Cave Science

The Transactions of the British Cave Research Association

BCRA

Volume 14 Number 3 December 1987

M2 Cave, Picos de Europa, Spain

B.C.R.A. Symposium abstracts

Ankarana Caves, Madagascar

Caves of Glomdal, Norway

Caves and Mines of Hawkstone Park

Leptospirosis among British Cavers

Cave Science

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TRANSACTIONS OF THE BRITISH CAVE RESEARCH ASSOCIATION

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Contents

Geology and speleogenesis of the M2 Cave System, Western Massif, Picos de Europa, Northern Spain
Kevin J Senior 93

B.C.R.A. Cave Science Symposium, November 1987
Abstracts 105

The Crocodile Caves of Ankarana : Expedition to Northern Madagascar, 1986
Jane Wilson 107

Caves of Lower Glomdal, Rana, Norway
Simon Bottrell 121

Caves and Mines of Hawkstone Park, Salop
Terry Middleton 125

Leptospirosis among British Cavers
C A Self et al 131

Cover: The M2 Cave, Spain. By Kevin Senior

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CAVE SCIENCE Vol. 14, No. 3, December 1987
Transactions of the British Cave Research Association

Geology and Speleogenesis of the M2 Cave System, Western Massif, Picos de Europa, Northern Spain

Kevin J. SENIOR

Abstract: The geological history of the Picos de Europa has been particularly favourable from a speleological point of view with 1200 metres of carbonates thickened by overthrusting in 2000 metres of relative relief. The M2 cave system, in the Western Massif, has been explored to a depth of -986 metres. The upper part of the M2 cave originated as a single small phreatic passage which descended steeply to the major phreatic conduits below. Two models of the early development of the cave are discussed. The first model has a bathyphreatic system modified by vadose entrenchment while the second proposes that passages in the upper cave are para-phreatic and formed within an extensive vadose zone. Inclined ramps in the upper cave are vadose features formed where the base of each pitch has retreated headwards and cut downwards, Glacial meltwater is proposed as the erosive agent of the pitch-ramp systems. Sediments preserved within the lower passages strongly resemble 'Red Permian' materials and demonstrates the existence of a post-Carboniferous cover during the early development of the cave.

INTRODUCTION

The Picos de Europa mountains of northern Spain are divided into three massifs by spectacular gorges which dissect the range from south to north (Fig. 1). In the Eastern Massif several major cave systems have been discovered and explored by Lancaster University Speleological Society (LUSS) and the Seccin de Espeleologa Ingenieros Industriales (SEII) (Sefton, 1984), while in the Central Massif groups of French cavers have discovered major systems such as Torca de Urriello and Sima del Trave (Benoit, 1985). The Western Massif is divided into northern and southern sections by the ridge of the Picos de Cornion. Oxford University Caving Club (OUCC) have been working to the north of the ridge for many years where they discovered Pozu del Xitu (Singleton, 1981). However, the region to the south received relatively little attention from speleologists until 1983 when the area was explored by a combined team from York University Cave and Pothole Club (YUCPC) and the SEII from Madrid. The same group has returned to the area each summer since 1983 and has focused attention on the cave numbered 'M2' after it's discovery in 1984 in the Vega Huerta area to the south of Peña Santa.

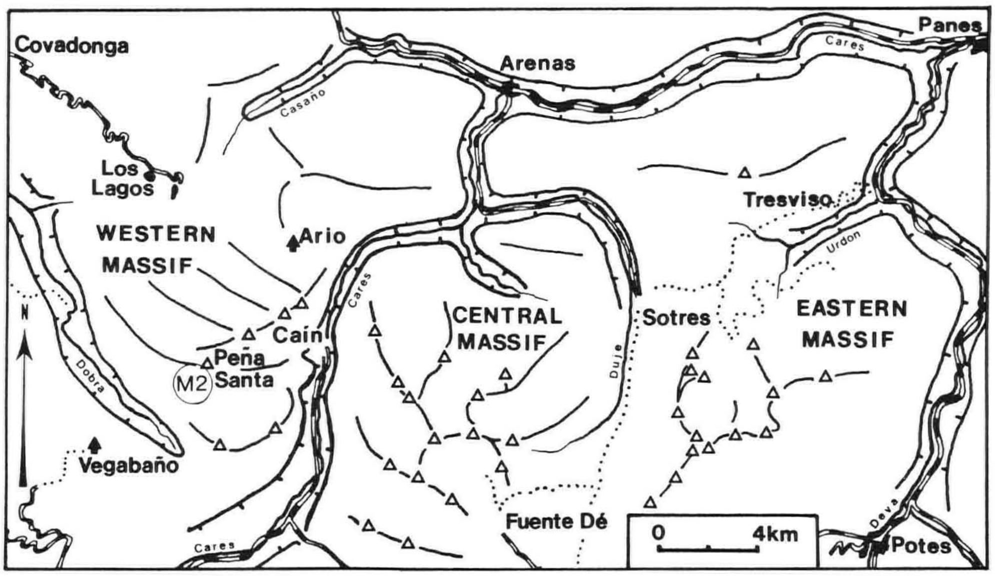
GEOLOGY

The three massifs are composed almost entirely of limestones which were laid down during the Carboniferous Period of between 290 and 345 million years ago. In the Western Massif approximately 1200 metres of carbonates were deposited with very few impermeable horizons so that most formations are suitable for cave development (Fig. 2). The geological history of the Picos de Europa since the beginning of the Carboniferous resulted in a region with large speleological potential and the development of cave systems such as M2 is intimately related to the geological structure and lithology.

The Carboniferous Period and Variscan Orogeny

During the Carboniferous Period the Picos de Europa occupied a palaeogeographic position which was favourable for carbonate deposition. While neighbouring regions experienced increasingly unstable conditions the Picos de Europa remained a relatively stable province in which carbonate deposition predominated for 55 million years. The Picos de Europa was located on the northeastern margin of the Cantabrian Zone, a palaeogeographic unit distinguished by Comte (1959). The province was bounded to the west by the Ponga Nappe

Figure 1 The three massifs of the Picos de Europa.



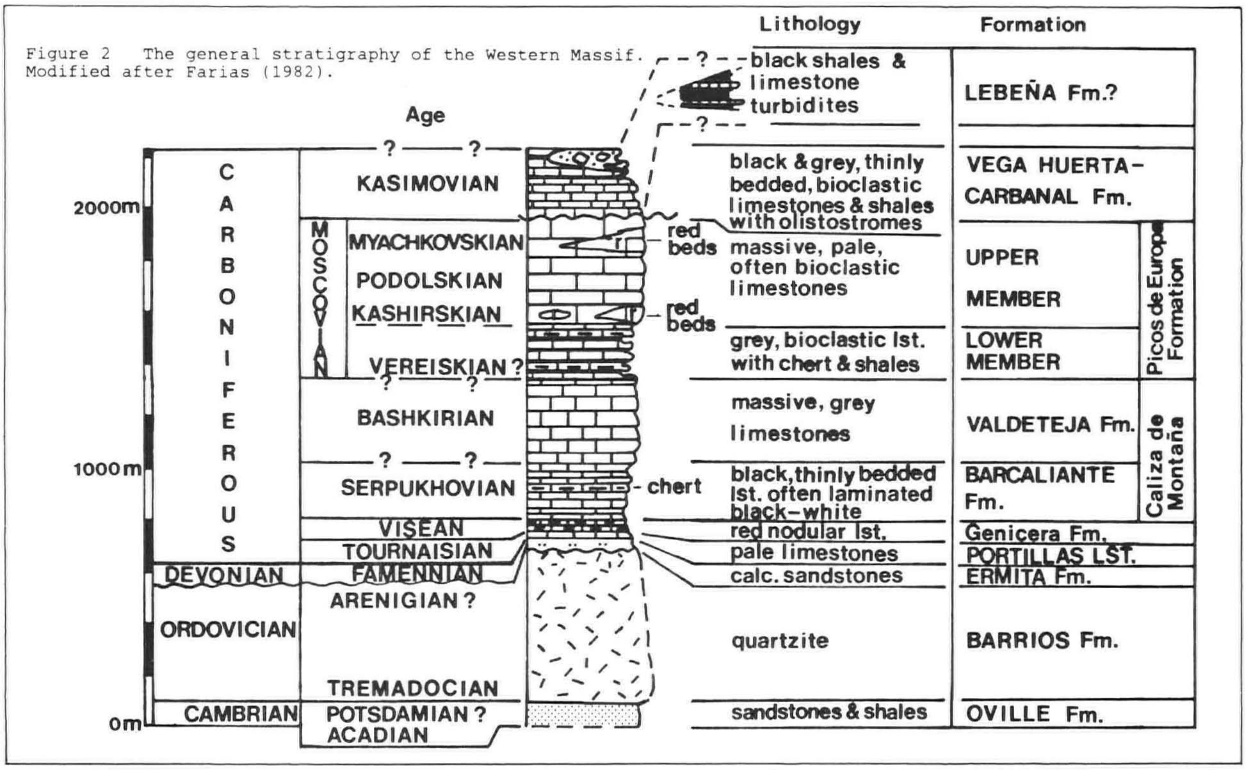


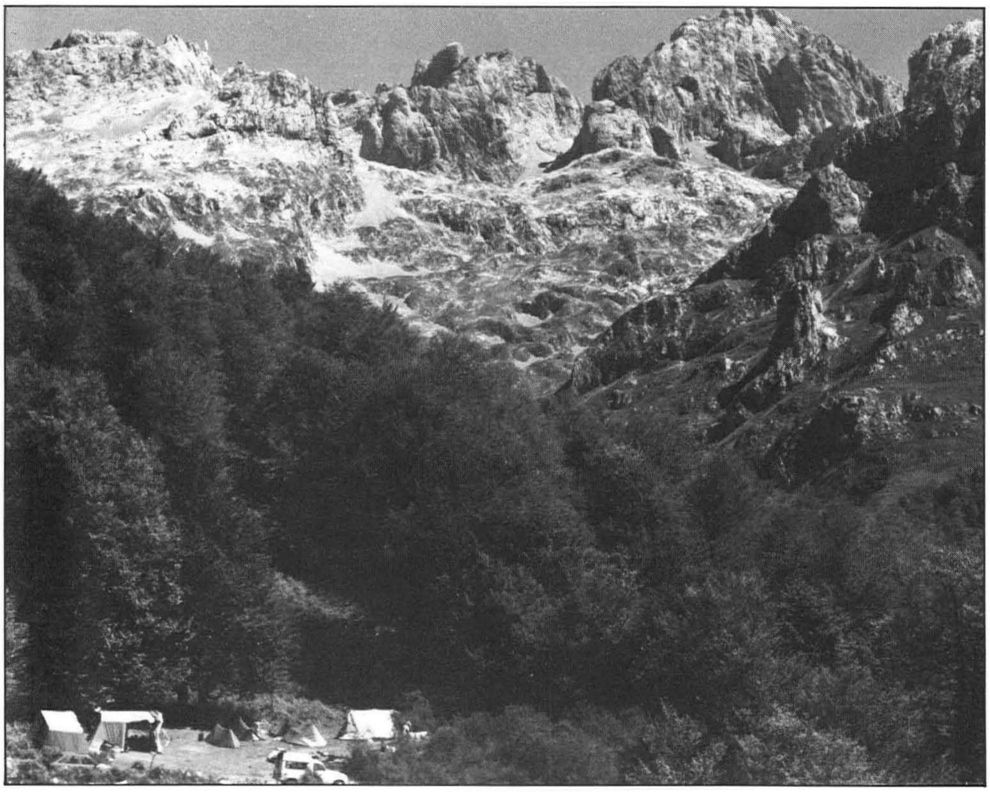
Figure 2 The general stratigraphy of the Western Massif. Modified after Farias (1982).

Province and to the south by the Pisuerga-Carrion Province.

At the beginning of the Carboniferous Period uniform marine conditions existed throughout the Cantabrian Zone resulting in the widespread deposition of a sequence of red, nodular limestones with chert and thin shales, the Genicera Formation (Fig. 2). At the beginning of the Namurian the black, 'Caliza de Montaña' was deposited but in the Ponga Nappe and Pisuerga-Carrion Provinces sedimentation became increasingly dominated by terrigenous material. Carbonate deposition continued in the Picos de Europa Province however, with intraformational breccias and slump deposits the only indications of tectonic disturbances.

The cause of the instability was the north-western movement of the African continental plate towards the Eur-American plate. The Variscan orogenic belt developed along the line of collision. The details of the Variscan Orogeny are complicated and several models have been proposed (see Windley, 1984 for a review).

The main period of deformation in the Cantabrian Zone occurred during the Asturian Phase of the Variscan orogeny, at the end of the Moscovian (about 295 Ma). Sediments were thrust into the core of a developing arcuate mountain chain (i.e. into the Cantabrian Zone) from the northwest, west and southwest. The Picos de Europa Province was the last to be affected by deformation because of it's position at the


View to the north from base camp at Vegabano. The escarpment on the right is the southern edge of the Frontal Nappe Unit. The main peak is Pena Santa and the entrance of M2 is located close to the imposing south face. The bottom of M2 is about 300 metres below the level of base camp.

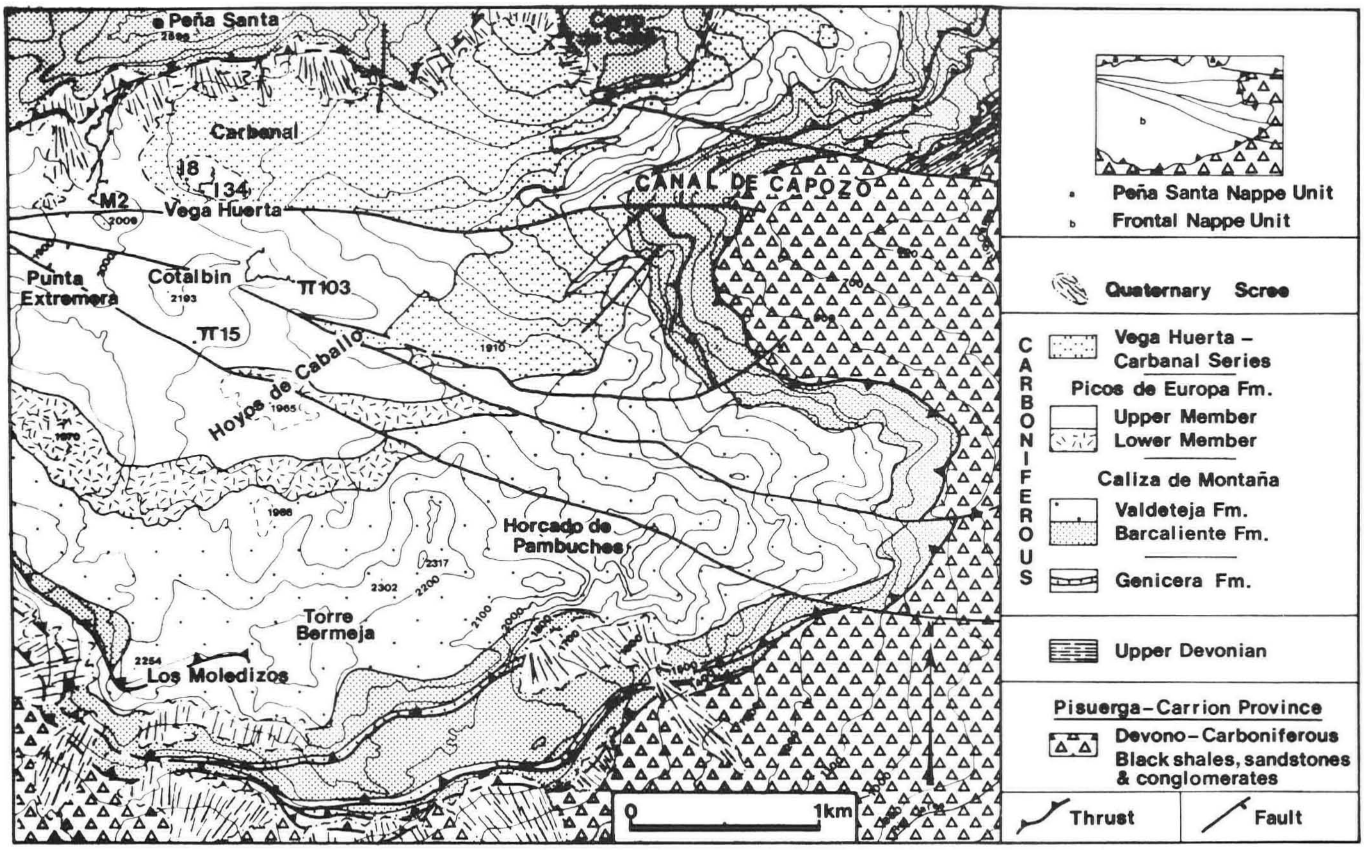


Figure 3 The Geology of Vega of Huerta. Largely after Farias (1982). M2, I8, I34, A15 and A103 are the major caves discovered to date.

northeastern margin of the Cantabrian Zone, away from the encroaching thrust sheets. The main phase of deformation within the Picos de Europa Province began in the Kasimovian and continued until the Autunian (Martinez-Garcia, 1981). Palaeozoic sediments, predominantly Carboniferous carbonates, were thrust from the north-northeast to the south-southwest over the Pisuerga-Carrion Province (Maas, 1976; Marquinez, 1978; Farias, 1982). The massively bedded limestones moved as a series of competent sheets with very little internal folding. Each thrust sheet was pushed over the one emplaced immediately to the south which greatly increased the total thickness of the carbonate sequence. Maas, (1976), estimated that the limestones moved at least 20km because the Pisuerga-Carrion facies is so different from that of the Picos de Europa.

Post-Variscan Events

During the Permian, Mesozoic and early Tertiary, a sedimentary sequence was deposited over the Picos de Europa limestones. This is inferred by the presence of Permian deposits within down-faulted regions, as at Sotres (Marquinez, 1978; Smart, 1984), and by the present drainage pattern which must have been superimposed on the Carboniferous limestones from a post-Variscan cover.

Post-Variscan deformation was extensional in character with fault-bounded basins controlling the pattern of sedimentation. In late Eocene and Miocene times, however, northern Spain experienced a further period of north-south compression, this time related to the Pyrenean Orogeny. The compression ended about 38 Ma ago and probably initiated the uplift of the Picos de Europa massifs (Le Pichon & Sibuet, 1971; Boillot & Depeuble 1982; Vegas & Banda, 1982). The Pyrenean deformation affected the Carboniferous limestones largely by re-activating existing Variscan and post-Variscan fractures. These are particularly important controls on cave development because they are less well 'sealed' by veining and provide the most open routes for water into the massif.

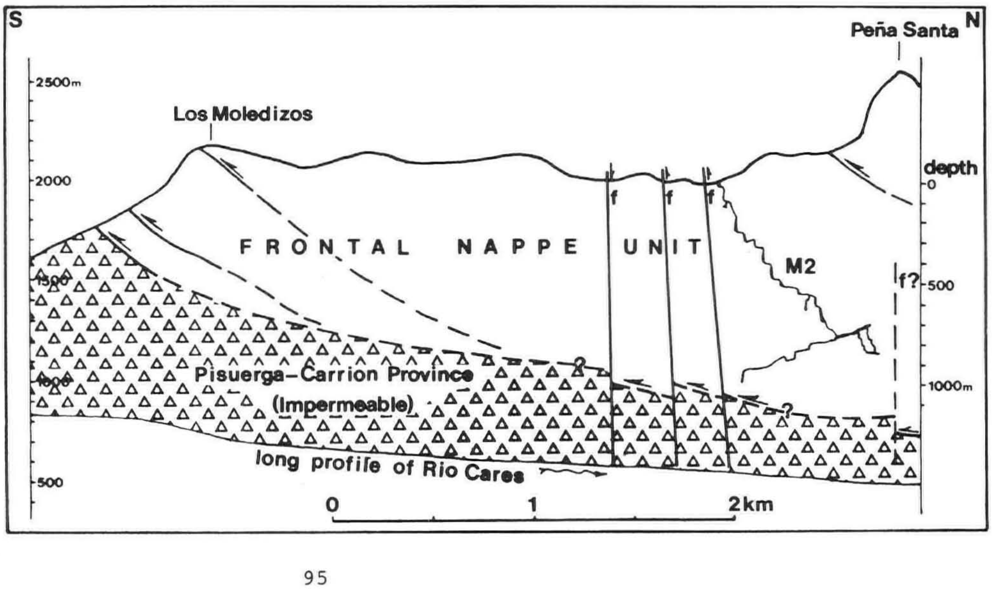


Figure 4 Diagramatic section through the Frontal Nappe Unit.

The Geology of Vega Huerta

The Western Massif has been mapped by Farias (1982) although only the eastern part of the range is covered (Figs. 3 and 4). Farias identified four major Variscan thrust sheets (or nappes). Each is overthrust on to the one immediately to the south so that the dip of the thrusts generally increases from south to north. Vega Huerta is located on the first (most southerly) nappe to be emplaced which is called the Frontal Nappe Unit. The highest mountain in the massif, Peña Santa, is located at the front of the second nappe, the Peña Santa Nappe Unit. Within the Frontal Nappe Unit the dips of the beds is generally 0° to 20° although the dip reaches 30° at the southern escarpment and steeper dips occur near major faults. This contrasts with the area to the north and around Treviso where the dip is rarely less than 45°.

All the limestones of the Frontal Nappe Unit are potentially cavernous although the Vega Huerta-Carbanal Series which has a significant shale content, contains only collapsed shafts at the surface with no negotiable entrances found to date. Erosion of this formation has produced 'windows' into the underlying Picos de Europa Limestone Formation within which the caves I8 and I34 are developed (Fig. 3).

Several major post-Variscan faults cut the Frontal Nappe Unit. These trend east-west and southeast-northwest and three come together just to the south of the entrance of M2. There are also many less persistent fractures, not shown in Fig. 3, but which are clearly important controls on cave development.

CAVE DEVELOPMENT WITH SPECIAL REFERENCE TO M2

The Frontal Nappe Unit differs from the nappes emplaced later (in the region north of Peña Santa) in that the limestones rest on the rocks of the Pisuerga-Carrion Province. These are largely black shales, sandstones and conglomerates and therefore provide an impermeable basement to the limestones. The Rio Cares has cut completely through the Frontal Nappe and now flows some 300 metres below the base of the limestones. Therefore vadose conditions must have existed throughout the Frontal Nappe for a considerable period (Fig. 4). At the present time, water draining to the base of the Frontal Nappe can be expected to flow down the dip of the basal thrust, approximately towards 010°. In part of the area explored by OUCC, between Peña Santa and Ario, there appears to be be a perched water-table which causes the caves to terminate in sumps at an altitude of about 1300 metres (Roberts, 1986). The existence of the M2 cave system, which descends almost to the base of the limestones, demonstrate the absence of a water-table at 1300 metres in the Frontal Nappe.

As Smart (1984) commented, cave development would have been initiated with the exposure of the Carboniferous limestones from beneath the post-Variscan sedimentary cover. At present there is little information to date this event but erosion of the post-Variscan cover would have both accompanied and followed the uplift of the Picos de Europa. Major cave systems probably developed while the post-Variscan cover supported large drainage catchments and concentrated water into a few sinks. Such systems will be termed 'cover systems' in this paper. As the cover was eroded however, an increasing number of smaller catchments would have developed as new fractures were exploited. Many of the existing sinks and cave passages would have been abandoned.

The glaciation of the Picos de Europa during the Quaternary had a number of important affects. Glacial periods are characterised by both erosion and deposition so many established depressions were undoubtedly choked with debris. However, cave systems were probably formed at this new time by glacial meltwater sinking into the limestones as proposed by Smart (1986) for many caves in the Eastern Massif. Essentially the glaciers provided large catchments and concentrated water into certain sinks. The Picos de Europa must have been a region of high relief before the Quaternary glaciations, so the majority of the post-Variscan cover may have been eroded (and major caves developed) before the onset of glacial conditions.

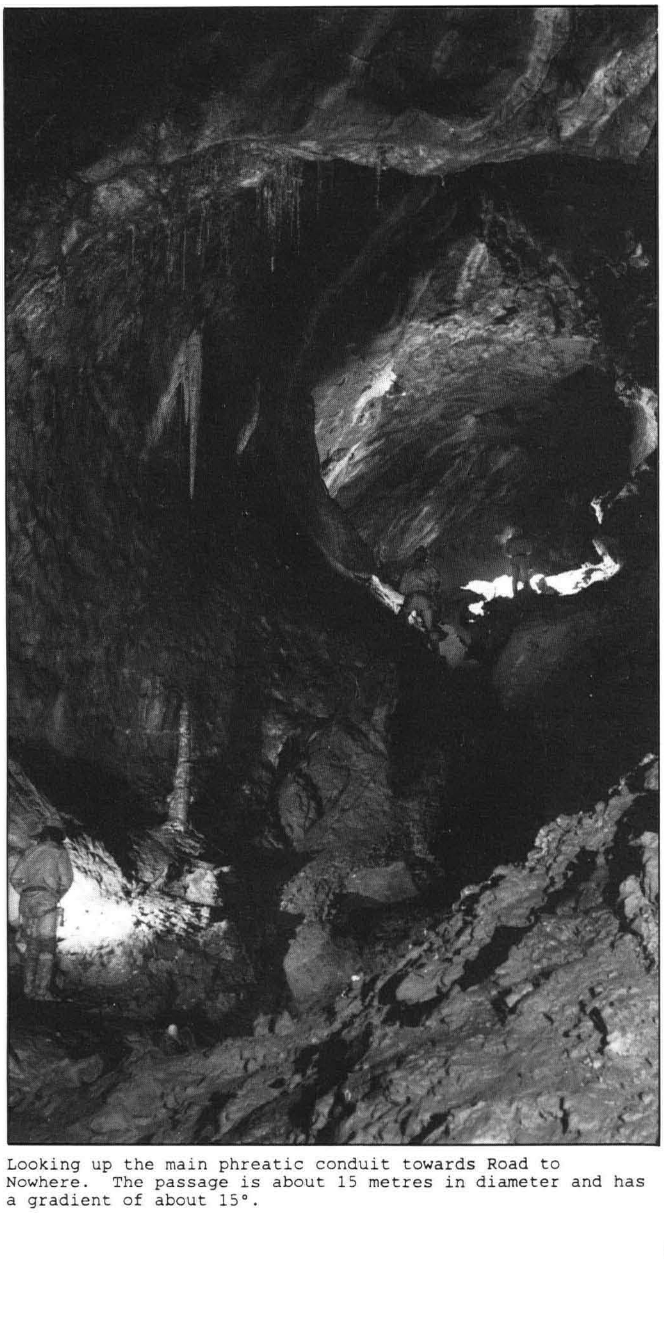
Since the retreat of the glaciers the surface of the Frontal Nappe has probably changed very little except that most of the larger shafts have gradually choked with scree. At present there are hundreds of shafts developed in the surface of the Frontal Nappe but very few lead to negotiable cave passages. The large number of fractures means that each one has only a small catchment area, often receiving water only from the snow-plug within it. These flows are insufficient to keep

Top camp below the south face of Pena Santa. The main face is composed of limestones from the Barcaliente Formation which are thrust over the disrupted Vega Huerta-Carbanal Series.

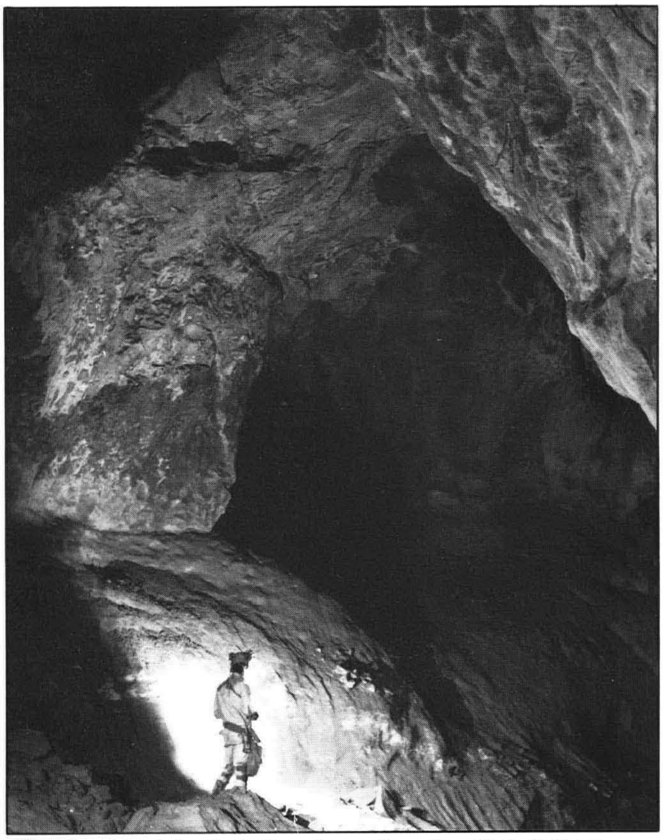
cave passages clear of the debris loosened by freeze-thaw action in the winter months. The entrances to the 'cover systems' are almost certainly eroded or buried, although deeper passages may have been preserved. The major cave systems discovered to date are usually those with entrance passages which have been created or enlarged by meltwater and which have then escaped infill because of a fortunate location or because they have high-level routes over the blockages created by debris from the surface (Laverty and Senior, 1981).

THE M2 CAVE SYSTEM

The entrance of M2 is located about 400 metres west of Vega Huerta beneath the imposing south face of Peña Santa. In this location ice accumulation was probably less extensive and less prolonged than on the north-facing slopes of the areas explored by OUCC and LUSS. Nevertheless, remnants of terminal moraines exist in the major depressions south of Peña Santa and glacial rounding is evident in the limestone ridge containing the entrance of M2. The entrance is on a minor fault dipping 65° to 020° which forms a linear depression along the long axis of the ridge. A possible explanation for this location is that crevassing occurred where the ice rode over the ridge so that supra-glacial and en-glacial meltwater was directed to the base of the glacier, where it then sank into the M2 cave.



Looking up the main phreatic conduit towards Road to Nowhere. The passage is about 15 metres in diameter and has a gradient of about 15°.



The phreatic tube just downstream from Ken Hill Gallery. Here it is mostly developed above a bedding plane within the Valdeteja Formation. Downward solution was limited by sediments.

Within the cave individual passages can be seen to exploit various geological controls but by far the most important are faults. The term 'fault' is used in the following sections only where movement can be clearly detected. The term 'fracture' is used in a general sense to describe all planar fissures and includes faults, joints and major bedding planes. In general, the orientation of the cave passages (Fig. 5) suggests that the overall trend is controlled by two sets of fractures which strike approximately 020° and 140°. Fractures with this orientation are mostly related to the period of extensional deformation which followed the Variscan orogeny. These fractures are the most important controls below Non-Stop Drop. Above this point the cave is developed down the dip of fractures striking approximately 280°.

The Upper Section of M2

The entrance fault runs into a more prominent reverse fault dipping 65° to 040° which is first encountered just beyond No Eighth (Fig. 5 and Fig. 6). This second fault defines the roof of the pitches between Watford Gap and Ivan's Other Oriface. The cave clearly developed down the dip of the fault plane and a small phreatic tube is preserved at the head of Watford Gap, its trend determined by a small phreatic tube which approximately follows the strike of another fracture. The Amapolo Series is probably a separate system which has been intersected by down-cutting of the canyon in the main cave. Scallops in the Amapolo Series indicate a flow direction from west to east.

The pitches developed along the second fault plane are linked by ramps which rise from the base of each pitch to the head of the next. Such ramps are common in M2 and are important features of many Picos caves. Fig. 7 summarises the morphology of the ramps and shows that they are vadose features formed by pitch retreat. They are not lithologically controlled and are not segments of phreatic tubes intersected by vadose canyons. Each ramp marks the foot of a pitch where it

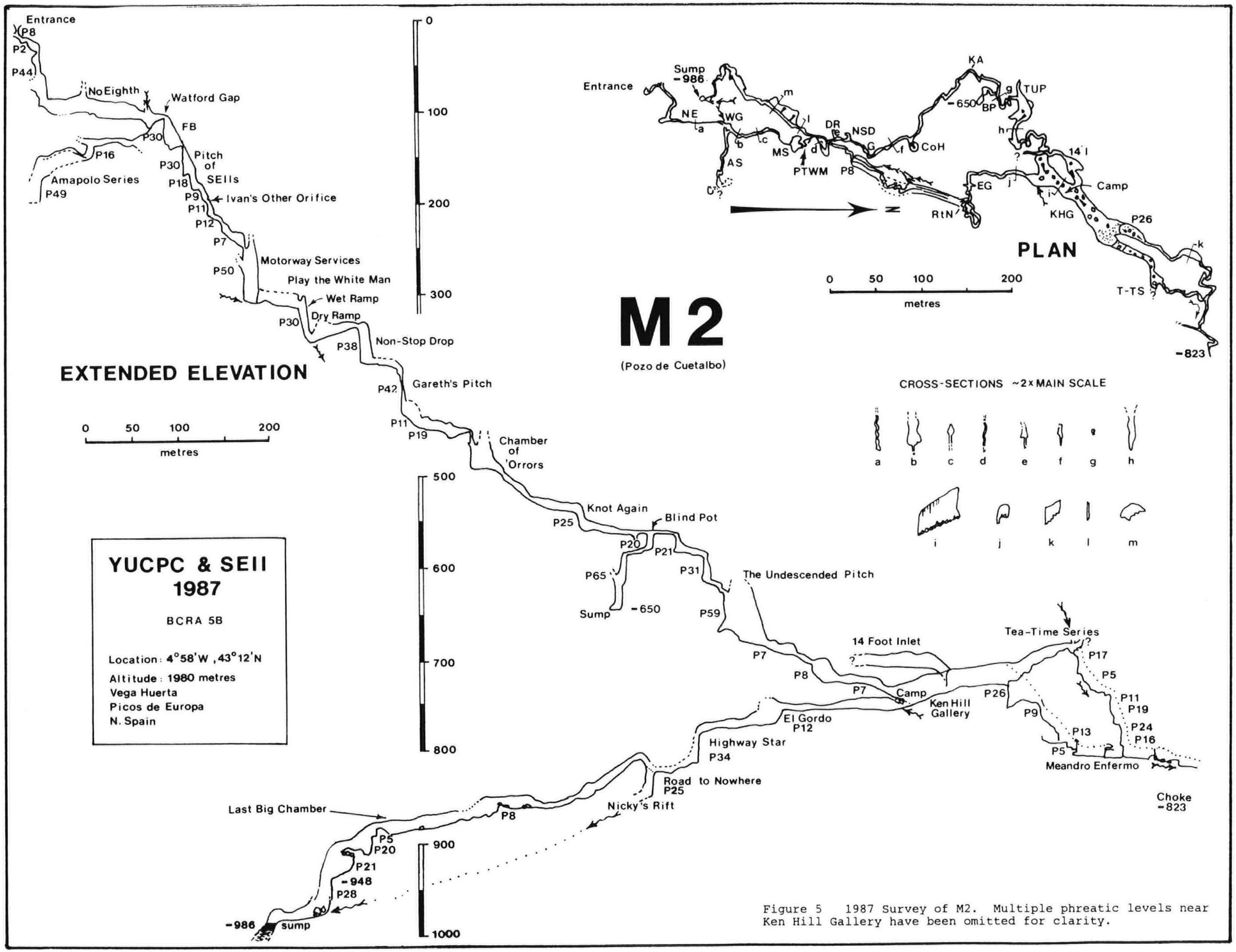


Figure 5 1987 Survey of M2. Multiple phreatic levels near Ken Hill Gallery have been omitted for clarity.

retreated headwards and cut downwards. The gradual decrease in width of both the ramp and the canyon towards the base of the pitch may be evidence of a decreases in discharge over time. Measurements of ramps in two caves, M2 and M103, have revealed mean gradients varying between 30° and 34° which suggested that the headward erosion rate is more than 1.5 times that of downcutting. The larger size of the pitches compared to the canyons demonstrates the greater erosive power of falling water compared to channel flow. The canyons are often too narrow to traverse so the only negotiable route through these 'pitch-ramp' systems is usually down the pitches then back up the ramps. The nature of erosion at pitches was studied by Brucker et al (1972) who measured a decrease in carbon-dioxide pressure in water as it fell down shafts. They attributed this change to de-gassing of dissolved carbon-dioxide from the thin film of water flowing down the walls. In M2 at present, very little water falls through the pitch-ramp system. In normal summer flow conditions only a thin film of water flows down the walls and the wetted area is restricted to a small section of the shaft below the inlet canyon. In the highest flows observed to date the inlet stream disperses into a fine spray as it falls which causes an increase in the wetted area on the shaft. If the erosion rate is equal over the whole wetted area, these observations infer that the length of a ramp depends on it's age whereas the width of a ramp is related more closely to the mean discharge. A consequence of predominantly low flows is that the wetted area on a pitch approaches that of a canyon so that pitch-ramp systems tend to evolve into steep, narrow canyons (Fig. 7b, stage 3).

Further work is required to determine the significance of the ramp angle in particular with respect to the angle of the dipping surface, usually a fault plane, beneath which the ramps develop. Potholes commonly develop at the base of the pitches because the mechanical erosion of swirling sediment in the plunge pool 'drills' downwards at a greater rate than the exit canyon can cut down (Ford, 1965). The absence of potholes at the base of the pitches in 'pitch-ramp' systems infers that the exit canyon could always cut down at the same rate as the base of the pitch. The simplest explanation for this is that there was insufficient sediment to create potholes, a conclusion which supports the earlier suggestion that glacial meltwater was probably involved in the formation of the upper cave.

At Motorway Services a small stream enters and flows down the tortuous Play the White Man canyon. This passage is similar to No Eighth in that it cuts through massively bedded limestones

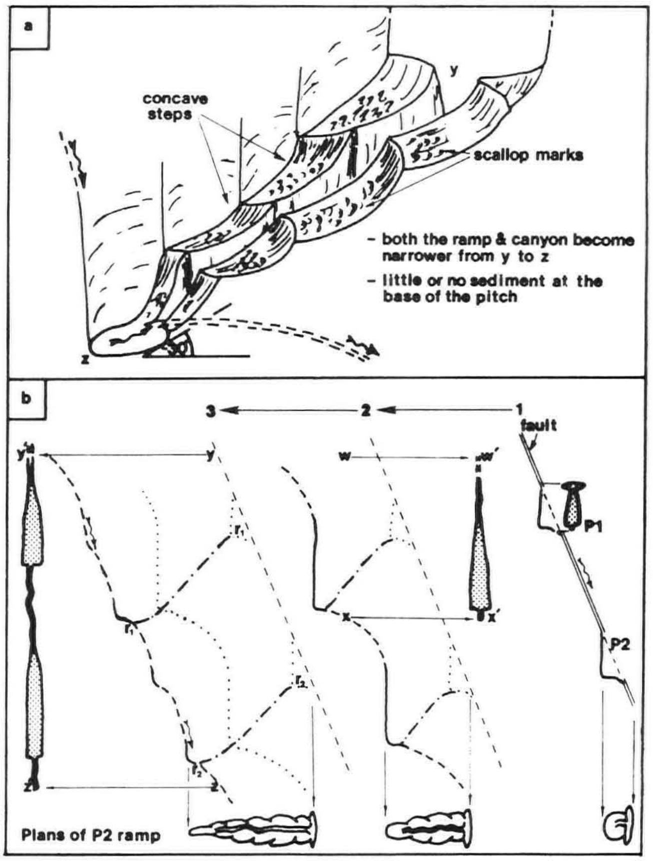


Figure 7 a) The general morphology of pitch-ramp systems. b) Schematic development of ramps r1 and r2 due to retreat of pitches P1 and P2.

to link one series of fault-guided pitches with another. On such links a narrow and meandering canyon has developed because it is solely the result of canyon incision. No pitch has retreated along it to form a ramp (Fig. 6).

The passage enlarges beyond Play the White Man as the stream cascades down the dip of a fault with calcite and dolomite veining (the Wet Ramp) to sink at the bottom in an immature rift. The way on is up the Dry Ramp, which is between 2 and 3 metres wide and rises approximately 25 metres to the head of Non-Stop Drop. The Dry Ramp has also formed as the result of pitch retreat beneath yet another fault (Fig. 6) but the ramp-forming pitch has been abandoned due to a capture down the Wet Ramp.

Below Gareth's Pitch the cave changes direction towards the northwest. The new trend is determined by a phreatic tube which rises and falls along another fracture inclined at 70° to 040°. A deep vadose canyon is developed below the tube and there has been extensive modification by collapse. Near Chamber of 'Orrors, for example, two parallel open fractures and one filled with ochre, dolomite and shale have contributed to a massive collapse.

Below Chamber of 'Orrors the tube continues in the roof of the passage and constantly changes direction and cross-section as it exploits successive fractures. There are several pitches along this section of the cave but only in the case of Blind Pot, an obvious capture, does the tube continue over the head of the pitch. At the other pitches the tube must have descended steeply down the dip of the controlling fracture. Subsequent modification of this dip segment under vadose conditions has removed signs of its original phreatic morphology, however the tube is always encountered again at the base of the pitch where it is developed along a suitable fracture.

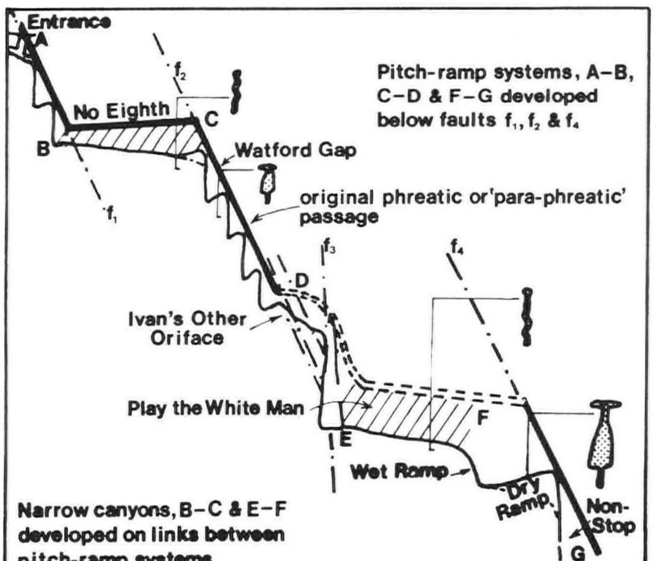


Figure 6 Diagramatic section of M2 between the entrance and the Dry Ramp.

The Lower Section of M2

At the Undescended Pitch the dimensions of the cave increase and a large meandering canyon leads to the junction with the lower section of M2 at Ken Hill Gallery. Remains of phreatic tubes more than 3 metres in diameter reveal the origin of this section of the cave although there has been substantial modification by collapse. Two major phreatic conduits meet at Ken Hill Gallery. One is the Tea-Time Series which has suffered two captures, one within Ken Hill Gallery where the Tea-Time Series enters and another at the limit of 'upstream' exploration. These two routes join and then choke at -823 metres. The second major phreatic inlet lies in the roof of the canyon between The Undescended Pitch and Ken Hill Gallery. Near the bottom of Ken Hill Gallery, below the camp, a stream joins the main gallery, flowing in a meandering canyon. A small phreatic tube in the roof diverges from the canyon in an upstream direction and terminates at a pair of perched sumps. In a downstream direction from Ken Hill Gallery, incision by the inlet stream gradually increases and eventually the large phreatic passage in the roof becomes inaccessible. The stream falls down some wet pitches (another relatively recent capture) and eventually disappears into Nicky's Rift. Fortunately the phreatic passage can be regained above the Road to Nowhere after which it again descends, clearly developed down the dip near and at the base of the Valdeteja Formation (Fig. 8). The main phreatic conduit exploits both faults and bedding planes but it's general trend seems to be controlled by the bedding of the massive Valdeteja Formation.

In Ken Hill Gallery and adjoining passages there are considerable thicknesses of sediments which are of five main types:

1. Unsorted, limestone boulder beds with rounded boulders up to 0.7 metres in length. These make up the largest volume of sediment.
2. Well sorted, well rounded, imbricated limestone pebble beds.
3. Cross-laminated and cross bedded sands and silts of many colours with lenses of unsorted sandy gravels, the material loosely termed 'grit' in Fig. 9.
4. Well rounded, brown to red, gravels and sandy gravels. These are an equivalent lithology to the lenses of unsorted, sandy gravel ('grit') within the cross-bedded sequence, however they have a much wider distribution.
5. Dark brown clay. This is found on top of the cross-bedded sequence and is the material filling the fissure in Fig. 9.

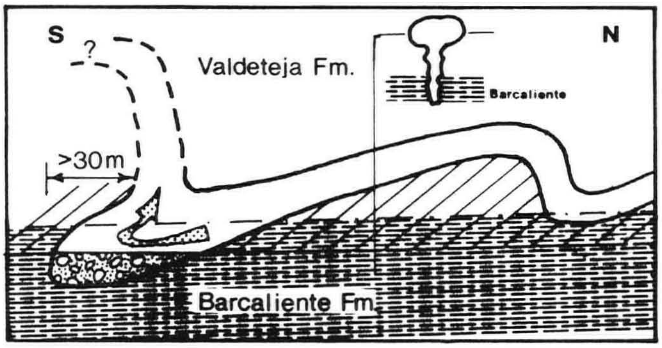


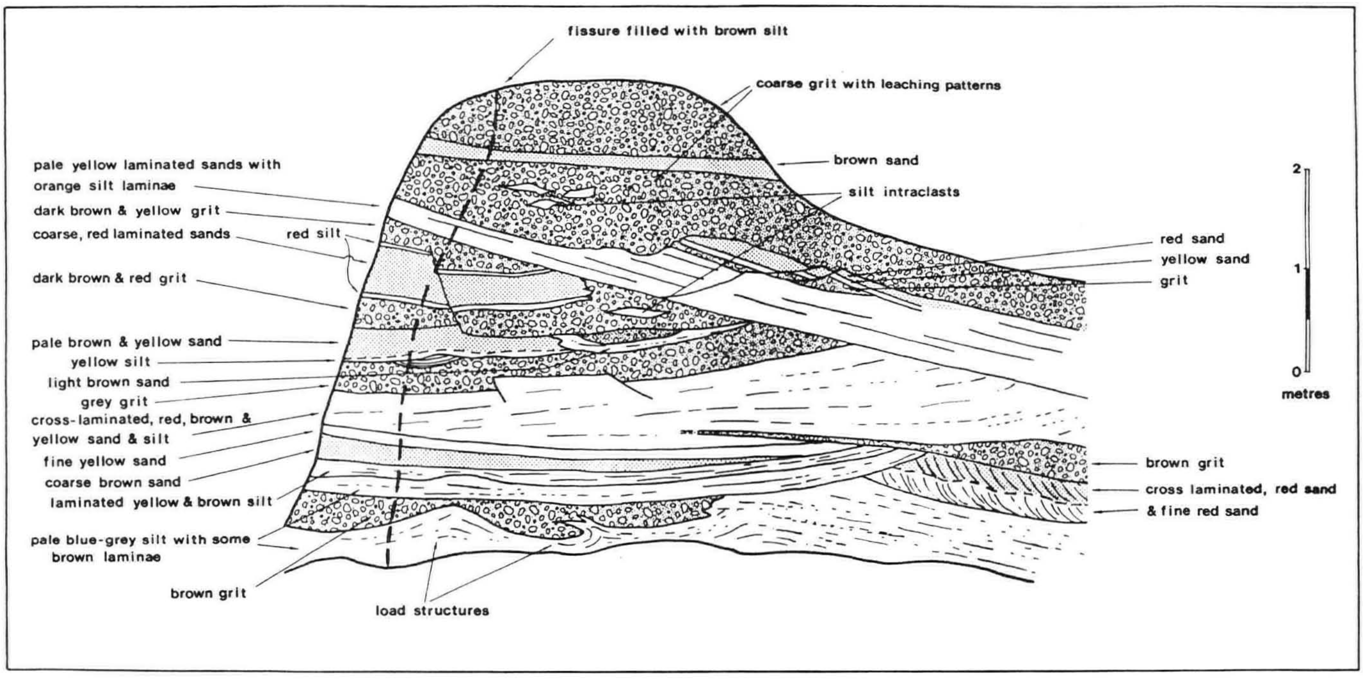
Figure 8 The relationship of the main phreatic conduit to the geology near Last Big Chamber showing how the chamber developed by solution at the bottom of a phreatic lift.

The sandy gravels are remarkable sediments. They are extremely porous and water moving through the deposits has produced spectacular leaching patterns. Some beds are weakly cemented by calcite but most are unconsolidated and form extensive talus slopes in Ken Hill Gallery.

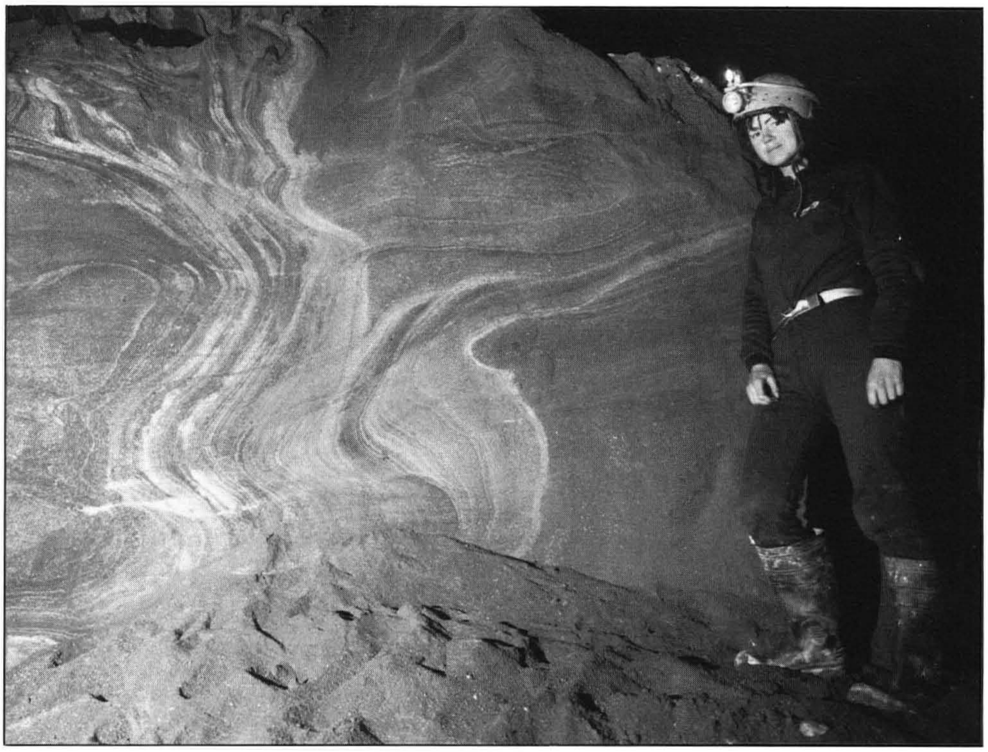
The cross-bedded sequence of silts, sands and sandy-gravels appears to be the oldest sediment preserved and represents alternating still and energetic periods. Most of the fine material, particularly the blue-grey silt, is found at the bottom of the sequence. The sandy gravels are found cutting across the beds beneath and become more extensive towards the top of the sequence. One lens has clearly been deposited in a channel with a steep bank showing that the phreatic conduit was at lest partly drained when the last of the coloured sediments were being deposited. The unsorted nature of the sandy gravels and the chaotic inclusion of silt intraclasts suggested that these materials were deposited suddenly at the confluence of a fast-flowing inlet (the Tea-Time Series?) with a relatively still river or lake within Ken Hill Gallery.

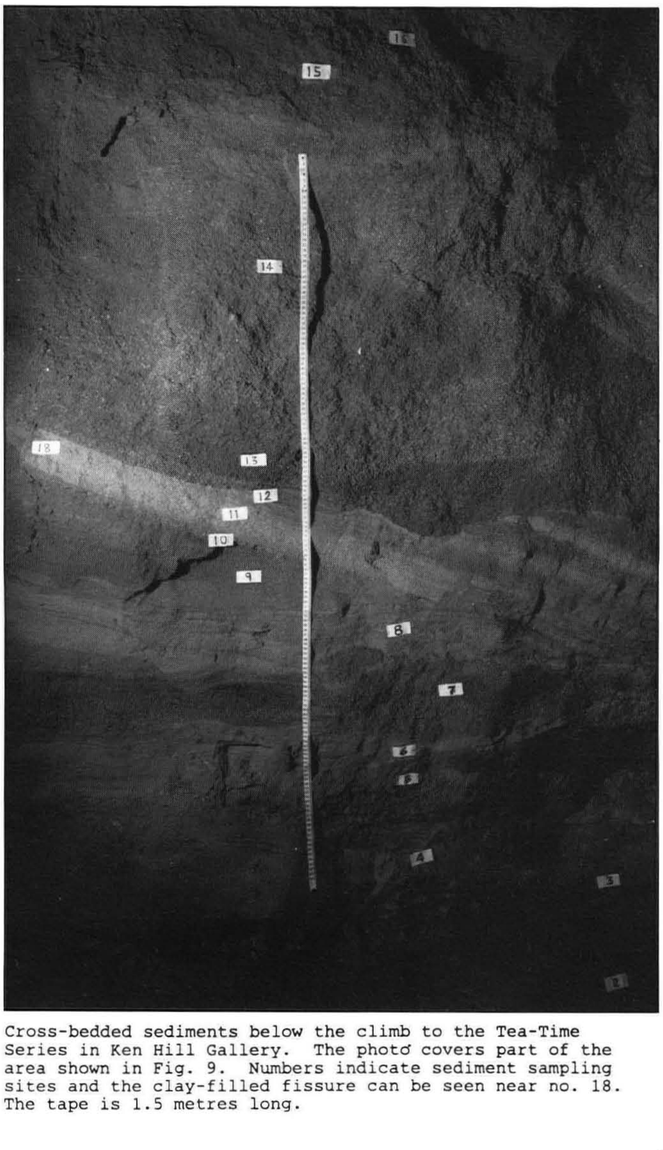
The Carboniferous succession in the Picos de Cornion (Fig. 2) contains no formation which could have provided these materials. They are most similar to the so-called 'Red Permian' formations like the Sotres Formation of the Eastern Massif (Marquines, 1978, Martinez-Garcia, 1981, Smart, 1984) or the Labra Formation (Maas, 1976). In the western Massif, a small outcrop of 'Red Permian' is preserved to the north of a mountain called Valdepiño, about 2km west of Vegabaño, but at an altitude of only 1400 metres. The M2 cave sediments provide the first direct evidence of a

Figure 9 Sketch of the sediments below the climb to the Tea-Time Series.



Leaching patterns in unsorted sandy gravels, Ken Hill Gallery.





Cross-bedded sediments below the climb to the Tea-Time Series in Ken Hill Gallery. The photo covers part of the area shown in Fig. 9. Numbers indicate sediment sampling sites and the clay-filled fissure can be seen near no. 18. The tape is 1.5 metres long.

post-Variscan sedimentary cover at higher altitudes in the Western Massif. Since the lower section of M2 descends from north to south the source of the cave sediments may have been to the north of the Peña Santa ridge.

The dark brown clay which covers the coloured sediments in Ken Hill Gallery is also found between the sediments and the wall of the cave, and infilling fissures. This shows that the coloured sediment dried, shrank and cracked before being re-submerged at the time the dark-brown clay was deposited.

The rounded limestone pebble beds and the boulder beds appear to post-date the coloured arenaceous sediments. This relationship is most clearly seen in the Last Big Chamber where the pebble beds can be seen on top of parallel-bedded yellow silts and fine sands.

Discussion

Passages with a phreatic morphology occur at -100 metres (Watford Gap), -140 metres (Amapolo Series), between -425 metres and -575 metres (base of Gareth's Pitch to Undescended Pitch) and within the lower section of the cave (-700 to -986m). The relationship between these passages is not clear but, as mentioned previously, the Amapolo Series is probably a separate development. The small size of the high-level tubes suggests that the upper part of M2 did not originate as a 'cover system'. If the highest phreatic passages are interpreted as having formed beneath a regional water-table then base level in the Rio Cares and Rio Dobra must have been some 1100 metres higher than it is today. Higher base levels have been proposed to explain the presence of phreatic passages at high altitudes within Pozu del Xitu (Laverty and Senior, 1981) and Sima 56 (Smart, 1984, and 1985). The fact that the phreatic tube in the upper section of M2 exploited fractures of various orientations en-route to the lower part of the cave shows that the local hydraulic gradient at the time was towards the lower cave and not towards either of the gorges. Therefore the lower part of M2 must be at least as old as the upper cave. If upper and lower cave originally formed as part of the same phreatic system, M2 is an example of a 'bathyphreatic' cave (Ford and Ewers, 1978). These authors describe such caves forming where groundwater hydraulic gradients are steep and the water table remains high because firstly the fissure network is immature and secondly the distance between point of influx and the resurgence is great. This interpretation implies that the main phreatic tube in the lower cave must rise again, perhaps by as much as 500 metres, to it's former resurgence level. According to the model of Ford and Ewers (1978) bathyphreatic caves evolve towards 'deep-phreatic' then 'water-table' caves as the fissure network matures and shorter routes are exploited between the point of influx and the resurgence. Such passages are not seen in the upper part of M2 and the single phreatic tube which controls the trend of the upper cave shows no significant increase in size with depth. These observations suggest that phreatic conditions existed for about the same length of time throughout the whole of the upper cave. The upper cave was possibly abandoned at an early stage then re-activated some time later under vadose conditions.

However, the earliest vadose canyon in the upper cave is everywhere developed below the small phreatic tube. It has not exploited other routes so the period of abandonment was not long enough to allow a significant increase in the permeability of the fissure network by the time vadose conditions become established. Within the bathyphreatic model, a very rapid drop in base level seems to be required to explain these observations.

The phreatic morphology of the earliest passage in the upper section of M2 may, however, be an extreme example of a 'para-phreatic' passage (Tratman, 1957). A para-phreatic passage is one formed where large volumes of water drain through a network of low permeability fissures within the vadose zone. Local phreatic conditions would have existed as long as the volume of water exceeded the capacity of the passage. If an immature fissure network is assumed, such conditions may have existed long enough for phreatic tubes to have formed on the more horizontal sections of the immature cave. Vadose conditions would have become established first on the more vertical segments where capacity to transmit water was greater. This model is proposed because it would explain the morphology of the phreatic passage in the upper cave without invoking a sudden drop in base level. The regional water table could have been fairly stable, probably close to the level of Ken Hill Gallery, at the time the upper cave was initiated.

Both models require an immature fissure network but the conditions in the aquifer are

Feldspathic conglomerates of the 'Red Permian' north of Valdepino. Rocks like these are the likely source for the coloured sediments in M2.

quite different, phreatic in the case of the bathyphreatic model and vadose in the para-phreatic model. At present there is insufficient evidence to prove or disprove either of these interpretations. Further exploration may show whether the phreatic riser inferred by the 'bathyphreatic' model actually exists.

The lower section of M2 was clearly a major phreatic conduit and acted as the 'focus' for several subterranean streams. The large passages and sediments in the lower cave may be remnants of a pre-glacial 'cover-system', formed within the phreatic zone, and exploited by caves initiated under glacial conditions. Torca de Urriello in the Central Massif appears to be similar to M2 although the author has no personal experience of the cave. From the published survey, the upper section of Torca de Urriello has developed down the general dip of the beds and major structures. This section of cave links into a much larger, and probably much older development oriented along the strike. It may not be coincidence that the lower sections of M2 and Torca de Urriello are both at similar altitudes.

The trend of the lower passages in M2 gives no clue to the location of the ancient river's resurgence but presumably it was in the Rio Cares or Rio Dobra. The stream which enters the lower cave at the bottom of Ken Hill Gallery sinks into Nicky's Rift and fluorescein dye has proved that the same water emerges again near the terminal sump. From there the water has been traced to the canal de Capozo some 4km to the east and approximately 350 metres lower than the terminal sump (Lloyd, pers. comm.). The major east-west fault located just to the south of M2 probably conducts the water to this resurgence and may prove to be a key feature controlling the trend of the unexplored continuation of the main phreatic passage. Further exploration is required to determine the destination of the ancient river which formed the main phreatic conduit.

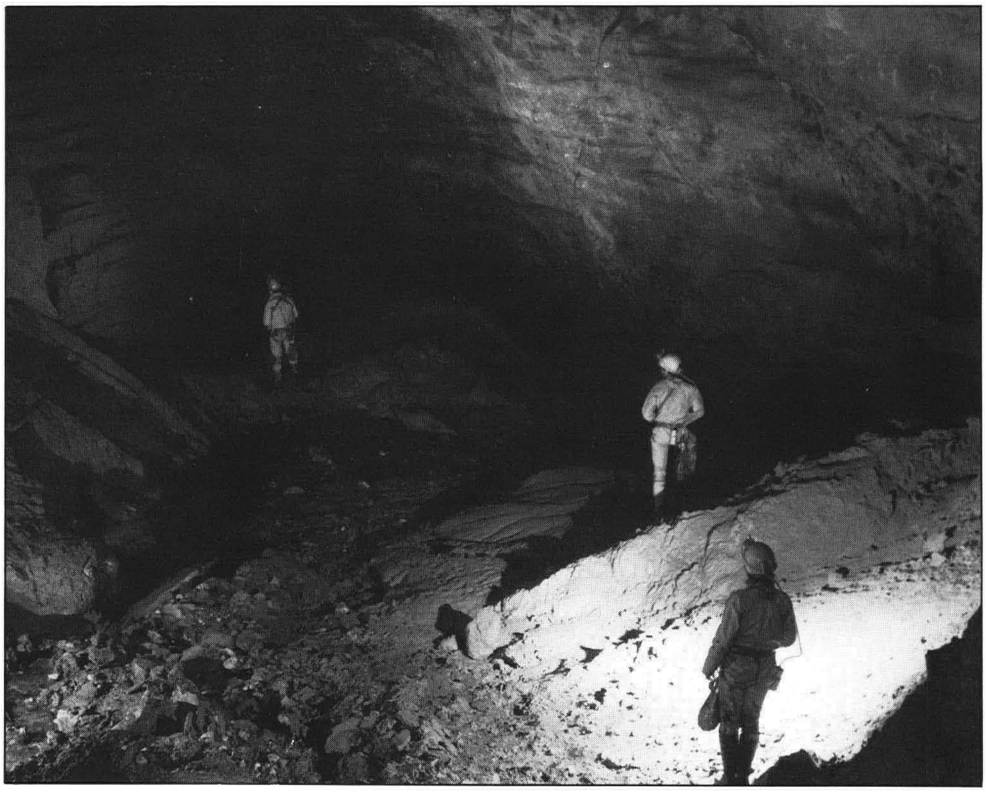
The geological section through the Frontal Nappe (Fig. 4) shows that perhaps 300 metres of limestone may exist beneath the sump at -986 metres. This interpretation is based on the fact that the top of the Barcaliente Formation is seen within the cave at an altitude of about 1100 metres (-900 metres depth) while along the strike to the east, in the Canal de Capozo, the Barcaliente Formation reaches 400 metres in thickness because of overthrusting (Fig. 3). The dip of the Barcaliente Formation in the lower passages is about 5° to the south and it is probable that the same resistant level is responsible for the termination of the cave at the -823 metre choke, in Nicky's Rift and at the final sump.

CONCLUSIONS

The discussion above and the conclusions summarised below are based on observations made during the 1986 and 1987 expeditions to M2. It is hoped that sediment analyses will be completed during 1988 which will identify the source rocks with more certainty and possibly provide a data for the deposits. The preliminary conclusions are:

1. The geology of the Frontal Nappe Unit provides different conditions for cave development compared to the other nappes because the limestones have an impermeable basement.
2. The ramps found in M2 and many other Picos caves are vadose features formed by pitch-retreat. Ramps form where sediment supply is low which prevents potholing at the base of the pitches. Glacial meltwater is proposed as the likely agent responsible for the erosion of the 'pitch-ramp' sections.
3. The phreatic tube in the upper part of M2 exploited various, low permeability fissures to transfer water down the local hydraulic gradient into the lower section of the cave. If the upper cave originated beneath the regional water table the whole of M2 is an example of a bathyphreatic cave. The phreatic tube in the upper cave may,

The Last Big Chamber. The thin beds visible in the far wall are within the top part of the Barcaliente Formation.



however, be a para-phreatic passage formed within an extensive vadose zone.
4. The lower section of M2 acted as a major phreatic conduit and formed before post-Variscan sediments were completely eroded from the Carboniferous limestones.
5. The sediments in Ken Hill Gallery are probably derived from 'Red Permian' formations now eroded from most of the Western Massif.

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Abstracts of papers presented the to meeting

Manchester Polytechnic, November 1987

SUB WATER TABLE QUARRYING AND AQUIFER DEROGATION IN THE MENDIP HILLS

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In the first County Development Plan for Somerset the Mendips were defined as an area of Special Landscape Value and quarrying was limited to the less aesthetic eastern part of the hills. To further reduce their visual impact it was recommended that quarries proceed downwards (constructive quarrying), rather than sideways through hills (destructive quarrying), with pumping being used to keep workings dry where they intercepted the water table. Where pumping is required, derogation of the aquifer may occur with the resultant drying up of springs and supply boreholes in the locality. The problem of predicting how much water will be intercepted by a quarry is complicated because karstified limestone aquifers often contain solutionally developed conduits which can transmit relatively large volumes of water quite rapidly.

Water storage and movement in the saturated zone is being examined by carrying out slug and dye dilution tests on boreholes in the area. Further knowledge is gained from pump tests on quarry sumps and analysis of long term water level records. These tests, along with examination of quarry faces should help to predict the likelihood of large conduits being developed and thus help to elucidate the long term effect of quarry dewatering.

GEOLOGY AND SPELEOLOGY OF LOWER GLOMDAL, NORWAY

Simon Bottrell; Department of Earth Science, Leeds University

The lower part of Glomdal, Rana, N. Norway, contains a large number of phreatic cave segments. Many of these are now dry "fossil" caves, but others have been invaded by modern drainage and, in some cases, extensively modified. The caves are formed in highly deformed marbles and the geology of the area is briefly described. The extent to which geological factors have affected speleogensis has been investigated by a combination of surface and underground geological mapping. This demonstrates that both lithological and structural features of the marbles have exerted strong controls on the genesis and morphology of the caves, and the nature and importance of these controls is discussed. The caves of Lower Glomdal relate to an ancient drainage pattern and give a fragmentary picture of the hydrology of the karst area at that time; interpretation of the palaeohydrology of the area can, therefore, only be tentative. Scallop morphology in the caves indicates a predominant southerly palaeoflow. It is suggested that the caves carried drainage from an ancient proglacial lake, of which Glomdalsvatnet is a modern vestige. The present underground lake outlet is therefore an active remnant of the ancient system, the rest of which has been truncated by river capture following the erosion of the modern river canyon.

SPELEOTHEM DATES AND RATES OF LANDSCAPE EVOLUTION IN THE ENGLISH MIDLANDS

Peter J. Rowe, Timothy C. Atkinson, Timothy J. Austin; School of Environmental Sciences, University of East Anglia

Where it crosses the Carboniferous Limestone outcrop in the south-west Peak District, the River Manifold has cut a deep gorge. G.T. Warwick identified remnants of former valley floors and suggested that the gorge had been deepened in six successive stages. Short caves in the sides of the gorge are truncated fragments of former phreatic tubes in which the Manifold formerly flowed beneath the gorge floor, as it does in dry seasons today. We have used U-series dating and palaeomagnetic properties to measure the age of speleothems in these caves and infer the maximum possible value for the mean rate of downcutting of the gorge floor. The oldest and most important site, Elderbush Cave, contains speleothems thought to have been deposited during the Olduvai event (1.67-1.87Ma), implying that the present relief has evolved over a timescale of at least 2 million years. The implications of this finding for the evolution of upland Britain will be briefly considered.

CARBONATE DISSOLUTION BY GROUNDWATER MIXING IN THE BLUE HOLES OF THE BAHAMAS

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J.M. Dawans; Koninklijke/Shell Exploratie en Produktie Laboratorium, Rijswijk, Netherlands.

Extensive cavern systems (Blue Holes) are developed along major fractures paralleling the bank margin on South Andros Islands in the Bahamas. Enhanced groundwater flow occurs in these cave systems, and also from them into the adjacent carbonate aquifer, giving considerable potential for carbonate dissolution by groundwater mixing. In-situ observations of the cave wall morphology, and petrographical examination of wall-rock samples show that extensive and highly pervasive carbonate dissolution is currently occurring at the base of the freshwater lens, where mixing with the underlying deep saline groundwater occurs. Geochemical studies indicate that the brackish waters from this zone of mixing are undersaturated with respect to calcite, permitting limestone dissolution at an apparently high rate. Significant production of carbon dioxide and hydrogen sulphide by bacterial activity also occurs in this zone. Transmission of carbon dioxide into the underlying deep saline groundwaters by dispersion and diffusion, may also allow dissolution of limestone by deep saline groundwaters. Carbonate dissolution by groundwater mixing is probably a significant porosity-creating process in emergent carbonate structures.

RADON LEVELS IN PEAK AND POOLE'S CAVERNS, DERBYSHIRE

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D. Prime; Geography Department, Manchester University

Uranium-bearing minerals contain radium which decays to the radioactive gas randon-222. Radon in turn decays through four short-lived "radon daughters", to lead-210. High concentrations of radon and its daughters may be present in poorly ventilated mines and caves. Radon may also be brought into such areas in solution in water. It is considered that the chief health hazard is from radon daughters and there is evidence that they can give rise to lung cancer. Recent legislation requires areas having potential radon daughter alpha energy concentrations of 0.03 working level (WL) and 0.1 WL should be designated respectively as supervised and controlled areas (a working level of 0.1 corresponds to an activity concentration of 3700 Bq/m^3).

Radon daughter alpha energy concentrations in the sections of Peak and Poole's Cavern's which are visited by tourists have been monitored irregularly since June 1987 using both the established Kusnetz method and a 'Radon Sniffer' which has the advantage of not requiring a mains power supply but the disadvantage of needing a longer counting time. In Poole's Cavern levels have fluctuated both in time and spatially through the cave, ranging from 0.17 - 0.98 WL. Variations in Peak Cavern have been much more dramatic with a minimum of 0.005 and a maximum of 9.1 WL! The origins of the radon and the causes of the variability are presently under investigation.

It should be stressed that even the highest of these levels poses no threat to tourists or to occasional visitor's. However, the risk increases with the number of hours exposure and could be significant for cave guides or speleogists making frequent visits to high radon areas. Perhaps a more significant problem is that unless radon levels can be reduced or an exemption obtained both caves may ultimately be designated as controlled areas. At best access would be restricted; at worst it could be lost altogether which would be disastrous in view of their scientific and sporting value. Moreover, it seems likely that other caves inside and outside the Peak District may also have high radon levels. Hence, there is an urgent need for a comprehensive monitoring programme.

UK SPELEOTHEM GROWTH AND WORLD SEA-LEVEL

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Calcite speleothem growth in the UK is thought to occur predominantly during 'warm' interstadial and interglacial periods. Analysis of the data from uranium series determinations has identified the presence and ages of three Upper Pleistocene interglacials and six interstadials. In order to test the assumption of climatic controls on UK speleothem deposition, this record has been compared with the high sea stand record from uranium series dated coral reef terraces in tropical and subtropical regions of the world. The presence and ages of eight Pleistocene high sea level stands have been identified. Spectral analysis has demonstrated that between 70000 and 140000 BP there is a high correlation between the UK spleothem and world coral reef dated records. (i.e. during the last interglacial complex when speleothems were growing in British caves there were also high sea level stands in the tropical and sub-tropical regions of the world).

PALEOMAGNETIC STUDIES OF SEDIMENTS FROM PEAK CAVERN, DERBYSHIRE

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T.D. Ford; Department of Geology, University of Leicester

To date a total of four sediment sections from two closely related phreatic tubes have been sampled. Storage tests indicate that on the whole samples carry a stable natural remanent magnetisation (NRM). Alternating field demagnetisation at 10 or 15 mT removes a small viscous component of magnetisation leaving NRM vectors with normal polarity inclinations. These appear to record a pseudo-periodic secular variation of the geomagnetic field against depth in the section. Two sediment columns in the same variation and that of magnetic susceptibility with depth. It is now hoped to extend this correlation to the palaeomagnetic record obtained from a recently sampled sediment exposure in a nearby passage developed at the same cave level. 'Stretching' of secular variation records will allow relative contemporary sedimentation rates to be calculated for different parts of the cave system.

AN INVESTIGATION OF PULSE-WAVE AND DYE-TRACER TECHNIQUES USING LABORATORY MODELS

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D.P. Butcher; Department of Geographical Sciences, Huddersfield Polytechnic

This reports an investigation of pulse-wave and tracer techniques which are used in karst hydrogeomorphological studies to determine the nature of inaccessible karst drainage systems. The study used laboratory models which were based upon the knowledge and experience of the authors and on a field study of the P6-P8 conduit system which forms part of the Castleton karst aquifer in the White Peak of Derbyshire. The field study is to be document as a subsequent paper.

Two contrasting laboratory models were used. Firstly, a variable storage model which was used to investigate the effects of vadose storage on dye-tracers/pulse-wave relationships. Secondly, a phreatic zone model, which was used to investigate tracer behaviour within flooded conduits.

Results indicate that the generation of the lag effects by vadose zone storage invalidates the assumption, implicit in the field technique, that dyes or other tracer substances used to tag pulse-wave experiments will remain in intimate association with the pulse-wave as it is transmitted through the vadose zone. Since the assumption also forms the basis of phreas volumetric calculation, these results show that pulse-wave techniques can produce highly variable results dependant upon the nature of the vadose zone storage. However further work needs to be done both in the laboratory and field to quantify the relationship between tracer lag and storage.

The phenomenon of upstream dye migration was observed in the laboratory phreas. This affects both the timing and distribution of dye recorded at the resurgence. Leading to the detection of bimodal tracer chemographs from a single conduit, this invalidates the assumption that multiple tracer peaks = multiple hydrological routeways. More research both in the laboratory and field is suggested, in particular noting that the technique should be redefined in conduits of known morphology before being applied to unknown conduits.

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The Crocodile Caves of Ankarana: Expedition to Northern Madagascar, 1986

Edited by Jane WILSON

Abstract: Ankarana is a small but scientifically unique limestone massif, notable for its huge river caves where Nile Crocodiles find refuge from drought and hunters. The 98km of cave passages not only provide some spectacular caving but also comprise diverse habitats for a range of cave fauna as well as important palaeontological and archaeological sites. Although the amount of new passage found during the 1986 expedition was disappointing, the scientific findings are highly significant.

INTRODUCTION

The Ankarana Massif comprises a small but spectacular area of tsingy (pinnacle karst) which is mentioned in many books on Madagascar. The Guide Bleu for Madagascar (Hachette 1968) contains a detailed description of the sacred caves and mentions the crocodiles which live in some of the caves. Blanc (1981) wrote of crocodiles in the subterranean rivers of Ankarana, and Paulian (1981) described the caves at Ankarana where bats were hunted. Blanc (1984) suggested that Ankarana's caves are virtually the last stronghold for Madagascar's crocodiles. Ankarana has been a Special Reserve for 30 years but little scientific work has been done there.

An inventory of Madagascar's caves (Decary and Keiner 1971) highlighted Ankarana as an interesting area even before the major finds of this decade. Twenty years of meticulous searching by Jean Radofilao and colleagues (Ravelonanosy and Duflos 1965; Duflos 1966, 1968; Radofilao 1977) and two French expeditions (Peyre et al 1982, 1984) have resulted in the discovery and survey of 93km of cave passage. Ankarana boasts Madagascar's longest cave systems. Indeed Ankarana's caves must be amongst the most extensive in Africa. The large subterranean rivers of Ankarana make the caves quite different to most tropical caves and provide a great diversity of cave habitats suitable for a range of cave-adapted animals. The river caves form a natural irrigation system which allows rich canopy forests to flourish inside the Massif whilst outside the karst area the vegetation of the savannah becomes parched during the six month dry season. The subterranean rivers, then, support the rich fauna existing above ground at Ankarana (see Wilson et al 1987) as well as acting as a reservoir which ensures a reliable water supply to local villages downstream. A selection of papers have been published on the geology (Rossi, 1973, 1974), hydrology (Rossi, 1975, 1976a) and the vegetation zoning (Rossi 1976b) at Ankarana.

The 1981 Southampton University Expedition gave one of its leaders a tantalizing glimpse of the biological and speleological wealth hidden within the spectacular pinnacle karst and convinced us that the area was worthy of more thorough attention. The resulting return trip in 1986 showed Ankarana to be even richer than our predictions (Chapman et al 1987b).

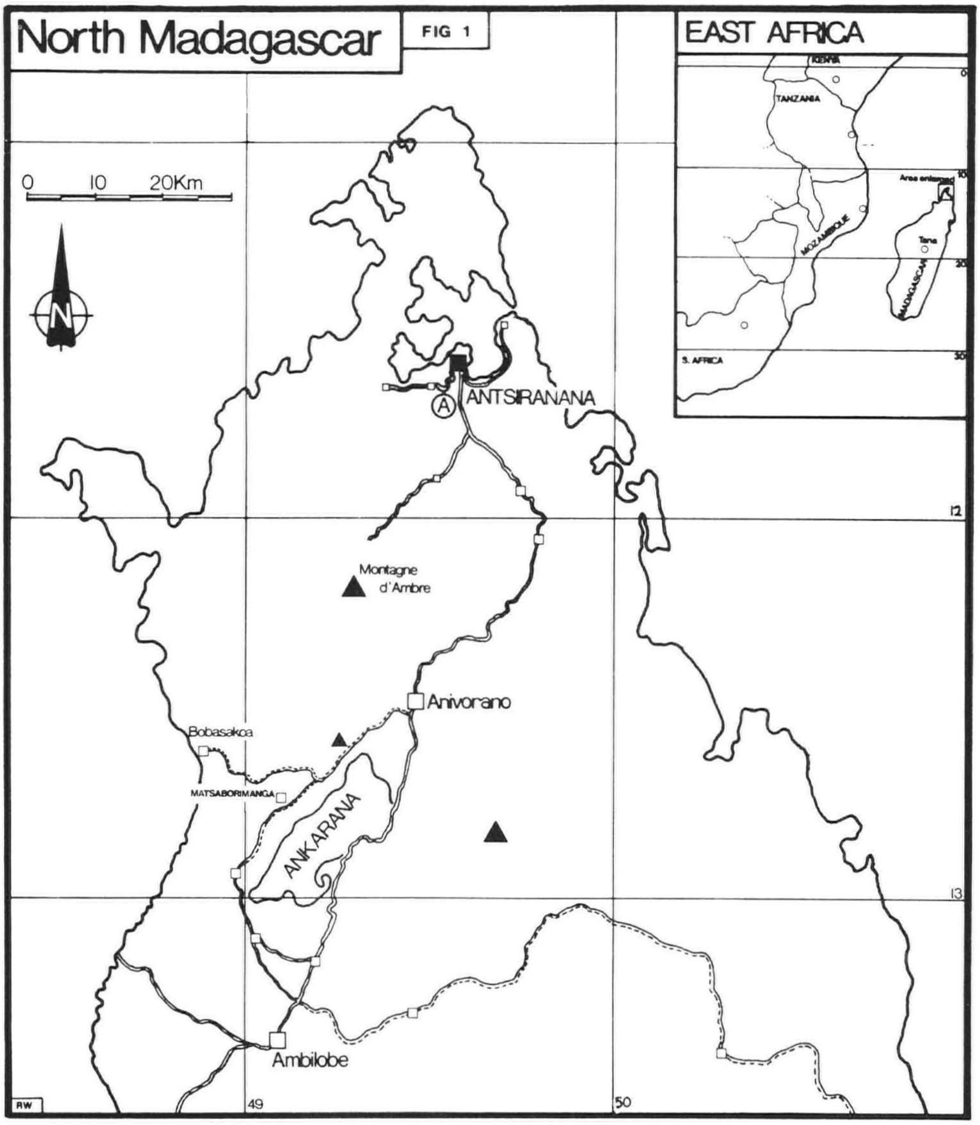
HISTORY OF EXPLORATION

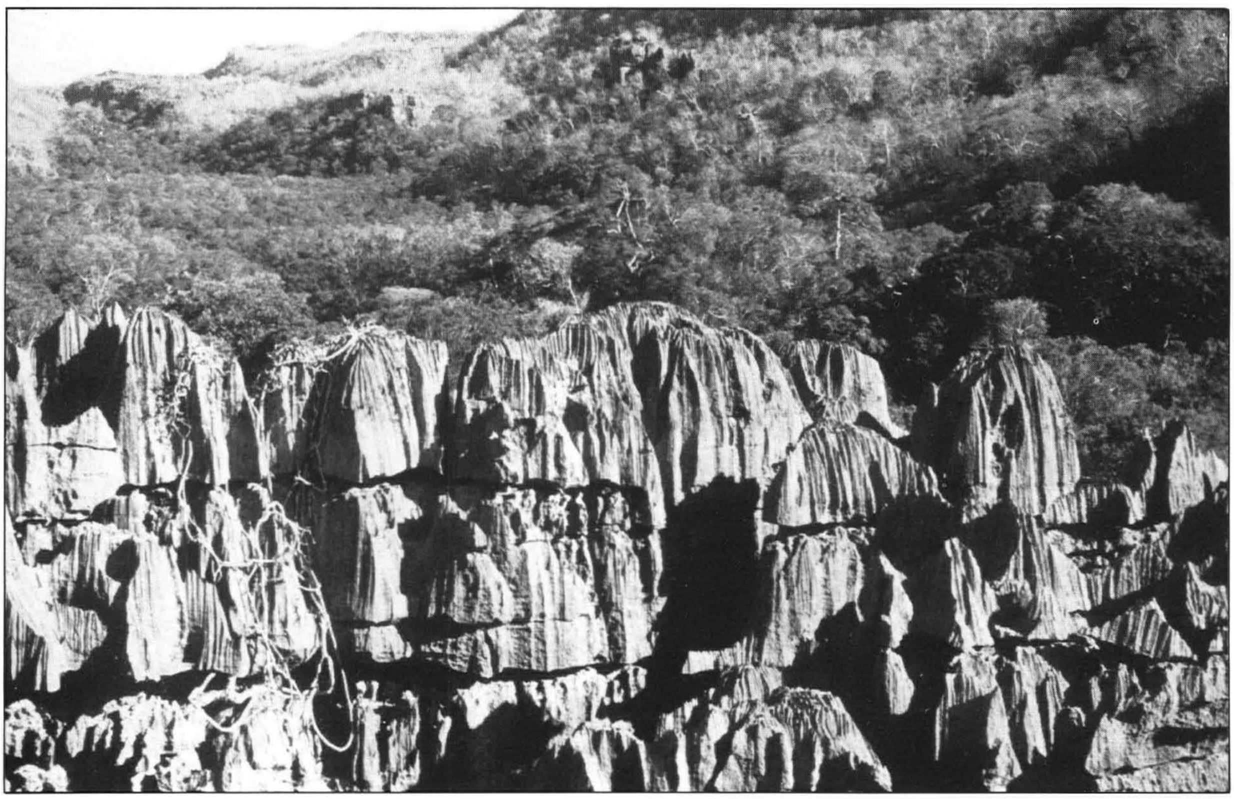
Jean Radofilao

The Ankarana massif contains an extensive and complex system of cave passages, but most of the cave entrances are difficult to enter, and even to find, due to collapse. There are a few with huge entrances, accessible at the base of the cliff. These obvious caves (Andrafiabe, Ambatomanjamana and the Mananjeba subterranean river) have been known by the local people for a long time; they have explored them with palm leaf torches. Inside are remains of fires and fired earthenware pots. During the colonial era, several Frenchmen visited these caves, guided by the locals; they wrote picturesque accounts for the local papers, but made no scientific observations. Early work was reviewed by de Saint Ours (1959).

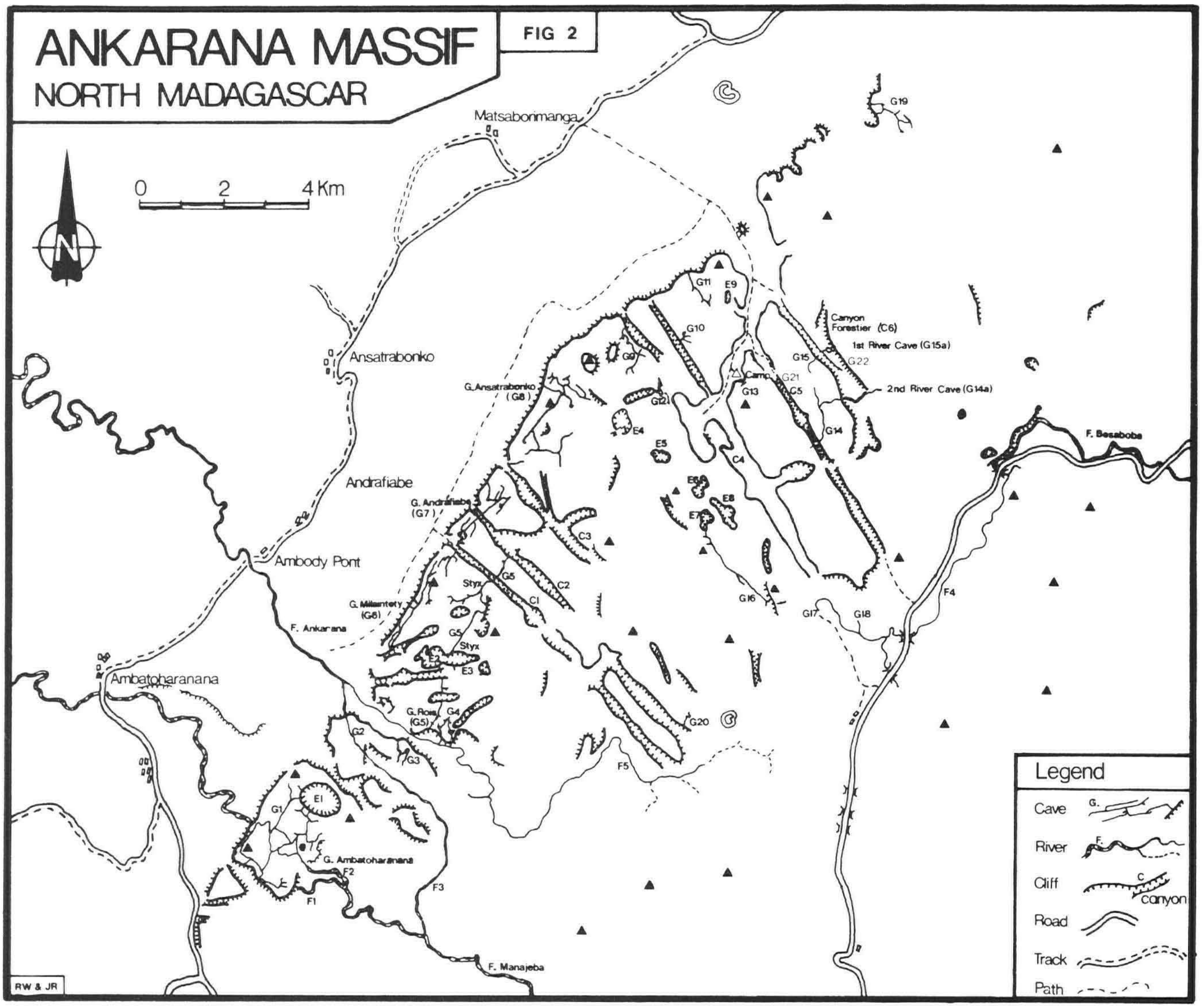
The first real cave exploration was done in 1963 when Jacques de Saint Ours accompanied by G Coquet surveyed 2.8km in the Grotte d'Andrafiabe and estimated that they had explored more than 5km. Almost every year between 1964 and 1972, building upon information provided by J de Saint Ours, the writer has explored the caves of Ankarana, leading a small team backed by the University of Madagascar. Initially we continued the exploration of la Grotte d'Andrafiabe and then searched for others. We explored Antsatrabonko,

Transport to our Ankarana base camp was by bullock cart. The photo shows a line of forest growing above a subterranean river and, in the background, the northern Ankarana limestones. (Phil Chapman)





The dry pinnacle karst tsingy is over 200m above the surrounding savannahs and canyon bottoms. This photo, taken above the Second River Cave, shows rich gallery forest in the foreground (growing above a subterranean river) and the Canyon Forestier stretching away to the left horizon. Some tsingy is covered in scrubby, thorny, xerophytic vegetation. (Jane Wilson)



Milaintety, Ambiky, the start of Ambatoharanana and the big river system and several smaller caves. When these explorations were stopped by lack of money, the total passage length surveyed was over 40km.

After 1972 the writer continued the exploration, usually alone. The largest caves surveyed during this period were Andetobe, Antsiroandoha and Ampandriampanihy (north). By 1980 the total of explored passages had reached 75km.

From 1981 several foreign expeditions came to Ankarana and made their contributions to exploration (whilst the writer continued alone during the rest of the dry season). These were:

August 1981 a team from University of Paris VI and a team from the Club Martel of Nice and Club Alpin Francaise (Peyre et al 1981).

September 1981 a team from Southampton University (Adamson et al 1984)

August 1982, 1984 and 1985 the team from Nice returned (Peyre et al 1982, 1984, 1985)

August - October 1986 a new multi-disciplinary team (cavers and scientists) from England (this report)

As a result of all this work the total passage length explored at Ankarana by the end of 1986 reached 98km.

THE GEOLOGY AND GEOMORPHOLOGY OF ANKARANA

J. Radofilao, P. Chapman, D. Checkley, S. Hurd and R. Walters

The Ankarana massif is situated about 30km north of Ambilobe and about 75km south of Antsiranana (Diego Suarez). It comprises a block of Middle Jurassic (Bajocian and Bathonian) limestone about 30km long by 8km wide and is bordered on the north-west by a cliff face up to 200m high, the 'Ankarana Wall' (Fig 2). The surface of the plateau is very difficult to cross, as it comprises unstable blocks of needle-like limestone pinnacles up to 20m high, separated by deep crevasses. This pinnacle karst, known locally as tsingy, supports a unique xerophytic vegetation. The massif is traversed by deep, straight, vertically-walled, fault-controlled canyons, the majority of which run NW-SE, almost at right angles to the Ankarana Wall. They are nearly always littered with huge limestone blocks and the wider canyons are thickly forested, especially where basaltic lavas have flowed in to form a substrate.

The Caves

Passage dimensions vary from very small crawling-sized tubes to the more common huge corridors which reach 50m width in Grotte d'Andrafiabe. Most of the biggest passages run NE-SW, parallel to the Ankarana cliffs.

Most of the explored passages are active or semi-active and situated close to the level of the foot of the cliff. Sumps are quite common and some sections have navigable underground rivers, the most notable being the 4km boat trip necessary to traverse the length of the River Styx (G5).

Higher, less active passages are smaller and much less numerous. Access to some need artificial climbing techniques. These higher levels are very well decorated and formations, debris, volcanic ash or clay often block the passage. La Grotte de Milaintety (G6) is probably the best decorated cave.

Collapsed Caves

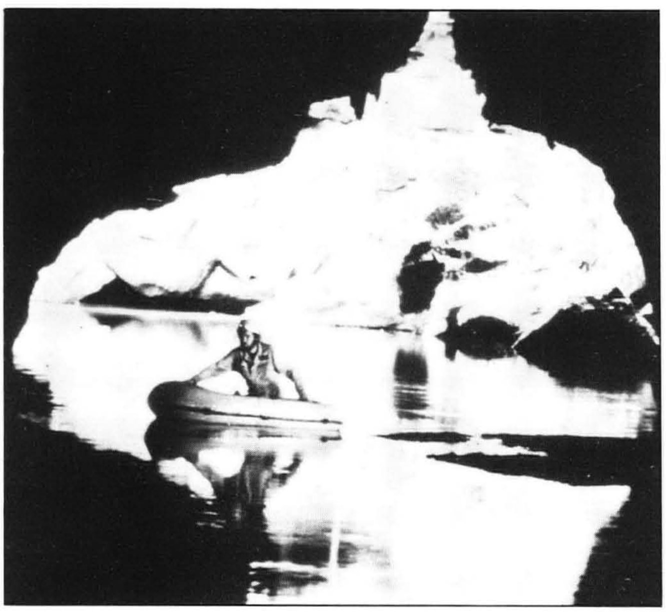
A huge collapsed cave was discovered during exploration in 1986. This was made up of several aligned collapses, with linking residual arches. This feature is very different from the fault canyons since the collapses are aligned over very short distances and are often sinuous, and their depth is clearly much less than that of the faults. This collapsed cave must have been huge and probably developed along a joint higher than the currently active streamway. Examination of air photos shows that there is no other comparable collapsed cave.

Very big collapsed chambers or 'interior plains', bordered on all sides by 100m sheer cliffs, exist in the heart of the plateau; access to these is generally possible only through the caves. The biggest is the Manily, in the southern part of the plateau. It is oval: 800m x 600m and 100m deep. In the centre is a curious calcite mound. Several large collapses lead off it and we suspect that it is all that remains of a vast chamber with a volume around 50 million cubic metres. The bottom of this and other collapses always contains an accumulation of lapiaz blocks. Some are also forested or occasionally marshy. Some are traversed by a river or stream.

Tectonics

The Ankarana Massif probably behaves as a rigid block. Earth movements in the Jurassic resulted in the downward displacement of the west of the massif. This continued to the Cretaceous with a general tipping of the massif to the west. Movement of the basement beds is thought to have occurred at this stage.

The first faulting brought about the sheer 200m Ankarana Wall bordering the NW of the massif. Simultaneously, the massif developed a shallow syncline with 4° dips to both east and west with an axis approximately 1km east of the cliff wall. This period of earth movement also produced a series of fault scarps approximately parallel to the main cliffs. Volcanic activity in the Pliocene formed the Montagne d'Ambre volcano and probably the canyons. The principal cave systems were truncated by this faulting. The massif at this stage was thrust upwards and the NW-SE syncline accentuated. These movements also led to jointing across the massif in the NW-SE direction. Cave development has frequently followed this the dominant joint direction. All major canyons are of tectonic origin being aligned along major joints or faults. None appear to be due to the collapse of cave passages.



Simon Fowler entering the River Styx

The 'Russian Mountains' inside the 11km Grotte d'Andrafiabe (Paul Stewart)

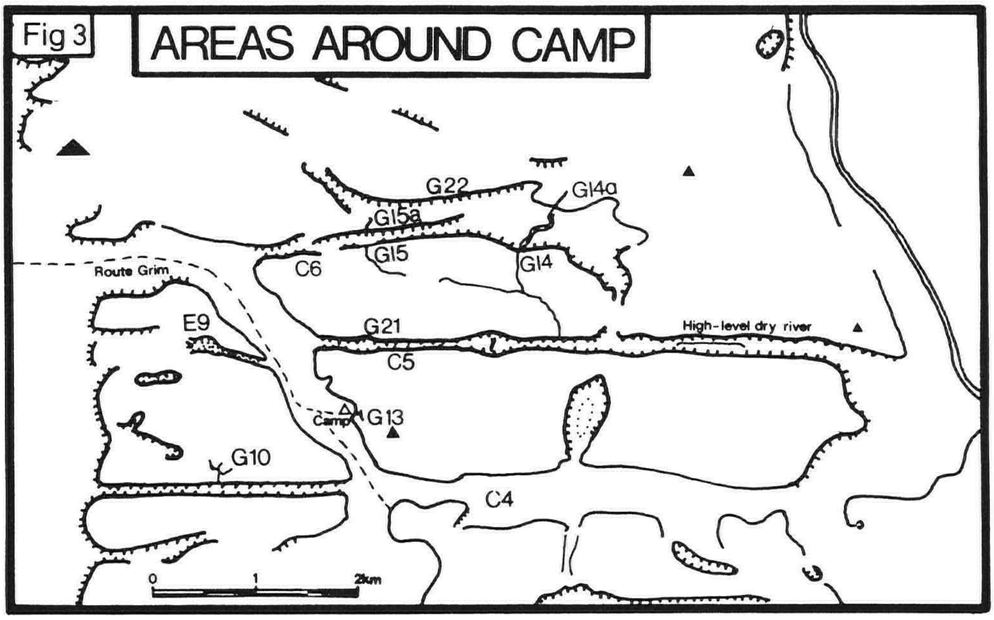
In the north of Ankarana, Quaternary volcanic activity formed a number of small ash cones which can be seen today. The lava penetrated some of the canyons and blocked a good number of the entrances in the north. In places the lava has backed up against the wall. Lava flows are less evident in the south.

Hydrology South of the Antenankarana River

The Mananjeba River (F1-3) continues to flow during the dry season, providing a reliable water supply for the villages downstream of Ankarana. It also floods frequently so the massif here has undergone strong solutional activity and only residual limestone blocks remain. The first of the three blocks is the largest. All underground flow in this southern part, depends purely on the Mananjeba River. It divides into three main branches, close to the plateau; the southern one skirts the southern flank of the third block and does not sink at all; the middle one flows under the second block for 2.7km in the very large passages of the Grotte d'Ambatoharana (G1) (which is 18.2km long); the northern branch flows for 600m through the first block, in part of the Grotte d'Ampanriampanihy (G1a) and by joining with the water flowing from the north, form the Antenankarana River.

Hydrology North of the Antenankarana River

The main karst region is north of the river. Numerous small rivers sink in the massif in the north and east, but only two flow in the dry season; a) Andranotsisiloha (meaning river without a start) comes from the Montagne d'Ambre and sinks into impenetrable boulders in the extreme north of the massif. Only some of the water disappears, the rest rejoins the Andranomandery which flows to the west of Ankarana. b) The Besaboba runs off the hills in the east and divides into numerous branches, most of which disappear into earth-filled hollows. The only two penetrable



sinks (G17, G18) both go for about 400m to a sump, and are only active in very heavy rains.

Little is known about the hydrology in the north and it is difficult to interpret. However, it appears that the waters from the north form the two large rivers and their associated caves in the Canyon Forestier (G14 and G15) and in canyon C5. We assume that these appear again as the river in Campsite Cave (G13) and eventually further south in the caves of Andetobe (G9), Antsatrabonko (G8), and the Andrafiabe gorge (C2). These then join to form single, strong flowing river, from the Buttes Chaumont, to the resurgence at Grotte du Rois (G5). Since much of the river is calm, deep and 10-20m wide, it is navigable. Flow rates (measured at the surface) at both the Buttes Chaumont and the resurgence were approximately 15cums/s. It appears, then, that the major north-south drainage follows the base of the syncline about 1km east of the Ankarana Wall and that most of the tributaries lead to this 'master' system.

CAVE AND ISOLATED FOREST EXPLORATION

R Walters

Our exploration efforts concentrated upon searching unworked areas of the massif and looking for links between mapped sections of cave. The areas neglected by previous French expeditions were largely in the north and east of Ankarana where much of the water sinks and very few caves are known. We also hoped that caves would provide access to many of the sunken forests which the biologists were keen to investigate.

Areas of study and exploration were selected using aerial photographs, taken in 1949 and available from FTM, the Government map shop at Ampasamieto, Antananarivo. We paid particular attention to obvious river sinks, steep-walled depressions where erosion debris was unlikely to have blocked cave entrances and deep gorges, since gorges elsewhere in the massif cut major cave systems. The large isolated forests of the central region (E4-E6) were considered worthy of the biologists' attention and a great deal of time and effort was spent trying to gain access to them.

Canyon Forestier

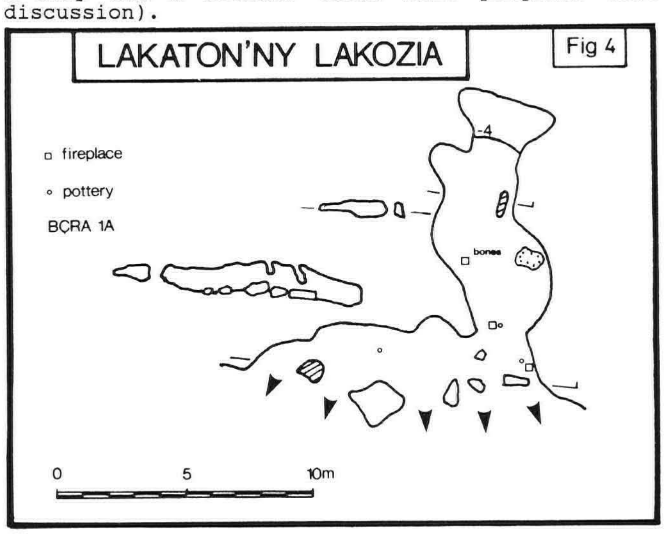
Here we wished to complete the exploration of the vast depression beyond the French discoveries of River Caves One and Two (G15a, G14a). En route both caves were explored and although no further discoveries were made, both yielded much to interest the biologists. The canyon area close to the River Cave One appeared to flood to a depth of 30m confirming an observation (Jean Radofilao, pers. com., 1986) that during the wet season storms some of the Ankarana canyons are completely flooded.

A rock shelter discovered between the First and Second River Caves, la Grotte Trans Sept, high in the north-east wall of Canyon Forestier yielded rich deposits of rodent bones.

River Cave Two was only about 3km from our base camp, but took around five hours to reach. Thick vegetation and lack of water made exploration slow and unpleasant. Beyond River Cave Two, a complete search of the depression revealed many small caves; these were all at relatively high levels in the walls of the depression.

Areas around the Camp

The first canyon (C5), just north of the camp, contained two rivers which had been thoroughly explored by the French (figure 3). Many small caves where found in the cliffs all along the canyon but all these were small and were 20-30m above the water levels in the nearest river caves. A rock shelter in the north-east wall of Canyon C5 which we called Kitchen Cave or Lakaton'ny Lakozia (figure 4) provided finds of pottery, hearths and bones to interest archaeologists. At the eastern end of the canyon an oddly situated dry river bed in a mixture of mud and boulders. It is some 5m deep and 10m across and runs across the canyon for its half kilometre width. The river appears to have sinks at both ends in boulder piles. A small entrance in the base of the dry river bed near the eastern end leads via a 30m climb to the water level where a sump and a boulder choke halt progress (see discussion).



A deep depression north of the camp (E9) looked promising. However, the canyon leading to it proved to be very hard going with very thick vegetation. Its walls contained many small caves but these all connected with the surface only 10-20m above and proved to be of no speleological interest. The depression itself is very deep but its walls are mantled by extensive debris which crushed our hopes of gaining access to any of the major caves. The central area showed signs of flooding, but there was no indication that the water comes from an underlying cave. One small shaft, at least 20m deep, was found in the WSW corner, but there was no draught. It looked dry and unpromising and was not descended.

South 'Table Massif' Area

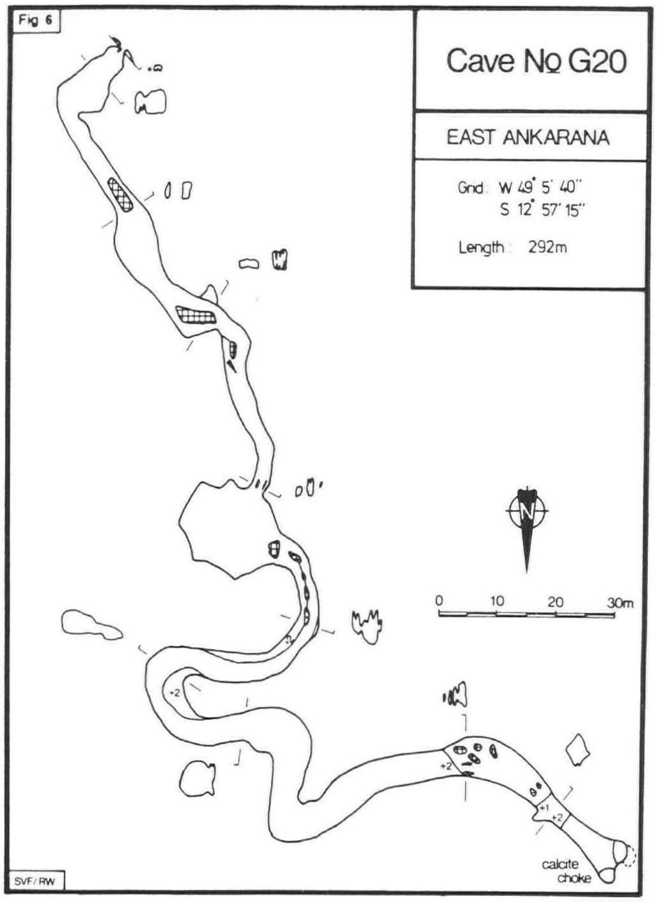
This area (figure 5) acquired its name from the prominent large rectangular block of limestone about 3km long by 0.5km wide. Aerial photographs suggested that the entire Antanatsimanaja River (F7) sinks just south-east of the 'Table'. However, our explorations revealed that the river does not sink but merely breaks up into smaller rivers in a wooded area; these reform to flow south and join the Mananjeba River (F1)

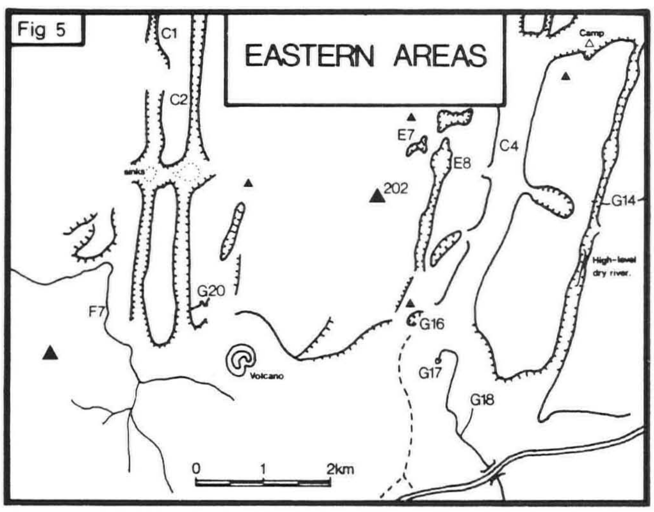
The steep-sided canyons around the 'Table' are not deep enough to reach the cave-bearing limestones and no major discoveries were made. One new cave (G20) was surveyed in the eastern canyon. It was very well decorated and had a strong draught, but ended in a calcite choke after only 290m (figure 6). The dry course of a river was followed north in the western canyon to the end of the 'Table' but it normally sank in an impenetrable mud choke.

Grotte d'Ampondriampanihy-Nord

We were tempted to explore this neglected area by two features: the sinks of the Besaboba River (G17, G18) and the Grotte d'Ampondriampanihy-Nord (G16). The first sink proved to be a spectacular location but the cave was totally blocked by debris after only 20m.

During our searches for the Grotte d'Ampondriampanihy-Nord (G16) another river was discovered beneath boulders in a depression to its south. It is presumed that this flows to the Grotte d'Ampondriampanihy-Nord as no other outlet was seen. The Grotte d'Ampondriampanihy-Nord itself is a most impressive cave. Its entrance, which is 60m wide and 50m high is hidden in a small depression at the extreme southern end of the massif. The entrance narrows to a passage 30m high and 20m wide which leads after 700m to a 700m long canal. To avoid possible encounters with crocodiles, negotiation of this part of the cave requires a boat since there is no dry land for its entire length. A further 2km of similar large cave leads to a boulder obstruction. An ascending passage on the right leads up to a depression (E7a) which had not been fully investigated. The cave requires a full survey but time did not allow us to complete this. We entered many passages from a large passage just on the other side of the canal, but surveys drawn by the French were rather inaccurate and gave no clues as to how much of the cave passages we were exploring was new. The depression was very deep with the river crossing the base of it beneath boulders, but no continuation of the cave was found. A route to the north led to a further depression (E7b) where the river was found again. This was particularly interesting as it showed that the river flowed north. However, the river emerged from an impenetrable boulder pile only to sink again in a cave which was sumped after a few metres.





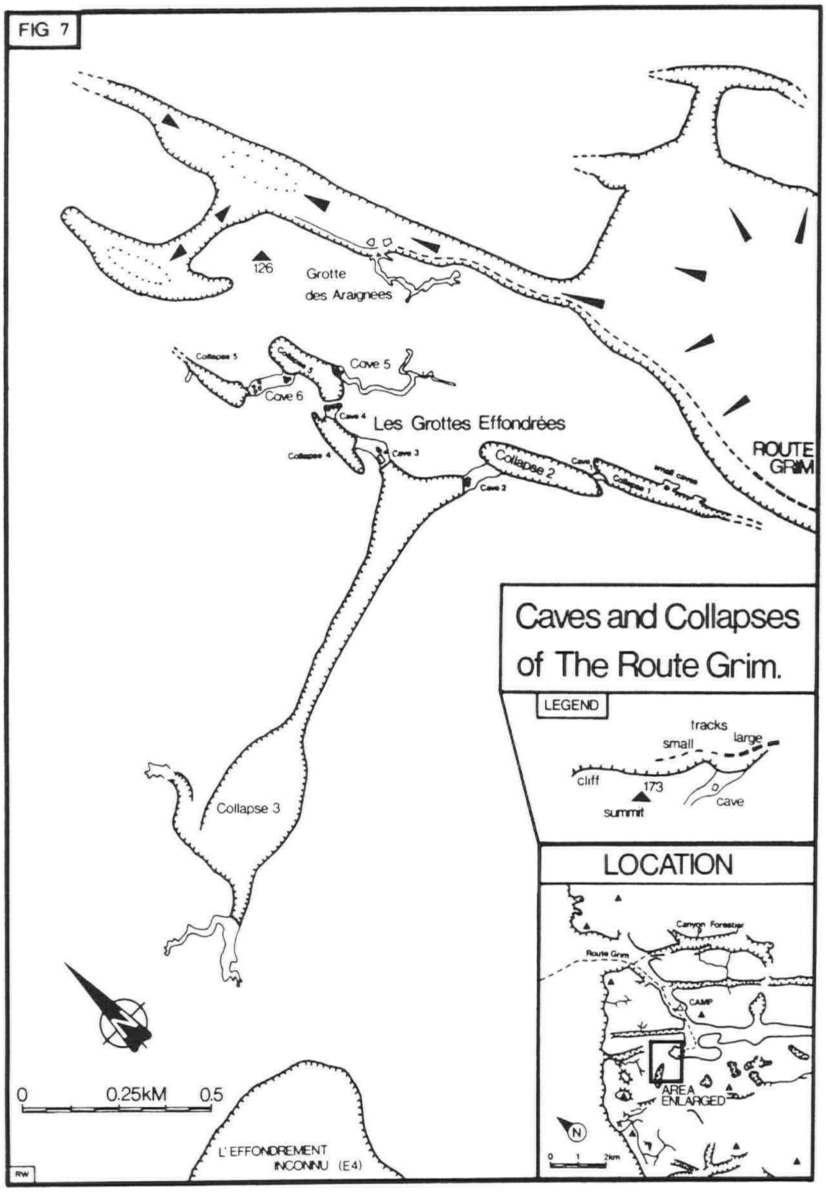
The Northern Area

During two trips to the area north of the camp, we only succeeded in finding caves which had already been explored by the French. The desperate lack of surface water made this area very difficult to investigate at the height of the dry season.

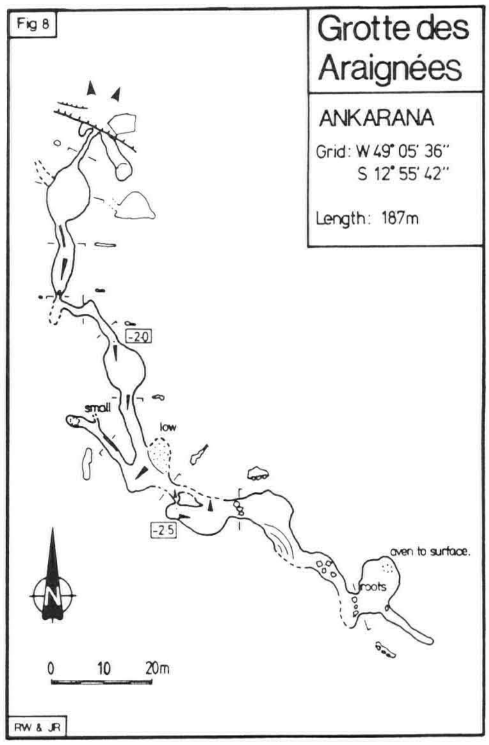
Isolated Forest Areas

The depressions to the south of the end of the Route Grim (the track which led to our base camp) were extensively explored (figure 7). From the depression a deep canyon running north-west looked very promising. However, extensive debris along the canyon walls blocked any existing entrances. A small high-level cave, the Grotte des Araignees, was discovered and surveyed (figure 8). It comprised 220m of low passages connecting a series of chambers.

A narrow canyon was discovered to the south-west of the first depression. This led, via several collapsed areas and short caves, towards the isolated forest depression (E4), one of the big central depressions and a target for the biologists. The caves and collapses became known as Les Grottes Effondrees (G12). Time did not permit us to find the way to E4. However soon after most of the cavers had left Ankarana, Jean Radofilao told us that he had reached it.



Caves and Collapses of The Route Grim.



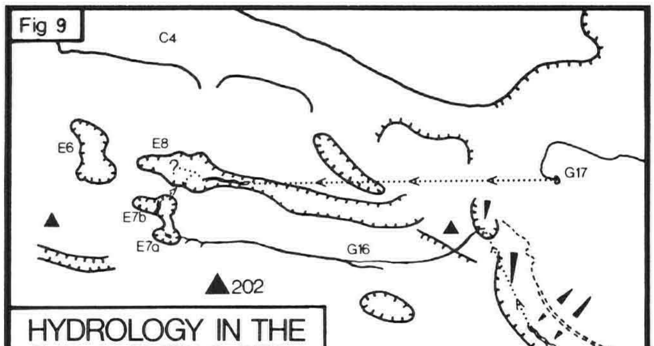
Grotte des Araignées

Other Caves Visited

During the course of the expedition, trips were made into Grotte d'Antsatrabonko (G8), Grotte d'Antsiroandoha (G11) and the Grotte des Rois (G5a) where the local kings are interred.

Discussion

The dry river in the first canyon, C5, near the camp, is interesting because it provides further evidence that the canyons flood to high levels on occasions. The dry river bed lies about 30m above normal water level in cave G14. The drainage in the area of the Grotte d'Ampondriampanihy (G16) seemed to differ from our initial predictions. A possible drainage pattern is shown in figure 9. The flows are all minute in the dry season and so dye testing was not practicable. Clearly the situation in the wet season is very different and drainage patterns may be completely altered. The river which sinks in the wet season at G17 and G18 appears to be very big indeed and yet the area around the sink shows only fairly local flooding and the river does not back up. It seems that the river does not go to G16 but further into the massif probably to the area around depression E8. This suggestion was supported by more recent aerial photographs than those taken in 1949 which are available from FTM in Antananarivo. These photographs indicate a large river draining into depression E8 which is situated directly north of depression E7. If this is so, then water is draining north through this part of the massif suggesting a more complicated pattern than has been suggested to date.



HYDROLOGY IN THE G.16 AND E7-8 AREA (Proposed)

Conclusions

The cave exploration efforts covered many areas within Ankarana which had not been previously investigated. The French suggestion that new caves would only be found through a great deal of hard work was certainly proved to be true. However, a few cave discoveries were made by Expedition members and a number of tantalizing leads have been left. Routes into the central depressions have now been found and the drainage predictions in the East might yeild cave passages in depression E8. Any future trip must investigate these.

BATS

Mick McHale

The Chiroptera of Madagascar have affinities with both the African and Asian faunas, Rhinolophus is absent from Madagascar but the giant Pteropus fruit bats are present and considered a delicacy there. Few biologists have worked on the bats of Madagascar, an exception being Dorst (1948). The first study of the cave-frquenting bats of Ankarana was by members of the 1981 Southampton University expedition (Adamson et al 1984; Wilson 1985). We wished to extend the 1981 study by collecting those species roosting in caves and compare them to those which could be trapped flying in the adjacent forests.

Ankarana has a varied and interesting bat fauna and the caves provide an important refuge for many species. In some areas bats enjoy a fady (taboo) status and are not molested, but in several regions of Madagascar including Ankarana the largest species are considered much tastier than lemur meat! Whilst frugivorous bats may raid local fruit trees, the insectivorous species contribute to local agriculture by reducing insect pest populations. Future studies might do well to quantify the threat to bats posed by hunting and the extent to which they are susceptible to habitat destruction.

The cumbersome Alcan Harp Traps proved to be very efficient in trapping forest-flying bats. In contrast, despite repeated efforts, we caught only one bat using the compact and readily portable mist nets. Representatives of each bat species were killed by neck dislocation and preserved in formalin (10%) or local alcohol (rum!). Preservatives were changed after three weeks.

Bats were observed in all caves visited by expedition members; the most common was the tiny insectivorous Miniopterus minor. These roosted in caves singly or in groups of about nine individuals. They could be easily removed by hand from the walls or low roofs of caves because they seemed to be in a state of torpor. The bats were collected towards the end of the six month long dry season when there was a dearth of insect food; it is possible that the bats' apparent lowering of metabolic rate was in response to shortage of food.

Trouessart's Trident Bat (Triaenops furculus) female; this is a species endemic to Madagascar (Ben Gaskell)

Another cave-roosting species which occurs at Ankarana, but less commonly than M. minor is Miniopterus inflatus africanus. This proved to be the first record of this animal from Madagascar (J.E. Hill, pers. comm 1987).

The large Hipposideros commersoni roost in hundreds in the deeper (dark zone) sections of the Grotte d'Andrafiabe and skeletons found in other caves imply they roost in lesser numbers elsewhere in the massif. Paulian (1981) wrote of the killing of Rousettus at Ankarana and we certainly found evidence that the local people light fires in the caves to disturb the bats, then hit them with sticks as they try to escape. These bats, which have a 60cm wingspan, turned out to be Eidolon helvum dupraneum which has not previously been recorded as a cave-roosting species (Martin Nicoll pers. comm 1986). In the large entrance chamber of la Grotte d'Antsiroandoha we discovered a roost of several thousand of these fruit bats; they also seem to roost in crevices in the canyons within the massif. Faeces beneath these colonies implied that these bats subsist almost entirely upon a single type of fruit; this appears to be the ebony Diospyros sp. A rich, varied and unique invertebrate cave fauna is based upon food brought into the caves by bats. Any ecological changes in Ankarana's forests would not only endanger the bats but also the interesting and specialised ecosystem which relies upon them.

Bats collected from traps in the forest were generally different from species found roosting in caves. Some species were found roosting deep inside caves in the Dark Zone (DZ), while others roosted within sight of daylight in the Threshold (ThZ) or Entrance Zones (EZ).

Chiroptera recorded from Ankarana

Species	Location	Zone
Eidolon helvum dupraneum	Grotte d'Antsiroandoha	EZ
Hipposideros commersoni	Grotte d'Antsiroandoha	DZ
	Grotte d'Andrafiabe	DZ
Miniopterus minor manavi	Campsite cave	ThZ
	First River Cave	ThZ
	Second River Cave	ThZ
	Grotte d'Andrafiabe	ThZ; DZ
	Grotte d'Antsatrabonko	ThZ; DZ
	other caves and rock shelters	
	also flying in forest	
Miniopterus inflatus africanus	Campsite cave	ThZ
	First River Cave	ThZ
Tadarida jugularis	Grotte d'Andrafiabe	ThZ
Myotis goudoti	forest	
Emballonura atrata	forest	
Triaenops furculus	forest	
Triaenops persicus rufus	forest	

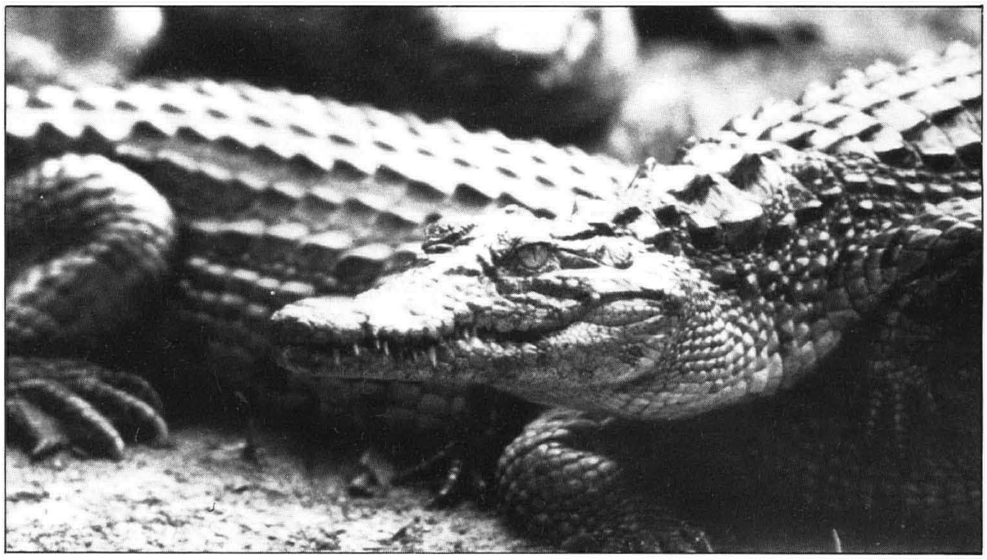
CROCODILES

Paul Stewart

The Malagasy population of the Nile Crocodile, Crocodylus niloticus, is generally considered to be under considerable threat. The subterranean rivers of the Ankarana Massif have been cited by Blanc (1984) as one of the last refuges for the species on the island and Ankarana harbours what appears to be the only population worldwide were individuals are regularly found within a cave system. It is also one of the few sites in the world where 6m long crocodiles still survive.

The crocodiles reach their greatest densities at Ankarana in the southern caves of the River Styx which flows down through the massif from the north. It appears that the crocodiles retreat into these caves to escape the drought in the dry season (May to October), when areas of the southern marshes and rivers dry up. The crocodiles are hunted unsystematically in this region for sport by foreigners and for leather and perhaps meat by some locals. Despite repeated searches, no evidence of crocodiles was found in the caves of the northern part of the massif.

The Nile Crocodiles found in the Ankarana caves were of normal pigmentation (Jane Wilson)



Their absence might be explained by the fact that these caves are isolated from the southern systems by long sumps and white water sections and also lack suitable basking sites in the open. The northern subterranean rivers are also considerably colder than the southern waters. For example, water in the northern Second River was at 21°C, whereas water flowing through the southerly Ambanemero Fault cave system was from 25 to 27°C.

It is likely that the crocodiles feed while in the southern caves as the water temperatures correspond to the low end of the active temperature range for the species (26-27°C). A variety of prey is available including crabs, shrimps, crayfish, and fish. The larger crocodiles may not only prey on smaller individuals but also upon the large eels described in the section below.

OTHER CAVE FAUNA
Jane Wilson

More than 80% of Madagascar's animals and plants are peculiar to the island and the cave adapted animals (Troglobites) which have evolved from this unique and rich fauna have the scope for being even more interesting and quite different to that of any other karst region. Ankarana is unique for other reasons. It is probably contains the most extensive tropical cave systems in Central Africa and the size of its subterranean rivers provide unusual tropical cave environments. It is also an essential dry season refuge for certain epigean species. Flooding during the wet season seems to be on catastrophic proportions for some canyons are submerged under 30m of water. And it is interesting to consider the effects this might have upon speciation, which seems to be going on at a great rate in some caves: further studies are sure to reveal much more.

Although the literature on the cave-dwelling animals of Madagascar is quite extensive, it is principally limited to taxonomic descriptions (Paulian 1961; Decary and Keiner, 1970; Remillet, 1973). No cavernicoles had been recorded from Ankarana until 1981 (Wilson 1985).

The entire food chain within any cave ecosystem is absolutely dependent upon energy from the outside environment. At Ankarana food is provided by bat guano, material washed in by floods and to a much lesser extent swift and lemur excreta. This reliance on the outside is particularly relevant at Ankarana, where deforestation is threatening the food supply of both frugivorous and insectivorous bats. Deforestation is also allowing increasing soil erosion and redeposited sedimants could possibly block cave passages. This was seen (by RW) in the Grotte d'Analamisondrotra in the north of the massif where a high-level passage some 5m by 8m was completely blocked with mud.

Within Ankarana's 98km of surveyed cave passages, there is a wide range of habitat types: large subterranean rivers (where the crocodiles aestivate), high humidity dry chambers, guano beds and chambers desiccated by warm through draughts with only 50% humidity. Cave temperatures are high: at the terminal collapse of la Grotte d'Antsiroandoha it was 24°C, for example. The existence of many varied habitats, even within one cave, explains the diversity of fauna. It is perhaps surprising that this rich area had been neglected by speleologists and biologists.

Animals were collected from the eight richest caves visited. Many of the species listed from the Andrafiabe and Antsatrobonko caves (Wilson 1985) proved to exist in other Ankara caves but very many other invertebrates await identification.

The 1981 collections revealed a surprising number of shrimp species: nine inhabiting two caves (Gurney 1984) and the 1986 collections included at least two more new records. It seems likely thet Caridina and Parisia shrimps form large species complexes at Ankarana, with troglobites, troglophiles and epigean species representing various stages in troglomorphic evolution. Shrimps known from Ankarana so far are:

Parisia dentata	Caridina xiphias	Cardina crurispinata
P.macrophthalmia	C.parvocula	C.typus
P.microphthalmia	C.norvestica	C.unca
	C.nilotica	C.isaloensis

Other Caridina and Parisia species await description. The "crayfish" Macrobrachium moorei also exists in the Ankarana streams but shows no cave adaptation. Other interesting finds included a new species of troglobitic millipede and probably the first Schizomid to be collected in Madagascar (Legendre 1972). An Amblypygid, probably Charinus madagascariensis was common in the entrance and threshold zones of a number of Ankarana caves; this species is probably endemic to the massif. Most caves had a resident eel, often over 1.5m long. Unfortunately these extremely strong animals foiled all attempts at capture so remain unidentified. They are likely to be a new species.

River Cave Two in the Canyon Forestier was of particular biological interest. Regular visits by Crowned Lemurs, Lemur coronatus, to drink within the cave have polished rocks smooth and since this cave water hole is used by rare species such as the Fosa, Cryptoprocta ferox, it is an excellent place to study both trogloxenes and epigean species. The cave contains slowly-moving water which is about 2m deep at the entrance and is at 21°C. Populations of eyed and blind cave shrimps and three new species of fish also live there.

Two Glossogobius species (Peter Miller, pers comm 1987) have eyes, are pigmented and presumably arrived (just as their next meal will arrive) by way of flood waters. Interestingly, some of these fish were found in a deep pool which was glazed over by a 2mm layer of calcite. The third fish, probably a Gobius sp., is a toglobite and was found even in the Entrance and Threshold zones of this cave. This is almost certainly endemic to Ankarana which implies it is restricted to to rivers flowing within a range perhaps measuring 10 x 30km. Like the 39 known species of troglobitic fish it should be considered an endangered species.

USE OF CAVES BY LEMURS
Jane Wilson and Paul Stewart

Accessible drinking water for both people and animals is at a premium at Ankarana during the dry season. The most reliable water holes were at cave entrances and lemurs and other wildlife were regularly observed drinking at the entrances of the Second River Cave (G14a), la Grotte d'Andrafiabe (G7) and at the Syyx River Cave (G5).

It is likely that lemurs have needed to use cave water holes at Ankarana for centuries and this might explain why the sub-fossil site inside the Grotte d'Andrafiabe is so rich. All skeletons were found just beyond the limit of light penetration and most were complete skeletons which must have arrived in the cave while the carcass was relatively intact. Many were lying on tops of boulders in positions incompatible with having been washed in by floods. We were unable to find any avens nor any evidence supporting the idea that the bones could have arrived by falling through a hole in the roof. No talus cones were evident in the cave system.

The most likely explanation for the arrival of the lemurs at this site is that they had come into the cave, probably to drink at a water hole

Sub-fossilized lemur bones found inside Grotte d'Andrafiabe. Two skulls of Hapalemur simus are on the left and the skull of a Mesopropithecus is bottom right (Jane Wilson)

in the cave entrance, and were scared into the cave by a predator (the Fosa,Cryptoprocta ferox will take lemurs and seemed to be hunting Crowned Lemurs at the Second River Cave). When frightened, lemurs often flee upwards and once they had fled beyond the limit of light penetration they would have been unable to find a way out. There is a reliable water source in the Dark Zone just beyond the sub-fossil deposits but it seems unlikely that lemurs could have navigated to this in absolute darkness. Carcasses lying in the cave's Dark Zone would be unavailable to scavengers and also protected from the decomposing effects of leaf litter. This explains why more fossils have not survived in Ankarana's isolated forests.

None of the lemurs repesented as sub-fossils at this site still survive at Ankarana as far as we know and Ankarana's extant lemur species were poorly represented in the remains. This is consistent with the drinking hole hypothesis since the entrance water hole no longer contains water during the dry season.

PALAEONTOLOGY
Martine Vuillaume-Randramanantena
and R Ralaiarison-Raharizelina

The Grotte d'Andrafiabe

In 1981 members of the Southampton University Expedition discovered a skull and limb bones of four Greater Bamboo Lemurs, Hapalemur simus (Wilson 1985). At this time museum skeletal specimens of this species totalled only about 15 worldwide (Vuillaume-Randriamanantena, Godfrey and Sutherland 1985). These finds implied that Ankarana might prove worthy of a special palaeontological survey. When we visited the same cave in 1986, the sub-fossil site at la Grotte d'Andrafiabe, proved to be unusually rich.

We were able to collect bones of 18 Hapalemur simus which is a great concentration of skeletons of a lemur rarely found in sub-fossil state. We left other sub-fossils in situ since they were too securely cemented to enable us to remove them, with the limited equipment we carried, without damage. Most sub-fossils (90%) were of Hpalemur simus. An unidentified tibia (a lower leg bone) probably a pathological lemur bone was also collected and skeletons of Lemur sp. were seen. Nearby were skulls of Propithecus diadema and Mesopropithicus. Propithecus has not been recorded from Ankarana previously and Mesopropithecus which is now extinct, was known only from a very few specimens collected more than 50 years ago in central and southern Madagascar. The first Mesopropithecus was described by Standing in 1905 and others were found by Lamberton in 1937 and 1939. The latter finds were in the cave site of la Grotte d'Ankazoabo on the south-west coast of Madagascar (Lamberton 1939, 1946, 1948). The 1986 finds included previously unknown bones of the Mesopropithecus which give valuable new information contributing to knowledge of the animal's lifestyle (Vuillaume-Randriamanantena and Ralaiarison-Raharizelina 1987).

One of the most interesting questions unanswered by palaeontologists, is the age of lemur sub-fossils. The most ancient Malagasy sub-fossils documented are from the deepest deposits at Ampazambazimba; these are about 8000 years old (MacPhee, Burney and Wells 1985). More commonly age estimations fall between 2000 and 1000 years before present (Dewar 1984). Other researchers, relying on oral evidence and reports of ancient travellers like Flacourt (1661), feel that the last Madagascar dwarf hippopotamus and the last flightless elephant birds only disappeared a few centuries ago. Sadly there were few sediments at the Andrafiabe sub-fossil site so excavations would be unlikely to reveal further information on the age of the skeletons although accurate dating would be possible if some bones were sacrificed. The remains seem to span a large time scale. Some of the sub-fossils might be a few hundred years old, others including bird and fruit bat bones are probably at most a few years old.

Micromammal Remains in Other Caves

We searched numerous rock shelters for skeletal remains and several proved to have rich deposits of recent origin. The richest was from the Grotte Trans-sept, in the north wall of Canyon Forestier. It seems that at Ankarana cosmopolitan rodents have not yet supplanted the local rodents which are endemic to Madagascar. In the Ankarana rock shelters surveyed, skeletons of local rodents outnumbered those of introduced species. This is in great contrast to the bones found in the caves of Anjohibe or in caves in the centre of Madagascar. On the contrary, introduced rats and mice represent the majority of species in these more southerly caves.

Part of the zoological work of the expedition was to attempt a comprehensive inventory of all animals inhabiting Ankarana, both in caves and on the surface. We expected to compile a species list of the local small mammals using Longworth Traps. However, even if the freight shipment containing the traps had arrived, such a survey would have failed since most small mammals were aestivating and inactive. Skeletal remains found in the rock shelters therefore provided unexpected information on the ecological isolation of forests within the Ankarana Massif.

ARCHAEOLOGY
Jane Wilson

Madagascar was probably only first settled by man about 2500 years ago. The first settlers were thought to have arrived by boat from Indonesia and the voyage across the Indian Ocean in a large out-rigger canoe was proved to be possible by the Sarimanok Expedition in 1985. Early archaeological discoveries are therefore most unlikely, although some people think that there was a population in Madagascar before the Indonesian settlement. When we discovered pottery, fire places and other evidence of human settlement at Ankarana we first assumed this to be evidence of people hiding at Ankarana between 1835 and 1838 when local people were hounded by the soldiers of Radama I. This may be the origin of some artifacts but it seems probable that the archaeological remains are from a range of dates. The Ankarana shards show similarities with pottery used on the islands off Madagascar's north-west coasts during the XVI - XVIII centuries (Dr Hilarion Rakotovololona, Musee de l'Universite, Antananarivo: pers comm, 1987). Dr Bob Dewar (University of Connecticut) felt that the pottery photographed in the huge entrance of the Grotte d'Antsiroandoha had been deliberately left in caves as offerings to a spirit or as part of a funerary ceremony. Ankarana seems to be a rich archaeological site, worthy of specialist attention.

CONCLUSIONS
Phil Chapman

The karst and caves of Ankarana, although packed into a small area of limestone, rank with other great karstic regions of the tropics such as the Mulu Caves in Sarawak or the Guangxi towers in China.

The intimate relationship between cave waters of Ankarana and the wildlife-rich forests which they support, lends the caves a biological significance over and above that afforded by their rich cavernicolous faunas. The caves also hold important palaeontological and archaeological remains.

Yet the area faces an uncertain future. Local, large scale deforestation maybe increasing silting within caves and is posing a direct threat to many forest species. Reducing forest habitats is likely to influence the food supply of cave communities which depend upon bats, swifts, etc. Uncontrolled hunting threatens Ankarana's unique subterranean crocodiles.

Intervention is required soon if this unique area is to be safeguarded for the future. The Malagasy Government has the political will to protect Ankarana, but sadly lacks the necessary resources. Thus an ambitious conservation project is underway to extend the work presented in this report. In autumn 1987 a small team, including some members of the 1986 Crocodile Caves of Ankarana Expedition, will make a film about the area, its caves and wildlife and it conservation needs. A parallel research project, involving mainly Madagascar-based personnel, will aim to draw up a Management Plan for Ankarana which will be implemented using money raised by public appeal through international conservation organisations.

We hope that the Crocodile Caves of Ankarana Expedition has started a process which will eventually lead to the permanent protection of this superb area for the enjoyment of cavers, scientists and the people of Madagascar.

KELIFELY RECONNAISSANCE
Dave Checkley

The Kelifely plateau, with 8000 sq km of limestone, is the second largest potential caving area in Madagascar. It is reputedly nearly all Jurassic limestone (Balazs 1980), and is approximately 60km long by 50km wide. The southern scarp rises nearly 1000m above the surrounding plain.

Kelifely is in a fairly remote area, 250km north-west of Antananarivo and 600km south-west of Ankarana. Road access may be difficult since several river crossings are required and the ferries no longer operate. However, there are regular flights from Antananarivo to Ambatomainty, a village 25km south of the massif with a good dry weather airstrip. The Mahakamba River lies between the massif and Ambatomainty, but this probably dries up for some of the year, as does the larger Mahavavy River to the east of the massif.

The only people to look for caves in the region previously were a French team that visited the most northerly area of Kelifely (Peyre et al 1981 and 1983). They found no significant caves, but their movements were severely ristricted by the presence of bandits in the region. The French approached the massif from the town of Sitampiky in the north and did not reach the massif proper. Bandits are no longer a significant problem.

We chartered a four-seater aircraft through Madagascar Airtours in Antananarivo at approximately £400 for the afternoon. We flew directly to Kelifely across the dry plains. From Ambatomainty we flew straight up to and along the southern scarp. West of Ambatomainty the scarp is steep and continuous. It has very few breaks in it and only occasional patches of woodland in the shallow valleys incised into it.

To the north east of Ambatomainty at the base of the massif there is an incredible landscape of tortuous canyons. These winding, steep-sided gorges were closely intertwined over a huge area. The gorges were perhaps 30m deep and were so closely packed that the area presented a vista of endless rocky pinnacles running up to the Kelifely scarp. There was no water in any of these gorges and no obvious caves at their heads in the massif. Woodland did however obscure many of these valley heads. At many gorge heads were steep cliffs, but with no sign of caves at their bases. The red sandstone in which the gorges have formed (Isalo formation) must be very soft to have been so heavily eroded by the limited run off from the Kelifely scarp. The scarp in this area has a stepped appearance with small (?limestone) cliffs and intervening grassy or sometimes wooded slopes.

North of the scarp is a plateau, an extensive area of grassland sloping very gently northward. These grasslands are only occasionally punctuated by clumps of trees in shallow depressions and by the winding, tree-lined river valleys. We saw only one region of apparently broken limestone pavement and a few shallow dolines. We followed the two major rivers draining the plateau for their entire lengths (the Kiananga and Tsiamadiovolana Rivers). Their blue-green waters occasionally plummeted perhaps 50m down great round bowls, forming spectacular waterfalls. We could not be certain that there were no caves at the bases of these wooded bowls, but the river gorges cut out of these bowls at their far sides appeared to carry the same quantity of water as went in at the top. The further north we went along these tributaries of the Mahavavy River, the wider and more wooded their valleys became. However, even in the higher frequently cliffed gorges of these rivers we saw not a single cave entrance. The rivers always flowed on the surface and generally there were very few karst features. We flew as far north as the Kasijy Forest.

Although we did not land at Kelifely we flew within 20m of much of the surface of the massif for one and a half hours. We were unable to certainly identify any cave entrances. I do not therefore believe that the area is worth a major speleological expedition. This comment is made in the knowledge that a small Malagasy team (based in Antananarivo) will visit the area this year (1987). It will be interesting to see what they find, but the development of major cave systems in the area does not seem very likely.

MEDICAL REPORT
Jane Wilson

During the dry season which is the most practicable time to work at Ankarana, the dearth of water on the surface makes it a remarkably pleasant and healthy place to be. It hardly rains so tents are unnecessary, there are no insects and the only noxious animals are the scorpions and centipedes. These animals do not really become a nuisance until the earliest rains in October, which is about the time that the biting insects appear. The largest and most unpleasant scorpion is Groophus palpator and the two of us who were stung by these were in great pain with rigors, sweating, etc for 24 hours and unwell for several days subsequently. Pain at the site of the sting resolved after just over a week but one victim was left with an anaesthetic finger for a month. Powerful pain-killers preferably opiate analgesics, should be available for the first 24 hours after such a sting. We used sustained release Morphine tablets, but parentral drugs might have been more appropriate. Scorpions favour hiding in dark corners during daylight hours and even manage to find their way into rucksack pockets when it has been suspended on a tree. Great care is needed to avoid stings which are reputedly rarely fatal on Madagascar (see also Wilson 1987).

Another important health risk at Ankarana is from trauma; the tsingy is sharp and unstable and very abrasive. Strong boots and leather gloves helped to protect us and we were fortunate that our most serious accident was a laceration from a palm leaf.

Other problems included travellers diarrhoea and sickness; Lasonil proved helpful subsequently for soothing over-active anal sphincters. Several of us were troubled by mouth ulcers which we eased by Tee-jel. Three of us caught worms which were diagnosed and treated after we returned to Britain.

We stayed healthy because of the easy conditions at Ankarana, having the right immunisations and malaria prophylaxis and good camp hygiene (with a latrine and compost heap away from the living area). We acquired most gastro-intestinal problems while we were sampling the excellent Malagasy food that is available in the towns. These usually settled within 24-48 hours taking only clear fluids but one of us required a course of Flagyl (Metronidozole) for presumed giardiasis. Malagasy doctors and local Aides Sanitaires are well trained and very competent but the service they can offer is extremely limited due to shortages of drugs and medical supplies. A more comprehensive account of the medical aspects of the Expedition, including a list of drugs taken, is in our report (Chapman et al 1987a).

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Caves of Lower Glomdal, Rana, Norway

Simon BOTTRELL

Abstract: The lower part of Glomdal, Rana, contains a large number of small cave segments and one larger cave. Most of the cave passage is of phreatic origin, relating to an ancient hydrological regime, and the caves are now abandoned and dry. The exceptions are caves which have been invaded by a modern streamway and now form part of the active drainage system. The most significant active underground streamway flows for 1100m northward across the area and may be entered in five separate caves.

INTRODUCTION

In July and August 1984 a small expedition from the University of East Anglia (UEA) visited Glomdal in Rana, Northern Norway. We undertook a systematic exploration of the lower part of Glomdal, between the road end at Fiskjornmoen and the southern shore of Glomdalsvatnet (Figs. 1 and 2). This area is an extension of the marble karst which forms the well known caving area higher up Glomdal with several large caves (e.g. Pikhauggrotte, Fosseholet, Storbekgrotte; see Hjorthen (1968) and St. Pierre and St. Pierre(1969)). Although several caves and entrances were known in lower Glomdal, no extensive exploration had been undertaken and few of the known caves had been surveyed. We aimed to produce a full inventory of the caves of this area and survey as many as possible in the time available. In the event, the discovery of a new active cave system in the north-east of the area meant that we were unable to cover the south and south-eastern areas. After the UEA expedition left Glomdal, members of Wessex Cave Club connected two of the newly discovered caves and in 1986 Simon Bottrell returned to survey the connections with the aid of members of Speleo-club Vauban.

The lower part of Glomdal is dominated by the steep sided canyon of the Glomaga river but on the east side there is an areas of small hills up to 270m high bounded to the east by the cliffs of the old glacial valley. Much of this area consists of outcropping marbles which are well karstified, with an abundance of open grykes, shafts and shakeholes. Most of the area is covered by dense birch forest and all access beyond Fiskjornmoen is on foot.

In 1984 the primary aim was to locate, explore and survey as many caves as possible in lower Glomdal and the majority of the available time was spent on these tasks. In addition, some dye-tracing experiments were carried out and a preliminary geological map of the area was made. In 1986 the emphasis of the work was shifted to more detailed geological mapping and studies of the morphology of the caves. The survey of the largest cave of the area was completed with the help of members of Speleo-club Vauban (Lille, France).

GEOLOGY OF THE AREA

Prior to the 1984 UEA expedition it had been thought that the marbles outcropping in lower Glomdal were an extension of the relatively simple geology higher up the valley and we had anticipated that the mapping of the lower valley would be completed during the expedition. In the event, the geology of the lower valley was found to be far more complex. In 1984 only a simple outcrop map in the area of the streamway caves was completed. In 1986 three weeks were spent on mapping the lower part of the valley and the complex structure unravelled. Samples were also collected from both lower and upper Glomdal for petrographic and laboratory studies. Only a brief description the geology of the area around the caves is given here. It is hoped that in 1987 the mapping will be completed and the detailed results published (Bottrell and Lauritzen, in prep.).

Three lithologies were recognised in lower Glomdal: GREY MARBLES of almost pure calcite, with minor amounts of quartz and mica. Bands are commonly 1-5m wide. YELLOW MARBLES composed of calcite with variable amounts of dolomite, mica, quartz and other minerals. Bands are between 3 and 30 m wide. These marbles are very heterogenous and exhibit compositional banding on a variety of scales from millimetres to about a metre, with some bands of being composed of almost pure calcite marbles. MICA SCHISTS composed of quartz, mica, feldspar and garnet.

The rocks of lower Glomdal exhibit three phases of deformation, the second dominates the large-scale structure and hence the outcrop pattern. The folding is tight to isoclinal and thus the groups of marbles outcrop as nearly parallel bands 100-150m wide trending north-south, and generally dip at between 30 and 60° to the east. This pattern is complicated by the effects of superimposition of the three phases of deformation, but within the area of the caves described here the marbles can be considered as near parallel bands. The folding also affects the

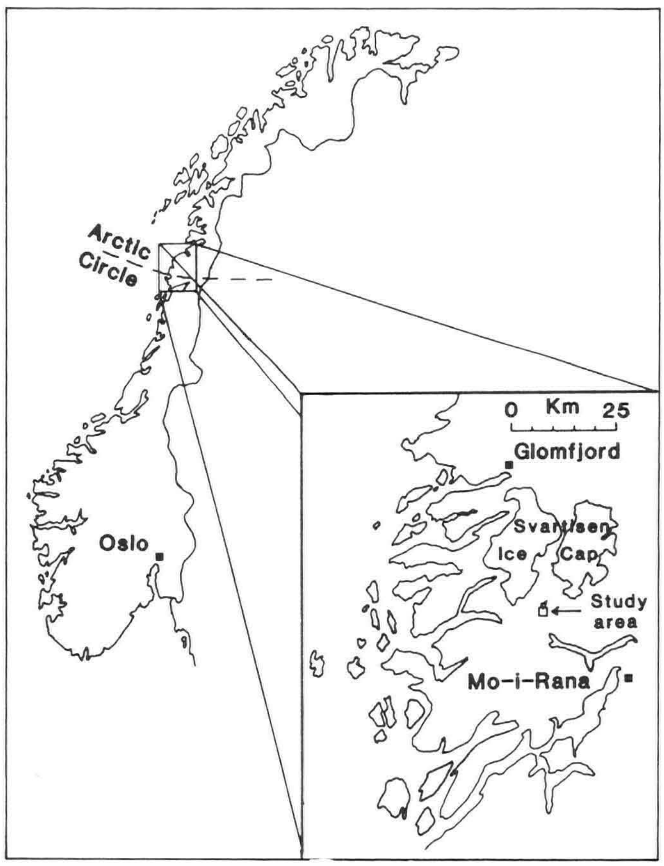


Figure 1. Location map for Glomdal in Norway.

thickness of the bands, the thickest marbles being found at the fold hinges and thinning out along the fold limbs. The dominant fractures in the area trend north-south and are near vertical.

THE CAVES

The caves of the area can broadly be split into two groups, presently active stream caves and segments of fossil phreatic caves.

<u>Active stream caves</u>

The now famous Glomdalsvatnet outlet cave (Lauritzen et al., 1985) lies in the north of the areas and was already well known. Our major discovery was a stream system draining from a sink at UTM507757 at 205m a.s.l. to a resurgence at UTM507768 at 129m a.s.l. This could be entered as five separate caves at the entrances marked in figure 2. The streamway connection was positively dye-tested through all the caves in the Neverslette-systemet and they are plotted together in figure 3.

The stream sinks among boulders at the head of a dry valley leading to a closed depression at the base of which a small entrance drops into the streamway of KJOKKEN-VASKEN (1100m). The cave follows the stream in an inclined boulder-filled rift which opens out into a large rift chamber with the stream flowing down a series of cascades to a sump. Opposite the top of the cascades an upslope crawl leads to another rift passage. Upwards connects back to the roof of the cascade chamber, downwards leads to two sumps and another upward crawl into the mainly dry upper series. The upper series consists of a number of small passages leading off from a main walking sized passage. Immediately before a large water-filled descending tube (the Moose Trap) is a crawl on the right leading to a vertical rift and the squeeze connection to the Galleries Francais, a maze of small phreatic tubes, and the second entrance to the cave. Beyond the moose trap is a 20m high vertical rift and a number of small passages which might give further extensions if pushed.

The streamway is rejoined in DE MURRENDE DOTRES GROTTE (32m) (DMD-grotte) where a small entrance in the large depression to the east of the path gives access to a few metres of streamway between a sumped rising and the stream disappearing into a small fissure. The stream reappears at the upstream sump of TROLLHOLET (125m), here the streamway is entered via an 8m entrance pitch. Downstream leads to a sump in a rift passage, upstream leads to near surface boulder chokes and low crawling to the upstream sump.

GAUDAGROTTA (188m) is entered by an 11m entrance pitch in a narrow shaft leading to a squeeze into a large stream passage. Downstream soon leads to a small maze of active and abandoned passages and the upstream sump in a large rift, approximately 20m from the downstream sump of Trollholet. This is the most interesting of the smaller caves.

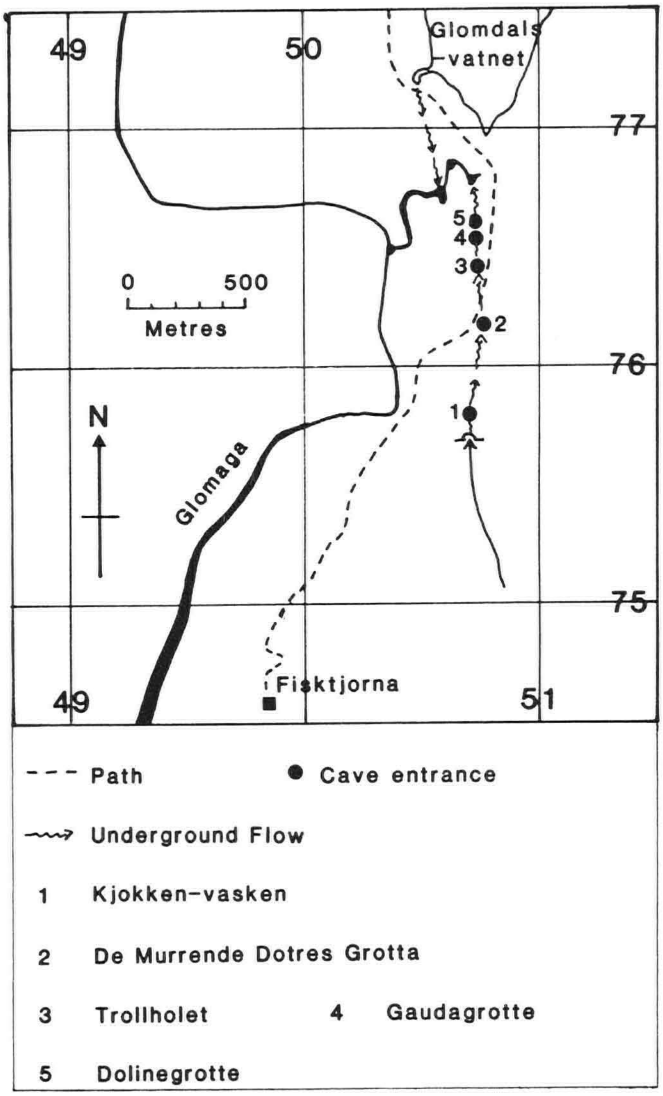
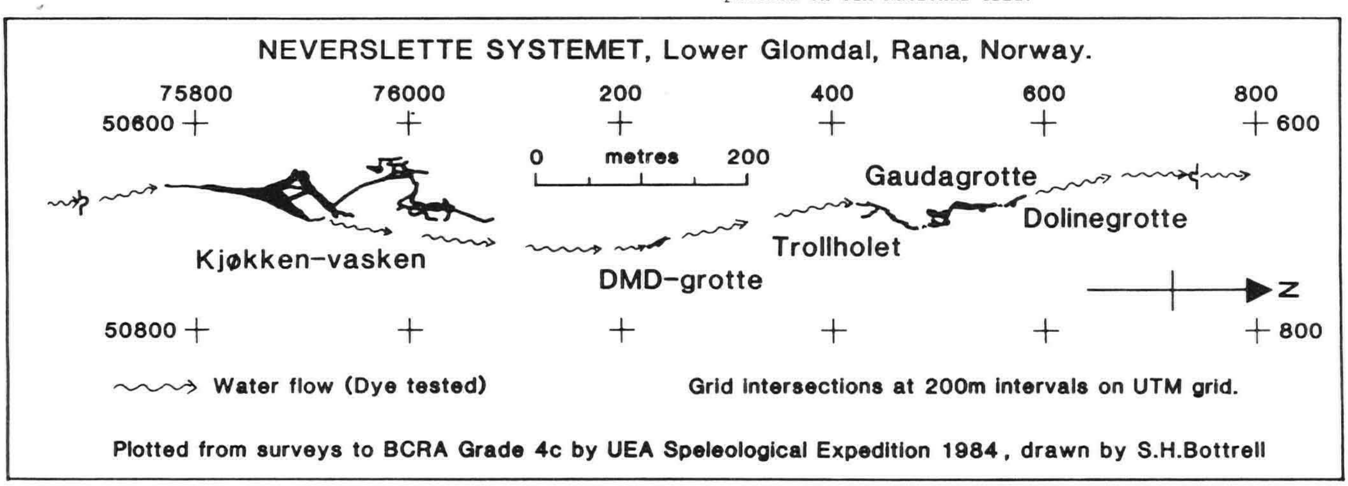


Figure 2. Map of study area in lower Glomdal, showing locations of entrances to streamway caves.

DOLINEGROTTA (29m) is the last cave in the system. A climb down through boulders at the base of a large depression leads into a short section of stream passage suited only to the masochist! The stream finally resurges among boulders to the south of a small lake at UTM507768. Above the resurgence is a small dry valley and a short dry cave which may be related to the system.

Figure 3. Surveys of caves of the Neverslette plotted on UTM National Grid.



Loc. No. (Fig. 4)	Survey grade	Length	Description
1 - 6	-	< 5m	Short choked segments of phreatic cave passage.
7 , 8	-	< 5m	Old phreatic passage invaded by modern streamway.
9	-	4m deep	Choked rift in gryke.
10	-	3m	Dry cave above resurgence.
11	-	3m deep	Choked rift in gryke.
12	4c	77m	Anneksgrotte (see text).
13,14	-	< 5m	Choked entrances to phreatic tubes.
15	3b	30m	Isgrotte - previously known phreatic remnant floored with ice.
16	4c	154m	Large remnant of phreatic tube network with several other smaller entrances.
17	4c	22m	Phreatic cave remnant.
18	4c	95m	Phreatic cave remnant.
19	3b	25m	Phreatic cave remnant.
20	3b	20m	Phreatic cave remnant.
21	3b	20m	Phreatic cave remnant.
22	3b	8m	Phreatic cave remnant.
23	3b	20m	Phreatic cave remnant.
Neverslette-systemet caves:			
NS1	4c	1100m	Kjokken-vasken.
NS1A	4c	-	Galleries Francais entrance.
NS2	4c	32m	DMD - grotte.
NS3	4c	125m	Trollholet.
NS4	4c	188m	Gaudagrotta.
NS5	4c	29m	Dolinegrotta.

Table 1. Cave localities in lower Glomdal.

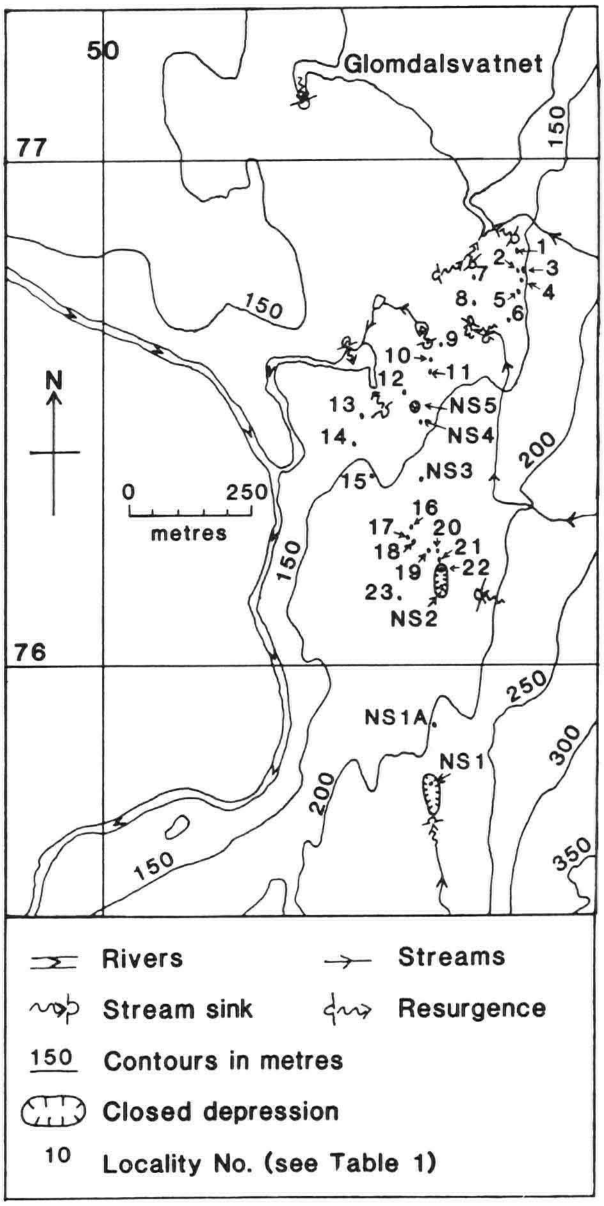
These caves form a very interesting drainage within easy walking distance of Fiskjornmoen. With the exception of the sloping rift streamway in Kjokken-vasken most of the caves are fossil phreatic passages which have been invaded by the present streamway.

Two other active stream systems were found in the area, one ANNEKSGROTTE (77m, UTM507766, loc.12 on Fig.4) was carrying no stream in 1984 and was consequently not dye-tested. In the wetter weather of 1986 it took a small stream. The cave is in two halves upstream and downstream from a large north-south rift on surface. The upstream passage starts from a chamber at a stooping height and becomes progressively smaller until further progress in the razor-sharp marble becomes either too wet or too painful; this section of the cave appears to be entirely vadose in origin. In the downstream cave the passage contrasts completely, after descending the surface rift a large keyhole section passage soon leads to a chamber with a sump pool. Attempts to free-dive the sump revealed a large completely flooded passage beyond. The other active streamway forms an obvious connection between sinks at UTM507767 and the resurgence 100m north at UTM507768 and can be entered via two small caves between (localities 7 and 8 and Fig.4), where the stream flows through old phreatic cave passage.

<u>Fossil phreatic cave segments</u>

A number of sections of old phreatic caves, now dry, were located and surveyed during the expedition. Some of these were previously known and where possible the local Norwegian names are used for these. Most were single or branched tubes, 1m to 3m in diameter, with lengths varying from a few metres to over 150m. Entrances are formed where surface erosion has intersected the cave passage, and the cave segments either connect two or more such entrances or terminate at chokes or static sumps. These caves relate to an ancient hydrological regime and are now abandoned with varying degrees of sediment infill. Attempts to establish the paleo-current direction in these passages from the morphology of scallops on the walls was often inconclusive, but there is a general trend to southerly flow direction in those cases where it could be established. All such caves found in the northern part of the lower Glomdal are shown on figure 4 and listed in table 1.

Figure 4. Detailed map of study area showing cave localities noted.



DYE-TRACING EXPERIMENTS

Fluorescein and Rhodamine dyes were used to establish hydrological connections in the active stream systems. In many cases a visible positive connection was made, but activated charcoal detectors were suspended in the water flow and subsequently used to confirm results (Atkinson and Smart, 1981). Most of the tests were concerned with the Neverslette-systemet streamway, but one was performed between the surface stream in the north-east of the area and resurgences on the south side of Glomdalsvatnet. All of the results are summarised schematically in figure 5.

Neverslette-systemet

The connection between the caves of the Neverslette-systemet was proved conclusively and a tributary to the system was traced from the surface stream sinking at UTM508761 to a side passage in DMD-grotte. The flow time through the system was somewhere between 2 and 12 hours from sink to resurgence (1100m) and the visible pulse passed quickly, indicating that there are no very large "dead volumes" of water in the sumps or between Dolinegrrotte and the resurgence.

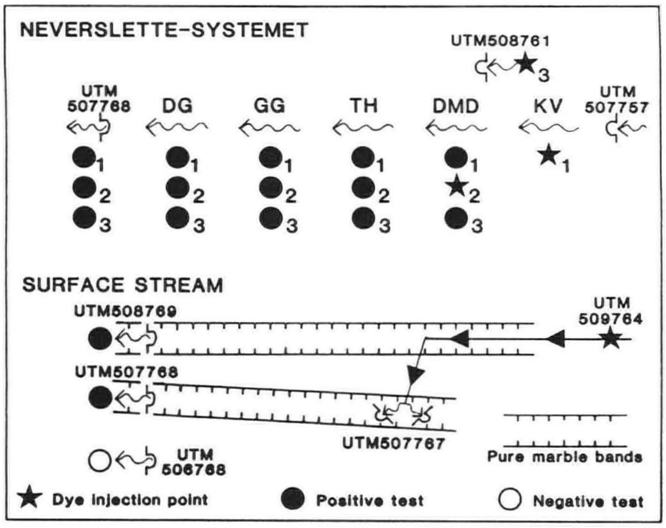


Figure 5. Schematic representation of dye tracing results in the Neverslette Systemet and surface streamway. DG = Dolinegrotte, GG = Gaudagrotte, TH = Trollholet, DMD = DMD-grotte, KV = Kjokken-vasken.

Surface streamway

In the north-east of the area a stream flows from a waterfall at UTM507757 to sink at UTM507767 (in high water it overflows to the small lake at UTM507768). Water in this stream was traced to two separate resurgences at UTM507768 and UTM508679 (Fig.4). One route from the sinks near UTM507767 to the resurgence at UTM5077768 is obvious but the route followed to the resurgence at UTM508769 is unclear. The stream flows through a small gorge in a pure marble band from UTM508765 to UTM508765 to UTM509763 and this band can be traced northward to the resurgence. It is thought that part of the flow of the stream may follow an underground route in this marble band, though no sink could be found. Flow time from the waterfall to both resurgences (1200m) was bout 1 hour. No connection was found between this stream and the resurgence in the dry river bed at UTM506768; this resurgence may be fed by drainage from the marshy ground to the west.

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Caves and Mines of Hawkstone Park, Salop

Terry MIDDLETON

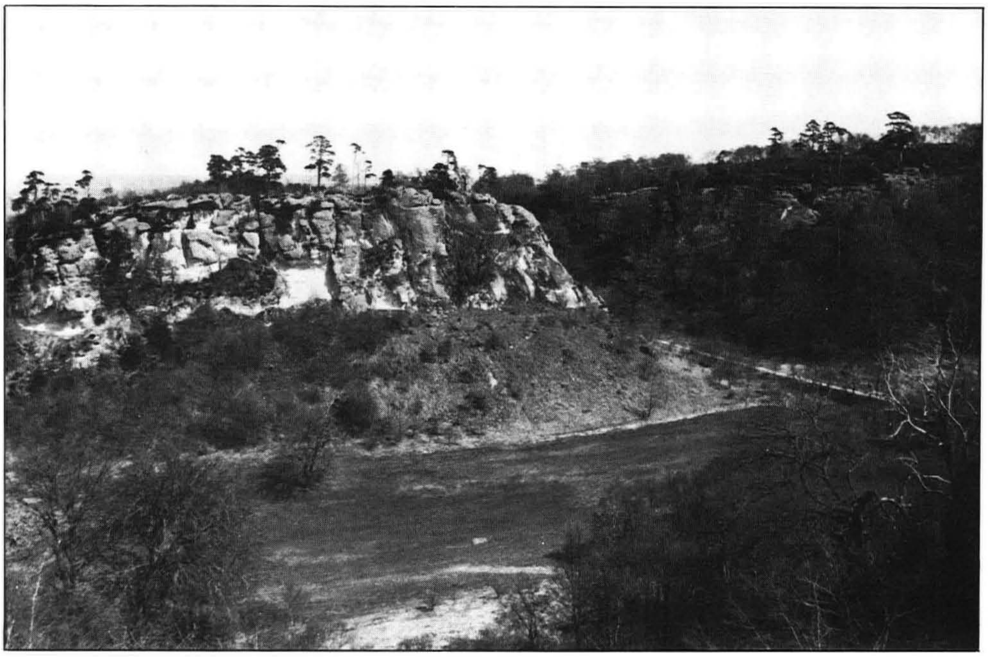
Abstract: Hawkstone Park contains a number of impressive outcrops of Triassic sandstone which have, over the years, been worked by man resulting in the production of both caves and mines. These workings have been described and where accessible, surveyed and a summary of the historical and geological setting of the site has been made.

Set within some of the most picturesque scenery in Shropshire Plain, Hawkstone Park provides a fascinating and indeed memorable locality for a visit. It is of interest to the speleologist because of the number of caves which lie within its boundary. Unlike the natural caverns of karst areas, the caves of the Park occur in sandstone and most of them are man-made having been constructed during the 18th century purely for the entertainment of visitors. The Park also contains to a limited extent evidence of mine working and this together with the caves forms the basis of this report.

The Park, which provides a superb setting for a golf course, is located some 11km north-north-east of Shrewsbury and 3km west-north-west of the village of Hodnet and can be approached from either the A49 or the A53. Three hills and an escarpment rise above and provide a sharp contrast to the rolling terrain of the golf course and these are known respectively as Grotto Hill, Red Castle Hill, Elysian Hill and the Terrace. At their highest point, the wooded slopes rise to a maximum elevation of 208m at a spot marked by the Obelisk on the Terrace. All of the land within the Park is private and anyone wishing to visit the locality must first obtain permission from the manager of the Hawkstone Park Hotel.

GEOLOGY

The rocks of the Park are Triassic in age and comprise, in chronological orser, red Bunter Upper Mottled Sandstone, buff-coloured Lower Keuper Sandstone locally known as 'Grinshill' Sandstone and Keuper Waterstones (Pocock and Wray, 1925). Under modern stratigraphical nomenclature the Lower Keuper Sandstone and the Bunter Upper Mottled Sandstone form the uppermost units of the Sherwood Sandstone Group whilst the Keuper Waterstones form the basal bed of the Mercia Mudstone Group (Warrington et al, 1980). Good cliff sections of all three lithologies are displayed at Hawkstone. The sandstone units, which are extensively cross-bedded, dip gently at an angle of 6 degrees in a north north-westerly direction. In consequence, the older, mainly red sandstones outcrop at the southern end of the Terrace and at Elysian Hill whilst the overlying 'Grinshill' sandstones, of which over 45m are exposed, are seen at the northern end of the Terrace and at Grotto Hill. Red Castle Hill comprises a small outlier of 'Grinshill' sandstone resting upon the red sandstones which continue beneath the undulating landscape of the golf course. A good section of Keuper Waterstones is exposed in the ravine at SJ582293. Faults bound the north-west and north-easterly edges of Grotto Hill and the Terrace (see British Geological Survey 1:63360 sheet 138 Wem; 1967 and explanatory memoir Pocock and Wray 1925). The Grinshill sandstone, which is locally an important building stone in the area, contains large numbers of small resistant crystalline nudules which were described by Pocock and Wray as 'nests of barite crystals'. However the nature of these crystals (or pseudomorphs?) is difficult to confirm without microscopic or chemical analysis. These nodules are also present, though less abundant, in some of the outcrops of the underlying red sandstones. Both sandstones contain subangular grains and in several areas the siliceous matrix of the bedrock has been replaced by a calcareous cement. The presence of the crystalline nodules, the variations in colour of the sandstone, together



Grotto Hill viewed from the Red Castle area. Note the path which traverses the base of the cliffs and the ruined arch which is situated by the summit at the southern end of the hill. The wooded slopes of the Terrace can be seen on the right hand side of the photograph.

with the fluctuating nature of the cementing material suggest that the sediments/rocks have been subjected to both penecontemporaneous and post-diagenetic changes.

Green copper ores of low grade may be found in the upper units of the Grinshill sandstone. These have been named as malachite by previous authors (Murchison, 1839; Pocock and Wray, 1925; Dewey and Eastwood, 1925; Carlon, 1981) however it should be noted that during recent field tests the ores failed to show any reaction to dilute hydrochloric acid! No detailed chemical examination of the ores is known to have been carried out. Blue copper minerals, possibly azurite, occur locally in very small amounts. The ores tend to be found impregnated between slightly coarser units within the cross-bedding. The mineralization does not appear to be associated with, or be localised by, fault structures.

THE MINES

Although the copper ores are of low grade there is some evidence to suggest that they may have been mined or that trials were carried out. Many authorities have suggested that Hawkstone Grotto (SJ.573297) was a Roman copper mine (Watkin, 1879; Kenyon, 1892) and if so it is the only mine, albiet modified subsequently, that is accessible in the Park today. It has also been suggested that the Roman villa found at Weston could have housed a mine official (Kenyon, 1892). However these tentative connections still have to be proved. Nevertheless there is ample evidence of the Roman occupation in the surrounding area. Roman coins and bronze implements have been found in the ruins of the Red Castle and more Roman artefacts have been discovered at the hill fort of Bury Walls which lies 2km to the south (Watkin, 1879; Kenyon, 1892). A hammer pick of possible Roman origin has been discovered at Hawkstone (Davies, 1935) and the Roman road connecting Wroxeter (Viroconium) with Chester (Deva) was described in the Victoria County History (1908) as climbing 'the western extremity of Hawkstone ridge'. There is also plenty of evidence to confirm that the Romans were extracting lead from areas nearby including Shelve Hill and the Stiperstones. Pigs of lead bearing the inscription IMP. HADRIANI. AVG. (Imperatoris Hadriani Augusti) have been found in the Snailbeach area of the Stiperstones just south of Shrewbury (Davies, 1935). The workings at Llanymynech Hill (Adams, 1970), which are also thought to have been worked by the Romans for either lead or copper, are likened in the Victoria County History (1908) to those at Hawkstone. However the proposed similarity does seem a little dubious! The grotto at Hawkstone was subsequently enlarged for recreational purposes and as a result for the purpose of this account its full description has been included in the section on caves.

Both Murchison (1839) and subsequently Carlon (1981) make reference to a shaft on the Terrace. The shaft is said to be located at SJ.576295 and was described as being 1.5m in diameter and capped by an iron grille with sandy spoil nearby. This area can be reached by following the footpath up the hill from C7 and C8 to the Terrace. The shaft should be located in the area immediately north east of the junction of this footpath with the main path along the top of the Terrace. This region is covered with rhododendrons and the undergrowth is so dense that a person could walk directly over the grille on the shaft without

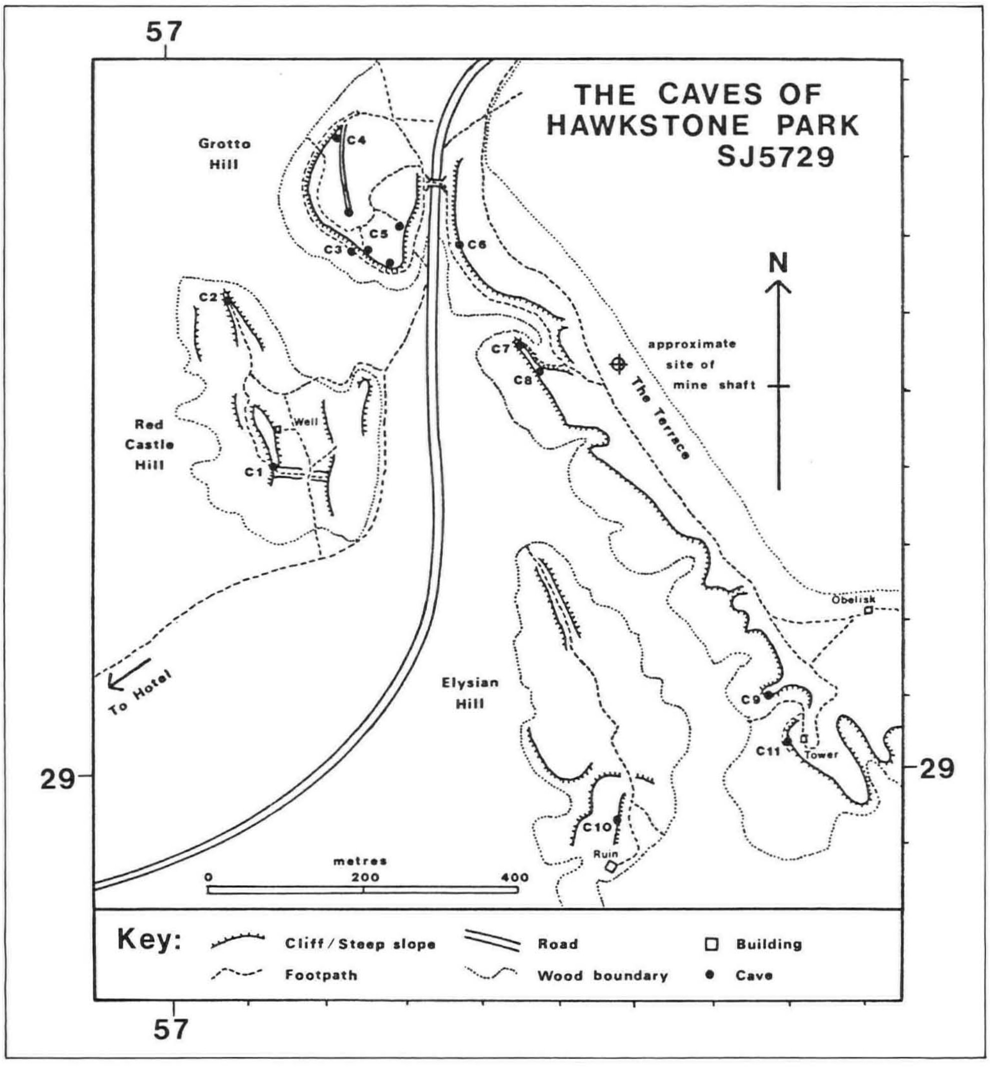
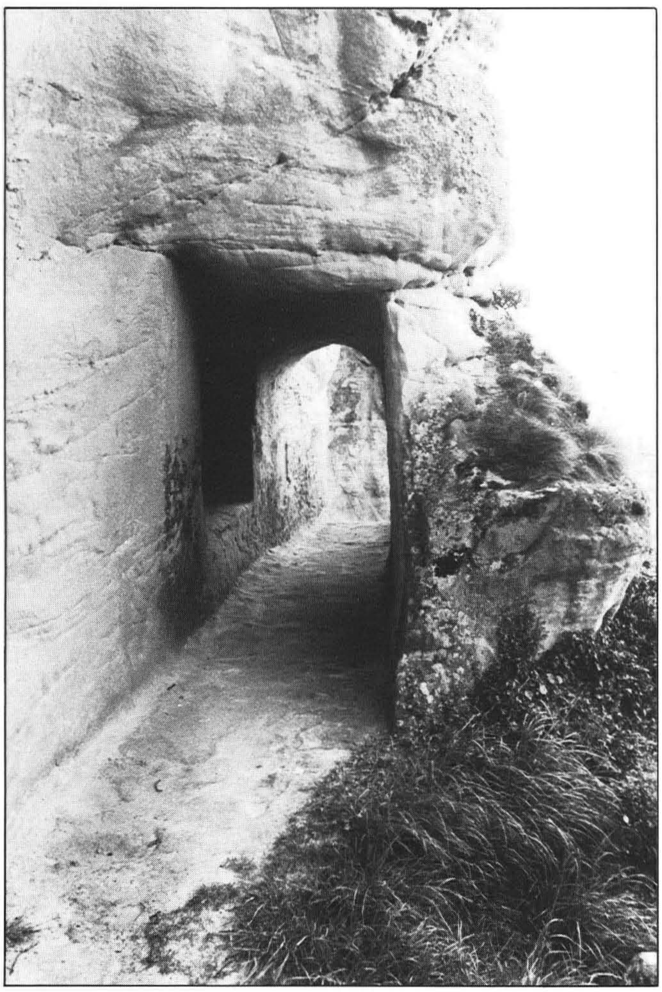


Figure 1. Map showing the location of the caves found within the boundary of Hawkstone Park. (Cliff details taken and enlarged from the 1:10560 Ordnance Survey map SJ52NE. Cave locations mapped by author - May 1987).

realising it! A search for the shaft during this survey proved fruitless. Disturbed ground composed of loose sandy mounds and tunnels covering an area of approximately 180 square metres was found within this region of woodland close to the boundary with the adjacent field. However this disturbed area appeared to be no more than an extensive badger's set! The shaft was last seen in 1952 (Carlon, 1981) and it is unlikely to be relocated until the rhododendron bushes are thinned.

More workings occur just beyond the boundary of the Park at SJ.587292 (Pocock and Wray, 1925; Carlon, 1981). The workings included a small shaft 3m deep connected to an 2.4m level driven to the south east which in turn linked to a 6m level running south-south-west to intersect the slopes of the Terrace. The workings, which were infilled in 1977, were said to contain deposits of azurite and malachite.

These 2 sets of workings (SJ.576295 and 587292), both of which are located on the Terrace, seem to have been little more than trials. It is difficult to date them, but they may have been excavated during the 17th or early 18th century prior to the purchase of the land by the Hill family in 1737 (Carlon, 1981). Documentary evidence of the dates of the mining at nearby sites may be relevant to this question. Sources sited by Warrington (1980) indicate that mining occurred at Weston and around Redcastle before 1740, and that the partnership was formed to mine in the townships of Weston-under-Redcastle and Wixhill in 1697. This activity probably took place at the sites noted by Dewey and Eastwood (1925) and Pocock and Wray (1925) between 1 and 2.5km south-west of Red Castle Hill. Some working at Wixhill also took place during the mid-19th century (Pocock and Wray, 1925). Carlon (1981) also referred to leases being granted in 1897 and



The arch (C3) and the footpath at the base of Cliffs on Grotto Hill.

1698 for mining at Wixhill. As noted by Warrington (1980), the documentary evidence of working of non-ferrous ore deposits in Cheshire and north Shropshire in the late 1690's contrasts with the lack of such evidence before that time and is consonant with the development of interest in them after the passing of the Mines Royal Acts. It would, therefore, seem reasonable to suggest that the mining trials found within Hawkstone Park were driven at the same time as those of similar localities in the vicinity.

THE CAVES

Much of the landscaping of the Park was carried out during the 18th century by its owner Sir Rowland Hill (Oswald, 1958). During this period a number of curiosities were contructed for the benefit of visitors including the Obelisk, the White Tower, a lion's den complete with stone lion, a hermitage and several 'caves' and rock shelters. A total of 11 such 'caves' can be found at Hawkstone (figure 1) and although all but one of them are very small, they are nevertheless of interest as tokens of the lengths to which the landowner was prepared to go to add interest to his Park. The caves can be subdivided into 3 categories:

1) Former mine workings that were extended or enlarged during the 18th century.

2) Tunnels not associated with mining that were constructed during the 18th century.

3) Natural alcoves or recesses in the cliffs.

These natural alcoves have been included in this report because they were named as caves in the old tourist guides to the Park and were mentioned in their itinerary. Typical excursions are described by Leach,1891; Davies, 1894; Haslam, 1985; and in the Hawkstone Handbook for 1938. The site of each cave is shown on the location map and plans of the larger systems (figures 2 and 3) have been included with this article. A number of caves are marked on the 1:10560 Ordnance Survey map (SJ52NE). All are described below:

C1

(SJ.57142940): situated at the western end of the obvious east/west trending gulley on Red Castle Hill. It comprises a single curved passage 12m in length (figure 2) which links the gulley with the west-south-west face of Red Castle Hill. The tunnel, which is cut through red sandstone, is 0.8m wide and 1.8m high and bears a multitude of pick marks. It is also gently inclined to the west and trends in an east/west direction.

C2

(SJ.57082963): located in a small isolated pillar of red sandstone at the northern edge of the ridge of Red Castle Hill. It is just 5m long and is S-shaped in plan with an entrance at either end. It trends in a north west/south east direction. The passage is 1.8m in height, 0.8m in width and is man-made (see figure 2).

C3

(SJ.57252970): a short man-made arch 5m in length with benches hewn out of the rock on either side. It can be entered by following the path which skirts the south west facing cliff of Grotto Hill (see photograph 1). The arch is 1.2m wide, 2m high and has been driven through a buff-coloured sandstone.

C4

(SJ.57232985): located at the northern end of Grotto Hill and has 2 entrances. It is best entered from the narrow ravine which cuts through the dip slope of the escarpment. The cave is man-made and links in an east/west direction and is 18.5m long. The low entrance sited in the ravine leads to a small circular chamber with a central pillar and 'window'. From the chamber, the passage becomes gradually lower and finally emerges into daylight (see figure 2). The latter part of the cave is wet with much mud on the floor.

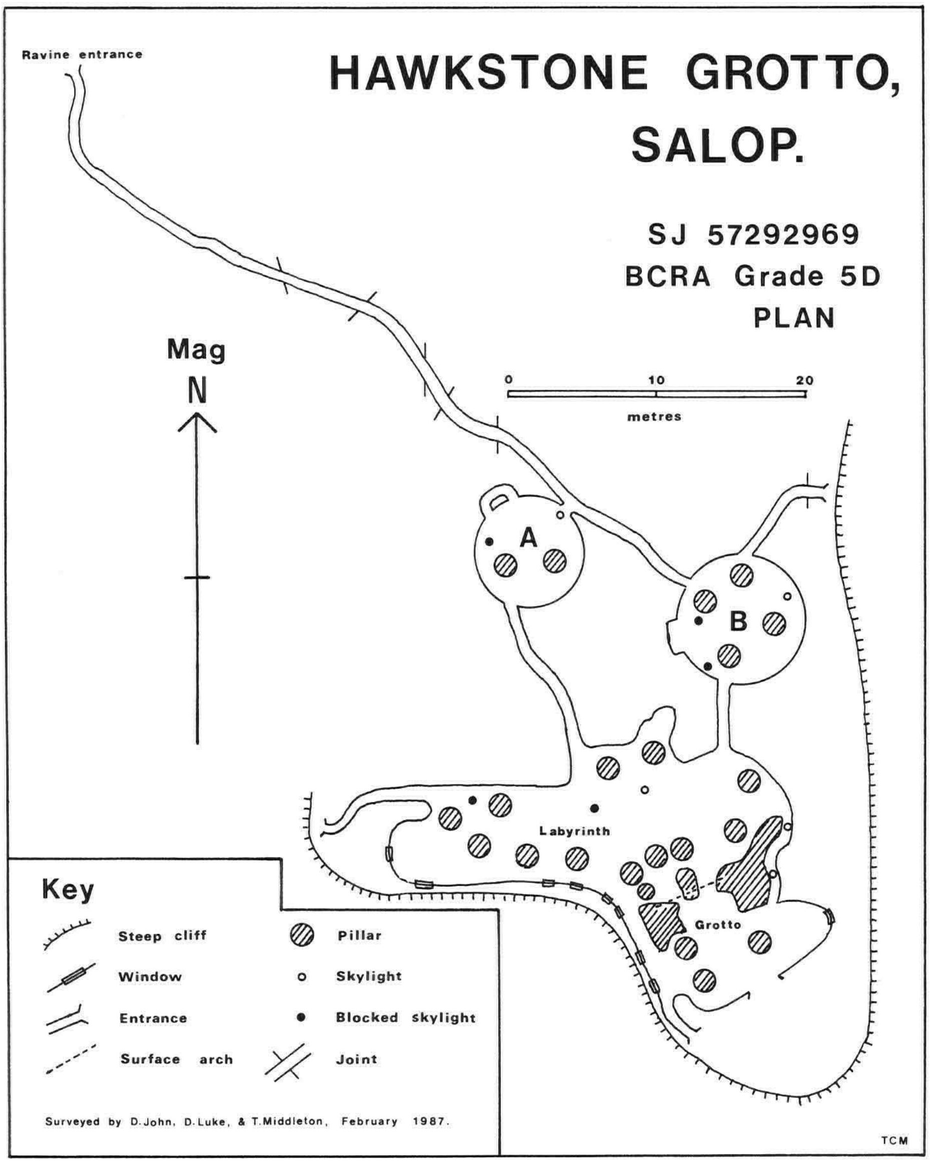


Figure 3

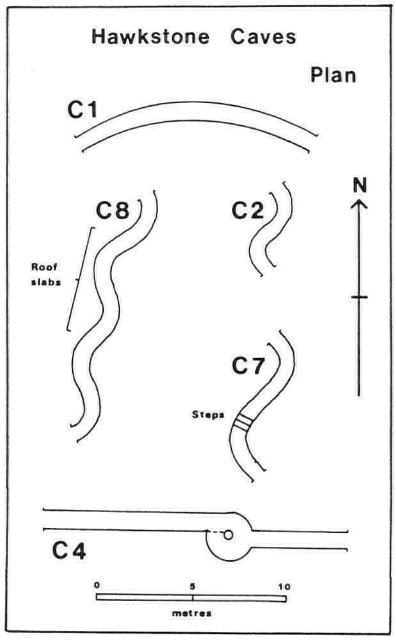


Figure 2. Surveys of some of the smaller caves found within the Park. (Details recorded by author January - May 1987).

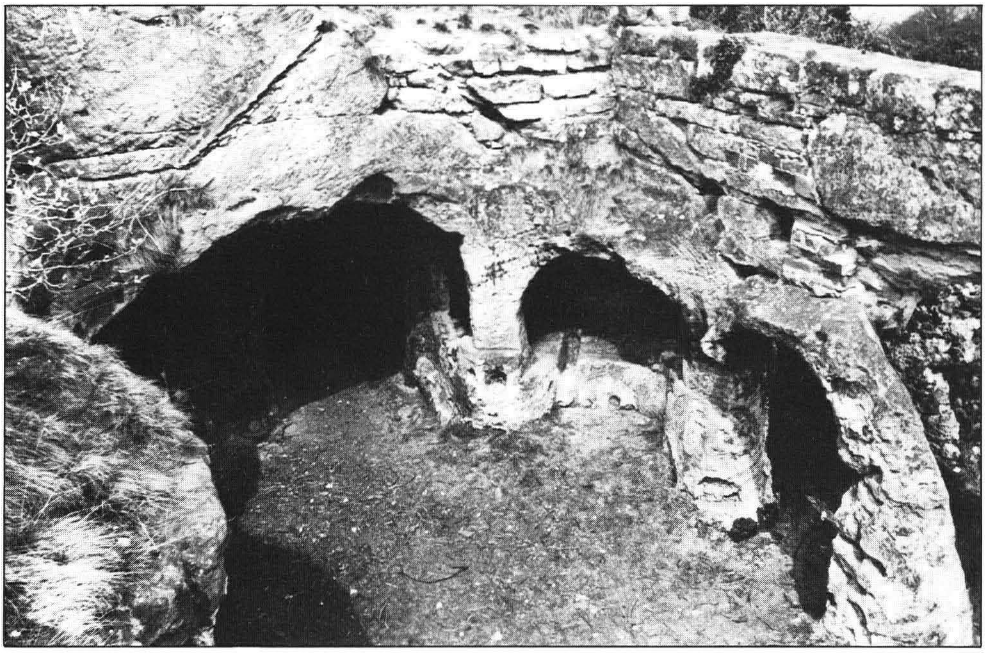
C5 - Hawkstone Grotto

(SJ.57302970): situated at the summit of Grotto Hill, it can be reached by either proceeding along the ravine to its southern end or by following one of the paths up the dip slope of the escarpment. The cave has 4 entrances and is by far the largest system in the Park and a detailed survey is presented herein (figure 3). Deposits of green and a little blue copper ore can be seen impregnated in the bedded buff-coloured sandstone units. The passage which leads into the system from the ravine is 2m high and 1m wide and trends in a north west/south easterly direction (figure 3). Oswald (1958) stated that this passage was constructed for Sir Richard Hill to connect with the main part of the Grotto. The rest of the cave appears to be much older than this passage and, as already mentioned, a number of authorities have suggested that it may have originated as a Roman Copper Mine. The cave was visited by Dr Johnson during his travels (Oswald, 1958).

Soon after entering the cave from the ravine the former position of the doorway can be seen cut into the passage walls. Although the plethora of pick marks in the passage tend to obscure the finer geological details, a number of near vertical sediment filled fissures can be seen on route to the Labyrinth. The position and trend of these joints have been shown on figure 3. Small amounts of water infiltrate down the penultimate joint just prior to the junction with the first chamber. A hole on the right leads into the first chamber ('A' on figure 3) which is approximately circular and has a diameter of 5.6m. The chamber contains 2 main pillars and 2 skylights one of which is blocked. These support pillars vary in size throughout the cave. However, for clarity, they have been shown on the survey as being equal-sized. At the north-western side of the chamber lies a short semi-circular passage around a further pillar. The solid sandstone at the entrance to this section has been carved to resemble a stone arch. At the far side of the chamber a passage leads into the Labyrinth whilst the original entrance passage continues into a second circular chamber ('B' on figure 3) with a diameter of 7.3m. It has 4 support pillars and one of these in particular has been beautifully carved and fluted. Out of the 3 skylights present only 1 is open. At the northern end of the chamber a short passage leads out into daylight at the edge of the cliff (take care!). The chamber also has a small alcove on its western side. A passage continues from the southern end of the chamber into the Labyrinth.

The Labyrinth is a most impressive cavern with shafts of light entering from skylights and windows at the western end. It is 28m in length and 9m in width and contains several rock pillars. At the western end a passage leads out onto the edge of the escarpment and the path may be followed to a carved viewing area. In several places the uneven walls of the Labyrinth appear to have been coated with a layer of green paint (also noted by Jones, 1974). At the southern end of the

The southern entrance area of Hawkstone Grotto. Note the remains of a roof on the back walls.



cavern a number of routes lead through old doorways into the Grotto. The following description of the site appeared in 'The County Seats of Shropshire' (1891);

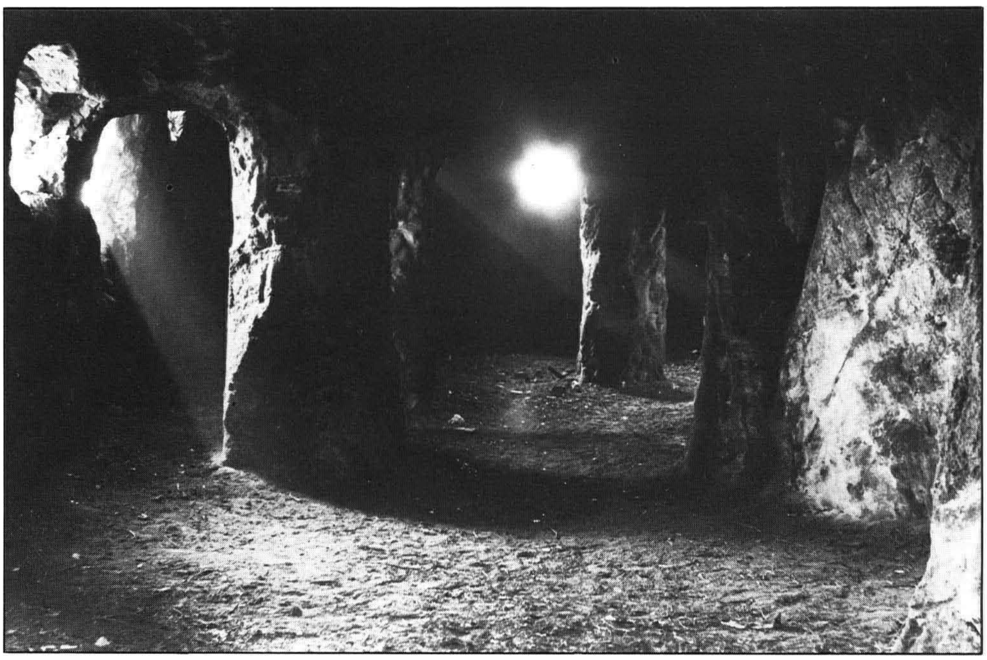
> "the visitor is introduced to the magnificent Grotto, a vast subterranean cave, in the midst of which is a spacious recess fantastically inlaid with a great variety of shells, fossils and other curious petrifactions"

Originally the windows of the Grotto were filled with painted glass, unfortunately however, none of this remains today. During the 2nd World War the Park was utilized first by an American military camp, then by a German Prisoner of War camp and finally by British troops waiting for demobilization. During this period much of the ornamentation in the Grotto was destroyed (J.Jones pers comm.). Nevertheless some of the decorations still remain and they are best displayed at the eastern end of the Grotto where numerous shells, mainly lamellibranchs and gastropods, have been set in a cement/plaster matrix together with much furnace slag. The remains of a tiled roof can be seen in places. The ruined arch which stands at the top of Grotto Hill (yet another folly) lies directly above the main passage which links the Labyrinth with the Grotto. The westernmost passage linking the Labyrinth with the Grotto has a beautifully arched roof and it was in this area that bats, at one time, were quite common. Unfortunately none of the caves in the Park appear to be used by the bats today. Most of the existing cave fauna can be found in the blocked skylights and the cave spider (Meta menardi) and the Herald Moth (Scoliopteryx libatrix) are the most noticeable species.

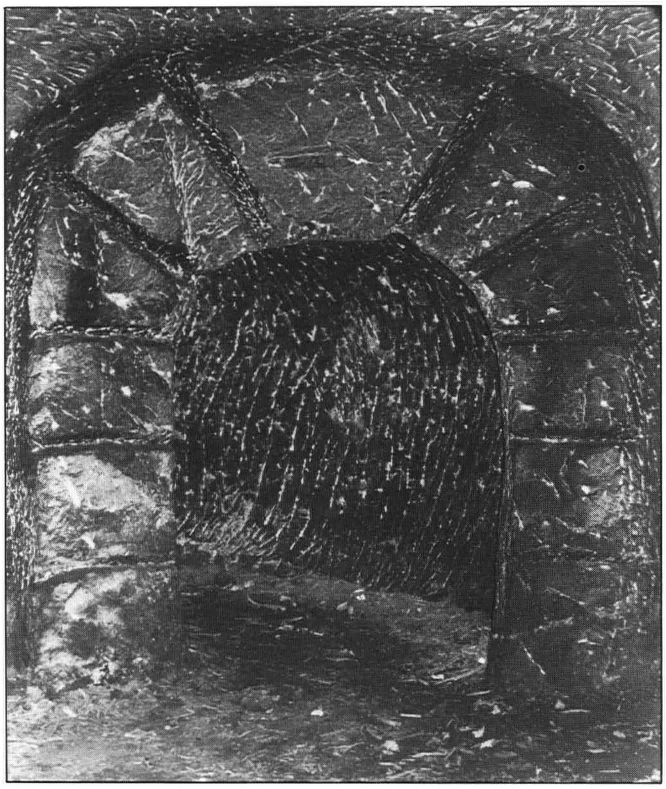
The Grotto may have been occupied by a hermit prior to the 18th century and, if so this could have been the reason why the Hill family later had an artificial hermitage complete with automaton (a papier mache figure worked by levers) built within the Park.

C6 - The Retreat

(SJ.57372973): a natural alcove located at the base of the cliffs immediately adjacent to the footpath which leads up onto the Terrace (figure 1). It is found in a buff-coloured sandstone and is only 3m wide and 4m high. It is included in this report because it was described as a cave in the itineraries of the Victorian tourist guides. A fissure infilled with a mottled calcareous fine-



The Labyrinth in Hawkstone Grotto



The carved arch in Hawkstone Grotto

grained sediment can seen at back of the cave. This line of weakness probably aided the development of the cave.

C7

(SJ.57462957): situated in an isolated tower of buff-coloured sandstone known both as the Fox's Knob or the Fox's Head which was named after the incident whereby a fox together with its pursuing hounds leapt to their deaths from the top of the outcrop (Leach, 1891; Oswald, 1958). The cave is 7.8m long and has 2 entrances which are linked by an S-shaped passage (see figure 2). The straightest section of cave follows a north east/south west trending fissure. The passage is 2m high and 0.9m wide and descends gently towards the north west. There are no pick marks in the cave but deposits of copper and iron ore minerals are evident in the surrounding rock.

C8 - St Francis' Cave

(SJ.57492954): situated immediately adjacent to the footpath. The cave takes a sinuous route which trends in a north-north-east/south south-west direction to emerge after 18m at the far side of the ridge (figure 2). The passage which contains many pick marks, is 2m high and 1m wide and is inclined towards the south west. The iron hinges of a former door can be seen set into the buff-coloured sandstone by the lower entrance. A number of insects in particular cave spiders and Herald Moths can be seen clinging to crevices between the roof blocks .

C9 - Reynards Banqueting House

(SJ.57772911): a natural alcove 5m high, 6m wide and 2m deep which has developed along a fault in red sandstone (figure 1). It is included in this report because it was described as a cave in the Victorian tourist literature. Its name derives from the numerous bones of hares, rabbits and poultry which have been found in the alcove (Leach, 1891).

C10

(SJ.57582895): located in the red sandstone of Elysian Hill. It is found in a low outcrop which faces east and is approximately 10m above the footpath which follows the bottom of the valley (figure 1). The cave , which is 1.5m wide and 2m long, is man-made and was used for the storage of tools when the lower half of the valley was a garden.

C11

(SJ.57812905): located in an outcrop of red sandstone by the footpath immediately below the ruined White Tower (figure 1). It is a small horse-shoe shaped shelter with a bench cut into the rock and it is man-made. The cave is 3m in diameter and 1.7m high. This may well be the cave which was mentioned as being used as a hiding place for one of the ancestors of the Hill family (Leach, 1891).

CONCLUSION

It can be seen from the account that although the caves and mines at Hawkstone are limited in size they are nevertheless of interest and are worthy of a visit. It is unfortunate, however, that there is presently insufficient evidence available to enable accurate dating of the mining activity. A detailed survey of the whole of the Park is at present being carried out by Shropshire County Council and it is possible that their findings may result in the site being opened to the general public.

ACKNOWLEDGEMENTS

The author wishes to thank Dr T D Ford of Leicester University and G Warrington of the British Geological Survey for kindly reviewing the manuscript and making a number of valuable comments. Thanks are also due to Jack Jones the local guide to the Park, Mr K Brazier, the General Manager of the Hawkstone Park Hotel, who was kind enough to allow access to the site and to D John and D Luke for assisting in the surveying of Hawkstone Grotto.

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Leptospirosis among British Cavers

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Abstract: Leptospirosis, known in its most severe form as Weil's Disease, is one of the few serious illnesses to which cavers are at risk. In 1985, a survey was made of 150 selected British cavers, to check for Leptospira antibodies in the blood. The sample featured some of the most active and experienced cavers in the country. In 22% of cases there was evidence suggestive of contact with the harmless Leptospira biflexa and in 9% with the parasitic Leptospira interrogans. We found no evidence of a regional bias for infection with Leptospira interrogans from any British caving region. Of the cavers with Leptospira interrogans antibodies, half had caught the parasite in the Gunong Mulu National Park (Sarawak). One had been diagnosed in the USA, while the remainder were mild or symptomless cases probably contracted in the British Isles.

INTRODUCTION

The Genus Leptospira

Man is an occasional host to a group of spiral organisms (spirochaetes) of the genus Leptospira. Leptospires are free-swimming and can be subdivided into two major categories: L. biflexa are saprophytic varieties living on the products of decayed vegetable matter in fresh water streams and ponds. L. interrogans are parasitic and live in animal hosts. A wide variety of wild animals, particularly rodents, carry the parasites, but even amphibians and reptiles have been known to do so (Benenson 1980). Of domestic animals, cattle, pigs and dogs are the usual hosts. Leptospires are 5-20 um in length (Thomas 1979) and infection is normally detected by the presence of specific antibodies in the blood. There are about 180 different strains (serovars) of L. interrogans which are defined by proteins (antigens) on their surface to which antibodies may be raised in man or animals. Serovars with important antigens in common are grouped together into 23 serogroups. Individual serovars may be specific for different animal hosts.

The predominant infecting serogroups found in the British Isles are icterohaemorrhagiae (carried by the brown rat), canicola (carried by dogs) and sejroe, particularly serovar hardjo (cattle). Until very recently hardjo was classified as a serovar of hebdomadis (Waitkins 1985). The host animal is quite often asymptomatic, but will carry leptospires in high numbers (10^{10} organisms/g of tissue) in their kidneys, excreting them in the urine (Waitkins 1985). In a warm moist environment leptospires can survive for several months. Conditions are most favourable in tropical areas, while in temperate countries there is a marked seasonal incidence of infection, most cases occurring in late summer and autumn.

The disease Leptospirosis

The Leptospira organisms usually enter the body through cuts and abrasions of the skin but may be inhaled or enter through the conjuntivae of the eyes. Both species of Leptospira may enter the body, but only L. interrogans will multiply and cause illness. In the past leptospirosis in Britain was mainly an illness of sewer and mine workers, whose working environments were infested by rats. Pest control, protective clothing and health education have done much to reduce the risk to these people. Those most at risk now are farm workers, particularly dairymen, who contract the illness (caused by the serovar hardjo) through direct contact with cattle (Waitkins 1985). The increasing popularity of water sports has meant an increase in incidence of casually acquired illness usually caused by the rat-borne serogroup icterohaemorrhagiae. In the tropics many of the fevers suffered by agricultural labourers (e.g. cane cutters' disease) are Leptospira infections (Wilcocks and Manson-Bahr 1972).

After entry into the body L. interrogans multiplies rapidly in the bloodstream and thence finds its way to all organs. The body responds by producing many different antibodies; as the patient begins to convalesce the infecting serogroup antibody predominates. The leptospires tend to localise in the liver and kidneys, sometimes causing serious damage. Those in the kidneys seem to be unaffected by antibodies and are shed in the urine for several weeks.

The incubation period for the disease is normally about 10 days, but can vary from 3 days to 3 weeks. The course of the illness varies from individual to individual, and also depends on the infecting serogroup. In many cases the patient suffers only a mild illness with loss of appetite, nausea, headaches, muscular pains and a low grade fever. The symptoms subside after a few days and are often attributed to influenza or "viral illness". The infection can be asymptomatic.

There is often a more severe febrile (feverish) illness of sudden onset accompanied by conjunctivitis, diarrhoea, mental confusion and such severe prostration that the patient may be unable to turn over in bed without assistance. It is frequently biphasic with a first phase lasting 4-7 days. The symptons then subside for a day or two before the fever returns, often with severe headaches.

Weil's Disease is the name given to the most severe form of the illness. Jaundice appears due to liver damage after 4-6 days and there may be haemorrhages into the skin or from the gut. The kidneys may fail. Most deaths occur at this stage of the illness but in less severe cases recovery occurs in the third week.

All serogroups respond to treatment with antibiotics, particularly penicillin, in the first week but some (icterohaemorrhagiae in particular) will not respond if treatment is delayed. Full recovery can take several months and antibodies remain detectable for 1-20 years (Wilcocks and Manson-Bahr 1972).

The most serious cases and the majority of cases of Weil's Disease are due to the icterohaemorrhagiae serogroup; hardjo infections appear to be less severe. In the most recent statistics of the Public Health Laboratory Service (Waitkins, 1986) there were 90 cases of leptospirosis identified in the British Isles in the year 1984. 37 cases were serogroup icterohaemorrhagiae, 32 were sejroe serovar hardjo. Two patients died.

The increase in incidence in recent years of serovar hardjo in Britain has mainly been among cattlemen who contract the illness directly. Few cases arise outside the agricultural industry. Forty five out of forty nine water sports victims contracted the severe icterohaemorrhagiae serogroup during the period 1978-1983 (Waitkins 1985).

Leptospirosis among cavers

Leptospirosis in its most severe form, Weil's Disease, gained a notorious reputation among British cavers when, in 1963, a Bristol pathologist, Oliver Lloyd, became ill after a caving trip down Stoke Lane Slocker in Eastern Mendip. He was at the time not only a famous figure in caving circles but also the Hon. Secretary of the Mendip (Cave) Rescue Organisation. Upon recovery from his illness he published the danger to cavers of rat infested streams (Lloyd, 1964) and, with the assistance of the local authority Rodent Officer, waged a private vendetta against the rats upstream from the entrance to Stoke Lane Slocker. This continued until 1972 when he retired from his post with the M.R.O.

Not surprisingly, Stoke Lane Slocker gained an evil reputation and the Mendips as a whole became considered a "risk area". There seems little justification for this, since in over 20 years there have only been two further cases of infection reported in the caving press from cavers in Britain. One of these (Frankland, 1978) again involved Stoke Lane Stocker. The other (Lloyd, 1978) was a mild case which occurred in 1974; the caver had visited several sites on the Mendips (Swildons Hole, Wookey Hole, Lamb Leer and others), any of which could have been the source of the infection. A review of the international caving literature for this period (1964-1985) failed to find any reports of *Leptospira* infection.

Recently several caving expeditions to the East Indies have been afflicted by undiagnosed fevers. The Mulu expeditions (Sarawak, Malaysia) have been particularly troubled. In 1978 most of the caving party became ill; in 1980 four were ill; in 1984 five out of sixteen had fevers (Buchan, 1985). The infection was finally attributed to the *Leptospira* serogroup *pyrogenes* and *sejroe* serovar *hardjo* (Waitkins, 1986), milder forms than the rat-borne *L. icterohaemorrhagiae* which is the main risk to cavers in Britain.

THE SURVEY AND METHOD OF ASSESSMENT

The Cavers

In September 1985, delegates attending the national congress of the British Cave Research Association were invited to give blood to be tested for *Leptospira* antibodies indicating previous infection. A good response from the delegates was anticipated and of the six hundred or so who attended the congress, 151 gave blood. A caving questionnaire was completed by all but one of the donors. The study sample is thus 150.

The 150 subjects are not thought to be representative of the caving community, as the group is strongly biased against novices by virtue of the type of person attending the congress. Cavers came from all over the country to attend the BCRA annual congress, so there is no obvious regional bias, but they tended to be older and more committed to their sport. Further bias arose from the fact that cavers who consider themselves to have been "at risk" are more likely to want to have their blood tested. The two regions in which cavers are known to have caught leptospirosis (Mendips and East Indies) may feature more prominently for this reason. Further bias towards those who have been caving for many years, and those who have caved abroad, seems likely.

Laboratory tests

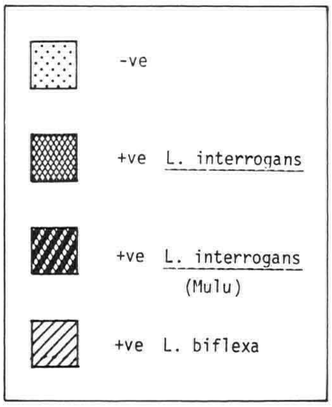
The blood samples were separated and frozen and sent to the Leptospira Reference Unit at Hereford. Four different laboratory tests were used to detect antibodies against *Leptospira* as the tests have a differing serogroup specificity and sensitivity.

The macroscopic agglutination test (Mac A) is performed on a microscope slide when antibodies in the serum sample agglutinate a particulate antigen. The antigen is genus specific but, because the test is insensitive, it only reacts to high levels of antibody, such as are produced by infection with *L. interrogans*, not by simple exposure to *L. biflexa*. The test may remain positive for months or years following recovery from the illness but is relatively insensitive, sometimes being negative when other tests are positive.

The complement fixation test (CFT) and the enzyme linked immunosorbant assay (ELISA) are more sensitive techniques for detecting antibodies. The preparation of antigen used in these tests is different and while both of the tests may be positive in cases of leptospirosis the ELISA is more sensitive and specific. The CFT may be positive as a result of contact with unrelated microorganisms such as *Mycoplasma*, *Cytomegalovirus* and *Hepatitis* and rarely due to contact with *L. biflexa*. For these reasons both tests are commonly employed.

The microscopic agglutination test (MAT) is used to identify the infecting serogroup and detects antibodies using live leptospires from 21 different serogroups.

Figures 1 to 4 show the percentage of cavers (ordinate axis) in the samples that were found to fall into the following categories related to their caving habits:-



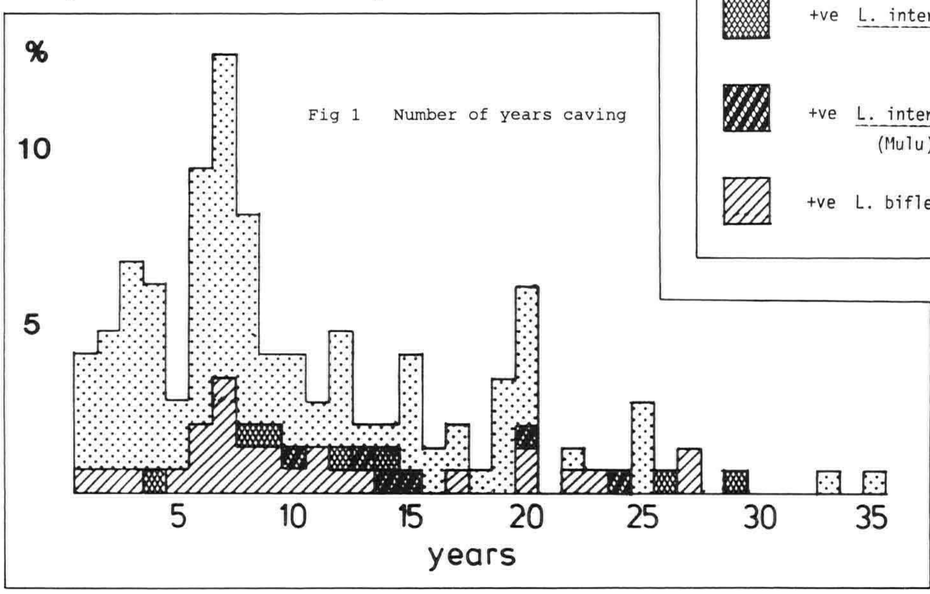


Fig 1 Number of years caving

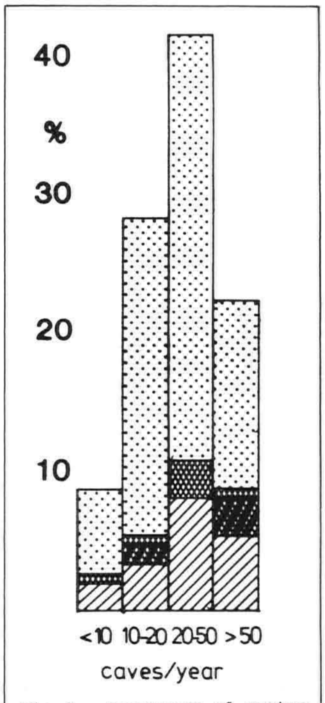


Fig 2 Frequency of caving

The questionnaires

A simple questionnaire was prepared which asked the following questions:

a) Number of years caving experience.

b) Frequency of caving. The answers were limited to 0-10, 10-20, 20-50 and 50+ times per year.

c) Popularity of the British caving regions: Yorkshire/North, Derbyshire, Mendip/Devon, Wales, Ireland/Scotland. Delegates were asked whether they "often" or "occasionally" caved in these regions.

d) Foreign countries visited for caving (excluding Eire).

A follow-up questionnaire was sent to subjects whose sera showed a positive response, asking if they had previously been diagnosed as having Leptospirosis or Weil's Disease, where and when they thought they had caught it, and a series of medical questions concerning their illness.

RESULTS

The results of the serological tests are presented in Table 1. A positive result in one or more tests was found in 46 of the 150 samples, an incidence of 31%. 33 cases (22% of the sample) are positive only by the complement fixation test suggesting contact with unrelated micro-organisms or with L. biflexa.

13 cases (9%) were positive in one or more of the other tests indicating infection with the pathogenic L. interrogans. A second questionnaire was sent to these people and the results are incorporated in Table 1. The cases which involved serious illness had mostly been identified at the time as Leptospira infections. All but one occurred on the Mulu expeditions, the exception being an American caver who had been infected in the USA 9 years previously. The remaining six cases were mild or asymptomatic and had not been previously diagnosed as leptospirosis. Only one of these subjects had caved in the tropics (in the Solomon Islands). None of the subjects had evidence of a specific serogroup infection (this is to be expected as specific antibodies decrease within a few months of infection and cannot be detected after a year or more).

Subject	Mac A	CFT	MAT	ELISA	Comment
1	-	-	-	+	No illness
2	-	-	-	+	"Bad" Flu 1959
3	-	-	-	(+)	Mulu fever 1978 and 1984
4	-	+	+	+	No reply
5	-	+	-	+	Mulu fever 1981
6	-	+	-	+	Mulu fever 1984
7	-	+	-	+	"glandular" fever 1982
8	+	+	-	+	Mulu Fever 1984
9	-	-	+	-	Mulu Fever ("malaria")
10	(+)	+	-	-	Mulu fever 1984
11	+	-	-	-	Diagnosed in USA 1976
12	(+)	-	-	-	Chronic malaise 1982
13	+	-	-	-	No illness
14-46	-	+	-	-	No illness

Mac. A., Macroscopic agglutination; MAT; Microscopic agglutination; CFT.; complement fixation test; ELISA., polyvalent enzyme linked assay. +, positive; -, negative; (+), weak positive.

Table 1 Positive findings in serological tests for Leptospiral infection

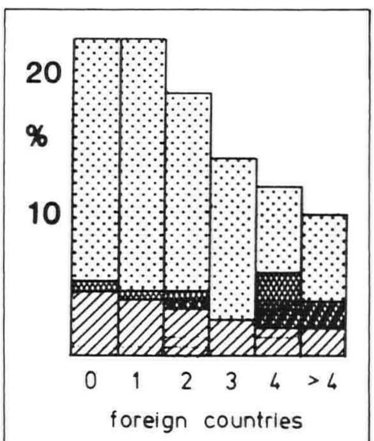


Fig 3 Number of foreign countries caved in

An analysis of the first questionnaire is presented in Figures 1-4. Owing to doubt over the identity of ten subjects, five of whom were CFT positive, these cases appear in the total sample but not in the CFT positive groups. The caving experience of those taking part in the survey as a whole and those showing antibodies is compared in Fig 1. Similar comparisons are made in Figures 2-4 of caving frequency, foreign expeditions and regional popularity in the British Isles. The Figures show that the 13 cases who have been infected with L. interrogans are more experienced, more active, and cave abroad more often but that the regional distribution is much the same as for the main group of cavers. The East Indies feature strongly as a caving region among the seropositive cases (other parts of the world show no difference). Two thirds of the Mulu cavers tested were seropositive.

The same analysis can be applied to the group who were positive only by the complement fixation test. There is a slight increase in caving activity but the main difference is seen in the regional popularity of the British caving areas.

DISCUSSION

In this study positive findings on the Mac A, MAT and ELISA tests are taken to indicate past infection with L. interrogans. The finding of a positive CFT only is suggestive of exposure to genus-specific antigen of non-pathogenic

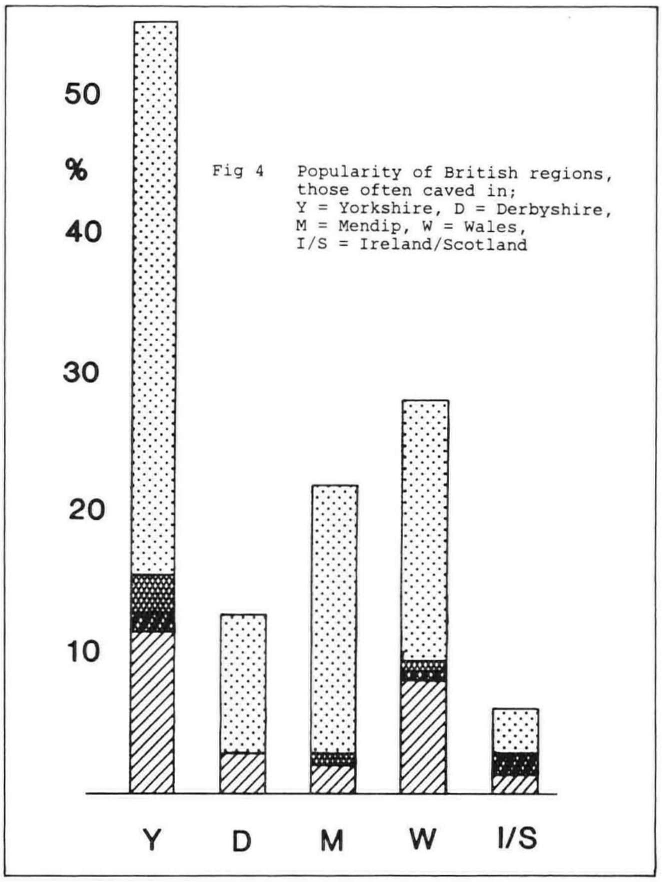


Fig 4 Popularity of British regions, those often caved in; Y = Yorkshire, D = Derbyshire, M = Mendip, W = Wales, I/S = Ireland/Scotland

leptospires or to other micro-organisms such as Mycoplasma. These findings are of considerable interest, despite the bias of our sample, in that this is the first survey to assess the risk to a large group of cavers of infection with pathogenic leptospires. In addition there is evidence to suggest wide-spread contact among cavers with non-pathogenic organisms such as L. biflexa.

The immediate impression gained from the data in Figure 1 is that the proportion of cavers with leptospiral antibodies rises steadily with an increase in caving experience. It is however important to appreciate that after contact with leptospires of either species antibodies do not remain detectable in the blood indefinitely. In some cases, particularly after serious infection, they may still be detectable after several years but they are unlikely to be reliably detected after a decade or more. The results probably represent relatively recent contact with leptospires. In many cases the original contact will have been years ago, but with repeated exposure to leptospires the antibodies are boosted from time to time and so remain detectable.

It is also likely that experienced cavers go to areas of higher risk. For example, all the Mulu cavers had 10 or more years caving experience (median 14 1/2 years) as compared with a median of 8 years for the total sample. The higher incidence among more experienced cavers is probably genuine and reflects repeated exposure and excursions to areas of higher risk.

The other seropsitive cases (excluding the American caver) probably reflect infections that were contracted in this country. In contrast to the compact group that comprises the Mulu cavers there is a wide range of experience among this group (4-29 years of caving experience). Both the mean and the median are about 2 years higher than for the whole group of 150 cavers though with only six cases there is no statistical significance in these differences.

There is no evidence that any particular region in this country represents a greater risk for infection with Leptospira interrogans. Those who cave regularly in Yorkshire (4 in 83) face the same small risk as those of Mendip (1 in 33). There is no "Mendip Factor" in our results.

If the cavers with only CFT positive results (who may have had contact with the genus specific antigen of L. biflexa) are examined in a similar way, the mean, median and standard deviation for the data in Figure 1 are almost identical to the values for the sample as a whole. There is a small decrease in incidence among inexperienced cavers but between 5 and 20 years the distribution is very even. The frequency of caving might be expected to be important and there is perhaps a very small increase for this group. An expeditions profile is almost identical to that of the main group, even down to the countries that are visited. The only significant change is in the regional analysis, where Wales shows an increased incidence and Mendip a markedly reduced incidence.

The regional incidence of L. biflexa exposure may be explained by the life style of the organism which favours damp moorlands and the streams that drain them; surface streams on the Mendips are short and few. While this finding is of some interest it is of no consequence to cavers as L. biflexa is entirely harmless. It is however important to point out that among the caving group the incidence of positive CFT is very high at 22%, while among blood donors it is somewhere in the region of 0.01%. There is some evidence that antibodies to L. biflexa are detectable only for a short time, in that 22 of our samples claimed not to cave "frequently" in any region; none had antibodies.

CONCLUSIONS AND RECOMMENDATIONS

On a survey of only 150 cavers our conclusions have to be tentative. Obviously leptospirosis does represent a small risk to cavers but our sample comprises the element of the caving community most likely to be at risk; the average British caver has had less experience and is less widely travelled. A prevalence of 9% infection with L. interrogans found in our survey would not be reflected in the caving community as a whole. Even the figure of 4%, those cases believed to have been contracted in the British Isles, is probably too high.

The greatest risk of infection is clearly in caves such as those in Mulu. The East Indies have been known to be a risk area for leptospirosis for many years. Among our sample as many cavers had been to Indonesia and Papua New Guinea as had been to Malaysia, but only Mulu cavers were seropositive. However the infection may not in fact have been contracted within the caves of Mulu but around the camp site, which was infested by rodents. A high incidence of infection has been found in the same area among soldiers undertaking training exercises in the jungle (S Waitkins).

The risk to Mulu cavers seems so great that the advice offered in the report of the 1984 expedition (Buchan 1985) is worth repeating here: any unexplained fever should be provisionally diagnosed as leptospirosis and treatment with penicillin started immediately. The British Army uses prophylactic penicillin when on jungle training in Malaysia (even then 20% of soldiers are seropositive afterwards, suggesting infection which was asymptomatic). We cannot recommend this practice for cavers as expeditions are in the field for extended periods and long term antibiotic treatment at the doses required would be potentially harmful.

The best protection for expeditions is physical rather than medical. Leptospires usually enter the body through breaks in the skin. The wearing of trousers instead of shorts when walking through the jungle and the use of gloves underground should significantly reduce the number of available points of entry for the parasite. Entry through the eyes and nose can be prevented by care in the choice of water used for washing. Drinking water should be boiled or chlorinated. Buchan (1985) recommends the use of rubber socks to prevent abrasions to the feet by grit particles (the scratches become infected and develop into the painful "Mulu foot"). This would seem to be an important measure as the feet are always in potentially infected water.

Compared with Mulu, the risk to cavers in the British Isles is very slight, but the same simple precautions ought to be taken. In particular we would recommend the use of gloves (rubber 'washing-up' gloves are adequate) for caving. Many cavers routinely use gloves in wet caves but do not bother when exploring old mines, where rat infestation is more likely. The Stoke Lane Slocker cave should be considered a health hazard.

Because leptospirosis shares common symptoms with many other diseases, the illness is under-diagnosed in this country. If a caver has a feverish flu-like illness, it is important to mention the sport to the attending doctor, as this may help the diagnosis and may indeed save the patient's life.

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