Cave and Karst Science

The Transactions of the British Cave Research Association

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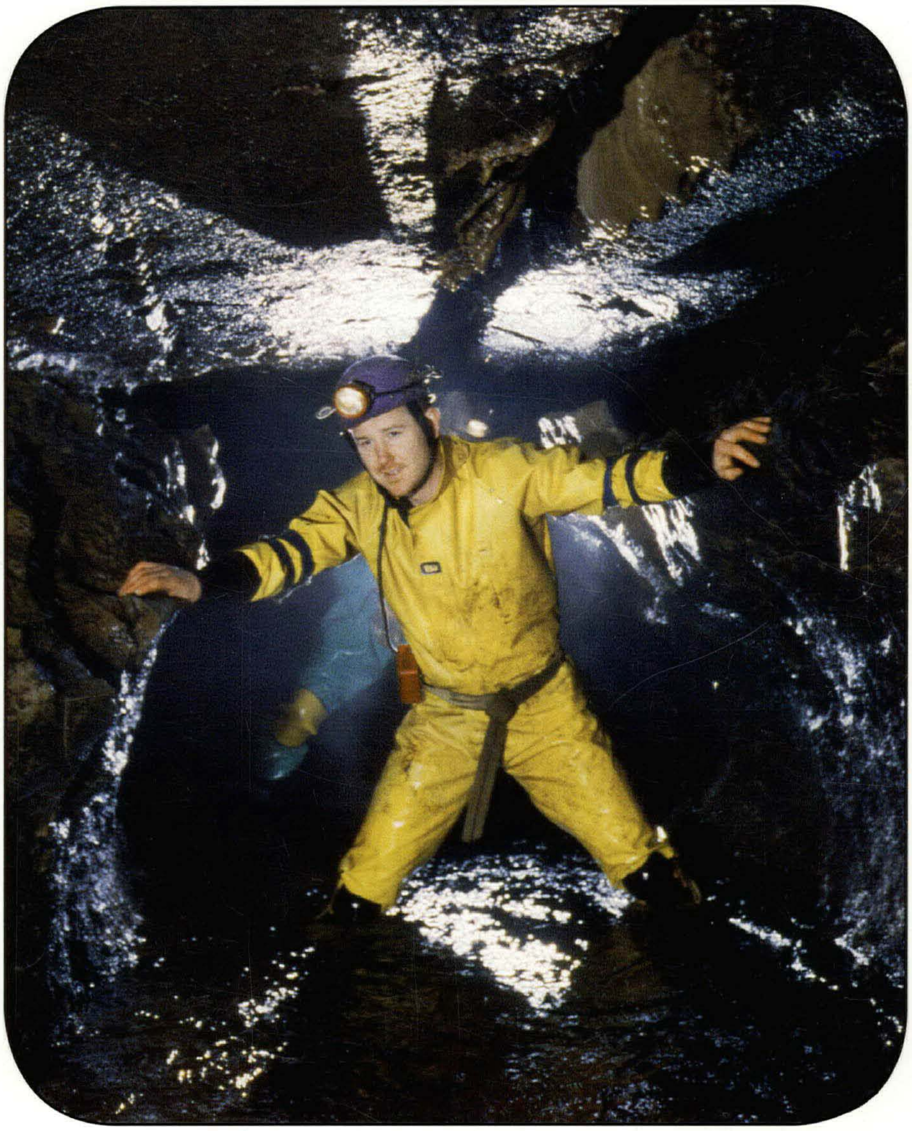

Trickle midges in Peak Cavern, Derbyshire, UK
Low-cost telemetry, Sorbas karst, Spain
Ingleborough Cave, Yorkshire, UK
Gypsum karst, Sivas, Turkey
Caves in Myanmar
Forum

Cave and Karst Science

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

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Cave and Karst Science

TRANSACTIONS OF THE BRITISH CAVE RESEARCH ASSOCIATION

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Cover photo:

Adrian Hall straddles the joint-guided fissure at the head of Lake Avernus in Ingleborough Cave, North Yorkshire. This spot, which provides a somewhat aqueous dive base for the submerged connection with Beck Head Stream Cave, is reached by crawling in the stream (Fell Beck) in a dangerously flood-liable area below Giant's Hall. The first explorers arrived here almost 167 years ago with little better equipment than old clothes and a few candles: a remarkable achievement [see also the paper by Stephen Craven in this Issue].

Photograph by John Cordingley, assisted by Adrian Hall and Gerald Benn.

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Caves in Myanmar

Tony WALTHAM [1] and Andy EAVIS [2]

[1] 11 Selby Road, Nottingham, NG2 7BP, UK.
tony@geophotos.co.uk
[2] Tidesreach, Redcliffe Road, Hessle, HU13 0HA, UK.
andy@andyeavis.com

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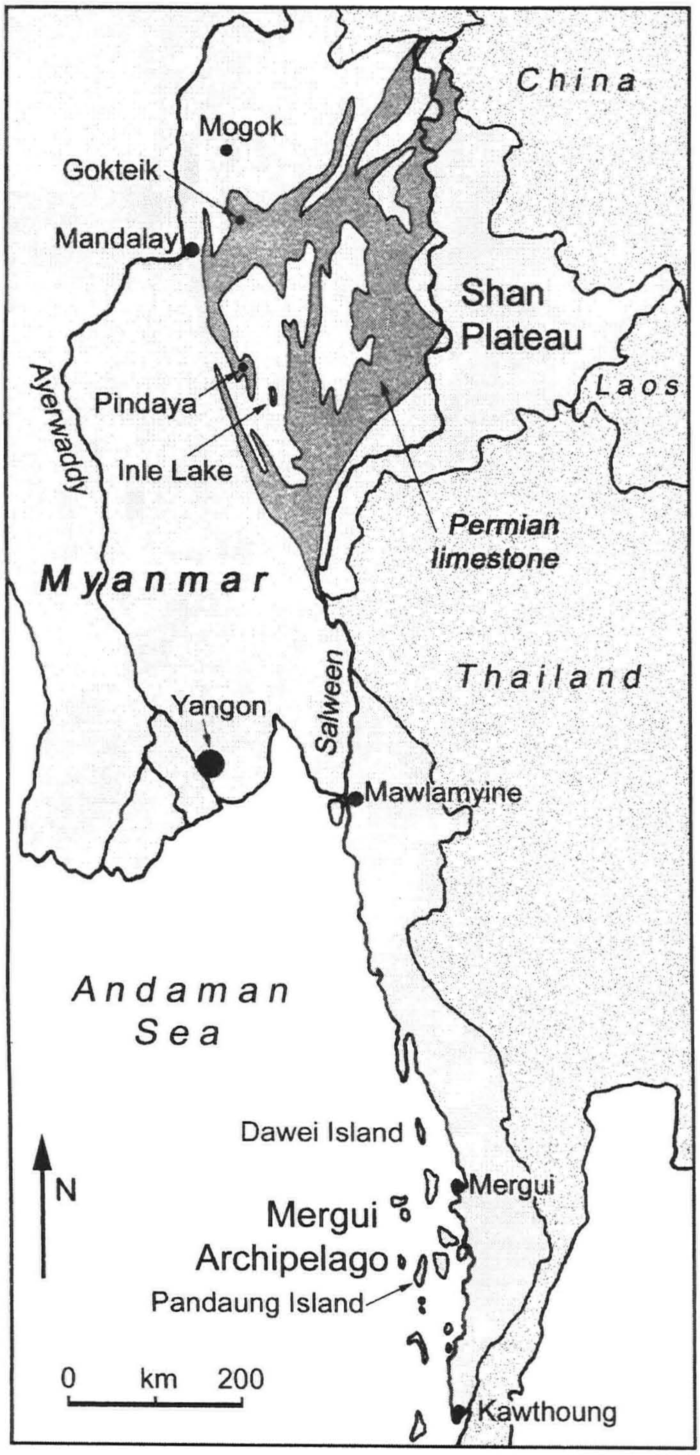

Figure 1. Locations of sites in southern Myanmar.

INTRODUCTION

Due to long-standing travel restrictions, the karst and caves have not been widely investigated in Myanmar (the country once known as Burma). Access is now easier to some parts of the country, though others remain virtually closed to foreigners. A useful overview of Myanmar caves was presented by Dunkley *et al.* (1989). More has been revealed since the Harrison Institute (based in England) has pursued its biodiversity research into the bats that occupy a critical site between the Indian sub-continent and the peninsulas of Southeast Asia.

CAVES OF THE ANDAMAN COAST

The southern part of Myanmar is a narrow strip between the Andaman Sea and the watershed frontier with Thailand (Fig.1). Its geology is complex, with major faults isolating scattered and

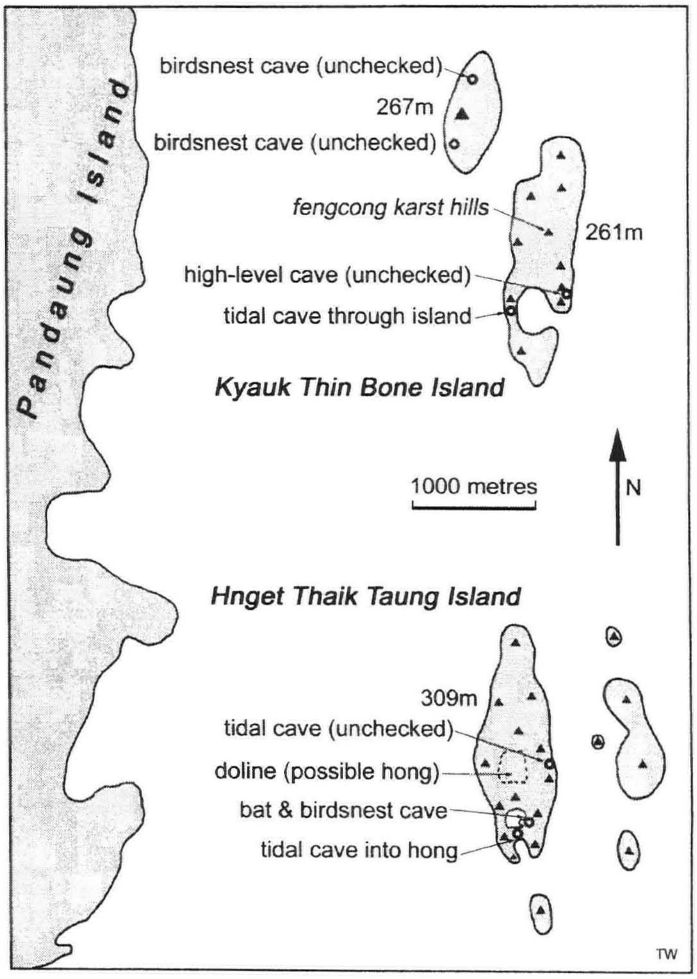

Figure 2. The limestone islands east of Pandaung in the southern Mergui Archipelago.

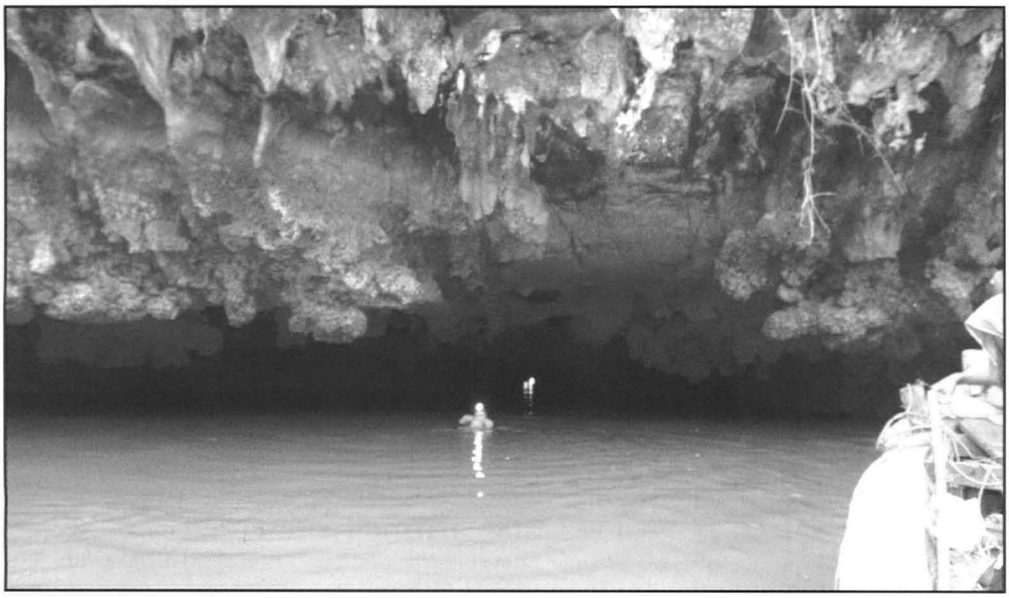

Figure 3. The tidal cave through to the hong in Hnget Thaik Taung Island (all photos by Andy Eavis except Figure 8).

unrelated outcrops of Permian limestones and Mesozoic granites within the dominant slates, shales and sandstones that are also mainly of Permian age. Karst and caves are therefore restricted to isolated patches, and access to most of the area is restricted because of almost continuous activity by uncontrolled rebel groups.

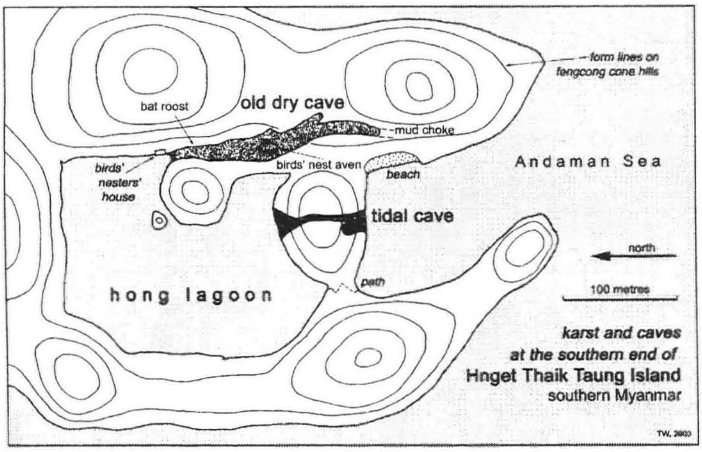

Figure 4. Sketch survey of the caves and hong at the south end of Hnget Thaik Taung Island.

The area around Mawlamyine (also known as Moulmien) is reported to contain fine tower karst, with high limestone hills rising from the alluviated coastal plains and along the valley of the Salween River. There are many caves, most with the large passage sizes and no great length that typify isolated karst towers (Dunkley *et al.*, 1989). Further inland and further south, there are other caves known in the scattered blocks of limestone.

The Mergui Archipelago (also known as Myeik Archipelago) is a cluster of islands off the southern coast of Myanmar (Fig.1). Sadly, it is not a chain of karst islands to rival Vietnam's Halong Bay, as it has only two small patches of limestone. At its northern end, Dawei Island (also known as Tavoy Island or Mali Island) is a long thin strip of limestone bounded by very steep and vertical cliffs that rise 200m or more from the Andaman Sea. Access is next to impossible, as it is guarded jealously by birds'-nest collectors. This implies that the island has a number of caves containing the saliva nests of the cave swifts (an incredibly valuable resource for supply to Eastern gourmets), but it is likely that these will be large, old, abandoned chambers, whereas extensive cave systems are unlikely to exist in the small limestone outcrop.

The only other limestone in the Mergui Archipelago forms a small group of islands on the eastern side of Pandaung Island (also known as Letsok-aw Island or Domel Island)). These are formed of steeply folded Permian Moulmein Limestone, whereas Pandaung is a Mesozoic granite. The limestone islands are the hills of a fengcong karst whose plains and doline floors were submerged by the end-Pleistocene rise in sea level; water depths indicate that the remains of the karst plain are now about 5 to 15m below sea level. Flooded dolines form two large bays in the islands and also at least one internal lagoon, known as a hong, that is reached through a cave (Fig.2). A second deep doline has been seen only from a boat, as a deep depression between steep cones. If the drowned karst was a mature fengcong, this could be expected now to be another hong, but this remains unconfirmed.

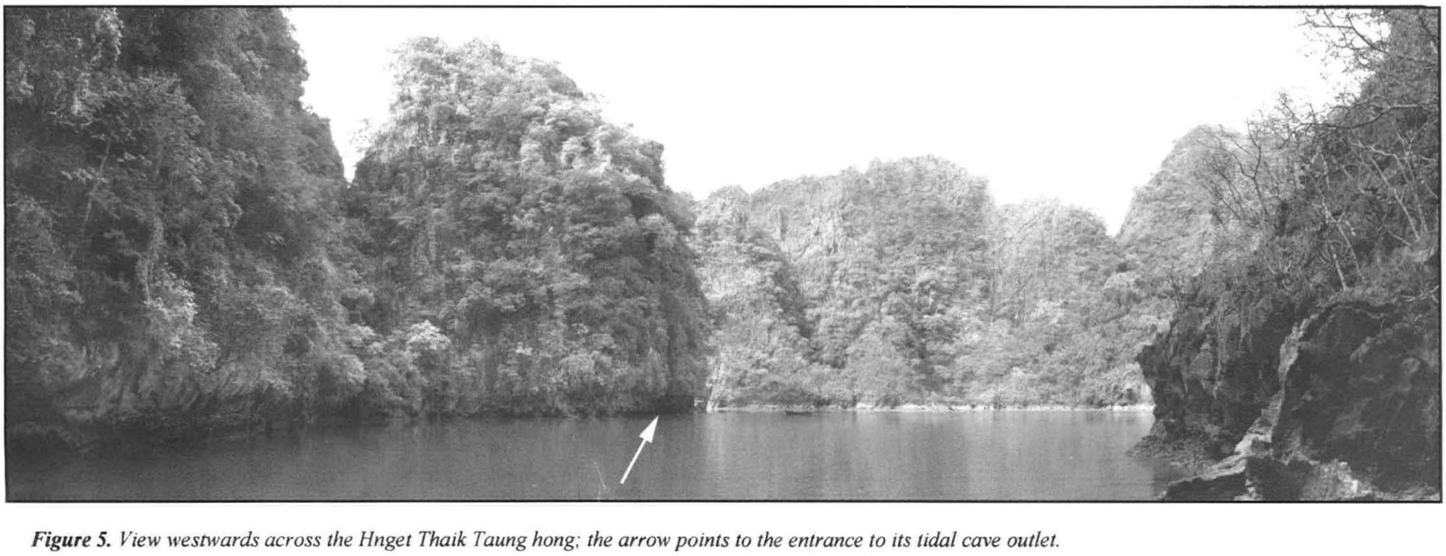

Figure 5. View westwards across the Hnget Thaik Taung hong; the arrow points to the entrance to its tidal cave outlet.

Figure 6. The large old phreatic tube in the cave behind the Hnget Thaik Taung hong.

All these limestone islands are scored by deep notches at the level of the tidal range, and at least two caves extend from the back of the notches. One cave passes right through Kyauk Thin Bone Island into the back of the flooded doline that now opens to the sea as a large bay. Of the other cave entrances seen but not checked, two on the unnamed northern island are also high-level remnants of old passages. Bamboo ladders and ropes up to their entrances suggest that these caves are, or have been, exploited for birds' nests.

The second tidal cave is at the south end of Hnget Thaik Taung Island. It is entered through a notch at the back of a flooded doline that is open to the sea as a bay. The 80m-long cave is submerged at high tide, carries strong flows at mid-tide, is an easy swim through around low tide, and is navigable by small boat at spring low tides (Fig.3). It passes directly beneath the crest of a conical hill, through to the hong lagoon that is another flooded doline (Fig.4). This is the hong previously described as giving "the impression of the crater of a volcano" (Chhibber, 1934). It is a typical depression within fengcong karst, ringed by conical hills, except that the sea now occupies its floor, and tidal notches have steepened the margins by undercutting the cones (Fig.5).

Accessible from the Hnget Thaik Taung hong, a remnant of old phreatic trunk cave that was formed along the limestone strike is now dry and floored with mud and clay. Its inner part is a splendid phreatic tube about 10m in diameter (Fig.6). The size of this passage suggests that it was probably a major conduit carrying a river that sank on meeting the limestone, before rising on the far side of the outcrop. This was when the area of the archipelago was continuous and hilly land, long before its dissection into fengcong karst. The first 50m of the cave houses many bats. Above the central chamber, a 30m-tall aven has birds' nests on its upper walls. These are harvested by a group of local people who have built a bamboo tower up the aven (Fig.7) and also a small longhouse at the cave entrance. For access when their boat route through the tidal cave is sealed off, the nest collectors have made a rocky path over the saddle that has been undercut and steepened into an arete between the hong and the bay in their adjacent drowned dolines.

The conical island hills, the old caves, the notches, the tidal caves and the hong are typical features of the marine-drowned fengcong karsts that characterise Southeast Asia (Mouret, 2004). Halong Bay, in Vietnam, is the type example, but the karst south of Phuket, in Thailand, and some other islands in the western Pacific also have a number of these beautiful hongs with their dramatic entries through tidal caves. This small part of the Mergui Archipelago is a comparable hong site.

CAVES OF THE SHAN PLATEAU

East of the Ayerwaddy Valley and Myanmar's central lowlands, large areas of dissected uplands are known collectively as the Shan Plateau. On the western rim, limestones form some of the hills and ridges between Inle Lake and the central lowlands (Fig.1). The northern sector of these contains the caves at Pindaya, famed for their thousands of Buddha statues (White, 1988). Bat researchers have been taken to many caves in the area, including some with large old chambers and others with passages that continue beyond the interests of bat collectors. Correlations are difficult in a country distinguished by numerous name changes of its geographical features, but it appears that there are many more caves of significant size than those listed by Dunkley *et al.* (1989). Further east on the Shan, outcrops of Permian limestones are known (Oo *et al.*, 2002), but await further investigation.

Figure 7. The bird's-nesters' tower in the Hnget Thaik Taung cave.

Figure 8. Pinnacled rockhead exposed in an opencast ruby mine at Mogok.

Further north, the main potential for karst development appears to be on scattered outcrops of the marbles and limestones of the Mogok Series. These lie in among much larger areas on Precambrian metamorphic rocks and granites. At Mogok itself, marbles are host to the famous ruby deposits, while sapphires occur in the adjacent granitic rocks. Both gems are worked mainly from extensive placer deposits in the valley alluvium (Waltham, 1999). Open pits have exposed pinnacled rockheads on the marble karst (Fig.8), and some of the mines have intersected cave passages, both open and sediment-filled, though no extensive cave systems have yet been found.

A cave directly beneath the high railway viaduct at Gokteik has a large river passage that is the best part of 300m long from sink to resurgence (Fig.9). The passage is well over 25m high and wide, except where it lowers over a deep lake, just beyond a huge flowstone bank that descends from the stalagmite-choked remains of an old high-level (Fig.10). The lake requires a swim that is only possible downstream in normal conditions. Gokteik Cave has looming rock walls, and a roof draped with stalactites. Rumours that is formed in travertine (reported by Dunkley *et al.*, 1989) are erroneous – it is cut in the Permian limestone. There do not appear to be any other large caves in the vicinity, but there are clearly many more caves to be found in the highlands of Myanmar.

ACKNOWLEDGEMENTS

These brief notes are based on three visits to Myanmar by the authors, two of which were by kind invitation from Paul Bates, Director of the Harrison Institute, who is especially thanked for the rare opportunity to visit the Mergui Archipelago. Thanks also to Liz Price for information on the Thailand hongs.

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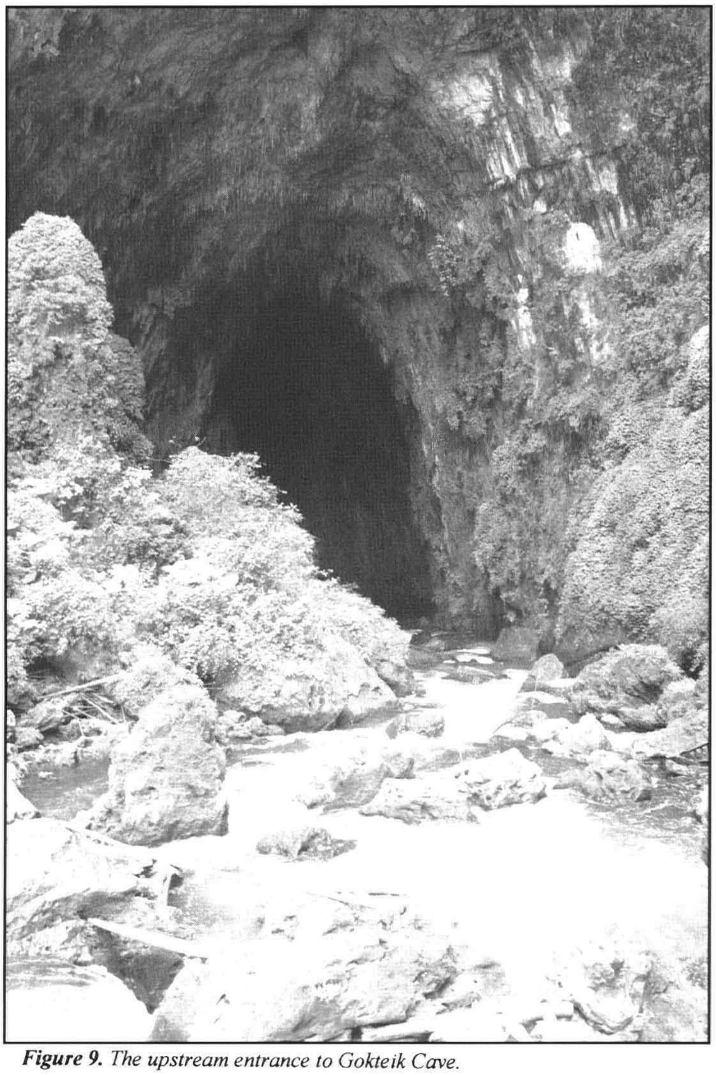

Figure 9. The upstream entrance to Gokteik Cave.

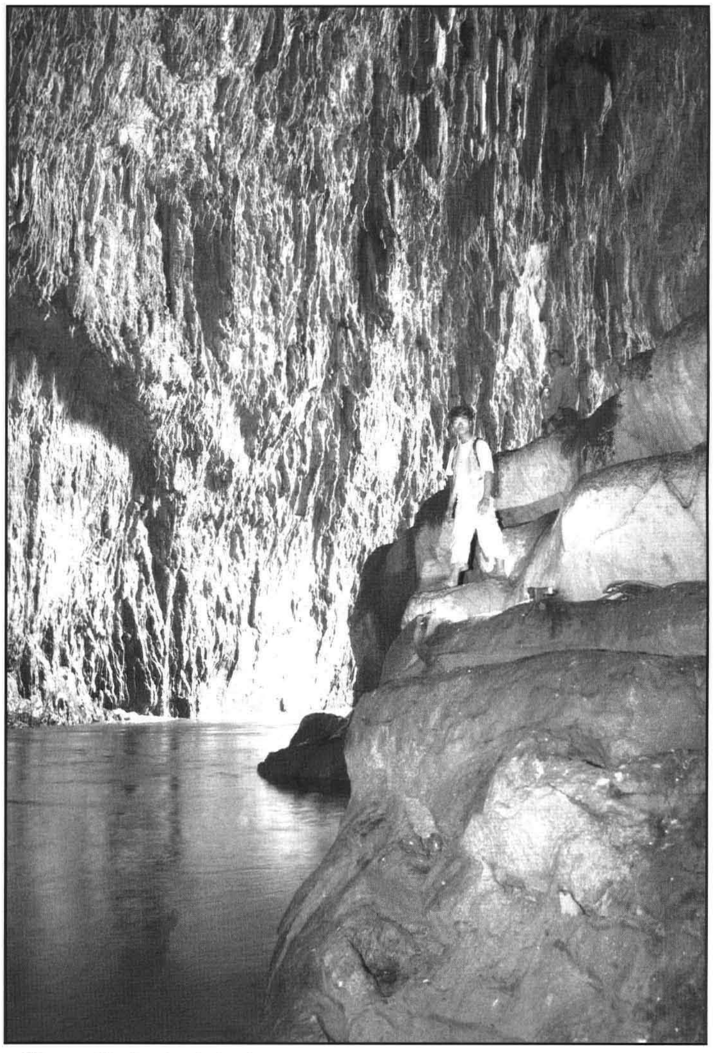

Figure 10. Inside Gokteik Cave, with flowstone banks from the high-level descending to deep water.

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Gypsum karst south of İmranlı, Sivas, Turkey.

Uğur DOĞAN [1] and Serdar YEŞİLYURT [2]

[1] Ankara University, Faculty of Letters, Department of Geography, 06100 Sıhhıye, Ankara, Turkey
E-mail: ugdogan@yahoo.com
[2] Ankara University, Faculty of Letters, Geography Student, 06100 Sıhhıye, Ankara, Turkey

Abstract: Sivas and its surroundings represent an important gypsum karst terrain, where gypsum occurs as massifs displaying many well-developed karst landforms. The area south of İmranlı forms the eastern part of this region. There are normally-outcropping gypsum formations as well as anticlinal and diapiric structures and gypsum ridges uplifted by gypsum tectonics cutting the cover formations south of İmranlı. Karstic features such as karren, dolines, swallow holes, blind valleys and caves are observed in this karstic terrain. South of İmranlı are some of the finest examples of polygonal karst, with a thickness of 500m normally exposed on a plateau developed on gypsum formations. In this region there are 80 to 100 dolines per km^2. The karst is generally most youthful in the area south of İmranlı, and there are no poljes or collapse dolines characteristic of more mature karst. Water sinking underground from dolines or blind valleys has formed gypsum caves, and major parts of the caves in the area are of swallow hole or spring type. The İnhas Cave System, which features in this study, comprises relict/semi-active (180m) and active (75m) levels, and is a multi-storey, multi-staged, swallow hole to spring cave, with a total length of 225m.

(Received 24 November 03; Accepted 07 January 2004).

INTRODUCTION

One third of the total surface area of Turkey comprises karstic terrain. Compared to the carbonate rock outcrops the area covered by gypsum formations is relatively small, with most of the outcrops in Central Anatolia (Fig.1). The gypsum successions are generally of Oligocene and Miocene age and were deposited in terrestrial environments such as lakes, playas and shallow sea/sabkha (Aktimur, 1988; Çubuk and İnan, 1998; Atalay, 1999; Günay, 2000; Koşun and Çiner, 2002; Doğan, 2002). Although gypsum sequences are seen in the Ankara, Çankırı, Çorum, Kırşehir and Kayseri regions of Central Anatolia (Fig.1) (Alagöz, 1967; Günay, 2002) the most widespread and thickest successions (more than 750m thick) occur east of Sivas (Alagöz, 1967; Kaçaroğlu *et al.*, 1997; Karacan and Yılmaz, 1997; Çubuk and İnan, 1998; Günay, 2002; Waltham, 2002). Gypsum strata in other regions generally occur as sequences of thin beds, with clay, marl and sandstone interbands. Thus, with the exception of some subsidence dolines south of Çankırı, no significant karstic development is found in the gypsum of these regions (Doğan, 2002).

Well-developed karren, dissolution dolines, collapse dolines, blind valleys, springs, swallow holes, caves, unroofed caves, canyon valleys and poljes occur on the massive Oligocene-Miocene gypsum sequences, especially those east of Sivas, near Hafik, Zara and İmranlı (Fig.1). There are magnificent examples of polygonal karst north of the Kızılırmak valley between Sivas and Zara, where youthful karst is present. Poljes and collapse dolines are found in the more mature karst region between Hafik and Zara, around the Kızılırmak valley. However, in a region that displays such a well-developed gypsum karst, no long gypsum cave has yet been observed (Waltham, 2002).

There has been only limited study of the Sivas gypsum karst and the surrounding region. Alagöz (1967) carried out the first comprehensive geomorphological study. Subsequently Mayer (1974) made a cave survey in part of the karst region south of Sivas, and published a short report. Studies of the hydrogeological features of the Sivas Gypsum Terrain were undertaken mainly by Kaçaroğlu *et al.* (1997) and Günay (2002). Finally, Waltham (2002) carried out a brief study of the general characteristics of the gypsum karst, providing a short introduction to the karstic landforms present.

The gypsum karst region south of İmranlı lies towards the eastern side of the Sivas Gypsum Karst Terrain (Fig.1). The study site covers a region between the south of the Kızılırmak valley, where İmranlı Town grew up, and the upper part of the Acıçay Stream, a tributary of Kızılırmak River. This paper deals with the gypsum successions south of İmranlı, the karstic landscapes developed upon them, and the exploration of a 225m-long gypsum cave. The geomorphological characteristics of this region as part of the Sivas gypsum karst were also determined.

A continental climate prevails in the region. Summers are hot and dry and winters are cold and snowy. Rainfall takes place mainly in spring, with an average annual amount of 424mm.

GEOLOGY

The Sivas Basin extends between the Northern Anatolia Mountains and the Taurus Mountains. The stratigraphical position of widespread massive white gypsum lying between the south and southeast of İmranlı, is within the middle and upper levels of the late Oligocene to Miocene-aged Ağılkaya Formation. Following a transgression that started in the Late Oligocene (Çubuk and İnan, 1998; Koşun and Çiner 2002), the Ağılkaya Formation was deposited in a shallow sea/sabkha environment. Thin clay, mudstone and sandstone layers are present between massive gypsum beds.

The Oligo-Miocene gypsiferous succession lies unconformably over Oligocene and Eocene formations deposited in river, playa and continental shelf environments, and was originally overlain by younger formations, some of which have since been removed by erosion.

Within those gypsum beds still covered by younger formations some changes in elevation, related to gypsum tectonics, have taken place in the south and southeast of the region. In these areas there are "S"-shaped lateral isoclinal folds in gypsum, which could only have formed due to vertical tectonics (Çubuk and İnan, 1998). Such structures are a typical indication of gypsum or salt tectonics (Çubuk and İnan, 1998). As a result of these effects the gypsum only lifted the overlying sediments and increased the slopes of the bedding in some areas. Elsewhere clastic sediments were removed from the surface above anticlinal gypsum buttresses and diapiric structures. The gypsum is thrust over the clastic cover layers in some areas. For

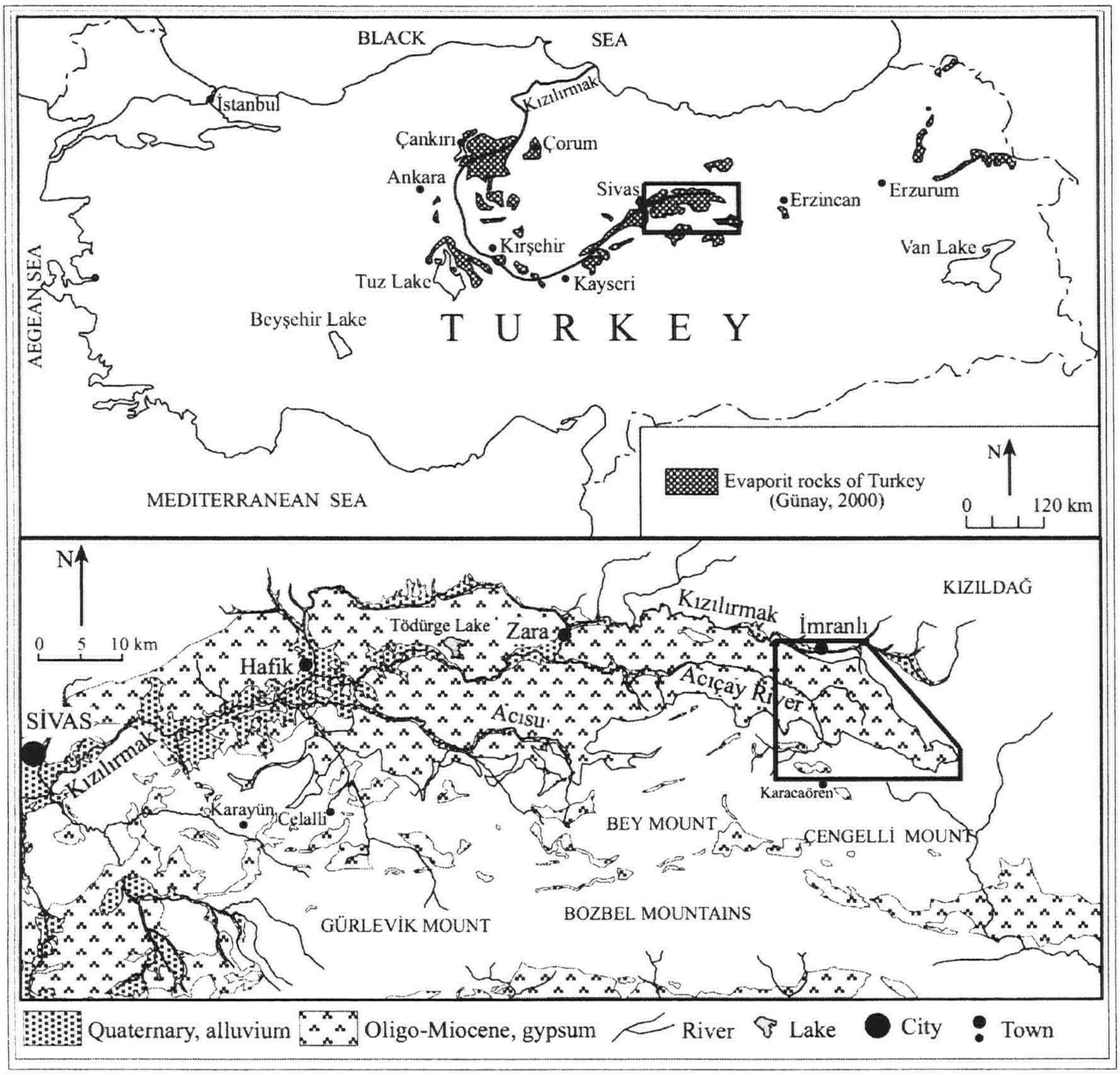

Figure 1. Location map of the study area.

instance the westnorthwest to eastsoutheast-trending Çorakgeçidi Gypsum Ridge formed by forcing through much younger layers and formations (Fig.2). In the south and north this gypsum ridge has a synclinal form. Another important gypsum tectonic structure is the Gelenli Diapir, which forced its way through much younger formations as it rose. The general structure of the diapir is dome-like, with onion-like layering and small folds. Some parts of this structure are overthrust onto much younger units. The uplift of the gypsum at this site took place in three stages: Early Miocene, post-Mid Miocene and between the Pliocene and the Present (Çubuk and İnan, 1998).

GENERAL GEOMORPHOLOGICAL SETTING

Based on the geological and tectonic features of the gypsum formations, the region generally south of İmranlı can be considered in two parts: that close to due south of İmranlı (around the Acıçay valley) and that to the southeast of İmranlı. Close to the south of İmranlı the gypsum is the eastern part of the succession (Sivas Gypsum Karst Terrain) that extends as an uninterrupted outcrop to the east of Sivas province (Fig.1). The thickness of the gypsum succession observed in this region reaches 500m around the Acıçay canyon (Fig.2).

The gypsum outcrops to the southeast of İmranlı are in the form of structures such as diapirs and anticlinal gypsum ridges that have pushed through the cover formations above them as a result of gypsum tectonics. The gypsum thickness at the surface ranges between 50 and 550m in these structures. The karstification is discontinuous, since it developed on these local structures.

The study area is at high elevation, at an altitude of 1600m in the Kızılırmak valley, reaching 2000m in the southeastern region where, some uplift of the gypsum has occurred (Fig.2). Also in this area is the watershed between the Kızılırmak (Black Sea) and Euphrates (Arabian Gulf) basins.

Erosion is extensive because the elevation is very high, reflecting the steep slopes of the anticlinal and diapiric structures, and the fact that the overburden formations are not very resistant. Thus, "V"-shaped valleys and badlands topography are widespread to the southeast of İmranlı. Apart from these areas there is a large gypsum karst plateau, cut by karstic features, where the Acıçay stream has entrenched a deep canyon valley.

The fact that the formations overlying the massive gypsum were eroded late, linked with the relatively constant elevation in some regions – depending upon gypsum tectonics – indicates that the karst is youthful. Dolines are the most common karstic landforms in the gypsum karst area south of İmranlı, though collapse dolines and suffusion dolines are rare. Apart from these, the region displays other features such as karren, caves, karstic springs, swallow holes, blind valleys and canyon valleys.

KARSTIC LANDFORMS

Karren

Microkarstic forms such as karren are developed and destroyed much more quickly in gypsum areas than they are on limestones. So, well-developed karren are seldom preserved in gypsum karst regions. However, there are good examples of karren within the gypsum karst terrain south of İmranlı. So much so that these karren constitute the most beautiful examples within the Sivas gypsum karst. Intact rinnenkarren and rillenkarren on the western slopes of Güneşönü Hill in the southeast of the area look like karren developed on limestone (Fig.2). The channel lengths, widths and depths of the rinnenkarren developed on gypsum with surface slopes of 60 to 70°, were 2m, 10 to 30cm and 30cm respectively (Fig.3). The karren channels developed best in the gypsum where there are no clay bands and lateral fractures. In fact, in regions where clay bands and fractures are present, destruction of the karren channels starts from these points.

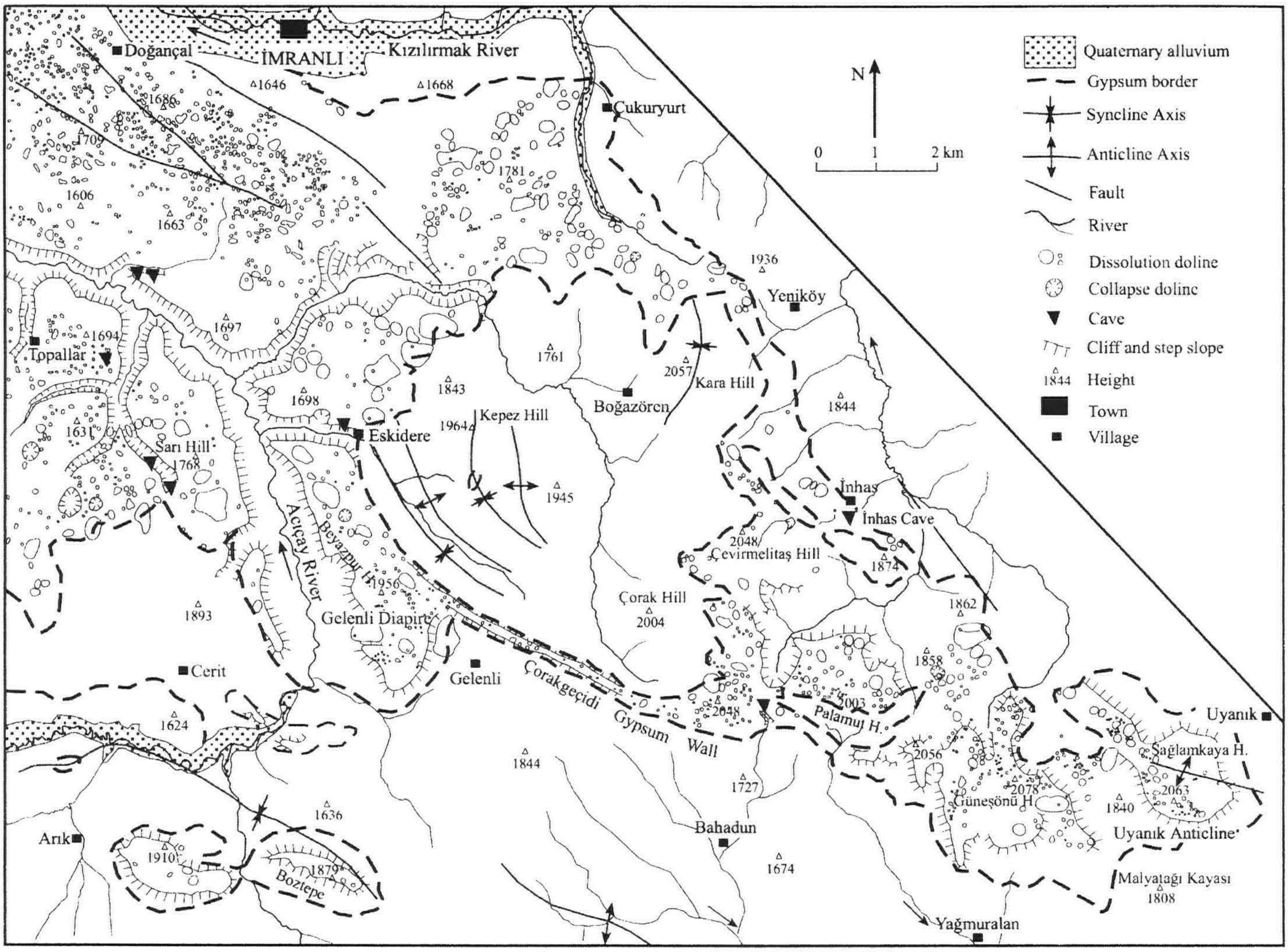

Figure. 2. Geomorphological map of the study area.

Another dominant karren type in the area is rillenkarren. These karren, where observed in gypsum rock blocks with a surface slope of 70 to 80° have a channel length of 30 to 50cm, channel width of 3 to 10mm and channel depth of 3 to 5mm. Formation of these karren depends on the melting of snow, and seasonal or annual rainfall, and they are destroyed rapidly.

Apart from these there are partly destroyed pits and tunnel karren that formed beneath the soil in different parts of the gypsum outcrop.

Dolines

The meteoric water of the region is drained largely by the Kızılırmak River and its tributary Açıcay stream. Although the Kızılırmak River flows outside the gypsum area to the north of the study site, the Açıcay has entrenched a canyon valley with a depth of 200 to 250m at the western side of the gypsum plateau. Around the Açıcay canyon and on the plateau there are numerous dolines. Dolines are also seen on structures such as the diapirs, anticlines and gypsum ridges formed by gypsum tectonics. These regions, where the gypsum thickness reaches 550m, are of high karstic plateau character, broken by dolines.

As would be expected, the karst on the gypsum outcrops south and east of Acıçay, where the overlying formations were eroded earlier, is more mature than in the regions where they were eroded later. In areas where the karstification started earlier the diameters and depths of the dolines are much greater, and some of the dolines have developed blind valley features. Most of the dolines lie in areas where gypsum tectonics remain active and funnel shaped landforms (Fig.4) are found at the edge of the outcrop. Southeast of İmranlı, south of the Kızılırmak valley, around Güneşönü Hill and west and east of the Acıçay Stream, are large dolines, 30m deep and with 600m long-axes (Fig.2). Most of these have swallow holes in their floors. Apart from these, a few palaeokarstic valleys and collapse dolines are also present in this region.

On the gypsum plateau southeast of İmranlı, where the cover formations were eroded most recently, the number of dolines per km^2 is higher, but these dolines are relatively shallow. This region is an exceptional polygonal karst area, and displays a truly outstanding karst landscape (Fig.5). Aspects of the landscape are in all stages of development, recognizable by dolines increasing in size and

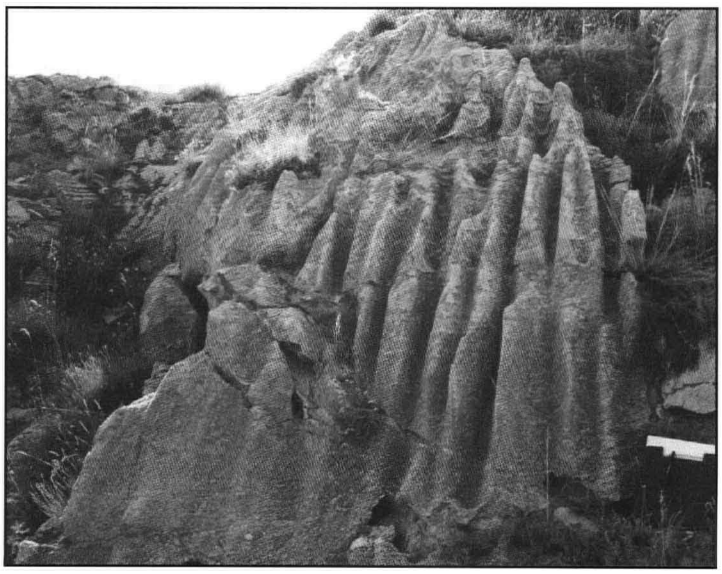

Figure. 3. Well-developed rinnenkarren on the 60 to70° slopes of Güneşönü Hill.

Figure. 4. *One of the big dolines with swallow hole character (funnel shaped) located at the margin of the gypsum outcrop.*

decreasing in number. Over much of the plateau a polygonal net of low "interfluve" ridges encloses shallow depressions with internal drainage into small sinks (Waltham, 2002). The number of dolines per km^2 is around 80 to 100 south of İmranlı. The regions with the highest doline density are southwest of İmranlı Town and the karstic plateau to the north of the Acıçay area. Although not as continuous as in this area, there are also good examples of polygonal karst on the anticlinal and diapiric structures (Fig.6). Because the geomorphological map was drawn at 1:25,000 scale, most dolines less than 10m deep were not marked on it. Thus it should be emphasized that there are many more dolines than are indicated on the map.

Clay and sandstone bands with thickness of 1 to 5m lying between gypsum layers at the bottom of the dolines support the formation of residual soils. The floors of some dolines that have an adequate soil layer and big enough area are utilized as agricultural land. Water falling on the gypsum surface or on the soil immediately drains underground. Rainfall hitting the doline slopes collects at the foot of the slopes and disappears into swallow holes. Most of the water that goes underground joins the subsurface circulation and seldom reappears in other dolines. Water that sinks within the gypsum area re-emerges as springs from valley slopes, boundaries of the gypsum formation or from the contacts with impermeable layers within the gypsum. Some water that starts to flow on the surface may go underground in blind valleys. Although not common, suffusion dolines do exist in the alluvial cover on the floors of the blind valleys.

Collapse dolines

Collapse dolines are not common in the karstic region south of İmranlı because this karst is most youthful. The constant decline in the base level of the karst, and local increases in elevation linked with gypsum tectonics gave very little chance for the development of lateral karstic cavities that may form collapse dolines. Since water

Figure. 5. *Polygonal karst southwest of İmranlı.*

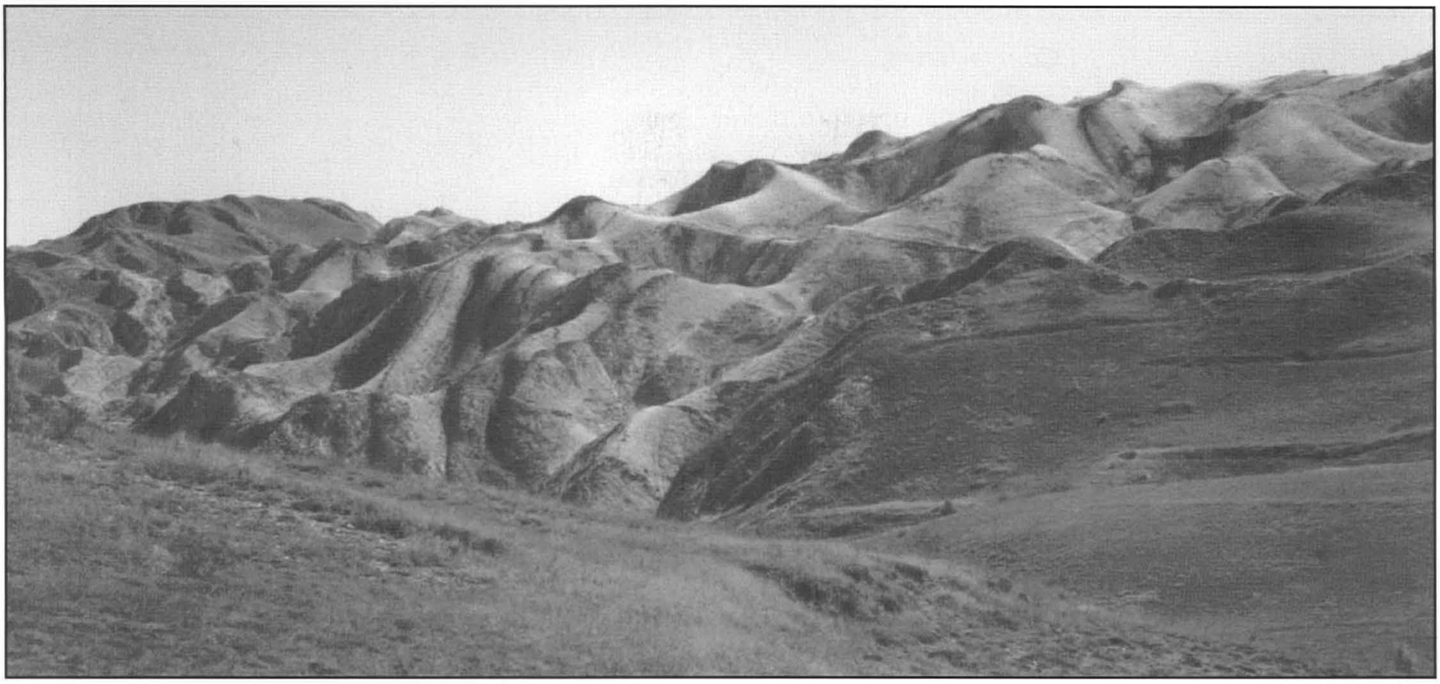

Figure. 6. Polygonal karst on an anticlinal structure southeast of İmranlı (Güneşönü Hill).

that disappears into the dolines drains into deep shaft-like swallow holes there is very little development of the type of karstic cavity that may cause collapse doline development. This is why big collapse dolines such as those found in the mature karst region into the south of Hafik and Zara at the west of the region are rarely seen in this area (Fig.2). The best-known among the latter is Yeşilgöl Collapse Doline, with diameter of 140m and a depth of 20m (Fig.7). There is a lake in the doline with a diameter of 80m and a depth of 20m.

Caves

Most of the caves south of İmranlı are of spring or swallow hole type. Waters that sink at swallow holes in dolines or blind valleys resurge from the valley floors or slopes as springs. Caves have been formed in the gypsum by the circulating underground water. Unfortunately collapses have taken place at many entrances, making their investigation impossible.

It is known that there are caves around the Acıçay canyon, lying to the west of the study site (Fig.2). However, as this study focuses on the investigation of the general characteristics of the gypsum karst south of İmranlı, the caves at the Acıçay canyon are ignored here and will form the subject of another comprehensive study.

Due to the deep incision of the bed of the Acıçay in the area of massive gypsum southsoutheast of İmranlı, other tributaries could not adapt and were left hanging, becoming small dry valleys. In due time dissolution dolines related to karstification formed in the floors

Figure7. The Yeşilgöl Collapse Doline, southeast of İmranlı.

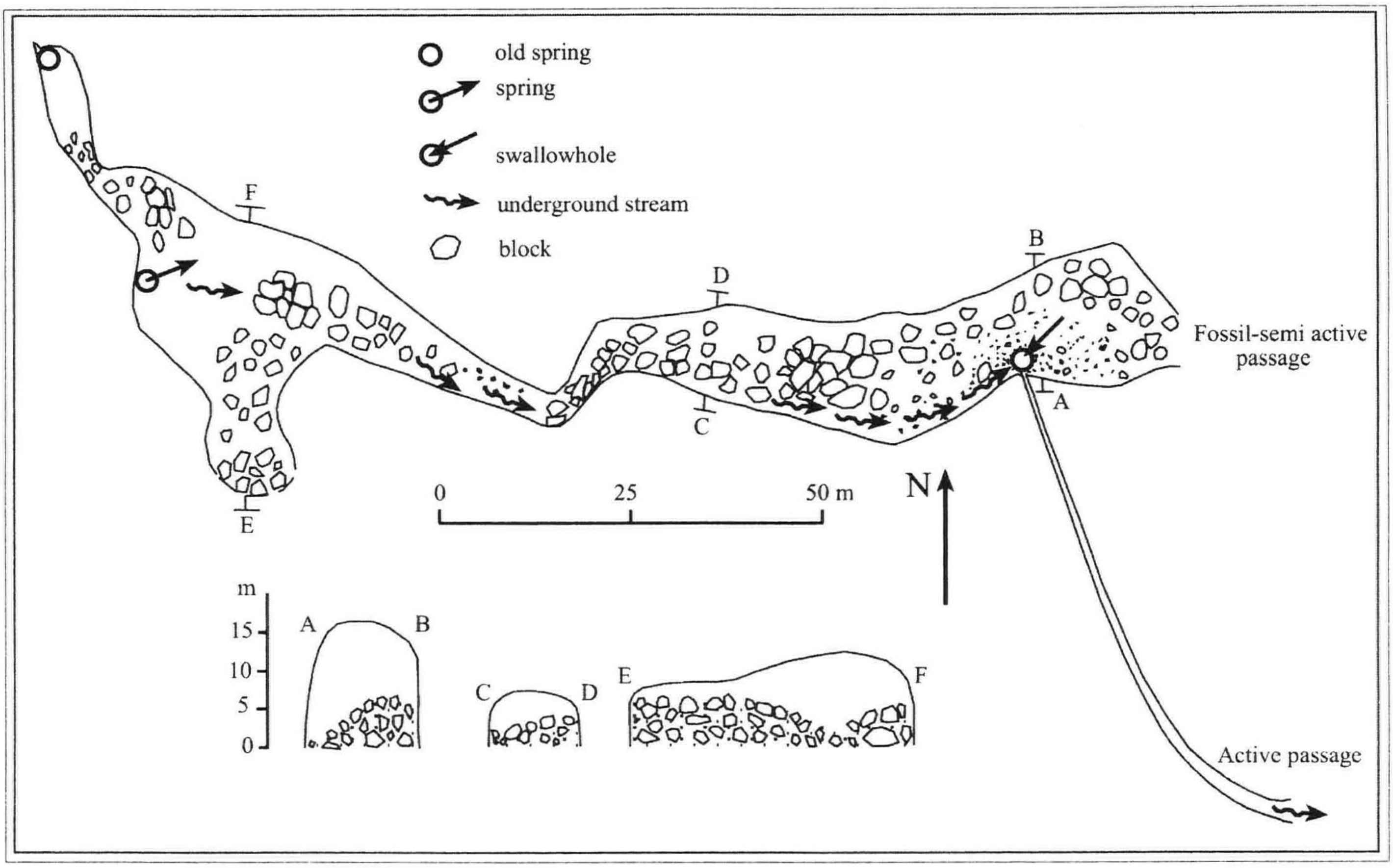

Figure. 8. *Plan of İnhas Cave.*

of the palaeo-valleys. Rain falling in the basins of these palaeo-valleys flows on the surface to the dolines, joins the underground drainage from the swallow holes located in their floors and then resurfaces from the slopes of the Acıçay canyon or from cave mouths as springs. The waters may resurface several times along the palaeo-valley and disappear again into swallow holes. Water going underground from big dolines or palaeo-valleys in the plateau areas where doline karst is observed formed gypsum caves.

Caves located to the southeast of İmranlı were partly investigated within this study. However, most of the caves could not be examined since their entrances were closed by collapses. Therefore these caves with lengths of 10 to 20m were not evaluated in this study. The cave that was investigated was İnhas Cave, located in İnhas Village southeast of İmranlı (Fig.2).

The entrance of the cave, in the southeastern part of the village, is at the base of the eastern side of a gypsum hill where the slope is 80°. The cave system extends in an east–west direction and can be evaluated in two parts. The first part is a 180m-long relict to semi-active storey, and the second is a 75m-long active storey formed 20m below the entrance level by the underground stream that enters a swallow hole in the first storey. The entrance of the active storey lies 60m southsoutheast of the entrance to the relict/semi-active storey (Fig.8).

The relict/semi-active passage entrance is 7m wide, with a roof height of 4.5m. Breakdown material seems to have come from the slope at the entrance of the cave, which was apparently larger before. The ceiling height of the relict/semi-active passage ranges between 1 and 16m (Fig.9), and the thickness of breakdown materials is from 8 to 9m. Eight metres inside the entrance of the cave the height of the present ceiling is 16m, and this is the region where the cave ceiling was highest (Fig.10). The width of the passage varies between 2 and 19m. The narrowest and the lowest part of the relict/semi-active storey is at the point where the accessible passage ends.

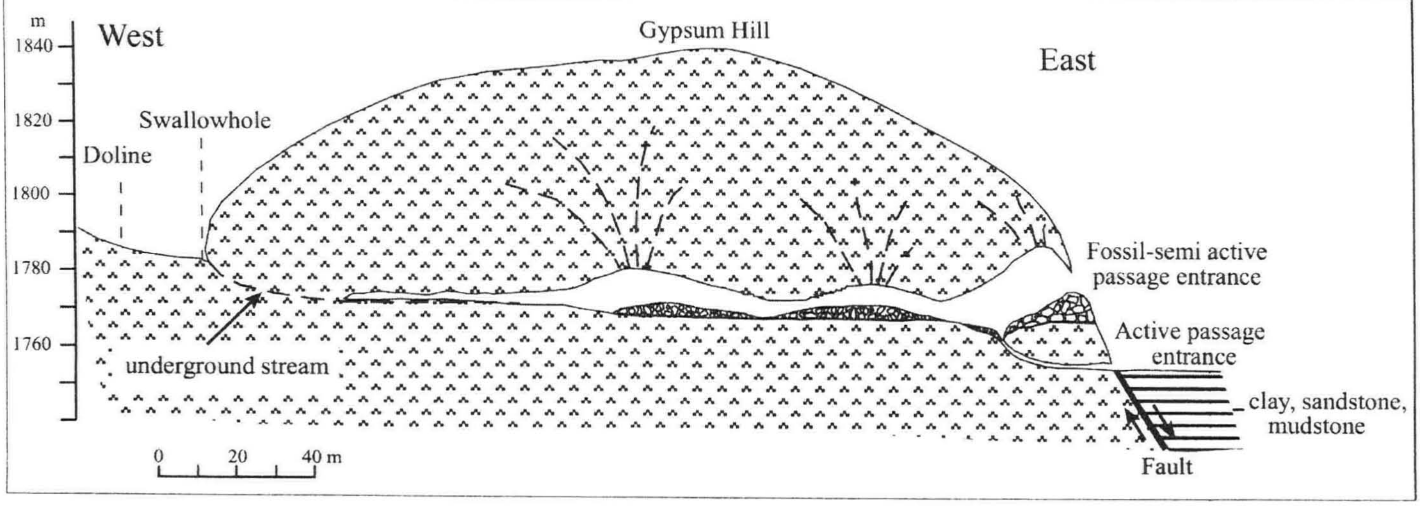

Figure. 9. *Cross-section of İnhas Cave.*

Figure. 10. *A view of the relict/semi-active storey passage of the İnhas Cave System. The picture was taken where the ceiling height of the cave reaches 16m. The opening of the in-cave swallow hole via which the underground stream passes to the active storey is apparent at the back.*

Another branch passage joins the relict/semi-active storey from the south close to its end. This 19m-long passage is 2m high and 6 to 7m wide, but was originally longer than it now appears, having been truncated by the collapse of the roof (Fig.8).

In the relict/semi-active passage floor there are small mounds formed by blocks that dropped as a result of stripping back of the gypsum, like the layers of an onion. In places the diameter of the fallen blocks reaches 3m. The underground water responsible for development of the cave continues to flow in the cave, leaking beneath the gypsum ridge where the cave terminates. Although the original source of this inner cave spring was in the place where the cave gets narrow and terminates, it later shifted farther to the south. The stream in the floor of the relict/semi-active storey flows through the cave, passing under or beside the block mounds, towards the swallow hole down which it passes to enter the active storey (Fig.8).

The active storey, with a ceiling height and width of 1 to 2m comprises a single tube-shaped passage (Figs 8, 9). In this passage, which has formed very recently, rock blocks are seldom seen. Dissolution ripples, formed during the stages when the water level of the underground stream was high, are apparent on the gypsum surfaces.

The development of the İnhas Cave System can be considered in two stages. The first stage was the formation of the relict/semi-active storey. During this stage the water that passes underground from the swallow hole at the foot of the doline to the west formed the main passage. This process is a typical reflection of the characteristic underground water circulation observed in the İmranlı Karst Terrain.

During the final stage of the gypsum tectonics observed in the region, after formation of the relict/semi-active storey, the gypsum sequence at the site was uplifted, and the first entrance of the Inhas Cave System was left hanging. Rock blocks that dropped alongside the fracture surface (see fault position on Fig.9) clogged the lower parts of the cave entrance, which is why the underground water was unable to resurge from the uplifted old entrance. Thus the water that had formed the relict/semi-active storey passed further underground via the swallow hole (which formed 20m from the old cave entrance) and shaped the active passage. The fault scarp formed by the uplift that took place as a result of gypsum tectonics is seen distinctly on the steep slope with an angle of 80° at the entrance to the cave (Fig.9). Based on this, it is apparent that the latest uplift as a result of gypsum tectonics (between the Pliocene and the Present) is around 11 to12m.

Cross-sections of the relict/semi-active and active storeys, whose shapes were partly deformed due to blocks falling from the roof, are elliptical. The active passage in particular, with its regular elliptical shape, shows the effects of underground water flow in pipe-full conditions (Fig.11).

Summing up, the Inhas Cave System has developed with active and relict storeys, and is a multi-storey, swallow hole to spring type system.

RESULTS

With so many well-developed karstic landscapes on massive gypsum, seldom matched elsewhere, the Sivas region is the most important karstic terrain in Turkey. The eastern part of that region lies to the south of İmranlı. Karstic forms in the area include karren, dolines, swallow holes, blind valleys and caves.

There are both normal outcrops of gypsum successions and formations such as gypsum ridges, anticlinal structures and diapirs, which are uplifted and have come to outcrop by breaking through the overlying formations as a result of gypsum tectonics.

Rillenkarren and rinnenkarren are found on gypsum surfaces sloping at 60° to 80°, west of Güneşönü Hill in the southeast of the area. The well-developed karren grooves look like those on limestone karst. There are also well-developed karren beneath the soil cover in most parts of the area.

The karst to the south of İmranlı is generally the most youthful. However, inevitably, the karst in gypsum areas where the overburden was eroded earlier is relatively older than in the regions where the overburden was eroded later. Dolines in the gypsum outcrops where the cover layers were removed earlier are much deeper and larger. In contrast, in areas where the cover layers were

Figure. 11. The active passage of the Inhas Cave System. Ceiling height is 1.5m.

eroded much later, such as to the southwest of İmranlı, the dolines are smaller and shallower, within a polygonal karst. In the polygonal karst there are 80 to 100 dolines per km^2 and the region has a truly karstic landscape. Doline karst dominates the uplifted areas with anticlinal and diapiric structures and gypsum ridges south and southeast of İmranlı, where the thickness of gypsum ranges between 50 and 550m. Clay and sandstone bands in the gypsum succession support the formation of residual soils in the doline floors.

In these regions there are no poljes such as those seen around the Kızılırmak valley between Hafik and Zara, and big collapse dolines with doline lakes are very rare.

Most of the caves to the south of İmranlı are of swallow hole and spring type. Water that goes underground via the swallow holes in the blind valleys or dolines resurges from the valley floor or valley slopes. Caves have formed in these situations as a result of the circulation of underground waters in the gypsum. Most of the entrances are closed due to roof collapse. The studied İnhas Cave System was formed as result of dissolution by water that passes underground from the swallow hole at the bottom of the doline. The cave system, which developed with relict/semi-active (180m) and active (75m) storeys, is 225m long and is of multi-storey, multi-staged and swallow hole to spring type. An uplift of 11 to12m in the level of the cave due to recent gypsum tectonics (since the Pliocene) drove the karstification of the İnhas Cave System.

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Ingleborough Cave, Clapham, North Yorkshire, England

Stephen A CRAVEN
7 Amhurst Avenue, Newlands 7700, South Africa.

Abstract: This paper gives a detailed account of the 1837 discovery, and subsequent exploration, survey, scientific significance and tourist development of Ingleborough Cave in the light of an early manuscript scrapbook that has recently been rediscovered.

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INTRODUCTION

Ingleborough Cave, also known as Clapham Cave and Clapdale Great Cave, is situated about 2km northnortheast of Clapham village in the Yorkshire Dales National Park of Northwest England. The cave entrance is on the west side of Clapdale, down which Clapham Beck flows southwards to the village and thence westwards to the rivers Wenning and Lune. Although it has a conspicuous entrance, (Figs 1 – 4), and although local people must have been passing the site since time immemorial on their way to and from Ingleborough to tend their livestock, it is not remarked until late in the historical record. Before the arrival of the railways in the mid-nineteenth century the tourist trade of the northwest Yorkshire Pennines was based around Ingleton, where the Keighley – Kendal Turnpike road crossed that from Lancaster to Wensleydale[1]. Indeed, the first cave tourist in the northern Pennines, the Rev. John Hutton towards the end of the eighteenth century, was vaguely aware that, "*...there are several other caves all along from hence on the south side of Ingleborough, above the village of Clapham...*" but he did not make the detour to visit them[2]. On 19 June 1792 the Hon. John Byng, having inspected some caves in Chapel-le-Dale, passed through Clapham without stopping[3], even though there were almost certainly three inns in the village[4].

Probably the first report of the rising in upper Clapdale appeared in 1781[5]. Descriptions from John Phillips (Fig.5) appeared in 1829[6] and 1836[7]. Although he was later well aware of caves and their geological significance, at those earlier dates Phillips dismissed "Clapham Dale" in one page. He noted, "*...a full stream flowing from the right bank out of a broad depressed cavern, with sand and pebbles on its furrowed floor*". This is clearly Clapham Beck Head, a few metres upstream from Ingleborough Cave. Either he did not bother to look into the not inconspicuous 50m of the Cave as far as the stalagmite barrier or he did not at that time appreciate its

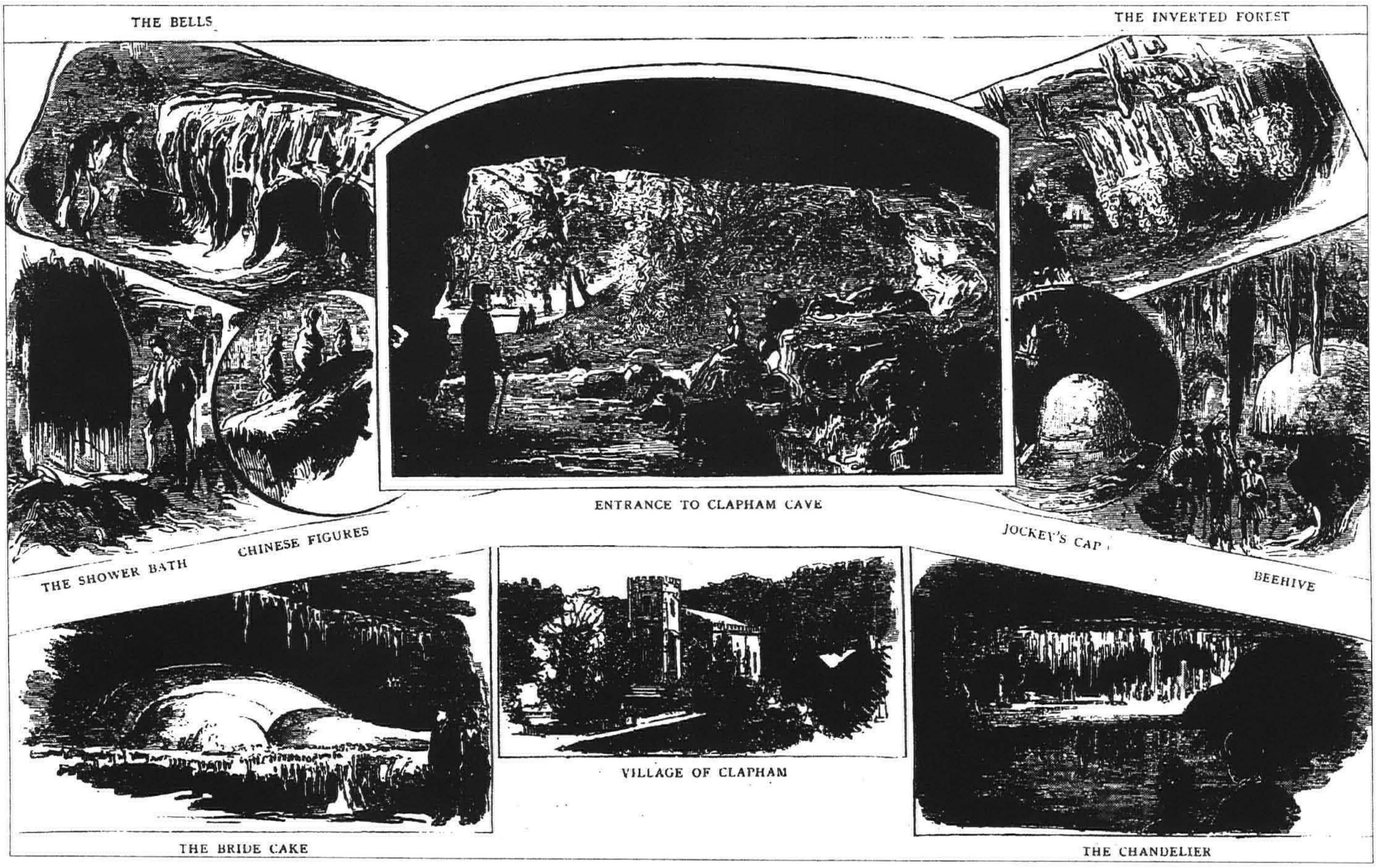


Figure 1: *The earliest (1885) published illustrations of Ingleborough Cave, artist unknown[117].*

Figure 2: The entrance to Ingleborough Cave; date about 1910[118]. Postcard published by A E Shaw of Blackburn.

significance. The latter is the more likely, because Phillips did not visit during flood conditions[8], and because he was at that time only at the beginning of his geological career.

Some details of the discovery and exploration of Ingleborough Cave were recorded in a green book, which for 109 years and four generations was in the possession of the Farrer family, Lords of the Manor of Ingleborough since 1 May 1856 (Table 1). Shortly after the death of Sydney James Farrer in 1946 his widow reluctantly loaned the diary to Eli Simpson of the British Speleological Association. He failed to return it and, because of the inevitable distractions, she forgot to recover it[9]. Extracts from the diary have been published[10,11], the later one during the time it was missing. Fortunately, in 1991 the manuscript appeared mysteriously at the Ingleborough Estate Office, with no indication of its recent provenance.[12]

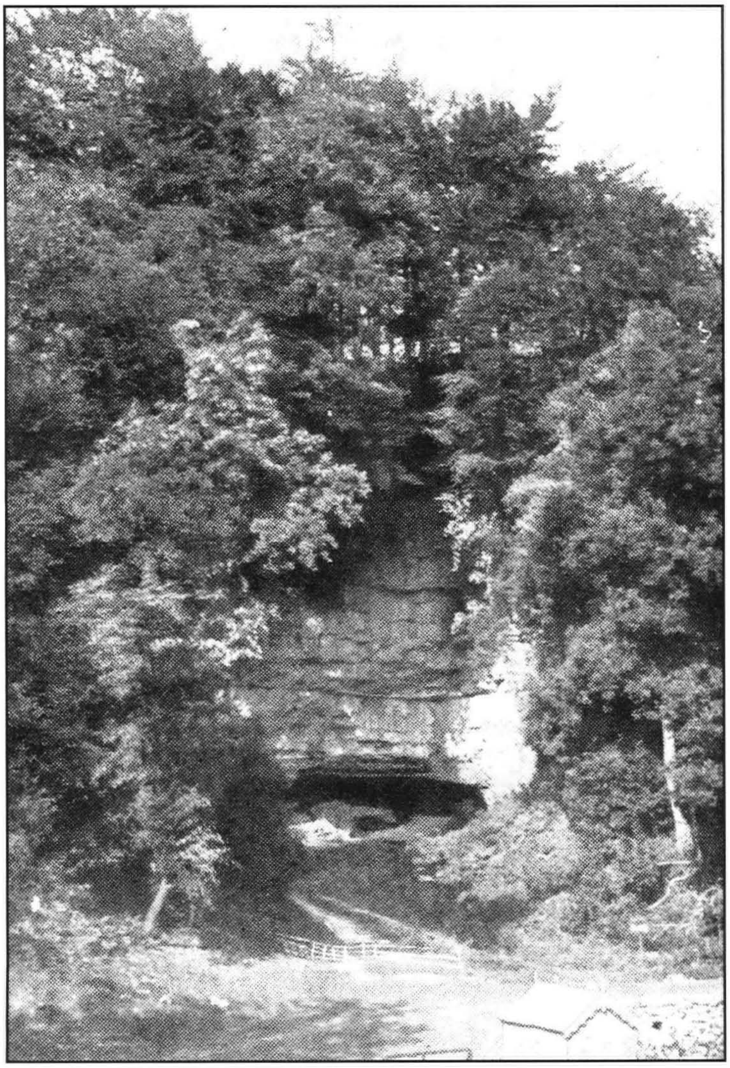


Figure 3: The entrance to Ingleborough Cave in the 1930s[119]. Note the small wooden guide's hut.

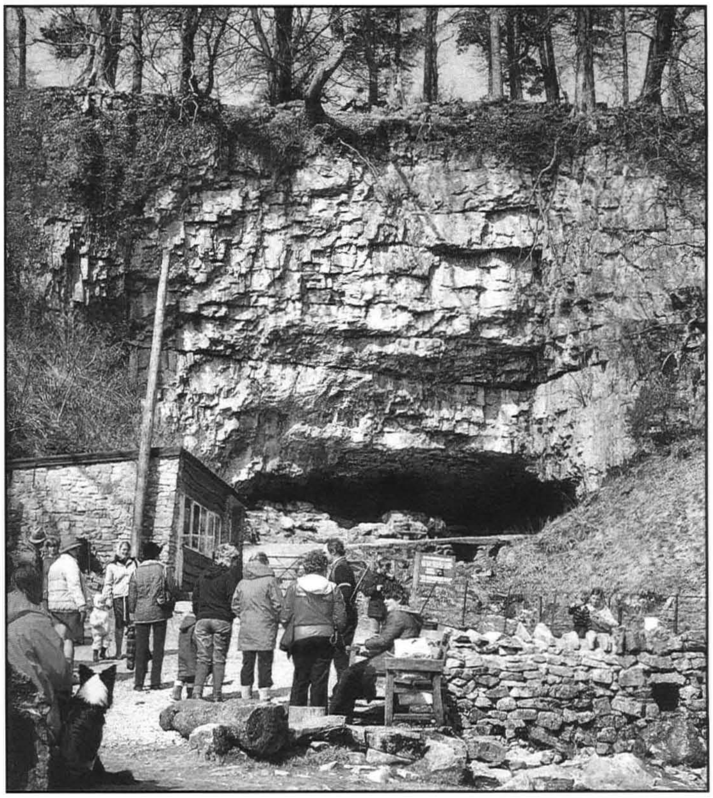


Figure 4: The entrance to Ingleborough Cave in 1986. Photograph by John Bell[120]. Note the modern stone cave-mouth building nearer to the Cave entrance.

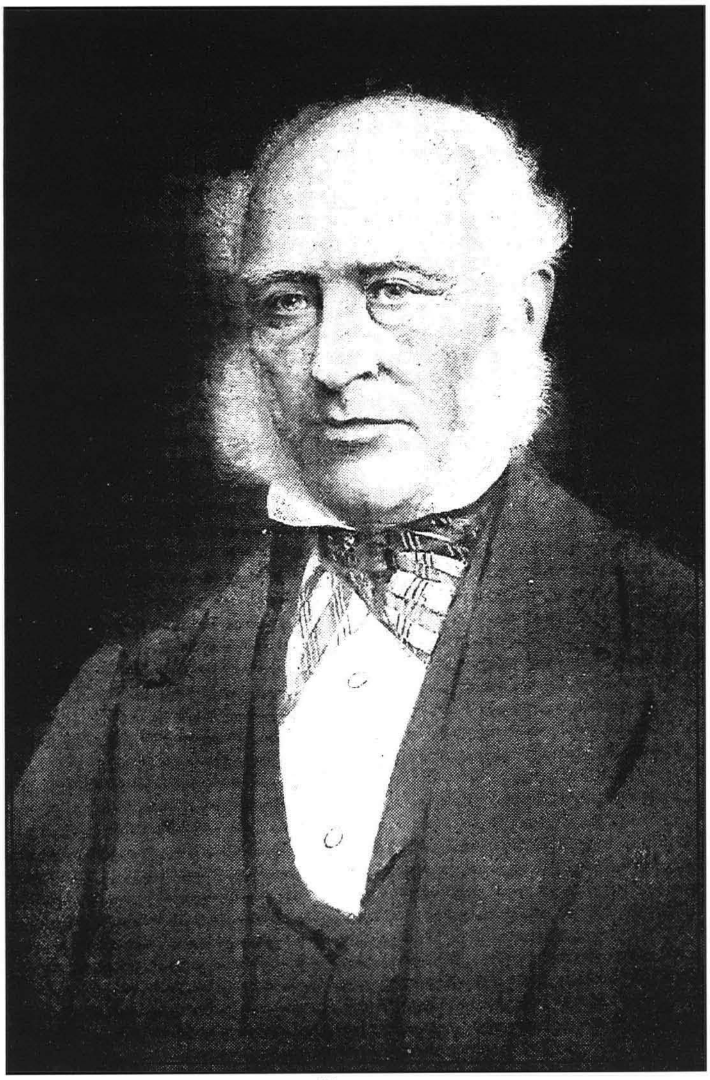


Figure 5: Professor John Phillips[121].

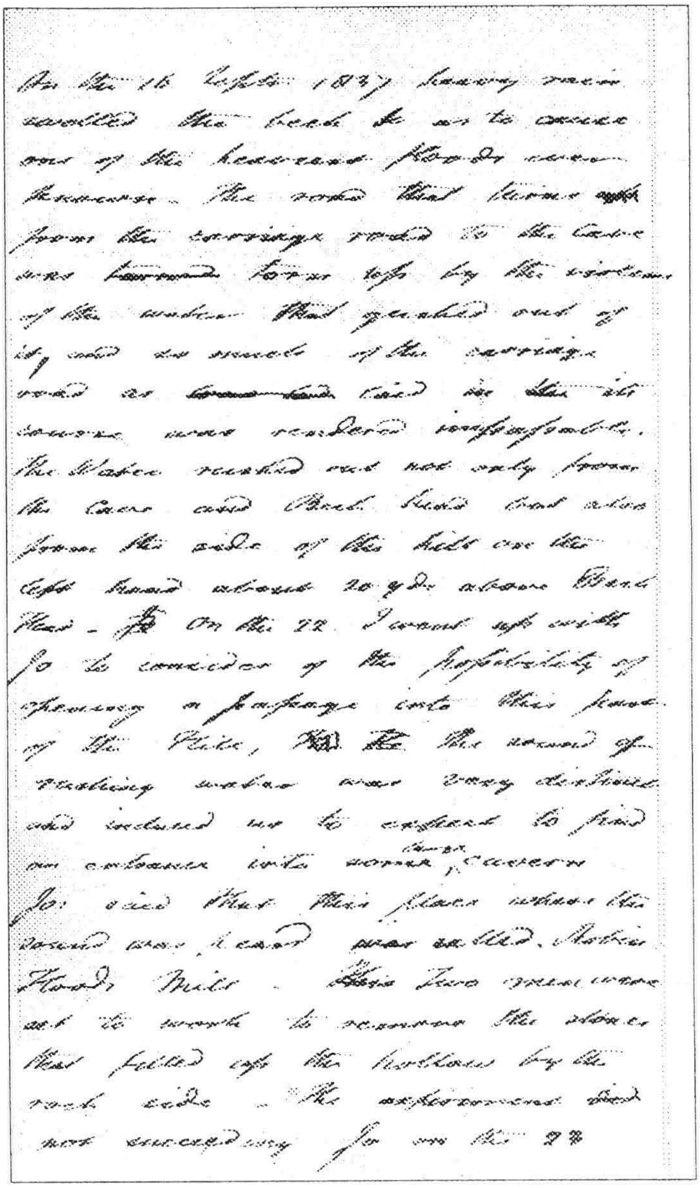


Figure 6: Page 26 of the green Ingleborough Cave book, recording the events of 16 and 22 September 1837.

The diary is bound in green leather, with 78 hand-numbered 185 x 229mm pages, plus several loose pages and glued inserts. It is entitled:

CAVE BOOK
CAVE DISCOVERED 1837

and, although kept somewhat haphazardly over three decades, and incomplete, it is a valuable historical document. Its earliest dated entries are from 1830 – 1833, recording accounts which indicate that the book was not originally intended to be a record of Cave exploration. There is no logical order to its contents, with some pages either left blank or containing few words. Other pages have been removed, but there is no indication when this may have been done. Some of the glued inserts record measurements made in the Cave, suggesting that they may be contemporaneous field notes. Some comments have been erased; others have been added between previously written lines. It shows that the Farrers were well versed in the classical literature and French and Latin languages. Family members were familiar with the limited geological and speleological literature of the day, and with caves in Europe and elsewhere in England. It is clearly a scrapbook, perhaps kept with a view to the later writing of a guidebook to the Cave.

DISCOVERY

The earliest dated Cave entry is for 16 September 1837 (Fig.6) and confirms that it was flood conditions that brought the Cave to the attention of the Farrers. They were unable to penetrate the adjacent Robin Hood's Mill and Beck Head Cave, and realised that these two risings were insufficient for the floodwater, the overflow from which came through the "Old Cave":

> *"After heavy rain it is so largely swollen as to be forced to seek another course, which it finds through the Cave, now called Ingleborough Cave."*

On 23 September 1837 they therefore turned their attention to what became known as Ingleborough Cave:

> *On the 16 September 1837 heavy rain swelled the beck so as to cause one of the heaviest floods ever known. The road that turns from the carriage road to the Cave was torn up by the violence of the water that gushed out of it, and so much of the carriage road as laid in its course was rendered impassable. The water rushed out not only from the Cave and Beck Head but also from the side of the hill on the left hand about 20 y*[ar]*ds above Beck Head. On the 22 I went up with Jo*[siah Harrison] *to consider of the possibility of opening a passage into this part of the hill. The sound of rushing water was very distinct and induced us to expect to find an entrance into some large cavern. Jo said that this place where the sound was heard was called Robin Hood's Mill. Two men were set to work to remove the stones that filled up the hollow by the rock side. The experiment not succeeding Jo on the 23 took the men into the old cave to the extremity of it, which was called "The Bay" and there broke a passage through the stalagmite that formed it. This opened to the New Caves, first into that small part which is now called The Porch and thence to the 1st Basin. John Grimes and Rob*[er]*t Bradley waded through this basin and thence through the 2nd basin to a point 76 y*[ar]*ds from the gate of the cave. In the afternoon of the 23rd Encombe and Matt reached the same distance. See ... Encombe's note.*

Written after the events, Viscount Encombe's "*note*" recorded the explorations of September and October 1837:

Sept. 23rd 1837. The New Cave was broken thro' by 3 labourers under Jo Harrison, two of whom penetrated to the point at 85 yards from Entrance Gate, which M[atthew] *T* [homas] *F*[arrer] *& Encombe reached later in the same day, being breast high in water at that time.*

Sept 26. James, Matt. Thomas, Henry [all Farrers] *&/c reached the pillar, and in a second exploring on the same day they penetrated to the point blocked up by stalactited pebbles at (supposed) 450 yards from Entrance Gate.*

Sept 29th James, Matt & Henry remained at a spot (supposed) about 790 yards, (?) a very shallow descent while two labourers proceeded to the deep water reached on Oct 11th.

Oct 11 1837. James, Matt. & Encombe, accompanied by W [illia]*m Hindley passed thro' the shallow waterfall & reached the deep water at the distance (supposed) of 940 yards from the Entrance Gate. James swam with a rope attached.*

NB. The distances are given not entirely at random guesses but by the length of balls of twine used as guides for returning.

This note was made by John 2nd Earl of Eldon then Visc [oun]*t Encombe.*

In early March 1838 a fox was found in the Cave:

James letter Ingleborough 7th March 1838.

Near the place where they (Jo & others) have been working we discovered the impression of a fox's foot so fresh that I am inclined to believe the animal had been in the cave not many hours before we noticed it. We distinctly tracked it over a sandbank on the left side of the cave till the lowness of the cavern prevented us from getting any further. This almost enables the certainty of their outlets to the cave with which we are unacquainted at present.

"Extract from a letter of James Ingleborough 29 March 1838.

On searching further this afternoon I discovered innumerable footmarks of the fox and almost traced him to his earth.

On 23 April 1838 James Farrer was again in the Cave:

We have been working this afternoon in the cave endeavouring to find a passage from one of the transverse Arches in the Cellar Arched part of the Cave communicating with the supposed continuation of that part which is blocked up with the sand and stones about 200 yards beyond the creeping part. When you come down it can be proceeded with. We have little doubt of being able to clear the passage having already disentombed several stalactites. The discovery of limestone gravel is also very remarkable with thick strata of clay above it. Should we at any time work thro' this we may reasonably expect to find remains of bones etc. The solid & compact form of the strata very much strengthens one's belief in its antiquity. The colliery party are still very sanguine & are now at a great depth – between 90 and 100 yards.

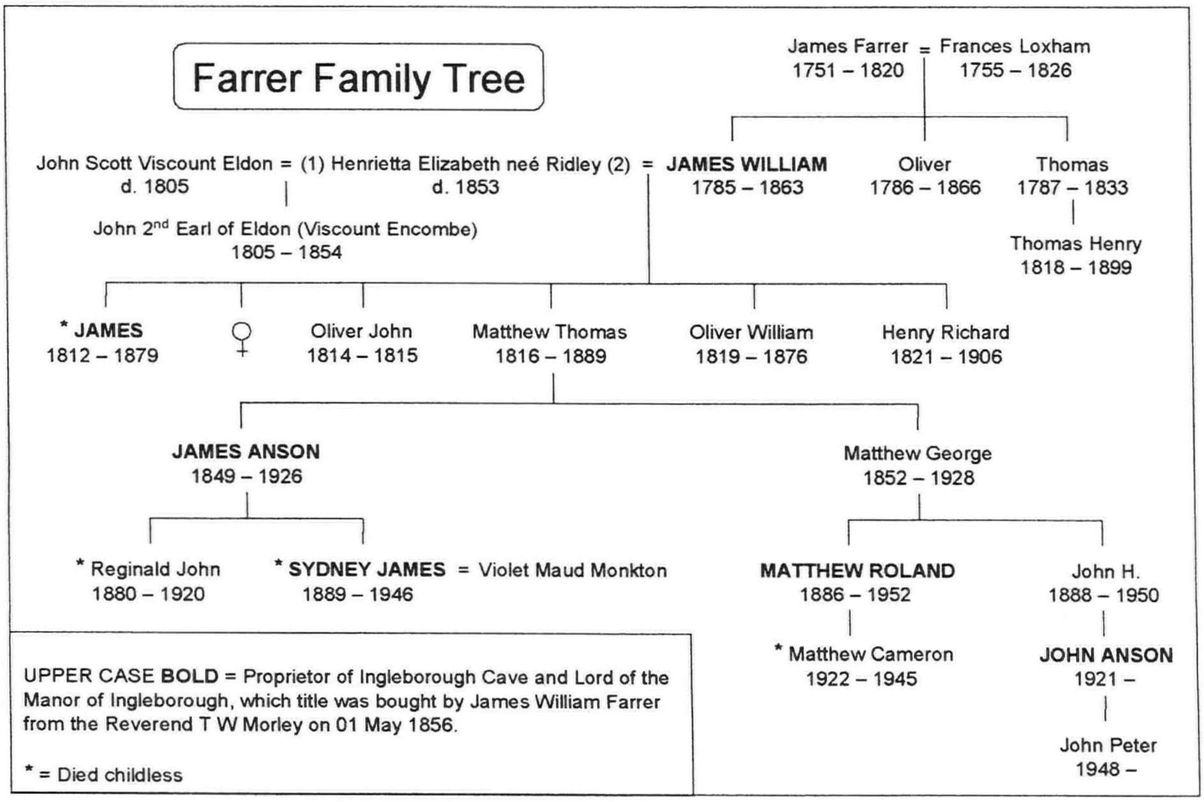
Further explorations were made on 4 and 5 September 1838, but no significant new cave was found.

Josiah Harrison was successively *"gamekeeper, forester and gardener"* to James William Farrer, and Oliver Farrer, of the Ingleborough Estate. Although he would have been acting on instructions from the joint landowner, James William Farrer (1785 – 1863), Harrison has been credited with the discovery of Ingleborough Cave beyond the stalactite barrier. Indeed, he was ordered "*to do nothing without noting it down*". John Grimes (who had a cross-joint named for him), William Hindley and Robert Bradley were presumably estate labourers. Matt[hew Thomas Farrer 1816 – 1889] was the second, and Henry [Richard Farrer 1821 – 1906] was the fifth, sons of James William Farrer[13, 14, 15]. Viscount Encombe, later second Earl of Eldon, was James William Farrer's stepson[16].

These transcripts confirm that within three weeks the Farrers had penetrated as far as Lake Avernus.

Even at that early time, it was necessary to protect the Cave from vandals and souvenir collectors:

Table 1: Farrer Family Tree



The Gate is sometimes called The Elephant Gate from the form of the stalagmite which is supposed to resemble an elephant. It was found necessary to protect the old cave against persons who broke off and carried away the stalactites by erecting a light but strong iron gate.

Despite the gate, the fence erected in 1842, and the vigilance of the guide, vandalism inside the Cave did continue[17].

TOPOGRAPHICAL DESCRIPTION

The Cave book contains many pages of Cave description, in illogical order. Some have been written in ink, others in pencil. Some have been erased but are still legible; some have been duplicated. Some paragraphs have been annotated "*leave this out*", suggesting that the Farrers' intention might have been to write a guidebook and / or a newspaper article. There follows an edited transcript rearranged in logical order, and with punctuation added.

The Old Cave and new caves at Ingleborough.

The mouth of the old Cave is under horizontal layers of compact limestone, a portion of the Great Scar limestone; each layer projecting a little beyond the other, presenting a face of limestone rock broken into a variety of zig zag and angular forms. The height of the rock is 18 yards. The mouth of the old cave is 54 feet. The lateral rocks are seen of the extent and at the angles given below.

In the mouth of the old cave a considerable quantity of stalagmite has accumulated and has been trodden under foot so as to form a floor upon the ground. From the mouth of the cave to the Gate is the distance twelve yards. At the gate from rock to rock it is 3 yards. On each side are masses of stalagmite in various forms. The roof is flat. In the fissures or chinks which are here very numerous, stalactites are formed in intersectional lines giving the appearance of net or fret work.

The gate on the left side is fastened in stalagmite which projects 1 yard. To the barrier end of the old cave is 56½ yards. This was formerly called the Bay from its form and the water that stood in it. The bottom is of limestone; sand has been washed into it since the water from above has been brought down in making the new caves accessible. The barrier was formed of very hard stalagmite. The thickness cut through to make a passage is one yard. This passage leads into a small entrance which is 2 yards in length. The roof is low and flat. This leads to the first Basin, the beginning of which from the gate is 59½ yards. The roof is much higher, and formed of horizontal limestone. There is a longitudinal fissure in the roof. It is ornamented with some beautiful stalactites. The Basin is made by stalagmite which has been raised from the floor and presents curvilinear walls which when discovered was full of clear water. The lowest depth of this basin is about 9 feet. The sand in the bottom about 2 feet 6 inches. There are also large fragments of limestone in it. On the right hand of the 1st basin at 64 yards from the gate is a magnificent mass of a stalagmite which when first discovered appeared to rise out of the water, but is in fact formed by gradual deposit from the side and projected over the surface of the water. The colour is almost white. The form is convex, one formation rising above another. Upon first seeing it, it strikes the eye as resembling several vast cauliflowers united, or gigantic wedding cakes joined together. The extent at a guess is 78 by 16.

The 2nd Basin begins at 76 yards from the gate. The difference of level between the 1st and 2nd Basin is 1 foot 6 inches. The depth of water when discovered varied from 2 to 10 f[eet]. The point to which Encombe & Matt waded on Saturday the 23rd is 85 yards from the gate.

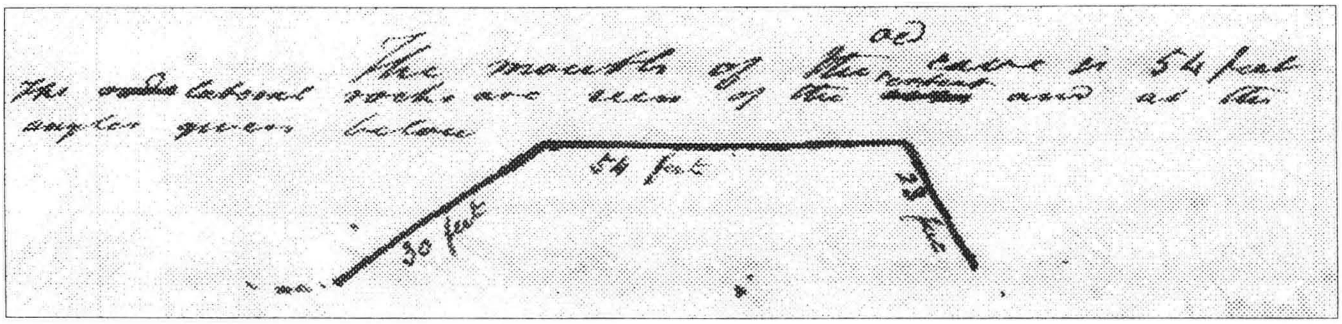
The bottom of the 2nd Basin on the floor of the Stalagmite Gallery which joins it is covered with sand. The roof is covered and full of stalactites. On the left side of the Gallery are beautiful specimens of stalagmite. One part resembles the Mammoth's legs another the Golden Fleece. On the right hand also are fine accumulations of stalagmite in various forms. The depth of the water when discovered was at the deepest about 2 yards. The sand is very deep. There are several beautiful stalactites. One from the middle of the roof of this Gallery resembles a large sword. When struck it gives a musical sound.

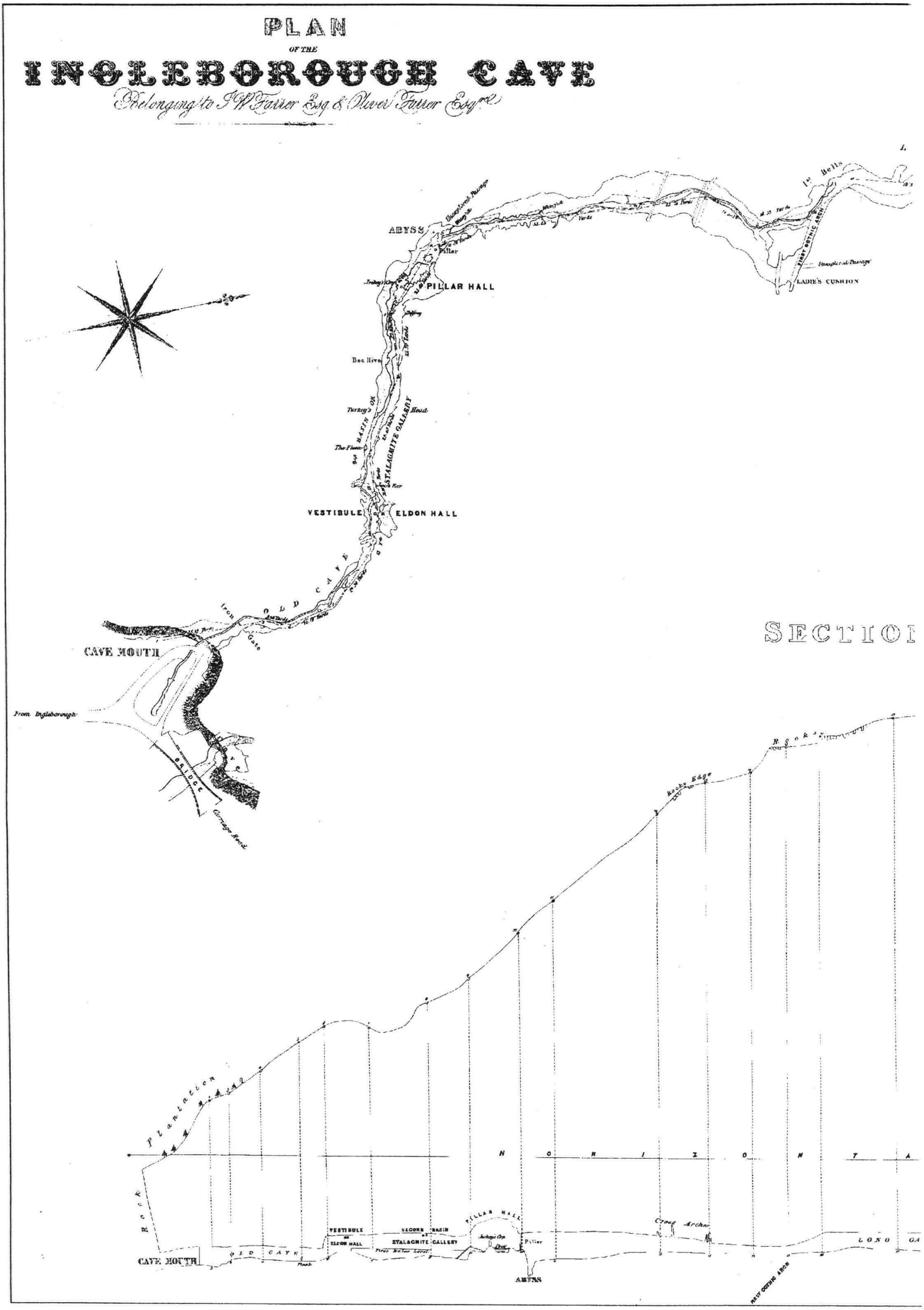
The Long or Stalactite Gallery terminates at the distance of 140 yards from the gate. It leads into the Pillar Hall. The entrance is between masses of stalagmite with stalactites meeting and in some places touching them. Here the Basin has been preserved entire full of water, there being no necessity to let it off for making the passage. At 150 yards from the gate is the White Beehive, a beautifully white accumulation of stalagmite raised by the dropping of water from the roof. It also resembles a large Jockey Cap. The roof is relieved by a transverse arched fissure adorned by stalactites.

At the end of the Pillar Hall are two Basins full of water. At the extremity of the 2nd is the Pillar. This is 167 yards from the gate. The height of the Pillar is 3 yards. The girth is almost throughout the same namely 33 inches from the top to the plinth or lowest part where it becomes of larger circumference. This plinth or lowest part is in circumference 53 inches and in height on the upper side 9 inches and on the lower side 18 inches. The floor is covered by sloping masses of stalagmite descending from the Pillar to the 'Abyss'. This is a sink or hole of considerable size into which the waters pour. The Abyss is from the gate 170 yards.

The Pillar Hall is the most spacious of the caves hitherto discovered. It is very lofty. The roof is divided by many deep longitudinal fissures ornamented by very beautiful & variously formed stalactites. The masses of stalagmite are on both sides of great dimensions, sloping upwards to the roof especially on the right hand so as to give a character of great vastness to this cavern. The Basins unbroken and full of water, perfect as made by nature, complete its beauty and interest. Here I rested at the end of Oct 1839 (not ... 1838). The discoveries subsequent to this attempt at a description are very considerable in extent and beauty.

Passing the Abyss the Rock Gallery commences, so called because the sides are formed of horizontal limestone projecting boldly in varied forms with scarcely any stalagmite. The floor is covered with pebbles & fragments of rock cemented by carbonate of lime. The roof is flat. At the entrance of this gallery are two handsome stalactites somewhat resembling bagpipes or a haunch of venison. At the termination of this gallery are some remarkable




PLAN
OF THE
INGLEBOROUGH CAVE
Belonging to J W Farrer Esq & Oliver Farrer Esqre
ABYSS
Pillar
PILLAR HALL
LADIE'S CUSHION
1st Bells
Bee Hive
Turkey's Head
STALAGMITE GALLERY
VESTIBULE
ELDON HALL
OLD CAVE
Gate
CAVE MOUTH
From Ingleborough
BRIDGE
Carriage Road
SECTIO
Rocky Edge
Plantation
HORIZONTAL
Rock
VESTIBULE
ELDON HALL
SECOND BASIN
STALAGMITE GALLERY
PILLAR HALL
Pillar
Cross Arches
LONG GA
OLD CAVE
CAVE MOUTH
ABYSS

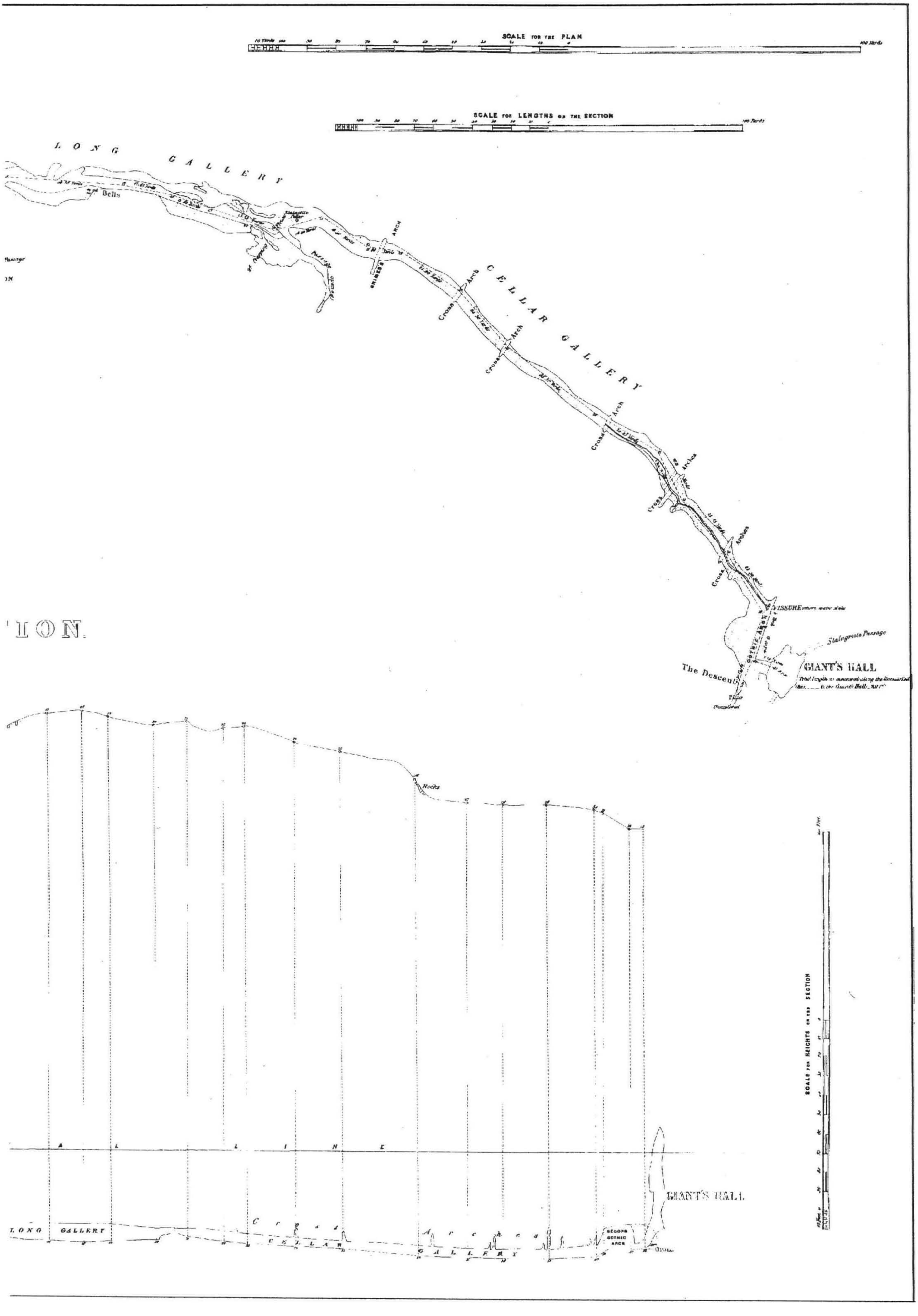


Figure 7: The (reduced and here split into two halves) 1845 lithograph of the 1838 survey of Ingleborough Cave.

stalactites resembling cascades. One is very handsome falling upon a large globe of stalagmite. Next to the Rock Gallery are the Stalagmite Stairs which from the gate are 220 yards. The roof is flat with fissures exhibiting various specimens of stalactite. At the end of these is the Lake from the gate 225 yards. The lake runs parallel with the Gallery being divided from it by a ridge of limestone supporting the roof. This part is remarkable for a number of small accumulations of stalagmite formed on the large mass that covers the floor. The head of the lake from gate is 240 yards. Passing a few yards under a flat roof a Gothic Arch, transverse or across the passage, intersects it at 760 yards from the gate. Between the head of the lake & this point the height of the roof rapidly diminishes to the height of about 4 feet. This is what we call the first Creeping Place.

After passing through the Creeping Place, supposed to be about 20 yards in length, a long Gallery presents itself to the view. The height of the cavern at this part will probably be 15 or 16 feet exclusive of the depth of water which varies from 3 or 4 inches to between 4 & 5 feet. Stalactite & stalagmite are both found here though not in so great an extent as at the former part of the Cave. At a distance of (supposed) 80 yards from the commencement of the Creeping Place is stalactite Bell Stone which when skilfully touched produces sounds scarcely to be distinguished from a church bell. The water is very deep here with a considerable quantity of sand.

Indeed it is only in very wet times that water flows over the Pillar. Having before reached the Gothic Arch after passing the 1st Creeping Place we pursued the course thro' a gallery called the Long Gallery till we reach the Second Creeping Place, which having passed through we come into the Cellar Gallery. These galleries are not rich in stalactites or stalagmites. The heights at which the water stood before it was let off are seen all along the limestone walls. In some places breccia (large & small rolled pebbles cemented by carbonate of lime) are attached to the wall by stalactitic matter formed by water issued thro' the fissures. These are at different heights. They appear to have formed at some periods the bed of the descending waters. The Cellar Gallery is so called from its arch-like roof. In many parts the floor is a sort of counter-arch. This gallery is intersected by transverse fissures, forming in the roof pointed arches in which generally are stalactites. In the roof also are hollows, smooth hollows scooped out assignable, I apprehend, to no cause but the action of water. Masses of the limestone are indented with small hollows or little basins or cups, more like dimples on a lady's cheek (comparing things so hard to things so soft). In some places these hollows apparently produced by the same cause are of various forms and larger sizes. Some of the transverse arches are strictly acute angled, formed by the junction of two masses of rock. In others the sides appear to rest upon or be supported by a longitudinal extension of rock forming the uppermost part of the arch. The rush of waters is loud at the end of the Gothic Arch. After passing thro' the 2nd Creeping Place, the water which before ran in the direction of the entrance to the cave now changes its course and runs in the line by which we advance in the Cave.

The entrance into the Baron's Hall is low, the rock impending towards the sandy bottom so as to drive you to crawl or stoop very low. On the right hand as you enter at a considerable height is an opening & projecting mass of breccia covered with stalagmite thro' which it appears that formerly the stream was projected ...

The Gallery then proceeds onwards on a further distance of (supposed) 120 yards at which point it appears to have been blocked up by stones & sand washed up against & covering masses of stalagmite. On the left hand side are numerous small stalagmites resembling candles; they are of various sizes. On the right is a small pillar of stalactite. A narrow passage leads away on the right which comes out into the Long Gallery a few yards below. Within 20 yards of the end of the Gallery there is a passage to the left, the height of which is only about 3 feet but which rapidly increases as well in height as in width. Here the shape becomes circular & from this point commences the measurement of this Gallery a string being fastened to a small pillar. The roof in about 60 yards is only about 5 feet in height with occasional pools of water. There are numerous transverse arches each more or less inlaid with stalactite. Many of the stalactites are transparent & ribbed like the teeth of animals. There are also some stalagmites but none very remarkable in their tone.

Proceeding further on hills of sand & numerous pools of water are met with, and with the exception of the Transverse Arches which vary considerably both in width & height. Nothing particular occurs till the long Gothic Arch is reached. This part of the Cave is rather narrow & is most beautifully inlaid with stalactite of different forms and sizes & finally after about 30 or 40 yards terminates in a low narrow point where the Arch has evidently been blocked up by stones & sand & accumulated stalagmite. The supposed distance from the small pillar to which the string is attached is about 310 yards. The passage turns to the left and becomes very narrow & the descent very sudden. On reaching the bottom the passage continues on a through line for about 40 yards at which point one end of the line of string terminates. It is here so low with much depth of water as at present to defy further passages. Returning therefrom about 40 yards the cavern turns to the right, which leads to a small but deep round hole sufficiently high to admit of standing upright.

Proceeding to the left again the passage becomes very low & the water, the current of which becomes much stronger, is of a dark colour & has every appearance of passed over the fell. Near this part another passage leads to the left, still very low with but little water. This passage remains yet unexplained. In some places the bed of the stream passes over solid rock, in others stones & sand intermingled from the course over which the stream flows. Here the noise of a rushing stream becomes much louder & after creeping about 20 yards further we enter a high but narrow passage probably about 4 feet in width into which the water falls. The water which is very rapid near the point where the stream joins the still water is within a distance of nine yards, very deep. The cavern is supposed to turn to the right but nothing further is at present known owing to the depth of water. There is no under current, the stream rather turns to the right & the water almost immediately becomes very deep. There is here neither stalactite nor stalagmite nor is there apparently any lower level of water. The distance to this deep pool of water from the commencement of the descent is supposed to be about 150 yards but owing to the numerous turns & passages this calculation is obviously very uncertain. Most of the masses of stalagmite present on the whole of their surface a continued series of little basins, generally of a circular oblong form but of very varying forms. The rims have delicate edges. The interior of each basin holds a crystal resembling in appearance filigree work & is filled with water. When the stalagmite has accumulated so as to unite with the roof and stop the overflow of water, the stalagmite loses its colour and becomes dark.

The deposit above referred to on these little basins is hard & clear whereas in the large basins the deposit under water is soft & of a dark sand colour. The variety of forms and appearances that the stalactites & stalagmites assume is endless. Botyroidal bunches and coatings, icicles, tubes, shells, ears, dentiform, pan-pipes, cascades, cushions, swords, spears, spires, columns, pillars, candles, feather beds, cauliflowers, coral, trees inverted & suspended from the roof.

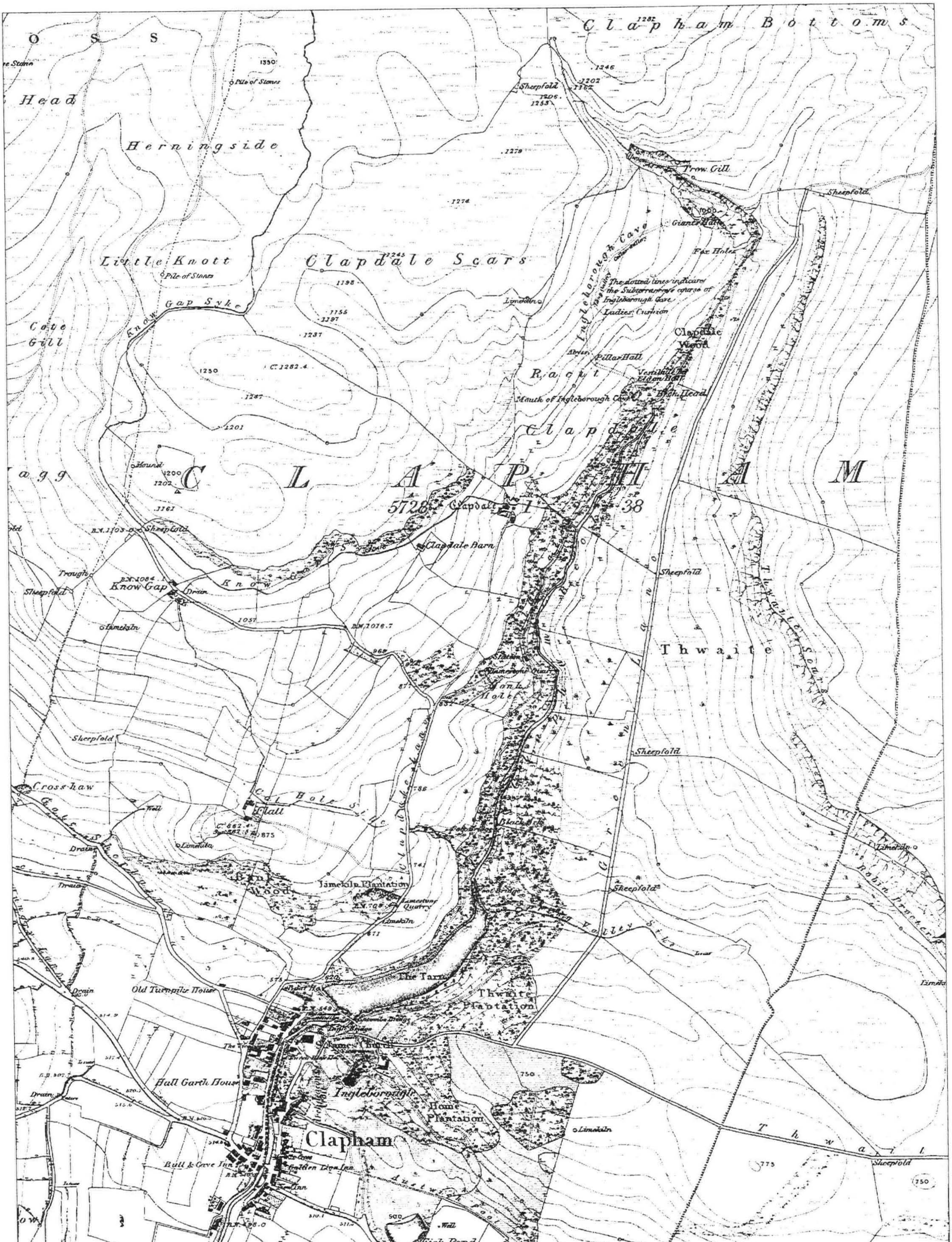


Figure 8: *Part of the 1851 1:10560 Ordnance Survey Sheet 113, showing the underground course of Ingleborough Cave, and Clapham village with the Bull and Cave, Golden Lion and New inns. [reduced slightly to fit page; hence not at original 1:10,560 scale].*

THE SURVEY OF INGLEBOROUGH CAVE

The Cave book contains several Grade I and II surveys, which serve to guide the reader through the Cave's topographical description.

The distances are given not entirely at random but by length of balls of twine used as guides for returning.

In Autumn 1838 the Cave, "*belonging to J.W. Farrer Esq. & Oliver Farrer Esqre.*" was professionally surveyed by Thomas Hodgson[18, 19, 20] of Messrs. Hodgson and Tayler [sic], Land Surveyors of Lancaster and Burton-in-Lonsdale[21]. The finished plan is dated 1839, and is remarkably accurate bearing in mind that it was only the third cave to have been surveyed in the northern Pennines[22]. Although the original survey is missing, it was lithographed in 1845, and copies printed. Presumably the prints were given to the Farrers' relatives and friends. It is possible that copies may have been sold to the tourists. One visitor in 1880 wrote that, "*An excellent plan of the cavern has been published, and the visitor can inspect a copy in the entrance hall of the Flying Horse Shoe*"[23]. Several of the prints have survived, one of which, hand coloured in blue to show aquatic features, was recently found in the Ingleborough Estate Office[24]. In August 2002 it was hanging in the Cave mouth building (Fig.7).

These lithographed surveys have a scale of 1:39000, with plan, elevation and overlying hillside. Their dimensions are 878 x 602 mm. overall, and 780 x 569 mm. within the frame. The various features of the Cave are named from the Mouth to Giant's Hall. Of particular interest are seven "*Cross Arches*", two "*Gothic* Arches", one "*Grimes's Arch*" and a further four unlabelled similar features, at right angles to the 650 m. of Cave passage. These fourteen Cave features are nowadays called cross joints. Nine of them were depicted on the re-drawn smaller scale survey (1:3032) which was presented at the Geological Society of London on 14 June 1848[25], and which prompted the President to comment on their significance for speleogenesis[26]:

> *Sometimes we find a crack or joint enlarged by the removal of the carbonate of lime of the rock by means of free carbonic acid in the waters flowing into them from the surface; at others no fissure or joint is apparent, and the loss of matter carried away in solution has been effected in the space between two beds, or by the gradual action of this cause from either fractures, joints, or planes of bedding, in such a manner that the connexion between the hollows of the cave and these fissures through which water can find its way is out of sight. Limestone regions, as you are well-aware, from the spaces between their joints and beds, which get gradually enlarged, often swallow up rains, so that streams in them are few, the absorbed water bursting out at some level beneath where the physical conditions are such that the waters can no longer freely descend downwards.*"

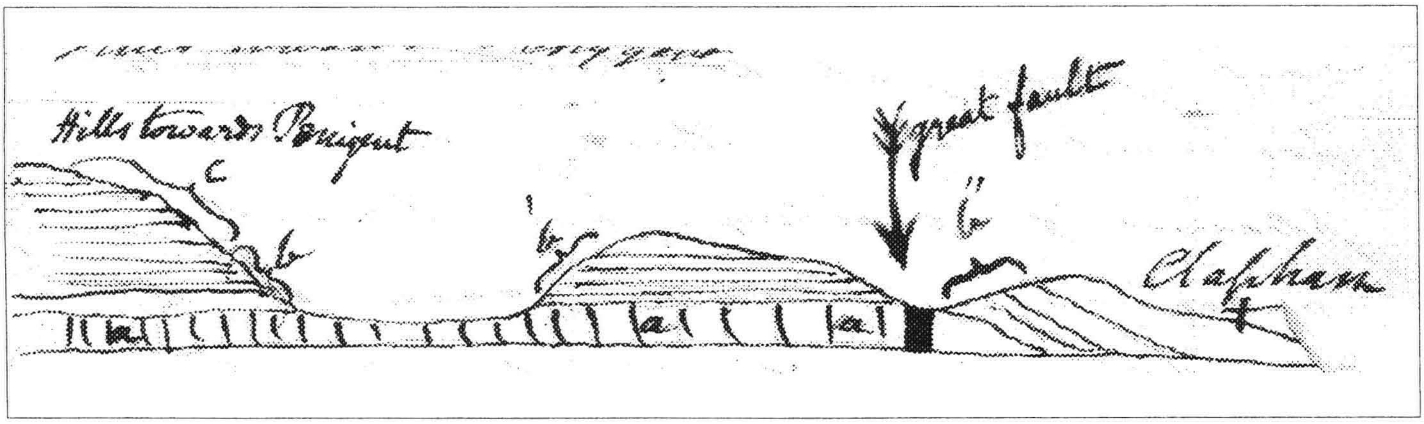
The survey was again re-drawn (1:3032) for William Howson in 1850, with eight similar "*arches*"[27]. This survey was by far the most informative of the three of that scale, with named features and twelve cross-joints.

The position and outline of the Cave were marked on the first edition (1851) of the 1:10560 (six inch) Ordnance Survey map, with *Eldon Hall, Vestibule, Pillar Hall, Abyss, Ladies' Cushion, Long Gallery, Cedar Gallery* and *Giant's Hall* identified (Fig.8)[28]. This is the only cave passage to have been depicted on Ordnance Survey maps in Britain[29, 30].

SCIENTIFIC OBSERVATIONS

The Farrers were not content merely to explore, describe and survey the Cave. It is clear from the Cave Book that they had read William Buckland's 1823 *Reliquiae diluvianae* and John Phillips' geological writings about Ingleborough. As mentioned below they contributed Hodgson's survey, taken from that in the Quarterly Journal of the Geological Society of London, showing fifteen "*prevalent fissures*", i.e. cross-joints, to Phillips' book[31]. As early as 11 October 1837 they were in correspondence with Professor Adam Sedgwick of Cambridge University (Fig.9):

> *Extract from a letter from Professor Sedgwick, Cambridge.*
>
> *I dare say that you are aware that your* [cave is in] *a highly interesting geological position. One of the greatest dislocations in England (not far from the great Craven fault) passes not far from the back of your house. I once examined the spot and passed through some gorges that lead to Horton. As far as I remember the position of the strata is somewhat as follows*



> *a are highly inclined beds of slate at base of Ingleborough*
> *b b' horizontal beds of the great scar limestone*
> *b" beds of great scar limestone tilted by the fault*
> *c Fell top limestone alternating with ... shale & thin beds of coal ...*
>
> *The two remarkable features are the unconformable position of the slate and overlying limestone plainly proving that the slate was dislocated & set on edge before the existence of the limestone. 2ndly the great fault (under the arrow head) which breaks off the limestone and ... it down towards the valley. This fault produces very fine features at the foot of Ingleborough where all the lime works are opened in the dislocated edge beds. It runs to the foot of Stainmoor passing on its way thro' my native valley of Dent & near Brough it meets a second vast fault which I have traced into Northumberland. Should I ever have the pleasure of visiting you I should endeavour to make again the kind of traverse indicated by this section.*[32]

The Farrers took the hint; but it was a year before Sedgwick was able to visit the Cave in October 1838[33]. The party tried unsuccessfully to extend the Cave beyond Giant's Hall by floating across the lake on a raft:

> *I spent a day or two with Mr. Farrer of Clapham, who has been making great discoveries under Ingleborough. He has blown away a great deal of rock with gunpowder, and so formed communications between a succession of very beautiful caverns richly adorned with stalactites, some of*

which reach the ground, and form beautiful white pillars. We endeavoured (at the distance of about three-quarters of a mile from the entrance of the cave), to make some new advances. But to this effect we were forced to use our abdominal muscles as sledges, and our mouths as candlesticks. On, however, we went (serpent-wise, though not perhaps wise as serpents), and wriggled our way about two hundred yards, when the roof became more lofty, and the water more deep. We were provided with a cork jacket, which one of the party mounted, anxious, like Hotspur, 'to pluck up drowned honour by the locks'; and so equipt (and over and above provided with a long cord fixed to said jacket) ventured on a voyage where man had never before floated. ... After running out 100 yards of rope the chamber closed, and the water seemed to escape through the many narrow sink-holes. So the voyager came back, and we all returned as we could, with our clothes almost peeled off our bodies, and our knees and elbows the colour of damaged indigo.[34]

In the Cave book we are told that the explorer on the raft was "James Farrer", but we are not told whether he was the father or the son. The Farrers made random meteorological recordings and speleothem measurements inside the Cave, but were aware of the shortcomings of their mensuration: ... *if our measurements are correct but it is not easy to be accurate.*

The temperature of the water Sept 28th 1837 was 40(°F), of the air in the cave 50(°F).

The Beehive or Jockey Cap is 9 f[eet] *10* [inches] *in circumference at the base, at the foot of the first mass it is 1 f*[oot] *3* [inches] *in circumference. The height is 1 f*[oot] *9* [inches]. *Measuring from the lowest side it is 2 f*[eet] *0* [inch] *in height. Water continues dropping upon it from the roof. In the centre is a hole into which the water continually falls and overflowing its sides, is unceasingly at work in increasing this stalagmitic accumulation. Measured from the roof by the side of the stalactite to the rim of the hole into which the water falls* [is] *7 f*[eet] *1¼* [inches].

Heights of the following points by reference to the plan of the Cave. See section and scale. Measurements taken [by] *Sturgeon (our carpenter) Oct*[obe]*r 1845.*

Cave mouth	*54 feet*
Plank	*115*
Pillar Hall	*121*
Jockey Cap	*143 & 154*
Pillar	*168*
Cross Arch	*231 & 248*
First Gothic Arch	*267*
Long Gallery	*279*
Cross Cellar	*240*
Second Gothic Arch	*233 & 222*
Giants Hall	*223*

We measured two small stalactites standing on the plank at the entrance to the newly discovered cave. They are on the right going in between two stalactites that extend from the roof to this rock underneath.
The length was 3¼ inch each.

	Fahrenheit
The temperature of the cave was	*48*
also of the water	*48*
I see that on 28th Sept 1837 the air	
according to my note was	*50*
the water	*40*

This requires further examination there must be mistakes.
One of the last days of Oct[ober] *1846 I left a register thermometer (Dixey's of Bond Street). On the 23rd Aug*[us]*t 1847 I took it up. The highest temperature was 51, the lowest temperature 46.*

Figure 9: *Professor Adam Sedgwick*[122].

26 Oct. 1845. This applies to that beautiful formation of stalagmite on the side of the wall before we come to the Pillar Gallery. The Jockey Cap at one time was called the Bee-hive.
The Beehive has increased. The increase may be judged by observing the stalactite line on each side which shews the height at which the water stood before it was let off. Indeed, the water line may be traced on the stalactite mass itself.
26 Oct. 1845. Josiah Harrison accompanied me this morning into the Cave. Since I made the former notes of this very interesting series of the hidden operations of nature, further discoveries have been made under the personal direction of James Farrer. The last cavern which he reached is called the Baron's Hall. In the autumn of the year 1838 we had a regular survey made [of] *the whole by Mr. Hodgson from which he drew the plan now in our possession. Upon his plan are noted the names of the different objects which were given by the discoverers.*
We measured again the Bee-hive, properly the Jockey Cap, and found it in the circumference at the base 10, (?16) f[eet]*: shewing an increase of 2 inches. At the foot of the first mass 7 f*[eet] *1* [inch]. *This gives so large an increase that I cannot but doubt its accuracy. The increase however is great. The height from the lowest side is 2* [feet] *11* [inches] *being a growth of 3 inches. We also measured from* [the] *junction of the stalactite at the roof from which the water drops onto the top of the Jockey Cap to the rim of the cup or hole into which it falls 7* [feet] *1¼* [inches], *and the stalactite from the roof to its lowest point 10 inches.*
The Pillar does not appear to have increased, at least our measurements were the same as in 18...

10th Sept. 1847. Went into the cavern with Wheatley carrying a small thermometer – went a little beyond the Pillar Hall – highest temperature 50°

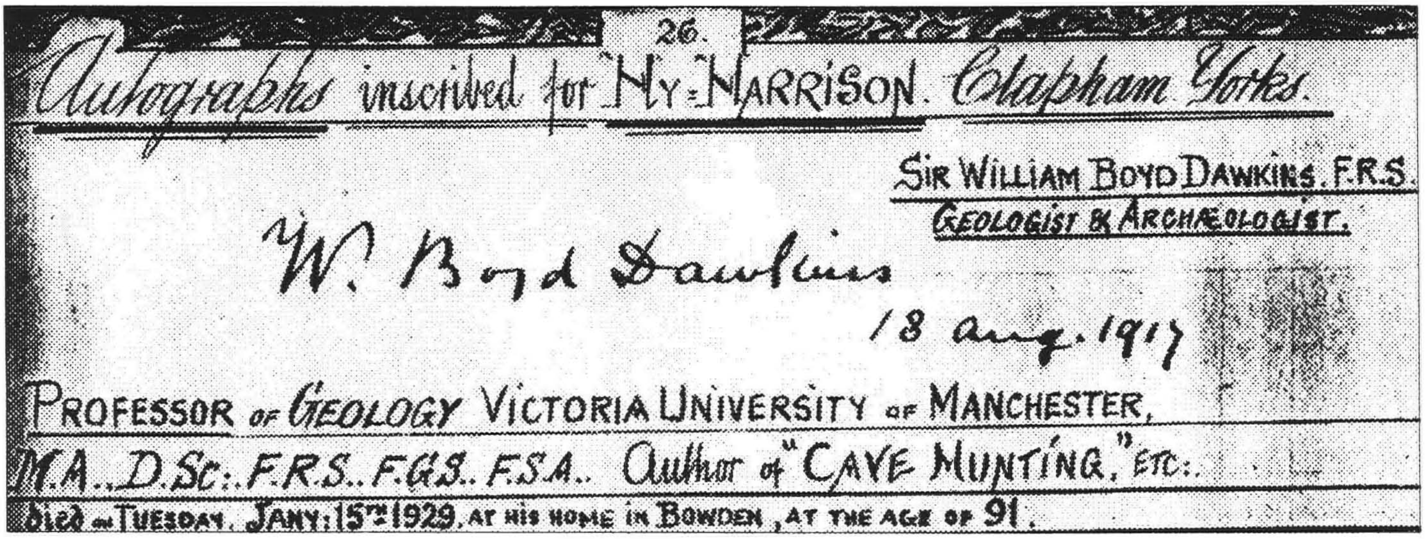


Figure 10: *Signature of Professor William Boyd Dawkins, who revisited the Cave on 18 August 1917, and who then signed Henry Harrison's red visitors' book.*

Measurements of stalactites taken March 30, 1853.
No. 1. (Standing on plank at the entrance to the New Cave) an irregularly shaped stalactite joined to a large mass of stalagmite which reaches to the floor of the cave, is 8½ inches in length on right hand.
No. 2. (Immediately on passing the entrance & joined to the same mass of stalagmite) a stalactite 4½ inches long & 3¾ inches in girth at its centre.
The Jockey Cap. Circumference at base 10 feet 7 inches.

Height from roof to the rim of the hole in the centre of the 'Jockey Cap' 7 feet 2½ inches.
Height 2 feet 5½ inches.
If taken in a sloping direction it is 3 f[eet] *1 inch. (This measurement is taken from the lowest side.) The small pendant stalactite overhanging the 'Jockey Cap' was broken off in the measurement. Its length was 14¼ inches*[35]*. The height from the roof to the centre hole of the Jockey Cap is 7 feet 2½ inches (this was measured three times & with the same result).*
In the Pillar Hall at the left side of the Pillar are two stalactites.
No. 1 adjoining & almost overhanging the 'Abyss' is 13¾ inches long.
No. 2 which is nearer to the Pillar but on the same side 8¼ inches.
On the same side are two rising stalagmites & adjoining the pool of water also close to the Pillar.
No. 1 is 3¾ inches high & 10¼ in girth at the base.
No. 2 is 2 inches high & 9¼ in girth at the base.

Above stalagmite (no. 1) is a stalactite 2¼ inches long. One drop of water in 12 minutes & 25 seconds falls on to the stalagmite.
Standing on the 3rd plank & at the entrance to Pillar Hall is a stalactite on the left side overhanging a rising stalagmite. The space between the two at present is 8 inches & a fraction (1 - ½).
Also on the left side measured from the 2nd plank is a double stalactite 21¾ inches in length.
James Farrer.

Bearing in mind that in 1853 James William Farrer was 68 years old, this observer was more probably his son, James Farrer[36].
The Cave book contains a description of, but does not name, cave rafts[37]:

Above this mud, on advancing some way into the cave, the roof and sides were found to be partially studded and cased over with a coating of stalactite, which was most abundant in those parts where the transverse fissures occur but in small quantity where the rock is compact and devoid of fissures. Thus far it resembled the stalactites of ordinary caverns, but on tracing it downwards to the surface of the mud it was there found to turn off [at] *right angles from the sides of the cave and form above the mud a plate or crust, shooting across like ice on water.*

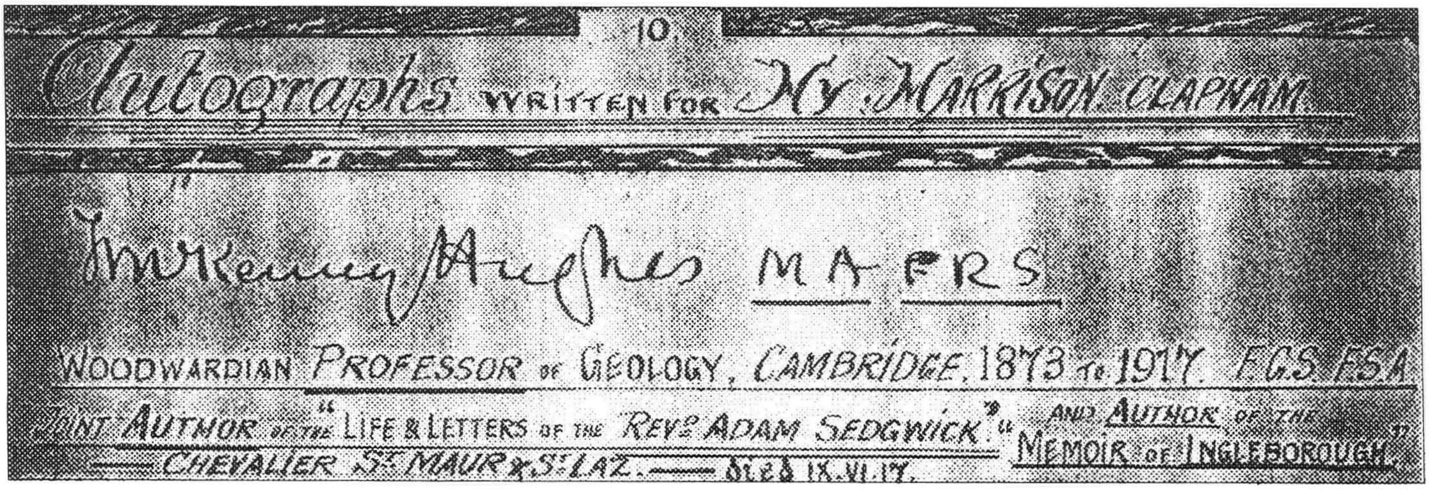


Figure 11: *Signature of Professor Thomas McKenny Hughes, who subsequently revisited the Cave and signed Henry Harrison's red visitors' book.*

Ingleborough Cave first appeared in the scientific literature in 1849. The inside temperature was recorded to vary between 8·9°C and 10·0°C. Very little geology was presented, other than that the Cave is formed in the Great Scar Limestone[38].

Professor John Phillips gave the first detailed topographical and geological description of the Cave. He quoted, and elaborated on, Farrer's 1848 description. He was among the first to appreciate that limestone caves are formed by "*...the corrosive action of streams of acidulated water*" i.e. by rainwater seeping through the natural fissures in the rock, and that the speleothems are subsequently deposited when that water evaporates, exposing "*...the free carbonic acid to the air and the salt of lime to the rock*". He also appreciated the significance of the cross-joints, prominently indicating fifteen of them on his re-drawn 1:3032 survey. He also was the first to describe cave rafts in the northern Pennines and in the English language:

> *... there is often a bright sheet of this sparry deposit spreading widely from the side over the surface of the water like a sheet of snowy ice or the leaf of a crystal plant, narrowing the area of these fairy lakes.*

This led Phillips to report the first attempt to establish the rate of growth of speleothems in the northern Pennines. He noted that the Jockey Cap, a stalactite in Pillar Hall, was fed by steady dripwater whose calcium carbonate content was analysed and rate of flow estimated. Farrer then estimated the increase in volume of the stalactite between 1839 and 1845. Thereafter Phillips calculated that it had taken 259 years to grow to its 1845 size[39]. With the benefit of hindsight this was a hopelessly inaccurate estimate, but its importance lies in the fact that it was attempted.

The next generation of geologists continued to take an interest in Ingleborough Cave. William Boyd Dawkins (Fig.10), Lecturer at the Owens College in Manchester, quoted Phillips at length, and visited the Cave in 1871[40] and on 13 March 1873[41]. He updated the previous work on the rate of growth of stalagmites, quoting annual increases of 1·73mm. and 0·35mm. For the Jockey Cap he disputed Phillips' calculation, and preferred an annual growth rate of 7·4828mm by 1873[42, 43, 44]. This superficially accurate calculation to four decimal places belies the inaccurate mensuration. Further measurements were made on 6 May 1892 by Harry Speight[45], who in 1895 estimated that the Jockey Cap was 308 years old[46]. On 2 November 1904 the Rev. George H Brown of Settle made further observations[47], which have been summarised by Trevor Shaw[48], with further comment by Donald McFarlane *et al.*[49].

In July 1872 Thomas McKenny Hughes (Figs 11 and 12), who had succeeded Sedgwick to the Chair at Cambridge, observed the flooded entrance to the Cave[50]. He returned after the waters had subsided, and proceeded as far as Lake Avernus[51]. His party included John Birkbeck III of Settle, Richard Hall Tiddeman (1842 – 1919) of the Geological Survey between 1864 and 1902[52], the Rev. George Style, headmaster of Giggleswick School from 1869 until 1904[53, 54], the Rev. William Mariner [sic][55] and the Rev. Edwin Trevor Septimus Carr[56]. On this occasion John Birkbeck attempted unsuccessfully to swim beyond Lake Avernus[57, 58].

In 1875 J. Clifton Ward misleadingly drew attention to what he believed to be the "*...precise analogy between the deposits of ice often formed on a rocky slope, and the deposits of carbonate of lime formed in caverns*". This theory is now known to be incorrect, but it was in Ingleborough Cave that sight of the micro-gours gave rise to his ideas[59].

DEVELOPMENT FOR TOURISM

The Farrers immediately appreciated the commercial potential of the Cave, and installed as guide the obvious person, Josiah Harrison, who had been the first to penetrate the Cave.

After the breaking of the stalagmite barrier, the Cave attracted tourists before the railway came to Clapham on 30 July 1849[60]. Its extent and spectacular formations were responsible for the decline of Yordas Cave, in Kingsdale, as a tourist attraction[61]. Indeed, the latter's admission fees were reduced in 1866[62], no doubt in an attempt to increase business. There were sufficient visitors to Ingleborough Cave to prompt Thomas Turner, the keeper of the Black Bull Inn, to change its name to the Bull and Cave Inn some time before 1846[63]. Turner was the *"respected landowner"* of that inn for nearly thirty years, and died on 10 May 1860 aged 81 years. Shortly before his death the inn closed, and became a private house[64]. By 1876 the Bull and Cave Inn had re-opened[65].

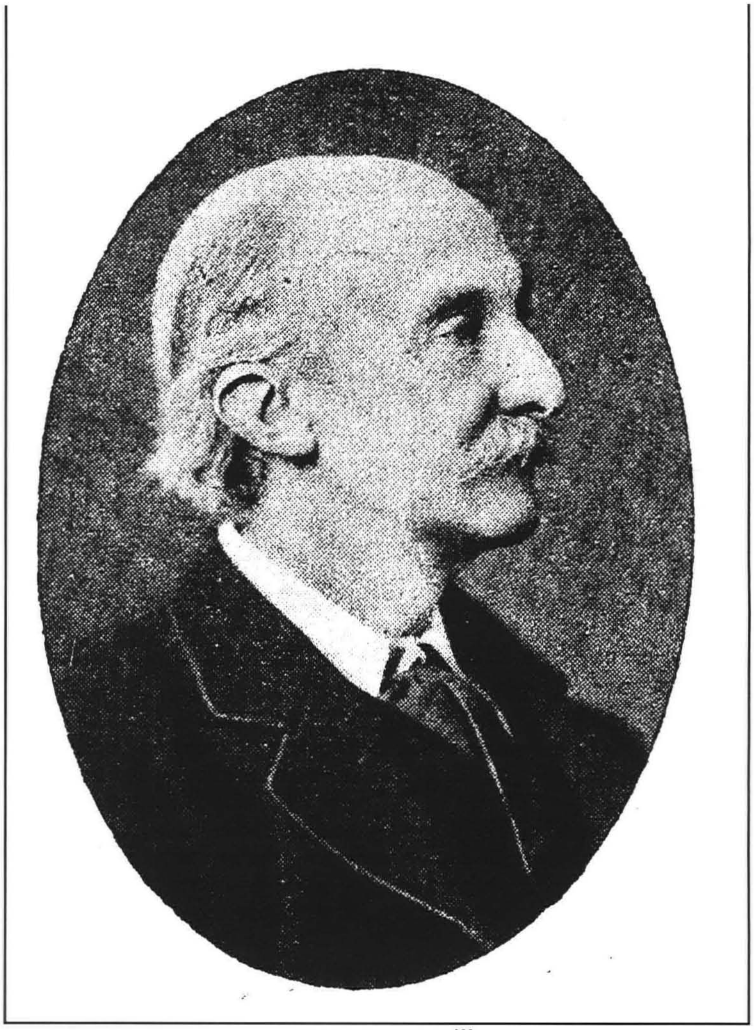


Figure 12: *Professor Thomas McKenny Hughes*[123].

One such early visitor, the fiftieth, was Frederic Montagu of London who wrote the first published description of Ingleborough Cave. Pleading ignorance of geological terminology, he deprecated the removal by visitors of the *"beauties of nature"* from the proximal part of the Cave. But he was impressed with the remaining speleothems, which had been protected beyond the iron gate. The arrangements for his visit had been made with Josiah Harrison who kept a visitors' book, and who deputed the tour to his two sons[66]. The first visitors' book has not survived, but a second (red) visitors' book is in the possession of this author[67, 68, 69, 70].

Josiah Harrison died during the spring of 1850, following which his widow was appointed temporary guide. Harrison's death prompted a letter dated 5 June 1850 from James William Farrer to his agent in Clapham, Mr. Stewart, in which was discussed the appointment of the new custodian. Farrer was well aware that excessive numbers of visitors would be detrimental to the Cave, and wished to limit parties to a maximum of twelve people:

John Street,
Berkeley Square.

5th June 1850.

Dear Sir,

My brother is so much engaged at the present moment, that he has requested me to express to you our intentions as to the cave. In the first place we must enter into no agreement that can in any event take from us the entire power over it, and the right to withdraw the privilege of shewing it from any person to whom we may give it. Jo Harrison enjoyed

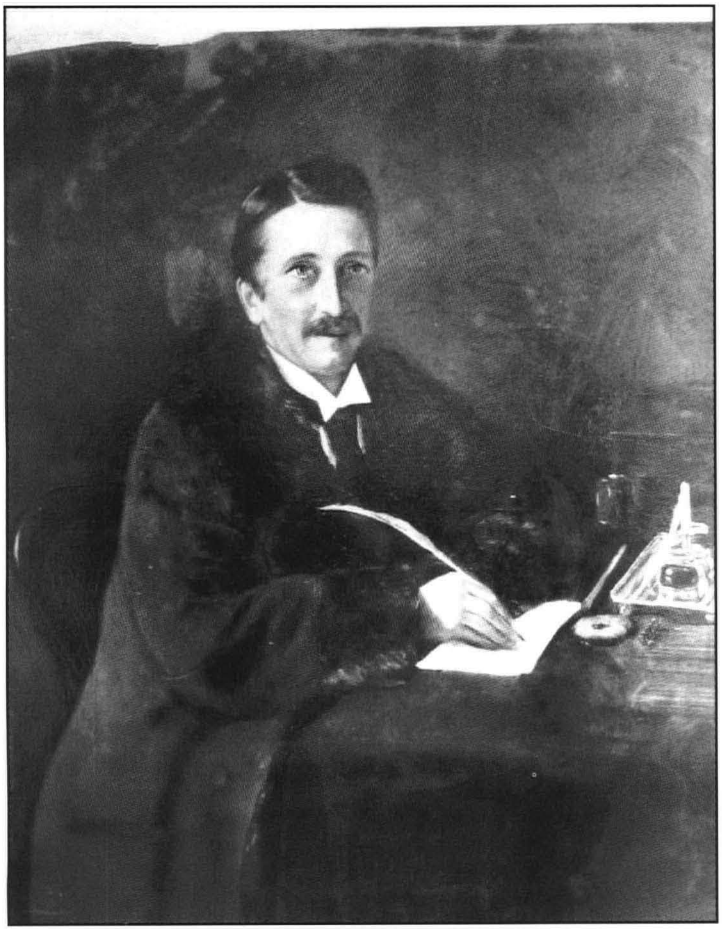


Figure 13: *James Anson Farrer 1849 – 1926. Portrait kindly supplied by Dr J A Farrer.*

that privilege without interruption till his death. Mrs. Harrison now has it but under a distinct understanding that she is to give it up when we wish to make any other arrangement about it.

We propose to grant the privilege in the same way to the tenant of the Clapham Station Inn, but revocable as heretofore. We propose that he should be authorised to ask the following payments for shewing the cave. One shilling each person if more than two persons. If two persons 2s.6d. the two. If persons in the lower ranks of life make a party of less than that he should have sixpence each. If a large body of persons should come as last year from any great town, then that he should be paid the same as Mrs. Harrison received for the Bradford operatives, I think 4d. the 12!

It should be understood that he should allow only 12 persons at a time to go into the cave. We should of course keep a key of the entrance to the cave and use it as we might wish for ourselves and friends. The tenant of the inn might of course charge less than the above mentioned rates if he chose to do so. For conveying visitors he would make his own charge. No carriage or horse would be allowed to go up our grounds to the Cave but there would be no objection to carriages and horses going as far as the house at Clapdale, and he might make an arrangement with the Clapdale tenants to go through their land and to put up horses in their stables. Mr. James Farrer inclines to have fixed days & hours for shewing the cave. We see difficulties to that plan, but we wish to reserve the right to do so in case it should be desirable, whether in the life time of my brother & self or after our decease. The best thing to be done is perhaps not to fix any days for visitors going to the cave up the Thwaite Lane, but to reserve the right to do so for visitors going up through our grounds.

The tenant of the Station Inn must employ proper respectable persons to shew the cave – such persons as would be careful to prevent breaking the stalagtites [sic] *& stalagmites & otherwise defacing the cave.*

We should allow no parties to take their food & meals in our grounds. Shewing the cave includes the privilege of taking parties on foot up Trow Gill but not of crossing the beck at Clapdale gate & returning through the plantations.

Be so good as to let Mr. James Farrer see this letter and consult him upon its contents. We are very desirous that he should be satisfied with any arrangement that is made, and, of course, are ready to vary the details which I written as to rates of payment or otherwise.

I have forgotten to mention that the persons or guides whom the tenant of the Station Inn employs must be particular in keeping together persons who go up, and preventing their straggling & going about by ones & twos & threes. Of course when more than a certain number of persons go up together, say six, there ought to be two persons as guides in the cave.

I am Dear Sir

J W Farrer.

Name	Appointed	Retired	Died
Josiah Harrison, and his two sons [95]	1837	–	1850
Widow of Josiah Harrison (temporary guide)	1850	1850	–
"An old soldier" [96] (guide)	1850	post-1879 [97]	–
Thomas Turner, Bull & Cave Inn landlord (guide)	1850 [98]	–	10 May 1860 [99]
C Knowles (guide) [100]	1850 [101]	ca.1887 [102]	–
Henry Coates, Flying Horse Shoe Inn (lessee)	1856	1914	21 Nov. 1917 [103]
Mr Tennant (assistant guide)	pre-1878 [104]	post-1883 [105]	–
Henry Harrison [106], grandson of Josiah [107] (Fig.14)	1888 [108]	01 Dec. 1938 [109]	16 Dec. 1938 [110]
Charles Barton Tomlinson (guide)	Dec. 1938 [111]	–	27 March 1939 [112]
Arnold Brown (part-time guide)	Aug. 1939 [113]	–	29 Nov. 1962 [114; 115]

Table 2: *List of Cave lessees and guides 1837 – 1962*

"Mr. James Farrer" was James William Farrer's eldest son, James Farrer (1812 – 1879) who inherited the Cave in 1863.

It appears that Mrs Harrison, who had charged a party of twelve Bradford workmen a mere 4d. (1.6 p.) for admission, was not a good businesswoman. The Farrer brothers may then, or later, have leased the Cave to the tenant of the Flying Horse Shoe Hotel at Clapham station. However the record here is not clear, other possible contemporaneous lessees and guides being *"an old soldier"*, C. Knowles, and Thomas Turner, the keeper of the Bull and Cave Inn (Table 2).

The Cave had to wait until 1850 before it featured in a tourist guide. No doubt the railway tourists made the guidebook financially viable. William Howson went as far as Giants Hall, and deterred the reader from proceeding beyond by warning that the further reaches are *"accessible only to the swimmer and adventurous explorer"*. The survey was again published to the same scale, but a new block was used with the various parts of the Cave identified by name[71].

The Cave continued to attract visitors during the nineteenth century (Table 3). In 1857 Walter White, well-travelled Librarian to the Royal Society[72], stayed at the Bull and Cave Inn and visited the Cave. The admission fees were 2s.6d. (12½ p.) for one visitor, and 1s. (5p.) each for parties of eight or ten. White complained about the litter left by the tourists, which had led the proprietor to close the direct path alongside Clapham Beck, but waxed eloquent about the formations inside the Cave. He described the cross-joints, but did not discuss their significance[73]. Another visitor was William Stott Banks, a Wakefield solicitor[74] in 1864 or 1865, who found the Cave to be *"cleaner, tidier and easier ..."* than Stump Cross Caverns. He reported *"flakes of froth ... which are really thin plates of carbonate of lime, formed from the impregnated water draining down to the little basins in which they appear to float"*, another early description of cave rafts[75].

A novel method of attracting visitors was a brass band contest held at the Cave on 9 June 1883[76].

The Cave was illuminated by acetylene lamps[77, 78], and by candles, for many decades well into the twentieth century. During the stewardship of Arnold Brown, a woodman on the Ingleborough Estate[79], the Cave was open only on weekends, public holidays, and summer evenings by arrangement[80]. Each visitor was issued with *"candles on three-pronged wooden holders"*[81]. One Victorian commentator was not impressed with these simple illuminations. He wanted an arrangement with the Midland Railway to provide electric lights, a refreshment room and dancing pavilion, a lift down Gaping Gill and a connection to Ingleborough Cave[82]! Although the Railway Company did not oblige the complainant, it did promote the Cave[83].

By 1895 the admission fees had been reduced to 2s.6d. (12½p.) for one or two persons, and 1s. (5p.) each for larger parties[84].

The eldest son of James Anson Farrer (1849 – 1926; Fig.13), Reginald John Farrer (1880 – 1920) could have been expected to inherit the Cave, and did inspect his intended inheritance[85]. However he had no interest in the Cave, being well known as a botanist, plant collector in exotic and mountainous countries, horticulturist and author[86]. Plant collecting in the Far East was an expensive occupation so, to supplement the allowance he received from his father, he owned the Craven Nursery in Clapham, which specialised in alpine species[87]. In 1910 he wrote to his father complaining bitterly that the Cave was receiving much more attention than was the nursery and associated alpine garden[88]:

> *For the ten or twelve parties who are annually shown my Cliff, you have four or five hundred who are allowed up to see the cave ...*

This suggests that in 1910 the Cave was receiving an average of ten parties a week, but the business would have been seasonal with crowds on Sundays and public holidays and few, if any, visitors mid-week and in winter. Despite the fluctuations in the visitor numbers, the Cave appears to have been more profitable than the nursery, which has long since gone out of business[89].

Despite the technical difficulties of underground photography, pictures were taken inside Ingleborough Cave by George Towler of Settle[90], sometime between 1888 and 18 January 1890. Seven of

Figure 14: *Henry Harrison, Ingleborough Cave custodian and guide 1888 – 1938*[124]*.*

these were awarded a special first class silver medal at the London Exhibition of Photography in 1890[91]. Other photographs taken by Towler were published a decade later by his associate, Michael Horner, a Settle photographer[92, 93].

Although Ingleborough Cave is a commercial undertaking, it has always been managed discreetly, and has fortunately escaped the vulgar publicity associated with some Mendip show caves[94].

TEMPERATURE CONVERSION FORMULA

$Tc = \frac{5(Tf - 32)}{9}$ where Tc = Centigrade (Celsius) temperature and Tf = Fahrenheit temperature.

MENSURATION EQUIVALENTS

1 inch = 2·54cm

1 foot = 12 inches = 30·5cm.

1 yard = 3 feet = 91·5cm.

1 mile = 1760 yards = 1·6km.

ACKNOWLEDGEMENTS

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1838	White, W: *History, Gazeteer and Directory of the West Riding of Yorkshire* ... Vol. 2, p.840 [Sheffield: R. Leader].
1838	Montagu, F: *Gleanings in Craven: in a Tour from Bolton-Abbey to Ambleside* pp.121 – 127 [London: Simpkin, Marshall, and Co.].
1840	*Ingleboro' Cave. 1840. Settle Chronicle and North Ribblesdale Advertiser* Aug. 1856 (No. 31); reprinted Anon. (1857) *The Poetical Works of Robert Storey* pp. 269 – 271 [London: Longman, Brown, Green, Longmans and Roberts], and *Journal of the Shepton Mallet Cave Club* ser. 4, (8), 12 – 14.
1842	Davis, H H *in* Otley, J: *A Descriptive Guide to the English Lakes, and adjacent Mountains* ... pp. 183 – 216 [Keswick: 7th. ed.]
1849	D(avis), H H *in* Otley J: *A Descriptive Guide to the English Lakes, and adjacent Mountains* ... pp.205 – 206 [Keswick: 8th. ed.] reprinted
1849	Davis, H H: *An Excursion from Lancaster, up the Vale of Lune, and from Kirkby Lonsdale, to the Caves of Yorkshire* pp. 37 – 38 [Kirkby Lonsdale: John Foster].
1849	De La Beche, H: Anniversary address of the President. *Quarterly Journal of the Geological Society of London* Vol.5(1), lxxxiv.
1849	Farrer, J W: On Ingleborough Cave. *Quarterly Journal of the Geological Society of London* Vol.5. 49 – 51.
1850	Howson, W: *Illustrated Guide to the District of Craven* pp. 87 – 90 [London: Whittaker and Co.].
1851	Davis, H H: *An Excursion from Lancaster, up the Vale of Lune, and from Kirkby Lonsdale, to the Caves of Yorkshire* pp.37 – 38 [Kirkby Lonsdale: John Foster].
1852	Anon. *Craven Itinerary* pp.75 – 81 [Skipton: J Garnett].
1853	Phillips, J: *The Rivers, Mountains, and Sea-Coast of Yorkshire* pp.30 – 35, 284 and plate 7 [London: John Murray].
1853	*Garnett's Craven Itinerary ... with an addenda containing sketches of Rambles in Craven* p.75 [Skipton: 4th ed.].
1855	Phillips, J: *The Rivers, Mountains, and Sea-Coast of Yorkshire* pp.30 – 35, 294 and plate 7 [London: John Murray; 2nd ed.].
1855	Henwood, G: *4 Lectures on Geology and Mining; 2nd. Lecture* pp.10 – 13 [London].
1856	W(ood), E: Geological Excursion. *The Naturalist*, 6(59), 6; reprinted *Settle Chronicle and North Ribblesdale Advertiser* (29), 02 June.
1857	Daffalem, J: Craven Reminiscences Clapham and Ingleborough. *The Settle Chronicle and North Ribblesdale Advertiser* No. 44 for 01 Sep. "Taken by permission from the Leeds Intelligencer."
1857	*The Settle Chronicle and North Ribblesdale Advertiser,* No.46 for 02 November.
1858	1-inch Ordnance Survey Sheet 92 marked the position of the Cave.
1858	White, W: *A Month in Yorkshire* pp.210 – 222 [London: Chapman and Hall, 2nd. ed.].
1858	*Chambers's Journal,* 9, 341 – 344, reprinted
1858	*Settle Chronicle and North Ribblesdale Advertiser* (54).
1858	Just a Peep at Ingleborough. *Settle Chronicle and North Ribblesdale Advertiser* (58) reprinted from the Bradford Observer.
1859	*Settle Chronicle and North Ribblesdale Advertiser,* (67).
1859	White, W: *A Month in Yorkshire,* pp.217 – 223 [London: Chapman and Hall, 3rd ed.].
1860	1-inch Ordnance Survey Sheet 97SW marked the position of the Cave.
1864	*Settle Chronicle and North Ribblesdale Advertiser,* (128), 01 September.
1864	Anon. *Cornhill Magazine,* 9, 84 – 85.
1864	Dobson, W: *Rambles by the Ribble,* First Series, pp.33 – 37 [Preston: W Dobson].
1866	*Leeds Intelligencer,* 07 April, p.5.
1866	Banks, W S: *Walks in Yorkshire I. in the North West, II. in the North East* pp.51 – 53 [London: J Russell Smith].
1867	(Heywood, A): *A Brief Description of the most Remarkable Places in Craven, with a Table of Objects visible from Ingleborough* pp.11 – 14 [Leeds: John Cooke].
1871	*Yorkshire Weekly Post,* 27 November, p.19.
1872	Dymond, C W, *Craven Pioneer,* 12 October, (No.670).
1873	Dawkins, W B: Observations on the rate at which stalagmite is being accumulated in the Ingleborough Cave. *Proceedings of the Manchester Literary and Philosophical Society,* Vol.12. 83 – 86.
1873	Anon. Manchester Literary and Philosophical Society, March 18, *Nature* 7, 455.
1874	Dawkins, W B: *Observations on the Rate at which Stalagmite is being accumulated in the Ingleborough Cave* p. 80 in Report of the Forty-Third Meeting of the British Association for the Advancement of Science held at Bradford in September 1873 [London: John Murray].
1874	Dawkins, W B: *Cave Hunting* pp.35 – 41, 442 – 444 [London: Macmillan and Co.].
1875	*Craven Herald,* 19 June, p.5.
1876	(Fagan H S): A Spring Day on the Fells. *London Society,* 29, (173), 460 – 461.
1876	*Craven Herald,* 13 May, p.5.
1876	*Craven Pioneer,* 14 October, p.3.
1876	Williams, F S: *The Midland Railway: its Rise and Progress* pp.470 – 471 [London: Strahan and Co.].
1877	*Craven Herald,* 09 June, p.4.
1878	*Craven Herald,* 28 September, p.3.
1878	Davis, J W and Lees, F A: *West Yorkshire* pp.49 – 50, 261 - 262 [London].
1878	Thomson, J R: *Guide to the District of Craven and the Settle and Carlisle Railway* [London and Settle].
1879	White, W: *A Month in Yorkshire* pp.184 – 189 [London: Chapman and Hall, 5th ed.].
1880	Thomson, J R: *Guide to the District of Craven and the Settle and Carlisle Railway* pp.62 – 65 [London: Simpkin, Marshall and Co., 2nd ed.].
1880	Dawkins, W B: *On the Action of Carbonic Acid on Limestone.* Report of the Fiftieth Meeting of the British Association for the Advancement of Science held at Swansea in August and September 1880, pp.573 – 574 [London: John Murray].
1881	Two days at Clapham. *The Bradfordian,* 3(16), 49 – 51.
1881	Brown, J, (1885): *Tourist Rambles,* 156 – 170 [London].
1881	*Craven Herald,* 09 July, p.4.

Table 3: *List of nineteenth century tourist guides and other reports that mentioned Ingleborough Cave (E & O E).*

1881	Dobson, W: *Rambles by the Ribble* First Series, 38 – 42 [Preston: W Dobson, 4th ed.].
±1883	Johnson, T: *A Pictorial Handbook to the Valley of the Lune and Gossiping Guide to Morecambe and District,* p.14 [Blackburn].
1884	Clarke, T T: *Natural History Transactions of Northumberland Durham and Newcastle-upon- Tyne,* 8, 50 – 67.
1885	Anon. Round and about Ingleborough. *The Graphic,* 07 November, pp.506 and 509.
1885	Brown, J: *Tourist Rambles* pp.156 – 170 [London].
1886	Anon: Cave-Hunting in Yorkshire. *Chambers's Journal,* 3. (146), 657 - 660.
1888	Pritt, E: *Around Settle,* pp. 66 – 77 [Settle].
1888	Anon: *Yorkshire Notes and Queries,* 1, 133 – 138.
1888	Brown, G H: *On Foot round Settle,* p.42 [Settle: J.W. Lambert].
1888	Hughes, T McK: *Journal of the Transactions of the Victoria Institute of the Philosophical Society of Great Britain,* 21, 77 – 106.
1888	Balderston, R R and M: *Ingleton Byegone and Present,* pp.55 – 59, 267 [London: Simpkin, Marshall and Co.].
1889	Hardcastle, C D: The Physical Features of Ingleton. *Transactions of the Leeds Geological Association,* (5), 20.
1889	Hewitson, A: *Guide and Visitors' Handbook to Ingleton and District in the West Riding of Yorkshire,* pp.42 – 46 [Preston].
1890	Tiddeman, R H: The Geology of Ingleborough. *Memoirs of the Geological Survey of England and Wales,* pp.33 – 40.
1890	*Leeds Mercury Weekly Supplement,* 25 October, p.8.
1890	Clark, J W and Hughes, T McK: (1890) *The Life and Letters of the Reverend Adam Sedgwick,* Vol.1, pp.518 – 519 [Cambridge University Press].
1891	Hardcastle, C D: *Craven Herald and Wensleydale Standard,* 19 June, p.2 (870).
1891	Taylor, R V: *Craven Herald and Wensleydale Standard,* 17 July, p.2 (874).
1891	Taylor, R V: *Craven Herald and Wensleydale Standard,* 24 July, p.2 (875).
1891	Taylor, R V: *Craven Herald and Wensleydale Standard,* 14 August, p.2 (878).
1891	Bedford, J E: Excursion to Ingleborough. *Transactions of the Leeds Geological Association,* (6), 103 – 106.
1892	Speight, H: *The Craven and North-West Yorkshire Highlands,* pp.153 – 158 [London: Elliot Stock].
1893	*West Yorkshire Pioneer,* 07 July, p.5.
1893	*Craven Herald,* 07 July, p.5.
1894	*Craven Herald,* 06 July, p.5.
1894	Robinson, J R: *Leeds Mercury Weekly Supplement,* 13 October p.8.
1895	Baron, J, (1895): *Ribble-Land,* p.27 [Manchester: John Heywood].
1895	Speight, H: *Tramps and Drives in the Craven Highlands,* pp.2, 151 – 153 [London: Elliot Stock].
1896	Brown, G H: *On Foot round Settle,* pp.163 – 170 [Settle: J.W. Lambert].
1896	Field, G: *The Bradford Observer,* 03 July, p.7.
1896	*Craven Herald,* 17 July, p.8.
1896	Martel, E-A: Sous Terre (Huitième Campagne, 1895) Marble Arch, Irlande, et Gaping Ghyll, Angleterre. *Annuaire du Club Alpin Français,* 22, 194 – 195.
1896	*Craven Herald,* 09 October, p.2.
1897	Martel, E A: *Irlande et Cavernes Anglaises,* pp.324 – 394 [Paris: Delagrave].
1897	*West Yorkshire Pioneer,* 26 February, p.8.
1897	*Craven Herald,* 19 March, p.6.
1897	Spurrier, W J: *Craven Herald,* 28 May, p.2.
1897	*West Yorkshire Pioneer,* 29 October, p.5.
1897	*Craven Herald,* 29 October, p.3.
1897	Martel, E-A: British Caves and Speleology. *Geographical Journal,* 10(5), 509.
1897	Viré, M A: Explorations de M. Martel en Angleterre en 1895. *Bulletin de la Société de Spéléologie* (11), 129, 142 – 143.
1897	*Yorkshire Weekly Post,* 27 November, p.19.
1898	*West Yorkshire Pioneer,* 04 February, p.5.
1898	*Craven Herald,* 18 February, p.6.
1898	*West Yorkshire Pioneer,* 18 February, p.8.
1898	*Craven Herald,* 06 May, p.6.
1898	*Craven Herald,* 20 May, p.3.
1898	*Craven Herald,* 05 August, p.4.
1898	(Martel, E-A) La Spéléologie. *Revue Scientifique (Revue Rose)* 4e. Série 9(21), 647.
1898	*Craven Herald,* 25 November, p.6.
1899	*West Yorkshire Pioneer,* 07 April, p.8.
1899	*West Yorkshire Pioneer,* 22 September, p.5.
1899	*Craven Herald,* 01 December, p.4.
1899	*West Yorkshire Pioneer,* 01 December, p.5.
1899	Norway, A H: *Highways and Byways in Yorkshire,* pp.348 – 350 [London: Macmillan and Co.].
1899	*West Yorkshire Pioneer,* 01 December, p.5.
1899	Cuttriss, S W: *Proceedings of the Yorkshire Geological and Polytechnic Society (n.s.),* 13. 433 – 443.
1900	*Craven Herald,* 26 January, p.6.
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Trickle midge larvae (Diptera: Thaumaleidae) in the Peak Cavern threshold zone, Derbyshire, UK.

Paul J WOOD and Malcolm T GREENWOOD

Department of Geography, Loughborough University, Loughborough, Leicestershire, LE11 3TU, UK.

Abstract: Records of larvae of the trickle midge, *Thaumalea verralli* (Diptera: Thaumaleidae) are reported for a three-year period from the threshold zone of Peak Cavern, Derbyshire, UK. Larvae inhabit thin films of water that flow over limestone and flowstone surfaces where algae occur. The temporal occurrence of trickle midge larvae and the potential to confuse this organism with other more common taxa are discussed.

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INTRODUCTION

The profile of subterranean ecology in the UK has been heightened in the last decade due to the initiation of new research (e.g., Moseley, 1997; Gunn et al., 2000; Wood et al., 2002) and through the re-assessment and investigation of historical data collected as part of the 'Biological Records' series 1955–1978 (see Proudlove et al., 2003). Most of the organisms recorded during these investigation either occur accidentally in caves, or are able to survive and complete their life cycle within caves, but also occur in surface habitats (troglophiles – terrestrial and stygophiles – aquatic). However, fauna from the threshold zone of British caves, where natural light facilitates some primary production, are still poorly studied (but see Jefferson (1983) and Pentecost (2004) for summaries).

The current report provides preliminary data for one taxon, *Thaumalea verralli* Edwards, 1929 (Diptera: Thaumaleidae) (Fig.1a), in the threshold zone of Peak Cavern, Derbyshire (NGR: SK 1486 8249) over a three-year period (2001–2003). Larvae were recorded on the surface of partially illuminated limestone and flowstone within the cave entrance. This artificial illumination encouraged the growth of algae on the rock surface, providing food resources for larval *T. verralli*. Larvae were observed throughout the year with the exception of the months of January and February. The greatest abundances were recorded between September and November each year when 20 to 30 individuals of mixed size classes (approximately 5 to 12mm in length) were observed on each occasion. Fully quantitative sampling was not undertaken due to difficulties in sampling this habitat and may have been potentially damaging to the population.

Trickle midges are widely distributed throughout the British Isles, although they have been poorly studied in the southern half of England. Trickle midge larvae have commonly been overlooked or incorrectly identified by many freshwater ecologists, due to their similarity in appearance, at a superficial level, to the most diverse group of aquatic Diptera, the Chironomidae. They are distinguished from the more commonly occurring chironomids by characteristic protuberances on the head capsule (Fig.1b arrow) and a distinctive sinusoidal movement, which is 4 to 5 times faster than a typical chironomid can crawl. The larvae most commonly occur in unpolluted springhead locations and other habitats where thin films of freshwater flow over rock surfaces that develop an algal cover. The larvae feed on the algae/biofilm and detritus by scraping the surface with their mandibles and collecting the detached material in a modified feeding apparatus (Disney, 1999).

Although the larvae are found in wet habitats they actively avoid flowing water, preferring to graze in marginal areas away from the current. In addition, the larvae are reported to be photophobic (Disney, 1999) suggesting that the threshold zone of caves may provide an ideal habitat. The extended period of larval occurrence (March – December), compared to those previously reported (June – September) (Disney, 1999) probably reflects the highly stable conditions recorded within the entrance zone of Peak Cavern. The apparent absence of larvae during January and February each year may reflect the increased flow of water over the rock surface at this time of year resulting in the redistribution of larvae to more secluded areas that are not easily sampled. Adult flies have not been recorded during the investigation, although in other investigations (Wagner, 1997) they have been reported to swarm around dawn. Trickle midge larvae have been recorded from perennial limestone springs throughout the Peak District, although the true extent of their distribution and occurrence in other caves is unknown and requires further investigation.

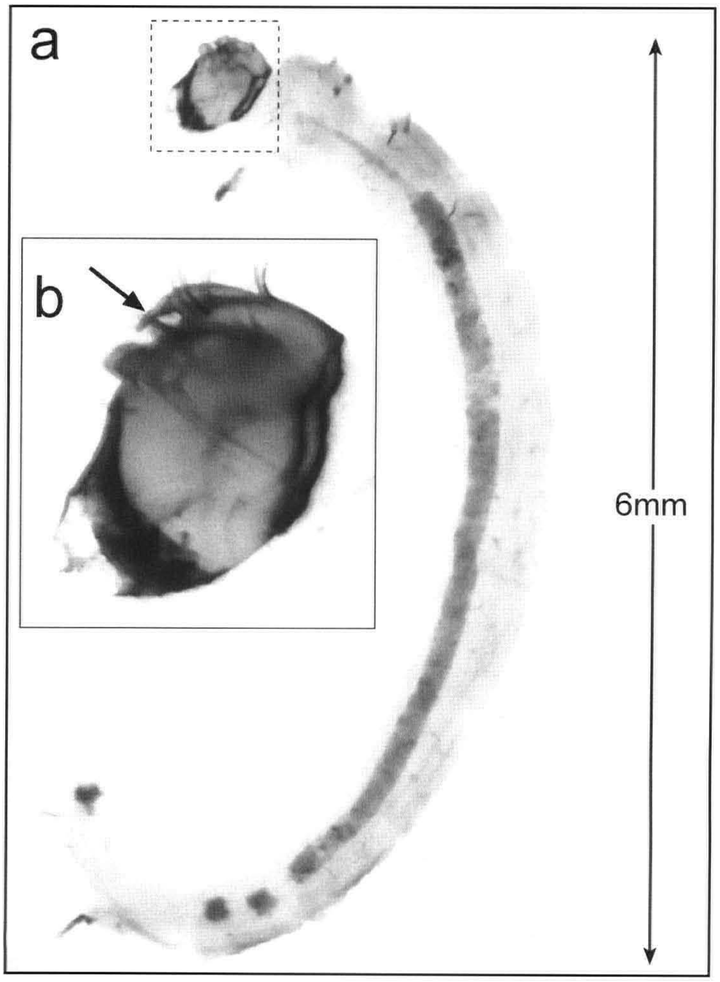

Figure 1. *Photograph of Thaumalea verralli (Diptera: Thaumaleidae): a) the whole organism – total length 6mm; and b) head capsule and protuberances (indicated by arrow), which are characteristic of the family and enable its ready separation from the more common family Chironomidae.*

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Low-cost telemetry monitoring of the cave environment: Sorbas gypsum karst, Spain.

José M CALAFORRA[1], Angel FERNÁNDEZ-CORTÉS [1] and José A GÁZQUEZ-PARRA [2]

[1] Department of Hydrogeology and Analytical Chemistry, University of Almería, Spain.
e-mail: jcalafor@ual.es; acortes@ual.es
[2] Department of Computer Architecture and Electronics, University of Almería, Spain.
e-mail: jgazquez@ual.es

Abstract: A cave environment monitoring system installed in the Sorbas gypsum caves (Almería, Spain) is described. The system was initially designed to study the anthropogenic changes within a cave, brought about by the beginning of tourism activities. Data of carbon dioxide concentration, temperature, relative humidity and the presence of visitors are sent by radio, in real time, to the University of Almería base station. The microclimatic information is published on the Internet (http://karst-yeso.ual.es), so that anybody can check the microclimatic conditions of the cave and recognize the influence and environmental recovery after an actual visit in real time. The combination of a remote location and the need to alter dynamically how readings are taken led to the development of custom hardware and software for a cave monitoring system. The system could be a very interesting tool for the management of a show cave.

Keywords: show cave, environment monitoring system, telemetry.

Note: the authors have published additional information, specifically technical details of the hardware and some results, in the *IEE Electronics Systems and Software Journal* (2003, 1(3), 24-27) and *The Cave Radio and Electronics Group Journal* (2003, 53, 6-8).

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ENVIRONMENTAL SIGNIFICANCE OF THE SORBAS GYPSUM KARST: SOME REASONS FOR CONSERVING THE CAVES

The Sorbas Karst (Almería) is a small gypsum outcrop, $12km^2$ in extent, which contains almost 1000 sinkholes and caves (Calaforra, 1998; Calaforra and Pulido-Bosch, 1997; Calaforra, 2003.). The high concentration and variety of surface and subterranean karstic forms (Calaforra and Pulido-Bosch, 1999, 2003) make it one of the most important gypsum karst environments in the world. On the other hand, some special environmental conditions, like a semi-arid climate and high levels of soil salinity, turn it into a biodiversity hot-spot area. With respect to the caves, research into the cave arthropod fauna of Sorbas, carried out by the University of Almería, has so far discovered six new species: *Pseudosinella sp. nov.*, *Chthonius sp. nov.*, *Coletinia sp. nov.* and *Tychobythinus sp. nov.* (Ruíz-Portero *et al.*, 2000, 2002), *Palliduphantes cortesi sp. nov*, and *Palliduphantes gypsi sp. nov.* (Ribera *et al.*, 2003).

In addition, the gypsum comprises a mineral resource that has been exploited since the middle of the last century. The mining sector has played an important part in the development of the region and has formed the socio-economic base of the area. The annual production in 1998 was close to 23.5 million € (Euro), generating an employment quota of about 400 direct and indirect jobs (Contreras and Calaforra, 2002). Lack of diversification of economic activities, together with the impact of mining on the environment, has brought this karstic area to an unsustainable environmental situation. The absence of a Natural Resources Ordination Project to plan the use and management of this natural area is the main problem nowadays. Historically, development based around the mineral resources has obviated all other functions and values of the natural heritage.

In 1988 the Spanish Administration recognized the area's rich environmental value and declared it a Protected Natural Space. An area of 23.75 hectares was protected using existing linear structures, especially highways and other roads, to define the limits of

Figure 1: The gypsum outcrop and Natural Space of the Karst of Sorbas, main caves, karstic springs and quarries (Calaforra, 2003).

Figure 2: Main gallery of the Covadura Cave system (Sorbas gypsum karst). Photo by Jabier Les.

protection. For this reason not all of the gypsum outcrop is totally protected. Karstic areas to the north and south, and where the gypsum mines are located, are outside the limits of the Natural Space (Fig.1). Note that mining activity and exploitation licenses pre-date the declaration of the Natural Space. Nowadays the karst outcrop and the mining activity are in a delicate environmental equilibrium. Mining activity is located at the limits of the protected area without any policed perimeter control existing between them.

Tourism and caves in the Sorbas gypsum karst

Currently the tourist development of the Sorbas gypsum karst is based around an "adventure-visit" scheme, which is used in several caves. Tourism represents the main sustainable economic alternative to the gypsum quarries. Some private companies have collaborated with the Administration to provide visits of small groups (up to 20 visitors per group) to the Cueva del Yeso and most of the subsurface galleries of the Covadura Cave system (Fig.2). "Adventure tourism" is based on speleology-type visits, with individual electric lamps and with no paths or artificial structures. Tourist exploitation of these caves has increased considerably during recent years (up to 25,000 visitors per year).

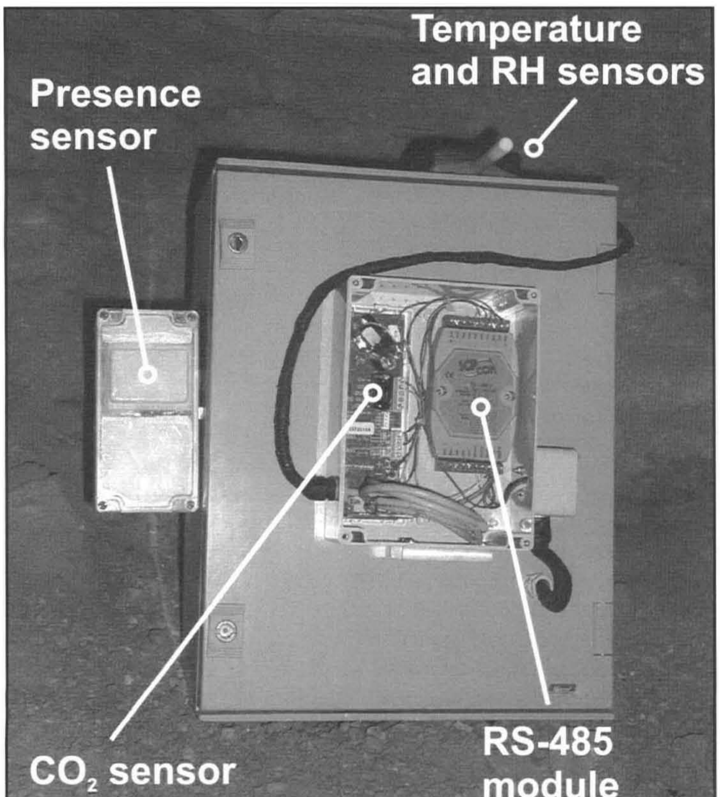


Figure 3: View of a remote microclimatic control station in the Covadura Cave System.

The "FEDER-SORBAS" research project: a framework for sustainable management of show caves

Show cave management should be able to preserve the cave environment within risk limits, and support a sustainable visitor capacity (Cigna, 1993; Calaforra et al., 2003). It is advisable to have some environmental management tools that facilitate and characterize the main parameters of the cave, and to obtain some environmental indicators under natural conditions. This database will be used as a reference for objective evaluation of the human impact during tourist exploitation of the cave. In this sense, the FEDER-SORBAS Research Project (Spanish Commission of Science and European Union Funds - FEDER, Project number: 1FD97-1577) constitutes the first phase of the cave tourist potential possibilities of the Sorbas gypsum karst. On the other hand, many cases of exploitation of the environmental heritage have assured conservation, because added economic and cultural value are factors that can be used to help develop their protection. Correct environmental management of a show cave can impact favourably when encouraging the environmental education of the visitors.

Objectives of the FEDER-SORBAS research project

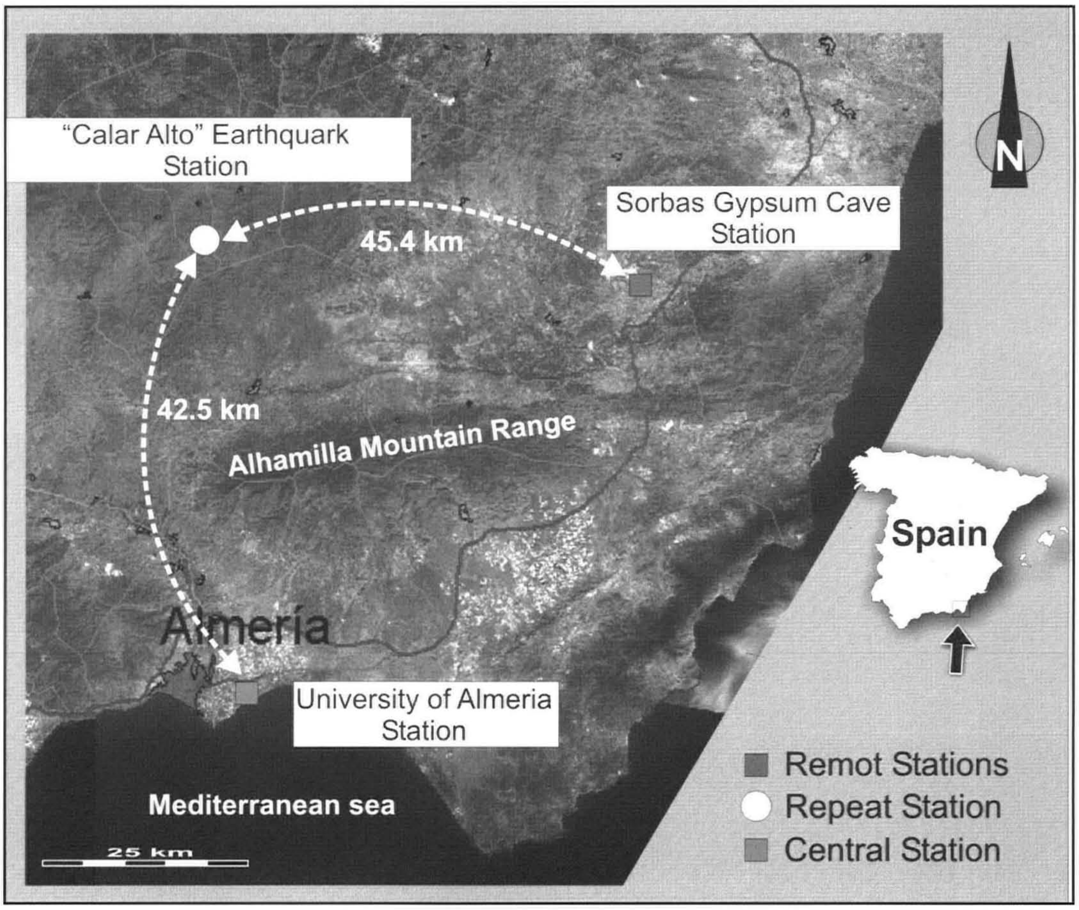
The main objectives of this research project are:

- to understand the environments of the most significant caves within the Sorbas gypsum karst;
- to determine the inter-annual variation, inside and outside the caves, of environmental parameters: temperature (air/ water/rock), relative humidity, natural ventilation, carbon dioxide concentration, relationship between rainfall and cave drip-water rate, etc;
- to compare the microclimatic stability of each cave and the inertia of their recovery after different types of human presence (mass visits, sporadic visits);
- to determine the caves that are susceptible to tourist use, evaluating the environmental impact upon them.

Intelligent environmental control system for caves

Monitoring of basic physical variables in show caves is highly recommended because cave lighting and the presence of visitors immediately modify cave environmental conditions. A cave that receives a continuous stream of visitors can suffer changes in

Figure 4: Radio communications between the local station (Covadura Cave system, Sorbas gypsum karst) and the central station (University of Almeria).



relative humidity, air temperature and CO_2 concentration, among other variables, as a result of the presence of visitors. Such variations could mean a change away from the optimal living conditions of any troglobitic fauna, or changes in speleothem growth conditions. Therefore, measuring these variables is of great value in trying to achieve appropriate environmental conservation of the cave.

The classical way of measuring and recording variables makes use of data-loggers. This confers the advantages of independence in terms of placement of the instruments, and autonomy in the acquisition and storage of the periodic measurements from the sensors. The limitations of such equipment relate to the battery life and the memory available for data storage. These data acquisition systems require periodic servicing to replace the battery and download the data. In addition, because they are isolated and have no communication to the surface, the frequency of readings cannot easily be modified in accordance with external events.

To determine the influence of cave visits on environmental conditions inside the cave, and to assess the degree of impact in terms of physical and biological conservation, it would be useful to be able to increase the frequency of data acquisition of all the sensors in the cave automatically, for example when people are detected inside. In the Sorbas Karst these requirements have been met by installing a microclimatic control system based on techniques of distributed control and telemetry, to allow intelligent and customized data acquisition (Gázquez *et al.*, 2003a and b). This system supports both measurement and real time transmission to the station located in the University of Almería.

Environmental control stations

The environmental control stations have the function of acquiring the different variables and transmitting these data to a central station, which is responsible of the storage, treatment and diffusion of this information. Each sampling station contains the following set of environmental sensors with an analog output: (1) carbon dioxide concentration, (2) air temperature and (3) relative air humidity. It also incorporates a human presence detector to monitor visitors to the cave (Fig.3). Data are digitized using a commercial data acquisition module.

Data communication network

In the first instance, the information collected digitally by the various data-sensors at the remote stations is transferred to a local computer situated in a small building close to the cave. This computer is responsible for formatting the data received from the sensors. Subsequently, the information is sent to a central computer located at the University de Almería for data processing and storage. To perform these functions, a mixed communications system is required. The first stage (remote stations to local computer) utilizes a 1km-long cable RS-485 communication, whereas the second (local computer to central computer) requires wireless communication via radio.

The data acquisition system has a protocol that allows the local computer to check, every 30 seconds, whether or not there are people present in the cave, and so to establish the counting rate for data acquisition, using the following criteria:

- (1 minute): measurements every minute if human presence was last detected less than one hour ago;
- (1 hour): measurements every hour if human presence was last detected more than one hour ago.

The system permits the sampling frequency to be increased to allow a more detailed study of the impact of a visit on the environmental parameters in the cave. Additionally, the established intervals of 1 minute or 1 hour can be adjusted if necessary.

The second stage of the communications network is the transfer of information from the local computer to the central station at the University of Almería. The Sorbas caves lie in a rather remote area with no telephone lines and so the two options available for data transmission are digital mobile telephone or autonomous communication using a radio-modem. The second option is better suited to the monitoring of ambient conditions inside show caves, because a constant connection is possible and it does not require private operators. In addition, the rugged topography of the province of Almería prohibits a direct link between the local station in the Sorbas Karst (cave) and the central station (University of Almería). Thus, a repeater was needed to cover both stations. This repeater

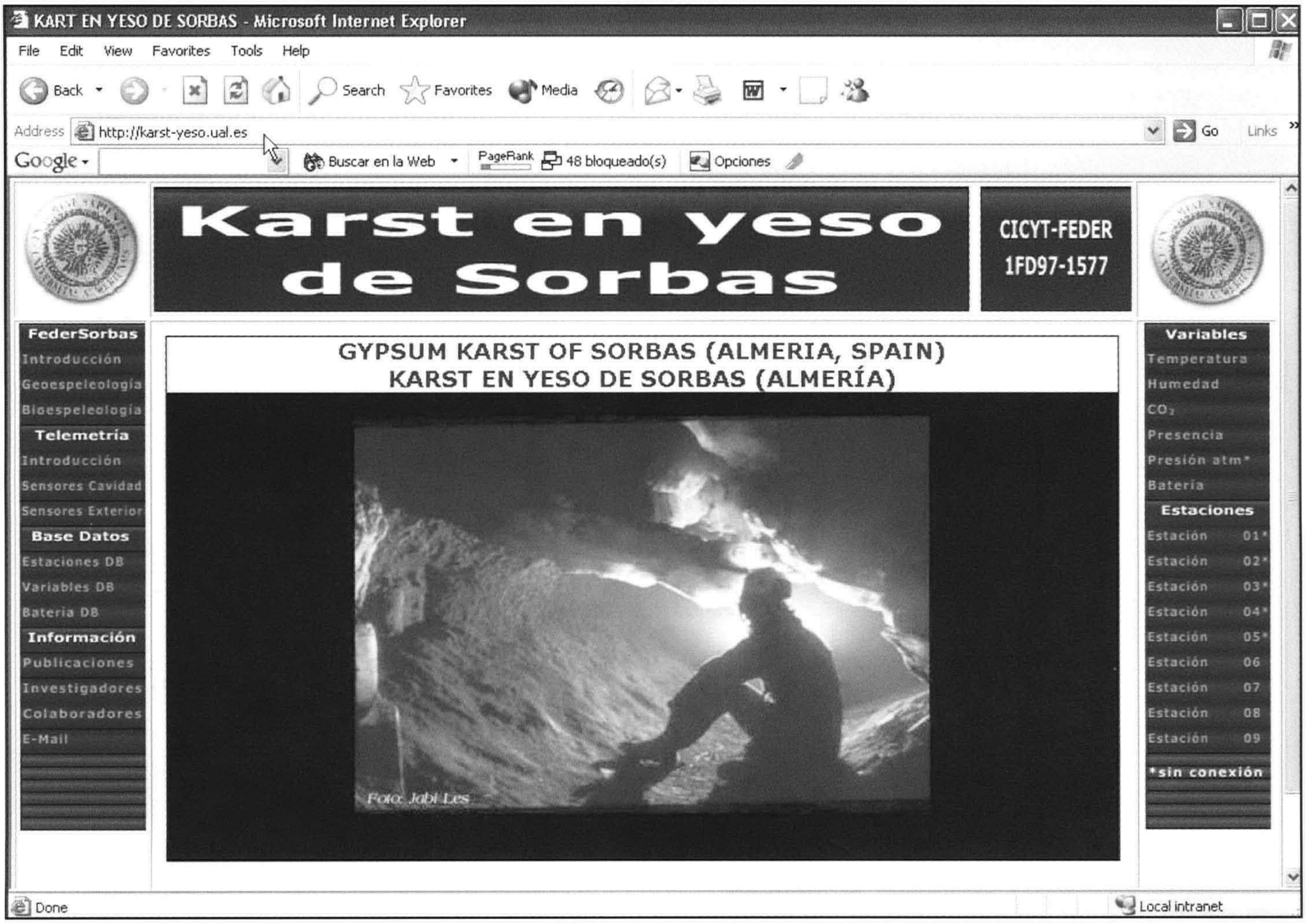


Figure 5: *Main web page of the FEDER-SORBAS research project (http://karst-yeso.ual.es).*

radio-modem was installed at the Seismological Station belonging to the Andalusia Geophysics Institute ("Calar Alto" Earthquake Station). Figure 4 shows the geographical distribution of the data transmission network.

Internet accessibility to the environmental control of caves in the Sorbas gypsum karst

The data acquisition system installed inside the Sorbas caves provides intelligent environmental control, potentially of great interest to the future management agents of shows caves. The system has been in operation for more than a year and there is already a considerable volume of data. What is more, the automatic increase of the data acquisition frequency of the system, according to the presence or absence of visits, offers detailed time series data for the main environmental variables in the cave. This record will facilitate determination of the ideal approach to visits, with respect to the incidence of each parameter in many areas of the cave (9 stations with 36 sensors in total have been installed).

Lastly, transfer of the research results is direct, and these are of immediate use to the Administration responsible for the caves (the Environment and Tourism offices of the Autonomous Government of Andalusia, the City Council of Sorbas and the speleo-adventure companies). With these results promotion of rural tourism in these interior districts can be increased, assuming there is opportunity to change or diversify the economic dependence of this area. The information is published in real time by means of the http://karst-yeso.ual.es (n.b. no "www") web (Figs 5 and 6), so that anybody can access details of the microclimatic conditions in the cave and observe the influence and rate of environmental recovery after an actual visit.

ACKNOWLEDGEMENTS

This study was undertaken within the framework Project 1FD97-1577, subsidized by the "Comisión Interministerial de Ciencia y Tecnología (CICYT)" of the Spanish Government (30%) and funds from the European Union FEDER Programme (70%).

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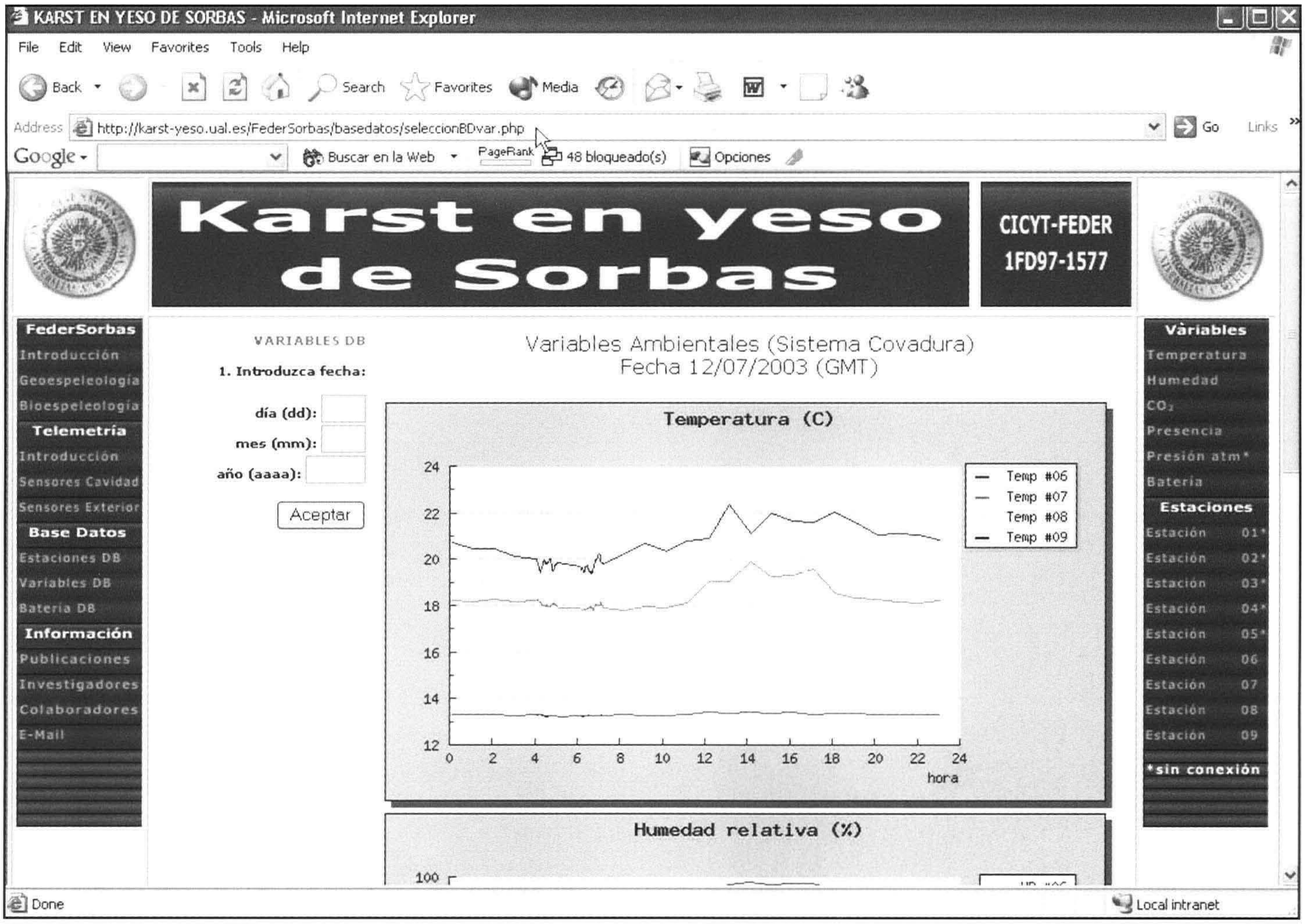

Figure 6: Real time graph of air temperature inside the Covadura Cave system.

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Forum

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

All views expressed are those of the individual authors and do not necessarily represent the views of the Association unless this is expressly stated. Contributions to the *Cave and Karst* Science Forum are not subject to the normal refereeing process, but the Editors reserve the right to revise or shorten text. Such changes will only be shown to the authors if they affect scientific content. Opinions expressed by authors are their responsibility and will not be edited, although remarks that are considered derogatory or libellous will be removed, at the Editors' discretion.

CORRESPONDENCE

Dear Editors,

I am writing with reference to the Guest Editorial by the BCRA Biological Recorder, Graham Proudlove, in *Cave and Karst Science*, Vol.30(2).

Following his appointment, Proudlove has tackled the job with vigour and he is to be congratulated on his efforts. Creation of the "Hazelton" database of Cave Research Group Biological Records is especially welcome and potentially useful: Mary Hazelton would have been delighted with this development. I knew Mary personally, and am sure that she would in particular have been happy to hear that (if I understand correctly) the database is soon to be made available to be mined for information by all cave biologists. That is very much in the spirit in which she herself approached things. Modestly she saw the onerous task of receiving specimens, distributing them to the taxonomists, keeping we collectors fully and promptly informed and then typing up the thousands of records for publication, as a service to all, and she never used her status as Biological Recorder selfishly for personal aggrandizement. Nevertheless, she would have been quietly pleased with the inspired tribute of naming the database in her honour.

It would be preposterous for anyone to argue that it is not high time that modern molecular biology and up-to-date research techniques are brought to bear in investigating our invertebrate cave fauna. The sooner the better! The British Isles are potentially a natural laboratory of the early stages of colonization and adaptation to the subterranean environment, and thus offer the opportunity for us to be in the forefront of progress in evolutionary cave biology. Possibly, even, at the forefront of evolutionary biology itself. Now that speleo-biology has finally shed the neo-Lamarckian claptrap of its early days the time has come to be admitted back into the wider fold. Once back in the mainstream it may in due course bring spectacular insights and results.

But, does it necessarily follow that the day of the serious amateur cave biologist is *"...quickly receding..."* as Proudlove contends?

Britain has a long and remarkable history of amateur scholarship: probably the best in the world. The tradition is very strong indeed in the natural sciences, and it is continuing. Certainly the day of the tweedy eccentric prowling the hedgerows of England with vasculum, butterfly net and killing bottle are gone. But so too are the days when the professional biologist was able to do much the same. The pressures of grants and publishing and teaching are too great to leave much time these days for such indulgences as collecting to fill the gaps on distribution maps. There are many other things that the academic biologist simply no longer has the time to do. A consequence is that, alongside the professional academic advancement of the science, there has actually been a growing need for the contributions of the amateurs, and their role is increasingly important. There are in fact probably more serious amateur field biologists in Britain today than at any previous time in history: just go along to any public library and ask for a list of local Natural History groups to see this.

Why is it any different in speleology, a field where (in Britain at least) fruitful cooperation and mutual respect between "speleologist-cavers" and "caver-speleologists" is nothing new?

I say this: *"It isn't."*

I would not have asked for the space to address this point had it not been made by the Biological Recorder of the BCRA and thus having more than a whiff of developing policy about it. If intended as a policy it goes against the grain of this organization. The ethos of the BCRA, and of this Journal, in which Proudlove wrote, is one of mutual professional–amateur support and partnership. If the revived position of Biological Recorder is used as a vehicle to actively encourage, support, facilitate and promote fruitful cooperation between professional career scientists and amateurs, then I am confident that we have not yet reached the high-water mark of what can be achieved by amateur cave biologists in Britain. But used to promote the interests of either group at the expense of the other, then both, as well as the Association itself, which has previously represented both, will be diminished.

Finally, one small quibble: the statement that *"Biological studies were restarted in 1998, with the work of Paul Wood and John Gunn ... at the University of Huddersfield"* is not correct or is, at best, misleading. For one example, my own study on the Isle of Man began in 1994 (publication, in CAKS, in 1997) and I do feel that I have some modest claim to have played a part in the revival of the mid-1990s. I am assuming that this was only an inadvertent oversight but, nevertheless, it's rather discouraging to be written out of the story.

Yours faithfully,

Max Moseley
Songkhla,
Thailand
8th March 2004
E-mail: maxmoseley@hotmail.com

Dear Editors

SCALLOPS AND DISSOLUTION RATE

The paper by Charlton (2003) discussed a project aimed at defining a scallop dominant discharge for vadose conduits in limestone. It raised the interesting question of whether dissolutional wall retreat rate can be deduced from scallop morphometry, as inferred by some earlier authors. Present understanding of the physics and chemistry of calcite dissolution derives especially from Palmer (1981 and 1991) and Dreybrodt (1990), supplemented by many later papers. However, there has been no modern theoretical integration of this knowledge with the properties of cave scallops, as identified by Curl (1966). In the absence of such a treatment, it appears that the connection between scallops and wall retreat rate is much simpler than previously understood.

Palmer (1991, Eq.6 and Fig.12) derived graphs to show how the wall retreat rate in a cylindrical tube varies with radius, length, flow rate and hydraulic gradient for laminar flow closed conditions with zero initial dissolved calcite. The rate always reaches a theoretical maximum value that is not directly dependent on the equilibrium saturation concentration (perhaps surprisingly) and is also independent of the other physical variables, providing that the tube radius, hydraulic gradient and flow rate are sufficiently large, or that the tube length is sufficiently short. This value is $31.56k/\rho$ cma^{-1}, where ρ is the density of limestone (c. $2.7gcm^{-3}$) and k is the lowest-order reaction coefficient, which varies with temperature and P_{CO2}. For a system at 10°C with P_{CO2}= 1%, k = c. 0.01mg-cm $l^{-1}s^{-1}$, giving a maximum wall retreat rate of about $1mma^{-1}$. This maximum is reached when the solution remains considerably undersaturated at the exit point (commonly below a limiting saturation ratio of 60 to 70% that is determined by the temperature and P_{CO2}), and occurs if Q/rL exceeds $0.001cms^{-1}$ (where Qcm^3s^{-1} is the flow rate along a tube of length L cm and radius r cm). Hence, the maximum dissolution rate applies whenever $Q>rL/1000cm^3s^{-1}$. Noting that $Q=\pi r^2V$ for a cylindrical tube (where V cms^{-1} is the mean velocity), the maximum rate occurs when $1000\pi Vr>L$ cm. If this relationship is not true, slower, higher-order dissolution kinetics apply beyond the first-order penetration length until V increases sufficiently at the slowly enlarging exit for "breakthrough" (Dreybrodt, 1990) to occur to fast, first-order, kinetics, commonly accompanied by a transition to turbulent flow with the same maximum wall retreat rate. The dissolution rate is similarly reduced if the recharge contains enough dissolved calcite to cause the saturation ratio limit to be exceeded before the exit.

According to Curl (1966, Fig.1), $\lambda V=300cm^2s^{-1}$ at 10°C, where λ (cm) is the scallop length and V (cms^{-1}) is the flow velocity. Substituting into the above tube expression, the maximum wall retreat rate occurs when $\lambda<3\pi10^5r/L$ cm. However, scallops do not form if $\lambda>2r$ (Curl, 1966, p.153). This means, in practice, that any observable scallop in the wall of a phreatic passage that is less than about 5km long ($L<3\pi10^5/2$ cm) formed when flow was turbulent, the solution remained below the limiting saturation ratio and the limestone in the wall was dissolving at the maximum rate possible, as was limestone in many passages without scallops and in many conduits too small to be entered or even to be observed.

The above conclusion applies to phreatic dissolution in conditions closed to further input of CO_2, without considering any extra effect of mechanical erosion. The saturation ratio is more likely to remain within the maximum dissolution limit at high stage, when the recharge contains less dissolved calcite and is most aggressive, so that scallop size provides an inverse measure of high stage flow velocity. The experiment discussed by Charlton (2003) is open to continuous re-supply of cave air, which may vary the CO_2 concentration in solution, and therefore change the reaction coefficient, the saturation ratio and the saturation ratio limit. However, the presence of scallops in vadose passages should also indicate dissolution at a maximum rate in most situations. Vadose wall and floor retreat rates probably remain less than $1.2mma^{-1}$, according to estimates at vadose shafts by White (1990, p.170).

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Trevor Faulkner
Limestone Research Group
University of Huddersfield
Queensgate
Huddersfield
HD1 3DH
UK.

SCIENTIFIC NOTE

A hypogenic cave formed by "connate" water from the Craven Basin?

Background and description:

Several years ago John Southworth and I decided to investigate the prospects of extending the little-visited Arthur's Cave (NGR SD 797.487), which is situated in limestone cliffs above the River Ribble near to Fooden Farm at Bolton-by-Bowland.

The earliest reference to the cave that I have found is contained in *'Rambles by The Ribble'* by William Dobson (1864: 2nd Ed.). The author visited the cave but didn't name it and went on to quote an earlier poem where it was referred to as 'Aithera Hoile', being the abode of local goblins Lob and Michil (p.65–66).

The cave is several metres above the Ribble and the stream from it has formed a tufa deposit over its steep, vegetated course down to the river. It is not known whether this tufa is actively forming or degrading.

The cave entrance is quite large but shallow, extending a few metres to a plug of rock and mud fill that completely blocks the passage. The small stream seeps from under this blockage. At some time in the past persons unknown have excavated over the left-hand upper corner of this fill, opening a route that leads back down to the stream. At this point the continuation consists of crawling in the stream following the left-hand passage wall. The roof and right-hand side consist of rocks and boulders. We managed to remove some blocks from the stream and extended the passage some 2 to 3 metres to a complete choke.

The stream in this tight section felt comparatively warm, smelled strongly of hydrogen sulphide and contained hundreds of freshwater shrimps tentatively identified as *Gammarus pulex* (L). In the roof of the excavated route down to the stream was a colony of large spiders *(?Meta menardi)*.

Area hydrology

Within a kilometre of the cave to the east are three other springs. One is Otter Well (NGR SD 801 486), thought to be the resurgence for the sinking water in a blind valley near Fooden Farm, partially choked with farm debris, northeast of the Well (NGR SD 802 487). Earp *et al.* (1961, p.30) state categorically that this sink is the source of the Otter Well water.

Brook *et al.* (1994, p.260) mention a sink "0.4 km north" (NGR SD 797 489) as the probable source of the Arthur's Cave water. However, the current farmer assures me that a dye test carried out some years ago was positive at springs (NGR SD 799 488) feeding the small stream that enters the main stream (Fooden Gill) just below Fooden Sulphur Springs.

The other locality is Fooden Sulphur Springs, below Fooden Farm (NGR SD 800.489). These emerge as smelly seeps from tight bedding planes within the limestone strata.

Dobson (1864, p.67) mentions a book, 'Spas of England', by a Dr Granville, but gives no date or publisher. In this, reportedly, the Fooden and Arthur's Cave waters were considered as being separate sources.

Just to the east of Arthur's Cave the Middop Fault runs north–south across the River Ribble, manifesting itself as a weir-like structure above Denham Wheel (NGR SD 798.487). This fault is the probable cause of the springs.

Sampling Results

A return was made on 13 July 1999 to sample the Arthur's Cave stream beyond the plug of fill for analysis. The results are given below:

Time: 14.00hrs;
Water Temperature 18.8°C;
pH 8.03;
Conductivity @ 25°C 1560 µS/cm.

	milligrams per litre
Alkalinity	342 mg/l
Dissolved Oxygen	9.6 mg/l (104%)
Chemical Oxygen Demand	19 mg/l
Total Organic Carbon	2.062 mg/l
Oxidised Nitrogen	1 mg/l
Ammonia	0.5 mg/l
Fluoride	2.19 mg/l
Sulphate	169 mg/l
Sulphide	0.022 mg/l
Chloride	219 mg/l
Sodium	226 mg/l
Lithium	< 0.1 mg/l
Potassium	3.1 mg/l
Magnesium	13 mg/l
Calcium	106 mg/l
	micrograms per litre
Lead	2.55 µg/l
Mercury	0.38 µg/l
Cadmium	0.162 µg/l
Total Arsenic (+ Se and Sb)	< 1 µg/l
Manganese	21.3 µg/l
Iron	152 µg/l
Copper	2.36 µg/l
Zinc	20.9 µg/l
Nickel	5 µg/l
Chromium	0.826 µg/l
Boron	232 µg/l
Phenols	0.02 µg/l

[N.B. upper part milligrams per litre; lower part micrograms per litre].

The inner cave air was also sampled and found to contain 0.04% (400ppm) hydrogen sulphide. It is not known whether the level of gas concentration fluctuates, and caution is advised if the cave is visited.

Discussion

The water sample results suggest that the stream contains expelled "connate" water from within the Craven Basin. There is no known shallow groundwater input to the cave. It is suggested that this "connate" water rises via the Middop Fault and it is likely that the Fooden Sulphur Springs are also related to this fault, although these springs have not been sampled and analysed.

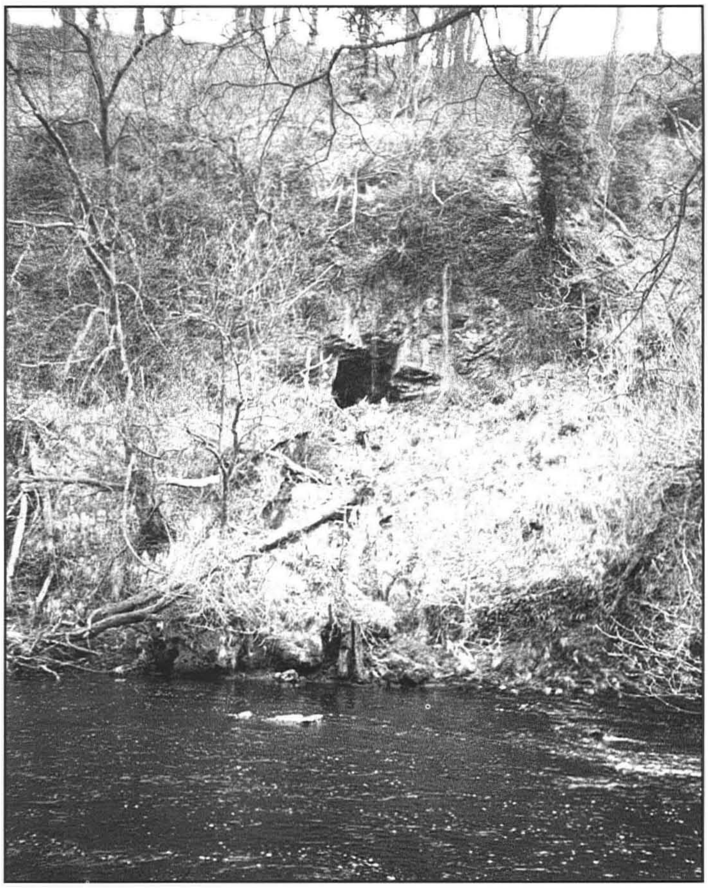

Figure 1. *The entrance to Arthur's Cave, in a limestone cliff above the River Ribble, near Bolton-by-Bowland*

Several questions arise. Is Arthur's Cave a truly hypogenic cave formed entirely by the "connate" waters or have these deeper waters intersected a pre-existing cave originally formed by vadose or shallow phreatic groundwater? Is the entrance blockage in situ breakdown or glacial fill? Has the River Ribble had any influence on the cave e.g. was the relatively large cave entrance formed by mixing corrosion when the river was at a higher level? Does the water analysis indicate possible mineral deposits? And so on.

I intended to investigate further but this now seems unlikely. Perhaps someone out there may consider extending this work as a university dissertation?

Barry M Hunt
June 2004.

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BOOK REVIEW

Encyclopedia of Caves and Karst Science edited by John Gunn. Published by Fitzroy Dearborn (Taylor and Francis Group, New Fetter Lane, London, EC4P 4EE, and New York). 2003. ISBN 1-57958-399-7. 902 pages. £95.

This massive compendium was compiled and edited by John Gunn and a team of 14 advisors. These are among the 200 or so contributors, drawn from speleologists and karstologists from all over the World. They have written nearly 400 entries on almost all karst-related topics, ranging from process-oriented topics to regional surveys, from historical reviews to reports on the larger individual cave systems such as Mammoth, Carlsbad–Lechuguilla, Mulu and Hölloch, and comments on archaeological caves and on biospeleology. Entries are arranged alphabetically and most comprise only two or three pages. They follow a pattern of reviewing the state of knowledge of their topic, giving a handful of cited references and a short list of Further Reading. Gypsum and salt karsts are included as well as pseudo-karst on granites, sandstones and other rocks. A few topics get extended treatment, e.g. 15 pages on Groundwater and 18 pages on Speleogenesis. Cave sediments were split between two groups of entries: 6 pages under the heading Sediments, and a further 6 pages under Paleoenvironments.

There are numerous black and white photographs, many diagrams, and a group of eight pages of colour photographs in the centre. Biographical notes on the contributors are provided at the back (with the exception of Peter Huntoon – author of the Grand Canyon entry), and there is a comprehensive index.

Karst sciences in the context of the Encyclopedia include cave archaeology and biospeleology – indeed there are so many entries in the latter category that a geologically minded reader may feel a little frustrated. Some other topics that I would have regarded as marginal to karst science include Limestones as Resources, aspects of limestone use such as road material, and quarry landscaping. Nonetheless, the book will make an essential reference work for anyone interested in caves and karst for many years to come. It will provide valuable starting points for many graduate theses, as well as providing cribs for undergraduate dissertations.

However, the Encyclopedia has its drawbacks. To start with I looked up a few topics that interest me. Hydrothermal Karst had no entry, though the enormous index directed me to material hidden under Speleogenesis: Deep-seated, and there was more on the subject under Sulfide Minerals in Karst, which was not indexed.

I looked up Sutherland Caves, but there was only a brief note on the archaeological caves near Inchnadamph, hidden in items indexed to Scotland, but not indexed under United Kingdom (presumably because the American index compiler did not know where Scotland is. I had expected some reference to Smoo Cave's vast entrance (second largest in Britain after Peak Cavern), and to the unusual exploitation of a thrust-fault plane by the Cnoc-nan-Uamh cave stream, but this may be a parochial view.

I looked for Lava Caves, but found no specific entry, though the index directed me to the entries on Hawaii Lava Caves and on Volcanic Caves. A surprising omission was anything about the recent studies by Chris Wood and others on Iceland's Laki lavas.

The Peak District entry has overlooked the dolomitized area in the southern part of the White Peak, with its periglacial karstic dolomite tors; the nearby solution collapse structures around Brassington with their fill of Mio-Pliocene sands and clays were dismissed in one line, with the misleading implication that they were Permo-Triassic features. The caverns developed at the dolomite/limestone contact, as at Matlock and in the Golconda Mine near Brassington were overlooked, though these could be regarded as of only parochial interest.

In connection with the drowned tower karst of Ha Long Bay, Vietnam, I looked for comment on the equivalent in the Palau Islands in the western Pacific (seen in David Attenborough's film of jellyfish in a flooded doline) and on the drowned tower karst at Phangnga Bay beside Phuket in Thailand (seen in one of the James Bond films), but found only the latter tucked away in the entry on Asia, Southeast.

There is an entry on the archaeological caves of Gibraltar, but no mention of St Michael's or other caves high in the Rock – how did these caves or their speleothems develop with their minimal catchment area? The ice-filled Grotte Casteret got only the briefest of mentions, with no discussion of the ice accumulation therein. I found no description of the deeply eroded karst exposed by exploitation of guano on some oceanic islands, such as Niue and Nauru. Perhaps these are indications that an encyclopedia, even of this size, cannot cover the entire world in detail.

I looked for an entry on Tufa but found only one on Travertine. Both appeared in the index with their own long lists of appearances, of which only some overlapped, and sadly the major data on genesis, within the Travertine entry, was not listed among the Tufa references, nor was the data on tufa formation listed among the Travertine references.

However, these are details that can easily be put right in a second edition in a few years time. The Encyclopedia is a volume that should be on every library shelf where there is any interest in limestones (and other rocks) with their caves and karstic phenomena, archaeology and subterranean biology. John Gunn and his team deserve all possible plaudits for their great effort.

Trevor D Ford
C/o Geology Department
University of Leicester
Leicester
LE1 7RH
UK.
March 2004.

Encyclopedia of Caves and Karst Science edited by John Gunn. Published by Fitzroy Dearborn (Taylor and Francis Group, New Fetter Lane, London, EC4P 4EE, and New York). 2003. ISBN 1-57958-399-7. 902 pages.

As stated in the Editor's introduction, *"...this is the first encyclopedia devoted to Caves and Karst Science."* The book consists of over 300 articles from 202 authors, all of whom are recognized as leading authorities in their field. The articles were categorized into eight broad themes, which include archeology, biospeleology, caves and caving, caves and karst regions, conservation and management, geoscience, history, and resources and development, and were *"...selected by a multi-disciplinary Advisory Board of leading scholars, all of whom are cavers."* The book is 902 pages in length and presents the articles in alphabetical order, with lists of works cited and further reading at the end of each article. Additionally, a thematic list of the articles is provided along with limited biographical information about each author near the end of the book. The central portion of the book provides the reader with eight pages of surface and subsurface colour photos, some of which include salamanders, bats, cave shrimp, cave art, cave pearls, flowstone, cave passages, epikarstic features, doline and cone karst, and glaciokarst.

No book published in any genre escapes the criticism of its readers, and the *Encyclopedia of Caves and Karst Science* is no exception. Previous reviews have pointed out the presence of errors, which every book ever published most likely includes. However, the minor errors identified do not take away from the enormous value of the *Encyclopedia of Caves and Karst Science*. As anyone would testify, a tremendous amount of hard work, and most likely added pressure and frustration, was involved with the preparation of this collection of our current knowledge about karst environments. In that respect, the Editor, Advisory Board, and authors have done a great job.

Many of the world's karst regions, settings, and important caves are mentioned in the *Encyclopedia of Caves and Karst Science*. Some examples include articles written about the Mammoth Cave Region, Carlsbad Caverns, Lechuguilla, Wind and Jewel Caves, Patterns and Hydraulics of Caves (Arthur Palmer), Fluviokarst, Quarrying of Limestone (John Gunn), Inception of Caves, Speleogenesis Theories Post-1890, Geoscientists (Dave Lowe); Speleogenesis in Deep Seated and Confined Settings, Gypsum Karst, Caves in the Ukraine, Evaporite Karst (Alexander Klimchouk), Speleogenesis in Coastal and Oceanic Settings (John Mylroie), Micro-organisms in Caves (Diane Northrup), Forests on Karst (Tom Aley), Burren Glaciokarst (Dave Drew), Speleogenesis in Unconfined Settings (Derek Ford), Dinaric Karst (Andrej Kranjc), Dolines (Paul Williams), Mathematical and Conceptual Models of Groundwater in Karst (Steve Worthington and Chris Smart), Cone Karst (Mick Day), and Littoral Caves (Dave Bunnell).

The *Encyclopedia of Caves and Karst Science* is a useful tool that should be on the bookshelf of anyone interested in learning more about the fragile environment known as karst. All of the articles I have read are well written and should be understandable to non-specialists as well as to the seasoned veteran. However, some articles are more technical, and additional reading would be required. Currently, the book is listed for $195.00 at Amazon.com and $150.00 from Speleobooks (www.speleobooks.com).

David M Bednar, Jr.
Michael Baker Jr. Inc.
White Hall,
Arkansas,
USA.
June 2004

THESIS ABSTRACT

Taxonomy and species status of cave-dwelling and epigean catfishes of the genus *Rhamdia* (Pimelodidae, Teleostei) from Mexico.

Axel Weber
PhD thesis, July 2003
Faculty of Biology
University of Hamburg,
Germany

Summary

In southern Mexico, the catfish genus *Rhamdia* (Pimelodidae) is represented by at least two epigean species and several subterranean populations (Weber, 1996). Until 1993, two of these cave populations had been described as species, *R. reddelli* Miller, 1984 and *R. zongolicensis* Wilkens, 1993. In comparison to the closest epigean relative *R. laticauda* (Heckel in Kner, 1858) they are distinguished by the parallel evolution of typical features of obligate subterranean animals (= troglobites or stygobites), e. g. reduced eyes and faint body pigmentation. In a recent revision of the genus *Rhamdia* (Sifvergrip, 1996), the species status of the stygobitic species has been denied because of an apparent lack of diagnostic morphological traits when the adaptations to the cave environment are excluded from the analysis. However, crossing experiments had revealed a developing isolating mechanism in these three species (Wilkens, 2001), indicating considerable genetic divergences despite morphological similarity. Additionally, some cave habitats are several hundred kilometres apart in different karst areas. This thesis tries to give an answer if we are dealing with a single species with several subterranean morphotypes or with a complex of different species.

The application and significance of standard morphometrics in fish taxonomy has been tested with regard to several stygobitic *Rhamdia* populations. In some cases diagnostic traits were found and two new species could be described. *R. macuspanensis* Weber & Wilkens,1998 is distinguished by the characteristic shape of spinous first pectoral fin ray and the statistically significant elongation of the barbles on upper jaw and chin (Weber & Wilkens, 1998). This increases the radius for tactile and gustatory stimuli. In contrast, *R. laluchensis* Weber, Allegrucci & Sbordoni, 2003 is characterized by upper jaw barbles of intermediate length: shorter than in any other investigated stygobitic *Rhamdia* but still longer than in the epigean *R. laticauda* (Weber, Allegrucci & Sbordoni, 2003). Another, still undescribed cave population also shows some traits that can be used for diagnosis: the chin barbles and the head are shorter than in other stygobitic *Rhamdia*; additionally, the distribution of the pores of the lateral line head canal system (compare Weber, 1995) shows a characteristic pattern. Accordingly, the description of this population as a new species is in preparation.

Despite these morphological differences, the study reveals a general limitation of classical morphometrics concerning stygobitic *Rhamdia* populations. Although a preliminary key is given it is still not possible to distinguish *R. reddelli* and *R. zongolicensis* with certainty. The direct comparison of the stygobitic specimens with the epigean relative *R. laticauda* is problematic because the denominator "standard body length" is influenced by the convergently evolved head enlargement in all investigated cave populations.

Therefore, a molecular genetic investigation based on sequence segments (412 base pairs) of the hypervariable domaine I of the control region in the mitochondrial DNA was conducted. Each investigated *Rhamdia* species was characterized by 1 – 4 haplotypes and diagnostic base substitutions. The phylogenetic reconstruction resulted in three clades. However, their relationships could not be resolved, resulting in a trichotomy. The epigean *R. laticauda* population included in this investigation forms a cluster with the close relatives *R. reddelli* and *R. zongolicensis*. Therefore it can be concluded that the two remaining clades, *R. macuspanensis* and *R. laluchensis* respectively probably originate from different epigean lineages and are the results of independent cave colonization events.

Under the assumption of a molecular clock, the genetic distances allowed a calculation of the phylogenetic age of the different lineages. Earlier ideas of comparatively recent origins (c. 10000 years) based on the low development of troglomorphic traits (Wilkens, 2001) could not be supported. Instead, the calculations indicate a divergence of the ancestor of *R. reddelli* and *R. zongolicensis* from the epigean *R. laticauda* about 450000 years ago. According to the sequence data the divergence of the three clades happened more than 1 million years ago. However, it must be taken into consideration that divergence time is not necessarily equal to cave colonization time. It is possible that the cave populations developed independently and at different times originating from epigean lineages that diverged already considerable time before.

The synthesis of the morphological and molecular genetic investigations suggest the recognition of several stygobitic *Rhamdia* species despite morphological similarity. Based on the current data it could be concluded that among several species concepts (Hennigian, recognition, evolutionary, phylogenetic, cohesion) the biological species concept seems to be the most appropriate one to describe the relationships between the investigated *Rhamdia* species.

Literature:

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Weber, A, 1995. The lateral line system of epigean and cave dwelling catfishes of the genus *Rhamdia* (Pimelodidae, Teleostei) in Mexico. *Mém. Biospéol.*, Vol.22, 215-225.

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DISSERTATION ABSTRACTS

Passage wall coatings in Joint Hole, a flooded cave system in Chapel-le-Dale, North Yorkshire

John Heneghan
BSc (Hons) Environmental Geology
School of Earth Sciences
University of Leeds
LS2 9JT

The presence of a dark brown sediment coating the rock surfaces has been noted in the phreatic conduits of cave systems in the Yorkshire Dales. However, no reference has been found of any work done on this coating, either to determine the source of the deposit or to evaluate its possible effects within cave systems. Work done with samples of this coating, collected from the main passage of Joint Hole, Chapel-le-Dale, indicates that the deposit originates from the peat bogs on the flanks of Ingleborough, from where it is carried by the waters that drain into Joint Hole. There is also an input of inorganic calcite to the composition of the deposit though whether the source of these particles is allochthonous or autochthonous is unclear. Limestone pills placed in the conduit were covered by the coating. These pills were subject to a dissolution experiment, the results of which suggest the presence of the deposit has no effect on controlling the dissolution effects on the passage walls.

A sedimentological study to ascertain the anthropogenic influence on the hydrology of the Gaping Gill Cave System, North Yorkshire

Samuel Allshorn
BSc (Hons) Geological Sciences
University of Leeds
LS2 9JT

A range of samples was collected from various sites within the cave system (Main Chamber, West Chamber, Sand Cavern, South Passage and West Slope). These were analysed using sieving, laser grain sizing and x-ray diffraction techniques. Gravimetric determination of calcium-equivalent content was also carried out. Statistical results have shown that none of the localities has the same grain size as another, throughout a sequence. There are some beds that are similar but not necessarily stratigraphical equals.

A review of the available historical data showed that major changes to sediment distribution in the Main Chamber have occurred over the last 150 years. The results show that although the sediment is most likely from the same source the style of deposition has varied. Deforestation in the drainage basin of Fell Beck started at 5760+/-60 BP and its effects on the sedimentology of the cave system can be inferred but not yet proven.

RESEARCH FUNDS AND GRANTS

The BCRA Research Fund

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

a) To assist in the purchase of consumable items such as water-tracing dyes, sample holders or chemical reagents without which it would be impossible to carry out or complete a research project;

b) To provide funds for travel in association with fieldwork or to visit laboratories that could provide essential facilities;

c) To provide financial support for the preparation of scientific reports. This could cover, for example, the costs of photographic processing, cartographic materials or computing time;

d) To stimulate new research that the BCRA Research Committee considers could contribute significantly to emerging areas of speleology.

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

Ghar Parau Foundation Expedition Awards

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

The E K Tratman Award

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

BRITISH CAVE RESEARCH ASSOCIATION PUBLICATIONS

Cave and Karst Science – published three times annually, a scientific journal comprising original research papers, reports, reviews and discussion forum, on all aspects of speleological investigation, geology and geomorphology related to karst and caves, archaeology, biospeleology, exploration and expedition reports.
Editors: Dr D J Lowe, c/o British Geological Survey, Keyworth, Nottingham, NG12 5GG, UK, (e-mail d.lowe@bcra.org.uk) and Professor J Gunn, Limestone Research Group, University of Huddersfield, Queensgate, Huddersfield, HDI 3DH, UK (e-mail j.gunn@bcra.org.uk).

Speleology - published three times annually and replacing BCRA's bulletin *'Caves & Caving'*. A magazine promoting the scientific study of caves, caving technology, and the activity of cave exploration. The magazine also acts as a forum for BCRA's special interest groups and includes book reviews and reports of caving events.
Editor: David Gibson, 12 Well house Drive, Leeds, LS8 4BX, (e-mail: speleology@bcra.org.uk).

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

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

Speleohistory Series – an occasional series.

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

BCRA SPECIAL INTEREST GROUPS

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

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

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

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

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

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

Copies of BCRA Publications are obtainable from: Ernie Shield, Publication Sales, Village Farm, Great Thirkleby, Thirsk, North Yorkshire, Y07 2AT, UK.

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