Cave Science

The Transactions of the British Cave Research Association

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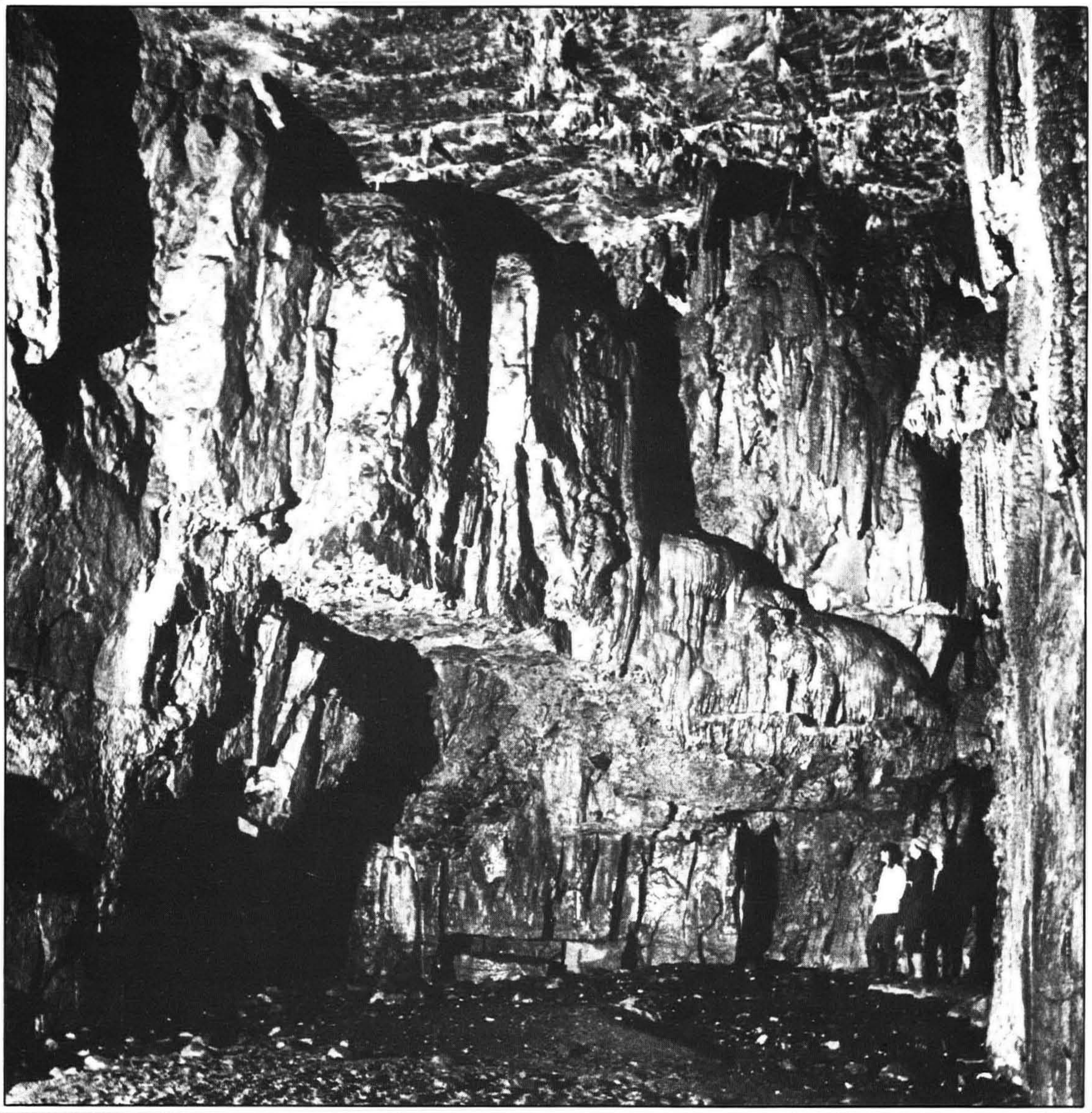
Volume 17 Number 3 December 1990



Triassic palaeokarst in Britain

Water tracing in Picos de Europa

Caves of South Nordland, Norway

Cave archaeology in Belize

Phytokarst in Ireland

Cave Science

The Transactions of the British Cave Research Association covers all aspects of speleological science, including geology, geomorphology, hydrology, chemistry, physics, archaeology and biology in their application to caves. It also publishes articles on technical matters such as exploration, equipment, diving, surveying, photography and documentation, as well as expedition reports and historical or biographical studies. Papers may be read at meetings held in various parts of Britain, but they may be submitted for publication without being read. Manuscripts should be sent to the Editor, Dr. T. D. Ford, at 21 Elizabeth Drive, Oadby, Leicester LE2 4RD. Intending authors are welcome to contact either the Editor or the Production Editor who will be pleased to advise in any cases of doubt concerning the preparation of manuscripts.

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Cave Science

TRANSACTIONS OF THE BRITISH CAVE RESEARCH ASSOCIATION

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Cover: Rock architecture in the main chamber of Yordas Cave, in the Yorkshire Dales. By Tony Waltham. See the note in Forum about readers' photographs for the Cave Science cover.

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Triassic Palaeokarst in Britain

Michael J. SIMMS

Abstract: Karst forms of Triassic age within older limestones are developed in Britain on a scale unmatched by any other pre-Tertiary examples. Large conduit cave systems are a prominent element of these karst assemblages, though open solutional fissures are also developed over a wide range of scales. Some fissures may be due to extensional tectonic processes but most appear to be largely solutional in origin. The abundance of these Triassic karst forms, particularly the conduit caves, indicates a significant humid episode within the predominantly arid climatic regime of the late Triassic. The age of the cave infillings indicates an early Upper Triassic age for the caves themselves. This is compatible with other evidence indicating the development of a wet monsoonal climate during the Middle and Upper Carnian substages of the Upper Triassic. The diameter of many of the phreatic conduits is large relative to their catchment area, as estimated from the configuration of the sub-Triassic unconformity, implying high rainfall. The history of many of the caves is complex, recording evidence of regional hydrological fluctuations as well as eustatically induced changes in hydraulic gradient. Many caves which developed in limestones adjacent to pyritous shales have since been infilled with haematite derived from the oxidation of pyrite in late Triassic times. The configuration of passages in these Triassic caves and the nature of the material filling them can provide important data on late Triassic landscapes. Triassic palaeokarst is found in Britain wherever limestones were subaerially exposed in late Triassic times. The apparent absence of karst of comparable age in Ireland may be due largely to the difficulties associated with identifying such features in a landscape which has experienced a long history of karstification with much of the limestone surface now obscured beneath till and blanket bog.

The occurrence of 'fissures' filled with Triassic sediment within the Carboniferous Limestone of South-west England and South Wales has been known for more than a century (Moore, 1867; Ford 1984, 1989). Almost certainly they would have been regarded as little more than a geological curiosity were it not for the frequent presence within the sediment fills of rich terrestrial vertebrate faunas, including some of the earliest mammals (Fraser, 1985). Inevitably, however, there has been a much greater emphasis on the investigation of these vertebrates than on the cavities and sediments containing them. There have been few first hand accounts of the latter and almost invariably these have been by those same researchers investigating the fauna. Most published accounts betray a lack of knowledge of karstic processes, with consequent misinterpretation of the nature and significance of the cavities and their contained sediments. Perhaps the most striking result of this is a general failure to recognise the obvious palaeoclimatic significance of large conduit cave systems which formed during a geological interval traditionally regarded as having an arid to semi-arid climate.

The following account is intended to correct some of the misconceptions which have arisen in the past concerning the genesis of these cavities as well as reviewing the present state of research on Triassic caves and karst. However, I have not yet had the opportunity to visit all of the areas in which Triassic karst is known, or suspected, to occur and hence this must be considered only as a preliminary account based on observations of certain areas and the interpretation of published descriptions of others. Further research will tend either to verify or disprove various of the conclusions reached here.

SOMERSET AND AVON

The area extending from the southern margin of the Mendip Hills northwards through Bristol to the Avon-Gloucestershire border has seen some of the most intensive research carried out on Triassic fissures. The most important sites to the north of Bristol are the quarries at Tytherington and Slickstones (Cromhall) Quarry. The Mendip Hills to the south of Bristol contain a number of important sites but this section is based largely on a review of the published literature.

Tytherington Quarry (Grid Ref. ST 6689)

This site comprises three large quarries, of which only the northern and southern ones are active, immediately to the west of the M5 Motorway near the village of Tytherington. Numerous fissures are constantly being exposed and destroyed during the course of quarrying. A somewhat degraded example can also be seen to the east of the M5 in the south side of the cutting which takes the road beneath the motorway.

The vertebrate fauna of fissures in the northern quarry was the subject of a Ph.D. by David Whiteside (Whiteside, 1983). He made many valuable observations on fissures which have since largely

Fragment of large phreatic conduit on the descending (dip-oriented) limb of a phreatic loop. This section of passage has been entirely filled with Upper Triassic sediments. These have fallen away on the right hand side to reveal the original form of the passage wall, with large scallops, solution pockets and ledges due to more solution-resistant limestone beds. Tytherington Quarry, near Thornbury, Avon.

Small Triassic cave passage in Carboniferous Limestone, with minor vadose trenching beneath an irregular phreatic conduit. The lower part of the passage has been infilled with dark laminated sands. The remaining cavity is lined with celestine suggesting a hydrological link with hypersaline lakes which developed in this area during the late Triassic. Tytherington Quarry, near Thornbury, Avon.

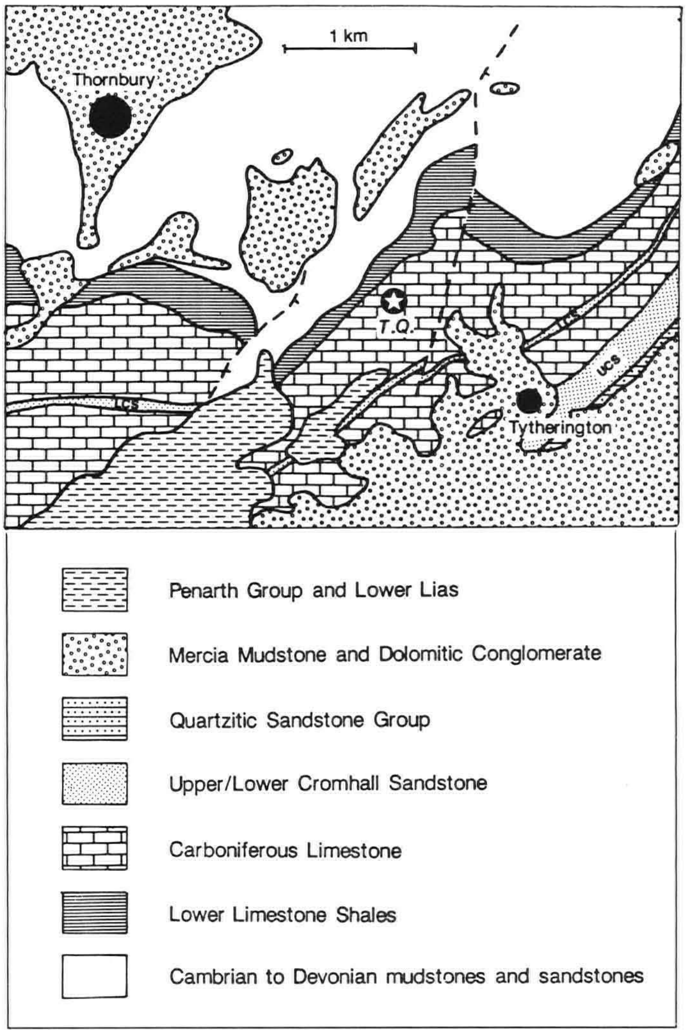


Figure 1. Geological sketch map of the area around Tytherington, Avon, to show the relationship of the Carboniferous Limestone and other Palaeozoic rocks to the Upper Triassic strata uncomfortable upon them. Relative altitudes on the sub-Triassic uncomformity surface indicate that only a narrow strip of Lower Limestone Shales and the adjacent Devonian sandstones served as a catchment for the Tytherington cave systems. (Reproduced from the Journal of the Geological Society with permission).

been destroyed. Fraser (1985) claimed that the Tytherington fissures were largely tectonic in origin but recent observations have found no evidence for this although, as in any karst system, existing structural discontinuities, such as faults and joints, have exerted a considerable influence on cave development (Simms, 1990).

Fissures in the Tytherington quarries show a considerable range of morphologies. Most appear to represent ancient cave passages. Tall, narrow slot-like fissures appear largely restricted to the upper two levels of the northern quarry and probably were drawdown vadose passages (Ford & Williams, 1989) or, in some cases, large grikes. In the lower levels of the quarries typical phreatic tubes, up to 4m or more in diameter, are present and have been observed to within about 25 m of the top of the northern quarry. They display solutional pockets, pendants and large scallops, up to 20 cm long, which indicate flow from north-west to south-east. The walls of these passages often show intense dolomitisation to a depth of 20 cm or more. A notable feature of many, if not all, of these phreatic tubes is the presence of a deep, narrow, vadose slot in the floor. Whiteside and Robinson (1983) figured a particularly good example of such a keyhole passage, with a vadose slot more than 4 m deep and less than a metre wide in the floor of a phreatic tube 4.5 m in diameter. Keyhole-shaped passages testify to an episode of significant hydroligical change at some point during the active period of the caves history. The exact nature of this change is difficult to ascertain on the available evidence. It may represent the re-routing of the main flow elsewhere but the prevalence of this passage type suggests an overall lowering of the zone of saturation causing vadose drawdown. This may have been associated with a fall in base level or due to the onset of more arid conditions causing a lowering of the zone of saturation.

Most of the Triassic caves in the quarries at Tytherington are completely choked with sediment. One short length of open passage encountered during quarrying appears originally to have been situated at the top of the steeply ascending downstream limb of a phreatic loop developed along a fault. Once the cave had ceased to be active, sediment deposited at the foot of this loop will quickly have plugged the conduit thereby preventing sediments from reaching the passage beyond. In places the walls are coated with a layer, up to 10 cm thick, of pink and white banded celestine now largely decomposed to the consistency of a soft clay.

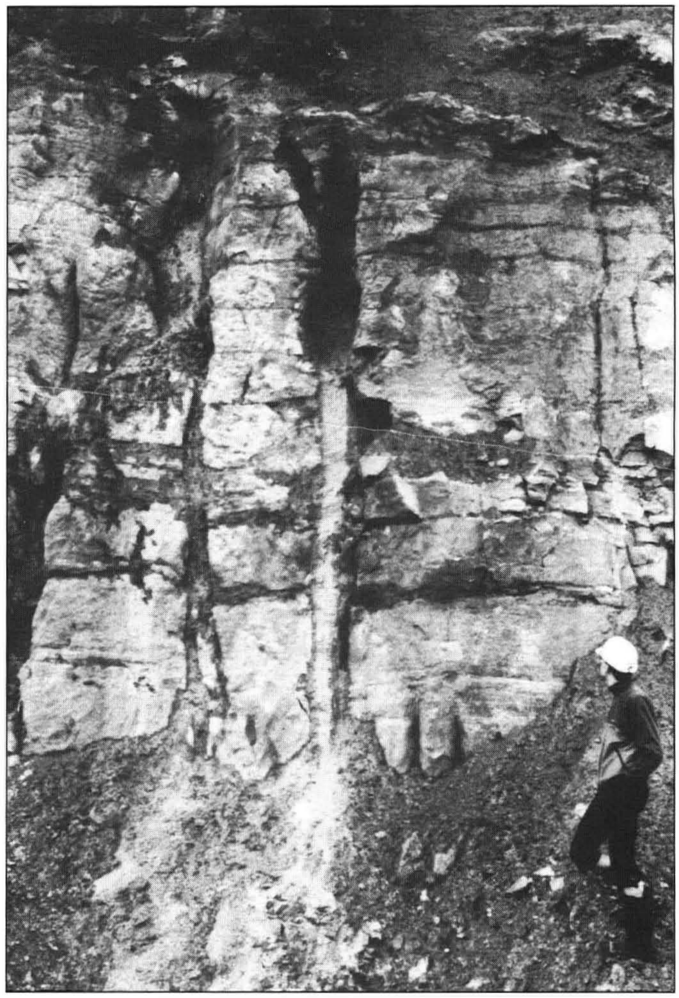
Sediments in the caves at Tytherington show a wide variety of lithologies and structures. Most typical are coarsely-bedded clays, silts and sands, though breccias and conglomerates, sometimes of quite coarse grade, have also been seen. Syndepositional dips are often comparatively steep, as is often typical of cave sediments. Many of the finer sediments show features characteristic of the waning phase of cave activity. Surge marks (Bull, 1978) and current lineations testify to occasional flood events. Crescentic cracks and microfaults sub-parallel to the passage walls are widespread and probably developed through slumping and sagging of sediment as the passages drained after these floods. Desiccation cracks demonstrate significant periods of inactivity between flood events. Many of the caves show evidence of a quite complex history of infilling, with several episodes of deposition and erosion. In the upper part of one of the keyhole-shaped passages Whiteside found a glauconite clay containing the dinoflagellate *Rhaetogonyaulax rhaetica* (Marshall & Whiteside, 1980; Whiteside & Robinson, 1983). Both the glauconite and the dinoflagellate indicate a significant marine influence during the final phase of infilling of this passage, suggesting that the passage lay below sea level by this time. The dinoflagellate also provides the most reliable date, in this case late Norian (Rhaetian), yet obtained from any of the sediments in the Tytherington caves though clearly the caves record a long and complex history prior to this very late-stage infill. Other elements of the biota preserved in these cave sediments include a wide variety of terrestrial vertebrates as well as occasional freshwater and marine vertebrates and invertebrates. Whiteside (1983) considered various elements of the fauna to indicate a range in age of the sediments from late Norian possibly as far back as late Carnian. The presence of celestine in some of the caves, particularly those not completely infilled by sediment, may also prove useful as a method of dating it can be established that deposition of the mineral in the caves was contemporaneous with the deposition of the Yate Celestine Bed nearby. The latter is Norian in age and lies some 10 m below the base of the Blue Anchor Formation (=Tea Green Marls) (Cave, 1977).

Cave passages followed during the course of quarrying generally have a prevailing NW-SE orientation. This is also apparent from the location of the fissures in the northern quarry, as documented by Whiteside (1983), with most being located either in the north-west or the south-east corners of the quarry. The direction of flow was to the south-east suggesting that allogenic recharge of the limestone aquifier was from the Lower Limestone Shales and underlying Old Red Sandstone outcrop to the north-west (Figure 1). The altitude of the unconformity surface beneath the Triassic outliers to the north and north-west of the quarry demonstrate that during late Triassic times much of the Old Red Sandstone outcrop sloped to the north-west and only a relatively narrow strip appears to have drained towards the putative sinks at the base of the Black Rock Limestone. If this was the case then quite high levels of runoff must have been generated during the main episode of cave development in order to produce phreatic tubes 4 m or more in diameter fed from a catchment area of little more than 2 km^2. As far as can be judged from the limited exposures of the cave passages, they show a similar style of development to several cave systems in the Mendip Hills, notably the Swildons-Wookey Holes system (Simms & Waltham, in press). These are characterised by phreatic loops with descending passages developed down-dip and the ascending limbs developed along joints or faults. It is unlikely that these conduits were able to penetrate the Clifton Down Limestone and Lower Cromhall Sandstone which lay to the south-east of the present site of the quarries, though it is possible that a route may have developed along the fault running between Tytherington and the quarries (Figure 1). However, it seems more probable that the resurgences lay either at the head of the Trias-filled valley to the north-west of Tytherington or in the Penarth Group filled valley adjacent to the Lower Cromhall Sandstone outcrop to the south-west.

Slickstones (Cromhall) Quarry (Grid Ref. ST 704916).

This site has been among the most intensively studied Triassic fissure sites, although most of this research has centred on the vertebrate fauna. However, limited attempts have been made to interpret the fissures themselves (Fraser & Walkden, 1983; Robinson, 1957; Fraser, 1985). Invariably these have concentrated on the main fissure lying along the west face of the quarry. It has been considered by some to represent a cave passage (Robinson, 1957; Halstead & Nicoll, 1971) or a series of separate chambers developed beneath dolines (Fraser, 1985; Fraser & Walkden, 1983). Neither explanation seems satisfactory and it is clear that this western fissure is far from typical of the Triassic fissures in this area. Its true nature remains somewhat enigmatic. The most notable features of this fissure are its development along a major north-south joint, and the thick layer of coarsely crystalline calcite which lines the walls of several of the cavities. This layer is up to 15 cm thick with large dog-tooth crystals projecting inwards. Individual crystals may be up to 10 cm across and show prominent zoning with thin iron-rich layers. Trace amounts of the element Yttrium are also present; its significance remains uncertain although it has also been found in vein calcites in Ireland (David Doff, pers. comm.). The surfaces of many of the crystals show evidence of subsequent corrosion and the sediment infilling clearly postdates this. The large, clearly zoned crystals are incompatible with any suggestion that the calcite layer might be derived from recrystallisation of flowstone. However, the general form of this fissure does bear a striking resemblance to the calcite crystal-lined passages in Jewel Cave, South Dakota (Deal, 1968; Ford & Williams, 1989). The latter has been interpreted as a fossil thermal spring conduit and so it is tentatively suggested here that the western fissure at Slickstones Quarry may also once have functioned as a thermal spring initiated along a major joint. The presence of active thermal springs to the south, around Bristol and Bath, perhaps renders such an interpretation more plausible.

Other fissures in Slicktones Quarry entirely lack the calcite lining of this western fissure and are readily interpreted as more typical meteoric karst forms. They are most abundant in the south-east corner of the quarry, where some 2 m of red siltstones with coarser bands are preserved in a shallow depression in the surface of the Carboniferous Limestone. Deep narrow fissures filled with red, yellow and green clays extend down for at least the full height of the quarry face (c. 12 m) and probably represent either deep grikes or small invasion vadose caves.



Grikes or small vadose caves a few metres beneath the Triassic unconformity. The fissures have been hydrologically reactivated as a result of quarrying, thereby flushing out the Triassic sediments which have filled them. Slickstones Quarry, Cromhall, Avon.

The Mendip Hills

Fissures filled with Triassic or early Jurassic sediment occur widely in the Carboniferous Limestone of the Mendip Hills and the Bristol area to the north. A good summary of some of these is given in Duff *et al.* (1985) while mineralised examples are discussed by Alabaster (1982). Some are clearly ancient conduit caves and have scalloped walls (Stanton, 1965). Similarly, Alabaster (1982) recognised that a significant proportion of the base-metal ore bodies in the Carboniferous Limestone of the Mendip Hills occurred as infillings of pre-existing solutional cavities. Hypogene mineralisation (deposited from ascending solutions) of pre-existing conduits, predominantly by lead and zinc sulphides, appears to have been comparatively rare. In contrast, supergene mineralisation (deposited from solutions descending from the surface), in which iron and manganese oxides predominate, is very frequently found in such an environment and is discussed in greater detail in a later section. Alabaster (1982) considered the hypogene mineralisation to have been initiated in late Triassic times and continuing at least until early Cretaceous times, although clearly the conduits themselves must have formed prior to the drowning of this area by the marine transgression in the early Jurassic. In contrast, the timing of the episode of supergene mineralisation can be constrained much more closely and he considered it to be of mid- to late Triassic age.

However, not all of the Mendip fissures can be considered as ancient solutional conduits and for these a different mode of origin must be sought. A common type of fissure in the Mendip Hills is open to the present surface and is developed along major joints. They may be any size up to several metres in width, several tens of metres in height and several hundred metres in length. Small examples were described by Stanton (1981) as "irregular, discontinuous or shallow-seated". The sediments within them often show evidence for accretion parallel to the fissure walls, often with a central calcite vein. Traditionally the formation of these 'sedimentary dykes' has been ascribed to sediment injection associated with extensional tectonic fracturing of the limestone (Duff *et al.* 1985; Robinson, 1957), though more recently Smart *et al.* 1988) have suggested an analogy with the Bahama Blue Holes, where fractures develop along the island margin due to mass movement and lateral unloading. Although this latter explanation is perhaps plausible for a few examples, neither mechanism seems particularly satisfactory to account for the formation of most of the sedimentary dykes of the Mendip Hills. The greatest challenge to these two theories arises from the apparent lack of similar fissures in non-carbonate strata. The obvious conclusion to be drawn from such a restricted lithological occurrence is that these fissures must have been formed by karstic processes. Brook & Ford (1978, 1980) and Jennings & Sweeting (1963) described areas of 'giant grikeland' in which solution corridors or 'giant grikes', up to 50 m deep and more than 1km long, may develop under semi-arid or periglacial conditions. There can be no doubt that many of the smaller fissures in the Mendips and elsewhere represent grikes and it is conceivable that much larger solution corridors may have developed under the semi-arid regime prevalent through much of the late Triassic. The apparent accretion of the sediment parallel to the walls in many of the fissures cannot be viewed as unequivocal evidence for emplacement by injection since this phenomenon has been observed in Triassic caves at Tytherington and is well documented in modern caves (Bull, 1981). Much remains to be done before the true nature of these fissures is understood. Research in progress by Gavin Wall, of the Department of Earth Sciences at Oxford University, may go some way towards a clearer understanding of the processes involved in their development.

SOUTH WALES

Fissures containing sediments of Triassic to early Jurassic age are common in many outcrops of Carboniferous Limestone in the Vale of Glamorgan and the southern flank of the South Wales coalfield. Like the examples in Avon and Somerset their vertebrate faunas have been the subject of intensive research and include some of the earliest mammals (Kermack *et al.*, 1968). Probably the best published account, ableit brief, of the caves themselves is by Ivimey-Cook (1974), with some additional comments by Fraser (1985) and Ford (1984, 1989).

During late Triassic times there were three main upstanding outcrops of Carboniferous Limestone whose margins are now blanketed by Upper Triassic sediments (Figure 2). The largest of these three outcrops occupies a narrow strip along the southern edge of the South Wales coalfield, between the Millstone Grit and Coal Measures to the north and the Old Red Sandstone to the south. To the south and west of this outcrop lie two so-called 'islands'; St Bride's Island in the Porthcawl-Bridgend area and, further east, the Cowbridge Island. Many of the fissures in South Wales, particularly those on the two 'islands', have been described as "slot fissures" (Ivimey-Cook, 1974), suggesting that they may represent large grikes or vadose cave passages. Numerous examples are exposed in the cutting on the M4 Motorway on the eastern margin of the Cowbridge Island. However, Ivimey-Cook (1974) also mentions "more mature cavernous fissures" and "mature underground watercourses" near Ruthin (SS 9779) and Bonvilston (ST 0674). The different fissure types appear to relate to the type of recharge for the Triassic karst aquifer, as one would expect. On the 'islands' recharge would have been largely autogenic, producing invasion vadose features (the slot fissures) without the development of large intgegrated conduits. In contrast, point recharge from impermeable strata adjacent to the limestone outcrop produced the "mature underground watercourses" described by Ivimey-Cook (1974). In the Ruthin and Llanharry (ST 0180) area alogenic recharge would have been from the Millstone Grit and Coal Measures to the north, whilst the conduits near Bonvilston were perhaps fed by water draining from the outcrop of Old Red Sandstone and Lower Limestone Shales on the north side of Cowbridge "Island" (Figure 2).

Most of the caves are filled with a similar range of sediment types to those in the Somerset and Avon area. However, at several places along the southern margin of the coalfield, notably around Llanharry, Garth (ST 1084) and Rudry (ST 1986), the conduits were filled instead by economic deposits of haematite. The significance of these haematite deposits is discussed in a later section. Dating of the sediment fills in the various South Wales caves has proved no less problematic than elsewhere. Those which have yielded mammal remains have been considered as early Jurassic (Hettangian or Sinemurian) in age based on evidence from plant material (Harris, 1957; Lewarne & Pallot, 1957) while Crush (1984) claimed affinities between certain elements of the fissure faunas and vertebrates from late Carnian and Norian sequences elsewhere. In a few instances, such as Westra Quarry (ST 144709) near Dinas Powis, Cardiff (Ivimey-Cook, 1974) the cave infills can be shown to be no later than Norian in age since they lie beneath the unconformity at the base of the Mercia Mudstone. The episode of haematite deposition can also be dated as Norian, pre-Rhaetian, on similar criteria. A fuller account of the latter evidence is given in a later section. Thus the infills of the caves in South Wales range in age from perhaps late Carnian to early Sinemurian.

Further east, in the Chepstow area, a highly irregular Carboniferous Limestone surface is blanketed by the Upper Triassic Mercia Mudstones and Dolomitic Conglomerate. The unconformity itself is superbly exposed on the north-east side of Chepstow at the junction of the A48 with the B4228 (the Sedbury-Beachley road) (Grid Ref. ST 542943). Red siltstones of typical Mercia Mudstone Group facies can be seen resting on an irregular surface of the Carboniferous Limestone, the top 10-20 cm of which is intensely dolomitised. Several narrow grikes containing green and red silts extend down from the surface of the limestone to a depth of at least one metre. Along the north side of the A48 itself the Carboniferous Limestone is exposed to a depth of up to 12 m, though large parts of the cutting are now obscured by concrete. Nonetheless, several large grikes can be seen extending

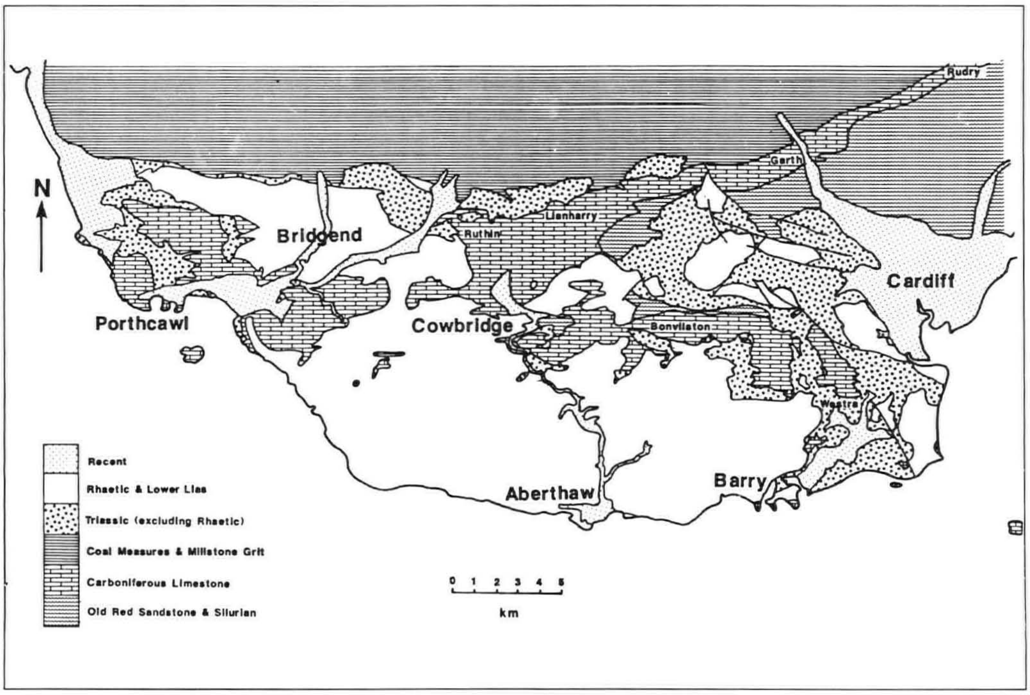
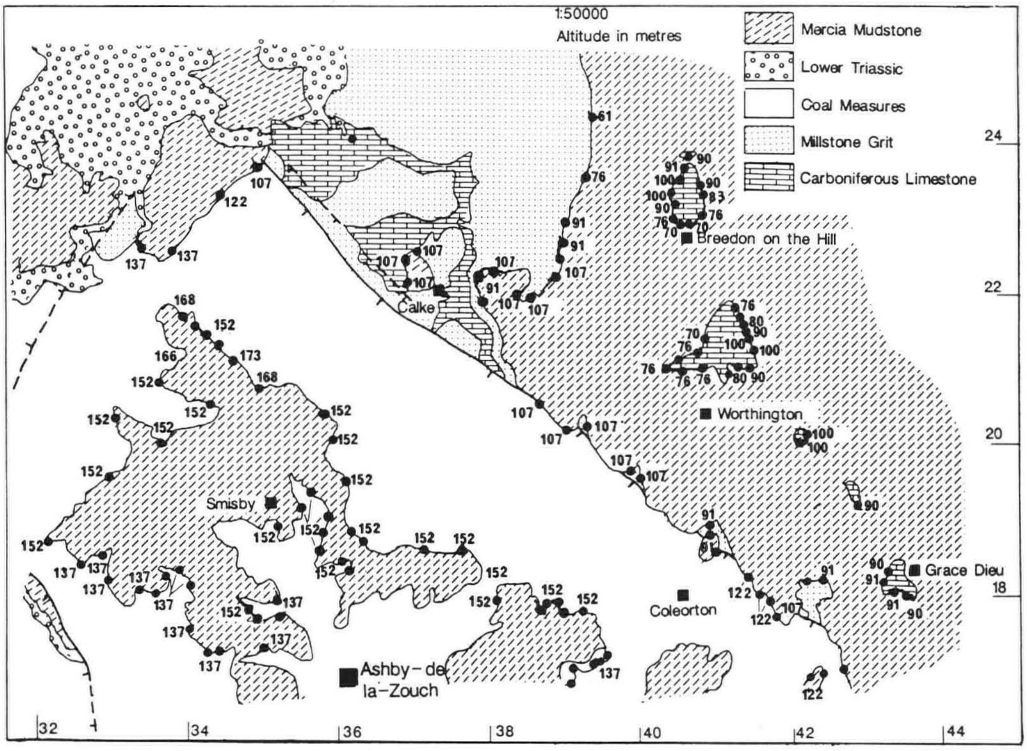


Figure 2. Geological sketch map of the southern margin of the South Wales coalfield and the Vale of Glamorgan, showing the relationship of the Triassic strata to the Carboniferous Limestone and other, impermeable, Palaeozoic rocks.

Figure 3. Geological sketch map of the Carboniferous Limestone inliers of Leicestershire, showing their relationship to the other Palaeozoic rocks and to the Triassic strata unconformable upon them. The numbers around the margins of the Triassic outcrops indicate the present altitude of the sub-Triassic unconformity surface.



down at least 8-10 m below the Triassic surface. At the south-west end of the cutting several small (c. 1-2 m^2) irregular cavities are present. Their walls show clear evidence of solution and they are now filled with red, green and yellow silts typical of the overlying Mercia Mudstone Group.

LEICESTERSHIRE

The Carboniferous Limestone outcrop in Leicestershire is restricted to a few relatively small inliers which extend from Grace Dieu (SK 435182) in the south-east to Breedon-on-the-Hill (SK 405230) to the north and Ticknall (SK 350235) to the north-west (Figure 3). Most of these inliers are now entirely surrounded by an extensive flat plain of Mercia Mudstone Group sediments, of probable Norian (Late Upper Triassic) age. Only the large Ticknall-Calke inlier still retains a significant cover of pre-Triassic strata, being largely surrounded by the Namurian (early Upper Carboniferous) Millstone Grit Series, although one small outlier of Mercia Mudstone straddles the limestone-grit boundary and proves both to have been exposed in late Triassic times (Figure 3). A major NW-SE trending fault, the Thringston Fault (Mitchell & Stubblefield, 1941), downthrows Coal Measures to the south-west against this area of Carboniferous Limestone and Millstone Grit. In places the Mercia Mudstone sediments blanket the fault but do not show any significant displacement, indicating that there has been little movement since at least Middle Triassic times. The dip of the limestone increases away from the fault, being at an angle of only a few degrees in the Ticknall-Calke inlier but increasing to about 60° to 70° at Breedon Cloud (SK 410233) and being almost vertical at Breedon-on-the-Hill. Only at these two inliers is limestone still actively worked in large quarries.

In 1985 at Breedon Cloud Quarry a phreatic tube some 3 m wide and 2 m high, and entirely filled with red and green silts of typical Mercia Mudstone Group lithology, was observed in the upper part of the workings. In the other large quarry, at Breedon-on-the-Hill, the limestone is more extensively shattered and dolomitised. It also contains numerous small patches of haematite, the possible significance of which is discussed in a later section. A few small irregular cavities filled with typical red Triassic mudstone occur in various parts of this quarry, which also contains the most spectacular Triassic cave passage yet discovered in Britain. On the eastern face at the northern end of the quarry is a section of circular phreatic tube more than 8 m in diameter. It can be followed for only a few metres eastwards to a blockage of collapse debris. Coarse breccias cover the floor and parts of the walls and are cemented by red mudstones and thin crusts of an unidentified white mineral. Low on the west face of the quarry and slightly to the south, a low wide passage was observed but could not be entered, having been blocked with quarry rubble. It is presumed to represent the continuation of this phreatic tube. Ford & King (1966) described several chambers up to 15 m across and 10 m high exposed in the quarries at Breedon Cloud and Breedon-on-the-Hill. They regarded them as isolated solution caverns of unknown age but it is quite probable that they represent fragments of conduits contemporaneous with those just described and now isolated by collapse.

Major phreatic tube in Carboniferous Limestone, partly filled with Triassic sediments. The enormous size of this passage (cross-sectional area of c.50m^2) and its location suggest that it may represent part of a late Triassic 'master cave', transmitting the combined flow from several sinks towards the resurgence. Breedon-on-the-Hill, Leicestershire.

Although no direct evidence has yet been obtained for the age of the major conduit at Breedon-on-the-Hill, there can be little doubt that it is late Triassic in age. There is no evidence for any significant hydrological activity within the system in Pleistocene of Tertiary times. Indeed it is probable that the Carboniferous Limestone inliers, in particular those at Breedon-on-the-Hill and Breedon Cloud, have been unroofed only very recently and, prior to this, the impermeable Triassic cover would have prevented any significant water flow through the karst aquifer subsequent to its burial in late Triassic times. The sediments within the cave also suggest a Triassic age, being red mudstones of typical Mercia Mudstone Group facies.

Just as for the caves at Tytherington, the present geology of the area allows a fair approximation to be made of the late Triassic topography. As well as the extensive plain of Mercia Mudstone Group sediments which now surround most of the Carboniferous Limestone inliers, other outliers of Mercia Mudstone occur widely on the Coal Measure outcrop to the south-west (Figure 3). In places the Mercia Mudstones straddle the Thringston Fault and demonstrate that there has been little movement since at least late Triassic times. Thus it is possible to calculate relative altitude differences on both the karst aquifer and the Coal Measure outcrop during the late Triassic. From this it is possible to identify major hydrological routes during late Triassic times and to estimate their approximate catchment areas.

By reference to Figure 3 it is clear that water would have drained north-eastwards from the Smisby plateau, now at c.150 m O.D., towards the outcrop of the Thringston Fault which lay about 50 m lower. Allogenic recharge of the northern part of the limestone aquifer probably occurred via one or more sinks where the limestone was exposed at or close to the Thringston Fault in the Ticknall-Calke inlier, perhaps supplemented by additional drainage from the Millstone Grit to the east. The present altitude of the Triassic unconformity on the Ticknall-Calke inlier is c.100-110 m O.D. while around the Breedon-on-the-Hill and Breedon Cloud inliers the same unconformity surface is at least 40 m lower. Allogenic water sinking along the western edge of the limestone in the Ticknell-Calke inlier would, therefore, probably have flowed eastwards, beneath the cover of Millstone Grit, to resurge in the vicinity of the Breedon-on-the-Hill or Breedon Cloud inliers. The large size of the phreatic tube at Breedon-on-the-Hill, with a cross-sectional area of c. 50 m^2, suggests that it may well represent a 'master conduit' taking the combined flow from several sinks draining an area of little more than 4 km^2 towards a major resurgence to the east of Breedon-on-the-Hill.

HAEMATITE DEPOSITS OF THE FOREST OF DEAN AND SOUTH WALES

Iron ore, in the form of haematite, goethite and lepidocrocite, has been mined in the Forest of Dean at least since Roman times. Smaller deposits have also been worked in several areas adjacent to the southern margin of the South Wales coalfield. These ore deposits are confined almost exclusively to the Carboniferous Limestone, where they occur as irregular masses occupying ramifying cavities and joints. Although there has been uncertainty in the past concerning the exact mode of emplacement of the ore, it is generally agreed that the iron-bearing solutions came from above rather than below and that emplacement occurred during Triassic times (Lowe, 1989; Sibly & Lloyd, 1927; Trotter, 1942).

In the Forest of Dean several lines of evidence, discussed by Lowe (1989), indicate that the iron was deposited in pre-existing cavities. The shallower, and hence older, workings are generally the most informative since the ore was often removed with relatively little modification of the surrounding limestone walls. They are characterised by complex phreatic networks of rifts and tubes connecting larger chambers, know to the miners as 'churns'. Occasionally passages encountered during mining were devoid of ore while invariably the ore was found to fail at depth or in passing beneath the impermeable Coal Measures (Trotter, 1942). The greatest development of ore was located close to the base of the Crease Limestone or at the Whitehead Limestone-Crease Limestone junction, the same horizons as most of the more recent cave development. As such the ore-filled cavities show remarkable parallels with active or recently fossil cave systems elsewhere in the Forest of Dean. Gayer & Criddle (1970) suggested that haematite deposition in this area occurred as a direct replacement of limestone through the action of acidic iron-bearing solutions. However, there is no evidence of any saturation of the entire limestone by iron-bearing solutions; the zone of haematisation in the limestone surrounding the ore bodies is invariably thin and grades into a broader dolomitised zone highly reminiscent of the dolomitised cave walls at Tytherington (see above).

Although the Crease Limestone is the dominant host rock for the majority of the significant haematite deposits in the Forest, there are by no means confined to this unit. Minor, localised occurrences have been documented in the limestone unit in the lower part of the Lower Limestone Shales, in the Lower Dolomite and the Drybrook Limestone. Significantly, haematite deposits attain their maximum development where the limestone outcrops adjacent to the Coal Measures. Ore bodies generally fail within 300-400 m distance of this. In gently dipping limestone the ore fails at relatively shallow depth whereas in near vertical limestone beds it may continue to a depth of as much as 300 m. These may reflect the development, under structural control, of shallow phreatic and deep phreatic systems respectively.

Only at one site in the Forest do haematite deposits, albeit very minor, occur in non-limestone strata. Trotter (1942) described the occurrence of small amounts of ore in shallow pockets or as veins along joints associated with the Yorkley Coal and the shales immediately above. This may perhaps be reconciled with the otherwise exclusively carbonate-hosted deposits when it is considered that the open joint networks in many coal seams permit significant fissure flow. Indeed, the Yorkley Seam appears to allow particularly high flow rates (Trotter, 1942, p. 45). Similarly, Alabaster (1982) noted that iron mineralisation in the Mendip Hills was largely confined to the Carboniferous Limestone and overlying Dolomitic Conglomerate. The only significant ore bodies found in the Upper Carboniferous Pennant Sandstone were encountered in fissures and breccias associated with major faults.

Although much of the haematite in the Forest appears to occupy ancient conduit caves, in the Barnhill Plantation area the ore is found in a situation highly reminiscent of surface karst topography (Trotter, 1942). Adjacent to the Coal Measures outcrop the limestone contains numerous pockets and veins of ore which descend to a significant depth in open-textured and well jointed limestone, inviting obvious comparison with modern examples of mature limestone pavement.

In South Wales similar carbonate-hosted haematite deposits are found along the southern margin of the South Wales coalfield, primarily between Llanharry and Rudry but in smaller quantities elsewhere. As in the Forest of Dean, the ore occurs largely as cavity fills, often infilling fault-controlled conduits, within the upper part of the limestone. However, the ore bodies may also extend up to 12 m into the overlying Upper Triassic marginal facies. The base of the Triassic succession in this area comprises up to 70 m of coarse breccias and conglomerates which are overlain, further to the west, by more typical facies of the Mercia Mudstone Group. This indicates a pre-Rhaetian age for deposition of the haematite, which is confirmed by the presence of derived material from these haematite deposits in adjacent Rhaetic sediments (Crampton, 1960).

The haematite deposits of South Wales occur in close proximity to an extensive catchment area of Millstone Grit and Coal Measure shales to the north which was known to have been exposed in late Triassic times (Figure 2). Similarly, all of the ore bodies in the Forest of Dean are confined to areas adjacent to the outcrop of the Coal Measures. In contrast, Triassic conduit caves remote from any Coal Measures outcrop, such as those in Avon, invariably lack any significant haematite mineralisation. This distribution strongly suggests that the iron was derived from the oxidation of pyrite in the Millstone Grit or Coal Measures shales, as suggested by Alabaster (1982), rather than from the iron oxide present in the overlying Triassic sediment itself. This pattern certainly holds true for the South Wales and Forest of Dean occurrences yet in the Leicestershire Carboniferous Limestone inliers there has been only minor haematite mineralisation despite draining a large catchment of Coal Measure strata during the late Triassic. The reason for this remains unclear although it may indicate a lower pyrite content to the Upper Carboniferous shales of the Midlands than those of the South Wales-Forest of Dean area.

The haematite deposits of the Morecambe Bay area show certain similarities to those of the Forest of Dean, such as in their failure at depths of more than 180 m and their absence beneath impermeable cap rocks, but they appar to contradict the model of iron derivation from the Coal Measures since they lie at a considerable distance from any outcrop of such strata. However, despite the similarities cited above, the Morecambe Bay ore bodies appear to be of a fundamentally different nature to those of the Forest of Dean. The presence of ore bodies beneath a cover of Lower Triassic St. Bees Sandstone suggests that the cavities, if they do in fact represent pre-existing karst features, were formed no later than the early Triassic. However, their absence from areas where there is a significant development of the overlying St. Bees Shales suggests that they may represent examples of interstratal karst which formed beneath the St. Bees Sandstone prior to deposition of the later Triassic mudstones. Hence it seems highly improbable that the Morecambe Bay haematite deposits occupy cavities significantly younger than early Triassic. In addition, fluid inclusion studies indicate an emplacement temperature of around 100°C while other evidence demonstrates that haematite deposition occurred through the in-situ replacement of limestone (Rose & Dunham, 1977).

NORTH WALES

Triassic karst has not previously been documented in the Carboniferous Limestone of North Wales. Indeed it is probable that most of the limestone outcrop was not unroofed until very much later. However, during Permo-Triassic times the Vale of Clwyd was an actively subsiding basin fault bounded against the limestone along much of its eastern margin. There appears to have been limited exposure of limestone in this area during the Triassic. Unequivocal evidence of Triassic karstification can be seen in the now disused upper quarry at Dyserth (Grid Ref. SJ 063787), near Prestatyn. The limestone here dips gently to the north and is fractured by numerous joints and en echelon normal faults orientated at c. 340° and, in the case of the faults, downthrowing to the west. A second, minor joint set is orientated at c. 100°. Solutional features are particularly well-developed along these faults and joints, though they are not restricted to them, and a clear sequence of events can be identified commencing with the initial faulting associated with the development of the Clwyd Basin (Table 1). Where the faults are exposed in section, phreatic solution pockets can be seen on and adjacent to the fault. Where the fault plane itself is exposed it is often highly modified by solution, with small anastomosing channels on fissure walls and large phreatic solution pockets in places. A range of silt to coarse gravel grade indurated sediment infills many of these solutional cavities. The clasts are predominantly of reworked haematite though vein calcite is also present along with rare, irregular clasts of bedded siltstones. The vein calcite clearly was derived from that deposited contemporaneously with movement along the fault while the silt clasts represent an early phase of deposition within the caves. Birds-eye structures within the largest of the siltstone clasts indicate rapid flooding of dried sediments (Bull, 1975). The source of the haematite is rather uncertain but the absence of any haematite fragments within the clasts of siltstone suggest that it represents a later stage infilling which has been reworked along with the siltstone. Coarsely graded bedding is apparent in some of the sediment fills, though the conglomerates are generally ill-sorted and poorly rounded. Those cavities which remained unfilled by sediment are now lined with large calcite crystals, often heavily iron-stained. Subsequent to this there was widespread speleothem deposition, with banded red and white flowstone sometimes approaching a metre in thickness. Stalagmites and flowstone false floors have been found among loose blocks on the quarry floor.

Table 1. A brief summary of the sequence of events, with tentative dates, evident in the caves in the upper quarry at Dyserth.

1.) Initial faulting with mineralisation by massive crystalline calcite (Westphalian - Middle Triassic).

2.) Development of solutional cavities, anastomosing channels and irregular phreatic pockets along faults and major joints (? Middle-Upper Carnian).

3.) Partial infilling by bedded siltstones. Flooding and drying events indicated by birds-eye structures.

4.) ? Deposition of haematite in remaining open cavities (? Norian).

5.) Reworking of siltstone and haematite into coarse gravels.

6.) Calcite crystals deposited in remaining cavities.

7.) Deposition of red and white banded flowstone. At least two episodes of erosion and sedimentation indicated by false floors.

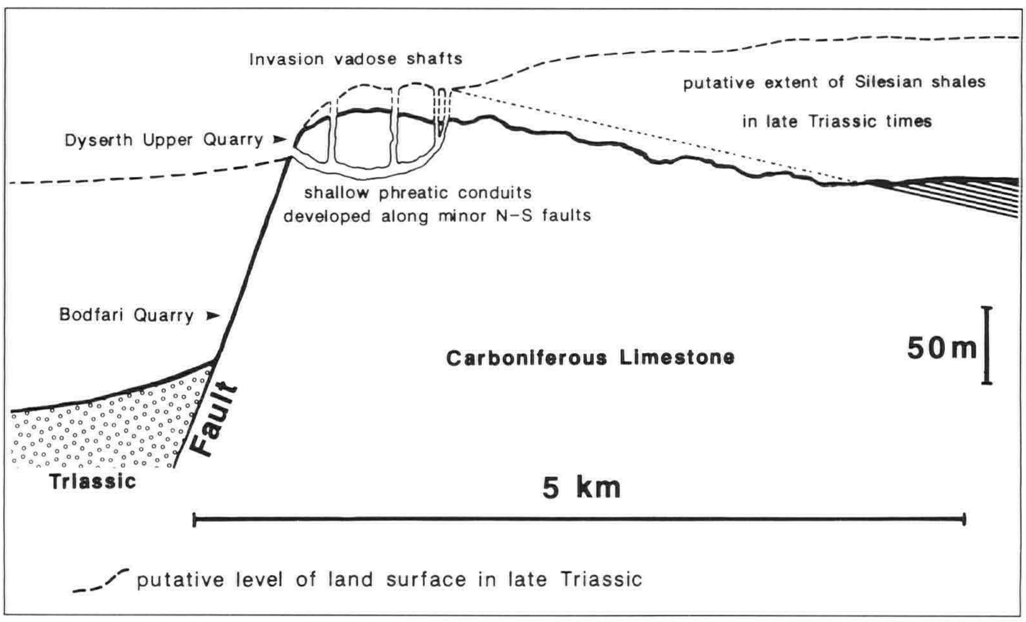
8.) Minor modification during late Tertiary-Pleistocene times.

Table 1.

By analogy with the haematite deposits of the Forest of Dean and South Wales it is suggested here that the iron was derived from the weathering of Silesian (Millstone Grit Series and Coal Measures) shales. The present outcrop of these shales lies several kilometres to the east of the quarry at Dyserth but this is almost certainly due to post-Triassic retreat of the Upper Carboniferous outcrop downdip eastwards. The presence of the haematite at Dyserth and the absence of any evidence of pre-Tertiary karstification of the limestone to the east suggests that during Triassic times only a narrow strip of limestone was exposed along the eastern margin of the Vale of Clwyd (Figure 4).

The supposed Triassic age for this episode of karstification remains conjectural in the absence of any direct evidence for the age of the infills. However, several features support this assumption. The development of the caves clearly post-dates any significant movement along the faults bounding the eastern margin of the Vale of Clwyd. These faults are Variscan structures and were probably active from Westphalian times until the Middle Triassic (Owen 1974): in places they cut the Permian and Lower Triassic strata preserved in the Vale. Although the caves now lie at an altitude of about 200 m O.D. and more than 150 m above most of the floor of the Vale, the predominantly phreatic nature of most of the cavities suggests than at their time of formation the floor of the Vale must have been more than 150 m higher than at present. Further evidence in support of this comes from the absence of any comparable karst features in the lower quarry at

Figure 4. Diagrammatic cross section, looking north, across the eastern margin of the Vale of Clwyd showing the relationship of the caves in Dyserth Quarry to the present landscape and to that during the late Triassic. The relative altitudes of Dyserth and Bodfari quarries are indicated. The orientation of the phreatic conduit has been rotated through 90° for the sake of clarity. It is probable that it drained to the north or north-west rather than directly west into the Vale itself.



Vertical fissures (? invasion vadose shafts) of presumed Triassic age in Carboniferous Limestone adjacent to the Vale of Clwyd. Dyserth Upper Quarry, Clwyd, North Wales. Field of view about 6 m wide.

at Dyserth (Grid Ref. SJ 062789), which lies at a present altitude of 130-170 m O.D. Some 8 km to the south at Bodfari Quarry (Grid Ref. SJ 095702), which also lies on the eastern margin of the Vale of Clwyd, the limestone is extensively reddened by haematite, particularly along the north-south faults, but there is no evidence of any palaeokarst development comparable with that at Dyserth upper quarry. This almost certainly reflects the much lower altitude of Bodfari Quarry, presently at 50-80 m O.D., which would have placed these limestone exposures at a depth of more than 120 m below the floor of the Vale during the late Triassic and hence well beyond the limit of most karstic processes other than deep phreatic circulation. The caves at Dyserth must be significantly younger than the youngest sediments now preserved in the Vale since they formed contemporaneously with a sediment surface more than 150 m higher than the present one. This suggests a later, rather than earlier, Triassic age for the caves. Tentative support for this comes from the abundant haematite infills, if haematite deposition here occurred contemporaneously with that in the Forest of Dean and South Wales.

Recharge of the limestone aquifer may have included a significant autogenic component in addition to allogenic input from the Upper Carboniferous shales to the east. Certainly the abundance of speleothems in these caves suggests that autogenic input was important in the later stages of infilling. Tall vertical 'chimneys' seen in the upper part of the quarry face perhaps represent invasion vadose inlets (Ford & Williams, 1989). Percolation water may then have been concentrated into shallow phreatic conduits associated with the faulting, as has been suggested for the Halkyn cave system (Appleton, 1989), which then resurged at the limestone margin to the north or west (Figure 4).

The comparatively open nature of many of the cavities, now lined with calcite crystals, and the often vuggy nature of the sediments themselves, suggests that the limestone outcrop itself may never have been entirely buried by Triassic sediments after the caves had formed. Furthermore, the complete absence of Jurassic marine sediments in any of the fissures sheds doubt on any suggestions that this part of Wales was submerged during the Jurassic.

OTHER AREAS

Minor or poorly documented examples of Triassic karst are known from several other areas of the British Isles. Steel *et al.* (1975) reported fissures, presumably grikes, filled with Triassic sediment within the Cambro-Ordovician Durness Limestone of Central Skye. Richter (1966) reported cavities and solutionally enlarged faults filled with sediment of presumed Permian or Triassic age within the Devonian limestones of the Torbay area. These were also mentioned by Proctor (1988). However, for many of the other Permo-Triassic filled fissures in this area Richter favoured an extensional tectonic, rather than purely karstic, origin. The most convincing evidence is derived from the way in which later 'neptunian dykes' cut across some of the earlier ones, a phenomenon difficult to account for by karstic processes alone.

In many other areas of Britain where Carboniferous or other pre-Triassic limestones are now exposed there is no evidence of Triassic karstification. Invariably this can be attributed to the fact that these limestones were not exposed during the Triassic. Perhaps the greatest, but as yet unfulfilled, potential for new discoveries of Triassic caves in the British Isles lies in Ireland. Carboniferous Limestone underlies a considerable proportion of the total land surface of Ireland and has experienced a long history of subaerial exposure and karstification. Only one example of Mesozoic karst has so far been identified, at Cloyne, Co. Cork (Higgs & Beese, 1986). Here clays occupying large solutional hollows have yielded a late Lower Jurassic to Middle Jurassic palynoflora. However, they stressed the fact that the discovery of these deposits was largely fortuitous and it seems probable that other examples, perhaps as old as Triassic, lie concealed beneath the till and blanket bog which covers much of the present Irish landscape.

CONCLUSIONS

Ancient caves and other karst forms have developed in abundance wherever potentially speleogenic limestones were subaerially exposed in late Triassic times. These karst forms were subject to the same constraints as modern karst and hence often show significant structural control. This has led to the interpretation of many of these sediment-filled fissures as the products of active extensional tectonism. Evidence for this hypothesis is, in most cases, equivocal, and the observed features can be accounted for largely by normal karst or karst-related processes. Indeed the absence of similar fissures in adjacent non-carbonate lithologies is further evidence in favour of a karstic origin for the great majority of these fissures and it is suggested here that many of them may represent large grikes or solution corridors.

Late Triassic conduit cave systems are best developed in limestone outcrops adjacent to non-carbonate strata, typically of either Old Red Sandstone or Millstone Grit/Coal Measures. In some cases the approximate catchment area for these cave systems can be estimated from the configuration of the sub-Triassic unconformity. Phreatic tubes in these cave systems are often quite large relative to the size of the catchment areas, suggesting that they were formed during a period of high runoff (compare with Lauritzen *et al.*). These caves therefore have significant implications for the climatic history of the late Triassic since they indicate an interval of much wetter climate during a period traditionally regarded as having been predominantly arid.

The time of formation of the caves themselves is impossible to determine directly but the sediments and mineral deposits within them can provide a minimum age for their abandonment as active conduits. Faunal and floral evidence from various sites indicates that the sediments range in age from early Jurassic to perhaps as old as late Carnian. Similarly, the timing of haematite emplacement in other caves can be established as late Triassic, pre-Rhaetic, with the celestine deposits in still others also being of probable Norian age. With the exception of the Morecambe Bay haematite deposits, which are no later than early Triassic in age, there is no evidence of sediments or mineral deposits of pre-Carnian age in any of the caves. This suggests that the main episode of cave development occurred in early late Triassic (i.e. Carnian) times. On several other lines of evidence it has been established that the prevailing aridity of the late Triassic was interrupted during the mid to late Carnian by a wet monsoonal climate (Simms & Ruffell, 1989, 1990). The age of the sediments and mineral deposits in the caves is fully compatible with the conduits themselves having formed during this wet monsoonal interval. Documentation of phreatic conduit diameter, scallop size (Curl, 1974) and catchment area for these cave systems may, in theory, allow some estimate to be made of peak rainfall during a later Triassic monsoon!

Many of the caves have fairly complex histories. Narrow vadose canyons are often incised beneath phreatic tubes, indicating a major hydrological change. Other passages have been extensively modified by collapse. Sediments within the caves show evidence of repeated flooding and draining as well as several episodes of deposition and erosion. Other caves have been partly or wholly infilled by minerals. Where Triassic caves lay adjacent to catchments composed of pyritous shales, such as those of the Coal Measures, they were often infilled by haematite from the oxidation of this pyrite. In other areas some passsages may be partly infilled by celestine, presumably due to a hydrological connection with nearby hypersaline lakes. Somewhat surprisingly, there is a noticeable absence of significant speleothem development in most of the caves, other than those at Dyserth, North Wales, even where sections of passage have remained open to the present day. In many cases post-Triassic speleothem development would have been prevented by the impermeable Triassic cover which blanketed the limestone. However, their failure to develop prior to burial of the limestone may well reflect considerable aridity (Brook, Burney & Cowart, 1990) prevalent during the latest Triassic (Norian). It also suggests that the change from the wet monsoonal climate of the Carnian, during which the caves were active, to the aridity of the Norian, when the caves were gradually infilled, was comparatively abrupt.

These Triassic caves are important for the reconstruction of past landscapes and sea levels as well as climate. In North Wales the existence of fault-guided phreatic conduits containing abundant haematite indicates that during the late Triassic times the sediment level in the adjacent Clwyd Graben lay at least 150 m higher than at present and that the outcrop of Silesian shales, from which the haematite was presumably derived, has retreated several kilometres eastwards since the caves were infilled. In South Wales and south west England there appears to be an inverse correlation between the age of the sediments within these caves and their present altitude. Infilling of these conduits may well have been related to reductions in hydraulic gradient as sea level rose and flooded caves at progressively higher altitudes. Low altitude systems would be inundated first and hence would contain the oldest sediments whilst those at higher alitudes would remain open much longer and hence are now found to contain younger sediments. Refinement of the dating of many of these caves may enable an absolute sea level curve to be constructed for the late Triassic.

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Water Tracing in the Vega Huerta Caves, Picos de Europa, Spain

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Abstract: Water tracing experiments using lycopodium spores and fluorescein dye have been carried out in the caves and surface sink near Vega Huerta, in the western massif of the Picos de Europa, Northern Spain. Water from the sump at −986 m in the M2 cave system has been shown to resurge in the Canal de Capozo, 3.5 km to the east. The exact altitude of the resurgence cannot be determined since it is buried by glacial deposits, but the vertical range may be as much as 1350 m. The drainage appears to be controlled by a major fault passing just to the south of the present end of M2, and continuing eastward into the Canal de Capozo. A second resurgence in Capozo, only 100 m from the M2 resurgence, appears to be unconnected and may drain the cave systems immediately south of Vega Huerta.

Between 1985 and 1987 considerable efforts were made to discover the resurgence(s) of the cave systems around Vega Huerta (4°58'W, 43°12'N) in the western massif of the Picos de Europa in northern Spain. This is an area in which York University Cave and Pothole Club (YUCPC) has been exploring, together with the Seccion de Espeleologia de Ingenieros Industriales (SEII) from Madrid (Fig. 1). The two most important caves explored have been the M2 system shown in Fig. 2 (Senior, 1987), with the limit of exploration at −986 m, and, more recently, β3, currently explored to −944 m. The hydrology of M2 is complex, with several streams, whilst β3 has a single active streamway leading to a sump at −944 m. Attempts have been made to trace three underground water-courses:

A. The Vega Huerta stream sink is a surface sink below the path from Vegabano to Vega Huerta, about 100 m before the remains of the Vega Huerta refugio. Although blocked to cavers by boulders, it takes an intermittent summer flow of up to about 5 litres per second from snowfields at the base of the peak Cotalbin.

B. The second streamway to be investigated was that entering M2 in the upper series at Watford Gap. A small, irregular flow of the order of one litre per second is found here.

C. The M2 lower streamway, where the most extensive investigations have taken place. Water is seen below El Gordo until it is lost in the too-tight Nicky's Rift, and also a stream enters the sump at −986 m. The flow is several litres per second.

The relative relief is very great in the area around Vega Huerta (2000 m asl). Three kilometres west-southwest is the gorge of the Rio Dobra, at approximately 1050 m asl. Three kilometres east is the bottom of the Canal de Capozo, a precipitous valley leading into the Cares Gorge and the Rio Cares at 600 - 700 m asl. The bottom of the Canal de Capozo is covered by glacial deposits, hiding the base of the Barcaliente Formation into which the M2 cave system extends. Farias (1983) suggested that the impermeable rocks of the Pisuerga-Carrion Province underlie this area, reaching an altitude of over 900 m at the southern edge of the Canal de Capozo. To the north of the Canal de Capozo, Farias shows the Barcaliente formation extending down to around 780 m asl. Thus waters sinking at Vega Huerta may travel underground over a vertical range of 950 m to reach the Dobra, or 1220 m or more to the Cares. Farias (1983) has identified three faults which pass through Vega Huerta, coming together just to the west of the M2 entrance. The most northerly of these extends eastwards into the northern part of the Canal de Capozo, whilst a branch of the adjacent fault continues into the southern part of the Canal de Capozo. This is illustrated in the paper by Senior (1987).

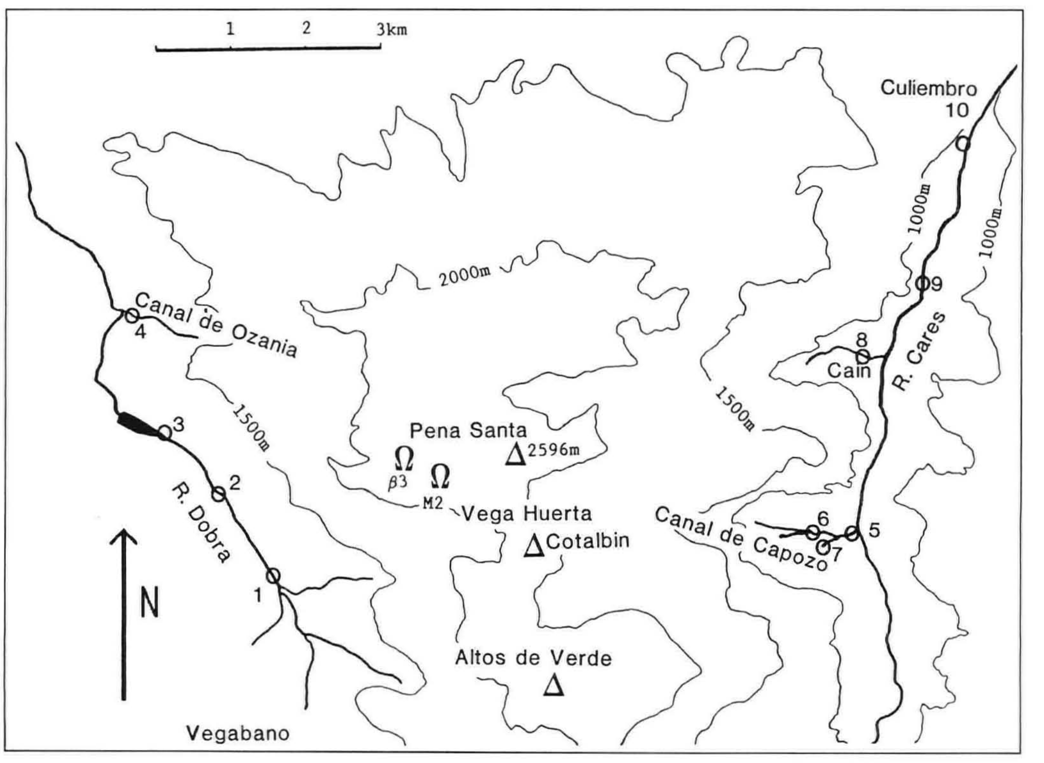
Resurgences in the Dobra and Cares Gorges

Possible resurgence caves and streamways where the Vega Huerta waters may appear occur in the Dobra and Cares gorges. These locations, and sites to which dye tests have been made are numbered on Fig. 1, and described below:

1. The source of the Rio Dobra, fed by surface drainage, is near basecamp at Vegabano. Some early tests were conducted in the upper Dobra, about 1 km northwest of Vegabano.

2. There are no major resurgences in the Dobra until a point directly to the west of Vega Huerta. In dry weather the river sinks in its bed here, only to resurge again in a deep pool a few hundred metres downstream. It is not known whether there is any connection from here to any other underground watercourse. Approximately 500 m downstream there is a large cave entrance in the eastern bank of the gorge, 5 m above river level. This is partially choked and apparently no longer active, but there is a small resurgence from a bedding plane just below (summer flow less than one litre per second).

Figure 1. The area around Vega Huerta. o — location of numbered resurgences, Δ — mountain peaks, Ω — cave entrances.



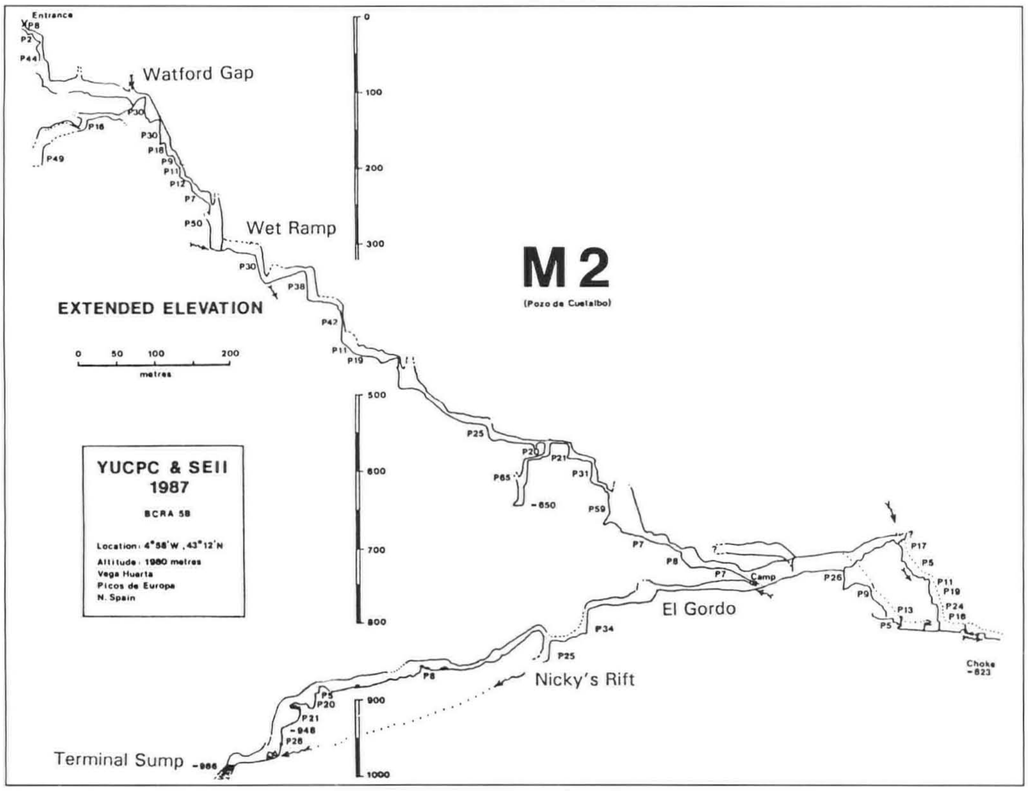


Figure 2. The M2 cave system. Lycopodium spores were used for water tracing from the Wet Ramp and Nicky's Rift. Fluorescein was used for water tracing from Watford Gap and Nicky's Rift. The only confirmed route of flow within the cave is the lower streamway from Nicky's Rift to the Terminal Sump.

3. About 500 m downstream from 2 the river deepens, forming a long lake behind the dam of the Dobra hydroelectric station, which hides any resurgences in this part of the gorge.

4. Just downstream from the point where the track from Amieva crosses the river, a large stream joins the Dobra from the Valle de Ozania. There is one large resurgence amongst boulders near the river, and a further, most spectacular resurgence about 100 m higher, which comes out of a cave 40 m up a cliff face. There are also other small resurgences higher up the valley. The total summer flow from all these resurgences approaches 0.1 cumec. The Ozania resurgences are 3 to 4 km from Vega Huerta.

The Rio Cares runs northward, to the east of Vega Huerta. The river has carved an imposing gorge through the mountains which is at its most impressive to the north of Cain. To the south of Vega Huerta and the Canal de Capozo the river flows over the mainly impervious rocks of the Pisuerga-Carrion Province. To the north it flows over Carboniferous limestones. The closest resurgences to the Vega Huerta cave systems are the group located in the Canal de Capozo, 3 to 4 km away.

5. This site is where the Capozo stream joins the Rio Cares. It is easily found 2 km south of Cain where the road passes over a small bridge across the Capozo stream. In summer the flow is typically 0.1 cumec. Going up-valley the stream quickly bifurcates.

6. Following the northerly branch of the Capozo stream, water flows above ground for some hundred metres or more in summer conditions. There is no resurgence cave, as the bottom of the Canal de Capozo is filled with glacial deposits. The stream simply resurges from its bed over a length of 50 m or more, welling up through sand and boulders. Above this point, the dry stream bed can be followed for nearly a kilometre. There are several tributaries, but the main course goes up above the glacial deposits to the limestone cliffs directly below Vega Huerta. Here there is a finely-sculpted open-air pitch of 20 m, leading up to the steepest part of the Canal de Capozo. To the south is a limestone cliff which forms part of the buttress between the Canal de Capozo and the valley below Torre Bermeja. This seems to follow the line of the most northerly of the Vega Huerta faults. The glacial deposits hide the cave resurgences of the lower Canal de Capozo, so there is an uncertainty of perhaps 150 m in estimating their true altitude. A small resurgence was found in the centre of the buttress in the middle of the Canal de Capozo, but its flow was only around a litre per second, nowhere near the flow seen in the streamway entering the Cares. It is probable that the steeply-sloping bare limestone surfaces in the upper Canal de Capozo allow little chance for water to sink underground, giving rise to rapid runoff, and resulting in the large surface streamways cut into the glacial deposits below.

7. The southern branch of the Capozo stream dries up within 100 m of the road. There is no resurgence cave, again water comes up through cobbles in the stream bed. The dry watercourse extends on up through the woods, headed towards the valley below Torre Bermeja.

8. To the north of Capozo there is a small stream entering the Cares at Cain. It is opposite the impressive Los Molinos resurgence which is fed from the central massif. The stream has a flow of only a few litres per second.

9. Some tests have been performed with detectors placed in the Cares below the dam at Cain. Further downstream there is a small resurgence near the Puente Bolin, again with a flow of a few litres per second under summer flow conditions.

10. Following the Cares at river level revealed no further significant summer resurgences until the large resurgence at Culiembro which Gale (1984) reports to have a baseflow of 0.7 cumec.

WATER TRACING

Both lycopodium spores and fluorescein dye were used to try and trace the Vega Huerta streams. Lycopodium was used extensively in 1985 and 1986. Fluorescein was used for tracing waters within the M2 system in 1986, and for identifying the resurgence in 1987.

Lycopodium was prepared in the manner described by Drew and Smith (1969). The experiments performed using this technique are summarised in Table 1. Each test used about 0.5 kg of lycopodium. The result of this work was that all tests proved negative.

Table 1. Water-tracing tests using lycopodium

Year	Sinks	Resurgences
1985	Vega Huerta surface sink; M2 Wet Ramp	1, 6, 8, 9, 10
1986	Vega Huerta surface sink; M2, Nicky's Rift	1, 6, 8, 9, 10

Because of the lack of success using lycopodium, it was decided to try fluorescein dye instead. Fluorescein tracing work was carried out in 1986 to try and find connections between the various cave streamways. Dye detectors were not placed in the cave, as short flow-through times were expected, and visual identification was hoped for. In 1987, fluorescein was the only tracing method used, and it was hoped to find the M2 resurgences in this way. Activated charcoal detectors were prepared, and placed into streams at the beginning of the expedition as controls. These were removed after one to two weeks, before any dye had been introduced into the caves. Fresh detectors were then placed, and the dye test performed. Because of the inaccessibility of many of the test sites the detectors were mostly replaced only once. The test results are summarised in Table 2.

Table 2. Water-tracing tests using fluorescein (and quantities used)

Year	Sinks	Resurgences
1986	Vega Huerta surface sink (300g); M2, Watford Gap (300g)	within M2
1987	M2, Nicky's Rift (3.5 kg)	2-10

In 1986 we were unable to visually detect dye in the lower M2 streamway after placement in either the Vega Huerta or Watford Gap streams. However, dye placed in Nicky's Rift in 1987 was seen within a few hours at the terminal sump, confirming this connection. The large quantity of fluorescein used in this test was due to growing frustration at the lack of a positive trace for M2 in previous year's work. The lack of success with lycopodium suggested that the flow-through time and dilution were likely to be large, which gave some confidence that a spectacular visual trace to the Cares or Dobra would not occur.

The detectors from the 1987 tests were brought back to the UK for analysis. The last set of detectors were recovered some weeks after the expedition left the Picos by members of the SEII. For analysis, 3 g of the charcoal from each detector was heated in 10 ml of 10% KOH in methanol to 60°C for half an hour. The liquid was then decanted off. Fluorescence spectra were measured using an Applied Photophysics fluorescence spectrometer with a mercury arc-lamp light source. The lamp has a predominant emission line at 365 nm, but there are also other strong emissions and consequently fluorescence excitation is not specific. Alternatively, observations were made using an argon-ion laser as an excitation source, with up to 20 mW of light at 454 nm or up to 1 W at 488 nm. Fluorescence was observed visually, either directly or through a narrow-bandwidth interference filter with a half-intensity bandwidth of 7 nm centred at 514 nm. This combination is well matched to the excitation and emission maxima of fluorescein.

The control detectors all gave strong fluorescence spectra, with broad maxima centred around 420 nm. Fig. 3a shows the spectrum obtained for the Capozo control. It does show a very slight deviation from a smooth curve at about 540 nm, close to the fluorescein emission maximum, as do several other samples. Presumably this is due to some naturally occurring fluorophore in the water. Using the laser excitation, all three controls gave some faint fluorescence. The Culiembro control gave a white fluorescence, whilst the Capozo and Dobra controls gave a greenish fluorescence. The last two may well have picked up naturally occurring green fluorophores from surface drainage in these heavily vegetated areas (Smart and Laidlaw, 1977). The detectors taken out after the dye had been placed in M2 all gave similar fluorescence spectra to the controls, except for the sample from Capozo (6), which had a significant maxima at 520 nm as well (Fig. 3b), corresponding to the fluorescein emission maxima. This was spectacularly confirmed using laser excitation, when the sample gave a very intense green fluorescence, far brighter than that of any of the other samples. The difference was much more striking than the size of the peak in the spectrum obtained with UV excitation would suggest. This positive trace was obtained from a detector which was removed after the expedition had finished, about four weeks after fluorescein had been added in M2. A detector in the same location which was removed two days after the dye had been added showed no significant difference in its fluorescence spectra to the control. No excess fluorescence was observed from the detectors placed in the more southerly of the Capozo resurgences.

DISCUSSION AND CONCLUSIONS

One of the primary questions concerning the hydrology of Vega Huerta has now been answered. The water in the sump at −986 m in M2 goes eastward and is seen again in the northern Canal de Capozo stream, three kilometres away. The resurgence appears

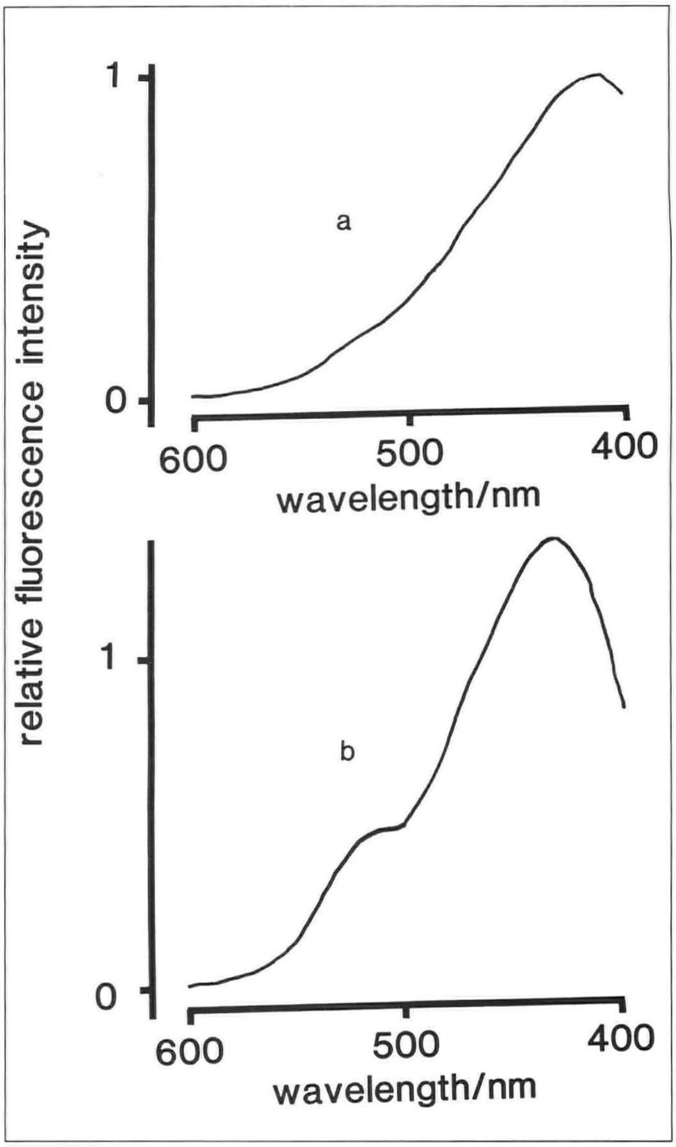


Figure 3. Fluorescence spectra for extracts from two of the dye detectors, obtained with mercury-lamp UV excitation (365 nm).
a) Spectrum obtained from the Canal de Capozo control detector (location 6).
b) Spectrum from a detector in the same location, one month after the addition of 3.5 kg of fluorescein into the M2 streamway at Nicky's Rift. The pronounced maxima at 520 nm corresponds to the fluorescein emission.

to be associated with the most northerly of the three faults passing through Vega Huerta, with the head of the surface stream bed located on the line of the fault. The time taken to traverse this distance has not been accurately measured, but it is more than two days but less than one month under summer flow conditions. The apparently separate nature of the Capozo resurgences suggests that a perched phreatic network of fractures in the limestone directly behind the glacial deposits in the Canal de Capozo is unlikely. Instead, it seems that flow occurs along a single fault-guided conduit all the way to the resurgence. The southern Capozo resurgence may be associated with the fault passing through Cotalbin, slightly to the south of Vega Huerta, which then runs through the southern part of the Canal de Capozo. This fault intersects an area containing many caves, and may form the main conduit for water from these systems. This could be a very interesting future dye test, which may confirm the presence of two drainage systems within the Canal de Capozo.

The lack of success with the lycopodium traces, and the low concentration of dye eluted from the detector after a trace using 3.5 kg of fluorescein suggest that either collection of the tracer is extremely inefficient, or that the dilution of the cave water might be very great. The apparent separate nature of the Capozo resurgences makes it unlikely that there is considerable ponding of water and dilution behind the glacial deposits at the base of the Canal de Capozo. Also, if it is assumed that the water is guided along the major northern Capozo fault, it would also be somewhat surprising if there was a large, slow-moving body of entrapped water further from the resurgence. An alternative reason may be the fine, sandy nature of the ground through which the water resurges. This may act as a filter for lycopodium, and organic material present may adsorb fluorescein. Also, the dye detectors were in place for a considerable period of time, and so leaching of the dye may have occurred.

Of the other significant streamways which could be tested, the most important are the Vega Huerta surface sink and the streamway entering the sump at −944 m in the recently explored β3 system. On the surface the Vega Huerta sink is very close to the fault which is thought to control the M2 drainage, although the fault running into the southern Canal de Capozo is also nearby. Probably the northern Capozo stream is the most likely resurgence. β3 lies to the west of M2, even closer to the large Ozania group of resurgences in the Dobra gorge. However, the depth of the β3 system is such that there is less than 100 m vertical range between the lowest Ozania resurgence and the β3 sump, making this an unlikely destination. Once more, the northern Vega Huerta fault appears to be the most likely conduit, taking the water eastward to the Canal de Capozo. If further tests are performed then fluorescent dye rather than lycopodium will be preferred. Green and orange fluorescent dyes should be favoured because of the blue background fluorescence of the Picos waters. The observations made by laser-induced fluorescence were quicker and more decisive than the spectra made with UV excitation. Using the argon-ion laser this technique should be applicable with both fluorescein (454/488 nm excitation) and rhodamine (514 nm excitation). With photoelectric detection the sensitivity of this type of measurement is such that direct quantitation of dye in water samples may be possible, with frequent direct sampling allowing measurements of flow times, dilution, and an estimate of the reservoir volume.

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Caves of Bjørkaasen and Elgfjell, South Nordland, Norway

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Abstract: Bjørkaasen is the site of an abandoned farm near where the river Jordbruelv meets road 803. Several caves have been explored here, the longest being Bjørkaasgotta and Anastomosegrotta. 6km to the north is Elgfjell, an upland area lying below the steep eastern slopes of Jordhulefjell. Long outcrops of nearly vertically banded crystalline marbles cross the fell. Over 80 caves have been recorded here, the most significant being Elgfjellhola, Ridge Cave, Pustehola, Sarvenvaartoehullet, Gevirgrotta and Sarvejaellagrotta. These are generally found near the summits of cols or ridges and have large dry passages unrelated to present drainage indicating either subglacial or pre-glacial origins. The report also describes the Fjellryggen area, Gaasvasstindhola, and Invasiongrotta, a new cave in the previously reported main Jorbruelv area.

This is the report of the 1988 Expedition to South Nordland, Norway, supplemented with relevant information from the 1986 and 1989 expeditions. The caves at Bjørkaasen were initially explored at the end of the 1986 expedition. The 1988 Expedition set Elgfjell as its main objective. This is about 6km north of Bjørkaasen and the new road 803. The nine members of the expedition were: Trevor Faulkner, Geoff Newton and Steve Tooms; Gordon Cooper, Alan Marshall and David St. Pierre; Nick Thompson and Steph and Pam Gough. Three cars left Newcastle on 16th July 1988, returning variously two to three weeks later.

A base camp was set beside the Jordbruelv bridge at Bjørkaasen as we completed the surveys of Bjørkaasgrotta and Anastomosegrotta and investigated Fjellryggen and Invasiongrotta in the main Jordbruelv area. (Fig. 1). On Friday 22nd July we walked up to Elgfjell, taking about 4 hours with heavily loaded rucksacks. Our mountain camps were beside two small tarns on the southern slopes of Elgfjell, west of hill 565.

The area was covered very widely in the first six days, finding many caves quickly, especially on the north of the fell. We then returned to the 803 valley for more food. The weather deteriorated badly during the second period of six days, losing us a day's effective time, but surveys were progressed and new caves found right up to the last day.

In 1988 we explored and recorded over 5km of cave passage in over 90 caves: the most productive expedition to the area in recent years. Our previous visits to South Nordland and the geology of the area are referenced in Faulkner, 1983 and 1987a. Other recent reports are: Faulkner, 1987b; Newton, 1987, 1989 and 1990; Whybro, 1988.

The 1989 Expedition completed the exploration of Elgfjell and prospected a number of other areas. Eight people took part: Clive Gardner, Geoff Newton and Jim Rands; Keith Bryant; Edgar Johnsen; and Nigel Graham, Mike Read and Andy Summerskill. Despite leaving Newcastle three weeks later than in 1988, high levels of snow cover were found. Nevertheless, about a kilometre of new passages were surveyed on Elgfjell. The other areas visited in 1989 will be reported separately.

Survey notes

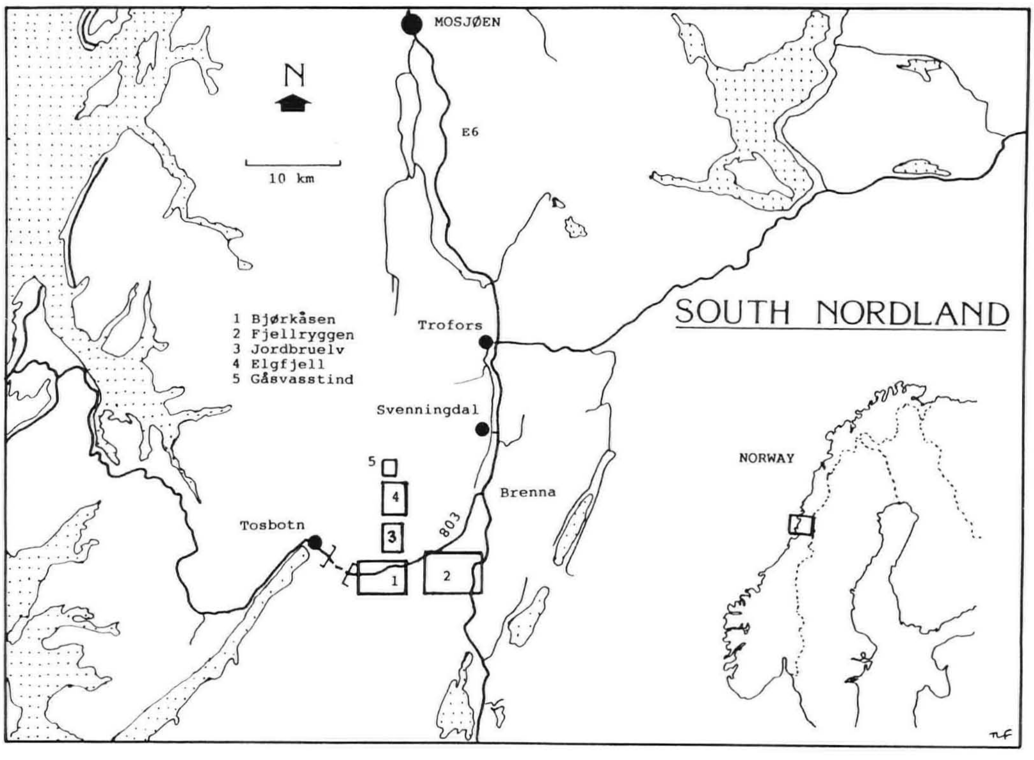
Rapid survey techniques have usually followed those used on previous expeditions, although in some caves the tasks of measuring compass bearings, measuring tape lengths and taking notes were split among two or three people rather than the surveyor doing all this with just one assistant. UTM coordinates in Grid Zone 33W, square VN, are provided for each referenced cave. In all descriptions and surveys A = altitude, L = length, D = depth, VR = vertical range, with all units in metres. Unpublished surveys of the shorter features are available from the authors. In order to save space, the lesser features are only listed in the appendix at the rear of this report.

HISTORICAL CONTEXT

From information supplied by Odd Johansen, who lives in Svenningdal, we learnt that there used to be a large farm beside the river Jordbruelv at Bjørkaasen for about 300 years, with many meadows and up to 10 cows. It was vacated in 1901/1902 after two children drowned in the river. The family emigrated to America, founding a minerals and engineering group. It is still possible to see a log cabin in the forest, and the foundations and fireplace of the main house. Unfortunately a forestry track has gone straight over the top of the remains. This untidy track, which reaches halfway to Etasjegrotta, was cut and blasted in 1987 by the state forestry organisation.

The British have had a connection with the area from about

Figure 1.



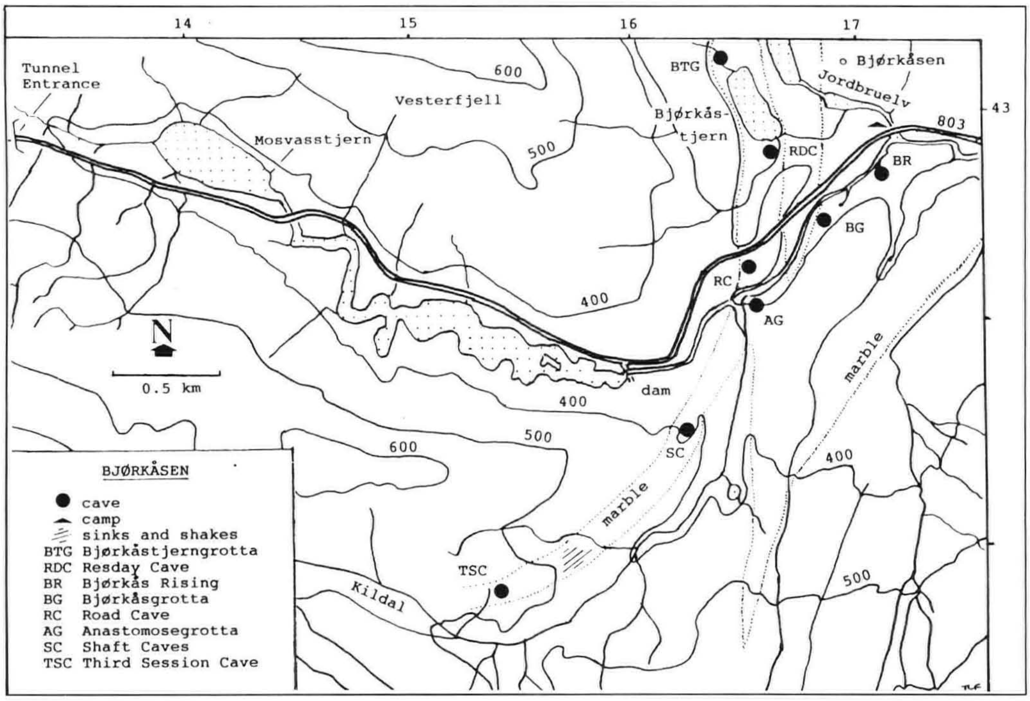


Figure 2.

1750 through a timber company. Logs were floated down the Jordbruelv and the Vefsn to Mosjøen from where they were shipped to England. Abandoned logs dating from this era can still be seen. Hence, due to farming and forestry, the Jordbruelv valley area is no longer primary forest, but has a thinner vegetation of silver birch and spruce.

Much more recently, the Tosen Tunnel has been built after 50 years of local pressure. This 5.5km long tunnel, together with the new road 803 which crosses the Jordbruelv at Bjørkaasen, connects the E6 at Brenna to the hamlet of Tosen at the head of Tosenfjord and thence to the port of Brønnøysund on the coast. The formal opening was in 1987, although we first used it in 1986, with special permission.

NW of Bjørkaasen is a remote wilderness area of mountains and lakes. It is one of the last unspoilt areas of Europe. Unique in Norway, it contains examples of all the wild fauna to be found in Scandinavia including reindeer, elk, lynx, golden eagle and bear. A government report estimated that 9 to 13 brown bears permanently live in the Helgeland area (Kolstad et al, 1986) and our expedition found bear remains in the caves of Elgfjell. Elgfjell is several km outside the area reported for the Helgeland population which, however, Kolstad believed to be increasing, although this is disputed by Elgmark, 1988. Other papers about the brown bear in Norway are Mysterud and Muus Falck, 1988a and 1988b. Visitors need to consider the possibility of seeing a bear as local sittings, footprints and sheep killed by bears are frequently reported.

The fauna in the area are protected by the banning of hunting and a National Park is being created. Near to Bjøkaasen a local businessman is building accommodation for visitors, and tourists are directed to Bjørkaasgrotta.

BJØRKAASEN

The marble outcrops of the Jordbruelv area continue south beyond the new road and the large tributary of the Jordbruelv which joins it at Bjørkaasen (Fig. 2). Two short caves north of the road were explored in 1984 and 1986, and two significant systems just south of the tributary were partly surveyed in 1986. Exploration was completed in 1988. The limestone in the Kildal tributary valley is more extensive than shown on geological maps, and some short features were recorded in 1988 and 1989.

Bjørkasgrotta 16904450 A 290 L 529 D 7

South of the tributary is a streambed leading to the smaller, hidden, entrance. A drop to a wide low chamber leads to a complex of large crawls and interconnecting passages going to Spring Chamber where a stream enters from a canal and sump.

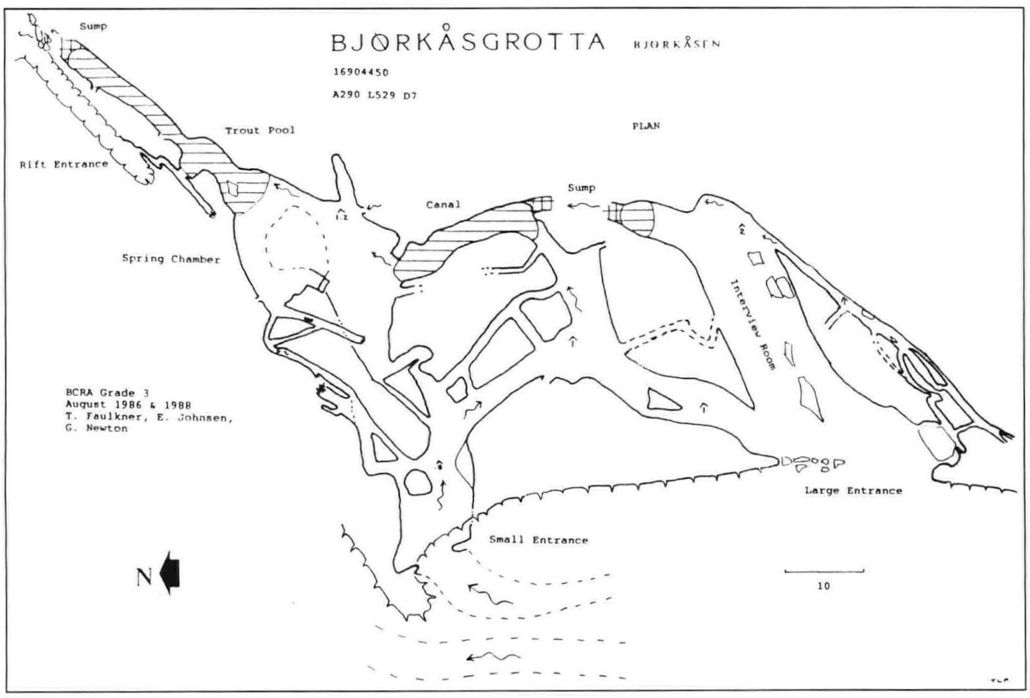


Figure 3.

Roof at Anastomosegrotta entrance. (Photo: P. Hann)

Another inlet wells up from a small side passage and the combined waters flow to a long pool containing trout. The roof lowers but a sump is not reached until the roof rises again and daylight is visible at an aven. A crawl from the side of the pool leads to a tight rift to an entrance near where the stream resurges from a jumble of boulders on the surface. A 1m high tunnel near the streambed entrance bears away from the Spring Chamber area and enlarges to reach the large sloping daylit Interview Room. At the lower end of this chamber is a sump, which is about 10m from the canal in Spring Chamber. At the upper end of the Interview Room is the larger entrance to the cave, a 10m long opening at the base of a cliff. Despite being formed in vertically banded marble, the cave appears to have developed in a pseudo 'bedding plane' gently sloping down to the stream course. The origin of the stream is a small passage south of the Interview Room (Fig. 3.).

Anastomosegrotta 16544412 A 300 L 238 VR c.20

The entrance is situated about 30m from the south bank of the large tributary of the Jordbruelv, near a corner about 1km from the road bridge. A dry streambed leads up to the wide low entrance. Climbing over blocks leads to a spacious entrance chamber exhibiting fine anastomosis in the roof. At the far end are two crawls. The dry right crawl gains a streamway after 22m, also accessible from the wet left hand crawl. Upstream the roof rises to a fine canyon ending at a large chamber with a waterfall issuing from a hole about 4m up. A climb up to the left reaches another chamber. A high level passage leads to crawls in a downstream direction and two passages heading parallel upstream. The higher level passage is a phreatic tube decorated with stalactites; the lower level has fine phreatic pendants. The passages unite near the end of the cave which is a boulder choke. The stream issues from a small impenetrable sump a short distance above the waterfall. The cave appears to have formed as an oxbow to the river at the corner, and is probably only active in flood conditions (Fig. 4).

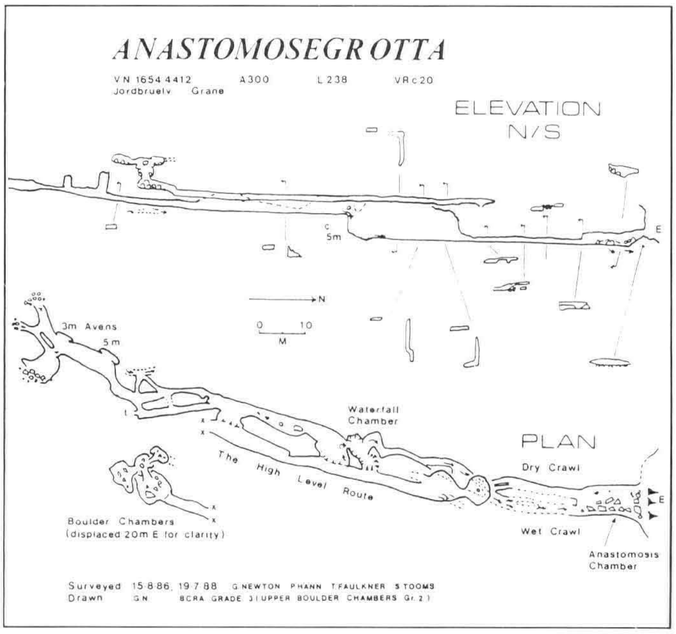


Figure 4.

FJELLRYGGEN

Two bands of marble ascend the slopes of Fjellryggen, meeting near the summit, 721m. The geomorphological effect of the marble is seen as a prominent notch on the skyline when viewed from the road. The shakeholes and features are generally immature in this area (Fig. 5). The short features Wildmarkskaffeenhulene 1, 2 and 3 are near the track which runs south of the main river.

A stream flowing north from Fjellryggen runs into a deep limestone gulley choked with flood debris at Stream Hole. Presumably this is the stream which resurges near Svartjern, passing below Svartjernhullet. A parallel stream to the east runs through Sparkly Cave and sinks 700m north.

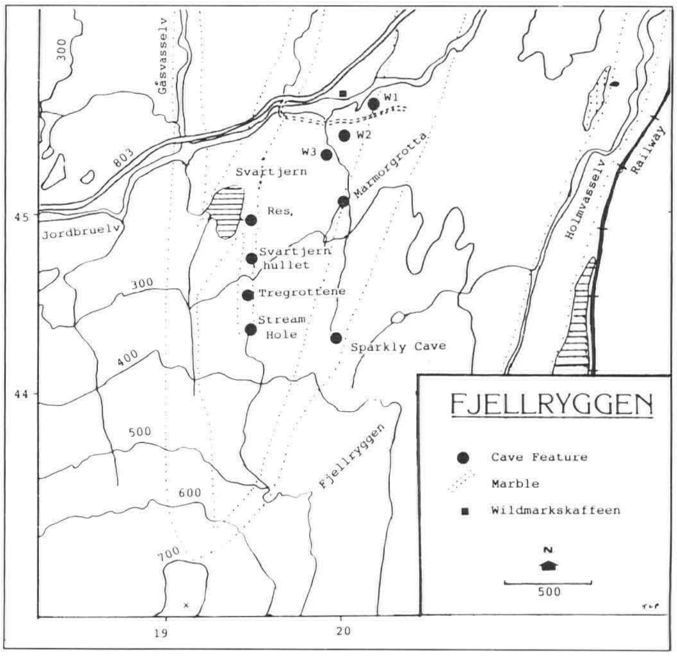


Figure 5.

Marmorgrotta 20004507 A 290 L 90 D 12

A short climb at the west of the stream sink drops into a 5m

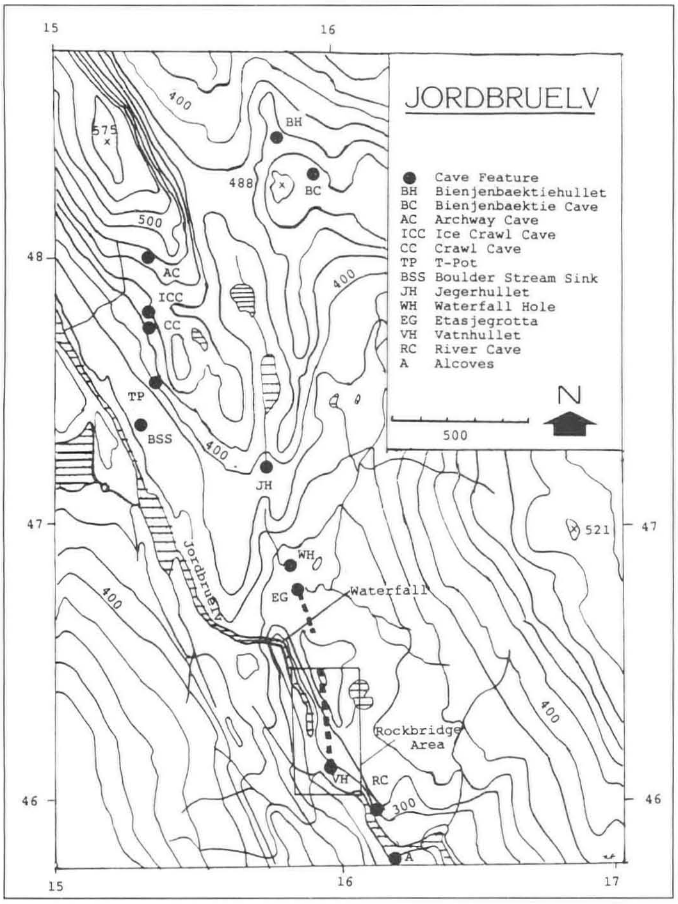


Figure 6.

wide chamber about 1.5m high. A dry oxbow leads to a strike passage 1 to 6m wide and 0.5 to 2m high which extends for 45m to a small chamber. The stream sinks to one side, where a low passage also leads to a sump. Forward over small boulders leads to a boulder choke, and Sand Passage across the strike leads to a continuation to another sump.

JORDBRUELV

This area (Fig. 6) was visited in 1984 and 1986, as described in Faulkner 1987a, pp 36-41. Since that report, Vatnhullet has been extended by diving a further 80m towards Etasjegrotta and it has also been connected to Main Rising (Whybro, 1988). Odd Johansen explored a new cave, Invasiongrotta, near Vatnhullet in autumn 1986. This was also visited by Whybro in 1987, and then surveyed by the 1988 expedition. Other features above the upper Jordbruelv were also explored in 1988. This section includes only the new or extended caves, building on the report of the 84/86 expeditions. With the availability of the new 1:50,000 Tosbotn map a new combined cave and surface map has been drawn for the Rockbridge Area (Fig. 7) and the coordinates and altitudes of the lower Jordbruelv features have been revised.

Invasiongrotta 16004620 A 318 L 354 D 27

This open rift entrance is 95m due north of the east end of the Vatnhullet shakehole. The stream from the lake near hill 362 sinks just above here. A climbdown leads to a descending incised meander into which the stream soon enters. 40m in and at a depth of 17m a 5m fixed ladder descends into the large Oddstue. The stream disappears down a slot before the pitch is reached to enter as a warm spray behind the chamber. A hole in the floor leads to very awkward vadose trenches and silty crawls where the stream is last seen.

South from Oddstue a large passage proceeds for 45m to a silt choke. A wall of sediment can be climbed on the north of Oddstue to enter Sand Passage which is mainly a wide crawl for 60m to a side chamber and aven. A smaller crawl continues with a strong draught for another 40m to a dig with ice formations.

Invasiongrotta was aptly named by Odd Johansen as clearly the existing stream has invaded an older phreatic tunnel (probably an early course of the Jordbruelv), washing away the 2m high sediments at Oddstue. The cave lies above the Vatnhullet sump, to which the water probably flows as evidenced by the signs of silty water backing up at the bottom. The southern end of the cave is heading directly for Vatnhullet. The ice at the northern end indicates the proximity of another entrance, and the survey (Fig. 7) shows that short connections to Cliff Cave and Beehive Cave could be dug.

Vatnhullet/Main Rising System 15964610 A 300 L 650 D 35

A black loose shakehole against an overhanging cliff has an impressive ramp leading to a gloomy lake. This has been dived in a very large passage for 340m at a bearing of 355 degrees via a maximum depth of 20m (Fig. 7). Exploration ends at small roof tubes at 5m depth. A shaft at 240m rises 5m to a passage with too strong a current. 50m from the dive start is the junction with a 150m generally large loop passage leading to the Main Rising. This loop passes below a large conical shakehole where vegetation enters. Sumped passages also head north towards the Jordbruelv Fourth Sink Area. There must also be an as yet unexplored connection to the sump in Ramp Cave. Upstream connections are also expected to the Jordbruelv Sink Areas 1, 2 and 3. It is possible that the water from the Etasjegrotta Surveyors Sump flows independently to a large unexplored sump at the east end of the Vatnhullet entrance ramp, rather than directly to Whybro Passage from which it is only 150m distant. All the sumps between Vatnhullet and Etasjegrotta share a common water surface at an altitude of 285m.

The total explored sump length in this system is about 580m, a similar length to Norway's previous longest sump at the Glomdal Underground Outlet in Rana. However, with no entrance at the northern end, a longer return dive has to be performed, and the unexplored potential is still high.

The system is worth visiting in winter. With lower, frozen, water levels it is possible to walk into both entrances and admire spectacular ice formations. If this system could be connected to Invasiongrotta, a cave well over 1km long would result.

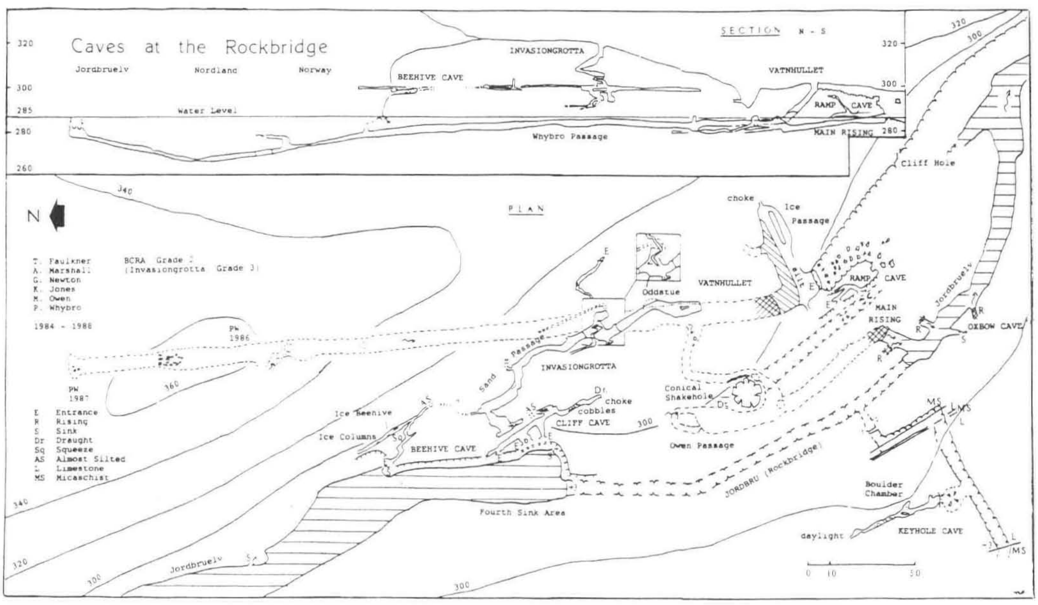
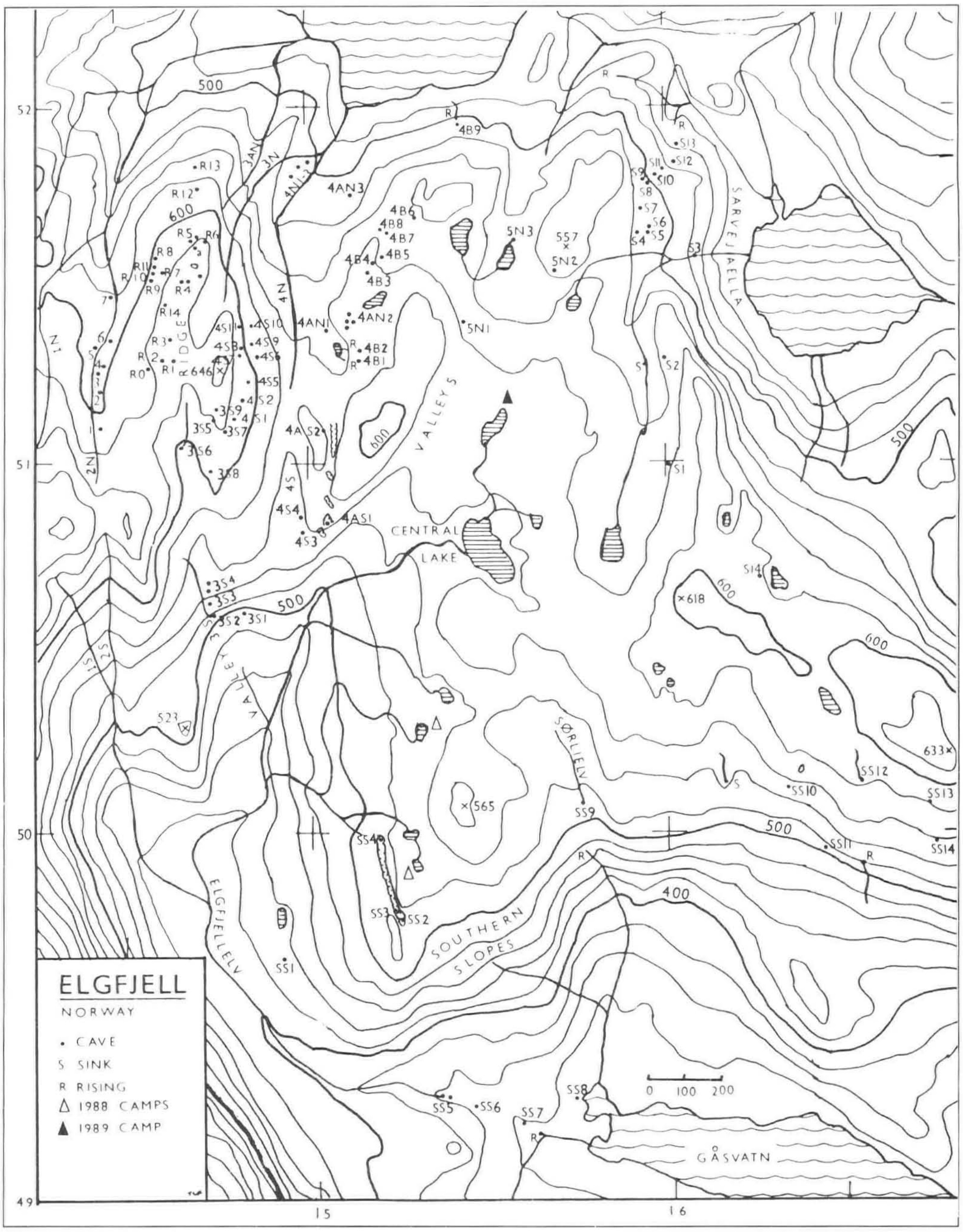


Figure 7.

Figure 8.



ELGFJELL

Below the steep eastern slopes of Jordhulefjell (1050m) lies Elgfjell, an upland area roughly 8 square kilometres in extent with several peaks about 600m high. It is also bounded by the two upper Gaasvandene to the north, the river Gaasvasselv to the east and the main Gaasvatn to the south. Several long outcrops of marble of Cambro-Silurian age traverse the fjell in a general northerly direction, the chief other country rock being mica gneiss. The Jordhulefjell ridge comprises mica schist and calc-silicate gneisses. The geology has strongly influenced the morphology of the area, with (particularly to the west) valleys and ridges running from the south parallel to the marble outcrops, with counterparts on the north side of the fjell.

Two main types of marble facies were observed: a pure grey variety and a yellow-brown striped variety, with locally some intermediate variations. The grey marbles often outcrop as attractive pavements with distinctive karren features. Many shakeholes were found at the junction of the two marble types, although caves are plentifully formed in both marbles. The geological controls on speleogenesis in marbles of similar appearance at Lower Glomdal, Rana, have been described by Bottrell, 1988. Unlike the near vertical bands of marble seen in most other areas near the river Jordbruelv, on Elgfjell the marbles usually dip at about 60-70 degrees to the west.

For convenience of exploration and description, Elgfjell has been divided into several sub-areas (Fig. 8). West of the Central lake, Valleys 1 to 5 have north and south counterparts and Valley 4 has important upper dry valleys. To the NE is an area marked as Sarvejaella on the local 1:50,000 map Tosbotn. (Sarvejaella is Lappish for Elgfjell: the remoteness of the area is indicated by the lack of distinguishing place names). "Southern Slopes" comprises the whole area south of peak 565, including features on the stream Elgfjellelv which drains a large snow patch at the foot of the Jordhulefjell wall.

The main drainage is from the Jordhulefjell ridge into Valleys 1S, 1N and 2S (none of which contain enterable karst features), into Valley 2N, and via mountain streams from ridges and tarns on Elgfjell into Valleys 3, 4N and 5, and into lesser valleys and into valleys on the side of Sarvejaella. The large valley 4S is dry in summer. 123 entrances on Elgfjell were recorded, leading into over 80 caves with a combined passage length of over 5km. Most of these caves are old, abandoned, often large and predominantly phreatic in development. Where present streams do enter them as in Elgfjellhola, Gevirgrotta, Buktgrotta and Sarvejaellagrotta these can be seen to be misfits or have caused a later stage of development. Several other streams sink underground into immature systems which cannot be followed very far: these are especially found in valleys 2N, 3N and 4N. Very few speleothems were observed in the caves. Spisestuehullet is somewhat unique with stalactites up to 20cm in length. However, with their open entrances or shafts, several caves contain the bones of large animals. One, which was not atypical, has been identified as the lower jaw of a brown bear, *Ursus arctos*. Complete skeletons were not observed, and many bones were gnawed indicating scavenging by smaller mammals. It is thought that the larger bones also derive from elk and reindeer. The accumulations of bones have

Entrance to Elgfjellhola at junction of grey marble and brown stripey marble. (Photo: T. Faulkner)

been left undisturbed for later scientific appraisal.

In summary it can be noted that Elgfjell contains the highest density of caves in South Nordland, and is indeed a significant new Norwegian caving area. Many of these caves occur in the ridges rather than in the valley bottoms, often near the cols separating the southern from the northern valleys. The large size of many of the abandoned passages, totally unrelated to present drainage, indicates sub-glacial development or perhaps pre-glacial origins in line with the theories of Tertiary formation for the caves further north in the Rana area of Nordland (Haugane and Grønlie, 1988). In several places on the plateau of Elgfjell are remnants of old stream courses which seem out of place. These may have formed sub-glacially, perhaps feeding the large remnant passages which are found today.

Although no attempt has been made to represent the complex sequence of marble outcrops on the Elgfjell Area Map, it would be an interesting exercise to map them and compare and contrast the caves formed in the two main types of marble.

A strong similarity among three separate systems would also warrant further study. These are: Sarvejaellagrotta, Pustehola, and Jordhulefjellhullet, which is on the other side of the mountain (Faulkner, 1987b, p. 42). These all have a large phreatic passage at depth reached via entrance crawls and climbs and terminate at ascending shafts which reach to (or near to) the surface. Captured misfit streams cut narrow deep slots in their floors. They all occur below sloping pavements of bare grey marble which are often overlain by thick snow cover, even in summer, and may therefore share a common history.

Four sink caves on the northern slopes of Elgfjell also share common features. These are Twisting Stream Cave, Gevirgrotta (the active streamway), Buktgrotta and Zig Zag Cave. These are all essentially vadose with incised meanders and reach depths up to 30m. They appear to have been formed by their present streams, indicating a probable post glacial origin.

Southern Slopes

This area collects together the rather disparate features south of hill 565. Valleys 1S and 2S drain to a snow patch at the foot of the steep Jordhulefjell wall. The stream named Elgfjellelv by the expedition runs out of this snow patch, flowing east. It sinks at Elgfjellelvgrotta and runs via the waterlogged Alligator Cave to an impenetrable rising near Gaasvatn.

The area between points 565 and 633 is characterised by a number of shallow valleys oriented roughly N-S toward the steep southern slope of the fjell.

Sørlielvgrotta (SS9) 15775008 A 510 L c.70 D c.15

500m east of hill 565, the small Sørlielv sinks into a steeply inclined shaft measuring 6m x 4m in a large depression. Downstream a 50m long gallery over a pebble floor leads to crawls to daylight. On the west side at the base of the shaft crawls lead to an ascending passage with connections back to the side of the shaft below the lip of the waterfall. The stream rises impenetrably on the hillside near the end of the cave.

Tackle: 10m ladder, 4m belay.

The second shallow valley is not initially on limestone, but some minor sinking occurs lower down. Further east again an obvious, massively bedded, band of grey marble has many superficial karst features some of which issue a surprisingly cold and strong draught, including Fewmet Cave (SS10).

Jolly Roger Cave (SS11) 16454995 A 510 L c.120 D c.35

A very cold draught blows outwards from the entrance squeeze which leads to a short arched crawl above a blind 6m rift. To the east (right) are two crawls which unite to form an ascending ramp along a blade of rock which can be descended underneath to a roomy climb down. This passes a blind tunnel before reaching the bottom where it interconnects an occasional streamway. Downstream is a crawl, climb down and a too tight rift. Upstream follows the draught through low sandy crawls to a roomy ascending ramp. This is interrupted by a short crawl before climbing to a cross rift and dig to a second cross rift. Daylight is seen from a climb above. The strong cold draught comes from an impassable rift opposite (east).

Valley 2N

About 1.5km long this valley runs northward for 1.2km before turning east along the foot of the "Ridge" and entering Øvre Gaasvatn. It has been investigated as far as the junction with the stream from valley 1N. Below this the stream can be seen running down a gorge without noticeable loss of water until it nears Øvre Gaasvatn.

The upper part of the valley contains marble bands running along the length of both sides and the valley floor. The marble is mainly of the pale grey variety. The bands are partially covered with grass but many areas of exposed rock are also present exhibiting well developed limestone pavement and karren. There are many shakeholes and open and partially blocked cave entrances.

Only the limestone in the valley floor had caves which were open for significant distances. The cave systems here are relatively superficial and immature but there is the potential for the discovery of one or more integrated drainage systems. Currently only 200m of cave has been found but pushing wet or tight passages or digging would undoubtedly yield worthwhile finds. The resurgences are impenetrable.

Shatter Pot (2N6) 14485134 A 590 L c.70+ D c.9

This is the most prominent feature in the valley, situated on the east side of its floor, against a mica gneiss wall. It is a shaft about 10m long, 3m wide and 5m deep with a snow plug. A further climb down at the north end becomes choked after 3m. To the south a choice of routes (one at a higher level) rejoin after 8m in the vicinity of a wide low passage. A side passage becomes too tight after 13m. The stream is met sinking under the west wall. Upstream past a window is walking sized before becoming wide,

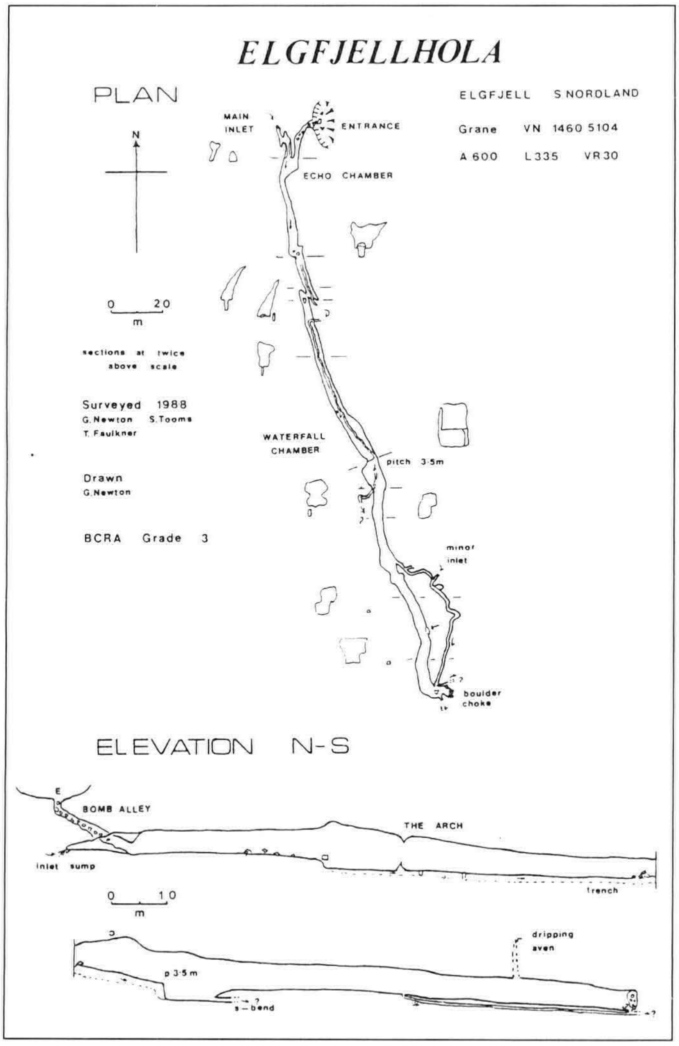


Figure 9.

low and possibly sumped, near surface shakeholes where the stream could be heard. Beware loose boulders!

Valley 3S

This is about 1 km long. It descends gently from the col between the "Ridge" and point 646 with a pronounced step downstream of Elgfjellhola before it enters Valley 5 as a hanging valley. The marbles run approximately N to S but are not strictly parallel to the valley.

The northern section of the valley is dominated by exposed bands of yellowish brown marble streaked with micaceous impurities. These merge into the western slopes of the valley in the vicinity of Elgfjellhola. Below the above mentioned step the valley floor is mainly grass covered. Grey marbles are exposed occasionally on the eastern slopes of the southern section and on the edge of the hanging valley.

Elgfjellhola is the main cave of note. It is in the yellowish brown marble. The grey marble also has some impressive but shorter cave features, notably The Big Pitch (3S5) and Secret Stream Cave.

Secret Stream Cave (3S8) 147511 A 610 L 72 VR 29

In the southwest facing flank of the spur just S and E of Elgfjellhola. The entrance is a large south facing passage in schist caused by collapse of the underlying grey marble. A steep slope descends to a crawl over blocks at the head of a short steep tube into a large phreatic passage. A stream can be heard from a small impenetrable hole in this vicinity. The main passage ends in a silt choke.

Elgfjellhola (3S6) 14605104 A 600 L 335 D 30

In a prominent shakehole in the west side of Valley 3S where two small streams sink in wet weather. A climb down over loose boulders leads to an arch. On the other side of the arch is a large chamber, where the main inlet enters in the right hand corner. This can be followed for 20m up a meandering rift passage to a sump.

The main passage continues up to 6m high and 5m wide in a

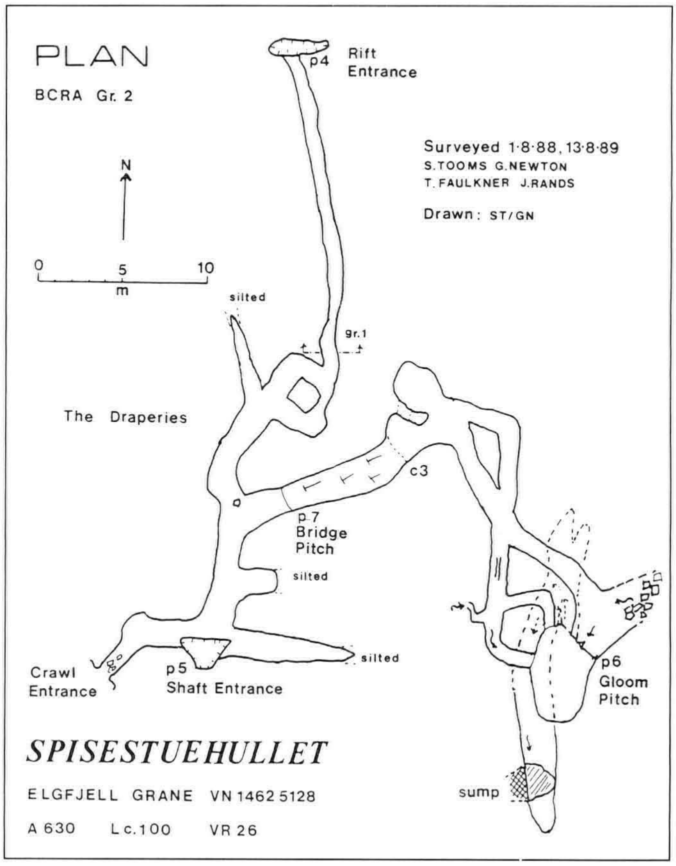
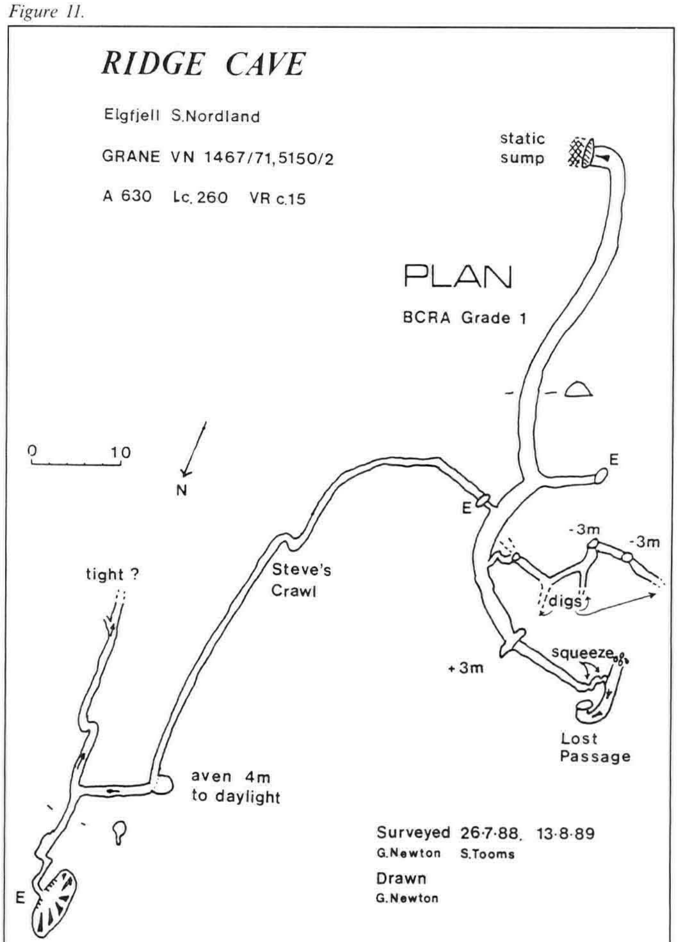


Figure 10.

Figure 11.



southerly direction. The stream runs in a narrow trench in the floor up to 2m deep. About halfway along the main passage is a 3.5m pitch into a magnificent chamber. Shortly after this the stream runs into a tortuous passage. The main passage continues beyond the stream sink and eventually ends in a massive draughting boulder choke. There is a 60m crawling oxbow and two tight avens about 10m high in the final section of main passage. Beneath the pitch the main passage is around 5m high and 3.5m wide. The passage profile here suggests an initial trunk phreatic phase, perhaps under an icecap, followed by a substantial vadose period. The current streams are invasive (Fig. 9).

The Ridge

The "Ridge" is bounded by Valley 2N to the west, the spur running east from Jordhulefjell to the south and parts of Valleys 3AN, 3N and 3S to the east. The predominant marbles are yellowish brown, streaked with bands of micaschist impurity. They generally run north to south, with local variations. The southern half is fairly level and slopes very gently down from the Jordhulefjell spur for 0.6km until a prominent knoll of mica gneiss is reached. This area contains the major cave systems found on the ridge to date. The whole ridge is largely covered with grass and is pockmarked with shakeholes and shafts. Those at the southern end are mainly choked.

The flanks of the ridge have more pronounced exposures of marble. The group of "Draughting Caves" on the slopes of Valley 2N are included for convenience under the Ridge. The northern slopes of the ridge are mostly of featureless birch scrub, which is difficult to search. The lowest northern slopes have not been examined.

Ridge Pot (R1) 14645128 A 630 L c.140+ D c.13

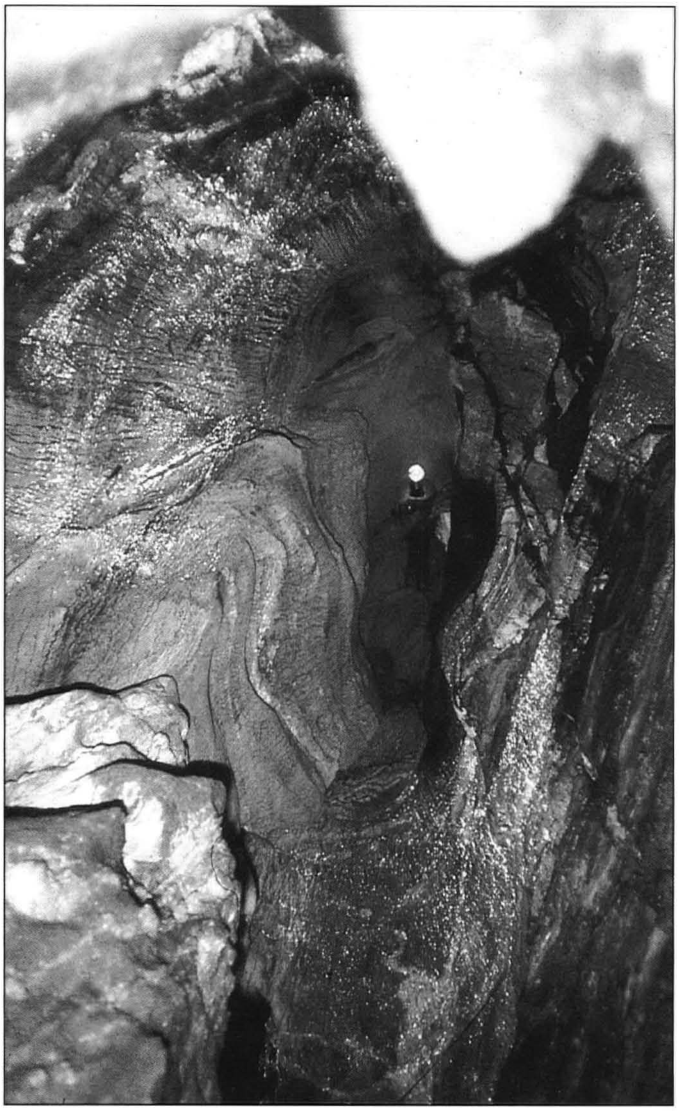
Two very large shafts on the centre of the ridge, in the same marble band as Elgfjellhola. The southern funnel-shaped shaft contains a snow plug and is blocked by boulders. However a high level passage gives access to the northern shaft. Passages leave this at three levels. The highest can be reached using traversing techniques. This is a crawl heading north for 22m, passing stalactites, a too tight shaft to the surface, and an 8m passage to a window. It ends at a partial silt choke. A ledge on the shaft at the same level gives access to a climbable shaft and the middle (longest) crawl ending in a partial silt choke. The lowest passage leaves the foot of the northern shaft and can be followed for 18m.

Spisestuehullet (R2) 14625128 A 630 L 100 D 26

A T-shaped 5m shaft to a high level series of dry passages can be bypassed by an entrance squeeze beside a boulder and by a narrow rift entrance into a crawl passage (Fig. 10). These passages contain the best formations on Elgfjell. A 7m pitch leads to a large shattered chamber where an intermittently wet pitch descends 6m (Plate 8). The passage from the foot of the pitch continues large, but soon lowers into a sump. Short side passages lead from the large chamber, which also has a boulder choke. This is probably underneath the choke at the bottom of Ridge Pot.
Tackle: 3m, 8m and 8m ladders, 2-5m belays.

Ridge Cave (R4) 14675150 A 630 L c.260m D c.15m

The cave is under the northernmost flat area of the ridge between valleys 2N and 3N. The main entrance is in a large shakehole immediately SE of a prominent knoll of mica gneiss.



Shaft at Upper Entrance, Brown Stains Cave. (Photo: J. Rands)

The cave has two other entrances and is largely a complex of crawls in phreatic tubes floored with wet sand with occasional avens and short climbable pits (Fig. 11).

Valley 3AN

About 0.6 km long, this valley leaves the eastern flank of the Ridge about halfway along its length and joins Valley 2N just before Øvre Gaasvatn. The lower 200m was not investigated.

At the entrance to Sarvenvaartoehullet with Gaasvasstind in the background. (Photo: T. Faulkner)

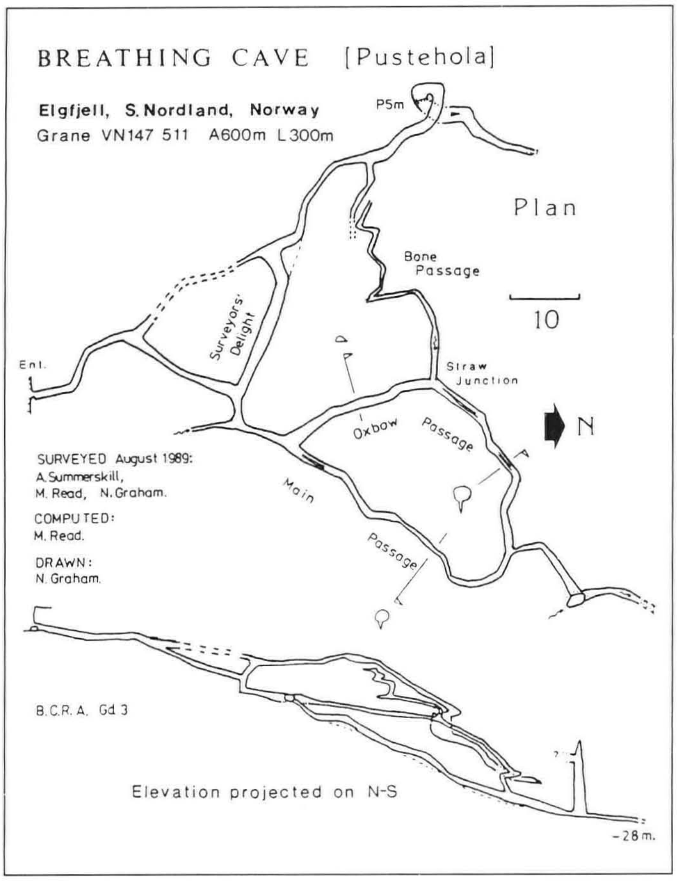
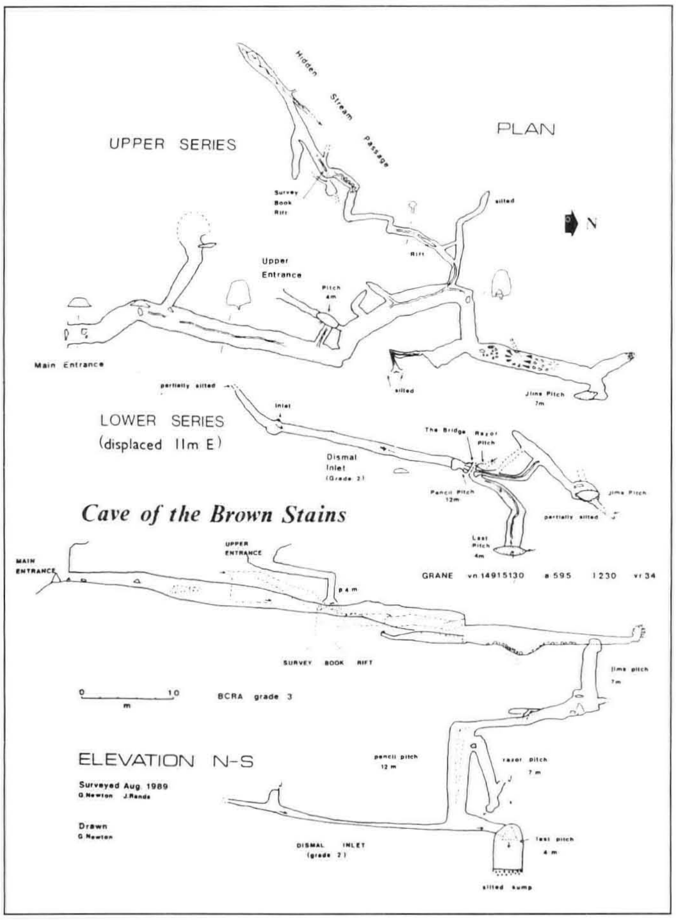


Figure 12.

Figure 13.



Although this valley has shakeholes, some marble outcrops and an intermittent stream, no significant caves were found. The wooded ridge between this valley and 3N contains at least one small remnant cave and others could well exist. Both the valley and its karst features appear to be immature and potential is limited.

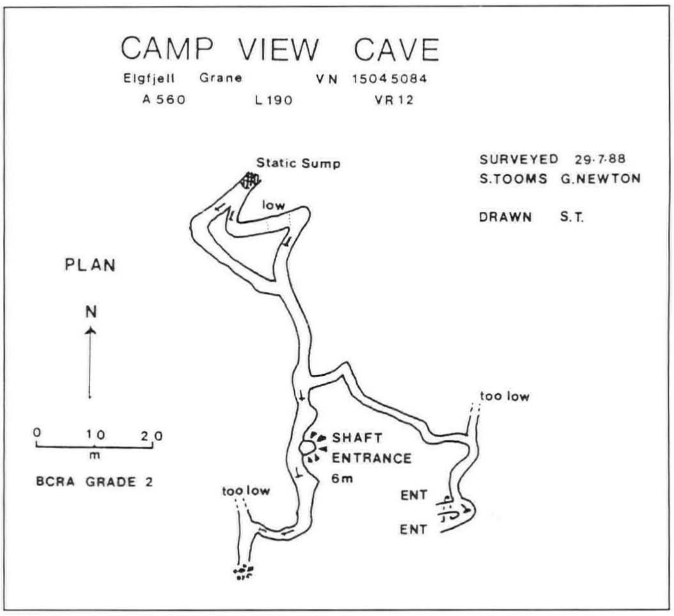


Figure 14.

Valley 3N

This runs north from the col between the Ridge and summit 646. Descent is first moderate, then fairly steep as it falls into Valley 4N. Marble and shakeholes are much in evidence but there are no enterable caves and both valley and underground drainage appear superficial. Ridge Cave main entrance is quite close to the valley and there are some major shakeholes in the downward continuation of the same marble band. All are choked with boulders.

Valley 4S

This runs south from the col with Valley 4N until it meets Valley 5 as a hanging valley about 0.5km later. There is no stream in the valley floor but there are many choked shakeholes and shafts. The western slopes of the valley are dominated by a large band of pale grey marble which forms extensive areas of limestone pavements which are visible from a considerable distance. These contain many caves among its clints and grikes and continue about 400m north of the col with Valley 4N. The caves however are all included in 4S for convenience. The eastern slopes are bounded by a low ridge covered in birch scrub which separates it from the higher Valley 4AS. Determined searching may reveal more caves in the limestone pavements.

Musk Cave (4S2) 14805117 A 610 L c.150 D c.30

In the grey marble band, 100m NE of 3S5. A short entrance rift enters a large meandering tunnel in white marble with a sandy floor. South trends up to a choke. North descends steeply, encounters a small stream and finally silts up. This cave was buried under snow in 1989.

Pustehola (Breathing Cave) (4S5) 147511 A 600 L 300 D 28

Situated about 100m south of 4S6, the entrance is partly obscured by boulders in a south facing edge of pavement 2m high. The cave is an interesting phreatic network, much of it walking size, with misfit streams. There are several avens, one with an unexplored lead at the top. The lower extremities of the cave end in chokes, one at the foot of a fine corkscrew pitch. Further extensions are possible. (Fig. 12).

Cave of the Brown Stains (4S6) 14915130 A 595 L 230 D 34

The main entrance is an arch partially obscured by a large boulder, situated in a low south facing wall of rock in the limestone pavement. The entrance gives access to a fine walking size phreatic tube descending to a choke. Just before this a short side passage leads to the lower series including 3 pitches. The final pitch, which requires a 5m ladder, ends in a choked sump. Other pitches may possibly be free-climbable. The upper series has several side passages of varying length, including one to an alternate entrance. A side passage in the lower series has potential for extension. The cave has a distinct odour from the brown deposits, reminiscent of Musk Cave. (Fig. 13).

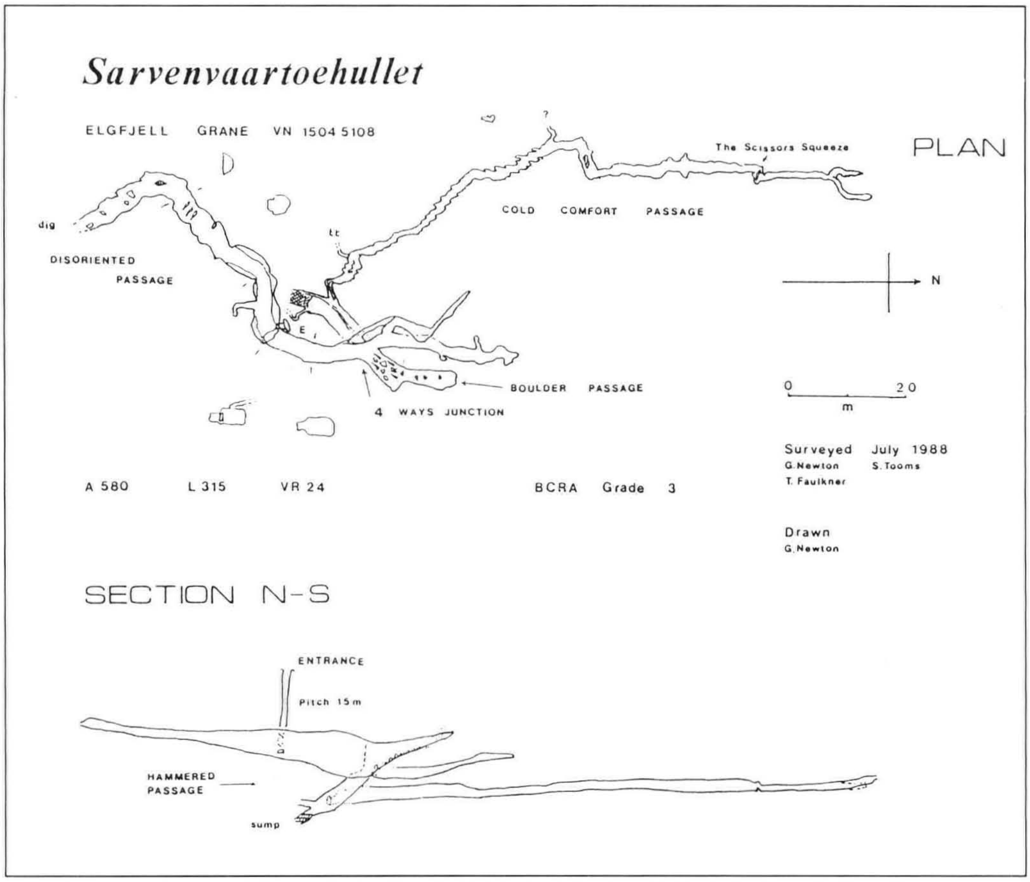


Figure 15.

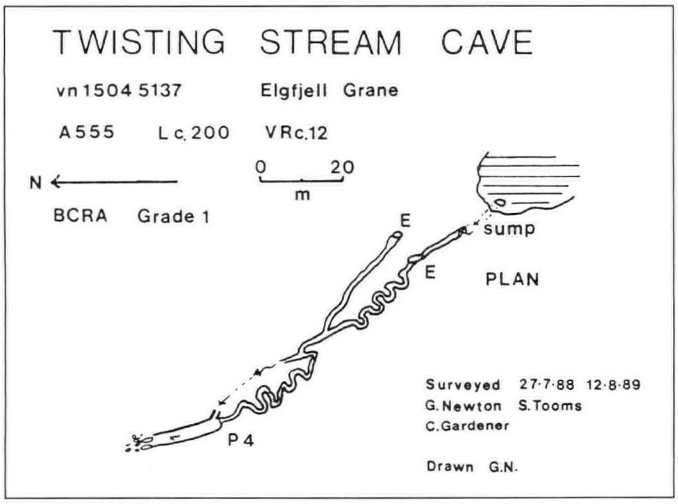


Figure 16.

Valley 4AS

A confusing mixture of grass and birch scrub between complex low ridges with more birch scrub. The valley, which overlooks 4S to the west, starts from the hanging area at the side of Valley 5 and runs for about 0.5km to a col.

Camp View Cave (4AS1) 15045084 A 560 L 190 D 12

Three entrances near the slope into Valley 5 give access to a complex of sandy floored tubes. Progress is mostly by easy crawling or stooping, ending in a sump (Fig. 14).

Sarvenvaartoehullet (4AS2) 15045108 A 580 L 315 D24

About 30m north of the crest of the col between Valleys 4AS and 4AN, near the crest of the ridge between Valleys 4 and 4AS, about 10m above the floor of Valley 4AS.

The small triangular entrance occurs in a tiny shakehole in a small mound at the junction of the stripey (west) and grey (east) marbles and leads directly to a pitch. Another route just inside gives slightly easier access. The tight entrance shaft is free climbable to a hole near the roof of a large dry passage 5m high and 3m wide. An 8m ladder is needed to gain a rock bridge in the passage, whose floor is 15m below the entrance. Descending tl passage leads to a steeper section to a sump pool. A tortuous inl above the sump pool was pushed 10m round a sharp corner. The are four ascending side passages in the right hand (west) wa before the sump. The longest is an inlet, Cold Comfort Passag about 115m long. Upslope beyond the rock bridge at the ladde passes some interesting floor deposits and mud formations befor choking. The cave is very cold (Fig. 15).

Valley 4N

This runs for about 1km from the col to 4S north to Øvr Gaasvatn. There is a low ridge dividing the wide valley into tw halves: the eastern half is separately referred as 4AN. Drainage ir 4N is underground in the upper southern part.

In the lower part the stream runs intermittently and the underground course can be followed from one entrance for a short distance. There are shakeholes and areas of limestone pavement and many choked flood sinks and resurgences.

Valley 4AN

This is conveniently divided into three sections. The southern section is relatively narrow and is dominated by marble bands in the valley floor which have many shakeholes choked with boulders. The valley is the continuation of Valley 4AS over the northern side of the col containing Sarvenvaartoehullet. The central section contains a small lake fed by resurgences along the length of the east bank. The lake drains from an obvious sink at its northern end and feeds 4AN1. In the northern section the stream runs mostly underground and there are many shafts, shakeholes and entrances. However, nothing can be followed for a significant distance as the passages are probably very immature.

Twisting Stream Cave (4AN1) 15045137 A 555 L 200 D 12

55m NW of the small lake. The entrance is a climb down into a streamway fed from a sump in the NW corner of the lake. Upstream becomes very wet within 20m. Downstream is a tight twisting canyon in grey marble, eventually degenerating into a low wet crawl not pushed. Shortly before this, a dry oxbow is the way on. A dangerous boulder choke is passed low down to more dry twisting canyon. Eventually it opens out in the roof of a large passage close to a fine waterfall which emerges from a very tight hole. The large passage enters an unstable area where further progress is difficult and dangerous. Near the main entrance a dry side passage leads to an obscure tight side entrance. (Fig. 16).

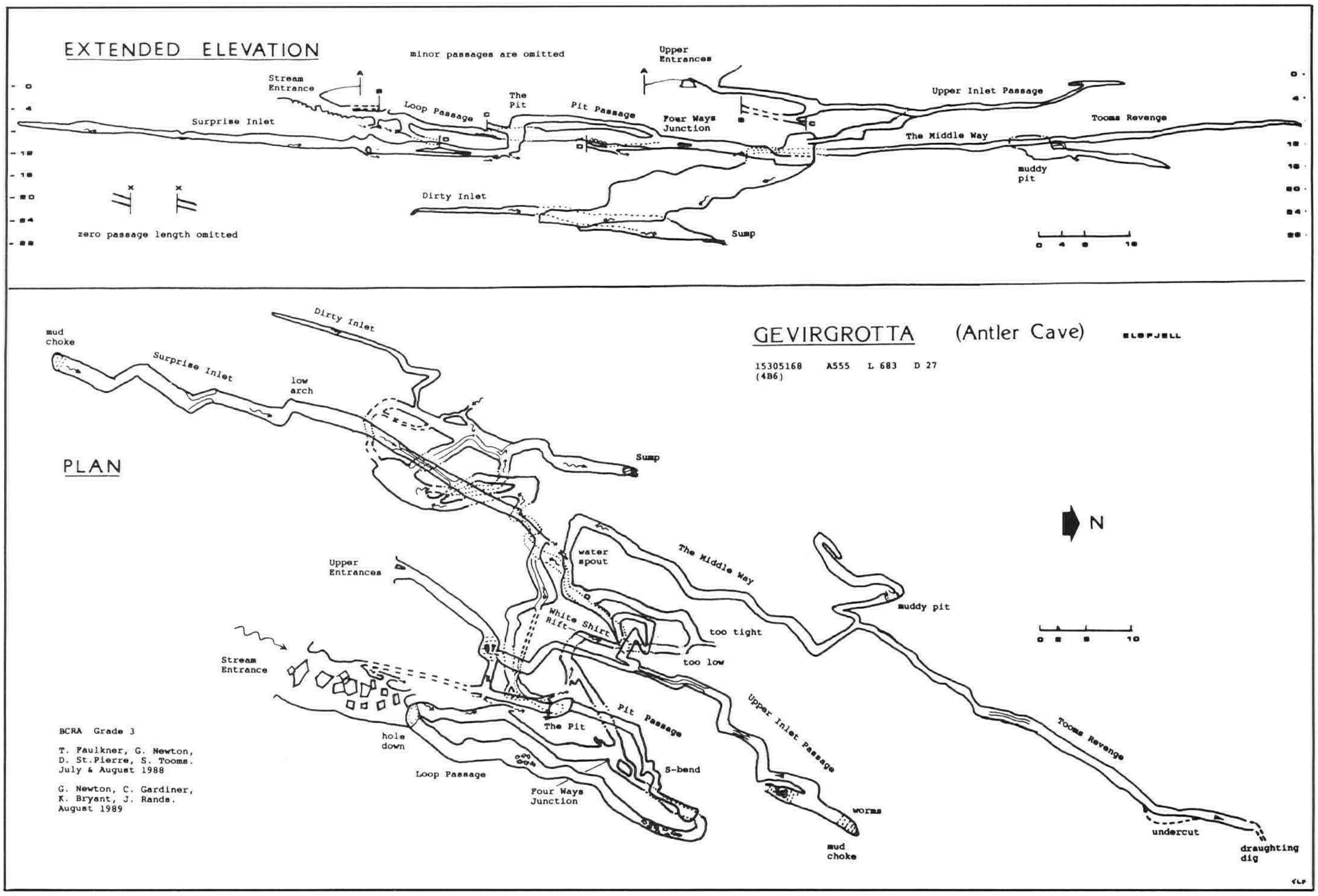


Figure 17.

Valley 4B

This is a closed valley about 0.8 km long draining to Antler Cave, to which the caves north of Snow Cave are probably related. The caves in the upper part of the valley are believed to drain to the small lake in Valley 4AN.

Gevirgrotta (Antler Cave, 4B6) 15305168 A 555 L 683 D 27

A complex fascinating cave with a lage entrance where a small stream sinks at the blind north end of Valley 4B. The system has clearly had a multistage development with passages formed at three levels (Fig. 17).

Upper entrances, to the west of the sink, lead to a sinuous phreatic tube which connects with the roof of the lower streamway. A route also leads down to the top of the Pit, and another passage ascends north towards the surface.

The rocky main entrance chamber ends at a hole down to the streamway. Across the hole a dry phreatic passage goes in a loop to rejoin the streamway, here temporarily abandoned. A connecting passage also reaches the far side of the Pit. Vadose downcutting forms a steeply incised meander with round roof tubes and passages, one of which goes northward at the middle level; a long small side passage leads to a long term dig. The stream itself drops to a chamber with a series of low crawls to a sump and small dirty inlet passages. From the foot of the Pit the large Surprise Inlet goes back under the valley floor, heading towards the small caves to the south. It passes mudbanks and a short crawl and terminates after 85m at a choke.

The resurgence near 4B9 is 200m away along the strike to the

View towards entrance, Gevirgrotta. (Photo: C. Gardener).

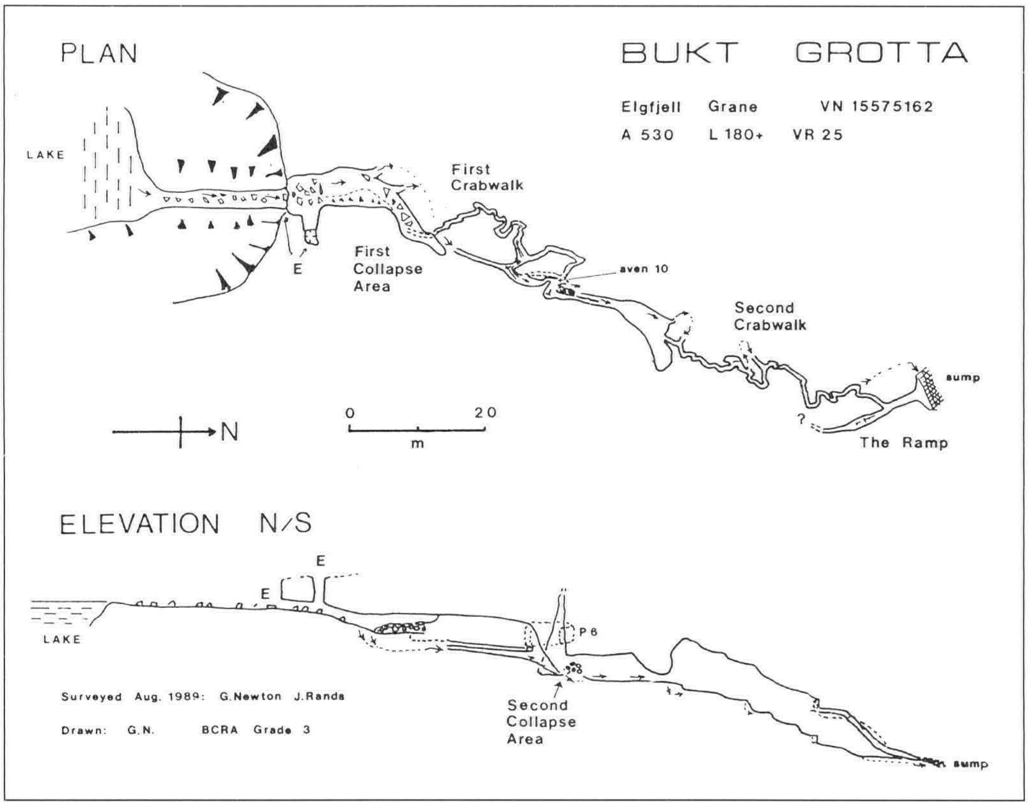


Figure 18.

north, and about 55m lower in altitude.

Valley 5S

This runs SW along the side of a large ridge, west of the Central Lake. The west bank receives valleys 4AS, 4S and 3S as tributaries. There are two significant streams and a number of minor ones entering from the east. The stream in the valley floor is intermittent at the upper end but underground drainage is superficial and immature. Although there are sinks and resurgences, none can be followed far. The eastern tributaries have a number of mostly grey marble bands with large shakeholes, karren and many shafts. All these features are very short and have not been individually recorded.

Valley 5N

North of Central Lake is a flat area gradually forming Valley 5N. East of Antler Cave a tarn drains east into a second tarn which is situated in the floor of 5N. The stream from this tarn runs into the obvious shakehole, 5N3. The steeper part of Valley 5N occurs below the sink and a few hundred metres north are more shakeholes, without entrances.

Buktgrotta (Crabwalk Cave, 5N3) 15575162 A 530 L 180 D 25

After 8m, the stream from the tarn sinks. A steep 2 x 2 passage descends until blocked by collapse. A roof level crawl over debris ends at an 8m climb down to the start of a dry meandering Crabwalk in solid marble. After 30m a drop into a similar stream inlet enters the foot of a 10m high aven. The right side of the Aven is formed by a band of schist which has collapsed into the streamway. Two ways over the debris go 10m to a drop to a passage and small chamber with a roof inlet. A second Crabwalk with climbs down leads after 40m to a junction just above a permanent stream sump. The cave is generally loose and steeply descending (Fig. 18).

Walking along the strike failed to identify the resurgence. It will almost certainly be east of the stream which flows in the northern end of Valley 5N. The resurgence marked on Fig. 8 north of hill 557 is rocky and impenetrable.

Sarvejaella

Marble crops out north and east of hill 618, but with few karst features. The stream draining the tarn east of Central Lake inter-

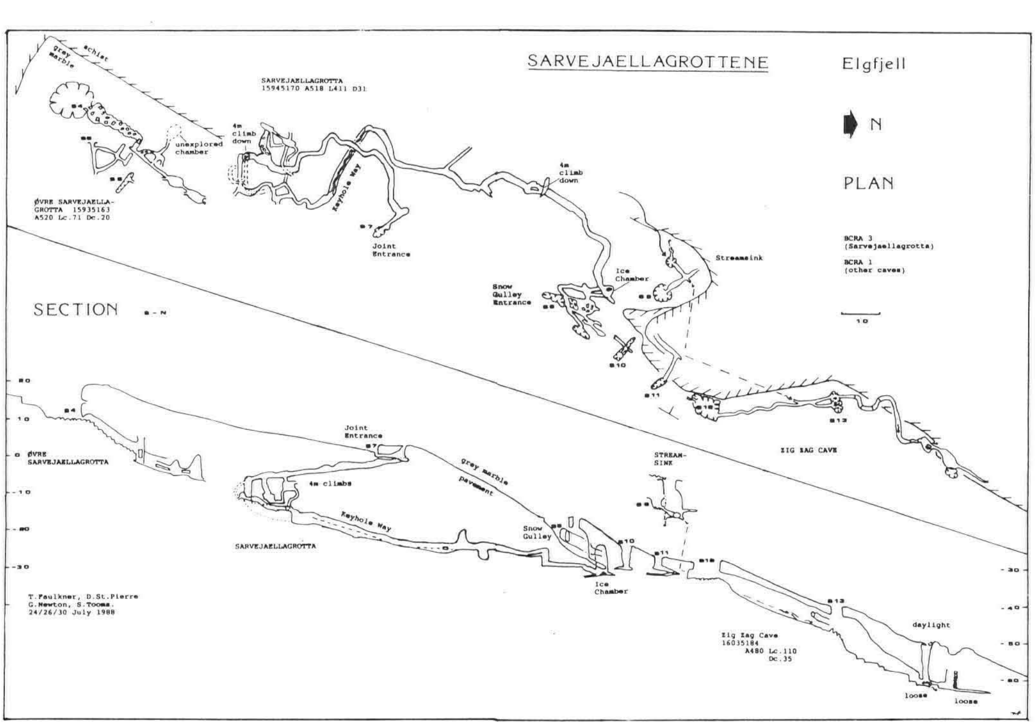


Figure 19.

mittently sinks near feature S2 before flowing east and joining a stream running from a small tarn south of hill 557. NW of the junction of these two streams a fine pavement of grey marble can be followed down the hillside to the north.

Øvre Sarvejaellagrotta (S4) 15935163 A 520 L c.71 D c.20

This has a dry shakehole entrance at the southern end of the outcrop. A dry rocky slope descends to a block at a cross rift. A drop down and left turn into a canyon leads to a junction. The passage on the left has tight connections back to the first passage and a narrow rift into a chamber which has been seen but not entered. The main route leads to a tall rift into two chambers with various alternate routes and squeezes forward (Fig. 19).

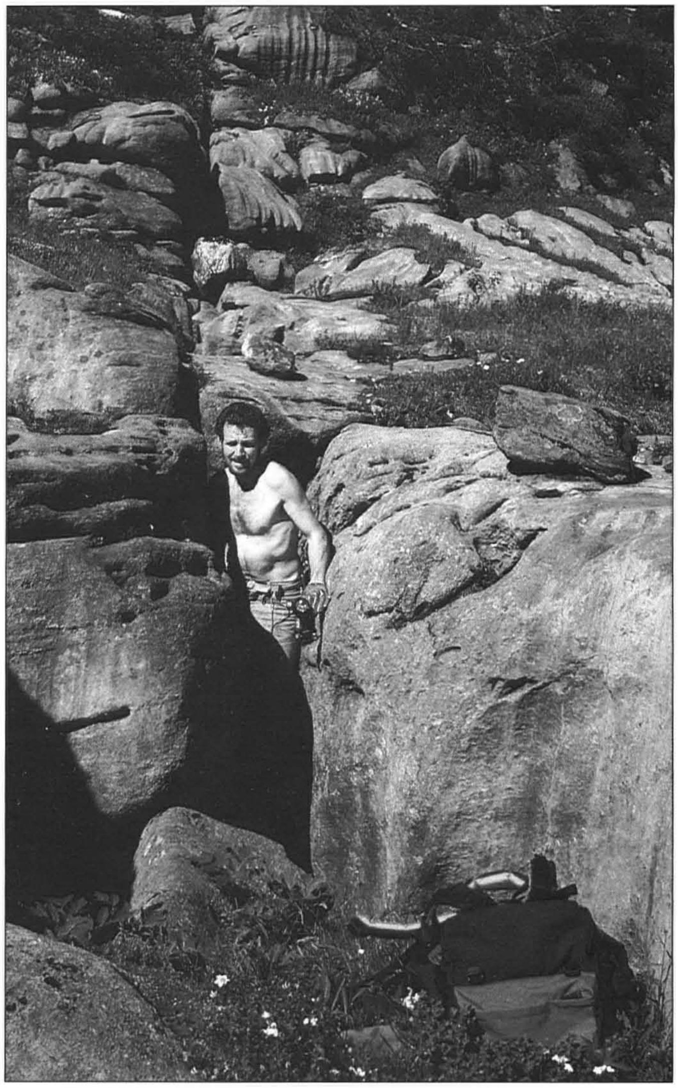
Sarvejaellagrotta (S7, S8) 15945170 A 518 L 411 D 31

About 100m north is a very large joint running across the marble pavement with the S7 entrance at the east end. A crawl along the joint surprisingly turns left and enlarges to a junction. The main route is to turn left to a tricky 4m climbable pitch at the head of a long trunk passage. This has a general keyhole profile with oxbowing roof passages near the start. There are also two other routes into this from the entrance passage, both involving climbs. The trunk passage becomes a circular tube with a narrow trench leading to a second 4m climb down at a rift. From its foot a crawl tube leads into Ice Chamber, with ice stalagmite and short crawls off. A 5m ladder pitch down enables this chamber to be reached by climbing down a snow gulley at entrance S8 which is situated further north and lower down the pavement. Lower passages below the snow gulley have an aural connection with the next entrance shaft, S10 (Plan and Section, Fig. 19).

Zigzag Cave (S12, S13) 16035184 A 480 L c.110 D c.35

Another shakehole, north of S11, has an entrance into a truncated 5m high meander passage with a zigzag profile. The stream from S9 enters via a tiny crack after 20m. Still descending, the meander passes below the second open entrance at S13. An upper passage also emerges here. Beyond the S13 shaft, the meanders become more incised with several metre high drops until a daylight shaft is reached. A dry loose crawl forward was excavated to reach a small chamber. A second even more frightening excavation into a tight rift ends at a choke. The small stream resurges impenetrably lower down the hillside.

The Sarvejaella caves are formed exclusively in the grey marbles which in the lower part dip at 60 degrees to the west under micaceous rocks. It is postulated that S4 - S11 (except S9) originally formed one phreatic system fed by the stream from the small tarn south of hill 557 before this stream diverted to the east. The vadose ZigZag Cave is fairly large and may have originally formed by the Sarvejaella stream rising at S11 and flowing over the surface before falling underground at S13 then S12. S9 is immature and the present underground stream purely a misfit capture. An alternate theory is that all the Sarvejaella caves have been formed primarily by spring snow melt running underground. A visit at May or June time would be interesting.



The Upper Entrance to Sarvejaellagrotta (Photo: T. Faulkner)

GAASVASSTIND

The marble outcrops crossing Elgfjell continue north across the highest lake of the Gaasvatn series, and small features G1 and G2 occur in dry valleys on the southern slopes of Gaasvasstinden, 925m. North of this peak a deep basin encloses an unnamed lake with several snow melt streams entering, but there is no surface outlet. Other valleys near the western headwaters of Gaasvassdal had no significant karst features.

Streamway in Gaasvasstindhola. (Photo: A. Marshall).

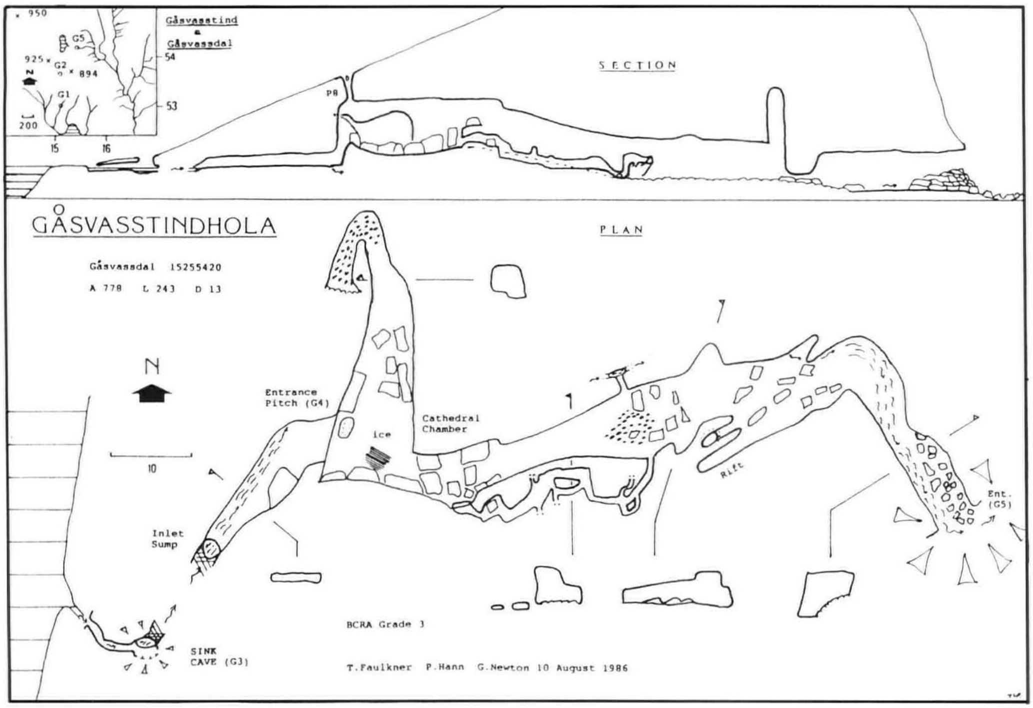


Figure 20.

Gaasvasstindhola (G4/G5) 15255420 A 778 L 243 D 13

The water from the lake runs into the short Sink Cave (G3) where it flows into a deep sump. A small hole (G4) in the hillside above is one entrance to the cave, an 8m ladder pitch into the huge Cathedral Chamber floored with ice. To the north a large dry tunnel littered with large blocks slopes upwards to end at a gravel choke. West of the ladder pitch is a low wide passage carrying the stream from a low sump. East from Cathedral Chamber a route over and between huge blocks leads into an even larger passage measuring 10m × 10m. The stream is briefly seen at the end of a short side passage before it emerges at an alcove in the left wall. This part of the passage is again strewn with large rocks and to the right are high rifts and avens. The roof drops and a climb down gains the final stretch of stream passage to a large entrance (G5) at the head of a steep waterslide down into Gaasvassdal. This entrance can be sealed in early summer by a 6m high cone of ice. South of the main passage is a complex of small passages and crawls connecting to it in at least two places (Fig 20).

Gaasvasstindhola has one of the largest passages known in South Nordland. It has formed by capturing water from the nearby lake, via the pitch entrance, now 10m above the present water surface, and via the northern limb of Cathedral Chamber, before the present Sink Cave was opened.

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APPENDIX: CAVES LISTING

Ref.	Area & Cave	UTM coords	S	A	L	VR	Notes S BCRA Survey grade * Reported previously in Faulkner 1987b
	BJØRKAASEN						
	— Bjórkaastjerngrotta	16404525	1	295	56	5	* Climb down to low ascending crawls
	— Restday Cave	16604480	1	290	55	4	* Near stream sink
	— Road Cave	16534430	1	310	25	6	20m south of the 803, chamber and canyon to sump
	— Anastomosegrotta	16544412	3	300	238	20	Linear cave formed at two levels
	— Bjórkaasgrotta	16904450	3	290	529	7	Complex maze with deep canals
	— Bjórkaas Rising	17134470	—		10	2	Submerged — undived (Plate 1)
	— Shaft Caves	16204353	1	395	40	15	6 shafts in line N — S with interconnections
	— Third Session Cave	15404275	—	520	10	2	Tortuous sink with pool at entrance
		Area Total			963		
	FJELLRYGGEN						
W1	— Wildmarksk. 1	20054560	—	230	16		Crawl to boulder blockage
W2	— Wildmarksk. 2	19954555	—	240			Dig
W3	— Wildmarksk. 3	19504545	—	245	6		2 levels — collapsed
	— Svartjern Rising	19454500	—	260	1		Small stream from tiny passage
	— Svartjernhullet	19424475	1	290	(16)	16	Dry shakehole to tight drop into chamber
	— Tregrottene	19424450	1	310	22	—	3 short caves at a limestone knoll
	— Stream Hole	19424433	1	350	(10)	10	Deep gulley choked with flood debris
	— Cave	19414430	—	350			Tight hole
	— Marmorgrotta	20004507	3	250	90	12	Wide chamber to strike passage to sumps
	— Sparkly Cave	20004430	1	370	18		45 deg. inclined rift with small stream from sumped sink
		Area Total			179		
	JORDBRUELV						
	— Bienjenbaektigr.	15804840	1	450	30		* Small cave at north end of Bienjenbaekti ridge
	— Bienjenbaektihul.	15834843	1	450	20	10	8m ladder or squeeze and climb down to choke
	— Bienjenbaekti Ca.	15954830	—	465	15		Fossil stream sink on scrub covered hillside
	— Bienjenbaekti Ent.	16004830	—	455			Unexplored
	— Archway Cave	15344800	1	475	30	20	15m below ridge, large shakehole to loose chamber
	— Ice Crawl Cave	15344780	1	430	18		Crawls connecting two shakeholes
	— Crawl Cave	15344773	1	430	23	3	Crawl to 2m shaft blocked by silt
	— T-Pot	15354755	1	400	20	10	* 6m climbable vertical shaft to chambers and crawls
	— Boulder Strm Sink	15304740	1	365	16		* Stream crawl
	— Jegerhullet	15724722	3	400	650	34	* Varied system with active and phreatic passages
	— Waterfall Hole	15804690	—	335			* Dig
	— Etasjegrotta	15824680	3	330	1085	42	* Complex multi-level stream cave
	— Dry Valley Cave	15724670	3	320	60	12	* Northern of 3 shakes into sloping rift
	— Ledge Opening	15804660	—	310	13		* Wide level crawl
	— Beehive Cave	15904630	1	295	61	4	* Crawls and larger passages with ice formations
	— Cliff Cave	15904620	1	295	66	4	* Spacious galleries
	— Keyhole Cave	15904605	1	310	50	4	* Diminishing passage to visible daylight
	— Invasiongrotta	16004620	3	318	354	27	Streamway invades old phreatic passage
	— Vatn./Main Rising	15964610	2	300	650	35	Active phreatic system
	— Ramp Cave	16004610	1	293	15	8	* 2 entrances to rising sump
	— Halfmoon Cave	16004608	—	293	40		2 entrances 10m above Ramp Cave. 3rd ent. too diff. to reach
	— River Cave	16104595	1	287	45	6	* Large tunnel to large sump
	— The Alcoves	16154580	—	285	6		* Short submerged tunnel
		Area Total			3267		
	ELGFJELL — Southern Slopes						
SS1	— Comforted Cave	14904965	—	430	10		Sink in yellow brown marble
SS2	— Karren Cave 1	15214980	—	510	(5)	5	) Shafts and
SS3	— Karren Cave 2	15214983	—	510	(4	4	) chambers in line
SS4	— Karren Valley sh.	15184997	—	510	(10)	10	) of shakeholes
SS5	— Elgfjellelvgrotta	15334927	1	360	50	10	Two sinks into large chamber and passages in white marble
SS6	— Alligator Cave	15404927	1	350	44	5	Deep canal and sumps to be dived
SS7	— Lake Cave 1	15554920	1	340	15		Sink cave at small rockbridge
SS8	— Lake Cave 2	15704930	1	330	6	1	Small sink cave
SS9	— Sørlielvgrotta	15775008	1	510	70	15	10m ladder in large inclined shaft to long gallery
SS10	— Fewmet Cave	16355015	—	550	10		Strong cold draught
SS11	— Jolly Roger Cave	16454995	1	510	120	35	A complex of ranges and crawls with strong cold draught
SS12	— Huge Sink	16555015	—	580			Collapsed. Resruges 60m lower from narrow rift
SS13	— Through Cave	168 501	—	580	10		
SS14	— Gethsemane Cave	168 500	—	560	40		A maze of shafts and through trips
		Area Total			394		
	ELGFJELL — Valleys 2						
2N1	— Scorpion Pot	14455109	3	610	58	12	Shaft to an upstream dig and low wet downstream
2N2	— cave	14455120	1	600	6		Upstream is too tight, downstream sumps
2N3	— Fourways Cave	14455126	1	595	33	5	3 entrances, upstr. & downstr. sumps. Fossil passage intersected
2N4	— cave	14465127	1	595	8	3	Upstream to sump. Downstream to boulders
2N5	— Sink	14445132	—	590	(3)	3	Shaft to boulder
2N6	— Shatter Pot	14485134	1	590	70	9	Large snow plugged shaft to upstream passage to possible sump
2N7	— Fummel Pot	14495146	—	580	24	5	Fossil passage descends at 20 degrees to sand chute
		Area Total			202		
	ELGFJELL — Valleys 3						
3S1	— Crowbar Cave	14805060	—	495	3		Could not be entered
3S2	— Boulder Sink	14725060	—	510	20	8	Tight route via boulders
3S3	— Crawl	14715063	—	530	2		Small tube
3S4	— Shafts	14715068	—	595	(16)	10	6m. 10m deep in grey marble
3S5	— The Big Pitch	14725112	—	620	18	16	10m ladder to choked sump
3S6	— Elgfjellhola	14605104	3	600	335	30	Major trunk passage in yellow brown marble
3S7	— Mouth Cave	14755109	—	620	25		Crawls, near Big Pitch
3S8	— Secret Stream Ca.	147 511	3	610	72	29	Large steeply descending passage
3S9	— Small Bridge Cave	14755115	—	625	16	9	2m shaft to 7m ladder pitch
		Area Total			507		

	ELGFJELL — Ridge						
R0	— Cave	14575126	—	620	10		Crawls
R1	— Ridge Pot	14645128	1	630	140	13	2 large interconnnecting shafts with passages at 3 levels
R3	— Spisestuehullet	14625128	3	630	100	26	3 pitches to chamber and sump. Well decorated upper series
R3	— Ice House Pot	14635135	1	630	45	15	Tortuous passages and shafts
R4	— Ridge Cave	14675150	1	630	260	15	Long complex of phreatic crawls with 3 entrances
R5	— Knoll Pot	14705162	1	620	42	13	2 shafts join and lead to pitch. Need 2 x 8m ladders
R5A	— Narrow Shaft	14705160	—	620	(5)	5	
R6	— Disappointment Pot	14725162	1	620	9	4	Tight passage heads for R5
R7	— Draughting Cave 1	14605153	1	615	15	4	Crawl to 3m climb down
R8	— Draughting Cave 2	14595157	1	605	(6)	6	Tight shaft to boulders
R9	— Draughting Cave 3	14575151	1	605)			(Small caves in yellow/brown
R10	— Draughting Cave 4	14585153	1	605)	19 total		(marble band surrounded by
R11	— Draughting Cave 5	14595155	1	605)			(low cliffs of mica gneiss
R12	— Low Cliff Crawls	14715177	1	585	32	2	Crawl to jnctn. Upstream is too tight, downstream chokes
R13	— Triangular Cave	14715183	1	570	24	2	Falling water heard near a junction
R14	— Halfway Cave	14635143	1	625	25	3	Crawl to choked sump
R15	— Rainy Day Cave	146 515	1	615	38		Crawls to skylight, parallel to valley 2N
		Area Total			770		
	ELGFJELL — Valley 4						
4S1	— Shelter Cave	14805110	1	615	78	3	7 entrances in grey marble to phreatic tubes used by Lapps
4S2	— Musk Cave	14805117	—	610	150	30	100m NE of Big Pitch. Meandering tunnel in white marble
4S3	— Through Cave	14975080	1	555	32	2	Phreatic tube in grey marble where Valley 4 meets Valley 5
4S4	— Two Sticks Cave	14975084	—	560	25		Crawls
4S5	— Pustehola	147 511	3	600	300	28	Breathing Cave. Network of large phreatic passages and shafts
4S6	— Cave of Brown Stains	14915130	3	595	230	34	5 pitches in large phreatic system modified by invasive streams
4S7	— Reindeer Rift	14825129	—	615	14	13	Covered entrance to 10m, 3m pitches
4S8	— Moss Pot	14825130	—	610	11	8	Slanting rift
4S9	— Slit Pot	14855132	3	595	41	23	15m pitch to large chamber and climb down to choke
4S10	— Disappointment Cave	14875136	1	590	6	1	Choked tube
4S11	— Fern Rift	14805130	1	600	10	6	Rift in 0.3m wide marble band
4AS1	— Camp View Cave	15045084	3	560	190	12	3 entrances to sandy floored tubes and a static sump
4AS2	— Sarvenvaartoehullet	15045108	4	580	315	24	15m ladder to large passage and many side passages
4N1	— Streamway 1	150 518	—	510	)		
4N2	— Streamway 2	150 518	—	510	) 30 total		
4N3	— Streamway 3	150 518	—	510	)		
4AN1	— Twisting Stream Cave	15045137	1	555	200	12	2 tight canyons to a waterfall
4AN2	— Blinding shafts	15105140	—	565	(15)	5	Group of 4 shafts. Water probably flows to lake at head of 4AN
4B1	— Extended Cave	15145128	1	565	28	4	2 entrances under micaceous rock to chamber. Streamway sumps
4B2	— Warm Cave	15145131	1	565	17	4	Chamber and streamway upstream of 4B1. Tight side passage
4B3	— Snow cave	15175153	1	565	20	5	Snow slope to mud choke
4B4	— Barrel Cave	15185155	1	562	33	2	2 entrances to tunnels used by Lapps
4B5	— Through Cave	15205157	—	598	10		
4B6	— Gevirgrotta	15305168	3	555	683	27	Antler Cave. Complex maze at 3 levels with streamway to sump
4B7	— Shorthorn Cave	15225163	2	555	34	5	Short passage with two holes down to lower passage
4B8	— Longhorn Cave	15195164	2	555	85	5	South trending passage to alternate entrance and choke
4B9	— Antler Resurgence Pot	15455195	—	505	8	7	7m shaft to stream
		Area Total			2565		
	ELGFJELL — Valley 5						
5N1	— Cave	15435139	—	560	5		Crawl
5N2	— Cave	15675153	—	545	5		
5N3	— Buktgrotta	15575162	3	530	180	25	Crabwalk Cave. Sink via 2 meanders and loose climbs to sump
		Area Total			190		
	ELGFJELL — Sarvejaella						
S1	— Overhanging Pit	16005100	3	560	10	9	Damp crawl or climb down to 5m pitch with tight outlet
S2	— Through Cave	16005130	—	540	5		
S3	— Sump Cave	16105157	—	470	5		
S4	— Øvre Sarvejaellagr.	15935163	1	520	71	20	Rocky descent to several small chambers
S5	— Steve's entrance	15965163	1	520	28	5	Tube entrance to passages near cross rift in S4
S6	— Geoff's entrance	15975165	1	520	7	3	Enlarged gryke
S7)	— Sarvejaellagrotta	15945170	3	518	411	31	Descending phreatic trunk passage to shaft up to
S8)		15965178		498			lower entrance
S9	— Stream Sink	15955179	1	505	28	11)	Nedre
S10	— Aural Passage	15985181	1	493	12	6)	Sarve-
S11	— Last Rising Pass.	16005182	1	490	16	5)	jaella
S12)	— Zig Zag Cave	16035184	1	480	11	35)	grottoene
S13)		16035190		465			Incised meanders to daylight avens and loose squeezes
S14	— Grykegrotta	16225067	3	580	28	2	Low crawls with 2 entrances
		Area Total			731		
		Elgfjell Total			5359		
	GAASVASSTIND						
G1	— Snake Pit	151 530	1	590	40	16	Exposed 8m pitch (long belay) to jagged streamway
G2	— Summit Cave	15095370	1	880	(14)	14	Loose rift to 6m pitch, 15m below ridge summit
G3	— Sink Cave	15225417	1	770	10	2	Deep sump
G4, G5	— Gaasvasstindhola	15255420	3	778	243	13	8m pitch to huge passage and stream exit high on valley side
		Area Total			307		
	E.JORDHULEFJELL						
	— 2 caves	13105265	—	940	14		2 cave remnants high on the eastern slope of Jordhulefjell

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Observations of Mayan Cave Archaeology in Belize

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Abstract: The paper describes the archaeological observations of Mayan cave use recorded on the British Speleological Expedition to Belize, Central America in 1989. A background to the study of Belizean archaeology is given with comments on the problems of looting from archaeological sites including caves . A description of the use of caves by the Maya is given and the evidence, particularly, of burial. The archaeological remains identified were predominantly pottery and human remains with occasional more specialised artefacts. The report itself concentrates on the human remains study and concludes with comments on the integration of specialist studies with the major aims of speleological expeditions.

Belize is located in Central America, bordered by the Caribbean sea to the east, Guatemala to the south and west and Mexico to the north (Fig. 1). It is a small country which is divided into northern and southern halves by the Belize River Basin. To the south the landscape is dominated by high hills and steep slopes with acidic geology and soils. To the north is low undulating relief (Hammond 1981). In the central and southern area of the country called the Maya Mountains, sub-tropical, largely uninhabited secondary rain forest and low lying limestone hills dominate the landscape; access is often hazardous and difficult. The first British caving expedition to Belize visited the northern Maya Mountains in 1988 (Marochov and Williams 1988) and investigated several areas, revealing around 20 kilometres of cave passage. In April 1989, a smaller caving expedition consisting of British and Canadian members based itself south of Belmopan, with the aim of finishing the exploration of dolines between Barton and Roaring Creeks and exploring further the depressions and sinks east of Roaring Creek to the Caves Branch River. The subject matter of this paper concerns the observed evidence of past human use of the caves explored during that expedition.

BELIZEAN ARCHAEOLOGY

Access to caves for exploration in Belize is strictly controlled by the Archaeology Department in Belmopan through the Ancient Monuments and Antiquities Ordinance. In addition, it is agreed that locations of caves discovered are never disclosed in subsequent reports. This is because virtually every cave contains evidence of past human use by the Maya. Unfortunately there is a severe problem of looting from archaeological sites of all kinds, including caves, by dealers who then sell Mayan artefacts on the black market. As Chase and Chase (19? :15) state, "There is an illicit world-wide market for antiquities, and more often than not many priceless Mayan relics appear on this market for sale to the collector". Gutchen (1983) carried out a statistical analysis of the destruction of archaeological and cultural resources in Belize to emphasise the increasing problem to the authorities. He concluded that the main reason for this destruction was, in fact, looting of sites for the art markets of the United States (Gutchen 1983:217).

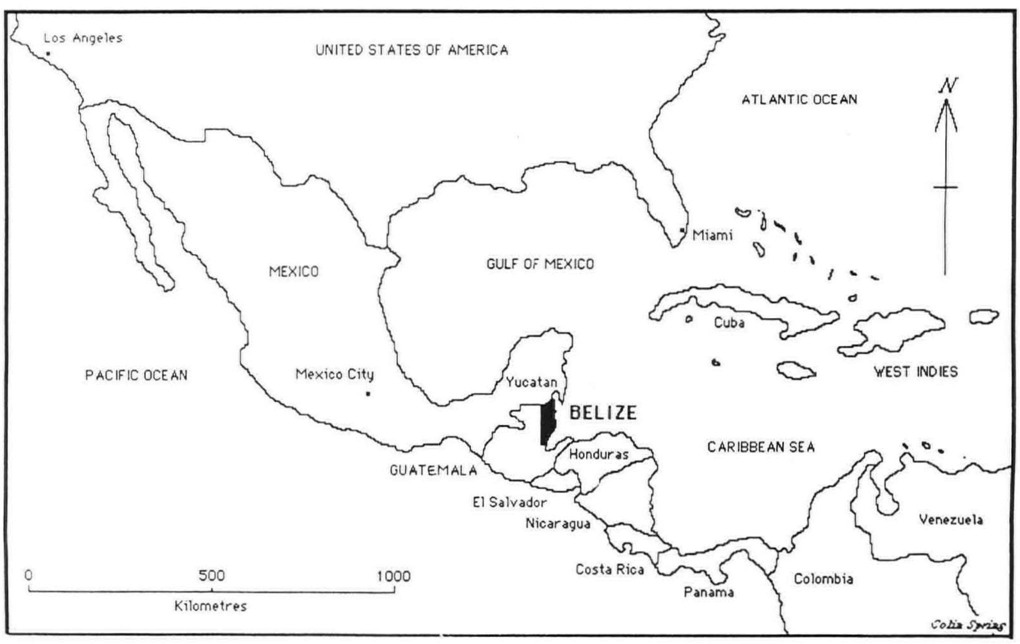
Until 1957 there was no official Department of Archaeology. From 1957 and the establishment of a Department and Commissioner's Office, records have been kept of archaeological sites in Belize; since 1969 ancient monument destruction has been recorded. Of the 396 sites Gutchen studied, at least a third of the sites had suffered some damage; major ceremonial centres appear to have been the most commonly affected (i.e. 74.3% of all major ceremonial centres). Even more disturbing is the damage recorded to cave sites; 43% of all those examined had been looted. Considering that many of the cave sites, and potential cave site areas, are located in heavily vegetated and often impenetrable jungle, it is especially worrying that this is not preventing looters from entering the caves; perhaps they are easier and more discreet sites to loot.

There appears to be an ever constant search for artefacts which, when taken out of context from the archaeological site, are virtually useless pieces for reconstruction of past human behaviour. A permit is therefore required to visit caves in Belize, and a visit to the Archaeology Department in Belmopan before and after the expedition is a pre-requisite. Information about new discoveries and sites which may potentially be under threat from human and natural intervention is welcomed by the staff.

The Mayans have left a long history in Belize dating back to around 1200 BC and the Formative Period when agriculture developed alongside ceremonial centres and a ruling class (Setzekorn 1975). The Classical Period, dated to between AD 300 to AD 900, saw the peak of civilisation and the development of large ceremonial centres. Between AD 900 and AD 1000 there appeared to be a migration of Belizean Mayans into Yucatan, and for the next few hundred years into AD 1500 and beyond, Mayan civilisation then disintegrated. With the Spanish invasion into Belize in the early 1500s pagan Mayan customs were suppressed but the people themselves survived. Much of the contemporary documentary evidence was burnt but the structural evidence, particularly archaeological remains in the form of cities, temples and ceremonial centres, survive in the sub-tropical forests of Belize.

The study of Belizean archaeology began late in the country's history. During the 1920s to late 1930s, several externally funded expeditions, mainly from the United States, undertook research

Figure 1. Location map of Belize.



projects on certain archaeological sites (Hammond 1983:21). With the establishment of an official Department responsible for the archaeology of Belize in the early 1950s, there was active encouragement for outside expeditions consisting of Mayan archaeology experts to come to Belize.

Throughout the 1970s Northern Belize was the focus of attention for archaeological excavations (Hammond 1983:24) with the first systematic surveys and excavations in Central Belize coming later during the decade. Since then the pace of archaeological investigation has accelerated. In terms of cave archaeology in Belize, there have been few publications describing evidence of past human use of caves of which the author is aware (but notably Boxt 1984; Coons 1986a and b; Graham *et. al.* 1980; Joyce *et. al.* 1928; Mason 1928; Mcleod 1978; Prendergast 1970, 1971). It appears that archaeological attention has focused particularly on ceremonial centres and not cave sites in Belize. Reports detailing human remains (e.g. Haviland 1967; Hooton 1940; Ruz 1965; Welsh 1988 on funerary archaeology of burials from Belizean sites) are sparse and from caves rare (e.g. Perino 1967; Ricketson 1925; Saul 1972). If human remains were discovered, their only mention is in connection with grave goods or related funerary practices. This paper presents the findings, particularly the human remains, in the caves explored during the British expedition to Belize during April 1989.

Mayan use of caves

Prior to discussing the evidence for human use of the caves under consideration, it is useful to summarise the uses to which the ancient Maya put caves. Thompson (1975) summarised uses of caves by the Maya as follows: 1. Places to collect drinking water; 2. Places to hold religious ceremonies; 3. Burial; 4. As art galleries; 5. Depositories for broken artefacts such as pottery; 6. As a refuge.

The Maya were apparently preoccupied with divine forces and therefore their everyday life was controlled and directed by this preoccupation. This is probably the reasoning behind the building of large ceremonial centres deep in the Belizean jungle. Undecorated, utilitarian pottery water jars (called ollas and up to 60cm in diameter), limestone containers or hollowed out areas of stalagmite were utilised to collect dripping water for religious ceremonies, Thompson (1975:xvi) maintains that some caves, such as Eduardo Quiroz Cave in west central Belize, were altered by the construction of limestone blocks to hide water collecting points. In other caves, however, it is quite evident that water collecting was not the prime use of the site. At Actun Balam (Prendergast 1969) there was no evidence of water; this dry cave was not for collecting water and may have been a 'ceremonial dump' where offerings to spirits in the cave were made.

The Maya believe, even today, that the rain gods live in caves along with the jaguar god, the deity of the underworld and of the night sky. The earth deity, called Tzultacaj, is apparently supposed to make his home in caves, (according to the Alta Verapaz people close by in Guatemala), and lies in a hammock made of deadly poisonous snakes called Fer de Lance (or *Bothrops sp.*). If any person sins, the Fer de Lance is supposed to punish them with fatal bites. (Pope and Sibberensen 1981:18). The great respect with which local Belizeans hold these snakes is understandable if this is the belief.

Although few adequate reports have appeared which deal with Belizean cave burials, burial of the dead was commonly undertaken in the caves of Belize by the Maya; whole burials or fragments of human burials have been discovered. Caves were thought to be entrances to Mayan Hell and therefore people were buried there to assist the soul (personal communication N. Marochov with Harriot Topsy). Caves, however, were only one location for burial. Simple burial in the ground or in fills of buildings with no associated funerary architecture, cist (stone slab or wall enclosed burial) deposits, crypts, coffins and burial chambers all provided a resting place for the dead. Skeletal mutilation after death has been observed (Welsh 1988) including, apparently, decapitations, hand and foot removal and intentionally smashed or drilled skulls and long bones. What should be remembered is that it is often very difficult to determine whether postmortem skeletal mutilation such as decapitation was deliberate, and whether a skeleton has been disturbed by natural forces acting on the body position. Once a body has been deposited there are many intrinsic and extrinsic factors operating which may disturb the body (see Henderson 1987). Grave goods were a common accompaniment of burial both in and out of caves; artefacts include jade beads (often placed in children's mouths), discs, pendants and figurines, pottery, shell beads, flint and obsidian artefacts, clay objects, especially whistle figurines, objects made from coral, pyrite, pearls, textiles and mosaic masks, stingray spines and copal or incense.

In addition, some burials were covered with red paint, probably cinnabar (Ruz, 1965 :443). The cave sites of archaeological importance which were visited during the British Expedition are described as follows. Virtually every cave entered by members of the expedition revealed some evidence of past Mayan use, usually in the form of broken pottery vessels or human burials.

CAVES EXPLORED BY THE BRITISH EXPEDITION

Actun ya 'ax kan (Cave of the Amazing Green Snake)

The entrance to this cave, in the heart of the Belizean jungle, was the least well provided for in terms of archaeological remains but the effort required to enter it probably prevented both the Maya reaching the areas desired or the population in the area today. Two complete pottery vessels were located high up on a ledge, presumably placed there to collect water dripping from the roof of the cave. To negotiate the difficult entrance of free climbs carrying large pot vessels would have been an achievement in itself. The cave itself was not particularly significant in length or depth and eventually closed down without further evidence of Mayan use.

Actun Yaxteel Ahau (Roaring River Cave)

A preliminary report on the archaeology of this cave had already been given by Coons (1986b) but there was little detail of the artefacts and human remains observed. In Coons' 1986 report, four separate locations for artefacts were noted, some of which appeared to have been looted. The second ledge mentioned by Coons, the most extensive, was investigated thoroughly in 1989. In his report Coons notes that, "... the site seems significant and undisturbed". The cave was certainly used as a major religious/ceremonial centre (witness the pottery vessel fragments found on the other three ledges) but it was Ledge 2 which appears to have been used for burial. The climb up out of the stream proved technical in places and certainly not easy. At the top of the climb, on to the ledge, (about 15m from the stream level) lay balanced a metate (c. 37cm x 25cm in size), a granite axehead (12.8cm x 5.3cm and 4cm thick) and an incomplete Mayan clay whistle. Small fired clay figurines such as the latter were produced all over Mesoamerica at this time and were usually in the form of whistles. Many were associated with religious ceremonies and often complete whistles are found in graves of children (Rands and Rands 1965:539).

Table 1: Fragments observed

Adult	Left	?	Right
femur	4	3	4
tibia	1	5	1
fibula	—	2	—
scapula	1	—	—
humerus	—	4	2
radius	1	3	—
ulna	1	1	4
pelvis	1	—	—
calcaneum	2		
talus	1		
metatarsals	2 (unsided)		
1 right foot			
(all tarsals, metatarsals, proximal foot phalanges)			
ribs	—	5	1
mandible	6		
maxilla	1		
skull vault fragments			
rib shaft fragments			
scapula blade fragments			
Juvenile			
humerus	—	1	1
mandibular			
condyle	—	—	1
pubic bone			1
several fragments of animal bone			

		Stature (male)	**Stature (female)**
Tibia 1:	TiL1	right: 370	1,6627m ±2,182cm	1,6442m ±3,515cm
Tibia 2:	TiL1	left: 330	1,5843m ±2,812m	1,5354m ±3,515cm
	TiE1		1,5843m ±2,812cm	1,5354m ±3,515cm
Femur 1:	FeL1	left: 330	1,4096m ±3,147cm	1,3521m ±3,816cm
Femur 2:	FeL1	right: 400	1,5678m ±3,417cm	1,5334m ±3,816cm
Humerus	HuL1	right: 270		

Table 2: Metrical data (mm): Skeleton 1 (measurements taken from Brothwell, 1981)

From this point the ledge opened out and sloped upwards away from the stream back to the cave wall and a smaller cave passage approximately 2m high, 3.5m wide and 14m long. Beyond this passage the dimensions of the cave became very small. The passage of this floor was covered with potsherds and both sides of the passage were lined with charcoal. There were two fragments of granite metates, one 26cm x 21cm and the other 27cm x 28cm. Metates were used for grinding corn during the Classical period and they could be manufactured from limestone, quartzite, clay, hardwoods, flint, obsidian and granite (Coe 1965). The metates discovered in Actun Yaxteel Ahau were of granite, a material which can be obtained in the Maya Mountains. In two areas of this passage disarticulated human bone was found. At the back of the passage where the area becomes much smaller, the femoral shaft of a juvenile individual, and vertebral and rib fragments and some metacarpals of an adult individual were located. Towards the front of the passage were a left femur shaft and left and right clavicles. Moving forward, and back to the main ledge of Actun Yaxteel Ahau, disarticulated human bone fragments of adults and juveniles were identified with loose teeth and accompanying grave goods. Table 1 lists the fragments observed.

It was calculated that, based on bone counts, there were a minimum number of seven individuals buried on the main ledge; all were adults except one juvenile. Coons (1986b) noted that there were, "... at least 20 burials .... many articulated". It was not possible to differentiate any sexual characteristics by observation of any of the bones. However, the bones observed were small and slender and some of the measurements taken on the long bones were small, suggesting female individuals. Crude measurements (Bass 1987) were taken in situ using a tape measure on the more complete bones; these gave an indication of the size of the individuals represented.

Stature was calculated using the regression tables of Genoves (1967), as indicated in Table 2; both male and female statures are given due to the impossibility of assigning a sex to the bones. In five of the mandibles present it was possible to record the dentition. Two individuals were adults, having a full set of permanent teeth. Two mandibles had all the teeth present except the 3rd molars; these may have been congenitally absent or undeveloped (in the latter case the individual could have been between the age of 12 and 21 years). The 2nd permanent molars of two individuals were unerupted, suggesting children aged approximately 6-12 years old. One of these mandibles had retained deciduous teeth of which a 2nd molar tooth had a carious lesion on the occlusal surface. The final individual had lost the 2nd and 3rd molars antemortem; this may be an indication of an elderly person although antemortem loss of teeth may be observed without advancing years. One right side of an upper jaw (maxilla) had the premolars and 1st and 2nd molars in situ. Table 3 shows the dentitions of the jaws observed.

The human remains had obviously been disturbed at some stage since the report by Coons, possibly by flooding (the bone was very friable and wet to touch).

Associated with the scatter of human bones were many artefacts, either fragmented or complete. Potsherds were common and perforated shells. Towards the edge of the ledge above the stream passage, in and around a depression in the ledge surface (probably originally a gour pool) were several jade pieces. The pieces consisted of a small disc with a smaller circular groove on one side, an irregularly shaped carved piece and a square piece perforated at one edge. They appeared to be associated with bones from a juvenile skeleton. Jade was a highly prized stone in Mayan society and was often subject to carving (Rands 1965). It was apparently a sacred substance associated primarily with water and secondarily seen as a symbol of wealth. Jade beads were often used as money and sometimes placed in the mouths of the dead at burial. Jade was believed to be the currency to obtain food and entrance to the next world (Coe 1965) and tended to be associated with male juvenile individuals; clearly, the jade pieces found in Actun Yaxteel Ahau appeared to be associated with juvenile skeletons.

```
NP  not present
C   caries
V   unerupted
/   lost postmortem
X   lost antemortem
-   area of jaw lost postmortem

1.
    8  7  6  5  4  3  2  1 | 1  2  3  4  5  6  7  8
    NP                     |                      NP

2.
    8  7  6  5  4  3  2  1 | 1  2  3  4  5  6  7  8
    NP V                   |                   V  NP

3.
    8  7  6  5  4  3  2  1 | 1  2  3  4  5  6  7  8
    -  /     /  /  /  /  / | /  /  /  /  /     /  -

4.
    8  7  6  5  4  3  2  1 | 1  2  3  4  5  6  7  8
    -  -  -  -  -  -  -  - | /  /  /  /  /     X  X

5.
    8  7  6  e  3  b • a | a  b  3  d  e  6  7  8
    NP       C  V  /   / |       V           0  NP

6.
    8  7  6  5  4  3  2  1 | 1  2  3  4  5  6  7  8
    -              -  -  - | -  -  -  -  -  -  -  -
```

Table 3: Dentitions (abbreviated as from Brothwell, 1981)

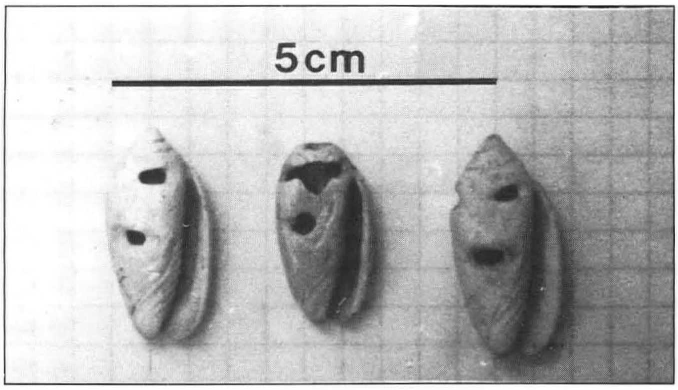
Sex	
Subpubic arch >90°	
Sharp orbital rims	
Small supra orbital ridges	
Age	
Epiphyseal union	
All upper limb bones fused	>20 years
Proximal femora fused	>18 years
Distal femora unfused	<20 years
Proximal tibiae unfused	<20 years
Distal tibiae fused	>18 years
Proximal left fibula unfused	<25 years
Pelvic bones fused	>20 years
1st sacral vertebra fused	>20 years

Table 4: Age and sex characteristics

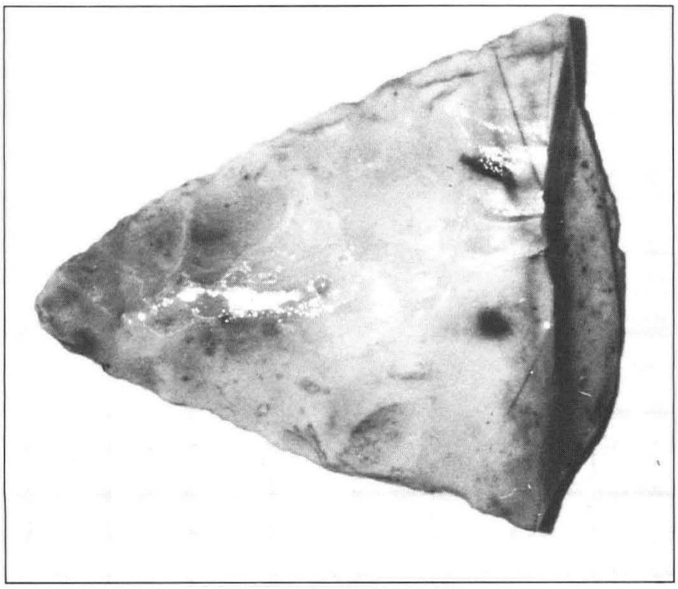
Two obsidian blades were also discovered close to the gour pool area; they had bevelled edges and were curvilinear in shape. Obsidian is found in the highlands of Mesoamerica (Vail 1988:133) and was extensively used to make tools in the Mayan era. At the back of the ledge and close to the wall of the cave were three perforated shells close to bone fragments. In addition, three flint blades were observed on the ledge. The flint was cream/white/grey/brown in colour and all the pieces were worked on both sides and edges of the blades.

Sunken Forest Cave and Actun Box Ch'iich'

Both of these caves were through trips carrying active streamways which must flood substantially during the wet season



Perforated shells from Roaring River Cave.



Worked flint blade from Roaring River Cave, 37mm long.

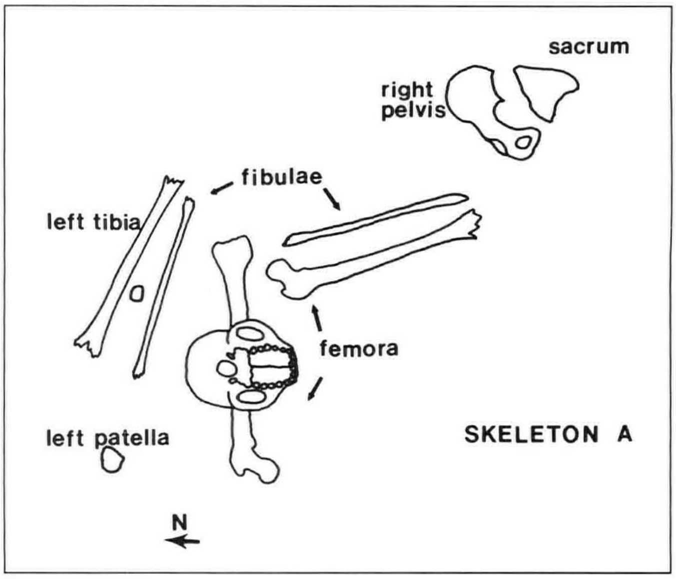


Figure 2. Skeleton A, Tunichil Muknal

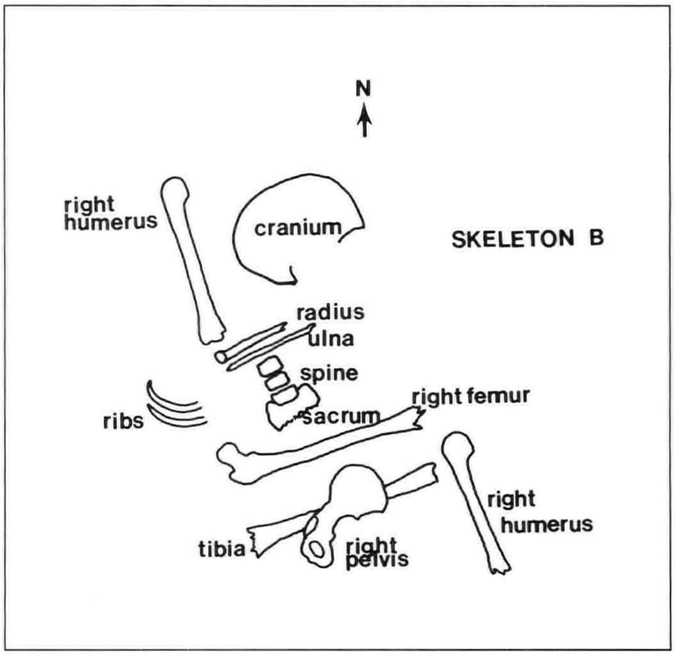


Figure 3. Skeleton B, Tunichil Muknal

FeLl:	left: 360	
TiLl:	left: 330	right: 310
FiLl:		right: 290
HuLl:	left: 280	right: 260
RaLl:	left: 200	right: 200
UlLl:		right: 215

Table 5: Metrical data (mm) of Skeleton 1

and hence the lack of artefacts is apparent. However, at the far end of Sunken Forest Cave (i.e. eastern end) the entrance is much larger and less prone to floods. A terrace was observed by the southern wall but it was difficult to say whether it was man-made; it had a mosaic of flat stones placed on the ground together with fragments of pottery. Pottery was also found along a side passage. No further observations of these caves were made.

Tunichil Muknal

Coons wrote a preliminary archaeological report in 1986 for Tunichil Muknal (1986a) based on a visit by himself and others in 1986 (Miller 1989). Most of his observations were limited to descriptions of the artefacts present, consisting mainly of pottery sherds, soapstone monuments and metates. Three well preserved burials were mentioned but clearly, from the following, not all the burials in the large upper level fossil passage were discovered. Perhaps they were not all considered as impressive as the "Crystal Skull of Tunichil Muknal" (Miller 1989:2).

The most distant skeleton (Skeleton 1) from the main streamway was in a small passage, mostly complete, lying on its back with the head to the south-west. The whole skeleton was covered in calcite crystals and partially embedded in the calcite floor. It is highly likely that this skeleton had been placed in a gour pool at death which had subsequently dried out. Burial beneath water was undertaken by the Maya because Mayan hell was believed to be a watery world entered by sinking beneath water surfaces. The skeleton was estimated to be female, based on morphological features described by Bass (1987). It was possible to examine the sub-pubic arch of the pelvis and the mastoid processes, orbital rims and supraorbital ridges of the skull to assess sex. Age was estimated to be between 18 and 20 years, based on epiphyseal fusion (see Table 4 for summary of age and sex characteristics).

The teeth of the skeleton were covered in calcite crystals and therefore comment was not possible. Long bone lengths were measured in situ with a tape (Table 5) and stature was estimated as 1.4298m ±3.816 cm and 1.5354m ±3.513 cm based on the left femur and tibia respectively. These measurements should not be taken to be precise due to, firstly measuring the bones in the ground and, secondly, their calcite covering; however they give an approximate value.

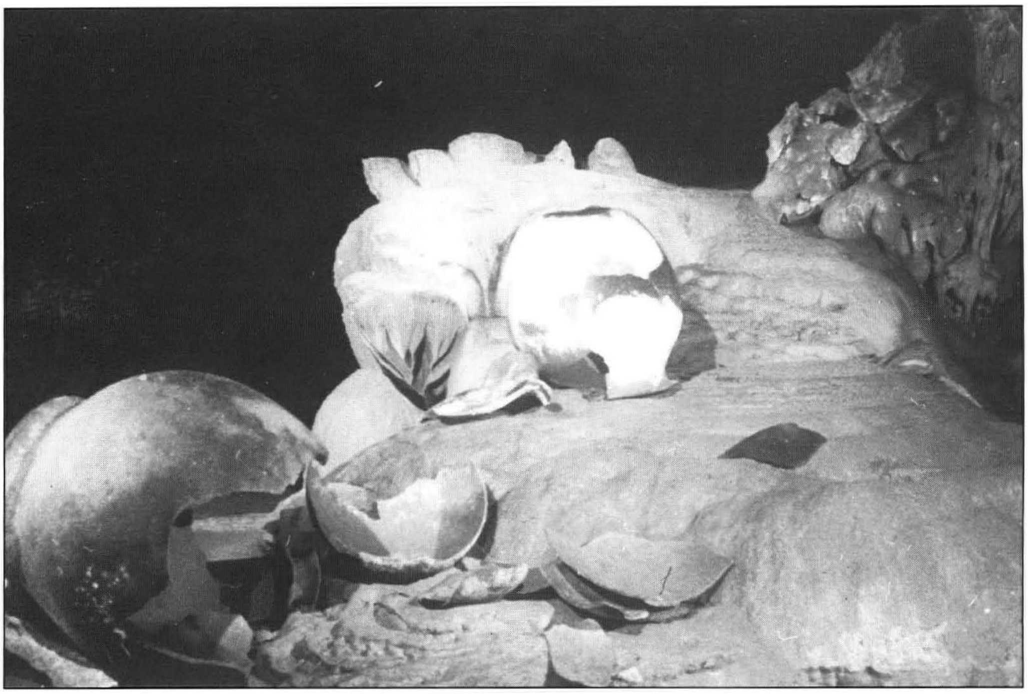
The frontal bone of the skull (forehead) of this skeleton was flattened, a common feature in Maya skeletons, and the left orbit showed evidence of pitting of the bone surface, consistent with changes caused by anaemia (Stuart-Macadam 1987).

On the opposite side of the passage another individual was represented by a jumbled mass of bones (Skeleton 2). Again, the bones were heavily coated with calcite crystals. Only the skull and femora of this individual were recognisable so little work could be undertaken on this burial.

Moving forward towards the streamway, another individual (Skeleton 3) was discovered in calcited boulders. The remains were those of a juvenile aged between 6 and 12 years old, based on the development of the dentition and on the fusion of the long bone epiphyses (Table 6)

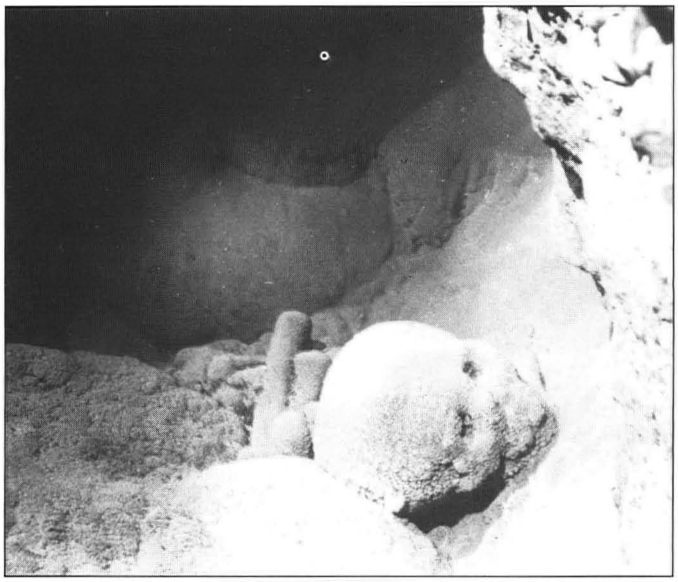
The skeleton was largely complete apart from the foot bones, left humerus and some ribs and vertebrae; however, it is likely that many of the missing bones had fallen through the boulders and were resting beyond visibility.

Pottery vessels and fragments in Tunichil Muknal.



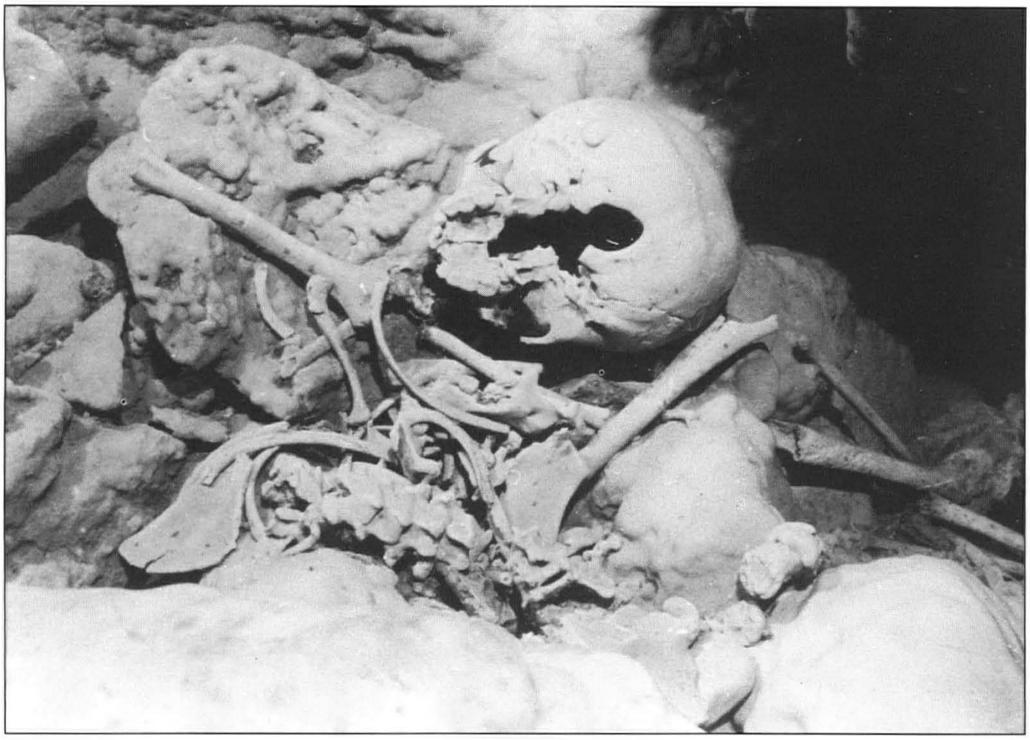
Close to the streamway, 3 more individuals were represented, two buried close together and all amidst an extensive scatter of pottery (Figs. 2 and 3). Skeleton A was represented by a skull, femora, left tibia and fibula, left patella, right ilium and sacrum. This individual was estimated to be a female, based on small mastoid processes, absence of the posterior zygomatic arch and a flat sacrum with a slight curve at the 5th sacral piece. The majority of the maxillary teeth had been lost antemortem and the tooth sockets had healed over. All the epiphyses of the long bones had fused and there was slight osteophytic lipping at the sacro-iliac joint, on the rim of the body of the 1st sacral piece and on the proximal tibial articular surface; osteophytes are a sign of ageing in individuals and may appear as one of the features of osteoarthritis. Measurements of the long bones were taken where possible (Table 7). Stature was calculated as 1.5354m ±3.513 cm, based on the left tibia maximum length.

Skeleton B was more complete, consisting of the skull, right pelvis, right femur, right humerus, an ulna and the 1st sacral piece. This individual was lying on its left side with the head to the north. It was estimated that the skeleton was that of a male, based on a prominent occipital protruberance, a large right mastoid process and a narrow right sciatic notch. The epiphyses were all



Skeleton 2: Tunichil Muknal.

Skeleton 1: Tunichil Muknal.



Skeleton 3: Tunichil Muknal.

fused and the pubic symphyseal face was estimated to be that of an old individual; a more precise age was not possible. There were severe osteophytes of the vertebral bodies present. Again, the frontal bone was flattened and an anomaly in the form of a cranial suture ossicle was present on both sides of the skull. The final individual, close to the double burial, was represented only by a skull (Skeleton 4) with the occipital bone embedded in the calcite floor. The skull had a flattened frontal bone and the maxillary incisor teeth had grooves in their surfaces. Only the upper dentition was present:

Dentition

```
0                 / | /                    0
7  6  e  d  c  b  a | a  b  c  3  d  e  6  7
--------------------+-----------------------
7  6  e  d  c  b  a | a  b  c  d  e  6  7
0  /              / | /                 0
```

Epiphyses

right humerus unfused proximal and distal	<16 years
right clavicle unfused medial and lateral	<25 years
scapulae totally unfused	<15 years
right ilium and pubic bone unfused	<8 years
femora unfused proximally and distally	<15 years
tibiae and fibulae unfused proximally and distally	<15 years
neural arches of 3 lumbar and 4 thoracic vertebrae fused	3 years

Table 6: Dentition and epiphyseal fusion data

The 2nd left premolar and the 1st right premolar were affected by caries and the three left molars had been lost antemortem. It was estimated that this individual was probably a male adult. The practice of tooth mutilation was common from around 1000 BC to AD 100 in Mexico and continued until the Spanish Conquest (Perinol 1967).

None of these burials in Tunichil Muknal had grave goods associated with them; it is possible that these graves had been looted and the proximity of the burials to the cave entrance makes this highly likely. However, the absence of grave goods with Mayan cave burials has been interpreted by some as representing a lower stratum of society (Prendergast 1971:17) but, in this case, absence probably means looting. These burials were similar to others reported from caves in Belize.

TiL1:	left: 330
FiL1:	left: 340
FL:	30
FB:	28

Table 7: Metrical data (mm): Skeleton A (measurements taken from Brothwell, 1981)

Skeleton 4: Tunichil Muknal.

CONCLUSION

The study of the archaeology in the caves explored and surveyed during the British Expedition to Belize in 1989 has served to show the potential of the information recoverable through basic recording during 'normal' cave exploration. Belize has a wealth of archaeology which is fast becoming recognised, by archaeologists and looters alike. Cavers can help the Department of Archaeology in Belmopan by informing them of any archaeological finds during exploration. More detailed work on specific aspects of the archaeology, in this case human burials, provides a bonus but also contributes to the study of Maya population biology. Cave archaeology need not be a rigorous and extensive investigation with archaeologists working in isolation from the rest of the expedition. Rather, it can be integrated into the main aims of the expedition. A sensible approach to dealing with archaeology in caves is all that is necessary (Roberts 1986), and it is hoped that in future cavers may consider the archaeology of the caves they are exploring.

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Phytokarst and Photokarren in Ireland

Michael J. SIMMS

Abstract: Light oriented phytokarst pinnacles, or photokarren, have been found adjacent to unroofed sections in several ancient cave passages along the Burren coast, Co. Clare, Ireland. This is the first record of photokarren in a temperate marine setting. The preservation of scalloping, formed when the cave was originally active and sea level was lower, in the darkest parts of the caves demonstrates that direct solution of limestone by sea water in intertidal situations is negligible. The destruction, by development of photokarren, of the scalloping adjacent to unroofed sections of passage shows that most erosion of limestones in temperate intertidal situations can be ascribed to the actions of algae. Comparison of karst forms found within the cave with those on the adjacent intertidal and supratidal ledges indicate that the role of algae is greatest in the Littorina and Verrucaria Zones but is moderated by other biotic factors in the Barnacle and Mussel-Echinoid Zones. In Britain and Ireland photokarren has been found only in caves with a significant marine influence.

On visits to the Burren, Co. Clare, Ireland, light-oriented pinnacles (photokarren of Brook & Waltham, 1978) have been observed in parts of several fossil cave passages which now lie partly in the intertidal zone between Doolin and Fanore. Photokarren are erosional features produced by the boring and/or solutional action of red and blue-green algae and have previously been noted only in tropical cave entrances (Bull & Laverty, 1982). Their discovery in temperate caves is in itself of some interest but of greater significance are the implications which their absence from the darkest parts of the cave has for theories on the erosion of all limestone now lying within, or immediately adjacent to, the marine environment in temperate regions.

Limestones exposed along temperate marine coastlines often display a characteristic suite of erosional and solutional features quite distinct from those found in freshwater or subaerial situations. The extent to which solution alone has influenced the development of these karst forms has been a source of speculation. Since sea water is saturated with respect to calcium carbonate, no solution of limestone should occur in normal marine environments. Respiration of marine organisms in intertidal situations, particularly at night when there is no photosynthetic absorption of respiratory carbon dioxide, has been suggested as a mechanism for raising the pH of sea water and hence causing solution of limestone (Folk *et al.*, 1973; Holbye, 1989). However, it is now recognised that the activities of many marine organisms may have a more direct influence on rates of limestone erosion in the intertidal and subtidal zones.

Intertidal karst zonation

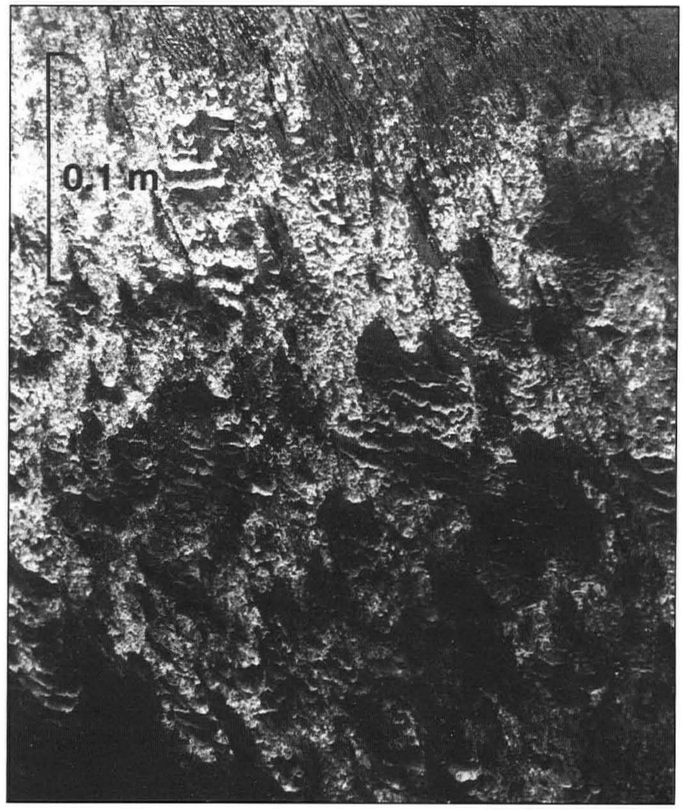
A clear zonation of karst forms has been documented on the Burren coast (Lundberg, 1977; Trudgill, 1977, 1985), extending from just below Low Water Mark (LWM) into the splash zone above High Water Mark (HWM). The karst morphology characteristic of each zone has been assumed to reflect the bioerosional effects of the dominant marine organisms at that level. The Mussel-Echinoid Zone, just above LWM, has sharp fretted pinnacles, often encrusted with mussels, surrounding pools crowded with echinoids (*Paracentrotus*), each of which occupies a small cavity which it has excavated in the floor of the pool. The Barnacle Zone, around mid-tide level, is characterised by rounded pinnacles heavily encrusted with barnacles. Extending from around HWM up to 2-3m above, are the Littorina and Verrucaria Zones, with shallow sharp-edged depressions, small pinnacles and a sharply pitted surface. In addition to the obvious macrofauna and flora of each zone, Trudgill (1977, 1985) found that microscopic boring algae form a significant element of the total biota and make an important contribution to limestone erosion . In many tropical situations, both terrestrial and marine, algae have been recognised as an important component of the development of particular karst forms, particularly types of pinnacle karst (Bull & Laverty, 1982). In temperate climates, however, less is known about the role of algae in karst development. Furthermore, although is it recognised that algae are important in the development of intertidal karst, the presence of other bioeroders renders it difficult to assess the relative contribution to erosion provided by the algae.

The existence of fossil conduit cave passages, now partly invaded by the sea, provides an opportunity to assess how important algae are in producing these intertidal karst forms. Solutional features found on passage walls must have developed when the cave was active and sea level was lower. Since algae require light to photosynthesise, and hence cannot survive in darkness, the extent to which these original solutional features have been modified in the darket parts of the cave provides a measure of the extent of non-algal erosion of the limestone since the cave was inundated by the sea.

PHYTOKARST ON THE BURREN COAST

Photokarren pinnacles have been observed in several marine-inundated caves along the Burren coast between Doolin and Fanore. Of these sites the most readily accessible are the 39 m long section of vadose canyon on the north side of Poulsallagh Bay (Self, 1981) and the partly unroofed vadose canyon, known locally as 'Hell', on Doolin Point (Boycott & Wilson, 1986; Jones, 1988). Since photokarren are better developed and more readily accessible at the latter site than elsewhere, only that site is described.

The main part of 'Hell' accessible to non-divers comprises a straight section of ancient cave passage developed along a major north-south joint. Remnants of four small elliptical phreatic tubes with minor vadose trenching, all developed on a single bedding plane, can be seen to meander across the surface of Doolin Point, roughly along strike. The two northern inlets enter high in the



Optimum development of photokarren pinnacles developed about 3.5m above Low Water Mark just to the north of the middle phreatic inlet. The dark areas represent the steep faces of large, blade-like pinnacles and are oriented parallel to the direction of the incoming light rays. These faces of the pinnacles are darkened by the presence of blue-green algae. The lighter areas represent more irregular and corroded areas of the pinnacles. They are oriented subperpendicular to the light rays and are colonised by red algae.

Elongate subhorizontal photokarren 'terraces' developed on steep faces in the more dimly lit part of the vadose canyon between the middle and the southern phreatic inlets. Remnants of scalloping (arrowed) can be seen in several places in the lower part of the picture.

walls at the southern end of 'Hell', which here is a tall vadose canyon up to 1.5m wide and about 6m high, while the two southern inlets unite before entering the vadose passage at its extreme southern end. Scalloping is well developed on the walls in places. Elsewhere, eroded remnants of flowstone can be seen adjacent to where the phreatic tubes enter. 'Hell' is unusual among Burren caves in having drained northwards against the dip, which is here about 2-3° to the south. Towards its southern end part of this vadose canyon has been unroofed. Northwards the roof descends at a shallow angle so that even at low tide much of the northern part of the passage is accessible only to divers. At its northern end the passage is considerably smaller and appears to be a vertically elliptical phreatic tube with a small vadose trench in the floor (Tim Fogg, pers. comm.). Other passages lead off to the east and west. The main passage is now truncated by a submarine cliff, from which it emerges at a depth of about 8m (Boycott & Wilson, 1986). Almost certainly it operated originally as an inlet to the major conduit of Mermaid Hole which lies a short distance to the north (Jones, 1988).

Photokarren are well developed in 'Hell' in the area adjacent to the unroofed section of passage. Precise morphology varies both with distance above sea level and position relative to the local light source (the unroofed section).

From LWM up to about 3m above LWM the limestone surface is fairly rounded, without pinnacles, and encrusted by red algae, particularly the encrusting *Lithothamnion*. The transition to the photokarren pinnacle zone is fairly abrupt, generally occurring over a distance of less than 0.5m, though *Lithothamnion* crusts may persist locally up to about 1m above this level on chert bands. The lowest pinnacles are rather coarse and blunt and often coated with pale *Lithothamnion* crusts. Above this the pinnacles are sharper and almost vertical. They are best developed about 3.5-4m above LWM, where they may be up to 60mm or more in length, tapering from a base about 20-30mm wide. They decrease in size upwards but are still found more than 5m above LWM, beyond which they give way to a black crust of the lichen *Verrucaria*. Locally, small photokarren pinnacles may occur up to 8m above LWM where the *Verrucaria* crust is absent, particularly where a coating of ancient flowstone is present. Pinnacles are best developed on steep, dimly-lit faces. On gentle slopes and horizontal surfaces the pinnacles grade into an irregular pitted surface (Figure 1). Overhanging surfaces have no pinnacles.

On fairly well-lit surfaces within the cave the pinnacles are sharply conical and usually less than 10mm long. Moving away from the light source pinnacles become larger and more blade-like

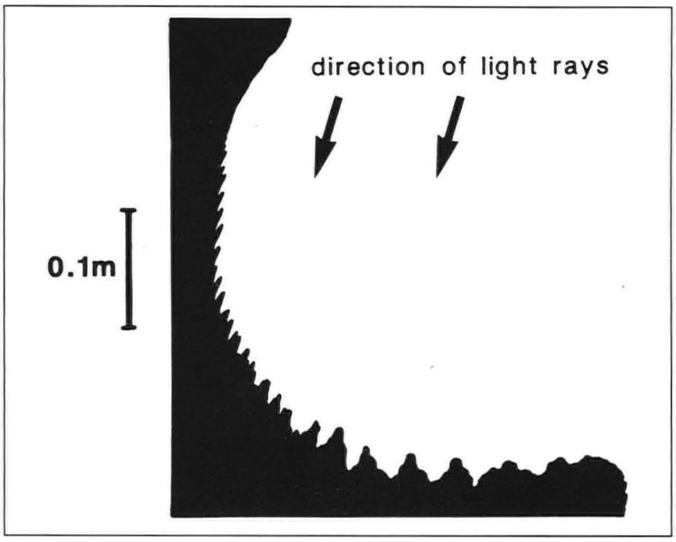


Figure 1. Diagrammatic transverse section through a concave shelf in 'Hell' to show the reduction in preferred orientation of phytokarst pinnacles on passing from a steeply inclined to a subhorizontal surface.

and are oriented towards the light at angles of 20-35° from the vertical. Still further from the light source these blade-like pinnacles merge into elongate flakes and 'terraces' (Figure 2). Relief on these flakes may reach 40mm or more while individual 'terraces' can be traced along the walls for a metre or more, with a vertical separation of 50-150mm between 'terraces'. In still darker parts of the cave these terraces and pinnacles become less distinct until, in the darkest areas, the original scalloping of the passage walls is clearly visible.

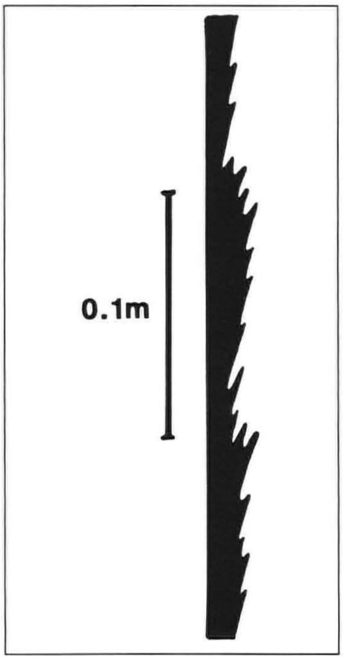


Figure 2. Diagrammatic transverse section through phytokarst 'terraces' seen in Plate 2.

Pinnacles in the more dimly lit parts of the cave have a strong surface coloration, presumably due to the presence of the algae responsible for the formation of the pinnacles. The relatively smooth vertical or steeply angled faces of pinnacles have a dark greenish-black hue while the pits and gentle slopes between pinnacles have a distinct purple coloration and a more corroded texture. Close to the surface in the better lit parts of the cave the pinnacles are much smaller and these colours are much fainter. The observed fauna in the intertidal and immediately supratidal part of 'Hell' where the photokarren pinnacles are developed is restricted to small numbers ($<5m^{-2}$) of patellid and littorinid gastropods (limpets and winkles) and a few balanid barnacles. Neither echinoids nor mussels have been seen at any level and there is no evidence in the cave of any of the distinct zones which have been recognised on the intertidal platform immediately outside.

DEVELOPMENT OF THE PHYTOKARST

The solutional scallops on the walls of 'Hell' clearly formed when the cave was active prior to its inundation by the sea. Hence their preservation, virtually unchanged in the darkest parts of the cave over probably more than 10,000 years, since the end of the last glacial maximum, testifies to the negligible dissolution of limestone directly by sea water. In contrast to these intact scallops, the walls adjacent to unroofed sections of passage display a varying degree of modification by the development of phytokarst. The size and shape of phytokarst pinnacles is related both to local light levels and to their position relative to tidal levels. Together these factors determine the degree of desiccation which the pinnacles experience during each tidal cycle. The phototropic orientation of the pinnacles proves conclusively that they are due to the action of algae, as demonstrated for tropical photokarren (Bull and Laverty, 1982).

The conclusion to be drawn from the preservation of solutional scallops in the darkest parts of the cave, the absence of typical intertidal zonation and the development of phototropic phytokarst pinnacles adjacent to a local light source, is that the boring and/or corrosional effects of marine algae represent the major component of karst development in intertidally exposed limestones. As such it is responsible for the distinctive suite of karst forms found on temperate limestone coasts. In temperate regions photokarren appears restricted to sites with a strong marine influence. It has not been found around any cave entrances further inland on the Burren or elsewhere but has recently been found in several ancient conduit caves developed in Ordovician limestones on the coast of Portrane, in north County Dublin.

Comparison with intertidal karst

The characteristic pitted surfaces of small pools and depressions in the Verrucaria and Littorina Zones bear striking similarity to the karstic features developed on gently sloping or sub-horizontal surfaces adjacent to the unroofed section of 'Hell' and suggest that most erosion of limestones in the splash zone occurs through the agency of bioerosive algae. The more rounded pinnacles characteristic of the Barnacle Zone probably reflect the way in which the encrustation of limestone surfaces by successive generations of barnacles prevents the development of typical phytokarst forms. Bioerosive algae may be able to colonise small areas of limestone exposed in the gaps between adjacent barnacles but are quite likely to be smothered subsequently by the settlement of later generations of barnacles. Any initial angularities in the limestone which are unfavourable for barnacle settlement will inevitably be subjected to more prolonged attack by bioerosive algae, causing the preferential removal of angularities and thereby accelerating the development of the rounded pinnacles typical of this zone. The complex fretted pinnacles and pools of the Mussel-Echinoid Zone clearly have a strong algal component to their formation but it is clear that echinoids are also major bioeroders of limestone in this region. Where present it is probable that echinoids are of considerably greater importance for limestone erosion that are algae, though where they are absent then algae probably assume the dominant role in this zone also, with various borers and grazers comprising only a subsidiary element.

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Forum

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

LITTLE NEATH RIVER CAVE

G. J. Mullan

In chapter 15 of the recently published Limestone and Caves of Wales, Sam Moore (1989) presents a picture of development in the Little Neath River Cave (LNRC) that must be challenged on several points.

1. He says that "The major passages in LNRC drain to the southeast and the stream may once have resurged in the Mellte valley. Passages such as New World Passage may date from this period." Apart from the Mellte argument having been disposed of by Standard *et al* (1971), it is evident from the morphology of LNRC 5 onwards that the present streamway in LNRC 7 and 8 is the direct continuation of both 5-6 and New World Passage and shows no indication to go anywhere but to the southwest and the resurgence R2. It is possible that Sam's analysis has been influenced by the views expressed by David Lowe in chapter 2 of this book, but his view is flawed by his not being aware of the proven resurgence of this cave, despite it having been successfully traced as long ago as July 1968 (Standing *et al* 1971). I know that this book was a long time in preparation, but not 20 years surely.

The route from LNRC 8 to the resurgence is no longer as speculative as Sam implies, either, as the extension to sump 8 went sufficiently deep to confirm that the stream passes beneath the Millstone Grit in a deep phreatic loop entirely within the limestone (Mullan 1988).

2. His argument seems to run that the river has captured drainage from the, early, cave but is now being re-captured by the cave. If one accepts the above argument that this cave has never resurged in the Mellte valley then it is important to remember that any springs in the Nedd Fechan valley owe their existence to the surface river having cut through the Millstone Grit to expose the tongue of limestone from Pwll y Rhyd to Pwll Ddu. Thus each stage in the development of the cave must have been preceded by a further downcutting in the river. Sam says that the river is quite juvenile in appearance and whilst it is true to say that no conventional 'knick points' are to be found along its course, there is a significant break of slope to be found where the surface river drops into Pwll y Rhyd and perhaps this has filled that particular niche in this case. It is therefore possible that this river, at least, is somewhat older than Sam says.

I would propose, therefore, that the history of this cave is somewhat longer and more complicated than Sam suggests; and that the development of the cave and of the surface river occurred in parallel rather than consecutively. The main cave, Mud Hall and the main streamway to sump 8, is a state-3 cave (Ford & Williams, 1989 p.262), in which the level of the phreas has been controlled by the Millstone Grit cap over the limestone. This basic pattern has been modified over time with the lowering of the resurgence level by river downcutting. This modification has taken the form of (a) increased vadose entrenching, both of the apices of upward phreatic loops and of watertable-levelled components; the Canal is a good example of the latter; and (b) the extension of phreatic loops downstream, such a process leading to bypassing and the abandonment of such loops as New World passage and Sump passage.

The situation at the extreme ends of the cave is especially complicated. At the upstream end there are multiple sinks, both active and abandoned, which have been utilised at various times, more juvenile ones coming into action as older ones are either blocked by sediment or abandoned by continued cutting down of the river bed. On this hypothesis, Bridge Cave is an inlet to the cave system channelling drainage from the river, and is only larger than other inlet passages in that it has been utilised several times. At the downstream end of the system it is likely that a similar profusion of small distributary passages will be found, connecting the main cave streamway to a series of springs at successively lower levels. Whilst none of these have been identified with certainty, it is possible that such as Ogof Cadno, Ogof Cagoule or Ogof Gwdihw may be candidates for this role.

3. On page 175 the water tracing of Ogof Cul is given as suggesting that there may be older passages passing beneath the river bed; yet on page 172 Ogof Cul is described as being itself juvenile. In the absence of further evidence it is difficult to see why Sam argues for age in this case.

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THE QUATERNARY EVOLUTION OF THE SOUTH PENNINES

The paper with the above title, by Peter Rowe, Timothy Austin and Timothy Atkinson, which appeared in Cave Science on pages 117-121 of volume 16, was a reprint from the Annales de la Société Géologique de Belgique, where it appeared on pages 97-106 of volume III (1988). The editors of Cave Science, and the authors of the paper, acknowledge the permission for the reprint kindly granted by the editors of the Annales.

CAVE SCIENCE COVER PHOTOS

There is a general shortage of interesting, high-quality photographs for the covers of Cave Science, and readers are invited to submit their own pictures. Where possible, photographs are used which accompany any of the papers in the particular issue of Cave Science, but many issues consist entirely of papers with no suitable cover material. In these cases, any interesting photograph, related to caves and karst, and of adequate quality, will be welcome.

The photographs may be from Britain or abroad. They do not have to be topical, but current interest is always an advantage; they may be of interesting new explorations (but should be of the caves, and not just of cavers and caving). An accompanying caption may be up to about 100 words.

Only black and white prints are useable; they should have high contrast, and are best supplied between 150 and 250mm wide. The subject should fit to a square format, but rectangular photographs can be cropped with no damage to the print. All photographs will be returned. Please send photographs, and captions on a separate sheet of paper, direct to the Production Editor, Tony Waltham (address on title page).

A NOTE ON DELTA-STAR TRANSFORMATIONS IN CAVE SURVEYING

Patrick Warren

It was shown in a previous paper (Kelly and Warren, 1988) on the least squares method that surveys of network caves could be broken down into traverses which connected the principal survey stations (vertex stations) lying at junctions or the ends of passages. The positions of the vertex stations are found from the solution of a set of simultaneous equations. The positions of the other stations (intermediate stations) which lie along the traverses can easily be found once the positions of the vertex stations are known.

Amongst the principal results of the paper were the replacement theorems which helped to reduce the number of vertex stations and hence the size of the set of simultaneous equations in the problem. One of the key ideas behind the theorems was that two traverses in series or in parallel could be exactly replaced by an equivalent single one. A familiar electrical analogy is the combination of resistances in series or parallel.

There is a further result from electrical engineering which allows one to replace a triangle (or delta) of resistances with a three pronged star or vice versa. This suggests the existence of the analogous transform for survey networks which is studied in the rest of this article (see Fig. 1).

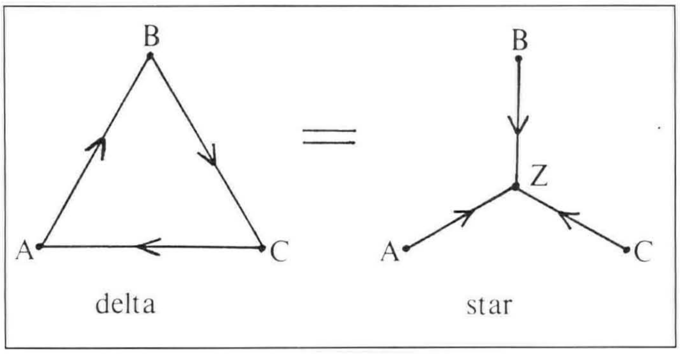

Figure 1. The delta-star transformation shows the equivalence of the two arrangements of traverses. A, B and C are vertex stations which are connected into the rest of the network. The vertex station Z, which occurs in the star, is only connected to A, B and C.

Before proceeding to the transformations themselves, I recap some of the properties of a typical traverse. The first three are the measured changes in easting, northing and height (Δx, Δy, Δz) which are calculated by summing the individual changes for each leg along the traverse. A fourth is the number of legs in the traverse (n). A traverse is completely specified by these four quantities and the stations at which its starts and finishes. I shall consider only the eastings (Δx) from now on since the same results apply without alteration to the northings and heights.

Delta to Star

Referring to Fig. 1, the transformation converts the three traverses A→B, B→C, C→A in the delta to A→Z, B→Z, C→Z in the star.

The quantities for the new traverse, A→Z, are found from

$$n_{AZ} = \frac{n_{CA}n_{AB}}{n_{AB}+n_{BC}+n_{CA}}, \qquad \frac{\Delta x_{AZ}}{n_{AZ}} = \frac{\Delta x_{AB}}{n_{AB}} - \frac{\Delta x_{CA}}{n_{CA}}. \tag{1}$$

The quantities for the other two traverses are found by similar formulae obtained by cyclically permuting ABC in eqn (1).

Note particularly the orientations of the traverses (indicated by arrows in Fig. 1), which determine the signs in the formulae for Δx_{AB} etc. The direction of a traverse may be flipped by changing the sign of Δx (and Δy, Δz).

The procedure in a network containing a delta is firstly to transform it into a star, using the above formulae to obtain the properties of the new traverses. Secondly reduce the transformed network to obtain the positions of all the vertex stations including the fictitious Z. Finally discard the position of station Z. The positions of the remaining stations (including A,B,C) constitute the solution for the original network.

Star to Delta

The opposite transform to that considered above converts the three traverses A→Z, B→Z, C→Z in the star to A→B, B→C, C→A in the delta.

The quantities for the new traverse A→B are found from

$$n_{AB} = \frac{n_{AZ}n_{BZ}+n_{BZ}n_{CZ}+n_{CZ}n_{AZ}}{n_{CZ}}, \qquad \Delta x_{AB} = \Delta x_{AZ} - \Delta x_{BZ}. \tag{2}$$

As before, cyclically permuting ABC gives similar formulae for the other two traverses. Again note the orientation of the traverses concerned.

The procedure here is to transform a star to a delta using the above formulae. Secondly reduce the transformed network to obtain the positions of the vertex stations. This gives the positions of stations A,B,C at the corners of the original star, but not the position of the centre station (Z). This can be found from

$$x_Z = \left(\frac{x_A+\Delta x_{AZ}}{n_{AZ}} + \frac{x_B+\Delta x_{BZ}}{n_{BZ}} + \frac{x_C+\Delta x_{CZ}}{n_{CZ}}\right) \Big/ \left(\frac{1}{n_{AZ}} + \frac{1}{n_{BZ}} + \frac{1}{n_{CZ}}\right) \tag{3}$$

The position of the centre station is a weighted average of its position as calculated from the three corners.

Discussion

The delta-star transformation may not at first seem to result in any simplification in a network, since the number of traverses is unaltered. However it is often the case that a network which cannot be reduced any further by the replacement theorems (and hence must be solved by simultaneous equations) can be transformed into a network which is reducible. For example the simplest irreducible network consists of four vertex stations, each connected to the other three, like a tetrahedron or Mercedes symbol. When the delta-star transformation is applied to one of the triangles of traverses, or its converse to one of the three-pronged vertices, the resulting network can be completely reduced using the replacement theorems.

The methods may be extended to cope with networks in which different parts are surveyed to different standards, achieved by replacing n for a traverse by δ^2, the sum of the variances of the legs in the traverse. This has been covered in more detail in Kelly and Warren (1988).

Incorporating the transformation into a computer program may make it more efficient as fewer sets of simultaneous equations need to be solved. Whether such an increase in efficiency is realised or not depends on the details of the program however. A more definite advantage of the transformation is that it makes many more networks amenable to reduction by hand.

Outline Derivation of Results

The least squares method uses the idea of the error per leg for a traverse. For example for traverse A→B it is

$$e_{AB} = (x_B - x_A - \Delta x_{AB})/n_{AB}.$$

It depends linearly on the end point positions X_A and x_B and its value can be calculated once these are known. The least squares solution requires that the algebraic sum of the e's be zero at each vertex station. This gives a set of simultaneous equations for the vertex positions.

If the delta and star are to be equivalent in any network we must have (Fig. 1).

$$e_{AB} - e_{CA} = e_{AZ}, \quad e_{BC} - e_{AB} = e_{BZ}, \quad e_{CA} - e_{BC} = e_{CZ} \tag{4}$$

satisfied for all values of the corner positions x_A, x_B and x_C. Adding the three equations together one arrives at

$$e_{AZ} + e_{BZ} + e_{CZ} = 0 \tag{5}$$

which is just the least squares equation for the centre vertex station in the star, showing the argument is self-consistent.

One possible way to proceed would be to solve (4) and (5) directly, and after various rearrangements reach (1) and (2) in the text. A more satisfactory way is to realise that one may obtain (1) and (2) more immediately by taking specific arrangements of the corners (the only proviso being that sufficient independent arrangements are used).

For the delta to star, disconnect each corner in turn from the network. In Fig 2a, station B is allowed to float about, and the single traverse A→C is considered. Using the replacement theorems previously mentioned one obtains

$$\begin{aligned} n_{AZ} + n_{CZ} &= \frac{n_{CA}n_{AB} + n_{BC}n_{CA}}{n_{AB}+n_{BC}+n_{CA}}, \\ \Delta x_{AZ} - \Delta x_{CZ} &= \frac{\Delta x_{AB}n_{CA} - \Delta x_{CA}n_{AB} - \Delta x_{CA}n_{BC} + \Delta x_{BC}n_{CA}}{n_{AB}+n_{BC}+n_{CA}} \end{aligned} \tag{6}$$

where the left hand sides are from the star and the right hand sides from the delta. Two more pairs of equations like (6) can be obtained by disconnecting C and A in turn. They could also be obtained by cyclically permuting ABC in (6), and this means that it is only necessary to identify which are the corresponding parts in the left hand and right hand sides of (6), and separate them. In this way one easily obtains eqns (1). Note however that the position of the fictitious Z is undetermined up to a displacement common to all three traverses which reach it. This means that Δx_{AZ}, Δx_{BZ} and Δx_{CZ} can all be shifted by a common amount without affecting the result. The simplest form has been chosen here.

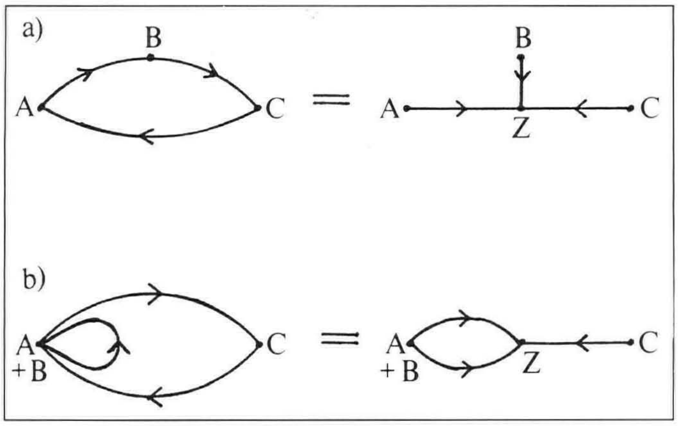

Figure 2. Different arrangements of the corner stations A, B and C are used to derive (1) and (2) in the text. In 2a, B is disconnected from the rest of the network and is free to assume its natural position. In 2b, A and B are forced to have the same position. In both cases the new traverses A→Z are then made equivalent.

For the star to delta, the alternative arrangement is to pair off each pair of corners in turn and force them to have the same position. In Fig. 2b, A and B are fixed together and for the traverse A+B→C one obtains

$$\begin{aligned} \frac{1}{n_{BC}} + \frac{1}{n_{CA}} &= \frac{n_{AZ} + n_{BZ}}{n_{AZ}n_{BZ} + n_{BZ}n_{CZ} + n_{CZ}n_{AZ}}, \\ \frac{\Delta x_{BC}}{n_{BC}} - \frac{\Delta x_{CA}}{n_{CA}} &= \frac{(\Delta x_{BZ} - \Delta x_{CZ})n_{AZ} - (\Delta x_{CZ} - \Delta x_{AZ})n_{BZ}}{n_{AZ}n_{BZ} + n_{BZ}n_{CZ} + n_{CZ}n_{AZ}}. \end{aligned} \tag{7}$$

In this case the left hand sides come from the delta, and the right hand sides from the star. Identifying the corresponding parts of each side of (7) leads directly to (2). The position of the centre station can be obtained from (5) if the positions of the corners are known. When the explicit forms of e_{AZ}, e_{BZ} and e_{CZ} are put in (5), a straightforward rearrangement leads to (3).

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B.C.R.A. Research Funds and Grants

THE JEFF JEFFERSON RESEARCH FUND

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

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

The award scheme will not support the salaries of the research worker(s) or assistants, attendance at conferences in Britain or abroad, nor the purchase of personal caving clothing, equipment or vehicles. The applicant(s) must be the principal investigator(s), and must be members of the BCRA in order to qualify. Grants may be made to individuals or small groups, who need not be employed in universities, polytechnics or research establishments. Information and applications for Research Awards should be made on a form available from S. A. Moore, 27 Parc Gwelfor, Dyserth, Clwyd LL18 6LN.

GHAR PARAU FOUNDATION EXPEDITION AWARDS

An award, or awards, with a maximum of around £1000 available annually, to overseas caving expeditions originating from within the United Kingdom. Grants are normally given to those expeditions with an emphasis on a scientific approach and/or exploration in remote or little known areas. Application forms are available from the GPF Secretary, David Judson, Rowlands House, Summerseat, Bury, Lancs. BL9 5NF. Closing date 1st February.

SPORTS COUNCIL GRANT-AID IN SUPPORT OF CAVING EXPEDITIONS ABROAD

Grants are given annually to all types of caving expeditions going overseas from the U.K. (including cave diving), for the purpose of furthering cave exploration, survey, photography and training. Application forms and advice sheets are obtainable from the GPF Secretary, David Judson, Rowlands House, Summerseat, Bury, Lancs. BL9 5NF and must be returned to him for both GPF and Sports Council Awards not later than 1st February each year for the succeeding period, April to March.

Expedition organisers living in Wales, Scotland or Northern Ireland, or from caving clubs based in these regions should contact their own regional Sports Council directly in the first instance (N.B. the closing date for Sports Council for Wales Awards applications is 31st December).

THE E. K. TRATMAN AWARD

An annual award, currently £25, made for the most stimulating contribution towards speleological literature published within the United Kingdom during the past 12 months. Suggestions are always welcome to members of the GPF Awards Committee, or its Secretary, David Judson, not later than 1st February each year.

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CAVES & CAVING — quarterly news magazine of current events in caving, with brief reports of latest explorations and expeditions, news of new techniques and equipment, Association personalia etc.
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