BCRA TRANSACTIONS

BRITISH CAVE RESEARCH ASSOCIATION

Volume 3 Number 2 July 1976

The Cerberus Formation, Enkoftu Mohu, Ethiopia

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ENKOFTU MOHU AND OTHER ETHIOPIAN DISCOVERIES

W. H. Morton

Summary

Enkoftu Mohu is a 192 metre deep pothole in southeastern Ethiopia. As well as being the deepest known in the country, it contains very fine active formations. Other recent discoveries in central and southeastern Ethiopia are also described.

Introduction

The British Speleologlical Expedition to Ethiopia published a comprehensive account of the caves of Ethiopia in 1973. Since that date several new discoveries have been made. Fig. 1 shows the locations of the new finds and some of the localities described in the 1973 report. As in that account no mention is made here of the many rock shelters and similar sites of great archaeological interest.

At Bedenno, Grawa and Nur Mohammed new exploration has been made in potholes and caves in the Jurassic Antalo Limestones, while at Debre Zeit and K'one in the Rift Valley lava tubes and fissures were investigated. The outcrop of the limestones shown in Fig. 1 is based on the new 1:2 million scale geological map published by the Geological Survey of Ethiopia (1973).

An unpublished report (Morton, 1976) contains details and large scale sketch maps of the locations of the individual caves and potholes described here, and some cave surveys (mainly Grade 1). Copies are available from the author, and have been deposited with the Institute of Ethiopian Studies, the Library and the Geology Department at Addis Ababa University, and with the Geological Survey of Ethiopia.

The Bedenno Area

Bedenno is a small market town half a day's drive west of Haar, the final part of the journey being along a rough track suitable for trucks and cross country vehicles only. The town is situated at an altitude of about 2100 metres on a ridge which runs southwestwards from Gara Mulata, the highest mountain in Hararghe Province. Gara Mulata is made up of Tertiary Trap Series basalts underlain by Cretaceous sandstones, and Bedenno lies at the contact of these sandstones with the underlying Jurassic Limestones.

The uppermost layers of the limestone in this area are interbedded with marl and sandstone, and are characterised by the horizontal development of caves. One of these, Goda Fuafuate (Waterfall Cave) provides an excellent water supply for the town. The main limestone outcrop below the town exceeds 400 metres in thickness, and many potholes are developed in the upper 200 metres where the limestone is relatively massive. Below the limestone exposures of the basal Mesozoic sandstone and Precambrian schists and gneisses are seen in the deep valleys of the River Ramis and its tributaries to the west and south of the town.

Our group from Addis Ababa first visited Bedenno in August 1973. Goda Fuafuate, 1 km. ENE of the town was explored on the first day. This resurgence has a flow of several litres per second and is piped into the town. We were able to follow the stream passage for about 100 metres; at first it was rectangular in cross section and around 2 metres high and wide, but it progressively became tighter and the roof dropped close to water level. That night the tap water in town turned to a distinctly brownish tint! Despite this many local people came around the next day to show us more caves and potholes, and by the end of that trip we had investigated three caves and ten potholes. The other two caves were short. One was a rock shelter with an overhanging entrance 15 metres down a 50 metre high cliff; it had been used as a hideout during the Italian occupation (1935-41) by descending on a rope and swinging into the entrance. The other cave was developed in the base of the sandstone close to the town. It is about 40 metres long, and a tight squeeze leads to a chamber with stalagmite columns running up the walls to a height of over 5 metres.

The potholes were more exciting. The first visited, Enkoftu Hade Kure, 2 km. south of the town, is a 66 metre deep shaft about 10 metres across at the top. 60 metres of ladder were just sufficient to enable us to reach a boulder slope at the bottom by hanging off the last rung. This slope is at the side of a lofty chamber about 40 x 25 metres across. At the far side of the chamber is a deep pool some 15 metres wide with no outlet.

Enkoftu Dideesa, 1 km. ESE of the town, is 80 metres deep and is descended by four ladder pitches of about 20 metres each with narrow ledges between them. On the second ledge, 40 metres down in almost total darkness we made an interesting find. Lashed to a small stalagmite column was a length of tree creeper, broken off about 20 cm. from the end. We continued down to the bottom, half expecting to find a heap of bones, but found no further signs of this pioneer descent. It must have been done many years ago, as nobody in the village knew of it, and evidently they made a successful trip and returned safely to the surface.

We were puzzled by this flood as the entrance to the hole is on a ridge, and the side passages we had seen showed no signs of carrying such volumes of water. Yet we remembered that all the boulder slopes between the pitches in the upper part of the pot were thickly coated with mud at the sides, but washed clean down the middle. What had happened was that the farmers had diverted the drainage from their fields into the hole in order to avoid soil erosion further downslope. The party

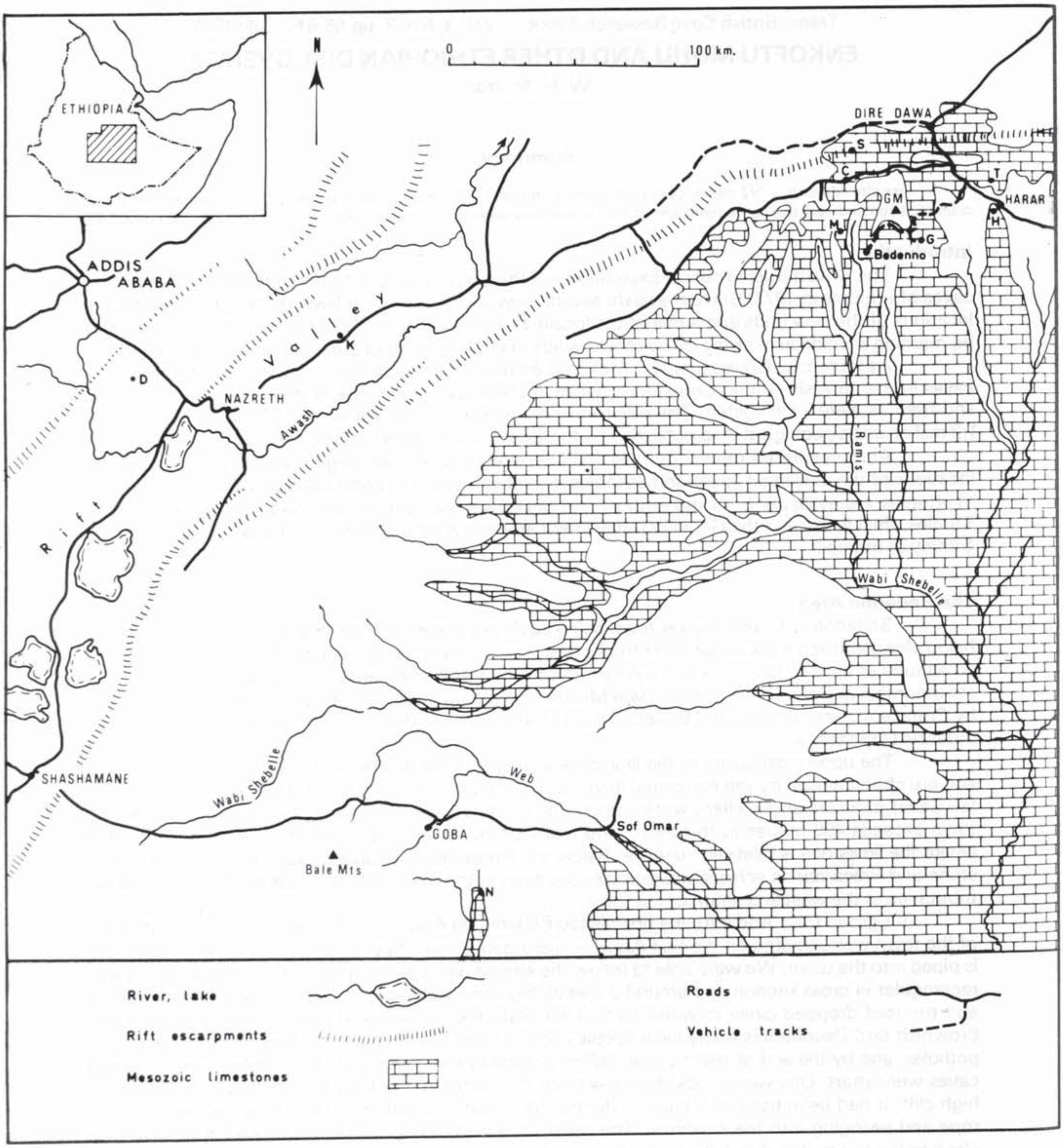


Fig. 1. Location map: caves and caving areas described in the B.S.E. report (1973) are identified as follows:
C = Chelenko; H = Gara Hakim; M = Muti; N = Nur Mohammed; S = Serkema; T = Tula.
Localities described herein for the first time:
D = Lava cave southwest of Debre Zeit; G = Grawa; K = K'one (Garibaldi);
GM = Gara Mulata mountain.

on the surface were also amazed at the volume of the torrent pouring in, and gallantly left their meagre shelter to block the ditches and divert the flow back down the main valley slopes. Hopefully the practice of draining water into the pothole can be stopped in the future, as backing up of flood-waters in a really heavy storm could spoil a lot of formations in Tingirt.

The side passages were not investigated in detail, and offer oppurtunities for further exploration. Mike's Passage, near the top of the third pitch, leads to a rift which is located above Tingirt. Perhaps a direct route down into this chamber awaits discovery. This passage also provides a good stalagmite column belay for the next three pitches.

Several people from the village made the trip down. This descent was livened up by several problems. On pitches a call for slack was invariably interpreted as "sarb" (pull) or vice versa and several versions of granny knots appeared on lifelines. One man, Seyoum, who described himself as a vagabond, made the entire trip barefoot!

Several other potholes near Bedenno were explored in 1975, including one 75 metres deep about 5 km. northeast of the town. A cave a short distance away from this hole proved to be about 250 metres long in the uppermost limestones. A stream in this cave with a flow of a few litres per minute runs over a bed of flowstones for about 50 metres near the upstream end of this cave. In all a total of four caves and sixteen potholes were investigated around Bedenno town during our visits there. All the potholes, apart from the four described above, are less than 50 metres deep. Many others are reputed to exist, especially on the long limestone ridges extending south from the town.

At Grawa, ENE of Bedenno (Fig. 1), several small potholes were investigated. The deepest was reputed to be 90 metres deep, but it proved to be a mere 25 metres.

While some or all of the caves in this region may be mainly developed under vadose conditions, the potholes all appear to be phreatically developed. Their location bears no relationship to surface drainage, and only in one, probably fortuitous, case was a shaft found in a small stream valley which was a sink for an ephemeral stream. The vadose downcutting of Yorkshire Channel in Enkoftu Mohu appears to be the only example of significant vadose development in an Ethiopian pothole discovered to date. These observations are in agreement with the findings of the British Speleological Expedition (1973) who concluded that the majority of Ethiopia's caves were of phreatic origin.

Bale Province

Sof Omar and Nur Mohammed caves were revisited (Fig. 1). Further investigations were made about 10 km. downstream of Sof Omar, near where a collapse feature over 100 metres across is clearly visible on aerial photographs to the south of the gorge of the River Web. It proved to be choked with basalt boulders at the bottom (the basalt forms a thin layer over the limestone in this area). We searched in the river gorge to the north but found only small caves and rock shelters; the local people also stated that there were no large caves known in the area.

At Nur Mohammed the pitch in the Far East beyond Guano Gallery was descended. It is about 8 metres deep as described by the B.S.E. (1973) and is covered with slimy mud and has no way on at the bottom. The behaviour of the bats in this part of the cave indicates that the end is near, instead of retreating ahead of a party they fly madly around in circles and escape by brushing past one back towards the entrance. Seeing this we decided not to battle further with the slimy guano to reach the undescended pitch in Sludge Row. The system is a large and complex one and there seems a good chance that further extensions will be discovered, but most probably not in the Guano Gallery - Far East series of the cave.

The Rift Valley

Two short lava caves have been found. One is in a basalt flow southwest of Debre Zeit, a town on the main road and railway southeast of Addis Ababa. This basalt flow, and the large cinder cone associated with it, is the youngest in the area, perhaps less than 100,000 years old. The cave is entered from the downslope end and can be followed for about 70 metres, past a small skylight in the roof and up a couple of ledges before it becomes too tight.

A second lava cave on the slopes of K'one volcano (often referred to by its Italian name "Garibaldi") is shorter but more interesting. An elliptical collapse pit about 30 x 20 metres across and 15 metres deep is choked by debris at the bottom. The walls of this pit are made of welded tuff (a volcanic ash welded by droplets of liquid lava) at the top underlain by a thin basalt lava flow and then an obsidian (black volcanic glass) flow. On the northern, upslope side of the collapse pit a cave entrance opened into the basalt, and one of the party immediately scrambled up and into it. He returned rather more quickly amid clouds of hornets, a not uncommon hazard of Ethiopian cave entrances. After burning all their little hanging paper nests we entered and followed a narrow lava tube gently upwards for 20 metres to the edge of a second large collapse pit which had not penetrated up through the welded tuff to the surface. This pit was some 20 metres across and about the same depth, and partly filled wilth a cone of debris and bat guano which was banked up on our side to leave a ladder pitch of 12 metres down a very loose rockface. As we descended this we passed down out of the basalt layer into the underlying obsidian and then down into volcanic agglomerate, the product of an explosive eruption. From the bottom of the pitch a passage led back downwards to the south into the top of another basalt lava flow. It seems likely that a large cave in this lower flow had collapsed at two points, revealing the small cave in the upper basalt flow at the same time. Unfortunately the cone of debris has blocked any passage which may have led into this lower cave.

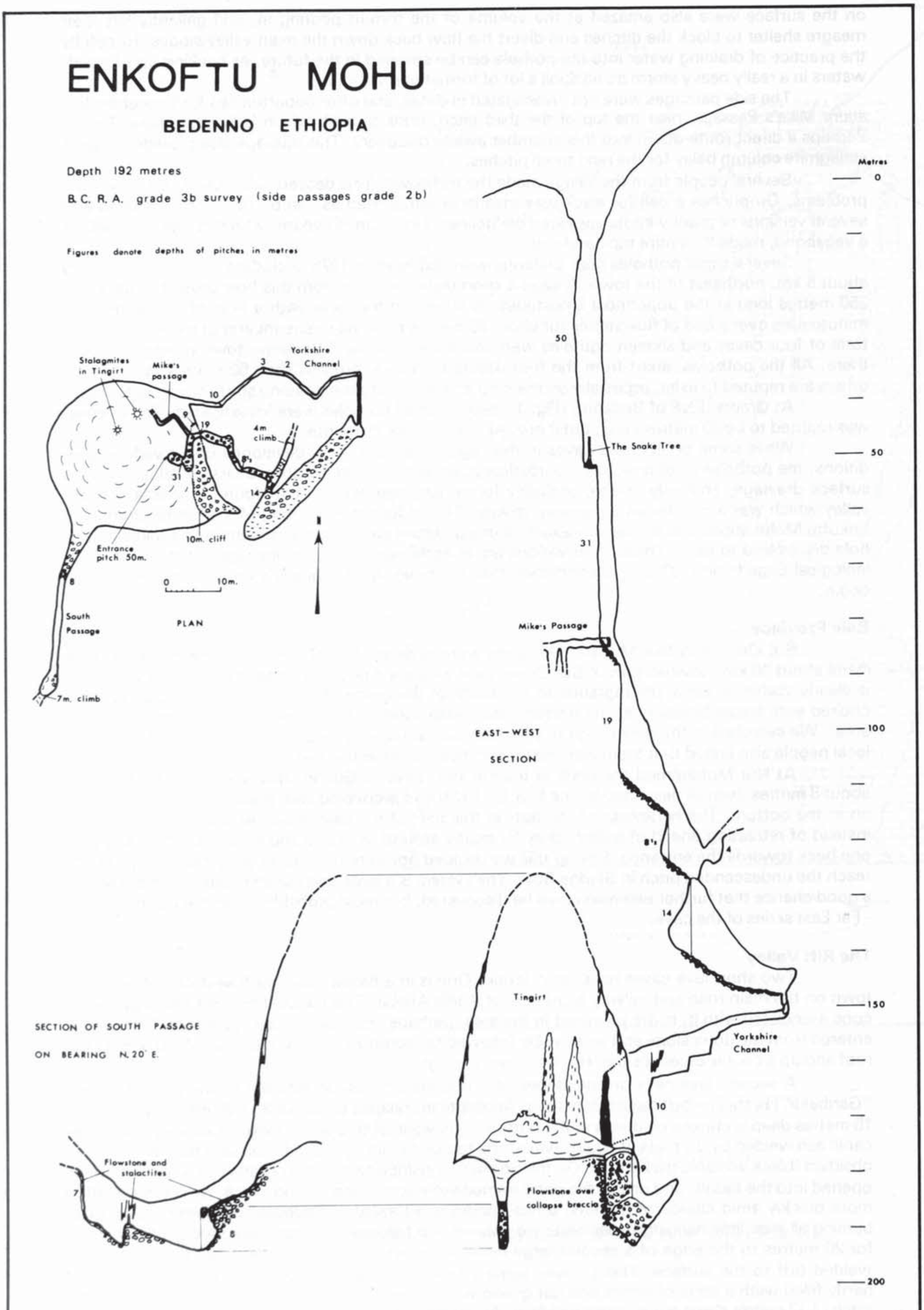
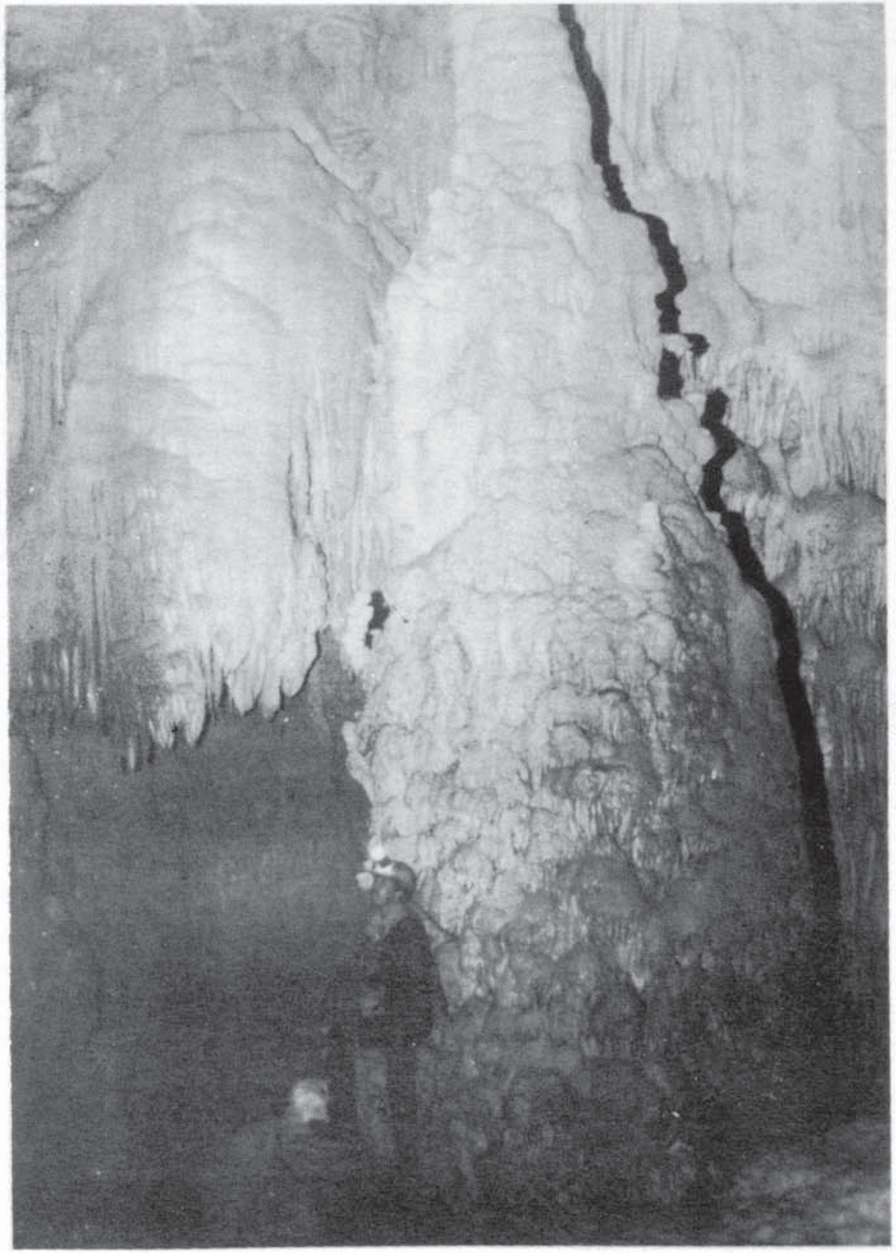

ENKOFTU MOHU
BEDENNO ETHIOPIA
Depth 192 metres
B.C.R.A. grade 3b survey (side passages grade 2b)
Figures denote depths of pitches in metres
Stalagmites in Tingirt
Mike's passage
Yorkshire Channel
3
2
10
9
19
4m climb
8's
31
14
10m. cliff
Entrance pitch 50m.
0
10m.
8
South Passage
PLAN
7m. climb
Metres
0
50
100
150
200
50
The Snake Tree
31
Mike's Passage
19
EAST—WEST SECTION
8's
4
14
Tingirt
Yorkshire Channel
10
9
Flowstone over collapse breccia
SECTION OF SOUTH PASSAGE
ON BEARING N.20°E.
Flowstone and stalactites
7
8

Fig. 2.

1. The 13 metre column.
Tingirt.



2. The 8 metre stalagmite and East Wall,
Tingirt.

At the bottom of Enkoftu Dideesa is a chamber around 20 x 30 metres across with a mud floor and a fine display of stalactites and flowstone decorating the roof and walls. The cave is relatively dry however, and the formations are inactive at present.

About 1½ km. north of the town we found the deepest hole, named at that time Enkoftu Amadi, after the owner of the land. A pitch of 50 m brought us to a small ledge, inhabited by a snake and a tree growing part way up the shaft. The tree was, of course, dead and closer examination showed that it was upside down, and must have fallen in such a way that the trunk was left pointing vertically upwards supported by the broken ends of three branches embedded in the boulders on the ledge. The snake was very much alive after its long fall, but it showed little interest in us and obligingly hid in a crevice amongst the boulders. The next pitch is 31 metres leading to a sloping passage down over boulders to the head of the third pitch.

Unfortunately we only had 60 metres of ladders at that time, and even the descent of the second pitch had entailed lowering them further down from the surface. We had no means of descending the third pitch. It was not until 1975 that we returned armed with 160 metres of ladders to complete the descent. In the meantime the Ethiopian Revolution had given the peasant farmers their land, and it was hardly appropriate to name the country's deepest hole after a feudal landlord. It was renamed Enkoftu Mohu (Victory Pot) after completing the exploration and survey (Fig. 2).

Three further pitches were descended in rapid succession to a chamber 140 metres down. At the far end of this chamber a small climb leads down into a narrow passage with a trickle of water along the bottom. This part of the cave is narrow and winding, with an apparently vadose trench incised down from a wider section at roof level, in marked contrast to the succession of wide chambers and pitches above. It was named Yorkshire Channel. It leads on past a couple of 2 metre drops to the head of a 10 metre pitch, with stalactites above. A few metres from the bottom of the pitch the passage abruptly leads into a magnificent chamber 30 metres across and at least 40 metres high. The floor is a great mound of creamy white flowstone from which rise fluted stalagmites as much as 13 metres high (Plate 1). Some of the smaller formations have unusual shapes. Cerberus - the dog monster of Hades - (Cover picture) is a unique overhanging formation whose development is difficult to explain. Some of the other columns have enlarged tops with small pools of water in them, and there are other small pools on the top of the flowstone mound. Some of these pools contain cave pearls up to 2 cm. in diameter, dripping water from stalactites high up in the roof presumably agitates the water in the pools sufficiently for their growth. Not only are the formations in this chamber by far the largest and finest in the country, they are the only major active formations so far discovered. This chamber and its formations made a deep impression on the Ethiopian cavers, some of whom had never seen formations more than a few centimetres long before. It was decided to name the place Tingirt, meaning fantastic or unbelievable.

The great mound of flowstone overlies a cone of collapse breccia, which is exposed in a large pit on the east side of the chamber. The small trickle of water from the Yorkshire Channel sinks before it reaches Tingirt, but the stream bed continues around the east side of the mound and down a 9 metre pitch into this pit, whose west wall and floor are made of the collapse breccia capped by the flowstone layer. The bottom of this pit, at 192 metres depth, is the end of the pothole, although the same depth is reached by descending an 8 metre pitch in a passage leading off Tingirt to the south. The pit appears to be a collapse feature suggesting the existence of further passages below, and we were suddenly presented with dramatic evidence that further extensions must exist beyond the boulder choke at the bottom. A noise like distant thunder was followed by a torrent of brown water as a flash flood roared out of Yorkshire Channel, with a flow of perhaps as much as half a cubic metre of water per second. This was readily absorbed by the boulder choke, although a muddy tide mark around the base of the flowstone mound indicated that some earlier floods had backed up, completely filling the pit with water.

The area south of K'one is cut by several geologically recent NNE trending normal faults, which belong to the active Rift Valley fault system. Where faults of this type cross massive flows of welded tuff with widely spaced vertical joints, deep fissures are often formed as described in the B.S.E. report (1973), and several such fissures occur here. Two of them, both a short distance southeast of the main road, are of particular interest. At both localities the welded tuff is covered by 3 to 5 metres of unconsolidated volcanic ash and soil, and large eroded areas have developed with internal drainage down the fissures which have engulfed several thousand cubic metres of soil. The whole area is underlain by highly permeable volcanic rocks and is high above the water table, so that there is no nearby resurgence; most probably the soil and sediment is dispersed into the joints and cavities of the rocks. One of the fissures was descended to a depth of 36 metres, the deepest in Ethiopia, and others in the same area to depths of 20 to 28 metres. It was not possible to follow them laterally for more than a few tens of metres before being stopped by boulder chokes.

Ethiopian Caving Potential

Present experience confirms the opinion expressed by the British Speleological Expedition (1973) that the more northerly outcrops of the Jurassic limestones in Tigre and the Blue Nile gorges are relatively unpromising, and that it is the southeastern outcrop, shown in Fig.1, which has the greatest potential. The limestones are up to 1000 metres thick locally, but this thickness includes many marl and clay layers, and the chance of any system extending from the top to the bottom of the limestones is virtually nil. Nevertheless the discovery of the Bedenno potholes does indicate a much greater depth potential than previously thought, and provides a range of cave phenomena unmatched elsewhere in the country. There still remain, of course, large areas of country awaiting investigation.

M.S. Received May 1976

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The Use of Optical Brighteners for Water Tracing

by P.L. Smart

Summary

Optical brighteners are colourless blue fluorescent dyes which adsorb strongly on cellulose. Their use as quantitative tracers using fluorometric detection is severely limited by a high photochemical decay rate and strong adsorption on organic matter. The blue fluorescent dye Amino G Acid is more suitable for quantitative work. However, in conjunction with cotton wool detectors, optical brighteners provide a useful tracer. A method for determining detector fluorescence is described, and controls on the detection of the optical brightener are discussed in relation to field and laboratory experiments. Bleached calico is found to be a better detector material than cotton wool. Stilbene-based optical brighteners have a very low toxicity to both man and aquatic organisms, and therefore do not cause any hazard in their use as water tracers.

Optical brighteners (or fluorescent whitening agents) are fluorescent dyes which absorb light in the ultra-violet region of the spectrum, and are therefore colourless in solution. They are synthetic dyes of the 'Direct' type and have a strong affinity for cellulose fibres, including cotton, wool and man-made fibres. The major use of optical brighteners is in the textile and paper industries (Furvik, 1973; Lindvall, 1973), where they are added to produce bluer shades of white in off-white products. Domestic detergents also contain brighteners which counteract the yellowing and soiling which occurs in textiles with use. Only 20 chemically different optical brighteners have significant usage in the detergent industry out of some 200 available chemical types (Stensby, 1967), though other brighteners are used in the paper and plastics industries. Approximately 80% of the brighteners used are derived from stilbene, and about one third of world production comprises compounds of the group, 4,4'-bis-(triazinylamino)stilbene-2,2'-disulphonic acid (Furvik, 1973).

In 1970 Crabtree carried out several experiments with the optical brightener Leucophor BS (CI Fluorescent Brightener 49, Sandoz Products Ltd., Leeds) as a water tracer, after earlier suggestions by Glover. Although it was originally intended to use these compounds with activated carbon, in a similar manner to Fluorescein (Drew and Smith, 1969), the high affinity of optical brighteners to cellulose suggested that cotton might make a suitable detector medium. It was found in laboratory experiments that cotton-wool treated for several minutes with 0.1 $\mu g\ l^{-1}$ brightener solution exhibited a characteristic blue fluorescence when examined under ultra-violet light. Furthermore, the fluorescence remained detectable on the cotton-wool after washing for 24 hours in a stream of tap water. Field experiments proved that Leucophor BS in conjuction with cotton wool detectors gave a reliable and cheap method of water tracing, which had the additional advantage of producing no visible coloration. However problems were encountered due to contamination of the detectors from the previously brightened nylon fabric used to contain the cotton wool, and from gross contamination (Crabtree 1970 and 1971).

Further field experiments were summarised by Glover (1972) who concluded that the method was successful, but suggested that further work was required to investigate the persistence of the tracer, and the possibility of fluorometric detection. Gascoyne (1974) reported successful traces in Venezuela with Leucophor BS and also another optical brightener, Leucophor C (CI Fluorescent Brightener 232). However, after the failure of three tests using Leucophor C, he concluded that Leucophor BS was the more satisfactory tracer due to its lower adsorption on naturally occurring cellulose. Leucophor BS and Leucophor C are now no longer available from Sandoz Ltd. though similar products are marketed by a number of firms (Colour Index 3rd ed.).Recently Quinlan (pers comm 1975) has used Calcofluor White ST (CI Fluorescent Brightener 28, CI No.40622) in conjunction with cotton wool detectors successfully to trace connections up to 16 km long in the Kentucky Karst, USA.

The purpose of this study was three fold:-

(1) to investigate the use of optical brighteners for quantitative tracer studies using fluorometric detection.
(2) to develop the cotton-wool detector system.
(3) to assess the toxicity of optical brighteners.

(A) Use of Optical Brighteners as Quantitative Tracers.

All of the optical brighteners discussed in this paper are 4,4'-bis-(triazinylamino)-stilbene-2,2'-disulphonic acids, the general formula of which is given in Fig.1. The substitutes X and R are not known for any of the brighteners studied, but X is normally a hydrogen atom and R an amine group (Zweidler, 1968). Table 1 summarises the information available on each of the brighteners studied, including Colour Index Number, Alternative Names and Manufacturers, and form of the commercial product.

Table 1. Colour Index Numbers, Alternative Names and Manufacturers, and Form of Optical Brighteners Studied.

Name	*Colour Index Number*[1]	*Alternative Name*	*Manufacturer*[2]	*Form of Commercial Product*
Photine CU	15		H & W	20% solution in urea with ethanolamine
		Photine UC	H & W	Undiluted powder
		Photine C	H & W	Powder[3]
Photine CSP	—		H & W	Approx. 40% powder with sodium chloride
Fluolite BW	49		ICI	Powder[3]
		Leucophor BS	S	25% Solution[3]
		Leucophor B	S	Powder[3]
Leucophor C	C		S	25% solution[3]
		Leucophor CK	S	Powder[3]

Notes: 1 The Colour Index Number refers to the Third Edition of the Colour Index and should be prefixed by C.I. Fluorescent Brightener Number in any description.

2 H & W Hickson and Welch Ltd., Castleford, Yorks, UK.
S Sandoz Products Ltd., Leeds, UK.
ICI Imperial Chemical Industries Ltd., Manchester, UK.

3 Additives and diluents not disclosed by manufacturer.

1) Excitation and Emission Spectra

The excitation and emission spectra of all the brighteners were determined using an Aminco Bowman Ratio Spectro-fluorometer (American Instrument Company, Silver Spring, Maryland, U.S.A.). The products were diluted to a known concentration in both distilled water and BDH buffer solutions of pH 4.0, 7.0 and 9.0 (BDH Chemicals Ltd., Poole, Dorset, U K). The spectra are shown in Fig. 2. The maximum excitation varied from 345 nm. for Photine CU to 355 nm. for Fluolite BW, which had an identical spectra to Leucophor BS. Both the Leucophor brighteners showed a secondary peak at 290 nm. and Photine CSP had a secondary peak at 250 nm. The maximum emission varied from 435 nm. for Fluolite BW to 455 nm. for Photine CSP.

All the brighteners showed reduced emission at pH 4.0 compared with that at pH 7.0 and 9.0, but the emission spectra did not change in shape. The excitation spectra of Fluolite BW and Leucophor C changed slightly with pH, the secondary maximum at 290 nm being absent at pH 4.0. There were no changes with pH for the other optical brighteners.

Using the excitation and emission curves for the dyes, primary and secondary filters were selected for a Turner 111 filter fluorometer (G.K. Turner Ltd., Palo Alto, California, USA), equipped with the far-ultra-violet light source (General Electric Company Ltd., G4T4.1). This particular source has several advantages in terms of reduced background, good sensitivity and general application (see discussion in Smart and Laidlaw, 1976). The primary filter, a Corning 7-37, has maximum transmission at the 365 nm mercury line, which is close to the excitation peak of the optical brighteners. The secondary filter, a Kodak Wratten 98, has peak transmission at 435 nm, which is slightly shorter than the optimum, but has proved to be quite satisfactory. Furthermore it exhibits a sharp cut-off at 490 nm which is necessary where these dyes are to be used in conjunction with green fluorescent dyes, for instance fluorescein.

The minimum sensitivity using this filter combination is about 0.2 $\mu g\, l^{-1}$ per scale unit on the most sensitive fluorometer scale. It is similar for all three brighteners and gives a minimum detectability of 0.36 $\mu g\, l^{-1}$ in distilled water. This figure is based on the stated concentrations of the commercial product and may vary considerably between batches and manufacturers.

2) Effect of pH

Fig.3 illustrates the effect of pH changes on the fluorescence of the optical brighteners. Fluorescence was measured on the filter fluorometer using the 7-37 and 98 filters, and the solution pH was adjusted with BDH buffer solutions, nitric acid and sodium hydroxide. Photine CU and Photine CSP are not seriously affected by pH variations between pH 6.0 and 9.0, though Photine CU shows a gradual reduction of fluorescence below pH 7.5. The fluorescence of Fluolite BW falls rapidly as the pH is reduced below pH 7.0.

3) Effect of Temperature

Fluorescence is normally inversely dependent on temperature, and in quantitative applications it may be necessary to apply temperature corrections to dye concentration values (Wilson, 1968). Experimental data, comprising fluorescence readings at a number of different temperatures, were fitted by a curve of the term:

$$F = F_o \exp^{-nt}$$

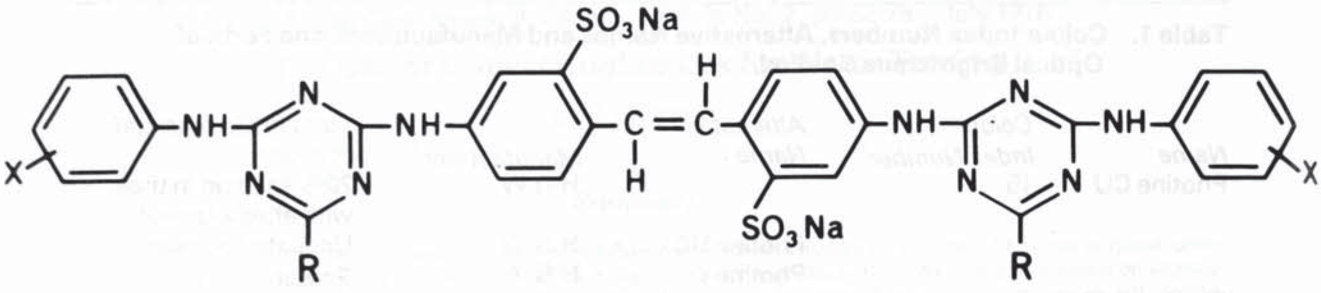

Fig.1 General formula of Stilbene Triazine optical brighteners

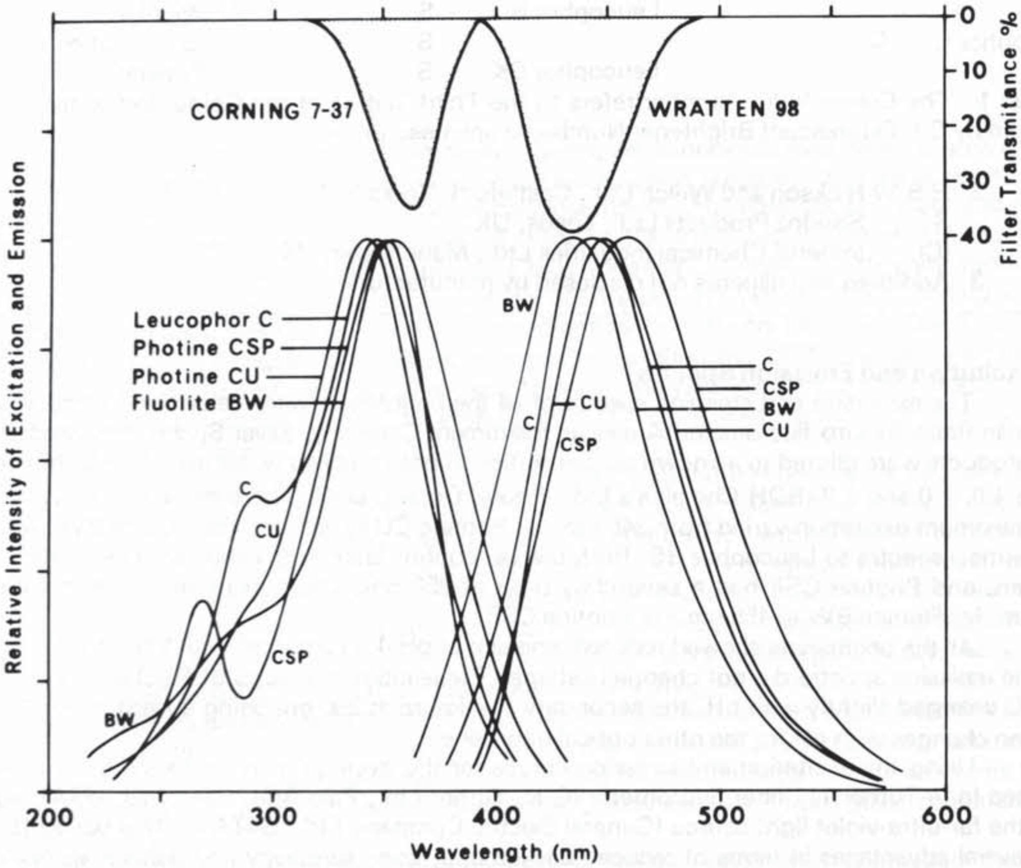

Fig.2 Excitation and emission spectra of the optical brighteners and characteristics of the primary and secondary filters (shaded)

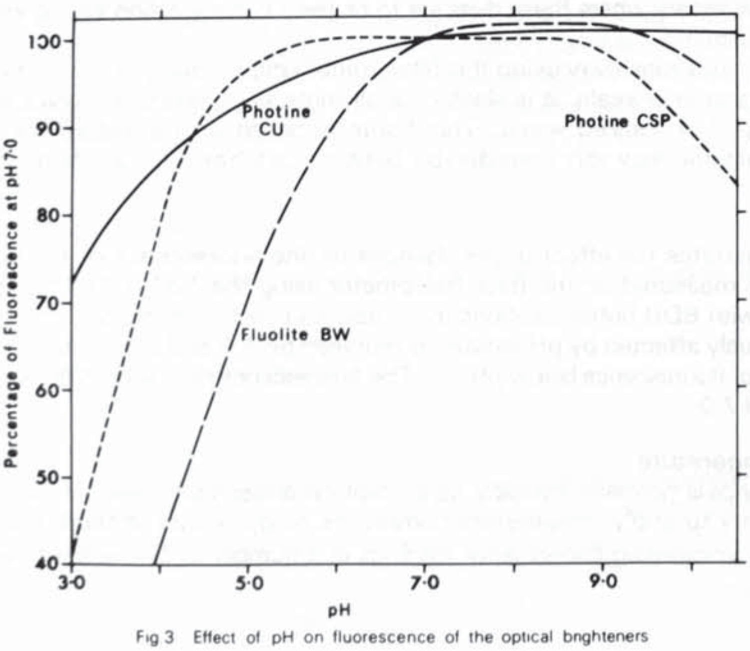

Fig 3 Effect of pH on fluorescence of the optical brighteners

where F is fluorescence at temperature t, F_0 is fluorescence at 0^0C and n is a constant for a given dye. The exponents for Fluolite BW, Photine CU and Photine CSP are given in Table 2. Photine CSP has the largest variation of fluorescence with temperature and Fluolite BW the smallest, but these values are lower than for rhodamine dyes, for instance 0.027 for Rhodamine B (Feurstein and Selleck, 1963).

Table 2. Temperature Correction Curve Constants for the Optical Brighteners.

Optical Brightener	*Constant*
Photine CU	0.012
Photine CSP	0.013
Fluolite BW	0.011

4) Effect of Water Quality

Experiments with Photine CU have shown that sodium chloride at concentrations of 0.5M and 0.1M causes no detectable decrease in fluorescence (Smart and Laidlaw, 1976). However, stilbene triazine brighteners are known to be affected by contact with iron and copper and it is therefore unlikely that these dyes would prove reliable in streams containing much iron. Table 3 presents comparative fluorescence values for several concentrations of Photine CU to which clean and iron stained detectors had been added (see below). It is clear that the fluorescence of the solutions which had been in contact with iron stains for 24 hours was much lower than for the control samples. The percentage decrease in fluorescence is probably influenced by competitive effects with adsorption on the detector at low dye concentrations. The average decrease for initial concentrations greater than 10 $\mu g\ l^{-1}$ was 63.5%. Further work is clearly needed on this effect because iron is a fairly common minor constituent of many natural waters.

Table 3. Fluorescence of Photine CU solutions after Contact with Iron Stained and Clean Detectors.

Initial Solution Concentration $\mu g\ l^{-1}$	*Final Reading* *Clean*	*Final Reading* *Iron Stained*	*Percentage Decrease*
200	69 x IND	21 x IND	65.4
100	77 x 3ND	31 x 3ND	59.7
50.0	80 x 1	27 x 1	66.2
10.0	62 x 3	24 x 3	62.5
5.00	58 x 10	37 x 10	36.3
1.00	40 x 10	27 x 10	32.5
0.50	39 x 10	23 x 10	41.1

5) Adsorption

Adsorption of the optical brighteners has been studied in batch systems. A known weight of adsorbant material was shaken with a measured volume of dye solution of known concentration until an equilibrium was established (normally after one day). Blanks were run to permit subtraction of background fluorescence caused by the adsorbents, particularly significant in the case of organic materials, and to correct for any non-adsorptive sources of dye loss. All experimental flasks were kept in the dark and the solutions prepared in a dimly lit room. Table 4 presents the results of a run using an initial solution concentration of $1 \times 10^4 \mu g\ l^{-1}$Photine CSP, and a number of sediments at three concentrations. The inorganic sediments kaolin (pure kàolinite $Al_2Si_2O_5 . (OH)_4$), orthoquartzite (100% quartz) and limestone (99% calcium carbonate) are comparable in the amount of adsorption at the three concentrations. However, the bentonite (a low silica member of the montmorillonite series) causes significantly higher losses, similar to those obtained for the humus and heather roots. Optical brighteners are designed with a high affinity to cellulose to enable them to bond onto textile fibres, therefore it is not surprising that they are adsorbed more on natural organic materials than on inorganic surfaces. The high adsorption on the bentonite may be due to the expanding nature of montmorillonite clays which permits greater adsorption of organic molecules than occurs in the fixed-layer clays such as kaolinite.

Fig.4 presents data for the adsorption of Photine CU from a solution of $1 \times 10^2 \mu g\ l^{-1}$initial concentration (data from Smart and Laidlaw, 1976). The kaolin and humus used in the experiment were identical to those used in the previous experiment, however the initial dye concentration was much lower. The results were obtained under different conditions and cannot therefore be compared directly. In general, adsorption from dilute solutions is greater in percentage terms than from concentrated solutions, although the dye mass adsorbed is in fact lower. As in the case of Photine CSP, Photine CU is adsorbed more on humus than on kaolin. The green fluorescent dye fluorescein, for which data is also presented, is adsorbed to a similar extent on the humus, but to a greater extent on the kaolin. Similarly Amino G Acid, a blue fluorescent dye which shows comparable adsorption to Photine CU on kaolin, is only about half as susceptible to adsorption on humus. These results again indicate the significance of organic sediments in causing dye losses by adsorption.

Complete comparisons of the adsorption resistance of the optical brighteners have not

Table 4. Comparison of Adsorption of Photine CSP on Different Sediments

Sediment Type	*Percentage of Initial Fluorescence*		
Sediment Concentration g l^{-1}	*10.0*	*2.0*	*0.4*
Kaolin	88	—	100
Limestone	80	98	100
Orthoquartzite	80	88	100
Bentonite	58	—	97
Humus	65	81	94
Heather Roots	50	84	97
Average for Inorganic Sediments (Excluding Bentonite)	83	93	100
Average for Organic Sediments	63	83	96

Initial Solution Concentration 1×10^4 μg l^{-1}

been completed, however some preliminary results are available (Table 5). These show that Photine CSP is adsorbed the least and Fluolite BW the most. The differences are however relatively small, compared for instance, with the differences between the different dyes. Thus it is thought that in practical terms there will be relatively little difference in the behaviour of the brighteners, as would be expected given the similarity of their basic chemical structure.

Table 5. Comparison of Adsorption of Optical Brighteners on Kaolin and Humus.

Optical Brightener	*Percentage of Initial Fluorescence*	
	Kaolin	*Humus*
Photine CU	72	23
Photine CSP	78	34
Fluolite BW	72	19

Initial Solution Concentration 1×10^2 μg l^{-1}.
Kaolin Concentration 6 g l^{-1}.
Humus Concentration 2 g l^{-1}.

6) Photochemical Decay

During initial laboratory experiments, it became evident that the optical brighteners were not stable to light, and decayed rapidly under artificial illumination and whilst irradiated with ultra-violet light in the sample compartment of the fluorometer. Dilute solutions decayed the most rapidly (Fig.5), probably because at high concentrations the solution acts as a filter such that molecules in the bulk of the liquid are effectively shielded from the incident light by the high adsorption near the surface. This effect will be less marked in stirred solutions. For Photine CU the critical concentration below which photochemical decay is relatively rapid is between 1×10^5 and 1×10^6 μg l^{-1}.

Table 6 presents the results of a comparative test on the photochemical decay of the optical brighteners. Pyrex glass conical flasks containing 50 ml. of 100 μg l^{-1} solution were exposed in a North facing window on a cloudy day for 12.5 hours. Photine CSP and CU have comparable decay rates, but Fluolite BW has a significantly lower rate. Smart and Laidlaw (1976) gave environmental decay coefficients (half absolute rates to correct for 12 hours of darkness per day) of 5.5×10^{-2} for Photine CU compared with 1.3×10^{-2} for fluorescein and 1.5×10^{-4} for the more stable Rhodamine B. Thus optical brighteners in general decay at a rate about four times that of fluorescein, which is generally recognised to be a poor tracer under daylight conditions.

Table 6. Comparison of Photochemical Decay Rates for the Optical Brighteners in Daylight.

Optical Brightener	*Initial Fluorescence*	*Decay Coefficient*[1]
Photine CU	21	0.056
Photine CSP	16	0.064
Fluolite BW	41	0.031

Notes: 1 For an exponential decay form $F = F_i \exp^{-kt}$ where F_i is initial fluorescence at time t and k is decay coefficient.

The reduction in fluorescence with exposure to light is caused by an isomeric change in the stilbene molecule from a planar TRANS form to the non-planar CIS form (Lanter, 1966; Stensby, 1967). Absorption of light raises the molecules to a high energy state in which the TRANS stilbene double bond is converted into radicals. Rotation of the stilbene phenyl rings occurs and the more stable CIS form of the molecule is formed. This change reduces the conjugation of the stilbene phenyl rings which no longer adsorb light to a significant extent at 350 nm. Consequently the phenylamino groups are now the most important portion of the molecule for light absorption and the maximum shifts to 270 nm. Furthermore, resonance in the molecule is greatly reduced thus inhibiting the conversion of absorbed energy into fluorescence. These changes depend on the total energy of the incident light and therefore photochemical decay rates will depend on light intensity and wave-

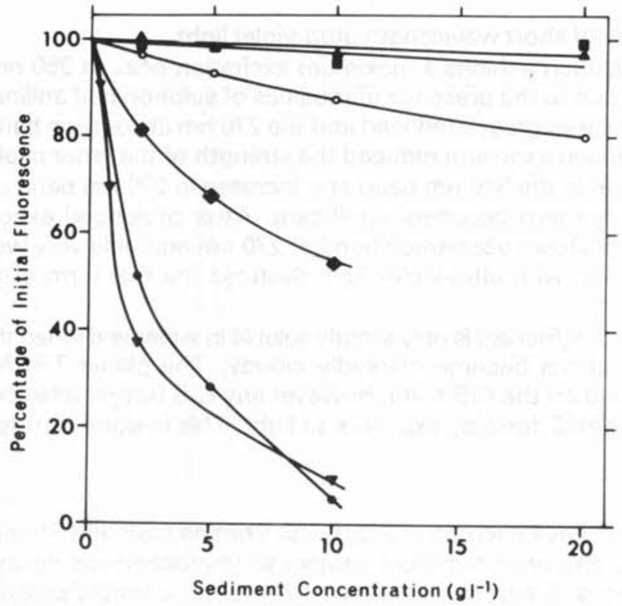

Fig.4 Adsorption of dyes on Kaolin and Humus, initial solution concentration 100µg l⁻¹

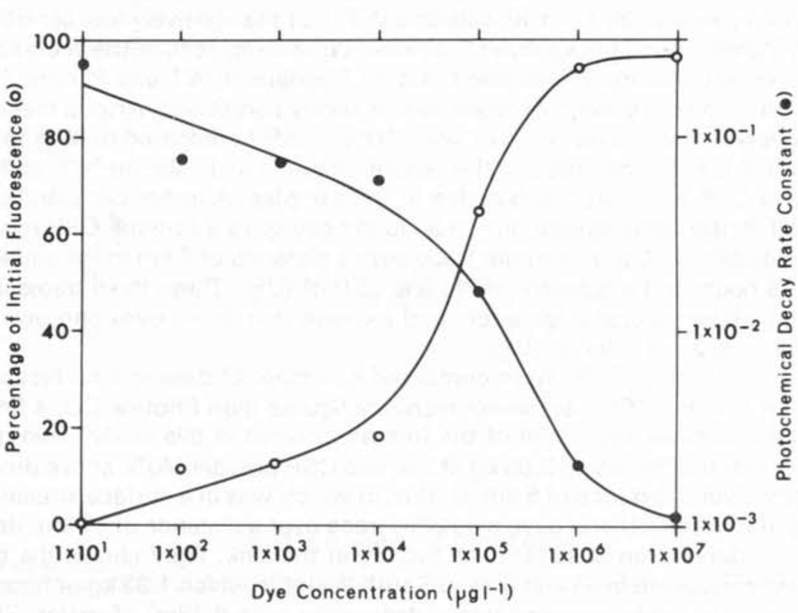

Fig.5 Effect of dye concentration on photochemical decay of Photine CU in daylight. Exposure for 12.3 hours. Rate constant for exponential decay

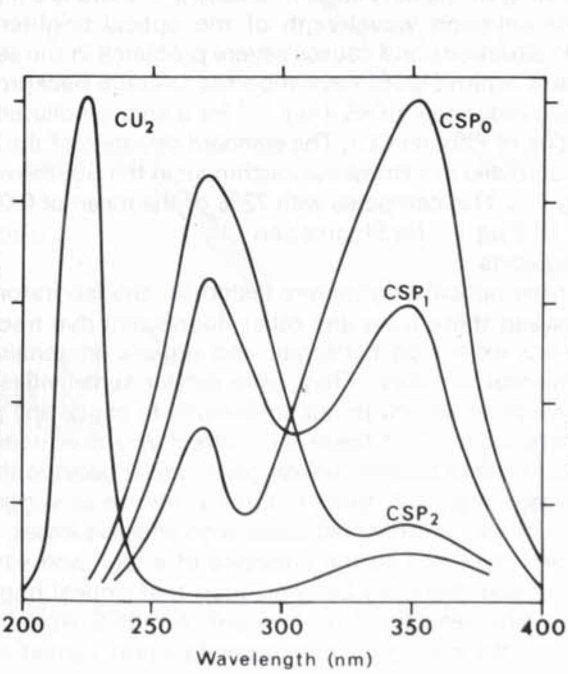

Fig.6 Excitation spectra of Photine CSP and Photine CU after exposure to daylight

length, in particular the proportion of short wavelength ultra-violet light.

Photine CSP in fresh solution exhibits a maximum excitation peak at 350 nm. but there is also a secondary peak at 270 nm due to the presence of moieties of sulphonated aniline (Fig.6). After exposure to daylight, fluorescence was greatly reduced and the 270 nm absorption band was equal in strength to that at 350 nm. Continued exposure reduced the strength of the latter peak even further. Photine CU also shows a reduction in the 340 nm band and increase in 270 nm band on exposure to light, but a further band at 225 nm also becomes significant. After prolonged exposure the peak excitation is at 225 nm with no significant absorption band at 270 nm and only very weak absorption at 350 nm (Fig.6). Further irridiation with ultra-violet light destroys the CIS form of the Brightener completely.

The CIS form of stilbene brighteners is only slightly soluble in water and when the TRANS/CIS change occurs concentrated solutions become markedly cloudy. The planar TRANS form has a much greater affinity for cellulose than the CIS form, however any CIS isomer adsorbed will be converted back to the fluorescent TRANS form by exposure to light. This is significant for tracing work using cotton-wool detectors.

7) Field Trials

A number of experiments have been carried out with Photine CSP and Photine CU; several of these were in surface streams and were therefore subject to photochemical decay which would not occur in underground situations. Smart and Laidlaw (1976) report a simple experiment in which 50 mg of several fluorescent dyes were injected into a small peaty stream. The recovery of Photine CU was 27% compared to 86% for Rhodamine WT, but the relatively low sensitivity of Photine CU and the much higher natural background fluorescence severely reduce the accuracy of determination of the brightener. A comparison between the dyes Rhodamine WT and Photine CSP was made in a small stream with a heavy growth of weed, under sunny conditions. After a mean residence time of 3.5 hours recovery of the Rhodamine WT was 100% ($\mp$5%) compared to 30% for the Photine CSP. After a further 7.4 hours in the stream, the recovery figures had fallen to 98% and 11% respectively, and the Photine CSP was barely detectable in the samples. Another comparative experiment with Rhodamine WT in the same stream but on a cloudy day gave a Photine CSP recovery of 70% after 3 hours mean residence. A groundwater trace over a distance of 3 km in the same area gave a mean travel time of 18 hours and a recovery of Photine CSP of 80%. These three traces illustrate the severe photosensitivity of the optical brighteners and indicate that these dyes can only be considered for quantitative use in groundwater tracing.

Smart and Smith (1976) have compared a number of dyes in a surface stream in Jamaica. They found that Photine CSP gave lower recovery figures than Photine CU, a finding supported by the higher photochemical decay rate of the former reported in this study. Two groundwater traces were also reported, the first using 2.90 kg of Photine CSP powder (40% active product) which gave a recovery of 45% over a distance of 5 km, 0.5 km of which was in a surface stream. The second trace utilised 2.2 kg of Photine CU and gave a positive trace over a distance of 11 km, despite the presence of much organic debris from a sugar cane factory in the sink. Fig.7 shows the time/concentration curves for a test conducted in a karst area in South Wales in which 1.93 kg of fluorescein and 1.90 kg Photine CU were washed into a depression with 6.38m^3 of water. The dyes were both recovered at a major karst spring 1.6 km distant and gave low but similar recoveries of 31% and 35% respectively. The large losses were probably due to storage of injected water in the aquifer.

Probably the most significant finding of the field experiments is that there is a high and very variable background fluorescence at the emission wavelength of the optical brighteners, which significantly reduces the sensitivity in field situations and causes severe problems in the separation of the dye from background levels.Smart and Smith (1976) have reported average background values ranging from 1.2 μg l^{-1} for unpolluted groundwaters to 85.4 μg l^{-1} for a spring polluted by bauxite effluent (expressed as apparent concentration of Photine CU). The standard deviation of the background fluorescence values for 203 water samples collected in a limestone catchment in the Southern Cotswolds, UK., was 47% of the mean value of 45 μg l^{-1}. This compares with 73% of the mean of 0.06 μg l^{-1} for Rhodamine WT and 39% of the mean of 18.5 μg l^{-1} for Fluorescien.

8) Quantitative Applications — Conclusions

The differences between the three optical brighteners tested in the laboratory were not large compared with the differences between these dyes and other fluorescent dye tracers. All the brighteners were adsorbed to a significant extent on bentonite and organic materials, but were reasonably resistant to adsorption on mineral surfaces. They gave similar sensitivities in distilled water and were affected by pH and temperature, although not sufficiently to cause any problems in karst waters. However the extreme photosensitivity of these dyes effectively precludes their application as quantitative tracers even for groundwater studies, unless great care is taken in the collection and analysis of the samples. Even if this was practical, there is some evidence to suggest that the brighteners may be sensitive to the presence of iron which would cause large effective losses. Finally there is a major problem with all blue fluorescent dyes due to the presence of a high and variable background fluorescence at this waveband. It must therefore be concluded that optical brighteners are not a practical water tracer where fluorometric detection is to be used. Amino G Acid may be used where a blue fluorescent dye is necessary for the tracing of three separate inputs (Smart and Laidlaw, 1976).

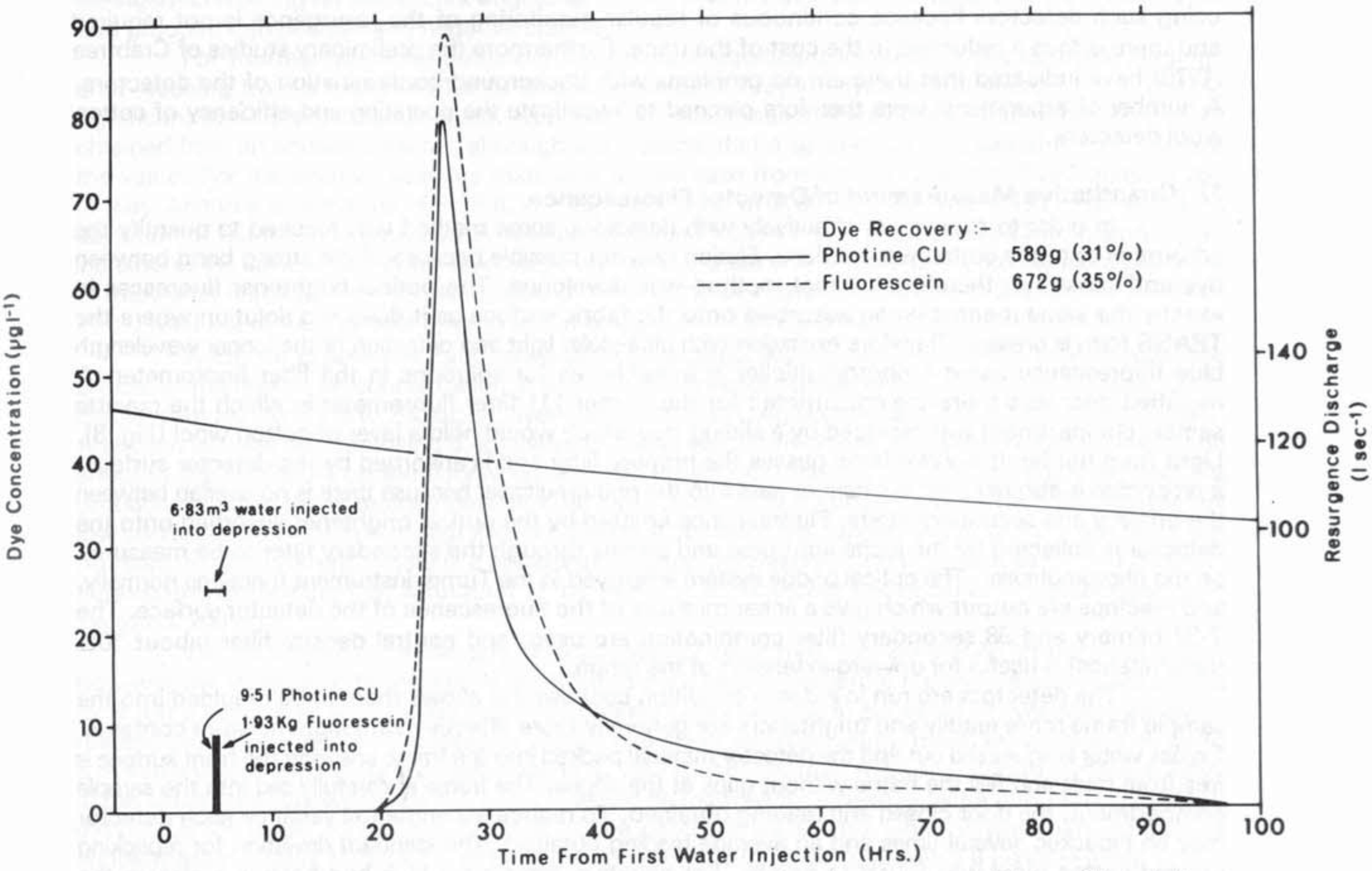

Fig.7 Comparison of time/concentration curves for a dye test from a surface depression using Photine CU and Fluorescein

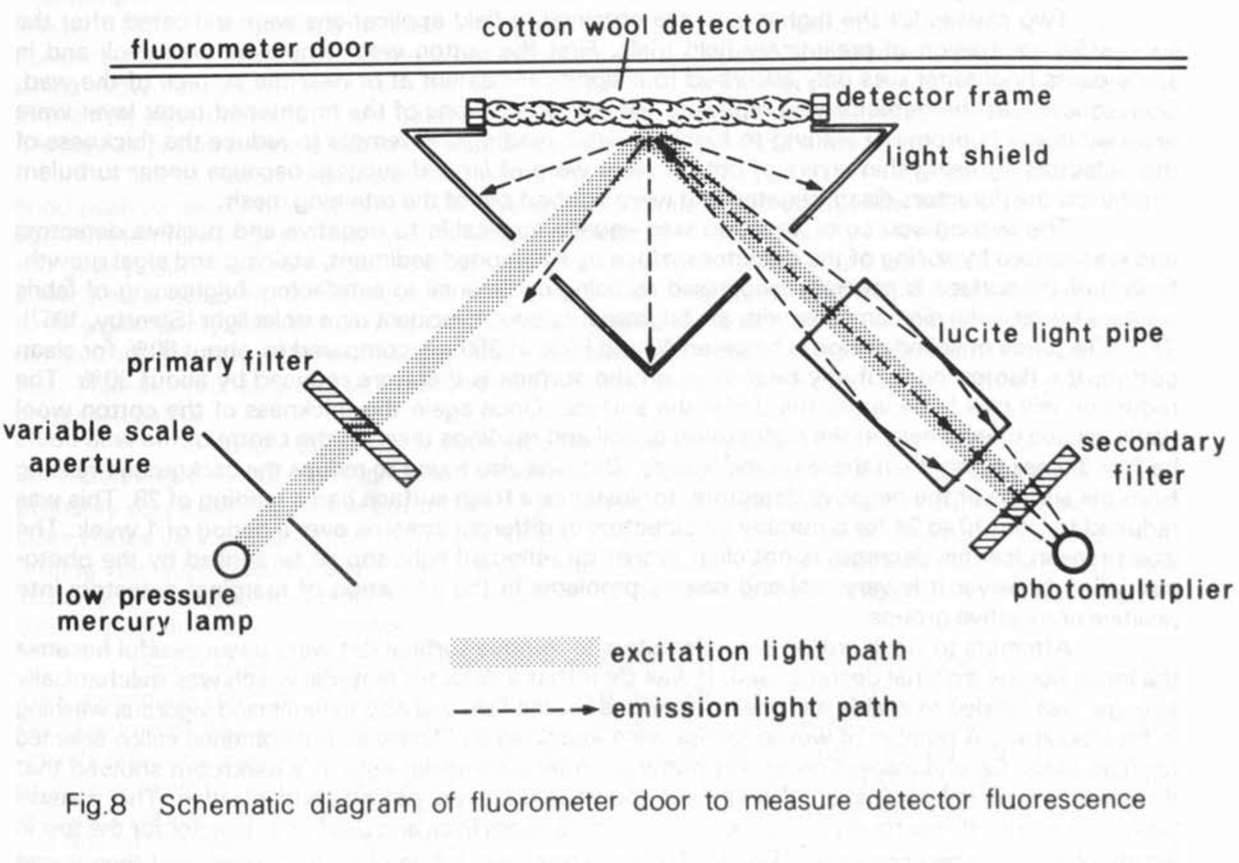

Fig.8 Schematic diagram of fluorometer door to measure detector fluorescence

(B) Use of Optical Brighteners with Detectors.

All previous applications of optical brighteners for tracing work have employed detectors made from cotton wool onto which the brighteners bind strongly. There are several advantages in using such detectors because continuous or regular monitoring of the resurgence is not required and there is thus a reduction in the cost of the trace. Furthermore the preliminary studies of Crabtree (1970) have indicated that there are no problems with background contamination of the detectors. A number of experiments were therefore planned to investigate the operation and efficiency of cotton wool detectors.

1) Quantitative Measurement of Detector Fluorescence.

In order to experiment effectively with detectors, some method was required to quantify the adsorption onto the cotton wool surface. Elution was not possible because of the strong bond between dye and substrate, therefore a direct method was developed. The optical brightener fluoresces in exactly the same manner when adsorbed onto the fabric surface as it does in a solution where the TRANS form is present. Therefore excitation with ultra-violet light and detection of the longer wavelength blue fluorescence using a photomultiplier is possible, as for solutions in the filter fluorometer. A modified door was therefore constructed for the Turner 111 filter fluorometer in which the cuvette sample compartment was replaced by a sliding tray which would hold a layer of cotton wool (Fig. 8). Light from the farultra-violet lamp passes the primary filter and is adsorbed by the detector surface, a proportion is also reflected but cannot pass into the photomultiplier because there is no overlap between the primary and secondary filters. Fluorescence emitted by the optical brightener adsorbed onto the detector is collected by the lucite light pipe and passes through the secondary filter to be measured on the photomultiplier. The optical bridge system employed in the Turner instrument functions normally, and readings are output which give a linear measure of the fluorescence of the detector surface. The 7-37 primary and 98 secondary filter combination are used, and neutral density filter (about 10% transmitance) is useful for upward extension of the range.

The detectors are run in a damp condition because this allows them to be moulded into the sample frame more readily and brighteners are generally more effective with high moisture contents. Excess water is squeezed out and the detector material packed into the frame ensuring the front surface is free from folds and fills the frame without gaps at the edges. The frame is carefully slid into the sample compartment, the door closed and reading obtained. To reduce experimental variance each detector may be repacked several times and an average reading obtained. The standard deviation for repacking unused cotton wool was found to be 6%. For negative detectors which had been in a stream the standard deviation was found to be about 10% for a single detector, and for a positive detector the value ranged from 20 to 35%. These figures indicate that the modified door gives an acceptable degree of reproducibility but that there are considerable sources of variance associated with field use of the detectors. These are discussed in the following section.

2) Laboratory Experiments

Two causes for the higher variance obtained in field applications were indicated after the successful completion of preliminary field trials. First the cotton wool employed was thick and in some cases brightener was only adsorbed to a significant extent at or near the surface of the wad. Consequently as the detector was repacked varying proportions of the brightened outer layer were exposed in the fluorometer leading to highly variable readings. Attempts to reduce the thickness of the detectors by using thin layers of cotton wool were of limited success because under turbulent conditions the detectors disaggregated and were washed out of the retaining mesh.

The second source of variation was equally applicable to negative and positive detectors and was caused by soiling of the detector surface by suspended sediment, staining and algal growth. Soiling of the surface is generally recognised as being detrimental to satisfactory brightening of fabric surfaces because the dirt competes with the brightener to adsorb incident ultra-violet light (Stensby, 1967). The reflectance of soiled cotton is between 40 and 50% at 350 nm compared to about 80% for clean cotton, the fluorescence of any brightener on the surface is therefore reduced by about 30%. The reduction will clearly be larger the dirtier the surface. Once again the thickness of the cotton wool wads caused unevenness in the distribution of soil and readings taken in the centre of the wad could be 2 or 3 times higher than those on the outside. Dirt was also found to reduce the background reading from the surface of the negative detectors, for instance a fresh surface had a reading of 28. This was reduced to from 10 to 24 for a number of detectors in different streams over a period of 1 week. The exact reason for this decrease is not clear in that no reflected light should be sensed by the photomultiplier, however it is very real and causes problems in the allocation of marginal detectors into positive or negative groups.

Attempts to wash cotton wool detectors to remove surface dirt were unsuccessful because the loose fibrous material decomposed. It was clear that a detector material which was mechanically stronger was needed to enable thin sheets to be used in the field and also to withstand vigorous washing in the laboratory. A number of woven fabrics were examined and finally an unbrightened calico selected for field trials. Careful inspection of this material under ultra-violet light in a darkroom showed that there was no general application of brightener, nor was there any patchy contamination. This material was made into swatches roughly 3 cm. square and three layers thick and used as a detector for the test in South Wales described previously (Fig. 7). The detectors were left in place for 1 week and then rinsed in clean water and run on the modified door. Three readings were taken on the back, front and inside surfaces, then the fabric was washed for 15 minutes in hot water with a concentrated laboratory detergent containing no fluorescent brighteners. After a 15 minute rinse, the detectors were then re-run and grouped into positive and negative classes.

For fourteen negative detectors there was a significant increase in the detector readings after washing from a mean of 21.8 to 28.8 scale units (1 Way Analysis of Variance, $F = 5.9$, $n = 14$, significant at 0.05 significance level). However the mean was still well below the initial value of 40 obtained from an unused detector, although it is possible that a second washing would further increase the value. For the positive samples there was an increase from a mean reading of 202 units to 263 (1 way Analysis of variance, $F = 16.6$, $n = 16$, significant at 0.001 significance level). The standard deviation of the mean negative value was also reduced from 43% of the mean to 27%, mainly by an increase in the value of the lower readings. Furthermore there was a decrease in the standard deviation of individual readings from a mean value of 4.5 for the unwashed detectors to 2.9 for the washed. Thus, washing of the detector prior to analysis appears to have significant beneficial effects.

A second experiment using calico detector material was carried out in order to investigate the effects of the brightener concentration in solution on detector fluorescence. Solution of Photine CU at concentrations from 0.5 to 200$\mu g\ l^{-1}$ were prepared and 0.4g segments of fresh calico were added. A second set was also run using 0.4g pieces of soiled calico which was also slightly iron-stained. The effect of the iron-stains on the fluorescence of the Photine CU has been discussed previously and this probably explains the difference between the two curves at high concentrations (Fig. 9). However at low concentrations there is no significant difference between the curves; and in fact the gradients are not statistically different. There is a consistent relation between solution concentration and detector fluorescence indicating that saturation of the detector surface does not occur until concentrations in excess of 200$\mu g\ l^{-1}$.

The initial reading for the dirty detectors was 22 compared to a figure of 45 for the clean calico, however the increase in fluorescence is similar in both cases. Therefore if clean detectors were used for a test a conclusive positive could not be obtained until a reading in excess of 51 was obtained (initial reading plus 20%), because a detector placed in a clean situation might maintain a reading close to the initial value, even though others decline to very much less than this value due to surface soiling. In this situation a concentration of 3.7$\mu g\ l^{-1}$ would be required for a clean detector and 14.5$\mu g\ l^{-1}$ for a dirty detector to be considered positive. If the detector were dirty when it was installed then a concentration of only 1.75$\mu g\ l^{-1}$ of Photine CU would be required to produce a positive result (initial reading assumed 22 plus 20%). In fact a concentration of 14.5$\mu g\ l^{-1}$ would give a 145% increase in the initial detector reading. This analysis is correct only if solution concentration is the major control on the resultant detector fluorescence, therefore this was investigated in several field experiments.

2) Field Experiments

A number of experiments were conducted in a surface river in Jamaica in which repeated injections of dyes were made under different conditions to assess environmental losses (Smart and Smith, 1976). The passage of each dye pulse was monitored fluorometrically to determine dye concentrations in the river. Cotton wool detectors were suspended in the centre of the river under similar flow conditions (velocity 0.7m sec^{-1}) and were changed at intervals of 15 and 30 minutes. In the first experiment duplicate detectors were run at the 15 minute interval and a third detector at this interval placed behind a barrier of rocks at the bank so that it experienced a very much lower velocity.

The background detector reading for the test (Fig. 10) was 21 ($t = 0$ to 15) and it is clear that good positive results were obtained with dye concentrations in the river of less than 6$\mu g\ l^{-1}$ ($t = 15$ to 30). Furthermore after the dye was no longer detectable fluorometrically in the stream the detectors still gave positive values for the next two 15 minute periods. There was a considerable range in the duplicate values of the 15 minute interval detectors, but when tested statistically they were not found to be significantly different (Paired t—test 0.05 significance level). However the slow flow detectors did give significantly different readings from the average of the 15 minute duplicates using the same test. This was probably due to exhaustion of the brightener in the vicinity of the detector surface as discussed below.

The 30 minute detectors did not give fluorescence values greater than the larger of the two corresponding 15 minute interval detector readings. In several instances they in fact gave lower values, probably due to soiling of the cotton wool. Similary the two detectors left in during the whole test gave values very similar to the maximum for the 15 and 30 minute interval detectors. This important finding was supported by other tests using Photine CU which gave maximum readings of 118, 102, 103 and 104 for detectors replaced at intervals of 15, 30, 60 and 120 minutes during the passage of a dye pulse of duration 100 minutes.

Thus it must be concluded that the most significant control on fluorescences of the detectors was maximum solution concentration rather than average concentration, or exposure time. This conclusion was also supported by the laboratory experiments. The adsorption process must therefore be very rapid and essentially non-cumulative even over the shortest exposure period used. This finding is in strong contrast to that observed for activated carbon in similar studies (Bauer, 1976), because activated carbon possess significant internal adsorption surfaces on which dye adsorption is limited by the rate of diffusion through the micropores (Smart, 1972). In contrast cotton wool fibres are very fine and the majority of adsorption sites are directly available so that diffusion, a relatively slow process,

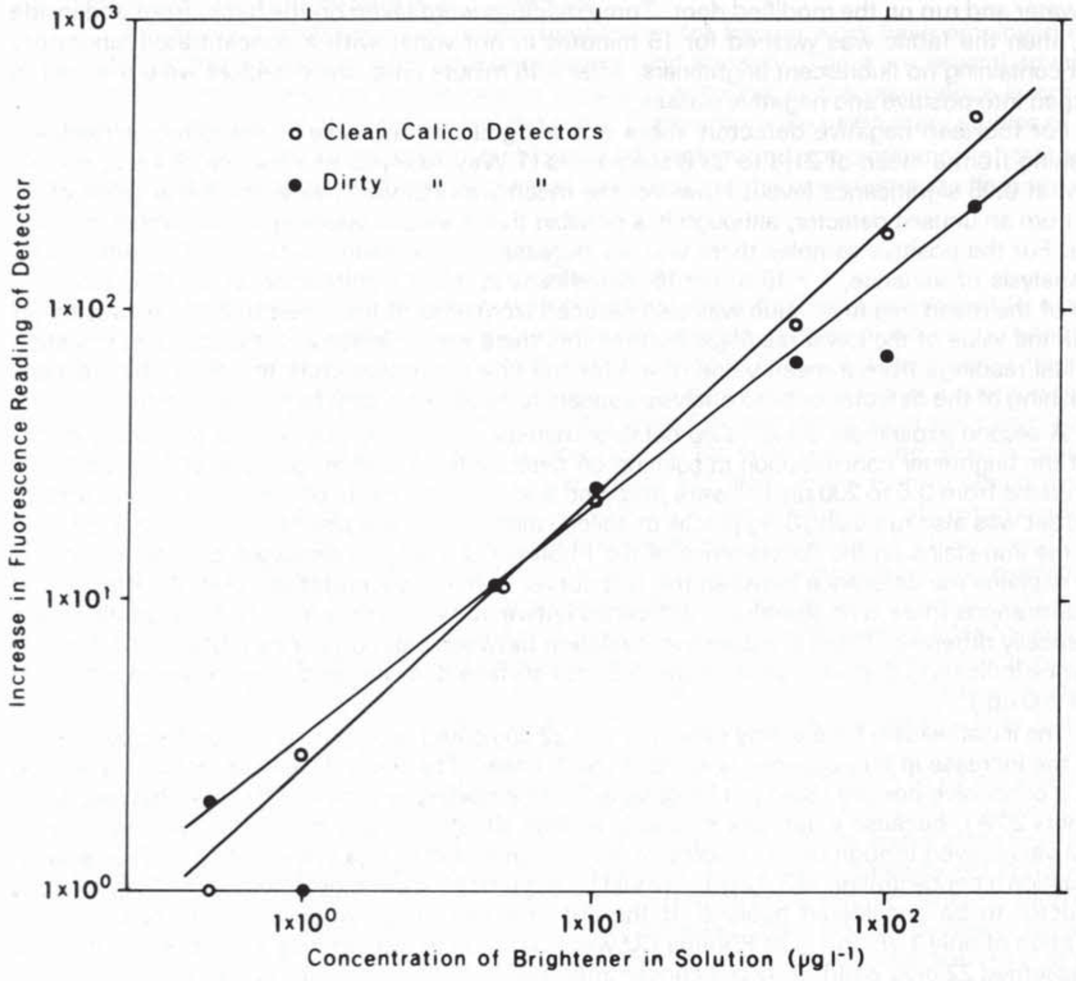

Fig.9 Effect of optical brightener concentration on detector fluorescence

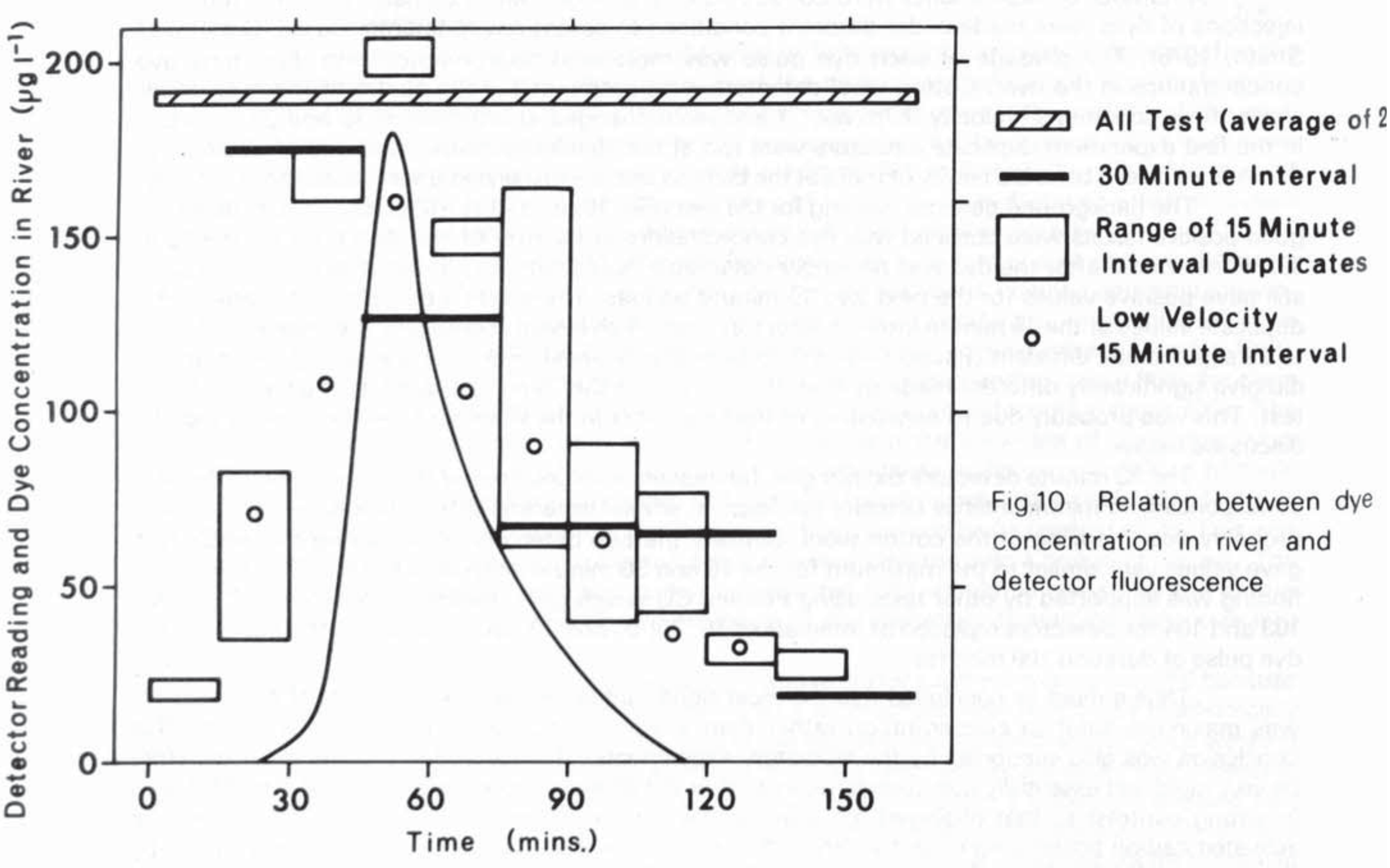

Fig10 Relation between dye concentration in river and detector fluorescence

is not the rate limiting step. This is supported by the difference between the slow flow and fast flow detectors, which indicates that solution dynamics, controlling transport of dye to the cotton surface, are the rate controlling mechanism.

4) Background Contamination

Under wholly natural conditions contamination of the detectors does not occur. The main problem in such situations is the different extent to which soiling occurs at various sampling locations and through time as was discussed above. However, in areas where industrial or domestic effluent is is discharged there may be significant amounts of optical brighteners present in the river. Between 30 to 50% of the brighteners used in laundry detergents are discharged unused and therefore quite high concentrations may be found in domestic waste water (up to 200 $\mu g\ l^{-1}$). The industrial usage of these compounds is more efficient and losses for the textile and paper industries are between 5 to 10%. Korte (1973) estimates that these two sources release respectively 20,000 and 1,300 tons of brighteners annually into the environment.

Measurements made in rivers indicate that concentrations of brighteners are normally below 1 $\mu g\ l^{-1}$ (Zinkernagel, 1973). The primary reason for this is dilution but Ganz et al. (1975a) have also shown that sewage processing removes a minimum of 56% brighteners for Primary treatment, 82% for Secondary treatment and 97% for Tertiary treatment. The major part of this removal is effected by adsorption of the brighteners on the sewage sludge as most brighteners are not biodegradeable. It is probable that similar adsorption on natural organic matter is responsible for the removal of much of the remaining optical brightener which is discharged into rivers. Furthermore conversion of stilbene from TRANS to CIS isomers on exposure to light will ensure that effective concentrations are very low. Therefore it may be concluded that background contamination will only be a problem in locations which are in close proximity to discharges of waste waters, particularly those which do not receive Secondary or Tertiary treatment.

(C) Toxicity.

No specific data have been obtained in this study on toxicity of the brighteners, because no information is available on the exact nature of the specific products investigated. It has, therefore, been necessary to conduct a general review of the toxicity of all stilbene triazine brighteners. The parameters investigated include only those with direct relevance to possible routes of absorption of the brighteners, for instance subcutaneous injection of compounds is not considered.

1) Acute Toxicity.

Acute toxicity is normally measured by the LD_{50} of a compound, defined as the amount in grams per kilogram of body weight which causes the death of half the control animals. Values reported in the literature are summarised in Table 7 including values of 16.0 g kg^{-1} for Photine CSP and 8.0 g kg^{-1} for Leucophor C and Leucophor BS. All the values are high and are comparable with a value of 8 to 10 g kg^{-1} for salt. The brighteners are therefore not particularly toxic in large doses and using the average toxicity of this type of brightener of 7g kg^{-1} (Akamatsu and Matsuo, 1975) the dangerous dose for a 60 kg man would be 420g.

Table 7. Acute Toxicity of Stilbene Triazine Optical Brighteners for Oral Administration.

Source	*Animal*	*Number of Compounds Tested*	*Ld_{50} $(g\ kg^{-1})^1$ Minimum*	*Maximum*
Gloxhuber et al., 1962	rat	8	› 2.5	› 10.0
	mouse	7	0.25	» 2.5
	cat	7		1.0
	guinea pig	7		1.0
Snyder et al., 1963	rat	2	› 2.3	16.0
	rabbit	2		›10.0
	guinea pig	2	»7.0	›10.0
Glover 1972[2]	mouse	2		» 8.0
Akamatsu & Matsuo, 1973	mouse	6	› 3.0	»10.0
	guinea pig	2		›7.0
Carter, 1973[3]	rat	1		4.5
Hess, 1973	6 species not specified	—	›1.0	›10.0
Hickson & Welch 1974[4]	rat	1		›16.0
Keplinger et al., 1974	rat	2		›5.0
	mouse	2		» 5.0

Notes:

1 » indicates 50% of animals were not killed at the highest dosage employed.
2 For Leucophor C and Leucophor BS.
3 For optical brightener in detergent; LD_{50} for detergent alone 4.2 g kg^{-1}
4 For Photine CSP.

2) Sub-acute Toxicity

Sub-acute toxicity is investigated by continuous feeding of the compounds under study to test animals in drinking water or food. After a given period the animals are sacrificed, and examined for pathological abnormalities and weight loss. Table 8 presents the findings of 14 individual experiments reported in the literature on a range of stilbene triazine brighteners. Only in one case was any harmful effect noted and in this case enlargement of the spleen was the only change noted. There was no difference in weight gain, food consumption, survival, reactions, hematologic and biochemical parameters, other organ weights or gross and microscopic pathological findings compared to the control group. The highest administration level of 1530 mg kg^{-1} day^{-1} is equivalent to a daily dose of 92g in a 60 kg man. Once again the experimental data indicated a very low level of toxicity for optical brighteners.

Table 8. Sub-acute Toxity of Stilbene Triazine Optical Brighteners for Oral Administration.

Source	*Procedure*[1]	*Effect*
Neukomm & De Trey, 1961.	1 5 mg injection and 0.5 mg/day in food (20 mg kg^{-1} day^{-1}) for 2 years with mice.	None
Gloxhuber et al., 1962.	Maximum 0.5 kg^{-1} day^{-1} (0.1%) in food given for 2 to 4 weeks in rats, rabbits and cats.	None
	0.2 - 0.5% in water (662-1530 mg kg^{-1} day^{-1} for from 362 to 464 days in rats.	None
	0.2% in water for 180 days in rats.	None
Akamatsu & Matsuo, 1973.	0.25 g kg^{-1} day^{-1} for 30 days in rabbits.	None
	0.30 g kg^{-1} day^{-1} for 91 days in rabbits.	None
	0.10 mg day^{-1} for 60 days for man.	None
Hess, 1973.	250 mg kg^{-1} day^{-1} for 90 days in 2 unspecified species.	None
	100 mg kg^{-1} day^{-1} for 2 years in 2 unspecified species.	None
Keplinger et al., 1974.	0.5% in food for 90 days in rats.	Spleens Enlarged
	0.1% in food for 90 days in rats.	None
	0.2% (50 mg kg^{-1}) in food for 90 days with rhesus monkeys.	None
	0.1% in food for 270 days in rats.	None
	0.2% in food for 270 days in beagle dogs.	None

Notes:

1 Maximum dosage levels in any particular experiment quoted.

3) Toxicity to Fish

As in the feeding experiments both acute and sub-acute toxicity studies are conducted for fish. However normally the sub-acute studies are concerned with the accumulation of significant amounts of the test compound in the flesh, which may prove harmful if eaten by man. Carter (1973) found no build up in the flesh of channel catfish *(Ictalurus punctatus)* and bluegill *(Lepomis macrochirus)* after periods of 90 and 105 days in solutions of 50 $\mu g\ l^{-1}$. Similar findings have been reported by Zinkernagel (1973) for concentrations of 12.5 $\mu g\ l^{-1}$ and by Sturm et al., (1975) for concentrations of 50 $\mu g\ l^{-1}$ for the same fish. Ganz et al., (1975b) using a maximum concentration of 1000 $\mu g\ l^{-1}$ were also unable to detect significant accumulation in Bluegill for exposure periods of 35 to 70 days. Furthermore they observed no preferential uptake of either the TRANS or CIS isomer, nor any accumulation of metabolites of the stilbene brighteners. It is evident that only in the case of water insoluble brighteners, such as that studied by Jensen and Petterson (1971), is accumulation in fish a problem.

The acute toxicity of compounds to fish is measured by the TL_{50} (also called LC_{50}), the concentration in solution at which 50% of the fish are killed. A standard test period of 96 hours is usually employed because mortality increases with the exposure time. Table 9 lists values for stilbene triazine brighteners reported in the literature. Only Sturm et al. (1975) solubilised the optical brighteners, and in the work of both Keplinger et al. (1974) and Akamatsu and Matsuo (1975) mortality was thought to be partially due to suffocation caused by suspended solid material lodging in the gills of the fish. The lowest reported value was 26 mg 1^{-1} in Bluegill which compares with a figure of 0.007 mg 1^{-1} for the pesticide DDT. Thus it may be concluded that the brighteners are relatively harmless to fish, compared to known toxic substances.

Table 9. Acute Toxicity of Stilbene Triazine Optical Brighteners in Fish.

Source	*Fish*[1]	*96-hour TL_{50} (mg 1^{-1})*	
		Minimum	*Maximum*
Akamstsu & Matsuo, 1973	Goldfish		2000
Carter, 1973	Bluegill		32
Little & Lamb, 1973	Fathead Minnow		180
Keplinger et al., 1974	Rainbow Trout	108	1780
	Rainbow Trout[2]	120	2000
	Channel Catfish	86	1060
	Channel Catfish[2]	105	2000
Sturm et al., 1975	Bluegill	26[3]	32[3]

Notes:

1 Bluegill *(Lepomis macrochirus)*, Channel Catfish *(Ictalrus punctatus)*, Fathead Minnow *(Pimphales promelas)*, Rainbow Trout *(Salmo gairdneri)*.
2 24-hour TL_{50}
3 Ethylene glycol used to completely solubilise optical brighteners.

4) Toxicity — Conclusions

Considerable work has also been carried out on other aspects of the toxicity of optical brighteners, their effects on the skin, eyes, and mucous membranes, the effects of inhalation as a dust, and on reproductive hazards. No detrimental effects have been reported even under extremely high concentrations and dosage levels, and it is therefore concluded that these compounds are substantially safe in the concentrations employed in the detergents industry. Normal brightener concentration in a wash liquor varies in the USA from 1 to 10 mg l^{-1} (Stensby, 1976) and effluent concentrations are approximately half this value; lower values are to be found at present in Western Europe.

The daily intake of water per man per day is about 3 l. Akamatsu and Matsuo (1975) have reported no ill effects for a man given 0.1 mg of stilbene triazine brightener daily for 60 days. This corresponds to a known safe solution concentration of 33 μg l^{-1}. If the average dosage for the sub-acute toxicity studies is calculated for a 60 kg man it is 24.4 g day^{-1}, however a safety factor must be incorporated. Using a value of 1000, a conservative estimate of maximum permissible continuous ingestion would be 24 mg day^{-1}, corresponding to a solution concentration of 8000 μg l^{-1} (8 mg l^{-1}). This amount is clearly three orders of magnitude higher than those needed to give positive results using calico detectors which leaves a satisfactorily large safety level for these materials. The only situation where high concentrations will arise is at the injection site, and because of the rapid dilution which occurs these levels are relatively transitory and do not therefore pose a hazard to aquatic life. In fact all the data indicate that optical brighteners have a significantly lower toxicity than some commonly used xanthene tracer dyes. Therefore a recommended maximum concentration of 50 μg l^{-1} may be suggested where water may pass into public supply, though no ill effects would be expected at concentrations much higher than this.

(D) Conclusions and Recommended Technique

It has been shown that quantitative use of the optical brighteners is not a practical proposition due to the high losses which are caused by adsorption, chemical and photochemical decay. Similarly, although fluorometric detection is possible, it is hampered by the high and variable background fluorescence found in natural waters and by the possible presence of brighteners in waste water. However the use of optical brighteners with cotton detectors has been shown to be a viable and sensitive technique. Furthermore, toxicity data indicate that no harm effects to man or aquatic organism will be caused by the use of these products as water tracers.

Optical Brightener. There appears to be little difference between individual stilbene triazine brighteners with regards to properties controlling their effective use as tracer, though products which are designed for low temperature application should be avoided. No specific products are therefore recommended. Maximum dye concentrations at the resurgence should be under 50 μg l^{-1}. Dosage amounts will have to be calculated individually because of differences in the adsorption expected in different locations, but minimum of 250 g is recommended.

Detectors. 2 or 3 thicknesses of undyed calico provide the best detector material, perhaps with some pre-dirtying of the surface by prior washing in a stream. Great care should be taken to avoid contamination from optical brightener dust and solutions, or from products containing optical brightener e.g. paper and textiles. The detectors should be held in a coarse plastic or galvanised wire mesh frame suspended in the most rapidly flowing part of the channel well above the bed. Nylon stockings, iron wire frames or string containing brighteners should be avoided. On removal the detector should be rinsed, washed in a non-fluorescent detergent, and then rinsed again. It may be examined visually under an ultra-violet lamp, or preferably run on a fluorometer modified to read from a solid surface. A set of background detectors should be obtained before the tracer test commences.

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The North Yorkshire windypits : a review

R.G. Cooper, P.F. Ryder, and K.R. Solman.

Summary

All the known windypits in the Rydedale and Hambleton HIlls area of North Yorkshire are described, and new surveys presented of many of them.

It is now more than 25 years since Dr. E. Paul Fitton and Doreen Mitchell published a detailed account of 'The Ryedale Windypits'; their 1950 article in *'Cave Science'* has remained the standard account of these features ever since. *'Northern Caves' vol. 5.* (Brook *et al.,* 1974) has provided accurate and in some cases enlarged descriptions of the windypits, but a considerable amount of the exploration and investigation which has been carried out since 1950 could not be mentioned in the context of a regional caving guide. Several detailed surveys have been carried out in recent years, and it is the purpose of this paper to present all the new information in the context of a general review of the current extent of windypit exploration.

The Area

The area in which the windypits are found (Fig. 1.) lies about 20 miles to the north-east of York. Here the Hambleton Hills rise to over 1000 ft. above sea level, at the steep Hambleton edge, overlooking the Vale of York and the Vale of Mowbray (Hemingway, 1969; Palmer, 1973; de Boer, 1974). The hills form a west-facing topographic escarpment, and the dip slope falls gently eastward to the valley of the River Rye. The valley is deeply incised and steep-sided; the right-bank tributaries of the river cut back westward into the Hambleton dip slope, forming the deep valleys of Eskerdale, Thorodale, Gowerdale, Caydale, Nettle Dale, and Flassen Dale.

The hills are formed of Corallian strata (Upper Jurassic) horizontally overlying Oxford Clay, which here is a grey, sandy shale. The Corallian rocks include sandstones with a calcium carbonate cement, and oolitic limestones (Fox-Strangways, 1892; Wright, 1972). The windypits are developed in the Corallian, and none have yet been found which penetrate as far as the Oxford Clay.

The Term 'Windypit'

'Windypit' is strictly a local term, used in the area around Helmsley, North Yorkshire, and along the north side of the Vale of Pickering to denote a hole in the ground from which draughts of air are from time to time emitted. Such emissions can be quite forceful: Fitton and Mitchell (1950, p. 163) described being 'positively assailed by great gusts blowing up from the depths' of Snip Gill Windypit. Rutter and Edlin (1972) remarked that the term 'expresses well the gusty winds encountered in such fissures'. Clearly the name originally described this one simple characteristic of such a 'hole in the ground', and did not carry an implication of the mode of origin. However Hayes (1963c) emphasised that 'the windypits are not caves', and so by implication excluded water-worn features from the term. All the windypits described by Fitton and Mitchell (1950) seemed to have been caused by gravitational sliding of detached Corallian rock masses; water erosion and deposition, where present at all assumed only a minor, secondary role. Therefore they attempted to explain the occurrence of the windypits in terms of cambering and gulling, as described by Hollingsworth *et al.* (1944).

In the present paper the term 'windypit' is used to denote a natural underground cavity, not formed primarily by the action of water, in which ledges, protrusions etc. on one passage wall are mirrored by overhangs, concavities etc. on the opposite passage wall.

Obviously the south-west corner of the North York Moors is not the only area where fissures formed by means other than water action are to be found. Similiar features have been described in many areas of the British Isles, as well as overseas (see the bibliography in Hedges, 1972). They have been described as slip-rifts, slip-fissures and fissure caves (although the latter term is often also used to denote high, narrow passages in water-worn caves). These terms, applied generally, would include the North Yorkshire windypits; the term 'windypit' is used here because the North Yorkshire windypits form a discrete, regionally isolated group, and because the term is already current for them. We suggest that the term 'windypit' should be restricted in its application to features in the area from which it originated.

Names of individual windypits

Over the years a number of inconsistencies have arisen in naming the windypits, with the result that several of them are now known by more than one name. It is hoped that the names which they are given in this paper will become standard. The most evident inconsistency has arisen over Buckland's Windypit: Fitton and Mitchell called it ''Buckland's Deer Park Windypit', but Thornber in *Britain Underground* (1953) and *Pennine Underground* (1959) followed the Yorkshire Ramblers' Club (1936a) in calling it 'Helmsley Windypit'. Thornber's example in this respect is followed in Northern Caves (Brook *et al.,* 1974). In the present paper it is called Buckland's Windypit in order to follow Fitton and Mitchell's example (perhaps a less cumbersome form) in paying tribute to the pioneer geologist who left the earliest written record of its descent (Buckland, 1823).

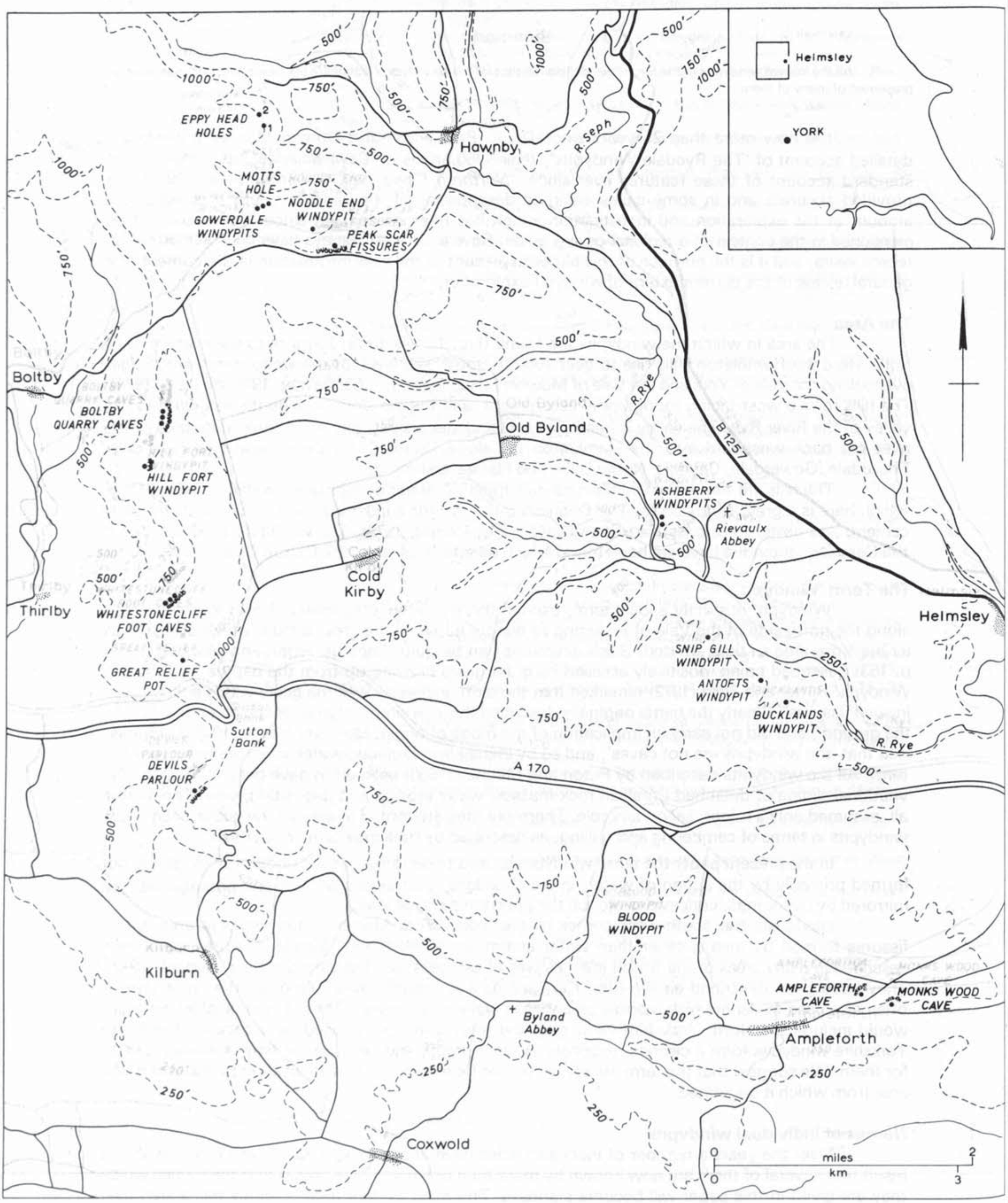


Fig. 1. The North Yorkshire Windypits - location map.

Snip Gill Windypit was referred to as 'Slip Gill' by Brook *et al.* (1974), following Hayes' (1963a) statement that although the stream concerned is labelled 'Snip Gill' on the 2½ inch and 6 inch maps, this is a mistake on the part of the Ordnance Survey. The present authors feel that when a windypit (or any cave) is named after a local topographic feature, the map's spelling should be followed even where it is wrong, in order to avoid confusion when attempting to find the place by means of a map.

Thomas Gill (1852) described three fissures in the area around Sutton Bank; the two to which he gave names are still marked on the Ordnance Survey 6 inch map (sheet SE 58 SW) as the "Devil's Parlour" at Roulston Scar, and the "Fairies' Parlour" at Whitestone Cliff. Apparently Fitton and Mitchell were unaware of the existence of these fissures, or considered that they were too far away to be included with the 'Ryedale windypits'. A few small fissures have been 'found' by the present authors; these include three at the foot of Whitestone Cliff, but it is uncertain whether any of these is the "Fairies' Parlour" or the 'other mysterious cavern' described by Gill. The other fissures 'found' by the authors are the Boltby Quarry Caves (Cooper *et al.*, 1976; Cooper and Halliwell, 1976), and Peak Scar Windypit 2. It will be noted that we have not followed Hayes (1963c) in proscribing the use of the term 'cave' in naming the windypits. As far as possible, we have tried to use the name most commonly applied to each of the known windypits, except that we have attempted to avoid the use of the term 'hole', which is thought to lack precision.

Following *Northern Caves* (Brook *et al.*, 1974) the windypits on the Noddle End spur are referred to here as Gowerdale Windypit 1, Gowerdale Windypit 2, Motts Hole Windypit, and Noddle End Windypit. However, there has been some confusion about which of these actually were described by the Yorkshire Ramblers Club. Fitton and Mitchell were apparently unaware of the existence of Gowerdale Windypit 2, and so the two fissures which the Yorkshire Ramblers found 'on the south side of Gowerdale' (Anon., 1938) were identified by Fitton and Mitchell as 'South Gowerdale Windypit' (Gowerdale Windypit 1) and Noddle End Windypit, while it now seems more likely that they were Gowerdale Windypits 1 and 2 respectively. Motts Hole Windypit, discovered on the southern slope of Gowerdale by the Bradford Pothole Club (Rider, 1962), was originally described in the early 1950s by the Yorkshire Ramblers (Anon., 1953), who named it 'Windypits VI'.

Williams (1966) gave a map of the locations of eleven windypits then known to pupils at Ampleforth College, including those described by Fitton and Mitchell, together with a 'North Gowerdale Windypit' and a 'Caydale Windypit'. Neither of these is described herein and neither has been found recently. It is possible that 'North Gowerdale Windypit' could be Gowerdale Windypit 2; as with Fitton and Mitchell's work, it is certain that 'South Gowerdale Windypit' is Gowerdale Windypit 1. 'Caydale Windypit' seems to be located at about SE555868, in a most promising area of subsided hillslope at Birk Bank, on the south side of Caydale between the mill and Tylas ('Tile House') Farm.

Britain Underground (Thornber, 1953) and *Pennine Underground* (Thornber, 1959) have entries for a 'Hawby Windypit' (SE525882; altitude 970 feet, depth 100 feet. It is described as an '85 ft ladder descent into a rift with right-angle corners'. Nothing is to be found at the grid reference quoted, and Brook *et al.* (1974) identify it with Noddle End Windypit.

In 1970 the Yorkshire Underground Research Team discovered and surveyed Hill Fort Windypit, on the Hambleton edge (Brown, 1970). Ampleforth College Venture Scout Unit have discovered and described Monk's Wood Cave, and Ampleforth Cave near to their College, Great Relief Pot at Sutton Bank, and Blood Windypit in Shallowdale, which they have also surveyed. The Moldywarps Speleological Group have made a detailed survey of the Ashberry Windypits (Ryder, 1973); in the 'smaller hole' of Fitton and Mitchell (1950, p.174; now Ashberry Windypit 2) they have made further extensions to a series of passages and fissures discovered a few months previously by a local archaeological group.

Two of the fissures described by Fitton and Mitchell have not been found recently. They are 'Fissure C' at Peak Scar, and 'Greencliffe Hag' Windypit. 'Peak Scar Fissure C' was described (Fitton Mitchell, 1950, p.182) as 'a small cave, about 30 ft. long, which opens at the extreme west end of the Scar, where the cliff is only about 15 ft. high. It runs eastwards and is of no importance' (SE528883; altitude about 870 ft). The 'Greencliffe Hag' windypit was described (Fitton and Mitchell, 1950, p.176) as 'A small hole, 2 or 3 ft. in diameter, completely blocked with the decaying carcasses of sheep'.It is situated in Greencliffe Hag Wood (SE569864; altitude about 550 ft). G.M. Davies (personal communication, 1973) writes that it 'no longer exists'.

The Windypits

A. The North Side of the Coxwold-Gilling Gap

The area between Coxwold and Gilling is a rift-valley, where the land between two subparallel faults running east-west has been dropped down into a trough (Palmer, 1973, p.33). The Gap separates the Hambleton Hills to the north from the Howardian Hills to the south. The northern fault runs along the foot of the Hambleton Hills, truncating them geologically and in some places topographically. Along much of the fault line, for example between Oswaldkirk and Ampleforth, the hills present a blank fault-scarp, but in several places re-entrant valleys have been carved, for examples Duckendale, Cockerdale, and Shallowdale, with streams flowing southwards. Of the three windypits found in this area, Ampleforth Cave and Monk's Wood Cave are on the fault-scarp, while Blood windypit is on the western slope of Shallowdale. The two windypits on the fault-scarp are also in quarries, and it is not known whether they had any surface expression before quarrying took place. The windypits are here described travelling from east to west.

1. Ampleforth Cave. (Fig.2.)
SE593791 Altitude 500 ft. Length 25 ft.
References: Coghlan, 1973b; Brook *et al.*, 1974.

This is situated immediately north of the road from Ampleforth to Ampleforth College. A low and tight letter-box squeeze at the base of a small overgrown quarry face leads immediately to a low cross-rift, subparallel to the quarry face. The quarry face is in a large block of rock which has tilted forwards, dipping at an angle of 47°, much of the cave seems to be in an opened bedding plane.

2. Monk's Wood Cave. (Fig.3)
SE597791 Altitude 550 ft. Length 110ft.
References: Coghlan 1973a; Brook *et al.*, 1974.

The entrance lies at the foot of a disused quarry face 30 ft. north of a ruined wooden hut in Monk's Wood at Ampleforth College. A very low crawl leads into a wide but low passage. The chambers of this cave are the widest spaces yet found in any of the windypits. There are two lines of avens in the roof, running subparallel to the slope and to the quarry face. The movement giving rise to the cave's formation may have been induced or reactivated by the quarrying operations.

3. Blood Windypit (Fig.4)
SE566799 Altitude 650 ft. Length 300 ft. Depth 52 ft.
References: Coghlan, 1973c; Brook *et al* 1974.

This windypit lies on the west side of Shallowdale, and has three entrances. The west entrance is among boulders in a hollow 200 ft. NNW of High Woods Farm at the head of the valley. The other two entrances are normally covered over and not used. The windypit is complex and unstable, with many passages lying close to the surface. It has an upper series very close to the surface (hence the three entrances), which is everywhere very unstable, sharp, and awkward. Then, below the letter-box, the fissure is deeper, and runs subparallel to the main valley side. The alignment of the upper levels, roughly at right-angles to the valley side, is subparallel to Pond Slack, a tributary valley which enters Shallowdale immediately to the north of the windypit.

B. The Hambleton Edge.

The formation of the steep, high scarp slope of the Hambleton Hills is usually ascribed to the glacial period. It is generally thought to owe its steepness, as also the high inland cliffs of Roulston Scar and Whitestone Cliff, to the action of meltwaters at the margin of a glacier which filled the Vale of York (Harrison, 1935; Versey, 1971). In the northern part of the scarp, the Oxford Clay outcrop beneath the Corallian is about 115 ft. thick (Senior, 1975), but in the south at Roulston Scar it has thinned to zero (Fox-Strangways, 1892, p.297). It is therefore surprising that five of the nine known windypits on the scarp should be concentrated close to its southern end: evidently slipping of the rock masses is not dependent on the thickness of the supposed 'mobile' or lubricated layer. The nine windypits have very dissimilar sites, and display a variety of forms; they are here described travelling from south to north.

4. The Devil's Parlour (Fig.5) (Plate1, Fig.1).
SE512816 Altitude c.850 ft. Length 30ft.
References: Gill, 1852; The Reader's Digest Association Limited, 1975.

This is most easily approached from the footpath at the top of Roulston Scar, by scrambling down a steep gully between vertical cliffs, just beyond two wooden gateposts on the path. The cave is to the right, up a 10 ft. staircase of bedrock sandstone blocks. It has a high, narrow entrance with a prominent wedged block above it. The sandy floor ascends steeply until the rift becomes too tight after 30 ft. The fissure is in an unusually soft and sandy facies of the Corallian, and appears to have been modified to some extent by wind erosion. However, the main cause of the fissure's opening was undoubtedly slipping, and a shale band (Odling, 1918) can be found on the cliff face a few feet above ground level, outside the cave.

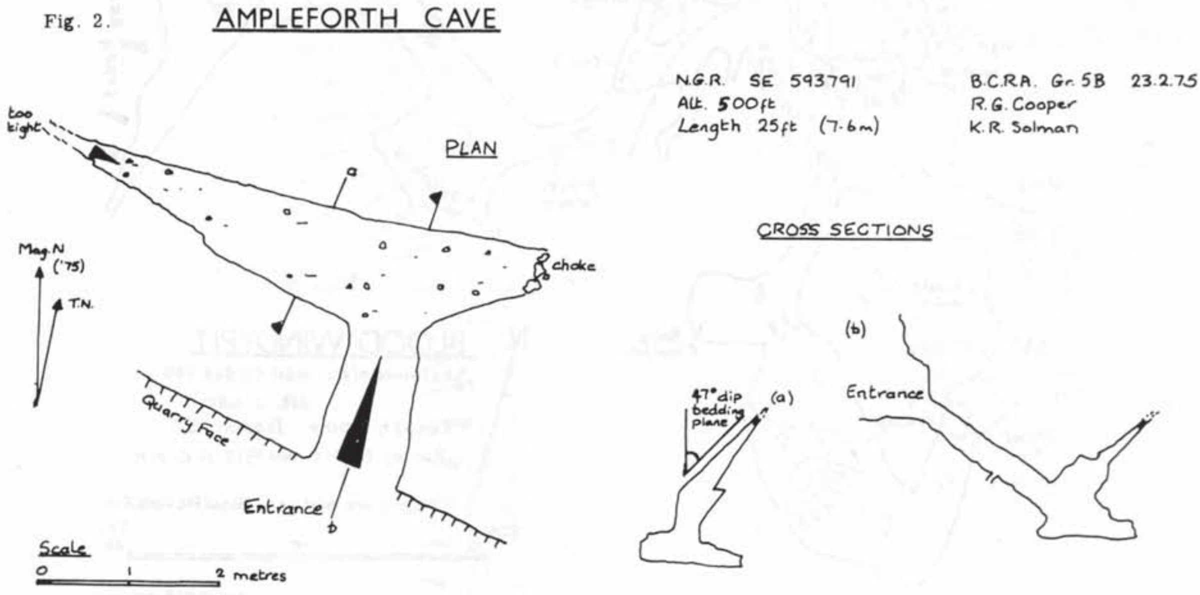
5. Great Relief Pot.
SE511833 Altitude 1000 ft. Length 12 ft. Depth 10 ft.
References: Brook *et al.*, 1974; Anon., (n.d.), p.4.

Situated at Sutton Bank, one third of a mile from the A170 road, beside the Nature Trail pathway and 30 ft. from the hilltop footpath, a small draughty opening provides a tight squeeze into a small fissure with very narrow cross-rifts at each end.

6. Whitestonecliff Pot. (Fig.6)
SE507836 Altitude 940 ft. Length 35 ft. Depth 42 ft.
Reference: (?) Gill, 1852.

The entrance is at the foot of Whitestone Cliff, ½ mile north of the car park at the top of Sutton Bank. A steep descent by rope down a sandy slope leads to a small chamber, giving access to a tight passage. After 20 ft. this meets an intersecting rift, where all ways on are too tight.

Fig. 2.


AMPLEFORTH CAVE
N.G.R. SE 593791
Alt. 500ft
Length 25ft (7.6m)
B.C.R.A. Gr. 5B 23.2.75
R.G. Cooper
K.R. Solman
PLAN
too tight
Mag.N ('75)
T.N.
choke
Quarry Face
Entrance
Scale
0 1 2 metres
CROSS SECTIONS
47° dip bedding plane
(a)
(b)
Entrance
K.R.S/H.C. '76

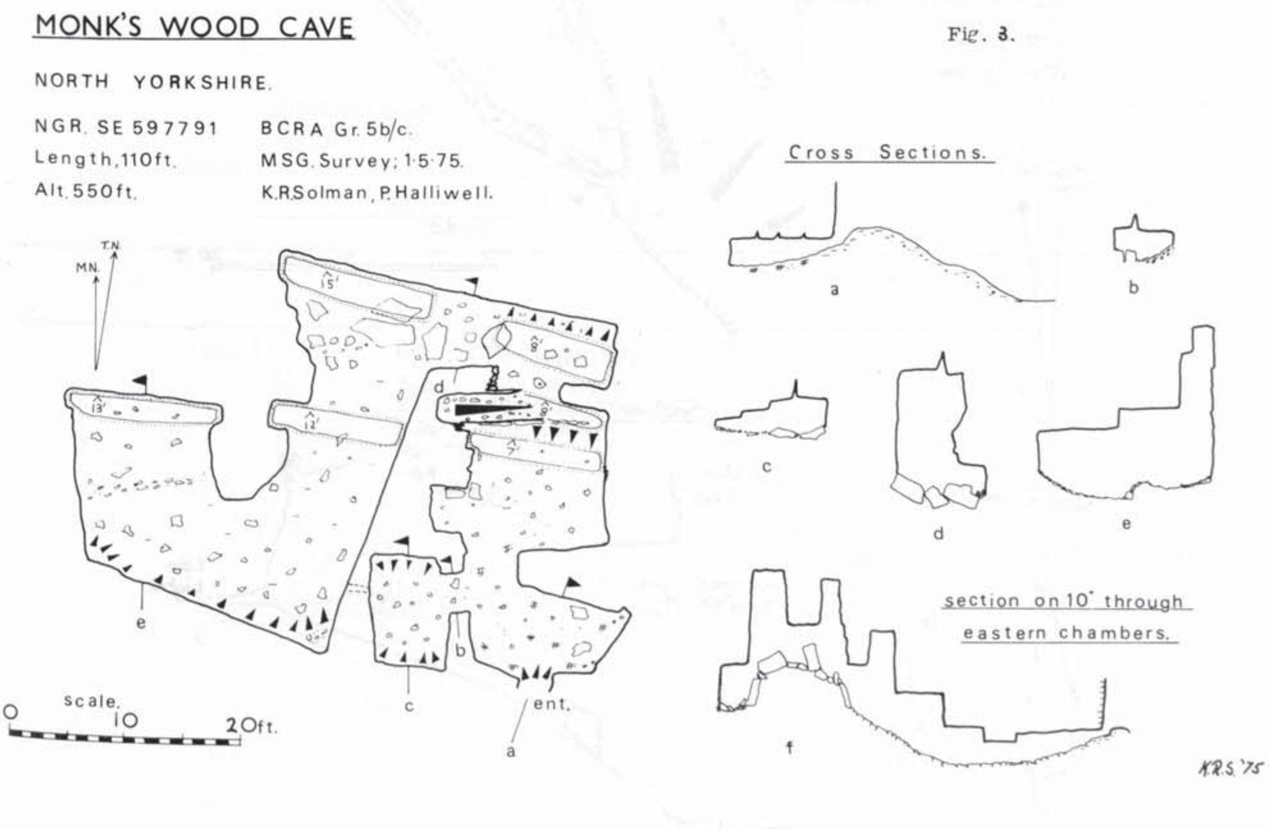
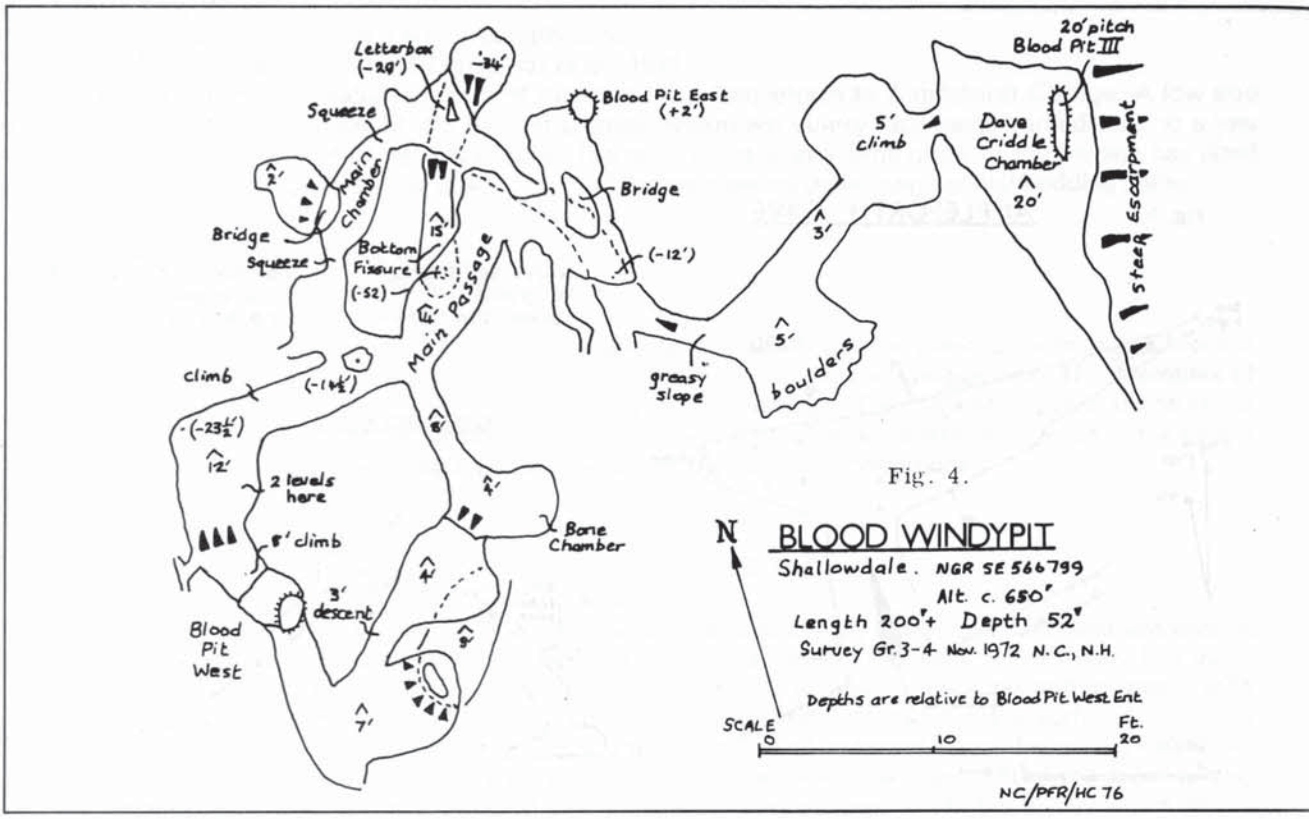
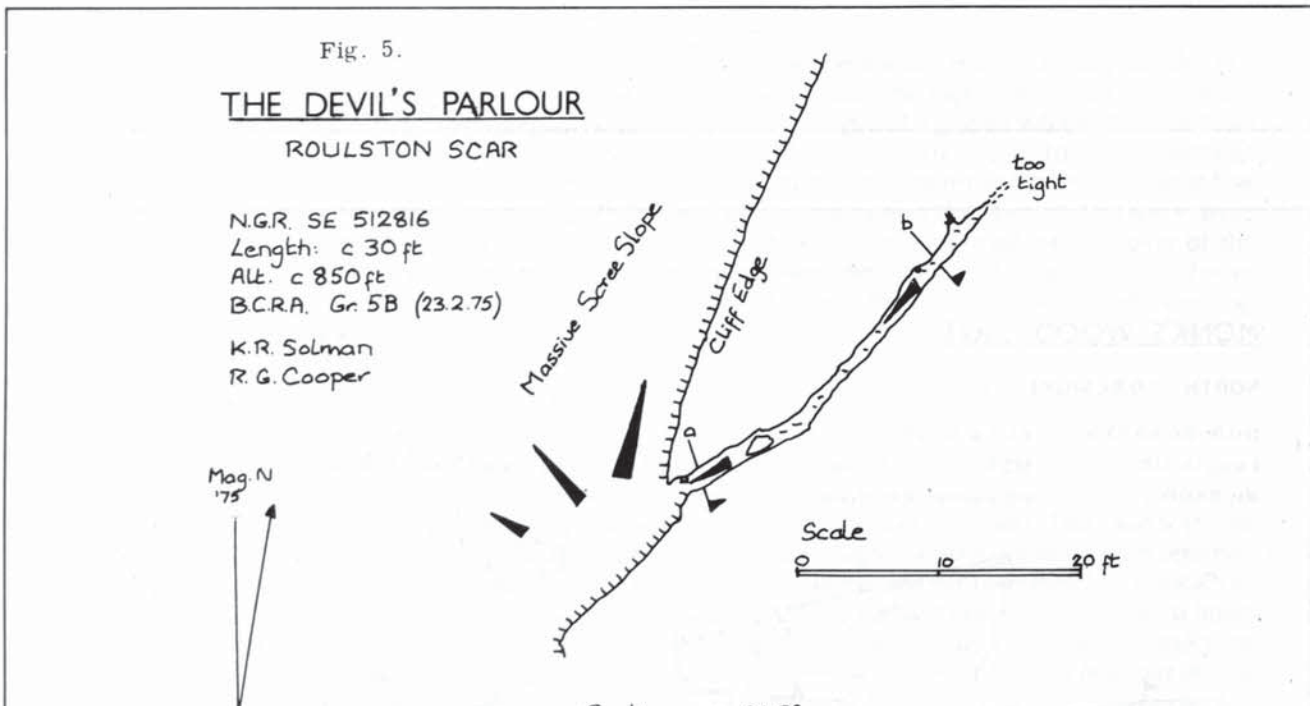

MONK'S WOOD CAVE
NORTH YORKSHIRE.
NGR. SE 597791
Length, 110ft.
Alt. 550ft.
BCRA Gr. 5b/c.
MSG. Survey; 1·5·75.
K.R.Solman, P.Halliwell.
T.N.
M.N.
15'
8'
13'
12'
7'
scale.
0 10 20ft.
ent.
Cross Sections.
section on 10° through eastern chambers.
K.R.S. '75

Fig. 3.


BLOOD WINDYPIT
Shallowdale. NGR SE 566799
Alt. c. 650'
Length 200'+ Depth 52'
Survey Gr.3-4 Nov. 1972 N.C., N.H.
Depths are relative to Blood Pit West Ent.
SCALE
0
10
Ft. 20
NC/PFR/HC 76
N
Letterbox (-29')
-34'
Squeeze
Main Chamber
Bridge
Squeeze
Bottom Fissure
(-52)
15'
Main Passage
Blood Pit East (+2')
Bridge
(-12')
greasy slope
boulders
5'
3'
5' climb
Dave Criddle Chamber
20'
20' pitch
Blood Pit III
steep escarpment
climb
(-14½')
(-23½')
12'
2 levels here
8'
4'
8' climb
Bone Chamber
3' descent
Blood Pit West
4'
8'
7'
Fig. 4.


THE DEVIL'S PARLOUR
ROULSTON SCAR
N.G.R. SE 512816
Length: c 30 ft
Alt. c 850 ft
B.C.R.A. Gr. 5B (23.2.75)
K.R. Solman
R.G. Cooper
Mag. N '75
Massive Scree Slope
Cliff Edge
too tight
b
a
Scale
0
10
20 ft
Section on 042°
cliff face
wedged boulder
too tight
Cross Sections
(a)
(b)
Fig. 5.

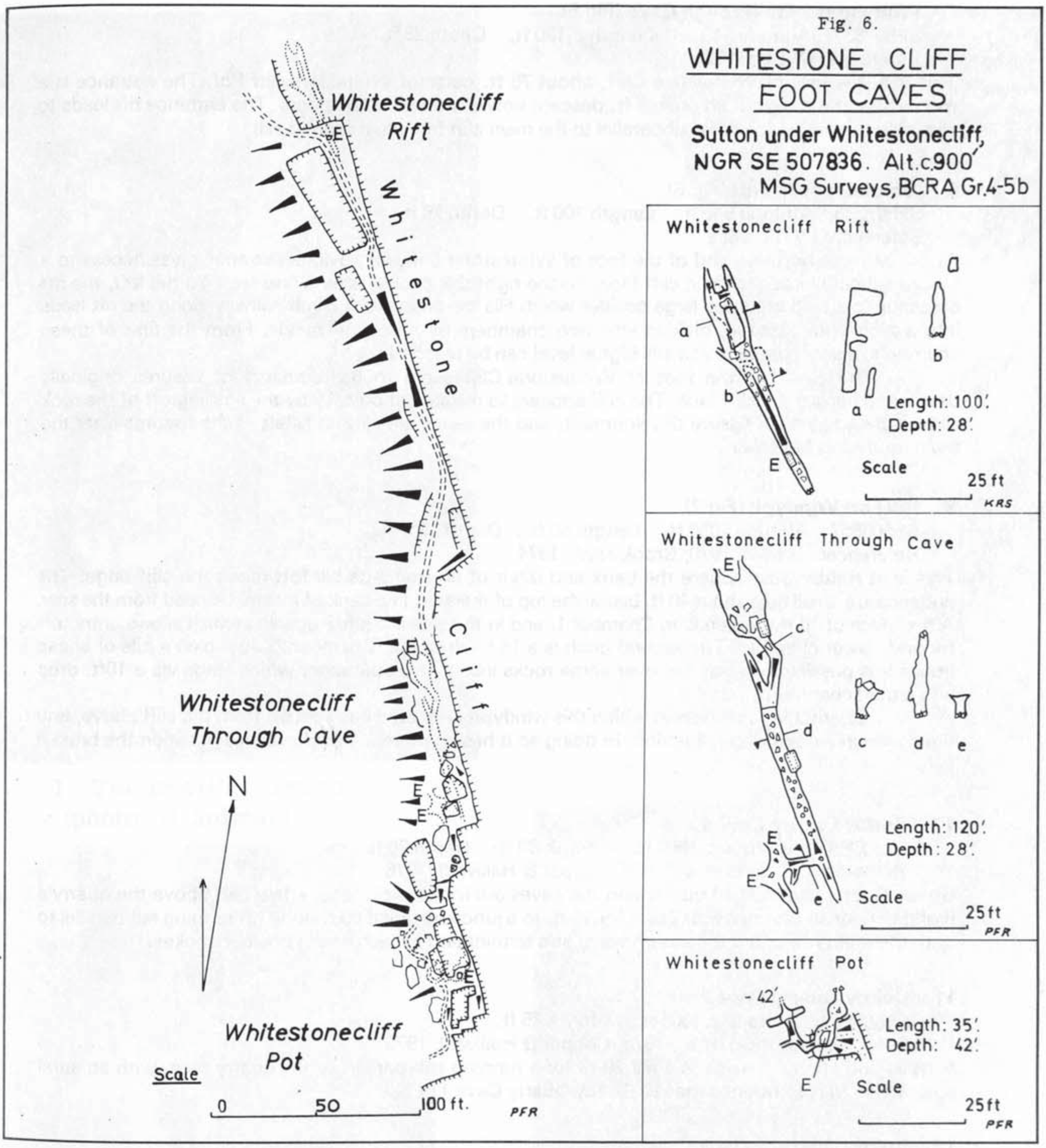


Fig. 6.
WHITESTONE CLIFF FOOT CAVES
Sutton under Whitestonecliff,
NGR SE 507836. Alt.c.900'
MSG Surveys, BCRA Gr.4-5b
Whitestonecliff Rift
Whitestone Cliff
Whitestonecliff Through Cave
Whitestonecliff Pot
N
Scale
0
50
100 ft.
PFR
Whitestonecliff Rift
Length: 100'
Depth: 28'
Scale
25 ft
KRS
Whitestonecliff Through Cave
Length: 120'
Depth: 28'
Scale
25 ft
PFR
Whitestonecliff Pot
42'
Length: 35'
Depth: 42'
Scale
25 ft
PFR

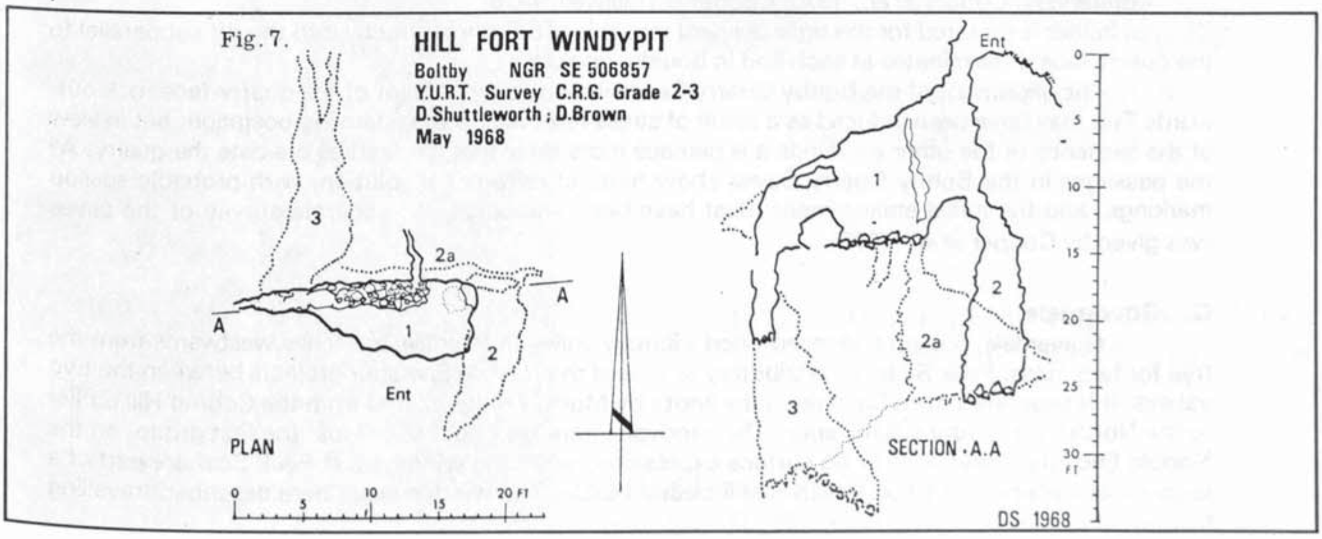


Fig. 7.
HILL FORT WINDYPIT
Boltby NGR SE 506857
Y.U.R.T. Survey C.R.G. Grade 2-3
D.Shuttleworth; D.Brown
May 1968
PLAN
Ent
SECTION A.A
DS 1968

7. Whitestonecliff Through Cave (Fig.6)
SE507837 Altitude 940 ft. Length c.120 ft. Depth 28 ft.
Reference: (?) Gill, 1852.

This is at the foot of Whitestone Cliff, about 75 ft. north of Whitestonecliff Pot. The entrance is a roomy slot at the foot of an open 8 ft. descent between tumbled boulders. The entrance rift leads to the main fissure, which runs subparallel to the main cliff face, to a second exit.

8. Whitestonecliff Rift (Fig.6)
SE507838 Altitude 940 ft. Length 100 ft. Depth 28 ft.
Reference: (?) Gill, 1852.

At the extreme northern end of the foot of Whitestone Cliff, an obvious entrance gives access to a fissure subparallel to the main cliff face. To the right this chokes after a few feet. To the left, the rift descends to a loop around a large boulder which fills the passage. A climb halfway along the rift leads into a high-level passage, divided into two chambers by a boulder ruckle. From the first of these chambers, a short passage at a still higher level can be reached.

The caves at the foot of Whitestone Cliff seem to be remnants of fissures originally developed behind the cliff face. The cliff appears to retreat periodically by the spalling off of the rock slabs isolated by such fissure development, and the caves are all that is left of the fissures after the main rock mass has fallen.

9. Hill Fort Windypit (Fig.7)
SE506857 Altitude 1050 ft. Length 50 ft. Depth 35 ft.
References: Brown, 1970; Brook *et al.*, 1974

This is at Boltby Scar, where the bank and ditch of an Iron Age hill fort reach the cliff edge. The entrance is a small hole about 40 ft. below the top of the scar, in a bank of material slipped from the scar. A first pitch of 10 ft. descends to Chamber 1, and in the side is a small opening which allows entry to a second, lower chamber. The second pitch is a 15 ft. drop into Chamber 2. Just past a pile of sheep bones it is possible to scramble over some rocks into a short passage, which leads via a 10ft. drop into a third chamber.

Clearly the rock mass in which this windypit is located has split off from the cliff above, and tilted over in a downslope direction. In doing so it has shattered, leaving spaces between the broken pieces.

10. Boltby Quarry Cave 1.
SE507863 Altitude c.1000 ft. Length 80 ft. Depth 26 ft.
References: Cooper *et al.*, 1976; Cooper & Halliwell, 1976.

Boltby Quarry is a disused quarry and the caves are in the main face, a few feet above the quarry's working floor. A phreatic tube leads for 15 ft. to a junction with a 65 ft. long rift running subparallel to both the quarry face and the escarpment, and terminating at each end in boulder chokes.

11. Boltby Quarry Cave 2.
SE507863 Altitude c.1000 ft. Length 35 ft.
References: Cooper *et al.*, 1976; Cooper & Halliwell, 1976.

A short phreatic tube leads to a rift 20 ft. long running sub-parallel to the quarry face, with an aural connection to the entrance tube of Boltby Quarry Cave 1.

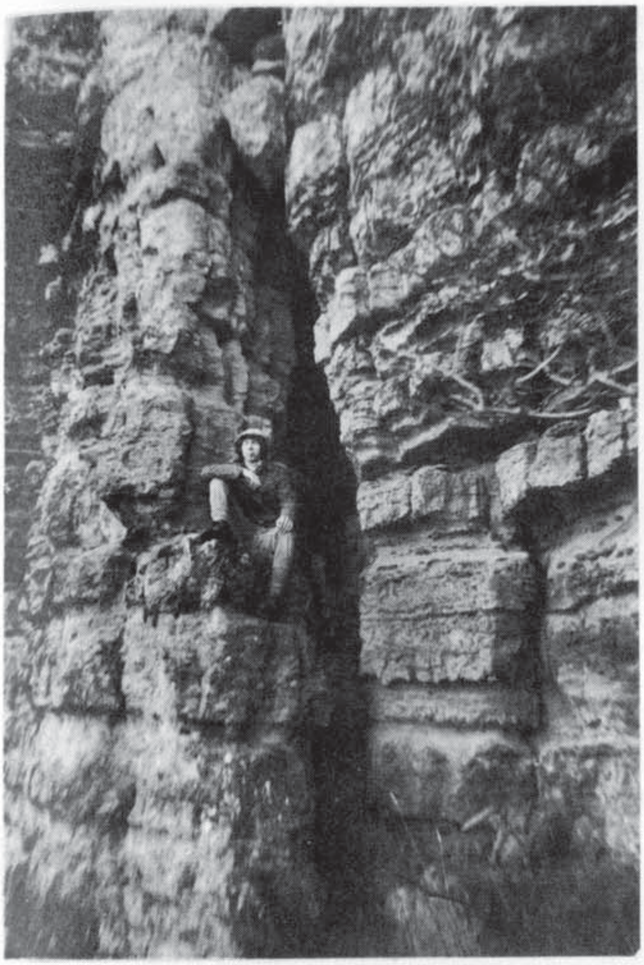
12. Boltby Quarry Cave 3.
SE507863 Altitude c.1000 ft. Length 70 ft. Depth 28 ft.
References: Cooper *et al.*, 1976; Cooper & Halliwell, 1976.

25 ft. of ladder is required for the tight descent into this rift. Entry is directly into the rift subparallel to the quarry face; it terminates at each end in boulder chokes.

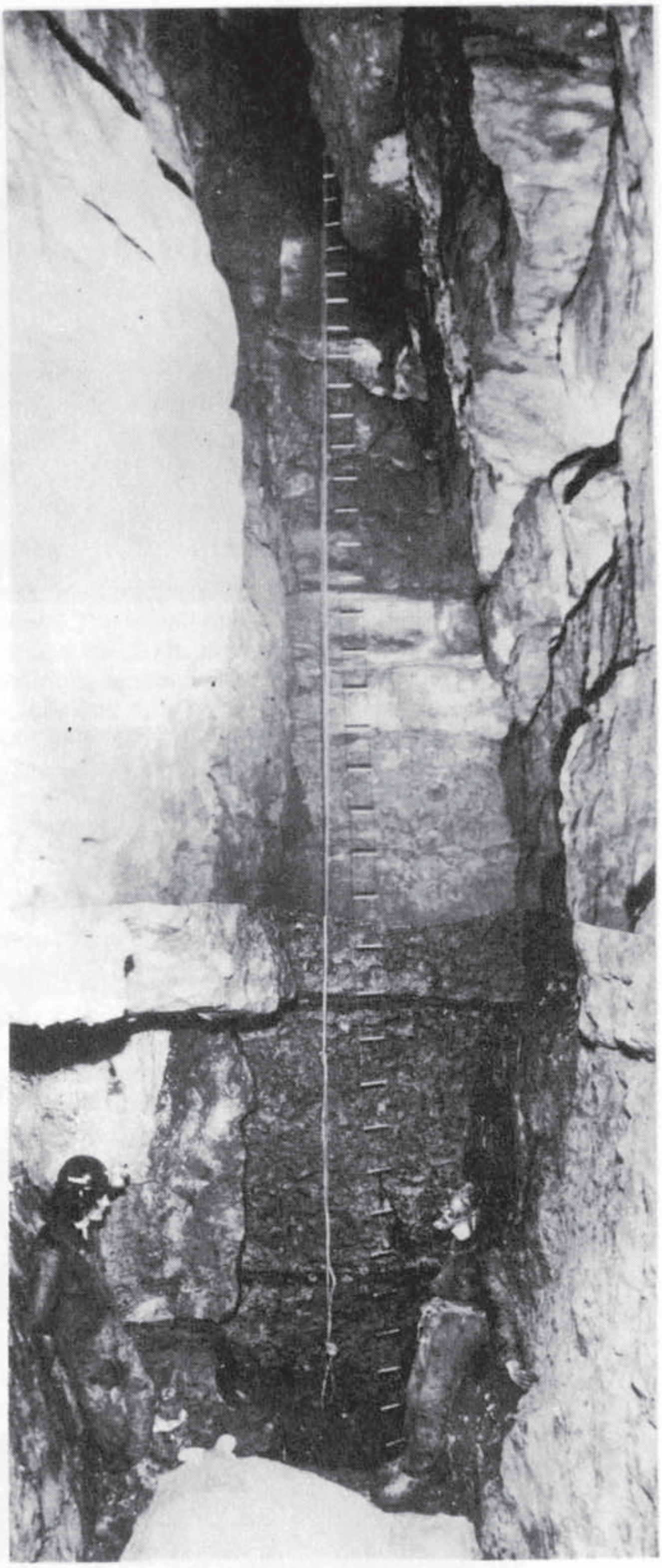
The alignment of the Boltby Quarry Caves indicates movement of the quarry-face rock outwards. This may have been induced as a result of stress-relief due to the quarrying operation, but in view of the existence of the other windypits it is perhaps more likely that the fissures pre-date the quarry. All the passages in the Boltby Quarry Caves show hints of differential solution, with probable scallop markings, and the initial enlargement must have been solutional. An accurate survey of the caves was given by Cooper *et al.* (1976).

C. Gowerdale.

Gowerdale, a deep and steep-sided tributary valley to Ryedale, stretches westwards from the Rye for two miles. Peak Scar Gill is tributary to it, and the Noddle End spur projects between the two valleys. It is separated from Caydale to the south by Murton Heights, and from the Coomb Hill outlier to the North by the Sunny Bank spur. The windypits here fall into two groups: the first group, on the Noddle End spur, have little or no surface expression, while the windypits at Peak Scar are part of a large-scale surface disruption which is still clearly visible. The windypits are here described travelling from west to east.



1. The Devil's Parlour
(photo: D. Solman).



2. Gowerdale Windypit No. 2.
(photo: K. R. Solman)

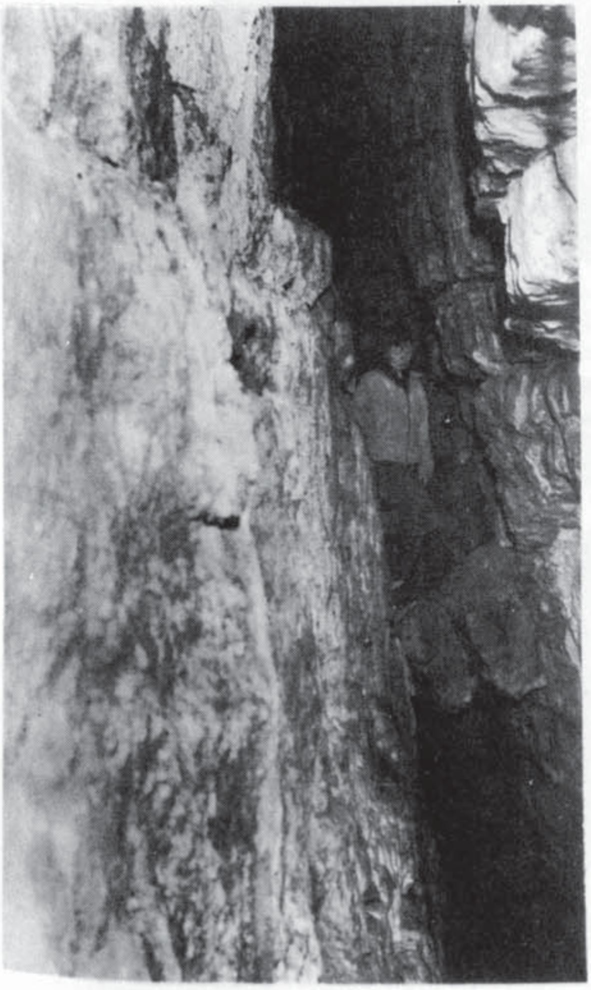
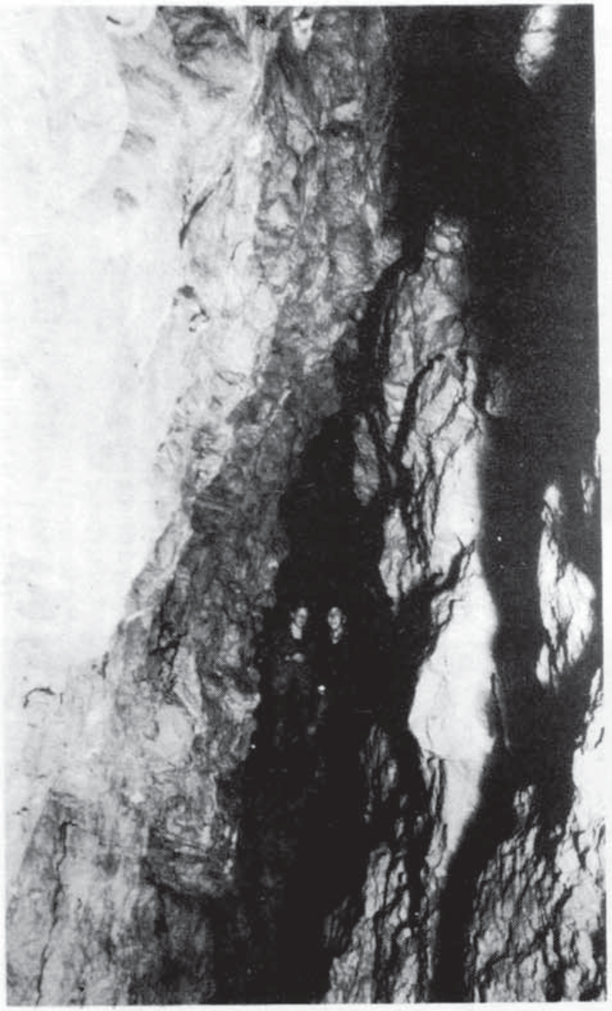


Plate 1. Hambleton and Gowerdale Windypits, North Yorkshire.

3. Noddle End Windypit
(photo : R. H. Hayes).

Plate 2. Ryedale Windypits, North Yorkshire.



1 & 2. Buckland's Windypit

3. Antofts Windypit.

(photos; R. H. Hayes).

13. Gowerdale Windypit 1. (Fig.8)
SE518889 Altitude 990 ft. length c.60 ft. Depth c.110 ft.
References: Anon., 1938; Fitton and Mitchell, 1950; Davies, 1973a; Brook *et al.*, 1974

This is possibly best approached from the bend in the Peak Scar Gill road, i.e. the road from Hawnby to Boltby. A track runs northwards, emerging into an open field. Here the wall is followed to the left, and the first wall running to the right, at right angles, reaches the side of Gowerdale. The windypit is in the next field to the west, about 150 ft. south-west of the wall corner. The first 70 ft. of the descent is straight, although obstructed by occasional boulder bridges against which the ladder hangs. A short slope leads to a further pitch over an oil drum and assorted rubbish to the bottom. The rift is straight with no side-passages, and can be explored for about 60 ft. before it ends in each direction in a blank wall; it is 2 to 3 ft. wide.

The entrance of this fissure is on the flat plateau surface , 185 ft. back from the head of the valley slope of Gowerdale. The opening of so deep a fissure in this position must have involved the movement of an unusually large volume of rock towards the valley.

14. Gowerdale Windypit 2. (Fig.8) (Plate1, Fig.2)
SE518889 Altitude 990 ft. Length c.290 ft. Depth c.90 ft.
References: Anon., 1938; Davies 1973a; Brook *et al.*, 1974.

This windypit lies on the edge of Gowerdale, 150 ft. east of the wall corner described above, in the next field to Gowerdale Windypit 1, within a wire fence. The open entrance hole descends to an earth and rubbish slope ending at a small hole about 20 ft. down. The ladder must be fed through this hole. The pitch then continues down one end of a chamber 8 ft. wide, 30 ft. high and 30 ft. long, with light-coloured walls decorated by small calcite flows. A landing is reached after 53 ft. To the right of the ladder a descending fissure floored with mud can be followed to a zig-zagging lower passage with three sharp bends roughly equidistant from one another. The passage ends in a choke. Back at the bottom of the pitch, holes in the floor lead into a lower chamber beneath, showing that the main chamber floor is formed of wedged blocks. The lower passage ends in blank walls. At the western end of the main chamber a traverse past a hole leads round a bend and through a short crawl to a fissure passage which passes over a 3 ½ ft. step down, to a 6 ft. upwards slope, and then chokes.

15. Motts Hole Windypit (Fig.9)
SE520889 Altitude 950 ft. Length 230 ft. Depth c.70 ft.
References: Anon., 1953; Rider, 1962; Davies, 1973a; Brook *et al.*, 1974.

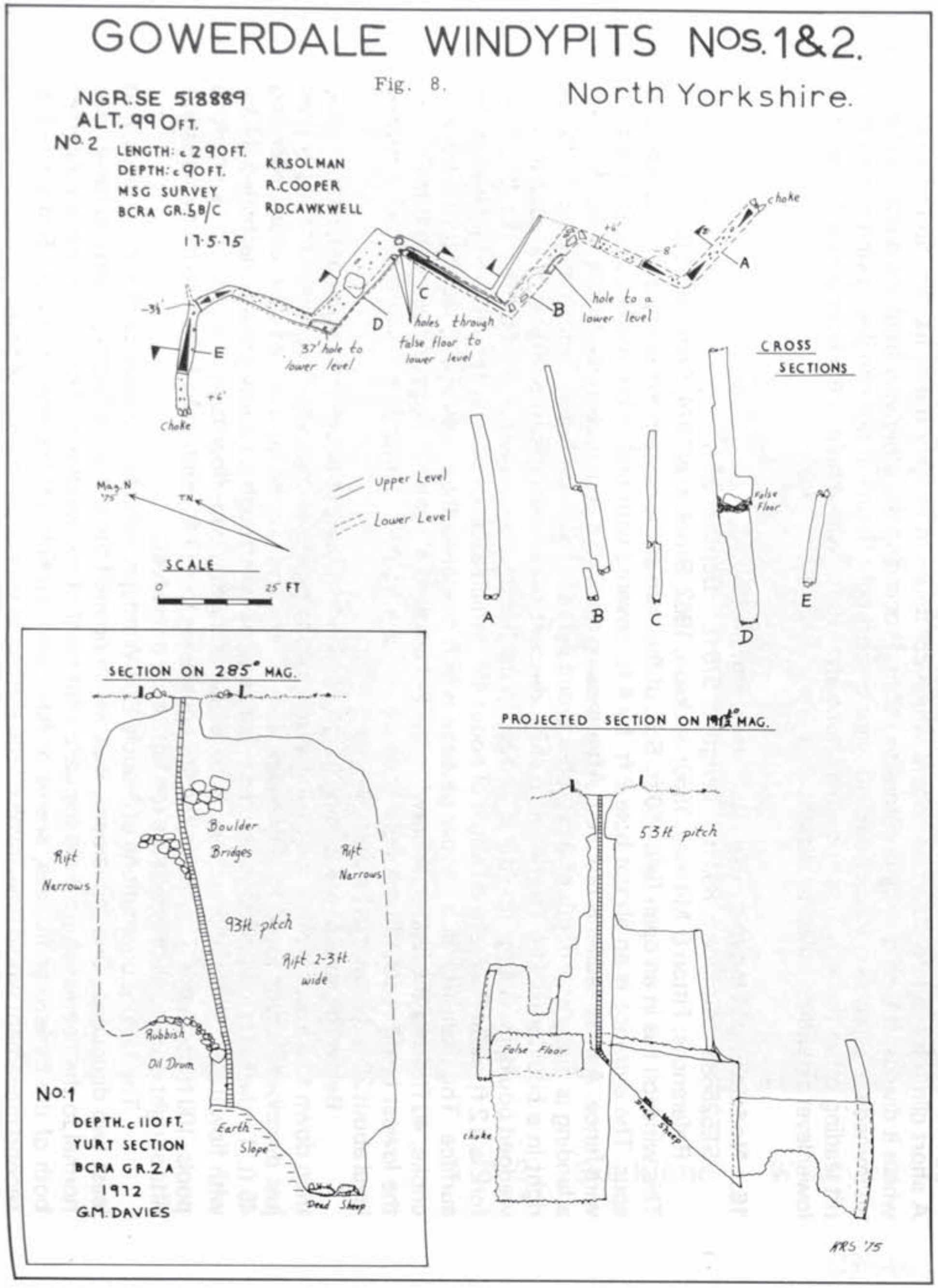
The entrance lies 150 ft. east of Gowerdale Windypit 2, and 60 ft. down the southern slope of Gowerdale, below a dead silver birch tree. A 25 ft. climb into the rift leads to a crawl and a further wriggle through boulders into another fissure with its floor descending steeply to the deepest point. A short climb leads into a narrow fissure which continues in roughly the same direction to a point where it divides. It then quickly becomes too tight. Proceeding the other way from the entrance pitch, an immediate climb over loose boulders gains a short tight fissure at right angles, giving access to a rift leading off to the left. This ends in a choke after 10 ft., with a hole in the floor giving access to a lower level extending the same distance.

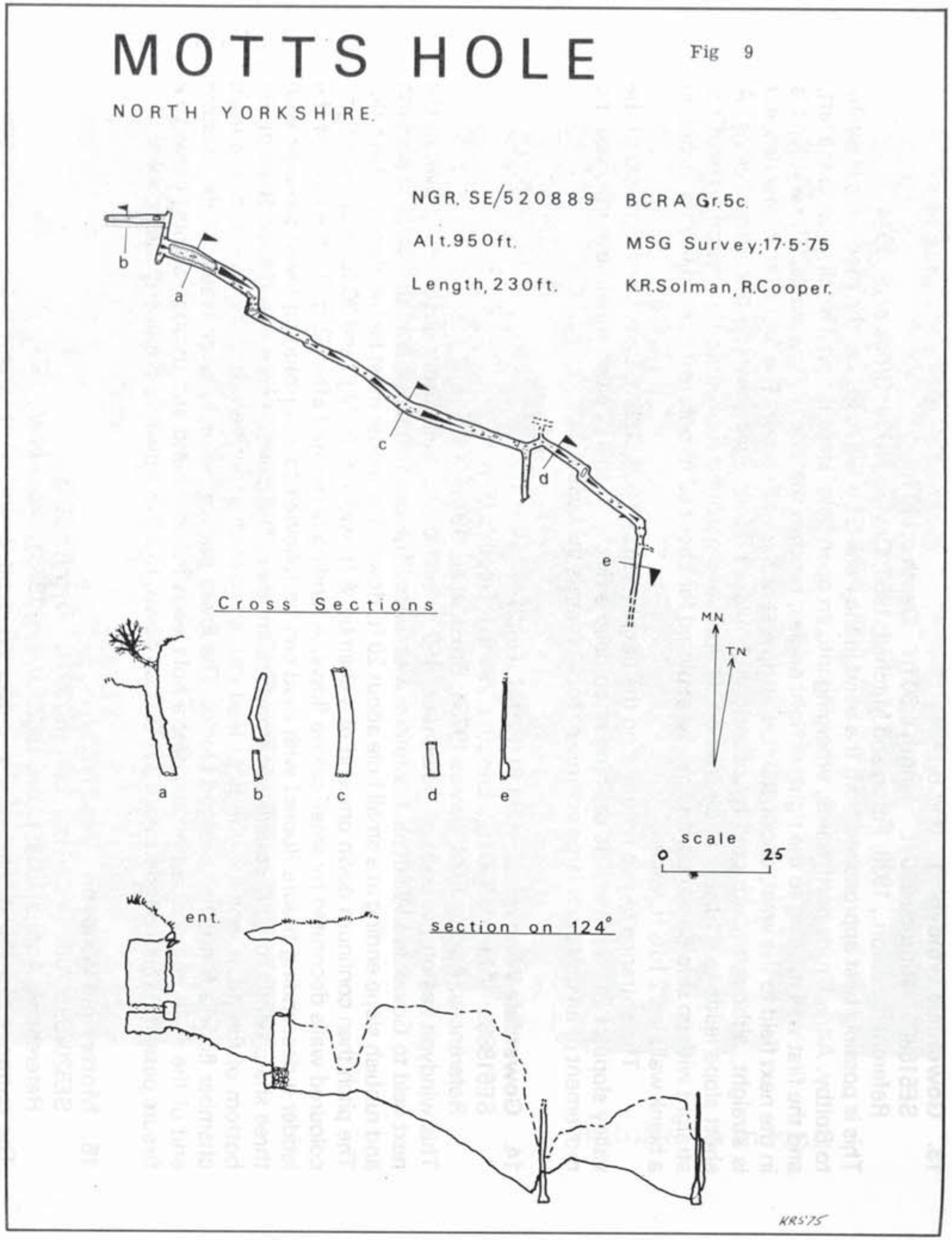
16. Noddle End Windypit (Fig.10) (Plate1, Fig. 3)
SE526886 Altitude c. 880 ft. Length c. 575 ft. Depth c. 95 ft.
References: Fitton & Mitchell, 1950; Jackson, 1962; Brook *et al* 1974; Solman, 1976.

This windypit lies in an open field 150 ft. SSE of the barn at the eastern extremity of the Noddle End spur. The entrance is an abrupt hole 2 ft. by 4 ft. covered with timber but made conspicuous by a wire fence. A 50 ft. ladder is required. After passing through a constriction the ladder hangs free and a landing is made at a depth of 34 ft. on a broad ledge in the main fissure, which ends 15 ft. to the right in a boulder ruckle. To the left a short descent over a detritus slope leads to a solid floor of wedged boulders. A large boulder is wedged in the fissure, beyond which the fissure forks. The right fork is a 2 ft. wide fissure at an angle of about 45^{o}, which ascends steeply to within a few feet of the surface. The main fork is a narrow passage which descends then rises again, leading to a boulder choke, 40 ft. from the ladder. A crawl to the left leads to a fissure at right angles, with three levels, the lowest being reached by a tight squeeze under a boulder. Through holes in the floor a further level about 20 ft. below can be seen.

Below the level of the landing ledge, the ladder pitch continues over some projecting rocks, then down to a lower level of the main fissure, extending in the opposite direction to the upper level just described. It runs for 30 ft. descending to a 'T'-junction. To the right is a narrow fissure extending 45 ft. To the left a long passage reaches a gentle slope up through a narrow passage decorated thickly with flowstone. The boulder-choke floor is also blanketed with flowstone which contains rimstone pools. 100 ft. from the 'T'-junction the floor descends to a 17 ft. pitch, which leads to four interesting rifts at right-angles, all of which are too tight after a few feet.

The fissure orientations of Noddle End Windypit indicate movements of rock masses in at least two directions. One movement, that which opened the entrance fissure, seems to have been normal to the nearest slope, as is the case with most of the windypits. Another movement,opening both of the transverse fissures, seems to have been straight off the end of Noddle End spur. This second movement would have involved the shifting of very large volumes of rock.


GOWERDALE WINDYPITS Nos. 1&2.
Fig. 8.
North Yorkshire.
NGR. SE 518889
ALT. 990 FT.
No. 2
LENGTH: c 290 FT.
DEPTH: c 90 FT.
MSG SURVEY
BCRA GR. 5B/C
K.R.SOLMAN
R.COOPER
R.D.CAWKWELL
17.5.75
choke
A
B
C
D
E
hole to a lower level
holes through false floor to lower level
37' hole to lower level
Choke
Mag. N '75
TN
Upper Level
Lower Level
SCALE
0
25 FT
CROSS SECTIONS
False Floor
SECTION ON 285° MAG.
Boulder Bridges
Rift Narrows
93ft pitch
Rift 2-3ft wide
Rubbish
Oil Drum
Earth Slope
Dead Sheep
No. 1
DEPTH. c 110 FT.
YURT SECTION
BCRA GR. 2A
1912
G.M. DAVIES
PROJECTED SECTION ON 1912° MAG.
53ft pitch
False Floor
choke
Dead Sheep
KRS '75


MOTTS HOLE
Fig 9
NORTH YORKSHIRE.
NGR. SE/520889
BCRA Gr.5c.
Alt. 950 ft.
MSG Survey; 17.5.75
Length, 230 ft.
K.R.Solman, R.Cooper.
a
b
c
d
e
Cross Sections
MN
TN
scale
0
25
ent.
section on 124°
KRS'75

17. Murton Cave (Fig.11)

SE529883 Altitude 750 ft. Length 140 ft.

References: Fitton & Mitchell, 1950; Marr, 1970; Brook, *et al.,* 1974.

This is Fitton and Mitchell's 'Peak Scar Fissure B'. It is situated at Peak Scar, just below the road from Hawnby to Boltby. It opens in a corner of the cliff, where one part of the scar juts out from the rest, about half way along. The entrance is 12 ft. above the bottom of the scar, and is reached by an easy climb, which is nevertheless made easier still by the use of a rope. The fissure runs south-eastwards, subparallel to the face of the cliff. The floor slopes up and then down to the top of a 12 ft. climb down into a lower rift, which is choked in one direction and too tight in the other. Traversing upwards near boulder bridges in the entrance gains a short higher level ending in a blank wall. It is possible, if equipped with climbing gear, to climb the walls of the rift to an exit on the surface above, close to road level (Marr, 1970, p.100).

18. Peak Scar Windypit 1.

SE530883 Altitude c.725 ft. Length c.30 ft.

Reference: Fitton & Mitchell, 1950.

This is Fitton and Mitchell's 'Peak Scar Fissure A'. It lies in the mass of slipped rock, beside the path at Peak Scar, having a large and very obvious entrance. It is formed by one section of the slipped rock mass leaning against another. After about 20 ft. the roof runs down to the floor, and after a crawl of a few feet, chinks of light can be seen entering from the outside.

19. Peak Scar Windypit 2.

SE531883 Altitude c.725 ft. Length c.20 ft.

This also lies in the mass of slipped rock at Peak Scar. Descending the steep path from the forestry gate on the Hawnby to Boltby road, double back behind some outlying tor-like remnants of the slipped rock mass, into a moss-draped gully. The windypit is an obvious hole at the end of this. A wriggle down a few feet leads to a passage about 10 ft. long, ending in blank walls each way.

Clearly the features at Peak Scar represent a sequence, with joints either pre-existing, or being initiated in the hillside parallel to the cliff face, huge individual slabs of rock so isolated moving out from the hill, and eventually tilting forwards. Murton Cave represents a stage in this process where a block (i.e. that part of the present cliff face which is in front of it) has split off and moved out some way, but has not yet tilted. Peak Scar Windypits 1 and 2 are developed in masses which have moved out and tilted over; their situation is very similar to Hill Fort Windypit. The process contrasts with that operative at Whitestone Cliff, where catastrophic cliff falls involve disintegration of the fallen mass into a chaotic boulder field.

D. Ryedale.

The stretch of Ryedale above Helmsley, as the river passes in a gorge through the tract of Corallian rocks, is flat-floored and steep sided. The windypits are all found at the heads of the slopes, just below the hill crests, on the summit convexities at points before the slopes assume their full steepness. There is disturbed ground, i.e. hummocks and hollows, on the surface around each of the windypits.

The second most northerly of the east-west trending tributary valleys of Ryedale is Thorodale. Close to the point where it meets the Rye there are three Corallian outliers: Coomb Hill, Hawnby Hill and Easterside Hill. Coomb Hill is the closest to the main Corallian outcrop and is separated from it by a narrow valley. Overlooking this valley are the Eppy Head windypits, situated on the main outcrop; they are included in this section because their position relative to the slope bears a greater resemblance to the situation of the windypits in Ryedale than does that of the windypits in Gowerdale. The windypits are here described travelling from south to north.

20. Buckland's Windypit. (Plate 2, Figs.1 & 2).

SE588828 Altitude 425 ft. Length c.400 ft. Depth c.195 ft.

References: Buckland, 1823; Anon, 1936a; Fitton & Mitchell, 1950; Mitchell, 1956; Hayes, 1962; Jackson, 1962; Hayes, 1963a 1963c; Brook *et al.,* 1974.

The description given here is based on notes made by N. Coghlan. The windypit is in Duncombe Park, and the present policy of the landowner is to forbid access.

The entrance is surrounded by a wire fence, and lies in open country a few feet uphill from a new forestry track crossing Far Moor Park. A heavy tree trunk has fallen across the entrance and divides it in two. A 25 ft. ladder is required for the larger entrance, but a chain fixed in place at the other entrance can be descended with little difficulty. Both routes lead to a fairly large, light chamber. A short climb and tight squeeze at the bottom of the ladder pitch lead under the entrance pitches, emerging high up in a cross-rift of the Letter-box Fissure. At the other end of the entrance chamber a descent through boulders leads to a junction. To the left a low crawl, the Letter-box, leads into the Letter-box Fissure, a 60 ft. long, 40 ft. high rift choked at one end. There are two cross-fissures part-way along this, the right hand one choked and the left hand one giving access to the crawl from the foot of the entrance ladder pitch. Right at the junction a 40 ft. mud slide followed by a short traverse leads into the main chamber. A fissure leading off to the right chokes after a descent of 10 ft. Ahead a 10 ft. traverse passes over a hole in the floor which by a zig-zag descent reaches the bottom. Above are various dangerous high-level routes among the boulders jammed in the rift.

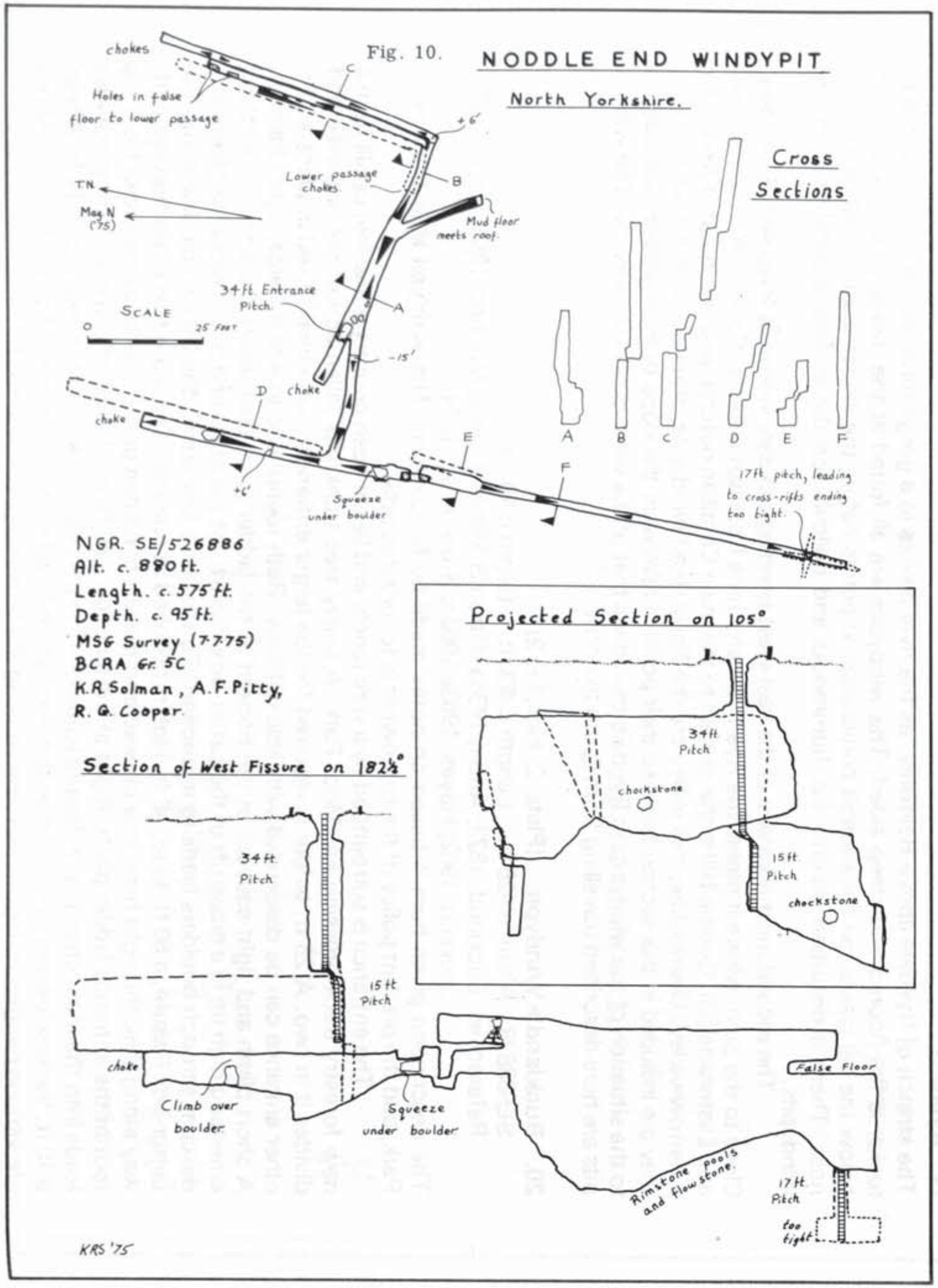


Fig. 10.
NODDLE END WINDYPIT
North Yorkshire.
Cross Sections
chokes
Holes in false floor to lower passage
T.N.
Mag N (75)
Lower passage chokes
Mud floor meets roof.
34 ft. Entrance Pitch.
SCALE
0
25 FEET
choke
Squeeze under boulder
17 ft. pitch, leading to cross-rifts ending too tight.
A
B
C
D
E
F
NGR. SE/526886
Alt. c. 880 ft.
Length. c. 575 ft.
Depth. c. 95 ft.
MSG Survey (7-7-75)
BCRA Gr. 5C
K.R. Solman, A.F. Pitty,
R. G. Cooper.
Projected Section on 105°
34 ft. Pitch
chockstone
15 ft. Pitch
Section of West Fissure on 182½°
Climb over boulder
Squeeze under boulder
False Floor
Rimstone pools and flowstone.
17 ft. Pitch
too tight
KRS '75

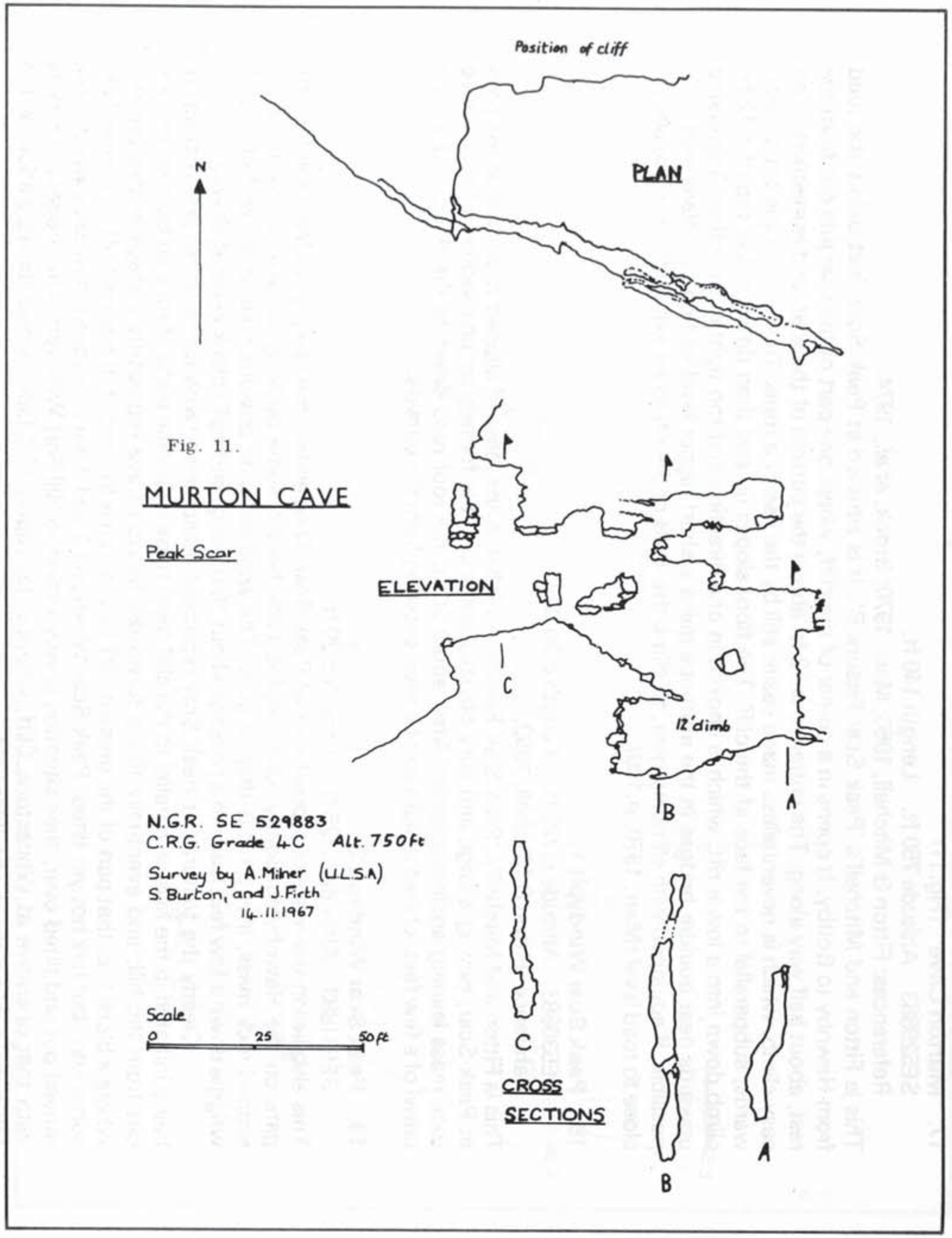


Fig. 11.
MURTON CAVE
Peak Scar
Position of cliff
N
PLAN
ELEVATION
12' climb
A
B
C
N.G.R. SE 529883
C.R.G. Grade 4C Alt. 750 ft
Survey by A. Milner (U.L.S.A)
S. Burton, and J. Firth
14.11.1967
Scale
0
25
50 ft
CROSS SECTIONS

Fig. 12.

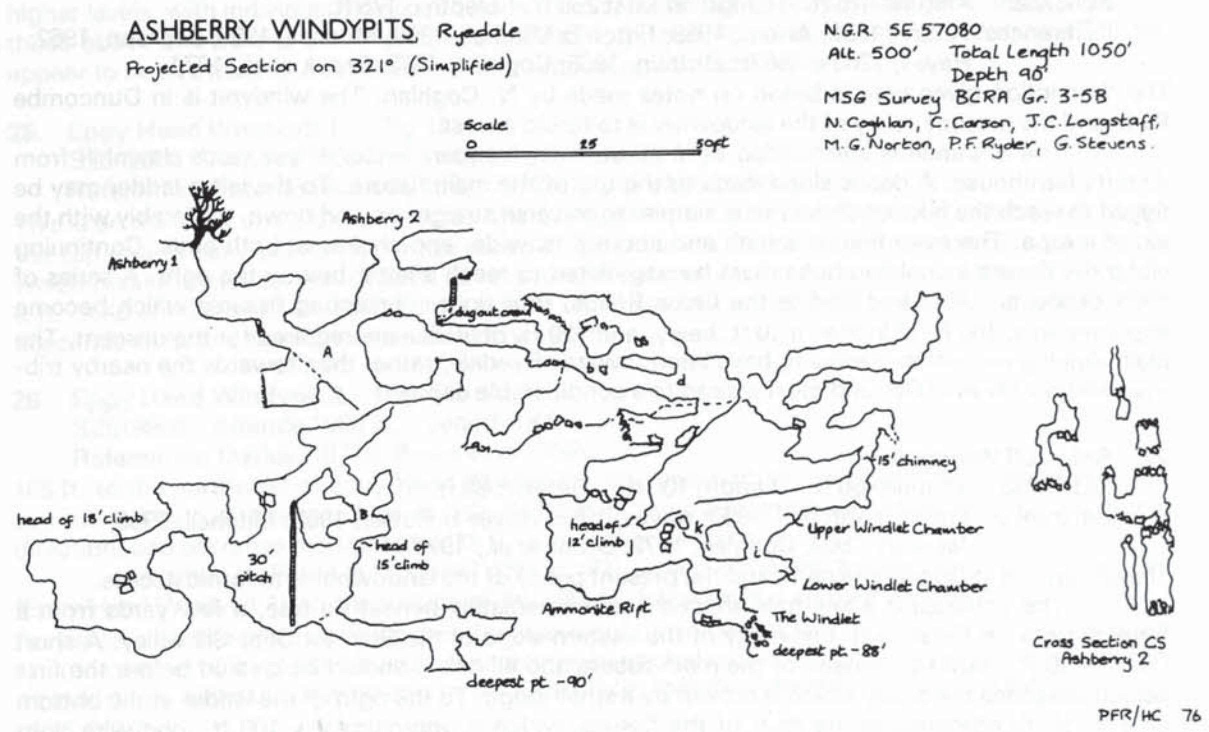
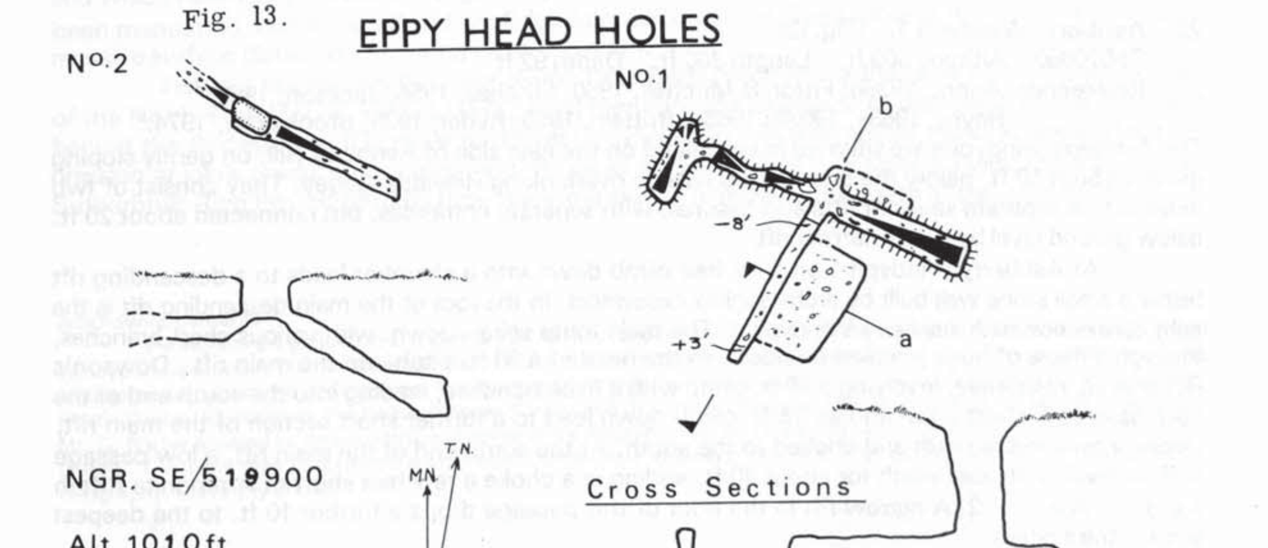

ASHBERRY WINDYPITS, Ryedale
Projected Section on 321° (Simplified)
N.G.R. SE 57080
Alt. 500'
Total Length 1050'
Depth 90'
MSG Survey BCRA Gr. 3-5B
N. Coghlan, C. Carson, J.C. Longstaff,
M.G. Norton, P.F. Ryder, G. Stevens.
Scale
0
25
50ft
Ashberry 2
Ashberry 1
15' chimney
head of 18' climb
head of 15' climb
30' pitch
head of 12' climb
Upper Windlet Chamber
Lower Windlet Chamber
Ammonite Rift
The Windlet
deepest pt. -88'
deepest pt. -90'
Cross Section CS Ashberry 2
PFR/HC 76

Fig. 13.


EPPY HEAD HOLES
No.2
No.1
-8'
+3'
a
b
NGR. SE/519900
Alt. 1010ft.
Length. 20ft.
BCRA, Gr 2b
MSG Survey. 18·7·75
KRSolman, RCooper.
MN
T.N.
0
10ft.
Cross Sections
a
b
KRS'76

The hill in which this windypit is situated is broken up into a pattern of large distinct blocks, which can be seen clearly from the Cleveland Way footpath on the other side of the valley. Various sections of the hill have subsided towards the valley in different directions, and the underground spaces produced must include fissures running in several directions.

21. Antofts Windypit. (Plate 2, Fig. 3)
SE582829 Altitude 475 ft. Length at least 250 ft. Depth c.175 ft.
References: Anon., 1936; Anon., 1938; Fitton & Mitchell, 1950; Mitchell, 1956; Jackson, 1962; Hayes, 1963a, 1963c; Brittain, 1965; Coghlan, 1972; Brook *et al.,* 1974.

The description given here is based on notes made by N. Coghlan. The windypit is in Duncombe Park, and the present policy of the landowner is to forbid access.

The entrance is surrounded by a stout, high wooden fence, a few yards downhill from Antofts farmhouse. A debris slope leads to the top of the main fissure. To the left a ladder may be rigged to reach the bottom direct but is simpler to traverse straight on and down, preferably with the aid of a rope. The main fissure is high and about 8 ft. wide, and chokes at both ends. Continuing along the fissure a boulder choke must be negotiated to reach a letter-box on the right. A series of short descents follow and lead to the Cross Roads, four tight intersecting fissures which become imprenetrable. 100 ft. of ladder, a 10 ft. belay, and 120 ft. of lifeline are required for the descent. The main slipping movement seems to have been towards Ryedale, rather than towards the nearby tributary valley of Sword Gill, and must extend to a condiderable depth.

22. Snip Gill Windypit.
SE575836 Altitude 500 ft. Length 100 ft. Depth c.80 ft.
References: Fitton & Mitchell, 1950; Hayes, 1955; Hayes & Rutter, 1955; Mitchell, 1956; Jackson, 1962; Coghlan, 1972, Brook *et al.,* 1974.

The windypit is in Duncombe park, and the present policy of the landowner is to forbid access.

The entrance is a key-hole shaped hole immediately beneath a tree, a few yards from a forestry track on the summit convexity of the eastern slope of the Snip (or Slip) Gill valley. A short climb of 10 ft. leads to the head of the main fissure and all debris should be cleared before the first person descends the pitch, which is broken by a small ledge. To the right of the ladder at the bottom an 8 ft. climb descends to the floor of the fissure, which is approximately 100 ft. long with tight crawls at both ends. A small passage can be gained by leaving the ladder halfway down; this re-enters at the foot of the main fissure. 60 ft. of ladder are required, with a 40 ft. belay and an 80 ft. lifeline. A narrow oblique fissure, 18 inches wide, enters the main fissure on its northern side.

The main fissure of the windypit is virtually at right-angles to the contours of the Snip Gill valley, suggesting that the main movement has been off the end of the Hollins Wood Spur, towards Ryedale itself rather than towards Snip Gill. Therefore the situation resembles that implied by the arrangement of the fissures at Noddle End Windypit.

23. Ashberry Windypit 1. (Fig.12)
SE570850 Altitude 500 ft. Length 360 ft. Depth 92 ft.
References: Anon., 1936b; Fitton & Mitchell, 1950; Mitchell, 1956; Jackson, 1962; Hayes, 1963a, 1963b, 1963c, Brittain, 1965; Ryder, 1973; Brook *et al.,* 1974.

The Ashberry windypits are situated in woodland on the east side of Ashberry Hill, on gently sloping ground about 10 ft. below the crest of the hillside overlooking Rievaulx Abbey. They consist of two more or less separate series of rifts and fissures, with separate entrances, but connected about 20 ft. below ground level by a very narrow rift.

At Ashberry Windypit 1 an easy free climb down into a chamber leads to a descending rift below a small stone wall built by archaelogical excavators. In the roof of the main descending rift is the tight connection with Ashberry Windypit 2. The main route spirals down, with various short branches, through a maze of huge jumbled boulders, to the head of a 30 ft. pitch into the main rift . Dowson's Route is an alternative, involving a 15 ft. climb with a fixed handline, leading into the south end of the main fissure. A short crawl and an 18 ft. climb down lead to a further short section of the main rift, closing down to the north and choked to the south. At the south end of the main rift, a low passage at floor level continues south for about 40 ft, ending in a choke a few feet short of Ammonite Rift in Ashberry Windypit 2. A narrow rift in the floor of this passage drops a further 10 ft. to the deepest point in the system.

24. Ashberry Windypit 2. (Fig.12)
SE570850 Altitude 500 ft. Length 690 ft. Depth 88 ft.
References: Ryder, 1973; Brook *et al.,* 1974.

This has a smaller entrance 30 ft. south of the gaping crater of Ashberry Windypit 1. It was long thought to consist of a single chamber only, with its narrow connection with Ashberry Windypit 1. However, in 1971 a local archaeological society, digging in this chamber, broke through into a considerable series of further passages and chambers. At present the way into these chambers has once more become blocked. The small entrance drops 12 ft. into a roomy chamber; a handline or short ladder is convenient. To the north is the narrow fissure connecting with Ashberry Windypit 1, and to the south is a strongly draughting slot at the foot of the chamber wall, which leads into the 'new series'.

The slot drops into a low bedding plane crawl, which, becoming roomier, opens to a 4 ft. drop down into a low boulder-strewn chamber with three ways on. The ensuing complexity is clear from the survey (Fig.12). A full description was given by Ryder (1973).

The slipping that has taken place in the formation of the Ashberry system appears to have been not quite at right angles to the joints or pre-existing fissures in the rock, and thus a zig-zag plan has resulted (Davies and Ryder, 1973). The same pattern of slipping is also seen in the more complex higher levels, with individual blocks of hillside moving in various directions, not necessarily parallel to those above and below, between different bedding planes. In parts of Ashberry Windypit 2 there appear to be two more or less parallel rifts running alongside each other.

25. Eppy Head Windypit 1. (Fig.13)
SE519900 Altitude 1000 ft. Length 12 ft. Depth 18 ft.
References: Fitton & Mitchell, 1950; 1973b; Brook *et al.*, 1974.

This is on the brow of the steep forested hillside opposite the ruins of Coomb Hill Cottage, just above the top of a forestry plantation. It has an open, pothole-like entrance, surrounded by a wire fence, which makes it easy to find. A walk down a boulder slope reaches the bottom of the entrance rift, 8 ft. deep and open to the sky. To the right a crawl chokes immediately, while to the left a fissure descends 10 ft. to a small chamber with no way on.

26. Eppy Head Windypit 2. (Fig.13)
SE519900 Altitude 1000 ft. Length 18 ft.
References: Davies, 1973b; Brook *et al.*, 1974

165 ft. to the northwest of Eppy Head Windypit 1, and at a slightly higher level, this windypit is also surrounded by a wire fence. A small hole drops 3 ft. into a fissure which chokes immediately in one direction, and becomes too tight after 12 ft. in the other direction.

As noted by Fitton & Mitchell (1950, p.182), 'a sort of natural terrace runs SE from the hole (Eppy Head Windypit 1) on the surface of the hillside, following the contour and apparently overlaying the fissure'. This seems to indicate that the valleyward movement of rock of which these windypits are symptomatic, is of far greater lateral extent than is suggested by the windypits alone. However, there is no indication, either in the windypits or on the surface, that the movement in this area extends to any great depth.

Comments.

It had been hoped to present new surveys of the windypits in Duncombe Park (i.e. Buckland's, Antofts and Snip Gill Windypits) with analyses of their form. This proved impossible as surveying activities were forbidden by the Duncombe Park Estate Office. These windypits are the deepest known, and their geomorphological significance is considerable.

The Hambleton Hills still contain several areas where it is likely that windypits will be found, and which have not yet been thoroughly explored with this aim. The south side of Caydale has already been mentioned, and the south side of Eskerdale, below Arden Great Moor in the north, has suffered massive surface disruption, meriting close attention.

Fissures not formed by water action have been found in another area of the Corallian tract of the North York Moors: Palmer (1973, p.58) mentions the existence of 'trenches' on the moor just behind the Bridestones, 6½ miles north-east of Pickering. He interpreted these as the surface expression of joints produced by cambering. Brook *et al.*, (1974, p.141) described a windypit-type fissure, Sutherbruff Rigg Pot (SE861867) from the same area, 2½ miles to the south of the Bridestones.

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Excavations in a Cave on Raven Scar, Ingleton, 1973-5

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The phenomenal response to my appeal, which appeared in an earlier issue of B.C.R.A. *Bulletin* (Gilks 1975), for information on the present location of previously unpublished and/or inadequately documented finds of human remains and material evidence, especially of Later Neolithic and Early Bronze Age date, from British caves, has prompted me to publish this short account (a detailed, illustrated, interim report will be appearing in the *Antiquaries Journal* in 1977) of some significant discoveries which have been made by two spelaeologists, turned amateur archaeologists, in a newly discovered cave in the Craven Highlands of North West Yorkshire.

The cave discovered in May 1973, by George Hollinshed, of Ingleton, is located high up in the steep face of Raven Scar (SD 73070757), a north-westerly facing Carboniferous Limestone escarpment which runs north eastwards from Ingleton to Chapel-le-Dale, at about 320m. above sea level. Mr. Hollinshed subsequently reported the finding of the cave (hereafter referred to as the Raven Scar Cave) to Bob Danson and Bill Dickinson, of Preesall, near Blackpool, who were working on the geological deposits in a nearby fissure at the time. They made a reconnaissance visit in June and this was followed, in early September 1973, by an exploratory excavation which yielded many small fragments of animal and human bone and numerous teeth, but no dating evidence.

There were few modern disturbances, either inside or immediately outside the cave, and test-holes dug to the top of a clay horizon, just inside the entrance to an inner chamber, produced more faunal and human remains. The investigators had established, with some degree of precision, that there was a fairly even distribution of archaeological material in the floor of the cave which could only be satisfactorily recovered by total excavation. Three seasons have been devoted to only a small section of the cave complex, though a considerable amount of valuable material, mainly of Later Neolithic and Early Bronze Age date, has been recovered. A further three seasons will be devoted to clearing a length of low passage at the rear of the cave, and I hope to be able to present the results of this work in a future Transactions.

Excavations 1973-5

At the commencement of excavation, late in 1973, access to the cave system was by way of a small hole, about 0.5m. square, in the rock face, which opened into a lofty north-west/south-east aligned chamber, 2.8m. wide, 4m. long and 9m. high. A passage, 1.2m. wide at the opening, narrowing to 1m., 1.2m. from its mouth, led back from the south-east corner of the chamber to a second, roughly north-south orientated, passage, 1.4m. wide, 14m. long and 1.5m. high. Covering the archaeological material and forming the floor of the cave when initially found was a layer of calcite, which in places had a very hard crust. There were numerous small shale fragments and water-rolled pebbles lying on its surface and amongst the debris in the chamber were several fragments from the stem of probably a late seventeenth century clay tobacco pipe and a series of copper-alloy objects, which include nine dome-shaped studs (possibly decoration from a ? leather belt) four flat pieces and lump of metal. It is not possible to date the studs with any degree of precision, though their association with the pipe fragments does suggest a post-medieval, possibly late seventeenth or early eighteenth century, dating. These finds are of some significance, as they provide incontrovertible evidence for the cave having been entered at this time. As no disturbances were noted in the calcite floor, it is presumed that entry on this occasion was not related to archaeological activity, but merely to satisfy the discoverer's curiosity.

The first objective was to make the cave more accessible, as it was almost impossible to manipulate even the smallest spoil container through the narrow entrance. Conditions in the cave were not conducive to working; the lighting was poor and it was exceptionally muddy, particularly on the west side of the chamber where a small fast-flowing stream, which issued from the passage system during periods of heavy rain, had carved a broad, shallow, channel in the cave floor; this caused considerable concern, as the excavations were repeatedly flooded and took many weeks to dry out.

It soon became apparent, after the removal of several tonnes of limestone debris from below and beyond the constricted entrance to the chamber, that the original cave mouth had been appreciably deeper and wider and that the existing size was not due to roof fall but to the presence of two large, vertical, pear-shaped, blocks of limestone (feature 1), each measuring 1.5m. high, 0.45m. square at the base, tapering to 0.45 by 0.3m at the top, which had been placed side-by-side in the opening. A portion of the limestone filling, which sloped away from the slabs at an estimated angle of 40 degrees, had been retained on the west side for recording and sampling purposes. A detailed examination of the exposed face showed that it was not a single uniform deposit, but a series of ill-defined, almost horizontally bedded, layers of medium to large, angular limestone fragments, with a total depth of 1.25m.; the sequence was capped by a deposit of smaller, but more angular, blocks on top of which had developed a thin scree soil, whilst at the bottom, was a paved zone, which in turn rested on 0.25m. of limestone rubble.

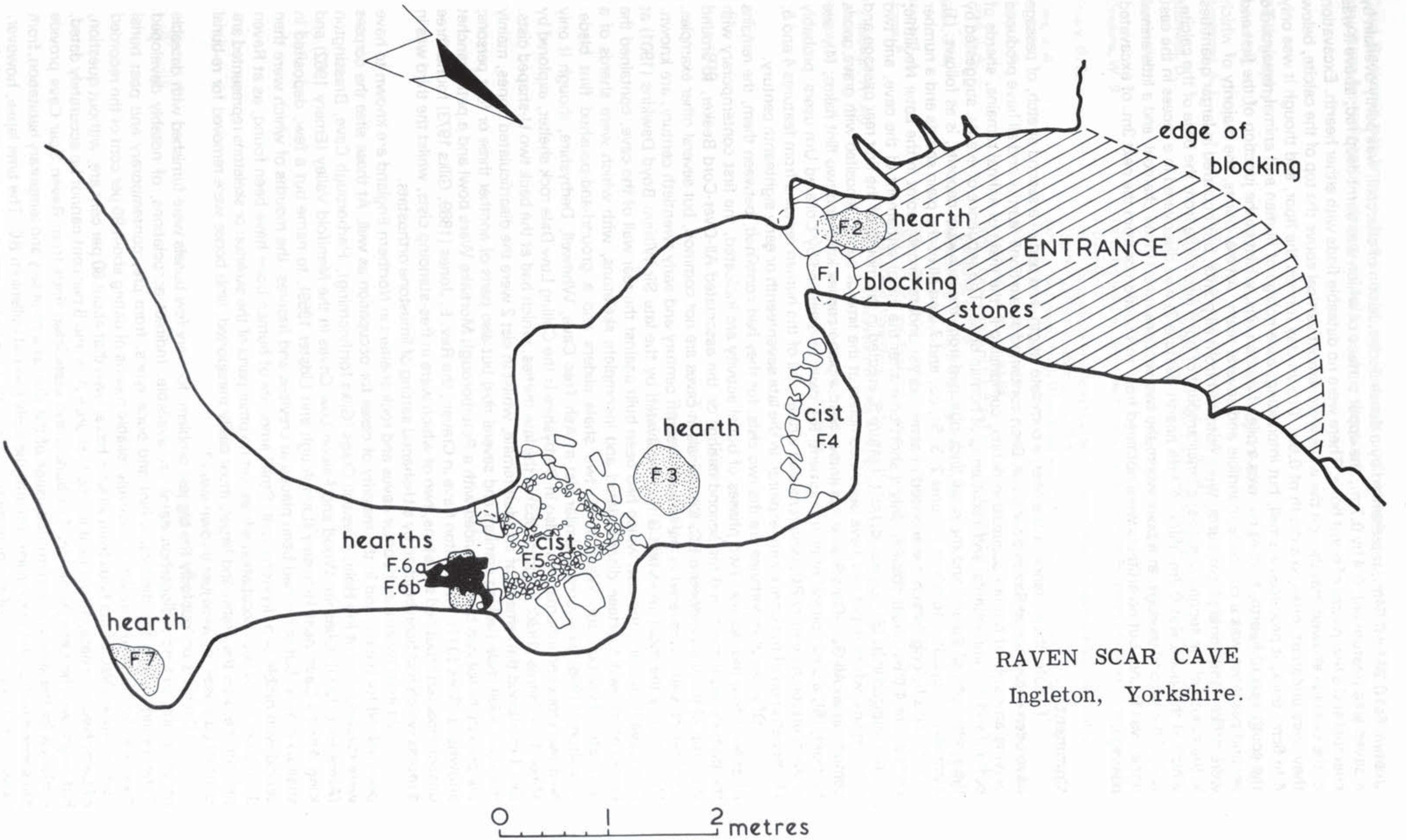
Apart from the thin covering of, presumably frost-shattered, limestone fragments, probably all of the lower layers, and without question the paved area, were laid by man. But why? Why should anyone want to seal the mouth of this cave? The answer to this question is provided by the finding, at the entrance and in the pilot-trenches cut in the chamber, of human remains, which clearly attest that the site had been exploited for burials. The sealing of the entrance, in a manner comparable to that identified at a number of megalithic tombs, probably took place shortly after the last corpse or corpses had been interred in the chamber, presumably to prevent others from using it for burials and/or occupation and to exclude predators. Evidence of blocking, though not of a directly comparable nature, was found at Dowel Cave (Bramwell 1959) and Fox Hole Cave (Bramwell 1971), Derbyshire, where total excavation has shown that both sites had been utilised, in the Later Neolithic and Early Bronze Age, for mainly funerary purposes, though the presence of small amounts of human refuse, including animal bones (many split and burnt), fragments of pottery and bone and flint implements, suggest some settled occupation of these sites, but whether this material was deposited at precisely the same time as the instruments, cannot, owing to the dispersed nature of the finds on both sites, be satisfactorily demonstrated.

The blocking device identified at the entrance to Raven Scar Cave, whose function had for some time evaded the excavators, could now, on the external comparative evidence for blocking, be explained, as it was abundantly clear that the style of the mechanism employed to seal it, and the two more fully excavated Derbyshire sites, were, as noted above, almost identical in both plan and elevation to the structures used to block the ends of the passages in some of the formal tombs, in both the Peak District of Derbyshire and North Staffordshire and elsewhere. The blocking of tomb passages was normally only carried out when the chamber or chambers and/or approach passage would not take further interments, or it was considered unsuitable for future use as a tomb. Clearly caves, and to some extent rock shelters, were seen as ready made sepulchres, the majority of which, like the chambered tombs, were used, often over an unknown length of time, for successive collective burials; when little, or no more, floor space was available, as at Dowel where at least ten individuals had been deposited in the cave floor, or it was felt that a new site would be more desirable for future exploitation as a cemetery, it was blocked, thus denying members of a different social group the right to utilise it, either for funerary or occupation purposes.

Now that it had been established, beyond reasonable doubt, that Raven Scar Cave had been used as a cemetery, presumably at about the same time as Dowel and Fox Hole, and following the removal of the retained section of blocking material at the entrance to the cave, several months were then devoted to stripping the calcite to expose the underlying brown clay horizon. The stream, which reached its highest level in winter and early spring, was controlled by a dam, which had been constructed across the mouth of the first passage, and by piping the water from it to just beyond the cave opening. The clay zone, which varied in thickness from 15 to 30cm., contained, as suspected by the large number of animal bones which had been obtained from the exploratory cuttings, particularly in the centre of the chamber, a mass of faunal material and about forty human teeth, many fragments of major and minor bones, a crushed mandible and several pieces of skull. Mixed with the remains, and presumably in a residual context, were four small unweathered sherds, three from at least two plain Later Neolithic bowls with heavy flat-topped rims and almost vertical sides; the fourth piece, which bears external finger-pinched rustication, might well be from a Beaker; there were also five fragments from a second Beaker, of All-Over-Cord type, which dates to around 2000 BC, and a small sherd from the lower part of the collar of a Collared Vessel which, on stylistic grounds, is ascribable to the Primary Series in the Collared Urn tradition, and probably dates to the fourteenth or thirteenth century BC. There was also a scattering of flint scrapers, mainly of end and convex types, a tanged-and-barbed arrowhead, and a perfectly preserved bone whistle. The bulk of the human debris was found in close proximity to a small hearth (feature 3), which lay close to the north wall of the chamber, represented by a patch of burnt soil and stones and charcoal. A second hearth (feature 2), which produced considerably more charcoal, was found in the entrance, immediately under one of the blocking stones; no finds, apart from a few splinters of animal bone, were recovered from the surrounding area.

Two features of considerable importance were uncovered during 1975 and 1976. Against the north wall of the chamber was an arc of edge-set limestone slabs (feature 4) defining an area approximately 0.54 by 1.36m., whilst in the mouth of the first rear passage was a trapezoidal-shaped cist (feature 5), 1.26m. wide at the broader end, tapering to 1m., by 1m. in length, of similar construction to the first but with one wall made of a double row of blocks and slabs and a partially paved floor of small, angular, limestone fragments. Feature 4, which was filled with the same type of clay as that found in the rest of the chamber, had at the bottom four joining fragments from a human cranium, two broken limb bones, two pieces of deer antler (species not yet identified) and a boar tusk. Feature 5, however, was not wholly filled with clay, but with a series of thin calcite bands interspersed by thicker layers of water-deposited brown clay, which unlike that found in the first cist and on the chamber floor, was completely stone free. From near the bottom came parts of a second crushed cranium, two broken limb bones and twelve teeth; with the remains were a much fragmented amber bead with a cylindrical perforation, two flint flakes, a plano-convex flint knife, a sherd from the All-Over-Cord Beaker and a piece of plain, possibly Later Neolithic, ware.

Feature 5 was found, on removal, to have been built directly on top of a silted-up depression, 0.4m. deep, which ran back for the whole width and length of the passage, a distance of 3.6m. On the floor of the depression, at the mouth of the passage, were two superimposed hearths; the lower,



RAVEN SCAR CAVE
Ingleton, Yorkshire.

(feature 6a) 0.26 by 0.54m., represented by a dense accumulation of charcoal, was partly overlain by a paved area (feature 6b), 0.4 by 0.7m., the upper surface of which was burnt deep red; above it was charcoal and a few pieces of burnt bone. There were no dateable finds with either hearth. Excavation of the passage showed that though the walls were almost vertical above the top of the calcite, below they were undercut, often to a depth of 0.6m. Brown clay formed the floor, and though it was only 4 to 6cm. thick, it produced a small, but interesting, assemblage of human and animal remains. To the south-east of hearth, feature 6a, was a pile of human ribs, whilst at the junction of the first and second passages was a complete mandible and several teeth. Animal bones, the majority of which were broken and some pieces burnt, were obtained from all points, but occurred in larger quantities in the mouth of the second passage; a small amount of bone also came from the base of the calcite, which at this point was 0.7m. thick. A fifth hearth (feature 7) was discovered in a recess in the east wall of the second passage, at a point where the two sections meet; much charcoal, and a little animal bone, was found, but no artifacts were obtained from this section or from the next 3m. of excavated passage.

Comment

To date, the entrance, a chamber, a complete length, and part of a second stretch, of passage have been excavated at Raven Scar Cave. Each contained at least one feature and all have produced varying amounts of human occupation debris, comprising in the main of animal remains, sherds of pottery and flint implements, and a scattering of human bone. The sequence of events, suggested by the stratigraphy of the site and the small finds obtained from the individual deposits, is as follows: (1), a primary occupation, to which features 2, 3, 6a, 6b, and 7, and all of the plain sherds and a number of flint tools belong, which commenced at some, as yet undetermined, point in the Later Neolithic; (2), feature 4 (cist), built possibly only a short time after the initial settlement of the cave, and two bodies interred in it; (3), trapezoidal cist, feature 5, erected in the mouth of the first rear passage and two corpses, which might well have been incomplete at the time of burial, deposited with grave goods comprising an All-Over-Cord Beaker, an amber bead,a plano convex knife and two flint flakes; (4), site blocked; (5), a short period of abandonment; (6), cave re-occupied by Collared Urn users, probably in the fourteenth century BC, who removed virtually all of the human remains from features 4 and 5; (7), penetration of the cave by an 'explorer' in the late seventeenth or early eighteenth century.

Of especial importance are the two cists, for they had contained, between them, the remains of at least four individuals. Two phases of burial activity are indicated, the first contemporary with the primary settlement, and the second dating, on the associated All-Over-Cord Beaker, to around the close of the third millenium BC. Cist burials in caves are not common, but several other examples, all of which were excavated in the late nineteenth century and early twentieth century, are known. Undoubtedly the most important is that excavated by the late Sir William Boyd Dawkins (1901) at Gop Cave, Flintshire; the cist, which had been built against the rear wall of the cave, contained the bones of at least fourteen disarticulated and incomplete skeletons, with which were sherds of a decorated Peterborough Ware bowl, two shale sliders and a ground-and-polished flint blade. Armstrong (1956) excavated a similar cist at Ash Tree Cave, Whitwell, Derbyshire, though it only held two crouched inhumations. Also in Derbyshire is the Calling Low Dale rock shelter, explored by Major T. A. Harris (1938; Piggott 1953) in the late thirties, which had at the back two U-shaped cists. Cist 1 contained the remains of an adult female, whilst in cist 2 were the disarticulated bones, mainly from one adult male (lacking cranium and several ribs) but also parts of another three or four persons; the primary burial had been provided with a Peterborough Mortlake Ware bowl and a petit-tranchet arrowhead (Gilks 1971). At Elbolton Cave in Craven, the Rev. E. Jones (1889; Gilks 1973) found three unaccompanied crouched skeletons, two of which were in free-standing cists, whilst the third was in a recess which had been blocked by a U-shaped setting of limestone orthostats.

At least twenty-eight other caves and rock shelters in Northern England are known to have been utilised for burials, and in the majority of cases for occupation as well. At these sites the corpses were invariably, as at Pin Hole, Creswell Crags (Gilks forthcoming), Harborough Cave, Brassington (Armstrong 1923), Cheshire Wood and Falcon Low Caves in the Manifold Valley (Emery 1962) and King Alfrid's Cave near Helmsley (Lamplough and Lidster 1959), to name but a few, deposited in shallow graves, but some had been placed in crevices and fissures, the mouths of which were then sealed with rubble or a drystone wall. Small amounts of human bone have been found, as at Raven Scar Cave, mixed with occupation refuse, yet no other parts of the skeleton or skeletons represented are present. Perhaps the crania and larger, more easily transported, limb bones were removed for re-burial or ritual purposes, or were just thrown away?

Dating is undoubtedly the biggest problem, for very few burials were furnished with dateable grave goods and no radiocarbon dates are available. Indirect associations, of notably developed Peterborough Ware and distinctive flint and bone types, from pre, contemporary and post burial contexts, do, however, provide a relatively reliable means of dating about 95 per cent of the recorded burials. An analysis of the finds from all sites has shown that about 80 per cent are, without question, of Later Neolithic date, 15 per cent are Early Bronze Age and 5 per cent cannot be accurately dated, but might well be Later Neolithic. The burials and associated finds from Raven Scar Cave provide evidence for the almost uninterrupted usage of the site, as a cemetery and temporary habitation, from the second half of the third millenium into the early second millenium BC. The time lapse, however, between the deposition of the primary burials and those which were accompanied by the All-Over-

Cord Beaker is not known, but it is hoped that charcoal samples taken from the two funerary structures for radiocarbon dating will help to clarify this point.

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The Strength of Bolt Belays.

by J. J. Childs.

Summary

In order to withstand all "reasonably expected eventualities underground", it is necessary for a belay to safely withstand at least ¾ ton suddenly applied force.

Laboratory tests have been carried out on a small selection of bolts detailed in this article. Some bolts in use are unsuitable as belays. Design features are discussed and conclusions reached about the best systems.

Introduction

Between 1965 and 1967, when I was actively caving in the Craven area, I took on the job of replacing some old beams used as belays for ladder pitches. Some of these were replaced by beams, some by rawlbolts, and at about the same time, several other rawlbolts were inserted underground.

In December 1968 an article by me appeared in the Speleologist entitled: "Artificial belays in caves and potholes". Since then, I have had an opportunity to inspect the condition of most of the beams and bolts for which I was responsible and I shall be commenting on this matter. Secondly, I have had additional tests done on a variety of types of eyebolt and the main object of this article is to record the information gained in these tests. But I make no apology for restating some of the salient points I made in my previous article.

In this article I propose, firstly to establish just how strong belays have to be, and then to indicate which bolt systems conform to the most severe requirements.

In normal caving practice belays at the head of a pitch are used in the following ways:

1. **As a belay for a ladder.** A permanent belay (over which use is not controlled) should be capable of withstanding the weight of **at least** two heavy men plus equipment — there are occasions when one man has to go to the aid of another. Moreover, as a man steps onto the ladder a load greater than his weight is temporarily developed. Nevertheless, one would not normally expect the belay to have to hold more than about 800 lbs.
2. **As a belay for a double lifeline.** It is common practice for the last man down a pitch and the first man up to be lifelined from below through a pulley or karabiner suspended from a belay (or less desirably from a ladder rung) at the head of the pitch.

If the climber, weight W, slips and the lifeline is being properly managed, the belay has to hold 2W. (In case of a frictionless pulley the climber's weight W is balanced by W exerted by the lifeliner). In my experience descents on double lifelines pose few problems but often, on returning to a pitch, the line is found not to run freely. Suppose a man climbs double lifelined and for some reason slack accumulates (particularly likely to occur on a wet pitch, noise causing lack of communication and discomfort causing the climber to ascend faster than the slack is taken up). Supposing now that the man slips:

For a highly theoretical situation in which the bottom end of the rope is held **rigidly** (static belay) and the pulley at the top frictionless, the forces developed can be calculated using the theory outlined in "The theory of belaying" by Arnold Wexler (published by the Mountaineering Association). These forces depend upon the weight of the man, the ratio of the height fallen to the length of rope available to absorb the shock and also upon the elasticity of the rope. The maximum tension developed in the rope

$$P = W + W\sqrt{1 + \frac{2kH}{WL}}$$

where W = the weight of the man, H = the height fallen prior to the rope absorbing the shock, L = length of rope available to absorb the shock and k = a constant for the particular rope. k depends upon the elastic properties of the rope, *i.e.* upon the material, the lay and the thickness.

$$k = P \div \frac{x}{L}$$

where x = the elastic extension of the rope, initial length L under stress P.

Even using nylon ropes, the forces developed for "static belay" conditions are large — thus a 150 lb man falling freely for only 5 feet onto a 50 foot 1 3/8" diameter nylon rope (H/L = 0.1). (figure 1) would cause a force to be developed in *each arm of the rope* of approx. 600 lb. (Wexler calculates 620 lb.) The total force on the pulley and belay = 2 × 620 = 1240 lb! For the same situation but using 1½" diameter manilla rope the force = 2 × 920 lb. Using dummies and an instrument called a dynamometer which measures impact loads, the theory can be shown to *approximate* the truth. In practice, the men at both ends of the rope are slightly resilient and of course in practice also the stresses developed are limited by the retarding force that the belayer can exert. Should the second man not be anchored the retarding force is limited by his own finger strength or weight depending upon how he is holding the rope. A snatch load may then cause some rope to slip through the belayer's fingers. The falling man is arrested more gradually and the forces developed in the rope are smaller than they would have been for "static belay" conditions. But should the belayer be anchored in such a way as to resist an upward pull, he may then be capable of exerting a very considerable force — 600 lb. or more being quite feasible (Cumming and Slessor, 1957). Using a double line through a pulley system he might therefore arrest the 150 lb. man who had fallen onto nylon rope in the first example (H/L = 0.1) without allowing rope to slip through his hands. The force on the belay would then approach the full 1240 lb. calculated (fractionally less due to body resilience).

In practice a Karabiner is often used in lieu of a pulley and the friction is such that the stress in the falling man's arm of the rope is approx. 1.8 times the stress in the other half. (for a 180° turn) (Cumming and Slessor, 1958). For a given fall and assuming a static belay, the total stress on the belay at the head of the pitch is greater than it would be using a frictionless pulley. Once again, of course, the actual stresses depend upon what force the belayer can exert but for any given retarding force provided by the belayer the total stress in the two arms of the rope can be 1.4 times as great as in the frictionless pulley case. Thus a man exerting a restraining force of 500 lb. could arrest a fall in which 900 lb. is developed at the falling man's waist and the stress on the belay would be 1400 lb. (0.62 ton).

This is not to say that such a sudden arrest is advisable but it could occur. I do not know what stress would be required to cause internal injury though I *suspect* a momentarily induced 900 lb. could be borne by a man wearing a harness and I *suspect 600 lb.* may not necessarily cause internal injury to a man using a waist tie.

It becomes abundantly clear therefore that our belays must be capable of safely resisting a suddenly applied force of at least ¾ ton.

3. **As a belay for an abseil rope.** A man abseiling usually does so in a series of rather jerky movements and it is generally recognised that the stresses developed (probably several times the man's weight) are greater than the stresses developed when he is steadily descending a ladder. I cannot, however, quantify the forces.

4. **As a belay for a prussik.** Under normal circumstances this technique should not provide any exceptional stress on the belay. However, Andy Eavis, (1974 p. 196) has drawn attention to an interesting possibility in which the rope snags at the back of a ledge and is released just as the caver reaches the lip of the ledge. I have calculated that for a 150 lb. man involved in this situation as drawn by Eavis and *using a 1⅜" diameter nylon rope,* the tension developed would be approx.1000 lb. in both rope and belay. Using ropes made of less elastic material, the stress would be greater still.

5. **As a belay to assist in heaving stretchers.** A man on a stretcher could be lifted up using a rope running through a pulley as in figure 2. Supposing the stretcher frame snags on a lip of rock: the three men depicted might continue to heave on the rope briefly and develop several hundred pounds tension.

Belays are of course used in a number of other ways but similar considerations apply. Belays at the top of a climb are used by the lifeliner and under normal circumstances are not subjected to any great stress. Belays part way up a climb may be used as runners. The stresses to which they may be subjected are referred to by Wexler and Cumming and Slessor and also in "Safety Chain" by Klaus Schwartz, (1974 p.410).

It is also well to note that, when a belay at the head of a pitch is used for a doubled lifeline, as soon as the first man up the pitch has passed the belay it becomes a running belay.

Thus there are several possible situations underground in which belays may have to resist forces of 1000-1500 lb. or even greater — usually short lived stresses but nevertheless *suddenly* applied.

Suitable types of artificial belay.

There are a number of places underground where a belay is needed, *e.g.* as a ladder belay, where no good natural belay exists. Having established the stress to which such a belay may be subjected, I shall make a few comments about the available types of artificial belay.

I discussed *beams* at considerable length (Childs 1968). Narrow passages in potholes often make beams a very practical proposition and a well positioned substantial beam can be ideal. However, it is not always possible to jam a beam into a secure position.

A well placed *piton* could provide an alternative, but in practice one has to be very skilled to judge whether a piton is well placed. In vertical cracks especially, it is exceedingly difficult to judge the security and very small loads could cause extraction. Cracks in limestone are often blind and in any case cracks occur most frequently in shattered rock. Moreover, pitons are prone to rusting. The shape of a piton and type of steel are particularly important (L. J. Griffin - British Mountaineering Council Circular N.454 - Pitons).

Rawlbolts on the other hand can be put into holes in solid rock, and provided they are properly tightened in the correct diameter hole, their gripping is enormous. They are available from Rawlbolt Co. Ltd., Rawlbolt House, London Road, Kingston upon Thames, Surrey. The design of a rawlbolt is apparent from figure 3. As the bolt is tightened, the sleeves are forced to expand over the stopper. In the "bolt projecting type", the stopper is integral with the bolt. In common usage underground are the G series bolts which are a nominal ½" diameter and a root diameter at base of thread = 0.393". The shell diameter is 7/8" and the recommended size of drill = 15/16". E series are nominally 3/8" dia, H series 5/8" dia. Steel is very strong in tension and the Rawlbolt Co. catalogues

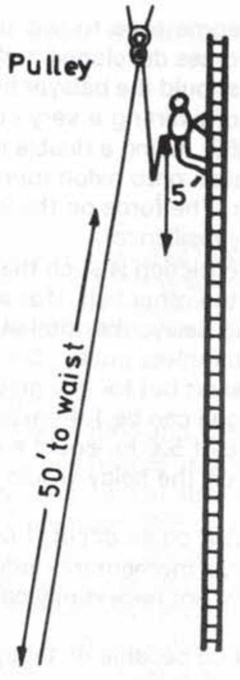

Fig. 1. Diagram to illustrate the forces developed in a static belay situation with a slack lifeline.

Fig. 2 Diagram to show the potential increase in tension if a stretcher snags on an overhang.

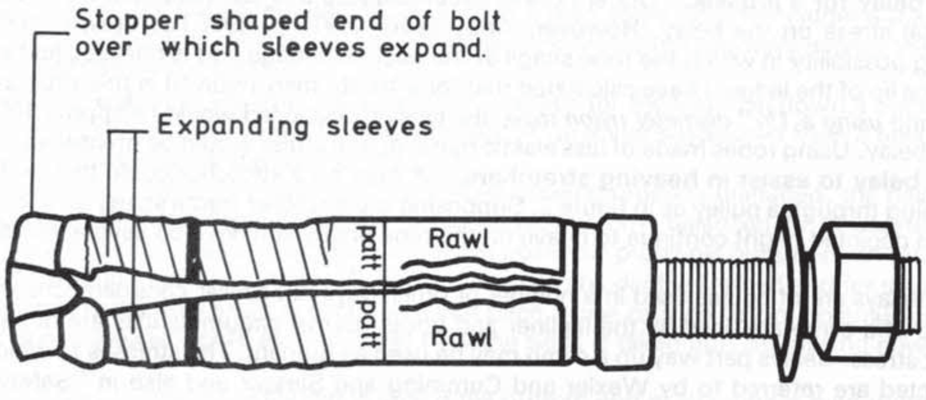

Fig 3 Bolt=type projecting Rawlbolt to which a plate may be attached

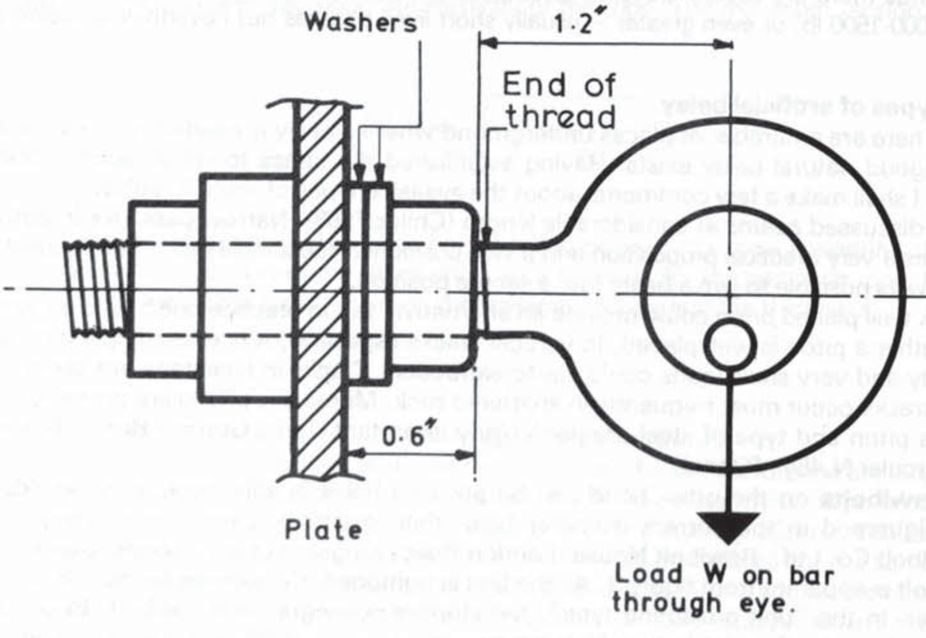

Fig 4 Eyebolt No 3 in test device showing load applied at right angles to axis

quote results of certified load tests. The rawlbolts were fitted into correctly sized holes in good quality vibrated concrete. In one set of tests, (old Rawlplug Co. catalogue), G6 bolts failed at 12,550 lb. (failing load average of three pulls) and in another set of tests, (a more recent Rawlplug Co. catalogue), G6 bolts failed at 9,550 lbs. (failing load average of 3 pulls).

Thus despite very considerable individual or batch variation, the bolts are very strong when the pull is in line with the bolt axis. Eyebolts were available (GE solid forged) which were designed to withstand pulls in this direction. In practice, however, underground it would be a virtual impossibility to insert bolts into the roof, and even were it possible the result could be disastrous for it would be difficult to make perfect holes. If a sleeve were to fail, the bolt would fall out and were the bolt to slacken the same thing would happen. Permanent belays receive intermittent loads and pulls in various directions and in practice, the bolt would eventually be loosened. In practice therefore bolts are usually inserted into wall or floor at right angles to the masonry or at a slight angle.

When a load is suspended from a bolt as in figure 4, the whole length of the lever arm is subjected to a shearing force = W. According to the Rawlplug Co. bolts are not as strong in shear as in tension but nevertheless in a situation in which bending is impossible they are permitted to carry up to 75% of the load permitted in tension. (Order of 1800 lb. safe steady shear load on G. bolts using a x5 safety factor).

Unfortunately, placing an eyebolt at right angles to a wall and loading it vertically from the eye *also* results in a bending moment = weight times lever arm with a consequent tendency to break off the neck of the bolt. (The bending moment is of course less if the bolt is placed at say 45° to the masonry but there must then be a greater risk of prising off a chunk of masonry).

The stress at the neck of the bolt is proportional to the bending moment and inversely proportional to the section modulus Z which is

$$\frac{\pi \cdot d^3}{32}$$

for metal of circular cross section, diameter d. It is possible to calculate safeworking static loads for a given lever arm, given the safe working stress for steel and the diameter d. The steel should obey Hooke's law over the region of safeworking. Actual calculations of the load to cause ultimate failure are complicated and allowance has to be made for bolt threading. Even for static loads, engineers introduce a safety factor of × 5 or × 6 in their calculations and for a *1.5" unthreaded ½" dia.* lever arm the safe load (using a safety factor × 5) is only approx. *160 lb. - assuming* a working stress of steel = 100,000 lb. per sq. inch. The threaded bolt would be approximately 50 per cent weaker *i.e.* it would have a terrifyingly low "safe steady working load" of the order of 80 lb.

A further complication is that of suddenly applied loading. The load to cause failure under these circumstances is less than (sometimes less than half) the static load to cause failure (depending upon the type of steel).

Because of the uncertainty in making theoretical predictions about ultimate failure loads, I decided to have a number of bolts tested in an Engineering laboratory. I had to be content with tests done under steadily applied loads and a logical extension is to carry out tests under suddenly applied loading. Some bolts fractured under higher loads than theory seemed to predict (approximately 3 ×) but the tests did bear out the undesirability of suspending loads on an unsupported lever arm threaded at the neck. No attempt was made to make theoretical predictions for the collared bolts which were in any case made from steel different from that of the Rawlplug Co. bolts.

The eyebolts were supported through a hole in a metal plate which simulated the masonry. Force was applied to a pin passed through the eye of the eyebolts and deflection was measured over a range of applied loads. In all cases, ½" Whitworth threaded nuts tightened to a torque of 40-45 ft. lb. The test system is depicted for a GE solid forged eyebolt in figure 4. Force was steadily applied and deflections measured at intervals, usually until actual breakage occurred. Results are tabulated (Tables 1 and 2).

Several other tests were conducted as follows:-

Bolt/plate system. A G2 bolt projecting type, nominal ½" Whitworth threaded bolt purchased from Rawlplug Co. in 1975 was positioned in the metal plate simulating the masonry. A load was applied to a 5/16" thick steel plate separated from the masonry plate by the width of one nut (Figure 5). A load of 2 tons was applied and left 16 hours. The bolt did not shear. Subsequently 3.1 tons was applied to break the bolt.

Hammer tests. Broken bolt stems were placed in a vice and struck with a 2lb. hammer. Although the blows were not scientifically controlled it is relevant to note that four blows snapped the WGE bolt (confirming its brittle nature) whereas a BS 529 bolt stem and a Centuryan bolt stem bent through a right angle without breaking.

Conclusions based on the tests.

1. The G.E. solid forged eyebolts were strong enough to withstand normally expected forces even when applied at right angles to the bolt axis, but there is insufficient margin of safety. Brittle type fractures occurred and the behaviour of the metal to shock loading would be suspect.
2. The collared bolts tested are evidently much superior to the GE bolt design, although, of course, the better performance may be due in part to superior steel.

TABLE 1

Bolt No.	Type	Nominal Diameter	Origin
1	Welded, galvanized	½"	ex Rawlplug Co. 1975
2	Solid forged, galvanized	½"	ex Rawlplug Co. 1967
3	Solid forged, galvanized	½"	ex Rawlplug Co. inserted into Ireby Fell Cavern at head of first pitch in 1970 or 1971, removed 1975.
4	Solid forged, BS 529 collared	½"	ex Austin McLeans 1975
5	Solid forged, galvanized, collared	½"	ex New Century Safety Appliances Ltd. 1975

Bolt No.	Lever arm outside of lock nut to centre of eye	Comment on deflection	Force to break	Type of fracture
1	1 9/16"	Hooke's law obeyed up to approx. 300 lb	1100 lb	Brittle
2	1 1/4"	Hooke's law obeyed over only a few hundred lb.	1340 lb	Brittle
3	1 3/16"	For deflections, See Table 2.	2000 lb	Brittle ?
	Inside of Collar to centre of eye			
4	1 1/16"	Several hundred lb caused only a small deflection as compared to bolts 1-3	3900 lb (1.75 tons)	Metal drawn out either side of break.
5	1 5/16"	For deflections See Table 2	9000 lb (4.05 tons)	Appearance of metal at break intermediate between bolts 2 and 4.

TABLE 2

Load (tons)	Deflection (Inches) Bolt No. 3	Deflection (Inches) Bolt No. 5
0.1	0.010	0.005
0.2	0.025	0.020
0.3	0.080	0.030
0.4	0.180	0.030
0.5	0.310	0.035
0.6	0.480	0.048
0.7	0.65	0.050
0.8	0.85	0.053
0.9	bolt broke	0.075
1.0		0.090
1.1		0.12
1.2		0.14
1.3		0.16
1.4		0.19
1.5		0.20
1.6		0.23
1.7		0.255
1.8		0.295
1.9		0.32
2.0		0.375
2.1		0.41
2.2		0.46

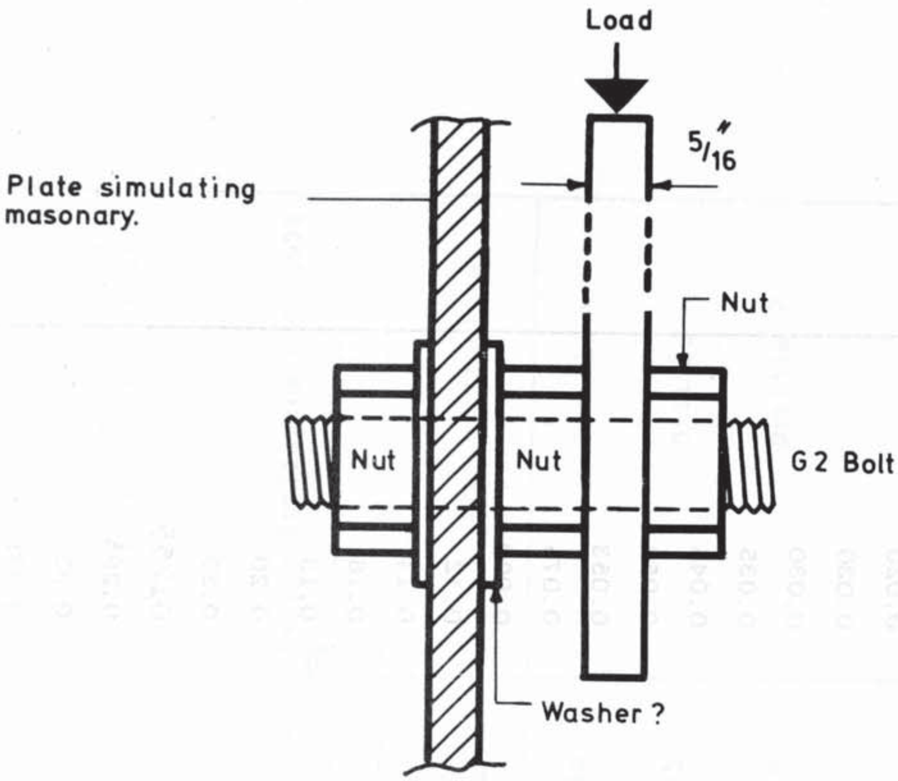

Fig 5 Bolt=plate system in test device.

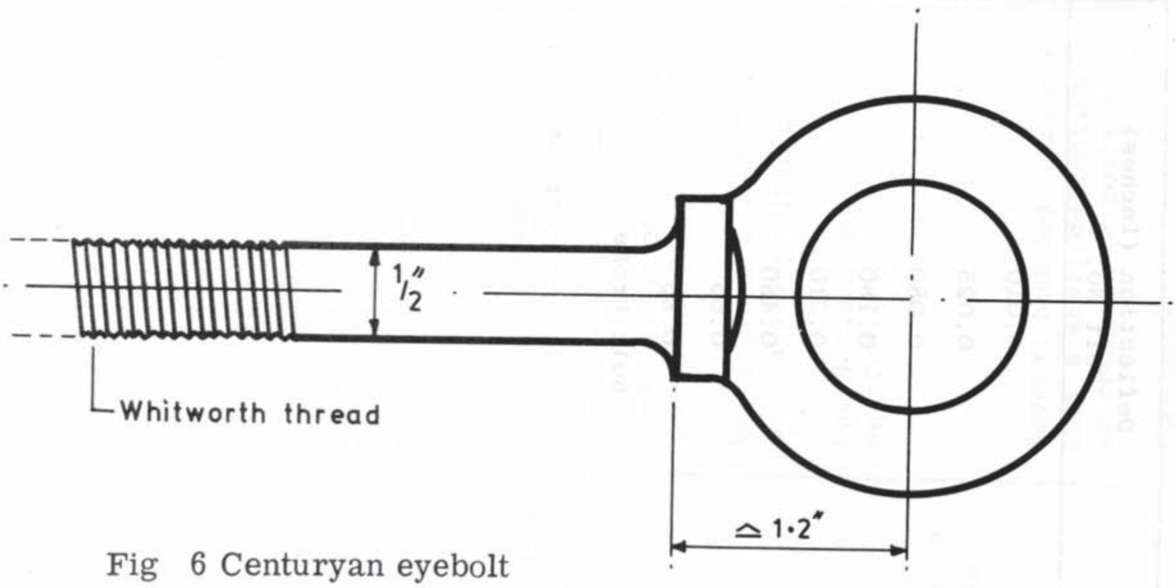

Fig 6 Centuryan eyebolt

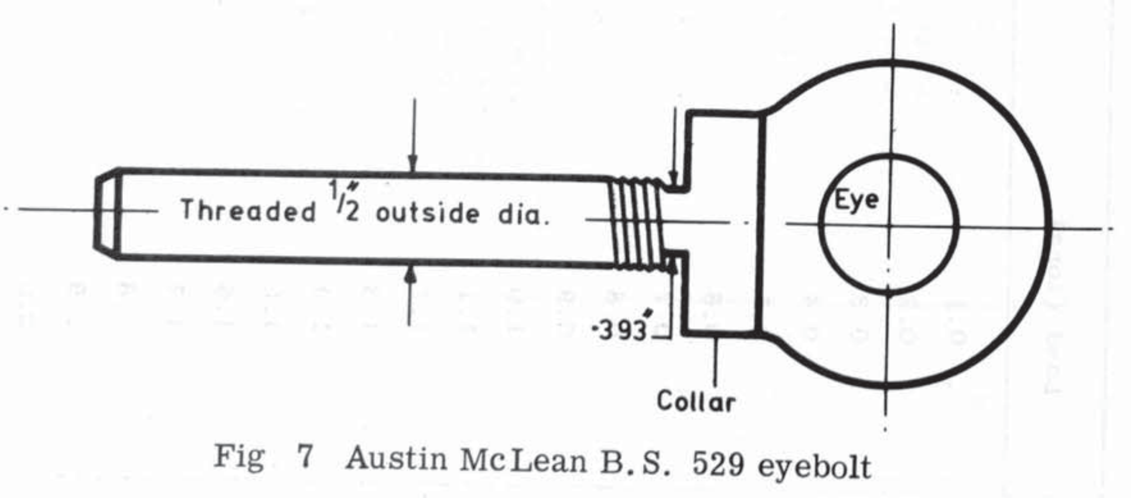

Fig 7 Austin McLean B.S. 529 eyebolt

3. The two GE bolts varied in strength quite considerably. (1340 lb., and 2000 lb.). There *may* be a similar variation between Austin & McLean's BS 529 bolts or between Centuryan bolts - more tests would be required to prove this.

The Centuryan design (figure 6) is better than the Austin McLean design for loading at right angles to the axis of the bolt (comparing ½" Whitworth threaded bolts). This is because in the "Centuryan", the threaded section of bolt does not extend to the collar and hence does not extend beyond the masonry. In the Austin McLean bolt a reduced section is apparent adjacent to the collar (figure 7).

Comment on Welds. Engineers are agreed that the solid forged eye is superior to the welded eye. In the particular example tested (WGE bolt), the weld was not the weakest link (although for a differently angled pull it might have been) but there would probably be considerable variation between welds. Moreover, during storage, strain ageing can occur, causing steels to change from ductile to brittle, and a similar process could occur in the short term by welding (or for some steels by galvanizing). Bolt No. 2 brittle fractured too and *may* perhaps have undergone deleterious changes during several years storage. A similar bolt tested in another engineering laboratory in 1966 (then recently purchased) bent drastically at 1300 lb. but was reported to be ductile.

Choice of bolt system for belay

Holes for ⅝" bolts would be extremely difficult to make using hand tools. If a single ½" Whitworth threaded bolt is to be used as a belay, it would appear that of those tested in this series the Centuryan Safety eyebolt is the one to choose. Note that the manufacturers recommend that holes be at least 4½" deep even in good quality masonry.

Some bolt/plate systems may be stronger but single bolted plates are subject to swivel (dangerous unless correctly lock nutted). If a plate is used, the hole in the plate to take the karabiner must be smoothed and the karabiner must hang freely. The plate may be bolted close into the rock on a bulge or the plate spaced out by a nut or an angled steel plate may be used. But in all instances it is important to keep the lever arm to a minimum and definitely not more than one inch. Sufficient metal must separate the bolt hole and the hole for the snap-link from the end of the plate. Let us assume the plate is made of mild steel of such a quality that the force per square inch cross section required to pull out the steel when loaded in tension = 80,000 lb. per square inch. Referring to figure 8, the force in lbs. required to pull the snap-link out of the plate =

$$80{,}000 \;.\; \tfrac{3}{4} \;.\; ad \quad or \quad 80{,}000 \;.\; \tfrac{3}{4} \;.\; 2bd$$

whichever is the smaller.

The best system of all is a plate, double or triple bolted with bolts spaced well apart. In the event of one bolt failing or the rock failing, the other bolt takes the stress.

In certain situations, e.g. that depicted in figure 9, a single bolted plate is totally undesirable. Apart from the fact that the karabiner would *not* hang freely, the plate itself would stick out creating a dangerously large lever arm (2½" in this instance). Were the bolt neck to bend enough to cause the plate to touch the rib R, further bending would be avoided but there would then be a significant extractive force trying to pull the bolt out of its socket. Should the bolt have loosened, this could be disastrous.

Criticism of tests

All the laboratory test were done using a bolt supported rigidly in a hole in a plate. More realistically the bolt should be expanded into a large block of concrete or, ideally of course, into limestone rock.

Examination of bolts underground and replacements

In my article in the Speleologist, I referred to the risk of corrosion of permanent belays, and I said that we had embedded bolts in grease (of the type used to grease nipples on a car). I am pleased to report that these bolts, examined over a period of 5-10 years, have not shown any signs of severe rusting. But they were examined and regreased periodically.

I will conclude by reporting on recent work-party trips. In December 1974 David Howitt and I examined the beam and bolts at the head of the Monastery pitch in Lost John's Pot on Leck Fell. The beam placed in 1966 appeared to have suffered only very superficial rotting at one end.

We removed and inspected the ½" bolt to which a ⅜" plate had been attached (separate belay entirely from the beam). It was slightly rusty. (Inserted 1966, regreased 1969). It was replaced by a new ½" galvanized bolt and the old plate reused.

We examined the condition of the ⅜" galvanized bolt and the two "redheads" to which ¼" plates are attached (and which serve to prevent dislodgement of the beam). One nut was slack and had to be retightened. The ⅜" rawl-bolt (inserted 1966, regreased 1969) was slightly rusty and therefore replaced.

The nylon rope joining the small plates to the beam was not replaced but ought to be at the first opportunity.

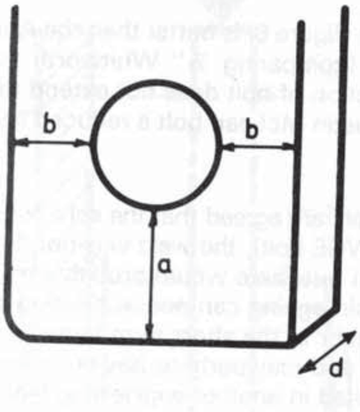

Fig 8 Details of belay plate

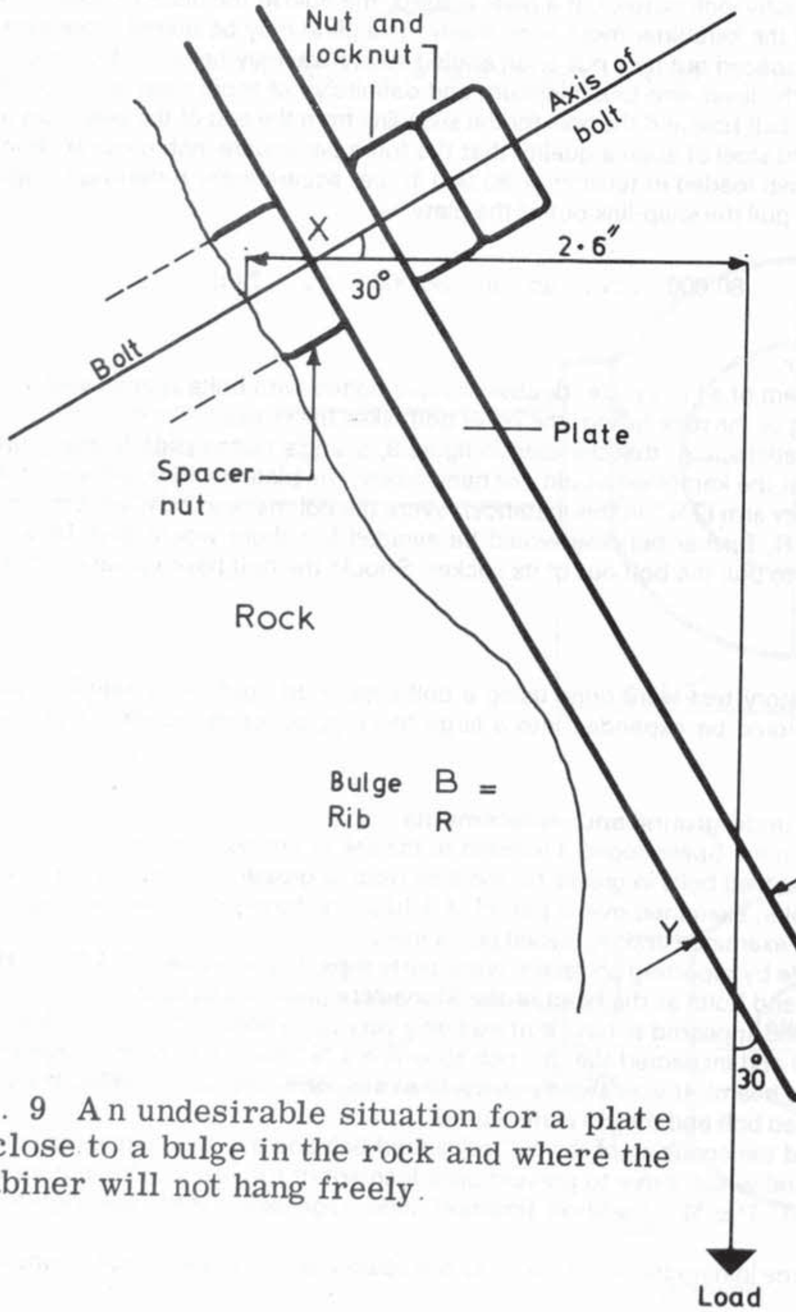

Fig. 9 An undesirable situation for a plate too close to a bulge in the rock and where the karabiner will not hang freely.

In August 1975 Alan Brook and I removed the welded bolt from the top of the first pitch in Simpson's pot and replaced it with a 4½" Centuryan solid forged eyebolt to which was attached a 3¼" long expanding sleeve. I subsequently had the old eyebolt tested (though not to destruction) and it withstood 1.8 tons. It was a solid eye welded to the hexagonal head of a loose bolt rawlbolt and in this instance the weld must have been a very good one. The strength of the bolt (compared with a G.E. solid forged bolt) was presumably due to the fact that the bolt was not threaded right up to the neck.

Also in August 1975 Alan and I replaced the G.E. bolt at the head of the second pitch in Ireby Fell Cavern by a single bolted plate but, after one caver expressed the view that swivel was causing the nuts to slacken, we returned in October 1975 and replaced with a double bolted plate. (G2 bolt and redhead approx. 5" apart). The plate itself was made from 5mm. thick mild steel, L section.

Also in September/October 1975 three 3" long Centuryan bolts were inserted into Ireby Fell Cavern, two being placed at the head of the first pitch and one at the head of the third pitch (above the beam). In order to use the existing approx. 3" deep holes, 2½" long sleeves were used and this necessitated a few extra threads being made on the standard Centuryan bolts. But the threading still stops short of the collar by at least 1". Of the two G.E. bolts removed at the top of the first pitch one had been noticeably bent and that despite the fact that normally this particular bolt would have received a load at approx. 60° to the bolt axis.

Incidentally, whilst in Ireby I discovered that the beam needs to be replaced. In one particular place, one can easily insert a penknife blade!

Correspondence on matters relating to this article would be welcomed.

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A Resistivity Survey over Stoke Lane Slocker

by Peter Hiscock.

Summary

A summary of electrical resistivity work carried out by the author over large cave chambers is presented. The main criteria for choosing the site are given and the field work executed is listed. No anomaly due to the presence of the cave was apparent owing to surface effects produced by a layer of clay over the limestone.

Introduction

The resistivity is mainly used for depth to bedrock determinations and the location of minerals, etc., but has also been used successfully for the location of filled sinks (Cook and Van Nostrand, 1954). However, little success has been achieved to date in the field of cave location using a theoretically sound resistivity technique.

During March and April 1976 an attempt was made to locate the chambers of a cave, Stoke Lane Slocker, in the Eastern part of the Mendip Hills at NGR ST667476. Two of the chambers are about 20m high by 10m wide by 30m long and only 10-15m from the surface.

Detection of Caves

At first sight, the detection of caves should be fairly simple since the resistivity contrast between the limestone and the cave is great (the resistivity of air tending to infinity). However, if the solid rock is hidden beneath overburden, then a wide enough electrode spacing must be chosen to ensure that a fair proportion of the current flows through the solid; otherwise any lateral variation in overburden thickness or resistivity will affect the measurements and, if large enough, could easily conceal the anomaly due to the boundary. To some extent, any effect caused by the overburden can be minimised by increasing the electrode separation so that a greater proportion of the total current flows through the solid, but if this is done, the measured apparent resistivity changes more slowly as the anomaly is crossed. The effect of this is to reduce the accuracy with which it can be located.

These problems are highlighted by the fact that all but the very largest of caves at shallow depth represent a very small volume beneath an electrode spread relative to a continuous layer of rock of the same thickness as the cave diameter. Some caves can be approximated to a horizontal cylinder for which Myers (1975) showed the limit of detectability in the field to be when the cylinder is buried to a depth approximately equal to its diameter.

Choice of Site

In order to stand a chance of finding a cave, it was necessary to choose a site situated over large chambers located close to the surface. The field over the chambers of Stoke Lane Slocker was considered suitable, and the adjacent quarries showed the structure of the limestone (dipping at about 80 degrees), and indicated the depth of the topsoil to be about 200mm. This depth should have been small enough not to obscure resistivity readings at the chamber depth of about 12m. However, the soil depth was subsequently found to be of the order of 1m, and therefore much of the current was confined to this layer.

Field Procedure

A 120m square grid was set out, this area being sufficient to cover all the chambers, and also some ground containing no known caves.

The work carried out was as follows (the Wenner electrode configuration and an A.B.E.M. a.c. Terrameter were used throughout).

1) A series of 26 traverses was run across the field using a 10m electrode spacing on a 10m grid.
2) A set of 61 depth probes comprising readings at 2m, 5m, 10m, 15m, and 20m was executed with the electrode spread orientated both North-South and East-West over 34 stations on a 20m grid. Some readings at a spacing of 30m were also taken.

From the data, traverse graphs, depth plots and iso-resistivity contours were drawn. From these it was apparent that the results bore no resemblance to those expected due to the presence of the cave.

Deductions

It can be assumed that most of the effects recorded are due to surface variations, i.e. a varying depth of topsoil over the area. A 4m deep shakehole in the field gave consistently low readings, and the general trends in results are the same for all electrode spacings. The values of apparent resistivity do, however, increase as the electrode spacing increases, indicating greater depth penetration.

The location of the cave was effectively prevented because most of the current was channelled into the thicker than expected overburden due to its high conductivity, and very little, if any, of the current penetrated to the depth of the cave. The resistivity contrast, as seen by the electric current, is much greater between the relatively conducting topsoil and the limestone, than between the limestone, which has a high resistivity and the "infinite" resistivity of the cave.

Since most areas will be covered with a layer of topsoil, the method seems to hold little promise of achieving reliable and consistent results for the location of caves. Since the results are influenced so dramatically by even a thinnish overburden, the use of the technique in its present form is probably so limited as to be almost worthless for the location of any but the largest cavities near the surface.

The likelihood remains that it may be possible to locate large cavities in chalk or sandstone since the resistivity contrast between the chalk and the overburden is much smaller. Although large chambers in chalk are relatively rare, artificially made "deneholes" and mines do exist.

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Finally I would like to thank D. P. Creedy for his advice on which approach to adopt, and to Dr, J. O. Myers of Leeds University for his help in assessing the results and checking the manuscript.

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Remains of Pleistocene man in Paviland and Pontnewydd Caves, Wales.

Theya Molleson

Summary

One of the most important Pleistocene sites in Britain is Goat's hole, Paviland, in the Gower Peninsula, South Wales. It has yielded the most important collection of earlier Upper Palaeolithic artifacts and the most complete Upper Palaeolithic burial from any cave in Wales. The skeleton, now thought to be male and not a "Red Lady" has been dated by radiocarbon to the Last Glacial Maximum but the contemporaneity of the artifacts with the skeleton is questioned. It is hoped that further dating of animal bones from the site will settle the question.

(a) Paviland Cave

In 1913 Professor Sollas wrote of Goat Hole at Paviland: "As a temporary habitation it would be difficult to find a more excellent cave than Paviland; situated on the face of the steep limestone cliffs of Gower, it looks out over the changeful waters of the Bristol Channel; behind it is a fertile land which must have provided a rich hunting-ground in early times; it is roomy, well lighted and dry, with a natural chimney to promote ventilation — serving also to carry off the smoke of a fire kindled beneath; in front of the entrance is a rocky platform with natural seats where the hunter can sun himself in the open air. Add to this that it is concealed from the landward view and difficult of access to those unfamiliar with the way. Evidently in every respect a highly 'desirable' hunting lodge! How its advantages appealed to Palaeolithic man in Glamorgan during the Aurignacian age is shown by the great kitchen midden which forms the floor. Here, it is plain, he fabricated his implements and weapons, here he roasted his meat, flesh of the horse, the bison, the mammoth, and the bear, and here on one solemn occasion he entombed his dead" (Sollas 1913).

It is evident that W.J. Sollas, then professor of Geology at the University of Oxford was much taken with Paviland.

Paviland cave or Goat's Hole is a limestone cave on the north coast of the Severn estuary, Rhossili, Gower peninsula, 24 km (15 miles) west of Swansea, Glamorgan (SS 437859, 51°33'N, 4° 15'W) (Fig.1). It is a narrow cleft, 70 ft deep, in the face of the Carboniferous Limestone cliff overlooking the Bristol Channel at a height of about 30 ft above present high-water mark. It was probably formed by marine action in an early interglacial phase. Later land emergence resulted in the Bristol Channel being replaced by a wide valley drained by a comparatively narrow river. The limestone cliff rises 100 ft above the mouth of the cave and below slopes at an angle of about 40° to the present water's edge. It is accessible only at low water. The waves of the highest storms occasionally dash into it so that recent bones and sea-shells are found there (Buckland 1823).

The cave was first excavated by John Traherne, L.W. Dillwyn and Miss J. Talbot between December 1822 and January 1823, Dean William Buckland joining them on 18th January (North 1942). They found many animal bone fragments in a disturbed context and mixed with recent bones and shells. Then Buckland found part of a human skeleton *in situ.* (Fig.2). In 1912 Sollas cut a transverse section across the floor of the cave 30 ft from the entrance and 8 ft in depth; he found an implement bearing deposit in a reddish brown earth with angular and rounded fragments of limestone. It extended to a depth of 4-5 feet and had been much disturbed. He noted that the sea had destroyed the section left by Buckland reworking or removing much of the deposit. Sollas completely excavated the remaining deposits finding a few hominid fragments as well as the abundant flint industry.

The skeleton found by Buckland was beneath a shallow covering of six inches of earth. The skull, vertebrae and extremities of the right side were missing, probably washed away by the sea. The remaining parts, appeared undisturbed, and lay extended in the usual position of burial and in their natural order of contact along the west side and parallel to the axis of the cave. In the middle of the bones of the ankle was a small quantity of yellow wax-like substance resembling adipocere. [Adipocere seems to form in burials that are placed in cold, wet, anaerobic conditions. Müller 1913]. The bones were all of them stained superficially with a dark brick-red colour and enveloped by a coating of a kind of ruddle, composed of red micaceous iron oxide which stained the earth and in some parts extended itself to the distance of about half an inch around the surface of the bones. The body must have been entirely surrounded by or covered over at the time of its interment with this red substance. Red iron oxide does occur abundantly in the limestone rocks of the neighbourhood.

Close to that part of the thigh bone where the pocket is usually worn and surrounded also by ruddle were about two handfuls of small shells of *Littorina littoralis* (L.). Those preserved in the Oxford University Museum show signs of crapulation or damage such as is incurred for the removal of the flesh.

In contact with the ribs were 40 or 50 fragments of small ivory rods, varying in diameter from ¼ to ¾ of an inch and 1 to 4 inches in length. None was complete. There were also small fragments of an ivory ring which when complete was probably 4-5 inches (62mm) in diameter, these too were stained red.

Near what he deduced to be the site of the skeleton, Sollas (1913) found a limestone boulder 22 × 10 × 6 inches, 2-3 feet below the surface, and about 6 ft further from the entrance at the same level were two others not quite so large. He suggested they may have been placed in

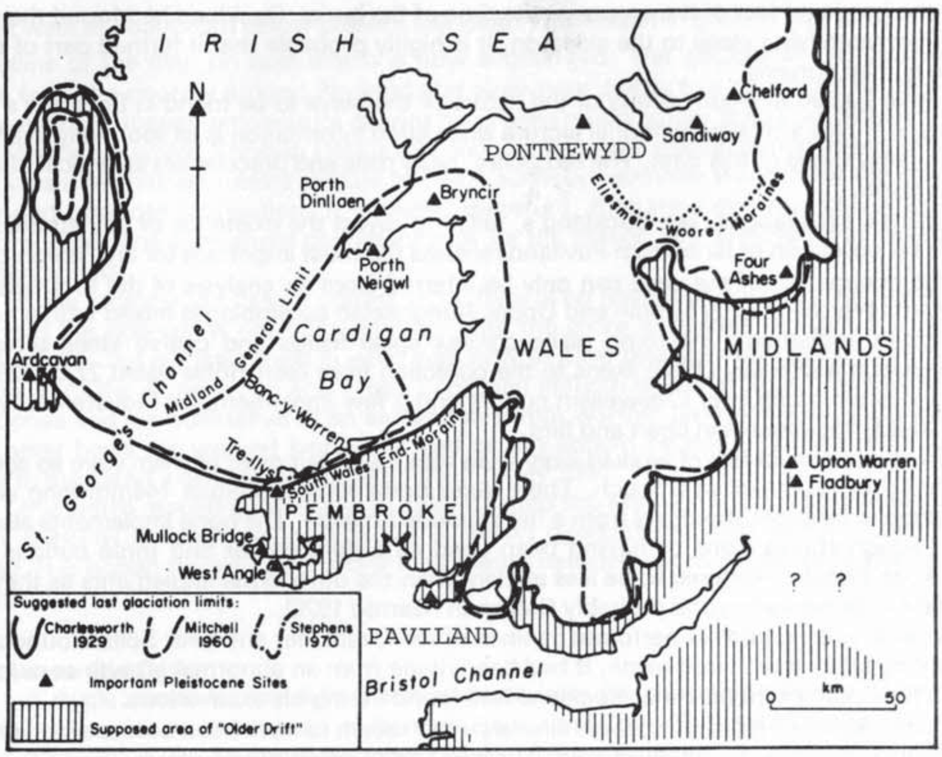
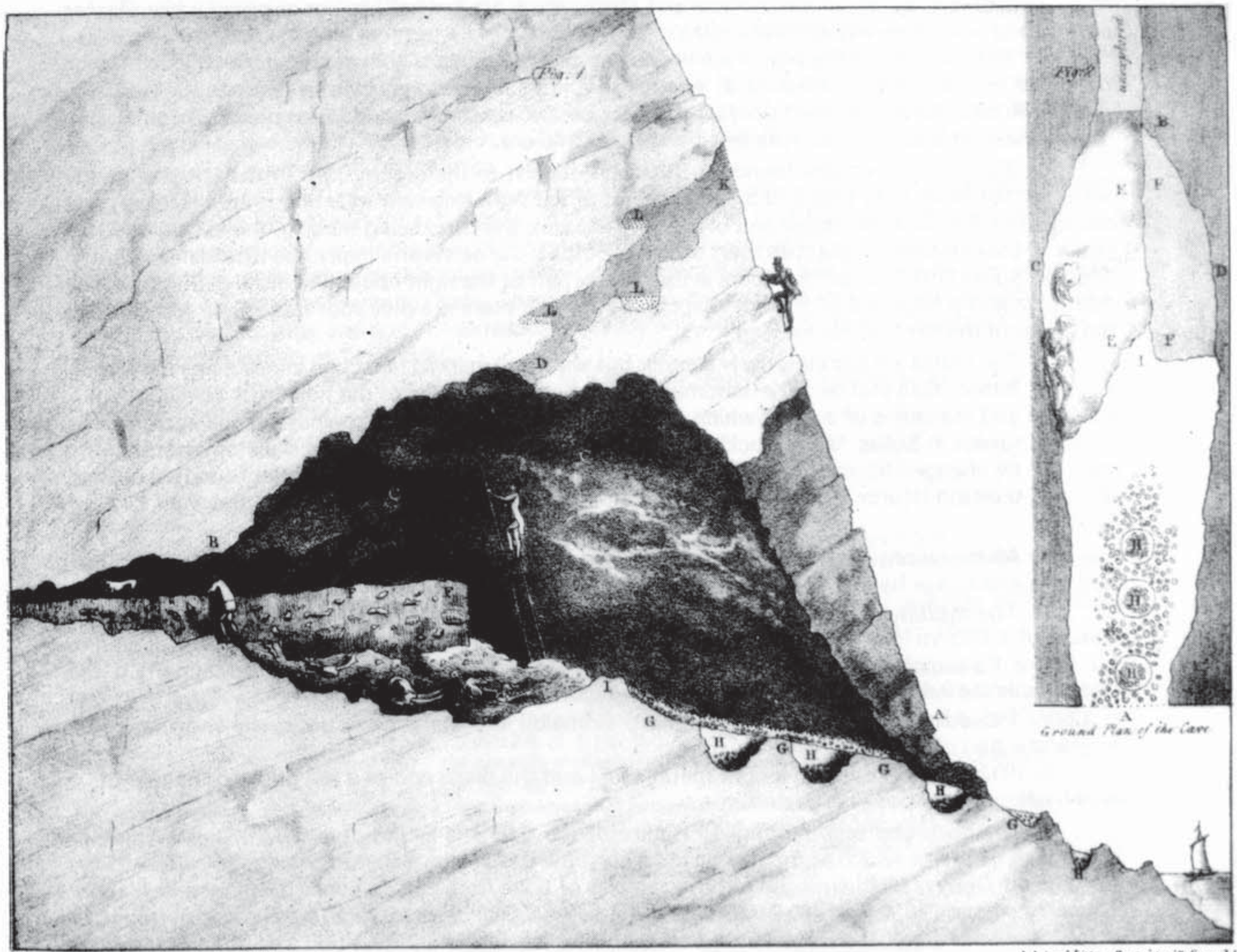


Fig. 1. Glacial limits and Pleistocene sites in Wales and the Midlands (from Bowen 1970).



Drawn by T. Webster from a Sketch by Prof. Buckland

SECTION OF THE CAVE CALLED GOAT HOLE.

In the Sea Cliffs 15 Miles West of Swansea

Fig. 2. From Buckland 1823.

position at the head and feet of the corpse at the time of the burial. Buckland had found the skull and tusks of a mammoth lying close to the skeleton. It is highly probable that it formed part of the interment of the human remains.

I have quoted at length details of the nature of the burial to be found in Buckland's *Reliquiae Diluvianae* and Sollas's Huxley memorial lecture since such information is all too rarely available particularly for excavations of this date. The red ochre, ivory rods and bracelet are all typical of an Upper Palaeolithic burial.

Sollas's excavations, like Buckland's, failed to reveal the existence of any stratification. In spite of this his collection of flints from Paviland remains the most important for any Welsh cave. The extent of the occupation of the cave can only be inferred from an analysis of the tool types. There are implements typical of Early Middle and Upper Aurignacian assemblages mixed with a number of Proto-Solutrean implements including plano-convex spear-heads and coarse steep-scrapers and wide blades which McBurney (1965) likens to the collection from Ilsen Höhle dated 27,000-29,000 BC. Also mixed in is the much later Creswellian culture and a few implements of Mousteroid type. In all there are 700-800 implements in chert and flint.

Great numbers of bits of worked ivory were also found but most of them were so soft and full of water that they crumbled at a touch. There were bone awls, a spatula 144mm long with a flat blade demarcated by slight shoulders from a flat expanded handle. The bone implements also include a fragment which shows signs of having been used as a compressor and three curious spatulas which the Abbé Breuil considered to be less ancient than the other bone implements as they are in a different state of preservation and probably Cetecean (Garrod 1926).

As well as a number of perforate canines of wolf, reindeer and bear Sollas found a curious pendant slightly stained with iron oxide. It had been made from an abnormal growth or pulp stone in an elephant (i.e. mammoth) tusk that Buckland had found during his excavations.

Finally Sollas noted a number of minerals which seem to have been collected — lignite, psilomelane, haematite, limonite, pyrolusite and a broken crystal of quartz.

The fauna found is characteristic of the later Pleistocene when the climate was cold and dry producing tundra and steppe conditions, and thus encouraging grazing and hoofed animals such as reindeer and horse (Grimes 1939). Apart from sheep, fox, badger, hog which can be readily referred to as recent intrusions there are abundant remains of *Equus caballus* and *Ursus spelaeus* (which is more likely to be *U. arctos,* Kurtén 1969), *Bos primigenius* is common as are *Rhinoceros tichorhinus* and *Rangifer tarandus. Megaceros hibernicus* and *Canus lupus* are present but not common while *Elephas primigenius* and *Hyaena spelaea* are rare.

The majority of the bones are broken, many are covered with scratches such as would be produced in scraping off the flesh with a racloir, but none has been gnawed by hyaenas (Sollas 1913). Allen & Rutter (1946) extended the fauna to include *Cervus elaphus* and *Bison priscus.* In total is an unusual assemblage if it is to represent a single climatic era.

The human remains found by Buckland consist of the greater part of the left side of the skeleton; the skull, vertebrae and the extremities of the right side were wanting; the remaining parts consisted of the humerus, radius and ulna of the left arm, the hand being missing; the left leg and foot entire to the extremity of the toes, part of the right foot, the pelvis and many ribs (Buckland 1823). In addition Sollas (1913) noted that there is the greater part of the right fibula, the distal extremity of the right tibia and a fragment of the left scapula; but of ribs there are only four fragments and some of the bones of the left foot are missing.

The bones are comparatively slender but with well marked muscular impressions at least on the ulna, femur, tibia and os coxa (innominate). The articular heads of the humerus, tibia and femur are large and indicative of a male, which sexing is confirmed by the narrowness of the sacro-sciatic notch (Knowles *in* Sollas 1913). Buckland's own first impression was that the skeleton was that of a male but he changed his mind presumably because of the ivory objects and armlet found associated with the skeleton (North 1942) hence the skeleton erroneously became known as the 'Red Lady of Paviland'.

All the epiphyses are fused but the line of demarcation is still evident and the age is, therefore, not much over twenty-five years.

The maximum length of the femur is 476mm and the tibia 398mm which give an estimated stature of 1.732mm (5 ft 10 ins) according to Pearson's formula. This is similar to estimates of stature for Upper Palaeolithic hominids of France including Grimaldi, Cavillon and Cro-Magnon. If the stature estimate is based on the length of the humerus (338mm) it is only 1.696mm. Sollas argues that in Upper Palaeolithic skeletons (Cro-Magnon, Grimaldi) the humerus is unusually short and that Paviland is part of the same race.

In 1912 Sollas excavated a right metatarsal I and the distal end of a left humerus neither of which belonged to the first skeleton.

The disturbed and unstratified nature of the deposits in the cave meant that it was not possible to decide to which of the Aurignacian horizons the human skeleton belonged (Garrod 1926). Accordingly Oakley (1968) arranged to have samples of bone from the leg bones dated by radiocarbon. The resulting date 18,460 + 340 BP (BM 374) = 16,510 BC (Barker *et al.* 1969) was arrived at from C14 measurement of residual collagen in the bones of the left femur and two tibiae as obtained from 62 grams of bone powder. This date pinpoints the skeleton to about the time of the Last Glacial maximum when the glacier ice was only 6km north of Paviland (Bowen 1970). The contemporary coastline was far to the west at about 95m below present sea level. The inhabited ground was probably adjacent to the coastline of the day, on land which is now submerged. The geological and geomorphological evidence from the country around Paviland and elsewhere points to a rigorous climate 18,000 years ago. The average annual temperature cannot have been much higher than that obtaining then in the West Midlands for which Shotton (1960) has deduced average annual temperatures below freezing point. It was a permafrost tundra climate but with sufficient summer warmth for the ground surface to thaw and promote solifluxtion. It is likely, therefore, that the cave was only used during the summer months. The permafrost conditions may be the reason why skeleton was covered with soil rather than buried.

If the radiocarbon date is correct (and there is no reason to doubt it, but see John 1971) it follows that the skeleton is not contemporary with the more temperate indicating animals such as *Bos primigenius,* but is a later burial in what was likely to have been an unoccupied cave by 18,000 BP. The artifacts of the Aurignacian and Proto-Solutrean industries may well be contemporary with the animal bones and representative of an earlier somewhat warmer time when the cave was occupied. On the other hand the worked ivory rods and armlet should be contemporary with the skeleton, contrary to Buckland's diluvian preconceptions (Oakley 1964).

It is worth repeating here that Buckland found the skeleton to be clearly undisturbed and *in situ* only 6 inches beneath the surface but overlying deposits that had evidently been extensively reworked. It is hoped to carry out further radiometric determinations on selected animal bones from Paviland.

(b) Pontnewydd Cave

A single human molar tooth is here reported from Pontnewydd, a horizontal cave in the limestone escarpment on the north bank of the river Elwy, near Cefn, St Asaph, Denbighshire (SJ 015710, 53°14'N, 3°29'W). It was found some years before 1874 by W. Wynn (Hughes & Thomas 1874) in a stiff clay, consisting of reworked boulder clay with angular and subangular fragments of limestone and a few polished pebbles of limestone, Denbighshire sandstone and grit. Mackintosh (1876) refers to this deposit as the Upper Boulder Clay. It also contained tools of a compact grey felstone, chert and flint. Felstone does not occur *in situ* in the drainage basin of the Elwy, but is common in the drift of the neighbourhood. The Boulder Clay would appear to be derived from the St Asaph Drift. Felstone cannot be worked as well as flint but must have been the toughest stone available in the absence of suitable flint. The artifacts represent a Mousterian industry of Acheulian tradition.

The mammal remains are often in the condition of waterworn pebbles (Dawkins 1874) and many appear to be gnawed by hyaena or wolf. Busk (in Hughes & Thomas) & Dawkins (1880) identified *Hyaena spelaea, Ursus spelaeus* (presumably *U. arctos), U. ferox, Equus caballus, Elaphas antiquus, Hippopotamus, Bison,* reindeer, *Rhinoceros hemitoechus, Cervus elaphus, C. capreolus, Canus lupus, C. vulpes* and *Meles taxus.*

Hughes (1887) regarded the deposits as later than the marine St Asaph drift and, therefore, post-glacial. The St Asaph drift, however, is now regarded as Last Glacial while the occurrence of *Rhinoceros hemitoechus* is indicative of the preceding Last Interglacial.

Busk considered all the faunal remains to be much of an age although some bones were rather less infiltrated with manganese. The human tooth he thought looked quite as ancient as the rest. "It is of very large size and in this respect exceeds any with which I have compared it, except one or two from Australia or Tasmania".

The present location of the tooth is unknown, but if any reader knows of it, would he please inform the writer?

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