°24'14.7" E43°58'34.4", alt.228m) lies in a shallow depression on the Lembalemba Ankikiky, a 7km walk from the village of Tolikisy. The open shaft is 60m across, with vertical sides plunging 70m to a boulder-strewn and vegetated floor without exit. French cavers have descended it several times in the past 40 years.

**Ankikikymaty** (S23°24'50.8" E43°58'35.9", alt.230m) is an impressive hole lying 15 minutes walk beyond Ankikiky Velo. A shaft 25m in diameter is just climbable for 15m down (Plate 2) to a soil floor, from where a passage 20m wide and 15m high descends over breakdown at an angle of 45° until levelling out at -85m (Fig.3). Lack of light precluded further exploration, but thrown rocks found no open shaft. Local guides stated that nobody had been down previously. It is difficult to believe that this cave is unrecorded, but the only other reported cave in the area is Gouffre de Tolikisy – a name that the guides did not recognise. This is recorded as 160m deep (Laumanns, 2002; Decary and Kiener, 1971), but no exact location is stated. Decary and Kiener note that a 205m rope is needed, but this still does not equate with this cave.

**Ankikiky Lava** (S23°30'29.1" E44°09'46.1", alt.171m) lies 3.3km from the Seven Lakes campsite along a regularly used cattle trail from the end of the lakes. A shaft 2.5m across has collapsed through limestone barely 0.5m thick that forms the roof of a great chamber, with a debris floor some 30m below. This cave also appears to be unrecorded.

**Amparihy-Fito** (S23°31'33.9" E44°09'16.1", alt.59m) is also known as the **Seven Lakes**, about 2km west of Ifanata. The Antsimaha stream descends through a series of azure-blue pools separated by tufa cascades and waterfalls. These lakes are up to 60m long and 4m deep, and the chain extends for over 700m within a superb gallery forest. Tufa deposits occur for a further 2km upstream



(but access is difficult). Tufa is also seen along the road from Tolikisy village to Seven Lakes (Salomon, 1981).

### MIKOBOKA

The Andabotoka plateau is a beautiful wilderness reached by a 23km walk (Fig.4), for which all food and water must be carried in. The plateau offers panoramic views over ancient savannah and xerophytic forests. There are numerous dolines, and those containing a few trees invariably host exposed limestone and shafts. Within an hour twelve shafts more than 10m deep were noted. Beyond the village of Andabotoka lie the slightly higher Manamby and Mikoboka plateaux. The local guide stated that all the Andabotoka, Manamby and Mikoboka lembalembas are riddled with shafts up to 200m deep, of which only a few had so far been descended by French cavers.

### MIKEA

The great expanse of Alan ny Mikea is low relief, very dry, very hot and covered in a dense xerophytic forest (Fig.4). Between Helodrano Fanemotra (Bay of Assassins) and Morombe the forest grows on a

Quaternary dune karst that also has exposures of eroded rock, a few collapse dolines and small caves to 175m in length (Middleton, 2000). South of Helodrano Fanemotra, horizontal Miocene limestone, mostly covered in deep sand, has scattered cenotes, collapse dolines and rock exposures fretted by large karren (Salomon, 1978).

Just 1500m south of the village of Amponanga, the cave of **Andranamba** (S22°14'09.2" E43°19'10.9", alt. 18m) is a vertical shaft 20m by 15m wide and 12m deep within thick forest. A scramble down leads to a cave 15m long and 10m wide floored by a lake where the blind fish *Typhleotris madagascariensis* is reported to live (but was not seen on our visit). The surface over the cave and beyond is fluted by impressive karren, with several holes breaching

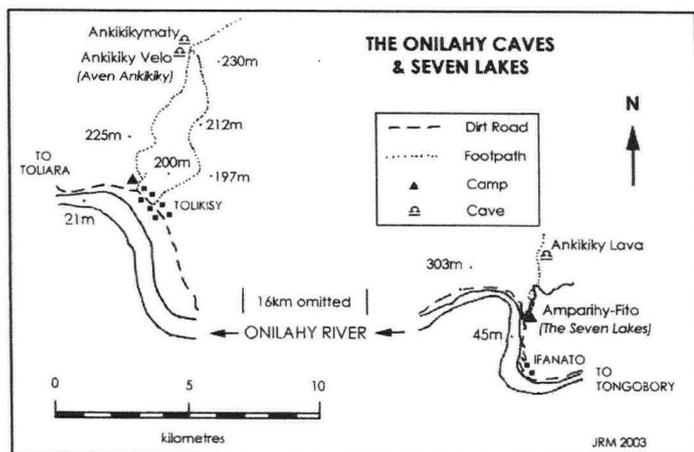


Figure 2. The Onilahy and Seven Lakes area within the Toliara karst.

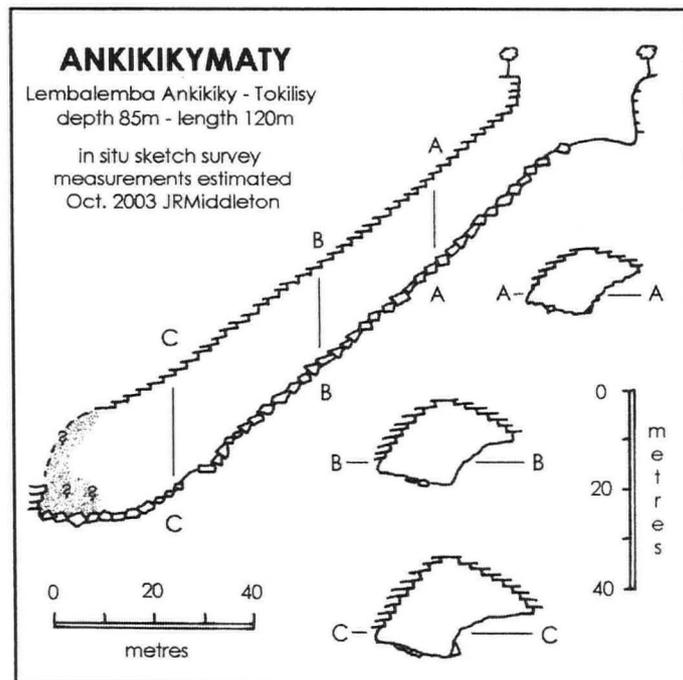


Figure 3. The cave of Anikikymaty.

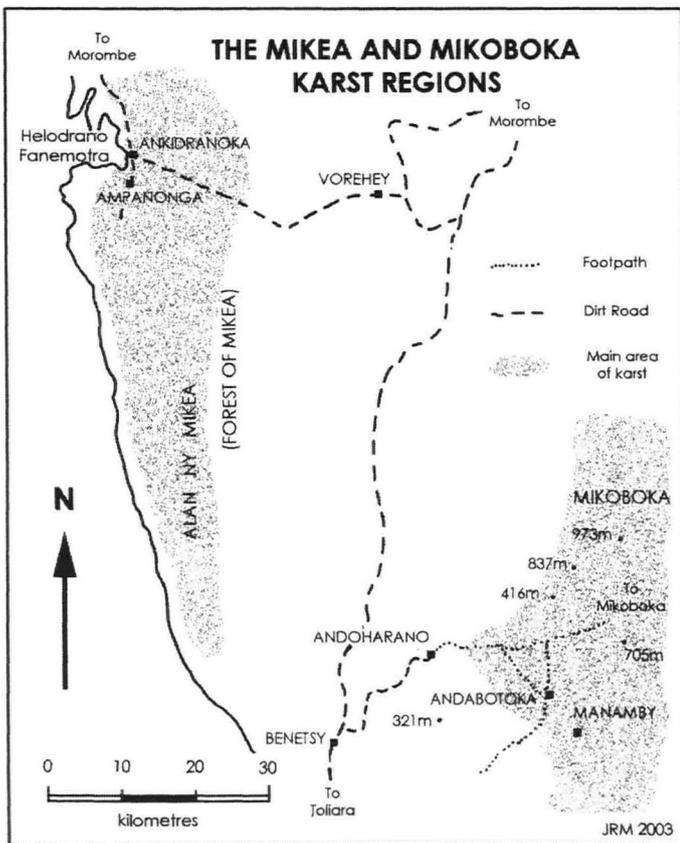


Figure 4. The karsts of Mikea and Mikoboka.

the cave roof formed in distinctly pink limestone. This cave appears to have been noted but not named by Salomon (1978).

### NARINDA NORTH

Further investigations have revealed the very beautiful cave of **Ampsekina** (700m long) and others in the Amboaboaka area (Middleton, G, pers. comm.).

### MOUNT IBITY

Mount Ibity (Plate 3), 2254m high, is a small but readily accessible massif of Precambrian quartzite, pegmatite and dolomite lying some 25km south of Antsirabe and west of the main RN7 road. Karst features are well documented (Decary and Kiener, 1970), and in 1991 German cavers explored **Grotte Albert** to 43m deep and 152m

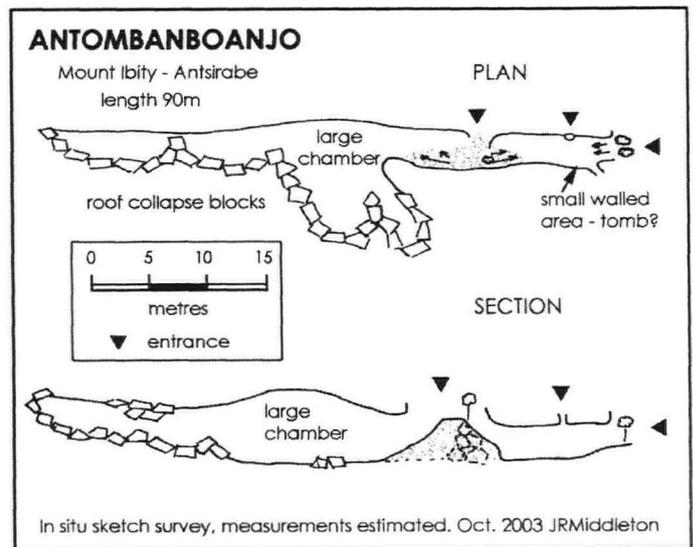


Figure 5. The cave of Antombanboanjo.

long (Laumanns, 2000). Our attempt to visit this cave failed, but instead we found **Antombanboanjo** (S20°05'50.0" E47°00'22.0", alt. 2112m) just below the north side of the summit ridge. It has three entrances with the easiest access through a much-vegetated roof collapse (Fig.5). About 90m of passage are strewn with breakdown but do retain dissolutional features on the solid walls and roof. Extensive Malagasy graffiti in the entrance area show that this cave is locally well known, and it appears to be the highest cave yet reported in Madagascar.

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## Preliminary LIDAR survey results from Peak Cavern Vestibule, Derbyshire, UK

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**Abstract:** A third phase of investigation of the Peak Cavern Vestibule, using cutting-edge LIDAR total station equipment, obtained a 16.8 million co-ordinate data point cloud, which was re-sampled into a digitally-rendered, 3-D triangular surface model. Visualisation software allows dynamic viewing of the data model from any angle or orientation, with editing software allowing picking, interpretation and horizon generation of geological features of interest. Model analyses of surface 'en-echelon' joints reveal an anticlinal fold hinge mid-way through the Vestibule. Bedding planes were found to be sub-horizontal but parallel to the Vestibule main body axis.

A CD-ROM of the data model and IMView visualisation software is freely available on request, contact Robin.Westerman@pet.hw.ac.uk

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### INTRODUCTION

This paper introduces a third phase of site investigation in The Vestibule, or entrance chamber, of Peak Cavern, Derbyshire, UK. Hancock (1999) used ground resistivity geophysical techniques to profile the cave earth deposits along a rope-walk and five artificial benches descending to a stream-bed at the side of The Vestibule. Pringle *et al.* (2002) built a multidata 3D-CAD model from Hancock's geophysical results plus new Ground Penetrating Radar (GPR) data and a Total Station laser theodolite survey.

The Peak Cavern Vestibule was re-surveyed on the 2<sup>nd</sup> June 2003 with ground LIDAR (LIght Detection And Ranging) equipment. Ground LIDAR is the next-generation surveying technique, wherein very rapid acquisition of co-ordinate data points creates a highly-detailed data point cloud of the object or area. LIDAR acquisition equipment scans objects in an 80° vertical range and a 150° lateral frame scan. A fully three-dimensional digital model of an object or survey area can be produced by combining scans, if artificial reflector patches are placed in overlap zones between survey swaths. LIDAR technology is developing rapidly and both the image quality and the scan rate are ever improving. However, equipment is relatively expensive and in short supply at the time of writing.

### VESTIBULE SURVEY AND RESULTING DIGITAL MODEL

A Riegl LMS-Z360 high-speed scanner acquired 16.8 million co-ordinate points of the Vestibule in 8 surveys (termed swaths) in four hours. Data points had a 1cm sample interval and 1.2cm resolution. The previous professional Total Station survey acquired 400 xyz points in four hours. The LIDAR data rate peaked at 18,000 data points per second. After combining separate swaths, the resulting data point cloud was re-sampled by InoMetric IMAlign software, firstly to remove duplicated swath points, then re-sampled into 8.5 million triangular apex points. A triangulated surface was then fitted through these points and rendered, vertex separation of the model being ~4cm in resolution. The vertex model however was still 200 Mb in xyz ASCII format.

Figure 1 shows a rendered model view of the Vestibule in IMView visualisation software, as would be seen by a very tall person on the approach pathway. This view is similar to Figure 1a of Pringle *et al.* (2002). Note the person of normal height standing on the path at lower right and the partial image of the kiosk above him (marked). The rope-walk benches are beyond the kiosk at lower

centre. The upper half of the picture shows the vertical head of the gorge approaching Peak Cavern and the Vestibule roof.

The advantage of viewing the digital model in IMView software is the ability to remove designated areas of the model, i.e. a cave side, so the viewer can see the model from any view and orientation, without the restriction of being either land-based, or of a particular view from conventional photography. Figure 2 shows a rendered view of the model, as though looking down through the country rock from Pevenil Castle on the surface above the cave mouth. The Swinehole entrance extends towards the viewer at lower centre. The head of the approach gorge abuts the right-hand margin. Note the subhorizontal bedding surfaces etched into the external cave wall. Subvertical, conjugate joint surfaces offset the cave axis.

Figure 3 shows a rendered orthogonal view of the digital model, as though seen through the country rock (with the back of the Vestibule removed), but from a position above Lumbago Walk. The line of sight is towards the entrance to The Vestibule and so opposite in direction to that of Figure 1. The stream down-cut and top bench areas are marked.

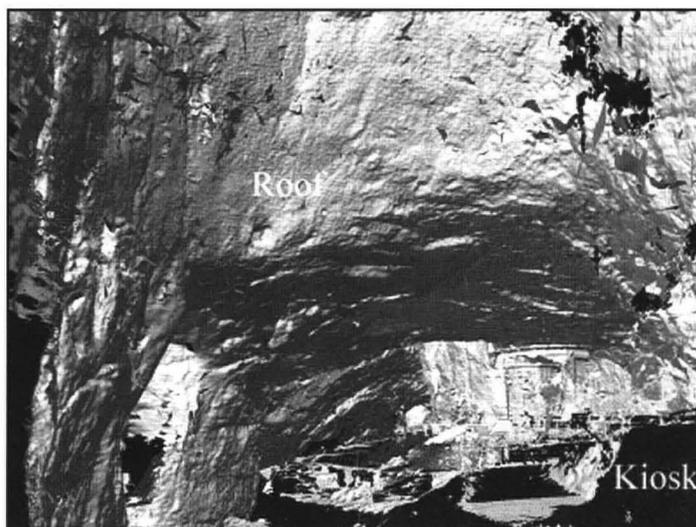
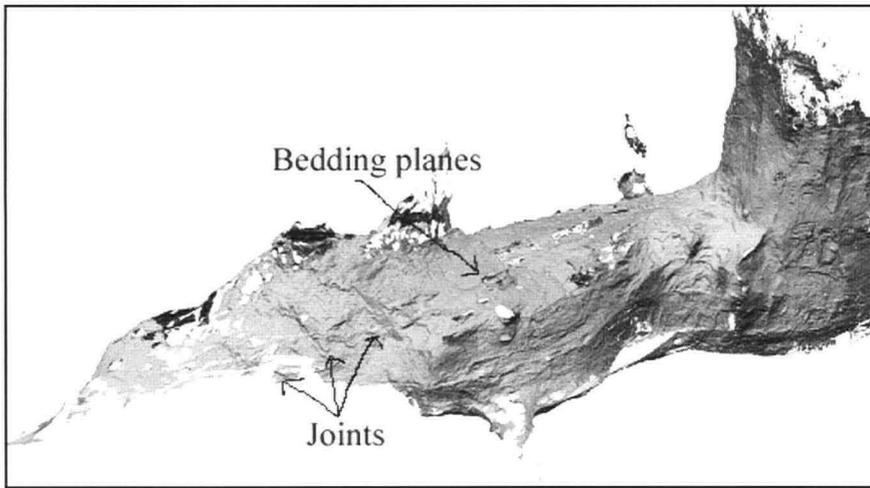


Figure 1. Rendered view of the Peak Cavern Vestibule digital model in InoMetric IMView visualisation software, looking past the kiosk (marked) to the rope-walks. Black areas indicate holes in the dataset.



**Figure 2.** Rendered view of the digital model, as though looking down through the country rock from Peveril Castle. Note the sub-horizontal bedding sections and 'en-echelon' joints.

### MODEL INTERPRETATION

From analysis of the digital model, stratigraphical and structural features can be discerned that are not immediately obvious from visual inspection of the Vestibule. A set of sub-vertical, 'en echelon' joints is observed in the digital model for example, and interpreted as controlling the main line of avens, though they are not well discerned in Figure 3. The 'en-echelon' joints also appear to pick out a subtle anticlinal fold hinge.

Bedding planes, which can be observed by visual inspection of the Vestibule, show interesting variations in the digital model. To the southwest of the visible aven, the bedding planes are sub-horizontal, whereas to the northeast of the aven, the bedding plane dip is towards the northeast. These abrupt dip variations seem to be aligned parallel to the axis of the main body of the Vestibule (Figure 2). Furthermore, the northeasterly dipping bedding plane, in the roof to the right of the visible aven, is parallel to a strong bedding plane etch feature beneath. Both bedding planes are sub-parallel to the diagonal line formed by the surface of the cave earth. As noted by Pringle *et al.* (2002), the slope of the cave earth deposit extrapolates along the base of the Swinehole, so evidence suggests the bank of cave earth deposits in The Vestibule may share the same lithological and structural controls as the processes that formed their host chamber. Indeed, the processes that formed The Vestibule might have left the cave earth bank as a residue (compare the discussion with Dr T D Ford in the Forum section of *Cave and Karst Science*, Volume 30, No.1, pp.44–45).

### CONCLUSIONS

#### AND COLLABORATION SUGGESTION

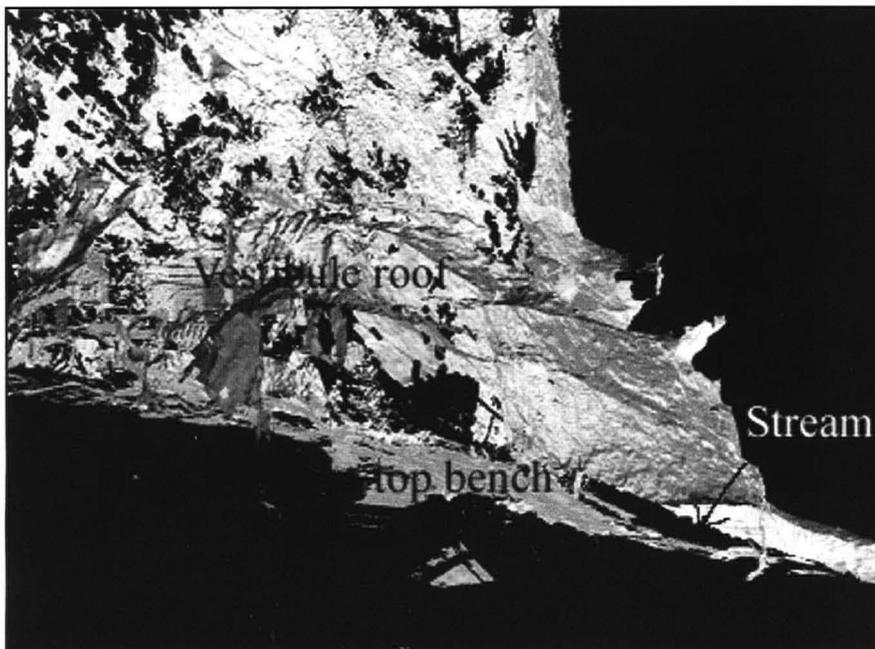
Additional LIDAR swaths are needed to fill existing holes in the data model. A more detailed analysis of the rendered LIDAR data model may resolve outstanding issues mentioned in this paper. As an inducement to further collaborative work, Laser Mapping Ltd. have agreed to make the Peak Cavern LIDAR digital dataset freely available to interested parties. The IMView LIDAR visualisation program used to view the model is also freely available from InnovMetric. A CD-ROM of the data model and software is available on request from Robin Westerman (contact details above).

### ACKNOWLEDGEMENTS

3D Laser Mapping are thanked for allowing open access to the Peak Cavern dataset and IMView visualisation software. John Harrison of Peak Cavern is acknowledged for access, assistance and advice. Dominic Tatum is acknowledged for data processing and software assistance. The ExxonMobil and Shell petroleum companies are acknowledged for financial assistance.

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**Figure 3.** Rendered view of the digital model from the rear of The Vestibule above Lumbago Walk, with the near-back surface removed. The lowest surface is the top bench forming the cave earth fill.

## 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.

### ABSTRACTS OF THE 15TH BCRA CAVE SCIENCE SYMPOSIUM DEPARTMENT OF EARTH SCIENCES, THE UNIVERSITY OF MANCHESTER, MARCH 2004

#### Bats and the caves of the Yorkshire Dales

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As the UK's largest karst region, the Yorkshire Dales holds nationally important populations of several bat species. Caves and other underground sites have an important role in the annual cycle of temperate bats. In winter they provide a cool, stable climate in which bats can hibernate when food resources are low. In the autumn they function as mating sites for bats gathering from large catchments, facilitating gene flow between isolated summer colonies.

By catching bats at cave entrances we have shown that five of the UK's 16 species visit most of the caves we have studied. Automatic logging of echolocation calls gives a measure of bat activity over days or weeks. Loggers placed at cave entrances are identifying important mating sites and we are looking at what cave and landscape features make a good 'bat site'. Loggers placed deep in caves at the start and end of winter are revealing important hibernation sites. The influence landscape topography and the distribution of caves have on gene flow and population structure is being studied through DNA analysis and ringing. We are also exploring methods of automatic species identification using loggers and new sound analysis methods.

#### The influence of hydroperiodicity on macroinvertebrate communities in groundwater-dominated headwater streams and springs

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The response of aquatic macroinvertebrate communities to flow permanence (hydroperiodicity) within limestone springs and headwater streams was examined within the English Peak District. At the regional scale, the macroinvertebrate communities of perennial and intermittent springs displayed significant differences

in the number of taxa, community abundance and diversity indices at intermediate discharge. However, no significant differences were recorded between intermittent and perennial sites at high discharge or when all sampling occasions were considered together. At the catchment scale, the number of taxa and community abundance of macroinvertebrates within the River Lathkill differed significantly between intermittent springs and perennial springs, the intermittent river and perennial river, whilst intermittent sites remained hydrologically active. Differences recorded between the two scales of analysis probably reflect the influence of reduced (re)colonisation potential due to the geographical and hydrological isolation of the headwaters of the Lathkill from other perennial water bodies.

#### Rhythmic sedimentation in the caves of north-west England

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Overlying the Ipswichian Hippopotamus fauna (OIS 5e) in chamber D of Victoria Cave is a thick layer of laminated silts and clays. The laminations consist of light to dark fining-upwards sequences with abrupt upper surfaces. AMS radiocarbon dates from Late Upper Palaeolithic artifacts overlying the deposit show it pre-dates the second phase of the Late Glacial Interstadial. In the literature, laminated sediments in similar stratigraphical positions are recorded from caves in the Morecambe Bay karst and Raygill Fissure near Lothersdale. This suggests that the mechanism responsible for the rhythmic nature of the sedimentation is regional rather than local to Victoria Cave.

#### The Lathkill: A losing river in the White Peak, England

John Gunn  
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Part of the Peak District in central England comprises a significant upland area, commonly known as the White Peak, which is dominated by carbonate lithologies, mainly limestone with local dolomite. The carbonate outcrop is dissected by a dendritic system of valleys that are dry for all, or most, of the year. Only two allogenic-fed rivers, the Dove and the Wye, maintain perennial flow across the karst. However, one other river, the Lathkill, maintains a perennial flow for some 4.3km across the carbonates, with a further 4.2km of intermittent upstream flow. The river, which runs through the Lathkill Dale Site of Special Scientific Interest (SSSI), is the only one in the Peak District to be sustained solely by autogenic recharge from rain falling onto the limestone. It is also unusual in that almost all of the recharge is dispersed. The permanent source of the Lathkill is Bubble Springs, near Over Haddon, above which the river is largely intermittent,

although a 450m reach above the Cowgate Pool weir (2.2km above Bubble Springs) appears to be perennial. Above this reach flow is intermittent for some 1500m, the source migrating upstream as a series of progressively higher springs are activated. Below the Cowgate Pool, weir flow is lost to the bed and the surface river migrates upstream from Bubble Springs, leaving a channel that is dry for 2 to 5 months of the year.

The discharge of the river, and particularly the duration of surface flow, are of concern to English Nature because the river supports, or has supported, typical White Peak aquatic faunal and plant communities, including several Biodiversity Action Plan Species. In the reach between Cowgate Pool and the Bubble Springs, the river's discharge decreases as part of the flow is lost through the riverbed and banks. Most of this loss is thought to be due to water draining into a 19<sup>th</sup> century lead mine drainage level (sough), although losses to natural conduits in the limestone are also possible. When the river is in spate the losses are only a minor proportion of flow, and at some points flow is reversed and groundwater is discharged back into the surface channel. However, as the discharge declines in late spring, the losses become increasingly important and result in prolonged low flows, losses of sensitive aquatic species and an increase of terrestrial vegetation in the channel. In terms of English Nature's SSSI condition assessment, the River Lathkill is the only unfavourable unit on the Derbyshire Dales National Nature Reserve that is not improving.

It is well known that the loss of flow is not a recent phenomenon and that it is exacerbated by upstream capture of flow by another sough. However, the key questions for river management are why and where flow is lost and whether the problem is getting worse. This paper presents some initial results from a research project being undertaken for English Nature that addresses these problems.

### **Bands and molecules: the use of biomarkers in stalagmites as environmental proxies**

**Alison Blyth<sup>1</sup>, Paul Farrimond<sup>1</sup>, Andy Baker<sup>2</sup>, Matthew Collins<sup>3</sup> and Shucheng Xie<sup>4</sup>**

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Stalagmites are increasingly being used in palaeoenvironmental research, owing to their high temporal resolution and the multiple signals that they can contain, including carbon, oxygen isotopes and organic fluorescence. Our current project aims to identify and develop an additional set of molecular tools, in the form of lipid biomarkers that become trapped during stalagmite formation. Lipids have particular potential as palaeoenvironmental markers, in preserving records of their source organisms and environmental factors influencing their composition.

Two approaches are being pursued in parallel. Firstly, the development of an optimum analytical protocol to derive the maximum amount of molecular information from the minimum amount of calcite, in order to increase temporal resolution of the palaeoenvironmental records. The second strand focuses on understanding how lipids are preserved in the carbonate of stalagmites, how they have arrived there, and what information they preserve. By analysing suites of soil, rock, sediment and modern stalagmite samples collected from sites that have contrasting vegetation/soil regimes, it is hoped to identify the signals deriving from the vegetation overlying the cave system, and also from the microbiota, including those in surface soils and especially from cave biofilms.

This project is in its earliest stages, but if successful, the research should make it possible to interpret past environmental changes

recorded in the lipids preserved in stalagmites, and for biomarkers to take their place among the valuable proxies that speleothems have contributed to palaeoenvironmental research.

### **Who needs carbonic acid?**

**Trevor Faulkner**

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Research during the 1990s clarified the physico-chemico dissolutional processes leading to the creation of the triple porosity hydrogeology described for karstic limestones. Caves commonly develop in three stages. Firstly, there is slow "higher order" dissolution along the whole length of a fracture during an inception and gestation stage. This is completed at "breakthrough", when the flow rate at the exit is sufficiently large for fast "first order" dissolution to apply along the whole length of the fracture. During this second stage, the conduit enlarges uniformly under phreatic conditions. The third stage of vadose entrenchment is entered if the conduit becomes large enough (or if the flow rate is reduced sufficiently) so that phreatic conditions cannot be maintained.

The time to breakthrough and the phreatic enlargement rate are controlled by several physical and chemical parameters, including the extent of saturation of the solution. Because maximum calcite saturation increases with increasing P<sub>CO2</sub> in the input stream, most models are illustrated with rather high concentrations of carbonic acid derived from water passing through vegetated soils. Other recent cave development hypotheses also assume the presence of stronger acids to dissolve the carbonate, such as humic and fulvic acids derived from soils, or sulphuric acid derived from sulphide reactions in bedrocks adjacent to the limestone. However, it also follows from the theoretical equations that conduits can enlarge at maximum rates if the flow through them is sufficiently great that the solution remains well-below saturation, even if the input contains no carbon dioxide at all. Examples of fractures that achieved breakthrough and then enlarged at maximum rates to exploratory dimensions in almost pure water are found in central Scandinavia, where many short caves formed phreatically during deglacial high-flow conditions at the start of the Holocene.

### **Work on documenting cave archaeology in the Yorkshire Dales National Park**

**Tom Lord**

The karst landscape of the Yorkshire Dales National Park constitutes a naturally defined upland region for archaeological and palaeoecological investigations. The archaeological excavation of caves began over 150 years ago with Joseph Jackson's pioneering work in the Settle area, and about 40 caves have some record of investigation.

Overall the publication record for these sites is poor. The majority of cave excavations were undertaken by local amateurs, and much early work has gone entirely unpublished. However, largely due to the efforts of the late Tot Lord of Settle, the primary site archives in the form of paper excavation records, small finds and faunal material commonly survive surprisingly well.

This project aims to produce comprehensive digitised records for caves in the Yorkshire Dales National Park, which underwent some form of archaeological investigation before 1990. At present the archives survive in disparate and commonly idiosyncratic forms that make them difficult to access and use. The current archive structure limits evaluation and interpretation, effectively rendering the results of the excavations inaccessible. A digitised series of records will preserve this fragile resource, and enable comparative analysis of the excavation results.

## **Evidence of site-specific factors affecting Late Pleistocene cave deposits in the Yorkshire Dales: evidence from vertebrate remains, clastic sediments and speleothem formations**

**Tom Lord**

The period from about 130,000 to 10,000 years ago (equivalent to Marine Isotope Stages 5 to 2) is termed the Late Pleistocene. It is characterized by major and repeated mid-latitude climate changes. Glacial erosion from about 22,000 to 16,000 years ago destroyed most of the Late Pleistocene sediments in the Yorkshire Dales, apart from underground deposits protected in caves. These are now the major palaeoenvironmental resource for reconstructing Late Pleistocene events in the region.

Victoria Cave and Stump Cross Cave contain Late Pleistocene vertebrate remains, clastic sediments and speleothem deposits in deep cave contexts. Both sites illustrate how site-specific factors affect depositional processes in deep caves and influence the nature of the palaeoenvironmental record. Site-specific factors affecting cave deposits are often overlooked by researchers and are still poorly understood.

It is useful to consider site-specific factors for deep cave contexts at macro and micro levels. The macro level examines differences between cave systems. Differences in the Late Pleistocene deposits in Victoria Cave and Stump Cross, for example, illustrate site-specific factors at the macro level. The micro level, on the other hand, examines differences within the same cave system. The effects of site-specific factors at a micro level are illustrated by coeval variations in the Late Pleistocene floor deposits of the Bowling Alley Passage in Stump Cross Cave. Cave topography and drip water hydrology are identified as key factors affecting site-specific depositional processes at both macro and micro levels. These factors particularly affect the timing of speleothem growth phases as revealed by published mass spectrometric speleothem dates for Stump Cross Cave and Lancaster Hole.

Drip water hydrology and hence speleothem formation in deep caves respond to changes in precipitation rates and intensity. A tentative regional Late Pleistocene climate model is proposed mostly using alpha spectrometric and mass spectrometric dates for speleothem growth phases in Victoria Cave, Stump Cross Cave and Lancaster Hole. The model illustrates how an understanding of site-specific factors is essential to interpret the timing of speleothem growth rates at a macro and a micro level. It also suggests greater caution when using dated speleothem to infer the age of Late Pleistocene vertebrate remains in deep cave contexts.

## **Caves, Chemistry and Climate: Evidence of drought in the Western Mediterranean 1200 years ago**

**Emily McMillan**

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Geochemical analyses of annual laminations in speleothems allow high-resolution palaeoclimate records to be retrieved. This study incorporates both calcite and aragonite mineralogies within the same palaeoclimate study, as the presence of aragonite layers within a calcite speleothem is thought to indicate extreme drying events. Previous work done on aragonite in speleothems has simply equated the driest period to that of aragonite precipitation, but this is shown here to be misleading. High-resolution analyses for trace elements were carried out on two stalagmites from Grotte de Clamouse in southern France. This study focuses on trace element behaviour before, during and after the youngest aragonite layer dated at 1200 years BP.

Modern monitoring of the site at Grotte de Clamouse has revealed high seasonality to rainfall. This is replicated in the speleothems by strong co-variation of Sr and Mg, with long-term Mg values peaking immediately before the sharply defined aragonite

nucleation surface. Crystallographic effects in the aragonite may mask what are potentially annual cycles illustrated by Sr. Mechanisms of Mg incorporation into aragonite are poorly understood therefore Sr and U – which are readily accepted into the aragonite lattice – are used for palaeoclimate interpretation.

The aragonite layer is 1 to 2mm thick. Sr concentration is at a maximum as aragonite starts to precipitate, and gradually decreases throughout the aragonite layer. This indicates that the point of maximum aridity in the region occurred prior to the aragonite layer and actually caused the observed change in mineralogy. The return to calcite is gradual, with inter-fingering crystals of calcite and aragonite. Once calcite precipitation is fully restored the variation in Mg and Sr values is vastly reduced compared with the 'pre-aragonite calcite'.

The authors suggest that there was a period of drought in the western Mediterranean around 1200 years ago that lasted approximately 100 years, and which eventually triggered the nucleation of aragonite at around 1167 years ago. This period correlates with evidence for extreme drought in Central America, thought to have contributed to the demise of the Maya civilization. Results from this study will be compared with similar work to be done on stalagmites from El Refugio cave in southern Spain in order to further constrain the extent of the drought in the western Mediterranean 1200 years ago.

## **Reanalysis of human skeletal remains from caves in Yorkshire: burials, beheadings or brunch?**

**Stephany Leach**

**Archaeology Department, King Alfred's College, Winchester, UK.**

Only minimal direct anthropological analysis has been carried out on this material in recent years. Methodologies are now being refined to allow more precise evaluation of skeletal remains. Neglect of the archaeological record derived from these sites has resulted in a lack of recognition of the key and unique role caves played in landscape development and interaction. Until recently, archaeological interpretations of cave use have tended to reduce these sites to quite mundane places.

Most of the human skeletal material from caves in the Yorkshire region was considered to be prehistoric, Neolithic or Bronze Age, and derived from articulated burials. These assumptions and ideas were formulated decades ago, with little regard to the human skeletal remains. After completing the reanalysis of skeletal material from several locations, it became clear that these sites were not simply repositories for burial. Their use and interrelationship with other features in the landscape were complex and significant. A range of activities with regard to the deposition of human remains can be identified; only one of these being conventional burial. By liberating the skeletal evidence from our preconceptions, a range of cultural and natural processes have been identified. Past societies' cultural perceptions of these natural locations may have been very different from our own modern view and their activities may not always fall into our spectrum of acceptable behaviour.

## **High resolution isotopic and amino acid data from an Ethiopian speleothem.**

**Jen Moss, Matthew Collins, Andy Baker, Mohammed Umer, Mabs Gilmour and Melanie Leng**

The 24cm-long speleothem from central Ethiopia grew continuously for 450 years about 5ka. The annual banding has a mean width of 0.56mm, allowing samples to be taken on average every two years. These samples were analyzed for oxygen and carbon isotopes, as well as amino acid content.

The racemization in the amino acids fluctuates widely, and must be driven by environmental and climatic conditions at the site. The

same is also true of the concentration of amino acids in the speleothem, with varying levels of amino acids each year.

The oxygen and carbon isotopes also fluctuate, varying in cycles, following broadly similar patterns. The oxygen isotopes reflect the moisture when the speleothem was deposited, with more negative values indicating more moisture. The carbon isotopic

signature is more complicated, and depends on numerous environmental and climatic factors. However, the carbon isotopes look heavier than expected.

It is hoped that these data can provide information on the rainfall in Ethiopia.

✍

## THESIS ABSTRACT

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I present herein the results of an ichthyofaunistic survey in epigeal (surface) and hypogean (subterranean) stream reaches from the São Domingos karst area, northeast of Goiás. This includes a morphological study of three undescribed species of troglotic (exclusively subterranean) catfish, genus *Ituglanis* (Trichomycteridae), and a troglotic electric fish, *Eigenmannia vicentespelaea* (Sternopygidae), which are compared to the epigeal species occurring in the same region, *E. trilineata*. Also included is an ecological and behavioural study (in the field and laboratory) of *Ituglanis* spp. and *Eigenmannia vicentespelaea*, which are also compared to the epigeal *E. trilineata*. For the faunistic survey, carried out between May 1999 and August 2001, the usual methods for fish collection were used (block nets, traps, sieves, hand-nets), in addition to electro-fishing.

Seven fieldtrips were carried out during the (April to September) dry seasons of 1999, 2000 and 2001, aimed at a population study of two species of *Ituglanis* (*I. passensis*, from Passa Três Cave, and *Ituglanis* sp.1, from Angélica Cave), using the mark-recapture method. For this, a 400m-long stream reach inside Passa Três Cave and a 300m-long reach of an upper tributary where *Ituglanis* sp.1 occurs inside Angélica Cave were divided, respectively, into 20 and 17 study sections. Catfishes detected by visual inspection were hand-netted, measured (standard length), weighed, marked by subcutaneous injection (tattooing) of biocompatible pigments, and released in the same section they were captured. A few specimens were collected for the study of diet (analysis of stomach contents) and reproduction (macroscopic examination of gonads) in the laboratory. In addition, visual censuses were carried out for *Ituglanis* sp.2, from São Mateus Cave, and *Ituglanis* sp.3, from São Bernardo-Palmeiras Cave.

The behavior of three troglotic (exclusively subterranean) species of *Ituglanis* catfish (*I. passensis*, from Passa Três Cave, *Ituglanis* sp.1, from Angélica Cave, and *Ituglanis* sp.3, from São Bernardo-Palmeiras Cave), The São Domingos karst area, in the State of Goiás, was studied in terms of the natural habitat by direct observation and in the laboratory in controlled experiments. During the naturalistic observations, the type of habitat, spatial distribution, hiding and gregarious habits, reaction to spotlight and agonistic interactions of *I. passensis* and *Ituglanis* sp.1 were recorded systematically using the *ad libitum* and focal-animal methods; observations on *Ituglanis* sp.3 were occasional. The three species were studied comparatively in the laboratory, with a focus on light reaction using the choice-chamber method, spontaneous behavior (focal-animal), feeding behavior (idem), and free-running (constant darkness) locomotor rhythmicity by automatic record of activity in an infra-red photocell device.

During seven fieldtrips during the (April to September) dry seasons of 1999, 2000 and 2001, two related species of electric fish (Gymnotiformes: Sternopygidae) from the São Domingos karst area, the troglotic *Eigenmannia vicentespelaea*, from São Vicente Cave, and the epigeal *E. trilineata*, were studied comparatively, with a focus on ecology (habitat, population densities) and behaviour (spontaneous behaviour, reaction to light and mechanical stimuli, activity), investigated in the field, and biology (diet, reproduction). For the ecological study, visual censuses were performed in six transects with variable areas along a 700m-long stream reach inside São Vicente II Cave. On all occasions, physico-chemical water variables were measured. The focal-animal method was used for the behavioral study, totalling 3h of observations for each species. Systematic observations of *E. trilineata* were done between 17:00 and 20:00h and, on two occasions, visual censuses were performed

every 10 min. in a 5 x 20m transect situated 100m upstream of the sinkhole of Terra Ronca Cave, in order to quantify the activity and to estimate the population density in this stream reach. On each fieldtrip, specimens were collected for study of diet (analysis of stomach contents) and reproduction (macroscopic examination of gonads).

Thirty-eight fish species were recorded in epigeal and hypogean streams in the São Domingos karst area, comprising 10 characiforms, 19 siluriforms, seven gymnotiforms and two perciforms. The most abundant epigeal fish were the tetra characins, *Astyanax* spp., and a new species of armoured catfish, genus *Parotocinclus*. Twenty-two non-trogmorphic (normally eyed and pigmented) species were recorded in caves of São Domingos karst area. Fishes regularly found in subterranean streams include the characiforms *Hoplerethrinus unitaeniatus* (Erythrinidae), *Astyanax* spp. and *Brycon* sp. (Characidae), and two catfish species, genus *Imparfinis* (Heptapteridae); among these, *I. hollandi* was the commonest in most caves. In addition, seven troglomorphic species (with total or partial reduction of eyes and pigmentation) were recorded: *Ancistrus cryptophthalmus* (Loricariidae), *Pimelodella* sp. (Heptapteridae), four species of *Ituglanis* (*I. passensis* and the three undescribed species), and *E. vicentespelaea*. São Domingos is the Brazilian karst area with the highest subterranean ichthyofaunistic diversity.

The three new species are distinguished from each other and from *I. passensis* by the degree of reduction of eyes, coloration patterns, number of opercular and interopercular odontodes, shape of vomer, palatine and uro-hyal bones, caudal skeleton, in addition to morphometric and meristic characters. No trichomycterid catfish was found in epigeal streams of São Domingos karst area, indicating that the four troglomorphic *Ituglanis* species are isolated in the hypogean environment and subject to allopatric differentiation. Differences in the degree of reduction of eyes and pigmentation suggest different times of isolation for these species. In the case of *E. vicentespelaea*, variability in eyes development and the presence of epigeal relatives indicate that this species is in the initial stage of differentiation, possibly parapatric.

The four studied species of *Ituglanis* have low population densities, even by hypogean fish standards. *I. passensis*, basically restricted to a 1,600m-long base-level stream inside Passa Três Cave, presents a small population (about 419 individuals). Mark-recapture data also point to a small population size for *Ituglanis* sp.1. However, actual population size is probably considerably larger because this species, as *Ituglanis* sp.2 and *I. sp.3*, apparently distributes through a wider area in the epikarstic habitat. When compared to epigeal trichomycterids, *I. passensis* and *Ituglanis* sp.1 move along relatively small areas. Recruitment patterns and a tendency of decrease in condition factor along the dry seasons were observed for *Ituglanis* sp.1, but not for *I. passensis*. Like epigeal trichomycterids, these species are generalist carnivores. *Ituglanis* sp.1 has an extended reproductive period. On the other hand, a reproductive peak at the end of the dry season is apparently present in *I. passensis*.

*I. passensis* would exhibit the lowest degree of specialization – predominant photonegative responses, accentuated cryptobiotic habits, bottom activity and lower feeding efficiency (higher times of food search and localization) in comparison with the other two studied species – suggesting a shorter time of isolation in the subterranean habitat. *Ituglanis* sp.3, on the other hand, would present the most specialized character states – indifference to light (possibly due to low light sensitivity), weak cryptobiotic habits, midwater and surface activity in addition to bottom activity, high feeding efficiency and absence of circadian components in locomotor activity. *Ituglanis* sp.1 is intermediate in relation to the studied behavioral characteristics. However, to test these hypotheses, it would be necessary to map the characters states into a phylogenetic scheme, not yet available for *Ituglanis* species.

These species occur in habitats with similar physical characteristics, showing strong preference for slow-moving water pools with large submerged boulders. Population densities of the cave *E. vicentespelaea* were low (0.04–0.172 ind. m<sup>-2</sup>), but still higher than those of *E. trilineata* (0.01–0.13 ind. m<sup>-2</sup>). Differences in body angle in relation to the bottom during foraging (30° in *E. vicentespelaea* and 90° in *E. trilineata*) may be due to a larger concentration of taste buds in the chin of the former, instead of only the lips in the latter, as observed for other troglobitic fishes such as the Mexican tetra characins, genus *Astyanax*, in comparison to their

epigeal relatives. A bimodal activity, with a pronounced peak just after the sunset and another, less pronounced, 5 h after sunset was observed for the epigeal *E. trilineata*. Apparently, the cave species exhibits an extended spatial and temporal use of the habitat. They are both benthic insectivorous, like other *Eigenmannia* species, and they reproduce during the dry season, but without any evidence of well-defined reproductive peaks near the rainy season, recorded for other species of the genus.



## RESEARCH FUNDS AND GRANTS

### The BCRA Research Fund

The British Cave Research Association has established the BCRA Research Fund to promote research into all aspects of speleology in Britain and abroad. A total of £2000 per year is currently available. The aims of the scheme are primarily:

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

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

### Ghar Parau Foundation Expedition Awards

An award, or awards, with a minimum of around £1000 available annually, to overseas caving expeditions originating from within the United Kingdom. Grants are normally given to those expeditions with an emphasis on a scientific approach and/or pure exploration in remote or little known areas. Application forms are available from the GPF Secretary, David Judson, Hurst Barn, Castlemorton, Malvern, Worcestershire, WR13 6LS, e-mail: [d.judson@bcra.org.uk](mailto:d.judson@bcra.org.uk). Closing dates for applications are: 31 August and 31 January.

### The E K Tratman Award

An annual award is made for the most stimulating contribution towards speleological literature published within the United Kingdom during the past 12 months. Suggestions are always welcome to members of the GPF Awards Committee, or its Secretary, David Judson (see above for contact details), not later than 31 January each year.

## BRITISH CAVE RESEARCH ASSOCIATION PUBLICATIONS

**Cave and Karst Science** – published three times annually, a scientific journal comprising original research papers, reports, reviews and discussion forum, on all aspects of speleological investigation, geology and geomorphology related to karst and caves, archaeology, biospeleology, exploration and expedition reports.

Editors: Dr D J Lowe, c/o British Geological Survey, Keyworth, Nottingham, NG12 5GG, UK, (e-mail [d.lowe@bcra.org.uk](mailto:d.lowe@bcra.org.uk)) and Professor J Gunn, Limestone Research Group, University of Huddersfield, Queensgate, Huddersfield, HD1 3DH, UK (e-mail [j.gunn@bcra.org.uk](mailto:j.gunn@bcra.org.uk)).

**Speleology** - published three times annually and replacing BCRA's bulletin 'Caves & Caving'. A magazine promoting the scientific study of caves, caving technology, and the activity of cave exploration. The magazine also acts as a forum for BCRA's special interest groups and includes book reviews and reports of caving events.

Editor: David Gibson, 12 Well house Drive, Leeds, LS8 4BX, (e-mail: [speleology@bcra.org.uk](mailto:speleology@bcra.org.uk)).

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

- No. 1 *Caves and Karst of the Yorkshire Dales*; by Tony Waltham and Martin Davies, 1987. Reprinted 1991.
- No. 3 *Caves and Karst of the Peak District*; by Trevor Ford and John Gunn, 1990. Reprinted with corrections 1992.
- No. 4 *An Introduction to Cave Photography*; by Sheena Stoddard, 1994.
- No. 5 *An Introduction to British Limestone Karst Environments*; edited by John Gunn, 1994.
- No. 7 *Caves and Karst of the Brecon Beacons National Park*; by Mike Simms, 1998.
- No. 8 *Walks around the Caves and Karst of the Mendip Hills*; by Andy Farrant, 1999.
- No. 9 *Sediments in Caves*; by Trevor Ford, 2001
- No. 10 *Dictionary of Karst and Caves*; by D J Lowe and A C Waltham, 2002.
- No. 11 *Cave Surveying*; by A J Day, 2002.

**Speleohistory Series** – an occasional series.

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

## BCRA SPECIAL INTEREST GROUPS

**Special Interest Groups** are organised groups within the BCRA that issue their own publications and hold symposia, field meetings, etc.

*Cave Radio and Electronics Group* promotes the theoretical and practical study of cave radio and the uses of electronics in cave-related projects. The Group publishes a quarterly technical journal (c.32pp A4) and organizes twice-yearly field meetings. Occasional publications include the Bibliography of Underground Communications (2nd edition, 36pp A4).

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

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

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

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

Copies of BCRA Publications are obtainable from: Ernie Shield, Publication Sales, Village Farm, Great Thirkleby, Thirsk, North Yorkshire, YO7 2AT, UK.

BCRA Research Fund application forms and information about BCRA Special Interest Groups can be obtained from the BCRA Honorary Secretary: John Wilcock, 22 Kingsley Close, Stafford, ST17 9BT, UK.

