BCRA TRANSACTIONS

BRITISH CAVE RESEARCH ASSOCIATION

Volume 4 Number 3 August 1977

Battlefield Chamber, White Scar Cave Photo Ian Davinson

INSTRUCTIONS TO CONTRIBUTORS

These notes are meant for guidance of contributors in the hope of reducing the amount of labour for both the editor and the contributors! Adherence to the rules is desirable but not absolutely essential.

As far as possible all material submitted for publication in the Transactions should be typed on one side of the paper only with double spacing to allow for editorial corrections where necessary. Paragraph sub-headings should be clearly marked. Metric measurements should be used wherever possible.

A very short summary of the principal conclusions should accompany every contribution.

References to other published work should be cited in the text thus . . . (Bloggs, 1999, p.66) . . . and the full reference with date, publishers, journal, volume number and page numbers, given in alphabetical order of authors at the end, thus . . .
Bloggs, W., 1999. The speleogenesis of Bloggs Hole. Bulletin X Caving Assoc. Vol. 9, pp. 9-99.

Italics are not normally used and only the volume number should be underlined. Periodical titles should be abbreviated in accordance with the World List of Scientific Periodicals, obtainable in any public library.

Illustrations: line diagrams and drawings should be numbered fig. 1, fig. 2, etc., and referred to in the appropriate place in the text. All such illustrations must be drawn in BLACK ink on clean white paper, card or tracing paper. Anaemic grey ink will not reproduce! Illustrations should be designed to make the maximum use of page space. If photo-reduction is contemplated all letters and lines must be of a thickness or size to allow for this. Captions may be typed on a separate sheet if space is left for insertion on the final illustration.

Photographs are welcome. They must be good clear black and white prints with sharp focus, and preferably about 6×4 inches. Captions may be appended by means of adhesive tape on the back.

If illustrations are submitted which have already been published elsewhere, it is up to the author to clear any copyright and acknowledgment matters.

Contributors in Universities and similar institutions are reminded that grants are often available from those which may help towards the costs of publication. The Editor will be pleased to advise.

If you have any problems regarding your material please consult the editor in advance of submission.

Authors may order reprints of their own contribution for their own private use, such as circulation to colleagues or for exchange purposes. The Editor should be notified of the number required at the time of submission of the contribution. Ten reprints are allowed free, if asked for, but the rest will be charged to the author.

TRANSACTIONS OF THE
BRITISH CAVE RESEARCH ASSOCIATION

Volume 4 Number 3 August 1977

CONTENTS

Published by and obtainable from
The British Cave Research Association

Bryan Ellis,
7 School Lane,
Combwich,
Bridgwater,
Somerset. TA5 2QS.

One copy issued free to members:
Extra copies to members £1.00
Non-members price £1.50

Trans. British Cave Research Assoc. Vol. 4, No. 3, pp 345-353 August 1977

WHITE SCAR CAVE, INGLETON

A. C. Waltham

White Scar Cave lies less than two miles northeast of Ingleton village in the county of North Yorkshire. It is cut in the Lower Carboniferous Great Scar Limestone beneath the western flank of Ingleborough and opens into the side of Chapel-le-Dale. Both entrances are only a short distance from the B6255 road up Chapel-le-Dale and are not difficult to find as White Scar has been a popular show cave for many years. The cave takes its name from the very conspicuous White Scars – the glaciated scars of limestone which overlook the entrance and the valley. White Scar cave is a resurgence system which carries water northwestwards from Crina Bottom and also collects all the percolation drainage from the White Scars and Lead Mine Moss limestone bench. The cave is therefore unique in Yorkshire, in that it is a major stream cave which can be entered from its resurgence. Furthermore, it is a very spectacular, thoroughly enjoyable and scientifically most instructive cave.

History of Exploration

Christopher Long, a Cambridge undergraduate, discovered White Scar Cave in 1923 when he spotted a likely looking entrance from a vantage point across the Dale on Scales Moor. The passage he explored was a miserable crawl in a stream with boulders and cold pools; it was 700 feet long and no longer exists since it was blasted out to accommodate the show cave entrance passage. The crawl led Long to the streamway at the foot of First Waterfall and from there he explored upstream – a magnificent feat considering his totally inadequate equipment, highlighted by short trousers and candles stuck on his hat for illumination. Long swam across First Lake but was then stopped by Long Stop Lake; this was later crossed on rafts made of oil-drums and timber, and the great boulder choke of Big Bertha (strictly the name of the first, massive boulder) was reached.

The next ten years saw progress in two spheres. The show cave was opened by blasting out the entrance crawl and placing plank walkways in the stream cave as far as the Barrier.

Meanwhile Tom Greenwood eventually engineered the very complex route through the Big Bertha choke, and the Far Streamway was open. With Colonel Swift, Eli Simpson and other members of the British Speleological Association, this was explored as far as the canal underneath the Hall of Justice, where the deep, cold water so far from daylight was too great an obstacle at that time. They had already had an epic series of trips to build rafts to cross Swift's Lake which is, however, only waist deep. The same team also explored the first part of Moonmilk Inlet and climbed up into Carrot Hall without finding the way on. After World War II, exploration was severely curtailed by the show cave owners. A few trips were permitted however, and members of the Craven Pothole Club, among others, explored as far as the first wet section, near Gem Inlet, in the Phreatic Series.

A second phase of exploration opened in 1967 when John Southworth, of the Happy Wanderers Cave and Pothole Club, explored the very cold and aqueous passages in from the active resurgence to the show cave. This fine piece of caving opened the way for a series of unofficial trips into the cave, always at night, using the wet entrance whenever the water was low enough to permit access. The Wanderers explored the rest of the Phreatic Series then dived the first two short sumps to discover the canal passages as far as Sump Three. In 1970, Alf Latham, again on a night trip, found the climb up into the Hall of Justice and he and other members of the University of Leeds Speleological Association then explored the Sleepwalker Series as far as Sump One. The next year, John Russom and more Wanderers dug a way upwards through the Big Bertha Choke and discovered the enormous Battlefield Chamber, and also explored the Western Front and Northern Line. Second Front was discovered later in stages, first by the Northern Cave Club and then finished off by Leeds University Speleological Association. The interest in White Scar at the time prompted the opening up of the Greenwood Pots, the major sinks for the cave. Greenwood Two fell to blasting by the Wanderers and the main stream was followed to a depth of 175 feet, but the way down to White Scar is hopelessly blocked. Greenwood Three was opened up by Leeds University Speleological Association but is not as deep as Two.

In 1975, White Scar Cave was sold and the new owner has adopted a very generous attitude of encouraging exploration and work in the cave. Unfortunately though, discoveries have not been as spectacular as in previous years. In the main stream, Sump Three was passed in 1975 by Geoff Yeadon and Oliver "Bear" Statham, who had previously dived part of it on a phantom night trip. In 1976, they returned with Phil Pappard and pushed Sump Four until it was dangerously constricted. In Sleepwalker, Alf Latham passed Sump One and later Rob Palmer dived Sump Two until it became ridiculous to proceed. The choke in Moonmilk Inlet was blasted three times by Clive Westlake to reveal an extension to another more solid choke. Various people, on parties led by Julian Barker, Ric Halliwell or the writer, have then found Gem Inlet, the two Roof Series in Far Streamway and Sleepcrawler, and the Leeds University cavers climbed Strategy Aven in the Battlefield. Other maypoling projects have so far been essentially fruitless.

Since the 1975 change of ownership, the main work in the cave has been directed into various scientific studies. The whole cave was resurveyed (see enclosed fold-out plan) by the writer and numerous friends. This was an essential step towards further geomorphological and geological studies, for the cave's development is most instructive in the field of speleogenesis. At the same time a major water sampling programme was carried out by Ric Halliwell. While some preliminary comments on the hydrology and germorphology of the cave follow below, the main results will be written up in a series of papers which will appear in future issues of the Transactions of the B.C.R.A.

Description

The Streamway

The Water Exit has been blessed with a brick blockhouse connected with the diversion of water into a couple of reservoirs, so now the only way into the cave is through a very narrow drain. Once in rock, the passage continues as low and wet joint-oriented crawls with limestone roof and walls but a floor of the Ingletonian slate. Only in very dry weather is there not a sump within 50 feet of daylight. Various side passages are choked, but some must connect to the flood risings to the north. The last wet bit is in a bedding plane with a duck 57 feet long which is discouraging for the hydrophobic in anything but extreme drought. Stooping passages continue to the First Waterfall where a gate is now installed. Leaving from the south side of the waterfall chamber is the show cave entrance passage, originally a miserable bedding plane crawl. Upstream and beyond a grovel beneath a flowstone bank (by-passed by a mined tunnel) the passage is a stooping height canyon to Second Waterfall. Here the roof rises to over 20 feet and an inlet enters from a choked bedding passage in the roof. The First Potholes are now buried beneath the planking of the show cave path and the canyon continues with comfortable dimensions, finely decorated with stalagmites and large flowstone banks. The Grotto is a phreatic roof rift impassable after a few yards.

The Main Streamway continues as a roomy, flat-roofed canyon with a scattering of stalagmites and a few fine calcite cascades. None of the inlets can be followed far. First Lake is a short wade, barely waist deep, and Long Stop Lake is just beyond. Both lakes are partially held back by debris piles from avens, but there is certainly overdeepening of the floor in Long Stop Lake. The water depth in this one is up to seven feet, but its whole 260 feet length can be traversed on underwater ledges, which are all on the outsides of the bends. With a little sporting effort, the caver need not get wet above his waist. The Big Bertha choke, at the end of the lake, is traversed by a tortuous route mostly at stream level. One low bit is a duck in wet weather, and just beyond it an upward squeeze was called Coat-Off Squeeze by Tom Greenwood. However, the boulders moved here in 1976 and it must now be avoided by a very low duck and tight squeeze on the left. The constrictions in the choke can cause water to back up in very light flooding, and exit from the cave then becomes impossible. Beyond the choke, the Far Streamway continues as a roomy canyon. Moonmilk Inlet is a canyon entering on a shelf eight feet up on the left. Its floor of soft calcite soon changes to boulders and the roof lowers into the constrictions of the Blasted Choke. After three squeezes and a canal, a high canyon with some narrow upper levels continues to a large, unpenetrated choke.

Back in Far Streamway, the canyon continues. Grit falls is a waterfall nearly twelve inches high, but it deserves its name because its lip is cut into Ingletonian grit – the only place where the basement rocks are seen in the upstream cave. Second Potholes are only shallow and above them the roof rises into a narrow joint. By the Oxbow, the canyon is an impressive 35 feet high and it continues as high, partly well-decorated, right up to the Tunnel. Swift's Lake is only waist deep and ends in a spectacular black rift leading to the Third Potholes, some of which are almost waist deep. The Tunnel passes under a boulder pile and, a few yards ahead, an obvious climb on the left wall leads up into a 15 feet diameter tube in the roof of the canyon. Downstream this leads to Carrot Hall, named after its red stalactites, with a slot in the floor down to the streamway; there is then a climb up over boulders to roof rifts beyond which the phreatic route cannot be followed because of a very solid fill. Upstream of Carrot Hall the high level route involves a delicate mud traverse and then wider ledges to the Hall of Justice. Down below, the canyon has beautiful wide ledges as far as the Canal, where a huge mass of boulders (below the Hall of Justice) rests on the ledges. Water level is four feet below the ledges and the Canal is the only way on in the floor's narrow trench – as a sporting traverse, a wade for some (it's up to six feet deep), or a swim.

Beyond the Canal, the wide ledges continue along the Traverses. A small phreatic tube can be followed 20 feet up in the roof. A boulder pile in a chamber at the end of the Traverses is overlooked by a hole high in the roof – this requires maypoles to reach the Roof Series. On the sharp left hand bend in the streamway, there is a climb on the right to a short series of tubes, and a harder climb on the left up to a boulder slope which leads into the high, decorated rifts in the Roof Series, all of which are choked. The streamway continues as a classic keyhole passage, and an obvious muddy slot on the left provides a greasy route up into Straw Chamber. The straws are up to six feet long, beautifully white and in a corner safely out of the way of all but the intentional vandal. Further upstream, the water cascades into a deep pool, but the largest way on is up a dry boulder slope to the left into the high, phreatic rifts of the Great Rift. All ways on are unfortunately choked and the Inlet ends where it shrinks down to a tube only six inches in diameter.

The cascade in the streamway is a classical nick point situated at the end of the vadose canyon, for beyond it the passage is a fine phreatic tube about half full of water – the Phreatic Series. It is a thoroughly enjoyable, very sporting passage, with deep wading interrupted by a series of ducks with varying amounts of airspace. Gem Inlet enters on the left; it contains a boulder-choked aven back over the streamway, and a route on the left up three loose climbs to a choked rift. Phreatic Series ends in a small wet chamber from where Sump One leaves – eight feet long, shallow and without a line. Sump Two follows immediately, twelve feet long and deeper, beyond which Sump Series continues as more canals and tall rifts broken by ducks, the last one involving a short dive. Sump Three is 430 feet long and descends to 23 feet before rising into the tall joint rifts of Taffy Turnip's Trepidation. These extend just over 100 feet to Sump Four which descends rapidly to a depth of 30 feet, and then continues as a meandering tube. Unfortunately the sump has a floor of fine, easily disturbed silt – hence the name Three Blind Mice – and exploration ceased where the space between silt and roof was intimidatingly small. This point is 8100 feet from the resurgence, yet still is at 300 feet depth beneath Crina Bottom.

Battlefield Series

A climb onto the top of the Big Bertha boulder and then upwards through the boulder choke leads to a body-sized hole known as the Foxhole. Above it is blackness, for it opens right into the middle of the floor of the Battlefield Chamber, 300 feet long, 60 feet wide and 30 feet high. The floor is a chaos of mud-covered boulders rising to a massive pile at the northern end. Some fine straws, numerous mud formations and some large stalagmite banks break the gloom of the chamber. Avens soar into the roof, the highest being Strategy Aven requiring maypoles and then a long climb in a rift. From the southern end, Western Front is a long tunnel containing an over-abundant share of sediment and collapse. Some of the passage is walking height, while much is for crawling only. Short stalagmites decorate the first section, an enlarged section midway contains a magnificent display of straws and the end chambers contain large dried out gour pools cut into a mud floor overlooked by hundreds of straws. The whole of Western Front is fragile and will undoubtedly suffer if many casual visitors travel it.

From the northern end of the Battlefield two passages continue. The obvious way round the left (west) side of the collapse pile leads to the Northern Line. This is a tall canyon passage with phreatic roof features and a floor of deep mud. It ends at a massive set of flowstone banks, some fine roof decorations, and just beyond a pool, an impenetrable choke. Eastwards over the debris pile in the chamber leads to a descending route beneath a collapse roof. A tortuous route back up through boulders leads into the roof of a massive phreatic tube which is nearly blocked by large amounts of collapse. This is the Second Front, and it continues through a couple of narrow squeezes into more open chambers which end at a complex choke with water trickling down through it.

Sleepwalker Series

The normal route into Sleepwalker is a spiralling climb up through the boulders at the end of the Canal in Far Streamway. Fifty feet above water level, the Hall of Justice is an enlargement in a massive phreatic tube. Downstream leads across a boulder floor and then traverses into Carrot Hall, above the streamway. Upstream in the tube is a spacious descent, past some fine red formations, into the Yard. Holes in the floor drop down into the Sleepwalker streamway blocked by boulders in both directions, downstream only a few yards from where the water pours through into the Canal. Hidden behind formations on the left of the Yard is a rift which continues as the Arm, tall and wide but choked with boulders after less than 200 feet. The main route continues over and round boulder piles, still well above the stream, to a sandy floored high rift from where an obscure hole leads into Sleepcrawler. This is an obnoxious succession of muddy grovels broken by one tall aven.

The next section of Sleepwalker is through, over and under a series of boulder piles which are loose enough to ensure that the great majority of cavers who have been through it have vowed never to return. A few mild contortions and a silly little squeeze round to the left of a massive boulder lead to the top of a loose boulder slope back down to stream level. Ahead and up over more boulders lies Peel Hall with fine formations but unfortunately no other way out. The way on is therefore down to the water and along the Grommiter crawl then up beneath high rifts (which are within feet of Peel Hall) and into the spacious Crescent Hall. The passage turns here along the line of a major fault zone and the south wall of Crescent Hall is on the fracture line. At the end of the Hall the floor is prone to collapse but the way on is a traverse over large blocks and along another high rift to an almost complete choke. A hole down through this is the Pincher – a delicate 20 feet climb down a tapering rift with the promise of oblivion offered by a gaping black hole in the floor. The hole opens into the roof of the streamway, and the route on is over boulders to a climb down, where the key handhold fell off in 1976.

The streamway beyond is pleasant as far as Jailhouse Rock. This massive block stands at the junction of various high and low level rifts containing boulder piles which involve a few climbs and a short wet bit down in the stream. At Whitehall Junction the high rifts turn right over a boulder pile into the fossil passages of Whitehall Series. At the two right hand bends holes in the floor lead back to the streamway, the first to the roof and the second to the floor. The following left hand bend has a fine cracked mud floor and various roof rift continuations. Just beyond, the Pit is choked 15 feet down, and a traverse across it leads to a boulder-strewn rift which gradually decreases in size and has many branches all of which are short. At the end the water emerges from a bedding plane above which an aven may be climbed for 70 feet to the highest point yet reached in the cave.

From Whitehall Junction the way back to the stream is a drop over boulders, and the route is then wide open. Various roof passages are easily climbed into, and eventually Beat Streeet develops into a fine keyhole passage, with some areas of good decorations. There is a wide bedding plane slot at floor level, and a roof tube which eventually offers the best way on where the canyon is nearly choked with boulders. Above the boulders Aven 49 soars into the darkness, and beyond it the old phreatic tunnel is almost canyonless. An old outlet on the right is full of glutinous mud and long straws but upstream is an easy walk as far as a sandbank beyond which lies a wide, shallow pool. This is the Final Sentence, a long wallow with decreasing airspace as far as Sump 1. The sump is 30 feet long, with joint guided airbells, but is deep and not free-diveable. The passage beyond is a high rift which develops into a wet crawl over a gravel floor. At a junction, right leads to another rift and an aven carrying water down from Crina Bottom almost directly above. Left is the very Shallow Sump 2 in the continuing phreatic tube. It has been dived for 120 feet to where it is nearly blocked by collapse, at a point 7350 feet from resurgence.

Hydrology

As it drains a significantly large portion of the western slopes of Ingleborough, White Scar Cave carries one of Yorkshire's larger underground streams. Its normal flow is a little under 2 cusecs, measured at First

Waterfall, but in the very dry summer of 1976 a minimum of 0.1 cusec was recorded. The cave stream has a very fast response to flooding, rising shortly after heavy rain to give a high flood peak followed by an almost equally rapid decrease of flow. The highest recorded flow is 34 cusecs but that is when the cave is still safely accessible, and the not uncommon floods which fill the show cave to the roof must reach double that figure. Under the measured conditions, the main stream from Phreatic Series normally contributes about half the total flow, with a quarter coming from the Sleepwalker stream and the remaining quarter being contributed by the many roof inlets. The number of roof inlets varies with stage, but in reasonably wet conditions there are about 30 significant inlet showers along the main streamway. With a total flow of much over 5 cusecs the Big Bertha choke is impassable, so little is known of flood conditions in the far end of the cave. The one party that involuntarily spent the night watching a flood peak in Far Streamway reported that many of the little roof inlets grew rapidly to sizeable cascades.

The main stream water is derived largely from Greenwood Pot and Red Gait Sink. Even though the large phreatic tube of Sump Series does not seem related to Greenwood or Red Gait, if it does have a source hidden under till, further up Crina Bottom, there can be little water coming down it. Water sinking at Gritstone Pot feeds the Sleepwalker stream, but the water from Boggarts Roaring Holes must cross this underground as it has been tested through to the Main Stream in White Scar. The two sinks in Crina Bottom, above the house, both feed into Sleepwalker – though it is not known just where in Sleepwalker the waters arrive (the links shown on the survey are only inspired guesses). Water disappearing in the lowest sink in Crina Bottom joins that from Rantry Hole and resurges at Skirwith Cave. The various Crina House sinks are only active in high stage conditions when they progressively receive overflow water from Greenwood Pot. Crina Bottom is therefore a superb example of a karstic valley which exhibits subterranean downdip leakage of its drainage along four parallel routes. In the upper end of the Crina Valley, water sinking at Quaking Pot flows to Granite Quarry Risings. The main stream sinks at Greenwood, feeding to White Scar, but overflow sinks at Crina House into Sleepwalker, and then into White Scar. Further overflow sinks to emerge at Skirwith while the surface valley continues down to Jenkin Beck. There are no other discrete sinks in the White Scar catchment, and the various minor inlets are all fed by percolation and seepage water from White Scars and Lead Mine Moss.

With Quaking Pot lying outside one boundary of the White Scar catchment, and Long Kin West (feeding to Moses Well) beyond the other, the catchment area can then be estimated – at 1.15 square miles. The "normal" flow, taken as 1.8 cusecs, therefore accounts for about 35% of the precipitation which lands in the catchment. The remaining 65% of the precipitation, together with "compensation" water for times of low stage, must be accounted for by evapotranspiration (probably about 20% on average), flood flows, and high-stage overflow down Crina Bottom into the Skirwith catchment. Nearly half the water in the catchment is therefore transmitted in flood peaks – in a very "peaky" pattern typical of a mature karst.

Geomorphology

On the general scale the geomorphology of White Scar Cave is very simple, as it has two main contrasting phases of development, in common with most other Yorkshire caves. A broad outline of the passage development is presented below. In detail, however, the cave is far more complicated and has much to offer the enquiring mind of the cave geomorphologist. The whole cave is developed in the lowest beds of the Great Scar Limestone, and yet only a very small proportion is actually on the limestone base – which is an unconformity on Ingletonian (Ordovician) slates and greywackes (grits). Most of the passages originated on relatively minor lithological variations some distance above the unconformity, and the subtleties of geological control, both structural and lithological, are probably demonstrated better in White Scar than in any other Yorkshire cave. Furthermore the various phreatic passages in the cave show some rather unpredictable irregularities which again may have some fundamental geological control. These geological and geomorphological problems are the subjects of continuing research and will feature in future published reports.

The oldest passages in White Scar Cave are clearly the large fossilised phreatic tunnels, partially filled with clastic sediments and stalagmite. There are two independent series of these old phreatic tubes. Terminated at both ends by boulder chokes is the massive phreatic segment from Second Front, through the Battlefield and along the length of Western Front. This was probably originally formed by Chapel-le-Dale water looping in under the flank of Ingleborough, but the inlet and outlet to the present valley are both unknown. Northern Line appears to be a later inlet, largely phreatic but with some vadose features, and some of the high levels at the end of Moonmilk Inlet may be related to the blocked continuation of Second Front.

Independent of the Battlefield tunnels were the old phreatic tubes carrying water westward from Crina Bottom. The main route was along Sleepwalker; it originated either near Crina House or higher on Dowlass Moss and is now inaccessible upstream of Sump 2. From Aven 49 a distributary is now visible in the roof of Beat Street, but the main route continued along the short, mud choked passage to the west, and is now untraceable, but appeared to disintegrate before re-coalescing and forming the main line out of Whitehall Series. From there it is continuous, though heavily collapsed, through Crescent Hall, Hall of Justice and Carrot Hall to an impenetrable sediment fill just west of Far Streamway. A major branch originated in Great Rift and now lies in the roof of the streamway except where it locally disintegrates through the Roof Series and is filled with clay for the last few yards into the Hall of Justice. The upstream continuation beyond Great Rift, whether it is beneath the boulder floor or out of sight in the roof, remains to be found, and Great Rift Inlet was just a minor inlet. The tube of the Phreatic and Sump Series is still active and difficult to date. It could belong to a younger perched phreas or could be an old tributary to the Great Rift tube. These upstream phreatic routes must have had their sources somewhere in the Greenwood Pot region of a proto-Crina Bottom.

The younger phase of development is represented by the long vadose canyons which form the present streamway. Downstream, the streamway probably had an early outlet through the bedding plane at the top of the Second Waterfall, but it then found a lower route, which was partially phreatic where ponded up by a rise in the basement, out through the Show Cave Entrance. Even later it found the lowest route, now wholly vadose, out to the Water Exit. Upstream the canyon is cut in the floor of the older phreatic tunnels as far back as an active nick point at the cascade out of the Phreatic Series at the Great Rift junction. A similar canyon is incised in the floor of the Sleepwalker Series as far up as a nick point just beyond Aven 49. Little collapse has taken place in the main stream branch, but the larger tunnels, in the more heavily fractured rock, undercut by a less powerful stream, in the Sleepwalker Series have resulted in extensive collapse. The Big Bertha choke and the size of the Battlefield are both due to the floor of the chamber breaking down into the underlying streamway. Moonmilk Inlet is a tributary with significant vadose downcutting, but all the other inlets in the cave are remarkably immature except the avens at the end of Sleepwalker.

Chronology

The two-phase, phreatic and subsequent vadose, development of White Scar Cave clearly relates to a massive regional rejuvenation associated with the cutting of Chapel-le-Dale, and it is almost inconceivable that this should not be a result of the climatic variations of the Pleistocene. A number of stalagmites from the cave have been analysed and dated on the basis of their uranium isotope contents. Most stalagmites, from both the Battlefield and the Main Streamway have yielded ages that are either post-glacial (i.e. less than 14,000 years) or are around 100,000 years, therefore placing their formation in the last Interglacial. Most significant however, is a single stalagmite from the roof of the Main Streamway which dates to 225,000 years ago. This can only indicate a "pre-glacial" origin for the old phreatic tubes, followed by rejuvenation probably by excavation of Chapel-le-Dale during the first subsequent glaciation, and then the development of the vadose canyons right through both subsequent interglacials (Hoxnian and Ipswichian) and into the post-glacial. Certainly the abundance of massive flowstone deposits in the roof of Far Streamway does suggest a considerable age for the vadose development, unlike many Yorkshire stream passages which may be entirely post-glacial.

Insofar as only one stalagmite has been proven to be so old, the above chronology must be regarded as a tentative suggestion. The analytical work has been done by R.S. Harmon of Michigan State University, and current and future work by Harmon and the writer is designed to either prove or modify this chronology.

The Survey

The plan of the cave published with this paper is the result of a completely new survey carried out during late 1975 and 1976. For this the writer is for ever indebted to the many cavers who acted as survey assistants and are listed below, and especially to some, notably the divers, who surveyed the extremities of the cave not visited by the writer.

Instruments used on the survey were Suunto compass and clinometer and fibron tape. The survey technique was what is almost the relatively rapid "Northern" method. Most of the passages were levelled with the clinometer, readings were to one degree and one foot, and stations were not marked. A grade 5 cannot therefore be claimed, though the survey is much better than grade 3, so it is best described as BCRA grade 4, though the grade falls off in the sumps and in the lesser inlets. A radio-location fix was taken from near the end of Sleepwalker up to Crina Bottom. The horizontal error was less than could be reliably measured off a 6 inches: 1 mile map and was not corrected — the survey of Crina Bottom is related to Sleepwalker as opposed to the Entrance. The vertical error was 28 feet, which was not unexpected in such a near-level cave, and was distributed. The survey was originally drawn at 50 feet to an inch, then photographically reduced in sections, fitted to a computer plot at 100 feet to an inch, and traced onto a master, which was further reduced in printing.

Acknowledgements

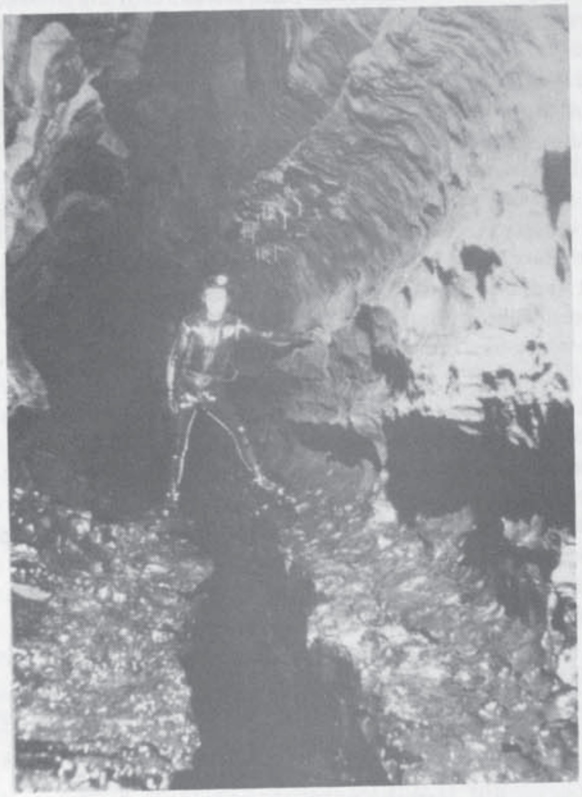
First and foremost, the writer is most grateful to A.F. Bagshaw, owner of White Scar Caves Limited, who not only permitted the current studies in the cave, but positively encouraged them, and through his generosity allowed many cavers to appreciate the splendours of White Scar as they assisted on the various work programmes.

The following are thanked for their patient work on the survey:- Alan Bailey, Julian Barker, Dave Brook, Mike Cowlishaw, Glyn Edwards, Jim Eyre, Dick Glover, Pat Halliwell, Ric Halliwell, Dave Hedley, Alison Hooper, Bob Hrindjj, Dave Irwin, Steve Jungnitz, Dave Kelsey, Alf Latham, Brian Matthews, John Middleton, Neil Montgomery, Jim Newton, Colin Ottway, Rob Palmer, Phil Pappard, Steve Pickersgill, Pete Seed, Pete Smart, Ray Smith, Phil Smyth, Oliver Statham, Steve Tarran, Chris Trevor, Vernon Unsworth, Dick Willis and Geoff Yeadon. The writer is also particularly grateful to:- Mike Cowlishaw who punched and computed the survey data; Stephen Levy who plotted the survey on the Trent Polytechnic computer; Rus Harmon who dated the stalagmites in his Michigan State University laboratory; Ric Halliwell who provided some of the hydrological data; Pete Smart who tested all the dye tracers, and many others who took photographs, held maypoles, carried bottles, etc., etc.

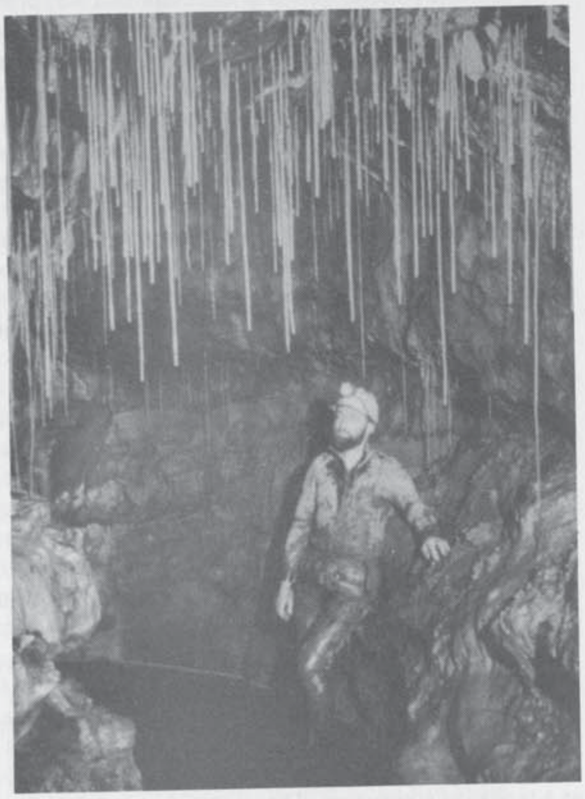
Finally the writer extends his special thanks to Julian and Leslie Barker, whose endless, generous and kind hospitality at the cave made the project both possible and enjoyable.

M.S. received 2nd June 1977

A.C. Waltham
Trent Polytechnic,
Nottingham NG1 4BU.



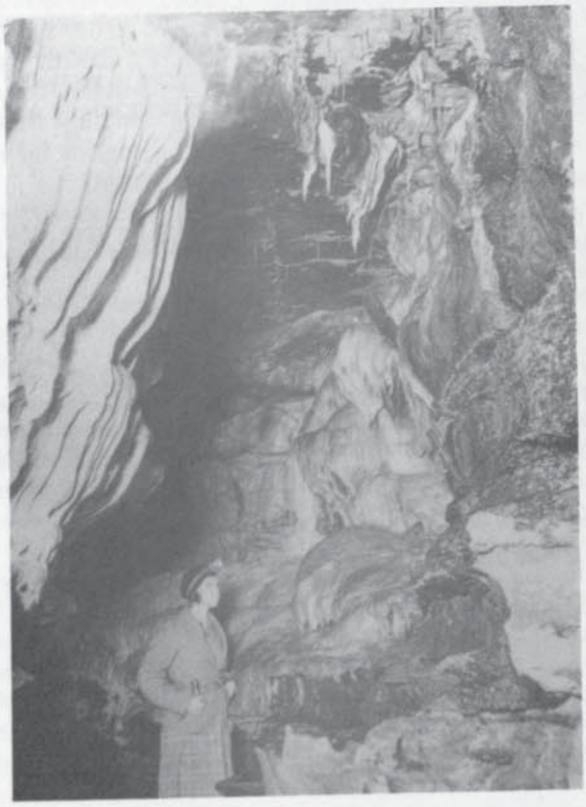
Traverse in Far Streamway
(photo A. C. Waltham)



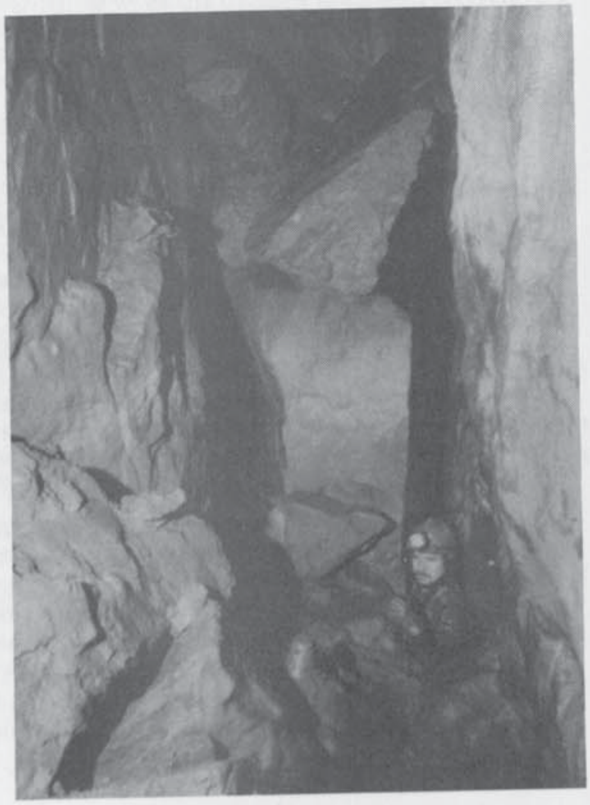
At the end of Northern Line
(photo A. C. Waltham)

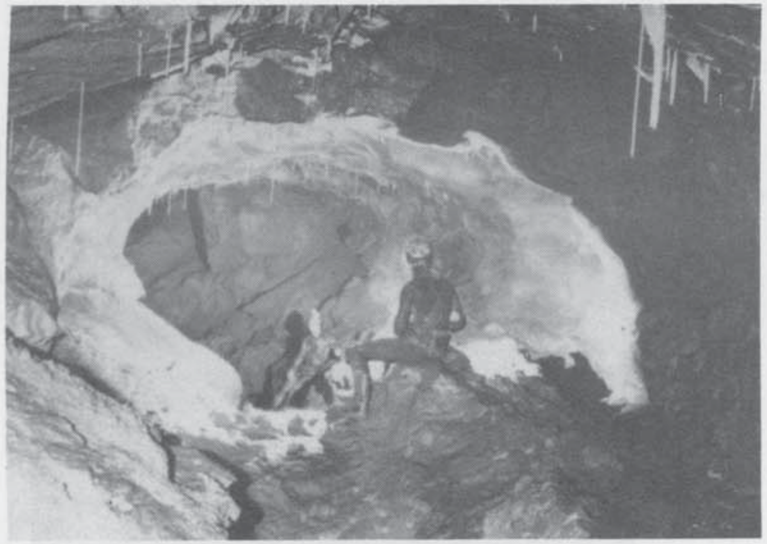
WHITE SCAR CAVE

Formations in Main Streamway
(photo E. Simpson)

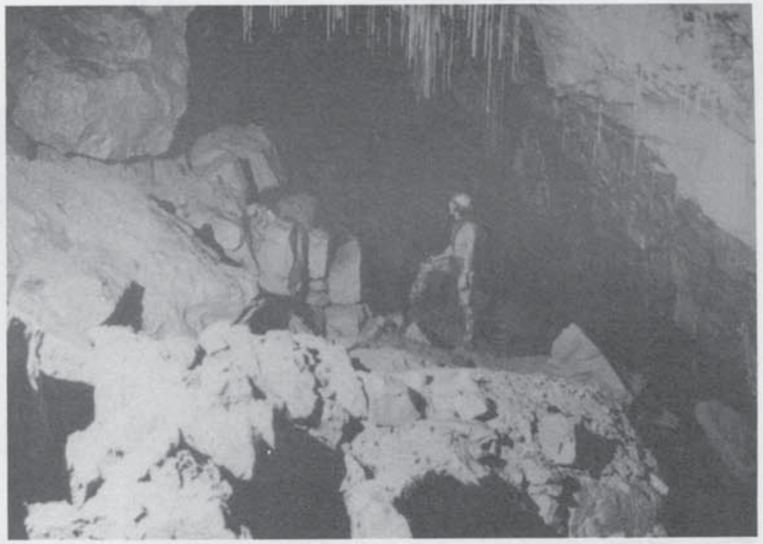


The Pincher, in Sleepwalker
(photo A. C. Waltham)





Roof-tube near Carrot Hall

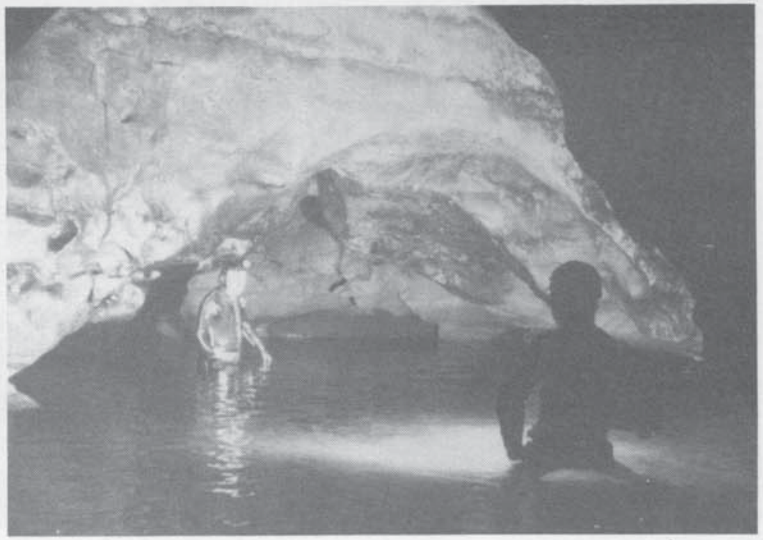


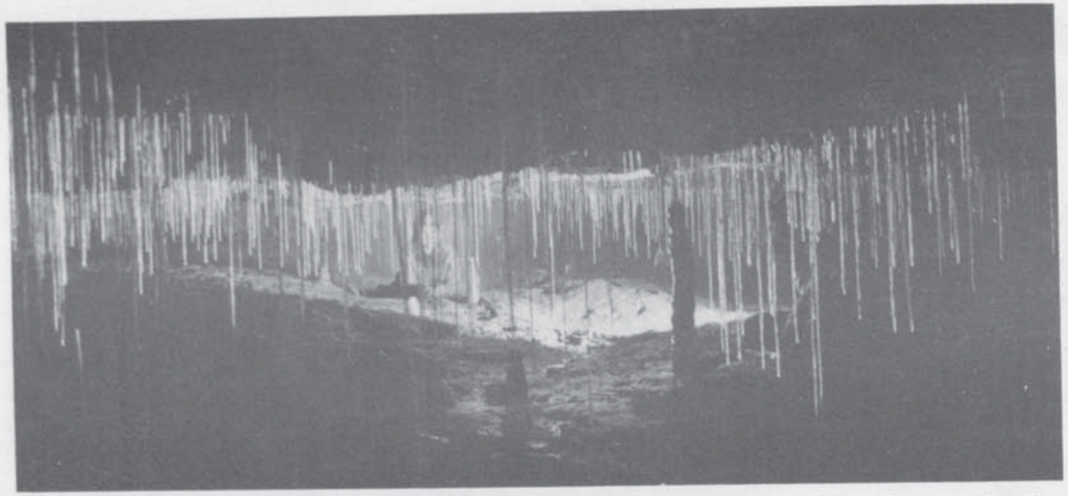
Boulder Pile in Battlefield Chamber

WHITE SCAR CAVE
Photos by A.C.Waltham

Whitehall Series

Phreatic Series

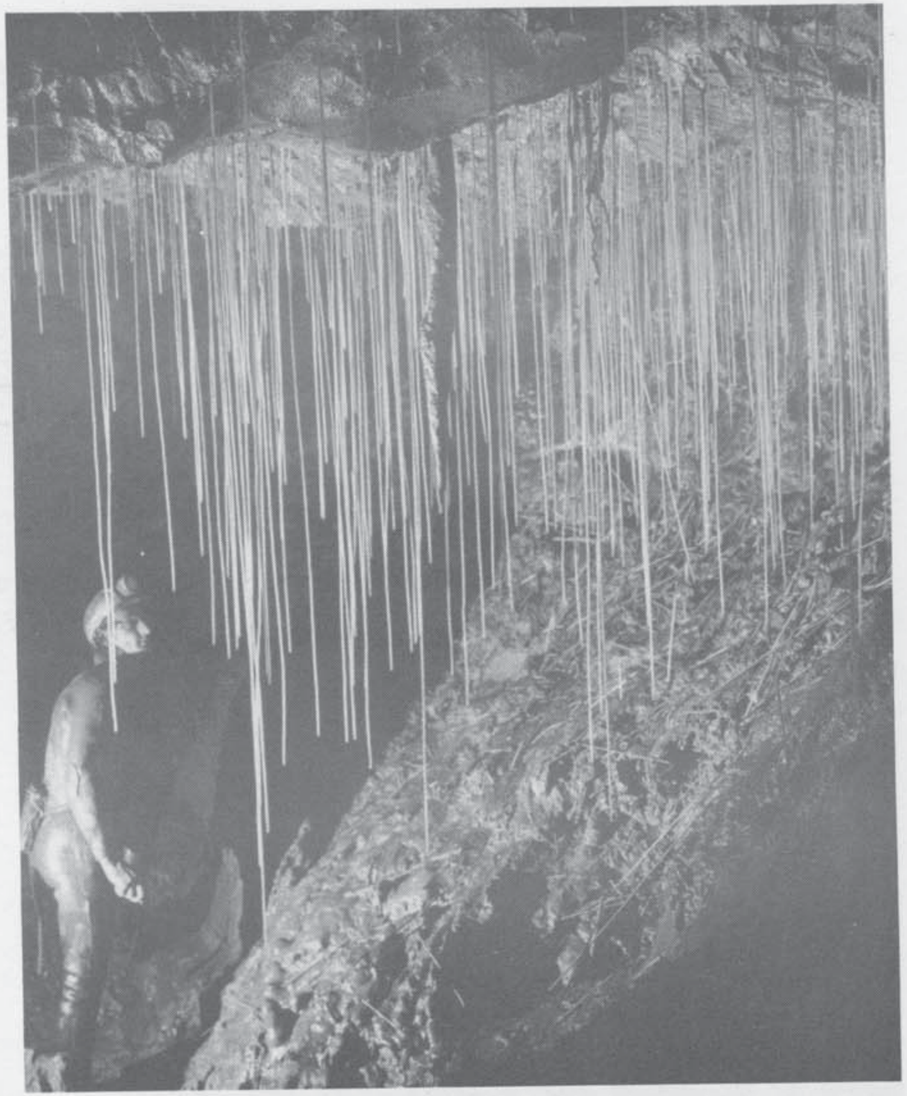




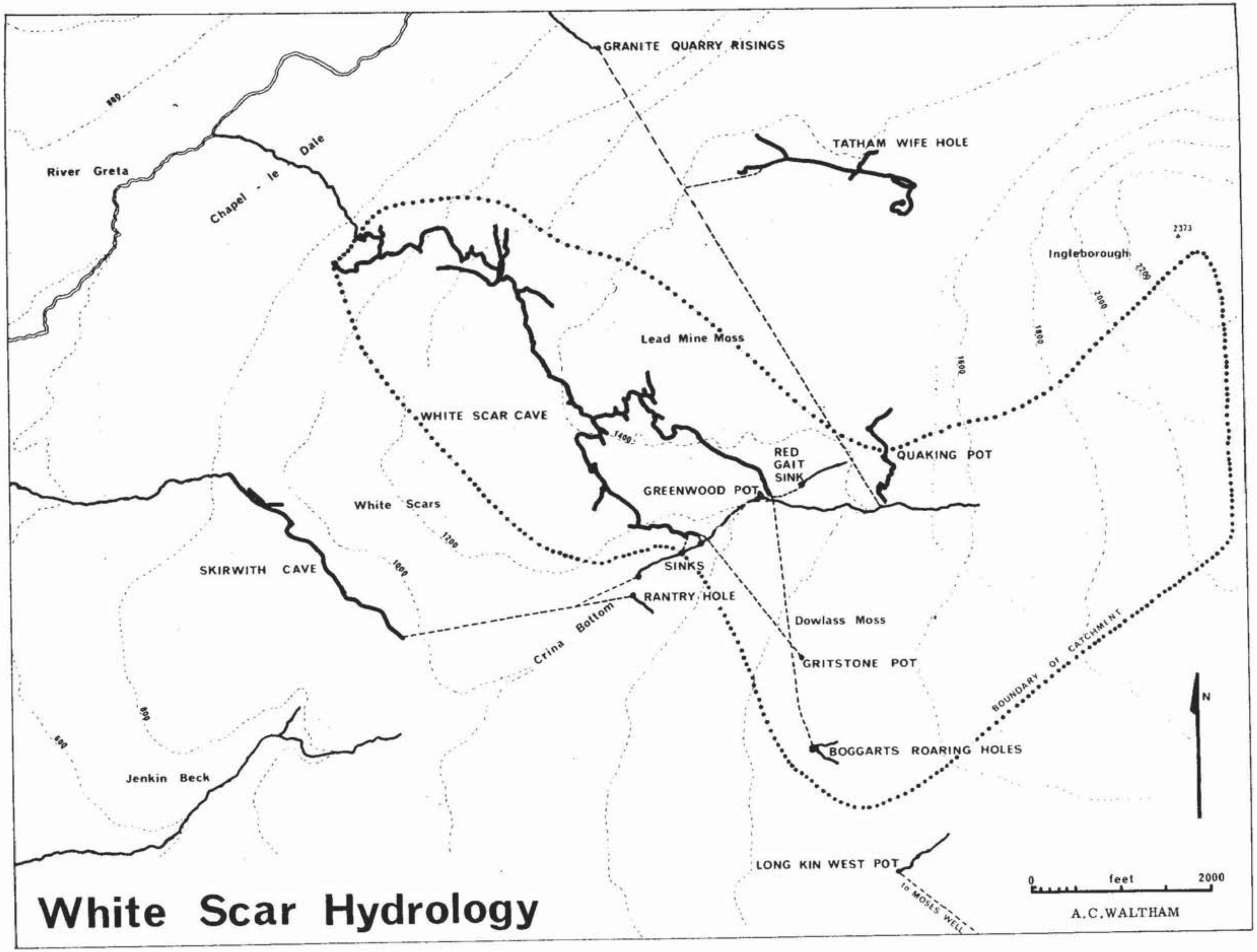
At the end of Western Front (photo by Ian Davinson)

Battlefield Chamber (photo G.M.Davies)

WHITE SCAR CAVE



Straw Chamber above Far Streamway (photo J.R.Wooldridge)


White Scar Hydrology
GRANITE QUARRY RISINGS
TATHAM WIFE HOLE
River Greta
Chapel - le Dale
Ingleborough
2373
2200
2000
1800
1600
Lead Mine Moss
WHITE SCAR CAVE
1400
QUAKING POT
RED GAIT SINK
GREENWOOD POT
White Scars
1200
SKIRWITH CAVE
1000
SINKS
RANTRY HOLE
Crina Bottom
Dowlass Moss
GRITSTONE POT
BOUNDARY OF CATCHMENT
N
800
Jenkin Beck
BOGGARTS ROARING HOLES
LONG KIN WEST POT
to MOSES WELL
0
feet
2000
A.C.WALTHAM

Trans. British Cave Research Assoc. Vol. 4, No. 3, pp 355-359 August 1977

LIMESTONE SOLUTION AND CHANGES OF DISSOLVED GAS CONCENTRATION AT STREAM SINKS OF THREE CAVES IN THE MENDIP HILLS, SOMERSET.

J.L. Bridge, C.M. Cooper, C. Kelly, S.D. Marsh and R.D. Stenner

Summary

An investigation was designed to assess the relative importance of absorption of CO_2 from cave air and the oxidation of dissolved organic matter in the solution of limestone near the entrance of a cave. At Swildon's Hole and G.B. Cave, Mendip, samples were taken from the surface and inside the cave. Increases of the order of 10% dissolved oxygen were measured in short distances. Chemic Oxygen Demand changes were not associated with either Dissolved Oxygen changes or limestone solution measurements. Results were supported by data from Grönligrotta, Norway, and St. Cuthbert's Swallet, where air in the entrance boulder ruckle was found to have more carbon dioxide than adjacent parts of the cave.

Large changes in concentration of dissolved salts were measured in G.B. Cave (Somerset) in the short distance between the surface sink and the chamber where the stream reappeared in the cave, (Stenner, 1970, 1973). Calcium, magnesium, bicarbonate and limestone analyses showed that the observed increases were caused by the solution of limestone in the boulder ruckle between the sink and the cave. In 9 out of sixteen measurements, the increments of total hardness and total CO_2 both exceeded 20ppm, $CaCO_3$, with maximum increments exceeding 70ppm. $CaCO_3$. The examination of correlation coefficients between increase of total hardness, total increase of CO_2, discharge and temperature showed that the solution of limestone was dependent on the time of contact between the water and limestone (a power factor of the discharge value of the stream), with enhancement of limestone solution whenever the stream temperature rose above 12°C (Stenner, 1973).

The source of the CO_2 which permits this rapid solution of limestone was not known. It may have been:

i) produced in the water itself by the biological oxidation of dissolved organic matter,

or ii) absorbed from air in the boulder ruckle which had been enriched in CO_2 by biochemical processes, or by a combination of both processes.

It is well established that the CO_2 content of soil air is higher than in the atmosphere. Work by Picknett and Stenner in 1972 showed that air in the entrance boulder ruckle in St. Cuthbert's Swallet (Somerset) was significantly richer in CO_2 than in adjacent parts of the cave.

This discovery needed further supportive evidence before any firm conclusions about the relative importance of the two postulated sources of the CO_2 could be made. A preliminary experiment in a cave in Norway was inconclusive (Stenner, 1977). More important, the ability of dissolved gas concentrations to change considerably in short distances along a cave stream had not been demonstrated.

A series of experiments was carried out in 1975 to find out more about dissolved gas concentrations and Chemical Oxygen Demand (C.O.D.) changes close to the entrance of a cave, and to relate them to limestone solution changes.

The results are given here, together with those obtained by Stenner in St. Cuthbert's Swallet in 1973 and in Grönligrotta in 1972, and some of the air CO_2 results obtained by Picknett and Stenner in St. Cuthbert's Swallet in 1972.

Experimental

Between February and May 1975 water samples were collected from the surface streams and from stations inside the cave at G.B. Cave, Charterhouse, and Swildon's Hole Priddy. Samples were analysed for dissolved oxygen at the site using the Winkler method, and for C.O.D. by the 1 hour 100°C permanganate demand method detailed by Bray and O'Reilly (1974). Samples were analysed for Ca, Mg, bicarbonate and aggressiveness to $CaCO_3$ by complexometric titration (Total aggressiveness) potentiometric titration (bicarbonate) and atomic absorption spectrophotometry (Mg) as detailed by Stenner (1971). The results presented in Tables 1-3 and 5 were obtained with the same experimental technique, except that at Grönligrotta the C.O.D. was measured by two methods, the 4 hr 28°C $KMnO_4$ demand (Bray, 1972) and the $K_2Cr_2O_7$ demand (in 50% H_2SO_4, $HgSO_4$ catalyst).

The results are the means of at least two determinations, and the precision of the determinations have been discussed in the papers previously quoted by Bray (1972 & 1975) and Stenner (1968, 1970, 1971, 1973, 1977).

Site Descriptions

At G.B. cave and St. Cuthbert's Swallet, the streams go underground in multiple sinks, following different routes from the various sinks into the cave. The sites have been described previously (Stenner, 1968, 1973,) and the pattern of distribution through the various routes is known to be changeable at both caves. In this study, changes were measured where major proportions of the streams flow through a boulder ruckle. Distances in each case were small. In St. Cuthbert's Swallet, the vertical and horizontal distances were approximately 32m and 15m respectively, and in G.B. the vertical and horizontal distances were 11m and 18m respectively. (straight line distances from sink to inlet).

At Swildon's Hole, although the water divides for a fairly short distance between two routes, the cave is open in nature throughout, without the mud-choked boulder ruckles of the other two sites. The sample was collected where the stream recombined, the vertical and horizontal distances from the sink being approximately 15m and 14m respectively.

Table 1

Changes in solute concentrations at G.B. Cave between the Surface and Boulder Chamber (B.C.) (Stable temperature of ruckle 8.5°C (Stenner, 1973)

	Surf.	B.C.	Surf.	B.C.	Surf.	B.C.
Date	19.2.75		5.3.75		30.4.75	
Stream state	High	-	Mod.	-	Low	-
Temperature °C	3	-	9	-	11	-
Alkaline hardness (10^5 x MCa)	8.0	-	10.6	-	15.0	-
Calcium (10^5 x M)	15.9	24.8	18.5	28.2	18.5	27.1
Magnesium (10^5 x M)	7.0	7.0	6.9	6.8	16.5	20.0
Aggressiveness (10^5 x MCa)	27.4	15.7	21.0	16.1	17.8	12.1
Limestone solution (10^5 x MCa) (Δ Tot. hard)	-	+8.9	-	+9.7	-	+12.1
Change of total CO_2 (10^5 x MCa) (Δ Sat. Tot. hard)	-	−2.8	-	+4.8	-	+6.3
Dissolved oxygen (mg. l^{-1})	11.7	11.4	10.7	11.2	9.8	10.5
C.O.D. (1hr 100°C permanganate demand, mg l^{-1} O_2)	2.3	0.9	1.0	1.55	1.7	1.4

Table 2

Changes in solute concentrations at Swildon's Hole between the surface and the stream passage in the cave

	Surf.	Cave	Surf.	Cave	Surf.	Cave	Surf.	Cave
Date	25.2.75	-	21.4.75	-	24.4.75	-	28.4.75	-
Stream state	Low	-	High	-	Inter.	-	Low	-
Temperature °C	3	3	9.4	9.4	11.3	11.1	11.0	11.0
Alkaline hardness (10^5 x MCa)	172		160		176		182	
Calcium (10^5 x M)	180	184	167.5	167.6	186.4	186.8	190.1	193.0
Magnesium (10^5 x M)	20	20.0	16.5	16.4	17.6	17.2	17.9	18.0
Aggressiveness (10^5 x MCa)	+4.0	-9.0	+2.0	-0.5	-15.0	-9.0	+0.5	+2.0
Limestone solution (10^5 x M) (Δ Tot. hard)	-	+4	-	0	-	0	-	+3
Change of total CO_2 (10^5 x MCa) (Δ Sat. Tot. Hard)	-	-9	-	-2.5	-	+6	-	+4.5
Dissolved oxygen (mg l^{-1})	8.7	9.5	10.15	10.6	8.8	9.6	9.9	10.3
C.O.D. (1hr 100°C permanganate demand, mg. l^{-1} O_2)	0.68	0.36	0.32	0.22	0.10	0.14	0.10	0.24

Table 3

Changes in solute concentrations at St. Cuthbert's Swallet between the surface and Arête Chamber, 19.8.73. (Stable temperature of ruckle 8.5°C (Stenner, 1968). Most direct flow route on date of sample collection to E. Inlet; N.E. Inlet dry, W. Inlet approx. 10% of E. Inlet discharge).

	Surface	E. Inlet	W. Inlet
Temperature, °C	13.5	-	-
Alkaline hardness (10^5 xMCa)	145	146	146
Calcium (10^5 xM)	143	144	147
Magnesium (10^5 xM)	13.8	13.2	13.2
Aggressiveness (10^5 xMCa)	–0.5	9.2	7.0
Limestone solution (10^5 MCa) (Δ Total hardness)	-	+0.4	+3.6
Change of total CO_2 (10^5xMCa) (Δ Sat. Total hardness)	-	+10.2	+10.9
D.O. (mg l^{-1} O_2)	9.3	9.9	9.8

Discussion

1. The results from G.B. were significant in the lack of relationship between limestone solution and change of C.O.D. between the surface and the cave, to be discussed in paragraph 3 below and succeeding paragraphs. The relationships between both limestone solution and change of total CO_2 with discharge follow the trend of earlier studies in the cave; both increased as discharge decreased. However, the stream had changed its route since 1969, and in 1975 was entering the cave upstream of the Devil's Elbow, using what in 1968-9 had been an overflow route (Stenner 1973). The precise magnitude of the changes would not therefore have been the same as those predictable from earlier data.

The results from St. Cuthbert's Swallet show a feature similar to G.B. features, with maximum limestone solution in the slower alternative route (W. Inlet). It may be significant that the total absorption of CO_2 was very similar in each of the routes.

Very little information about limestone solution was available from Swildon's Hole, except that a maximum was found in low discharge conditions. However, the Swildon's results yielded significant data of dissolved oxygen concentration changes, and similar changes may be seen in the D.O. results from G.B. and St. Cuthbert's Swallet. These results will be discussed in greater length in Paragraph 2.

2. Dissolved oxygen figures in Tables 1-3 all show that significant changes in concentration of dissolved gases can take place in short distances and times between the surface and the cave. In four of the ten measurements changes were close to 10% of the surface figures. Observed changes were in every case at G.B. and St. Cuthbert's those which would be expected in water approaching equilibrium with air at different temperatures inside the cave. The water at Swildon's hole was undersaturated at the surface – a characteristic of water in springs at the Old Red Sandstone/Lower Limestone Shales interface, with a relatively short gentle surface stream. The highly turbulent flow inside the cave provided the suitable conditions for rapid absorption of oxygen to approach the expected saturated level. In no case is it justifiable to interpret the changes in terms of consumption of dissolved oxygen during the oxidation of dissolved organic material. The changes in Swildon's Hole are especially noteworthy because of the extremely short distance and time involved, and the essentially open nature of the cave between the surface and the sampling point.

To summarize, direct measurements of the solution of oxygen have been observed, changes which are incapable of alternative interpretation. It is therefore justifiable to state that similar solution must be possible in the case of Co_2. In the sites which were studied, changes of saturated total hardness were most probably a measure of changes of dissolved carbon dioxide, and have been so designated in the tables of results.

3. The C.O.D. results were inconsistent with the supposition that limestone solution results from the oxidation of dissolved organic matter. On three occasions (G.B. 5.3.75 and Swildon's 24.4.75, 28.4.75) C.O.D. values actually increased between the surface and the cave, while at the same time CO_2 was being absorbed. It is possible that the increase of C.O.D. may have been connected with processes which generated CO_2 in the cave air.

4. The results have indicated that limestone solution near the entrance of G.B. and Swildon's Hole were not associated with C.O.D. changes. The suggestion previously made (Stenner 1973) that limestone

solution near the entrance of G.B. is a result of absorption of CO_2 by water passing through the boulder ruckle are given credibility by the discrediting of the alternative theory, and by the proof that dissolved gas concentrations can indeed change very rapidly. The supposition is further strengthened by work by Picknett and Stenner in St. Cuthbert's Swallet, who made a survey of air CO_2 concentrations, using Dräeger Gas Analysis apparatus with appropriate tubes for low concentrations of CO_2. The readings were made in January 1972, during an anticyclone when air was blowing strongly into the cave. A selection of the results are presented in Table 4.

Table 4

Air CO_2 content in St. Cuthbert's Swallet, % vol. per vol., 30.1.72

Site	CO_2 % vol. / vol.
Bottom of Entrance Pitch	0.04
Foot of Lower Ledge Pitch	0.08
Boulder Chamber, Quarry Corner	0.08
Traverse Chamber	0.09
Arête Chamber, Pulpit Passage	0.12
Arête Chamber, source of N.W. Inlet stream	0.12
Arête Chamber, N.E. Inlet, space in boulders	0.15

No reading was taken in Arête chamber itself, but as this chamber was in the main air flow between the Entrance Pitch and the Ledge Pitches, the air content of this large chamber was certainly not higher than 0.08%, which is considerably lower than the value in the N.E. Corner of the chamber. This last site is at the lower end of the boulder ruckle, and it would appear likely that the air deeper in the ruckle would contain more than 0.15% CO_2. Recent data (Picknett, 1973) show that at the stable temperature of the ruckle, 0.15% CO_2 would be in equilibrium with 117×10^{-5} M Calcium bicarbonate in solution, a figure of 0.30% in the ruckle would completely explain the observed limestone solution in the ruckle. This figure is lower than many values observed by Atkinson (1971), who reported values in excess of 1% in limestone soils. It seems reasonably safe to conclude that limestone solution in a boulder ruckle such as that at St. Cuthbert's Swallet results from the high CO_2 content of the air in the boulder ruckle.

5. Results obtained at Grönligrotta, Norway (Stenner, 1977) are shown in Table 5.

In Table 5 the results are similar to those in Tables 1 and 2, the gain of CO_2 being considerably higher than could be expected from the decrease of C.O.D. (by permanganate demand), so between the two stations the part played by oxidation of dissolved organic matter was of minor importance. The absorption of CO_2 was, however, small since water in the cave was apparently under-saturated with respect to the CO_2 content of the normal atmosphere.

6. The results so far discussed were concerned with changes in short distances between the surface and the cave. Work in Ogof Ffynnon Ddu (Bray, 1972, 1975, Bray and O'Reilly, 1974) has shown that in long stream passages, there is a direct correlation between Ca increase and C.O.D. decrease. The results from G.B. show C.O.D. values in Boulder Chamber which are high when they are compared with Swildon's Hole data, with similar data from Ogof Ffynnon Ddu, or with a single value from the Cheddar rising of 0.35 mg l^{-1}. This suggests that dissolved organic matter does make the longer-term solution of limestone possible, indeed likely, further in the cave. It is not possible to investigate this directly because the stream passage in G.B. cave is too short.

7. In conclusion, the results of the study suggest that limestone solution which takes place in a short distance in boulder ruckles close to the surface is caused by the absorption of CO_2 from CO_2-enriched air in those boulder ruckles. The oxidation of dissolved organic matter is a slower process. Both processes can take place simultaneously, so that in the boulder ruckles which have been studied, the effects of the first process are predominant, while in a long stream passage the effects of the second process become predominant.

Table 5

Solute concentration changes at Grönligrotta, 20.6.72

	Surface sink	Stream in cave
Temperature, °C	12.7	9.4
Alkaline hardness (10^5 xM)	15	17
Calcium (10^5 xM)	11.3	13.4
Magnesium (10^5 xM)	5.2	5.2
Aggressiveness (10^5 xMCa)	8.7	16.3
Limestone solution (10^5 xM) (Δ Total hardness)	-	+2.1
Change of total CO_2 (10^5 xMCa) (Δ Sat. Total hardness)	-	+9.7
C.O.D. (4 hr 28°C $KMnO_4$ demand, mg l^{-1} O_2)	1.9	1.7
C.O.D. ($K_2Cr_2O_7$ demand, mg l^{-1} O_2)	5.1	5.1

Acknowledgements

The author would like to thank the Royal Society for making this research possible, and the University of Bristol for making available the necessary laboratory space and equipment. The author particularly wishes to thank Dr. G. Nickless and Dr. R.G. Picknett for advice and criticism during the work and the preparation of this paper.

References

Atkinson, T.; 1971. Ph.D. Thesis (unpublished), University of Bristol.

Bray, L.G.; 1975. Recent Chemical work in the Ogof Ffynnon Ddu system; further oxidation studies, *Trans. Brit, Cave Res. Assoc.* Vol 2, (3) pp, 127-132;

1972 Preliminary oxidation studies on some cave waters from South Wales. *Trans Cave Res. Group. G.B.,* vol 14 (2) pp.59-66.

Picknett, R.G.; 1973. Saturated calcite solutions from 10°C to 40° C a theoretical study evaluating the solubility product and other constants, *Trans. Cave Res Group G.B.,* vol 15 (2), pp 67-80

Stenner, R.D.; 1968. Water tracing in St. Cuthbert's Swallet, Priddy, Somerset. *Trans. Cave Res. Group G.B.,* vol 10(2), pp.49-60.

1970. Preliminary results of an application of the procedure for the measurement of aggressiveness of water to Calcium Carbonate, *Trans. Cave Res. Group G.B.,* vol 12(4), pp. 283-289.

1971. The measurement of aggressiveness of water to Calcium Carbonate, Parts II and III. *Trans. Cave Res. Group G.B.,* vol 13(4) pp.283-295.

1973. A study of the hydrology of G.B. Cave, Charterhouse-on-Mendip, Somerset, *Proc. University Bristol Speleo Soc.* vol 13(2), pp.171-226.

1977. Some investigations in European Caves. In "Cave Notes 1975-77", Bristol Exploration Club, Caving Report No. 21, pp.29-34.

Dept. of Inorganic Chemistry,
University of Bristol,
Bristol.

solution near the entrance of G.B. is a result of absorption of CO_2 by water passing through the boulder ruckle are given credibility by the discrediting of the alternative theory, and by the proof that dissolved gas concentrations can indeed change very rapidly. The supposition is further strengthened by work by Picknett and Stenner in St. Cuthbert's Swallet, who made a survey of air CO_2 concentrations, using Draeger Gas Analysis apparatus with appropriate tubes for low concentrations of CO_2. The readings were made in January 1972, during an anticyclone when air was blowing strongly into the cave. A selection of the results are presented in Table 4.

Table 4

Air CO_2 content in St. Cuthbert's Swallet, % vol. per vol., 30.1.72

Site	CO_2 % vol. / vol.
Bottom of Entrance Pitch	0.04
Foot of Lower Ledge Pitch	0.08
Boulder Chamber, Quarry Corner	0.08
Traverse Chamber	0.09
Arête Chamber, Pulpit Passage	0.12
Arête Chamber, source of N.W. Inlet stream	0.12
Arête Chamber, N.E. Inlet, space in boulders	0.15

No reading was taken in Arête chamber itself, but as this chamber was in the main air flow between the Entrance Pitch and the Ledge Pitches, the air content of this large chamber was certainly not higher than 0.08%, which is considerably lower than the value in the N.E. Corner of the chamber. This last site is at the lower end of the boulder ruckle, and it would appear likely that the air deeper in the ruckle would contain more than 0.15% CO_2. Recent data (Picknett, 1973) show that at the stable temperature of the ruckle, 0.15% CO_2 would be in equilibrium with 117×10^{-5} M Calcium bicarbonate in solution, a figure of 0.30% in the ruckle would completely explain the observed limestone solution in the ruckle. This figure is lower than many values observed by Atkinson (1971), who reported values in excess of 1% in limestone soils. It seems reasonably safe to conclude that limestone solution in a boulder ruckle such as that at St. Cuthbert's Swallet results from the high CO_2 content of the air in the boulder ruckle.

5. Results obtained at Grönligrotta, Norway (Stenner, 1977) are shown in Table 5.

In Table 5 the results are similar to those in Tables 1 and 2, the gain of CO_2 being considerably higher than could be expected from the decrease of C.O.D. (by permanganate demand), so between the two stations the part played by oxidation of dissolved organic matter was of minor importance. The absorption of CO_2 was, however, small since water in the cave was apparently under-saturated with respect to the CO_2 content of the normal atmosphere.

6. The results so far discussed were concerned with changes in short distances between the surface and the cave. Work in Ogof Ffynnon Ddu (Bray, 1972, 1975, Bray and O'Reilly, 1974) has shown that in long stream passages, there is a direct correlation between Ca increase and C.O.D. decrease. The results from G.B. show C.O.D. values in Boulder Chamber which are high when they are compared with Swildon's Hole data, with similar data from Ogof Ffynnon Ddu, or with a single value from the Cheddar rising of 0.35 mg l^{-1}. This suggests that dissolved organic matter does make the longer-term solution of limestone possible, indeed likely, further in the cave. It is not possible to investigate this directly because the stream passage in G.B. cave is too short.

7. In conclusion, the results of the study suggest that limestone solution which takes place in a short distance in boulder ruckles close to the surface is caused by the absorption of CO_2 from CO_2-enriched air in those boulder ruckles. The oxidation of dissolved organic matter is a slower process. Both processes can take place simultaneously, so that in the boulder ruckles which have been studied, the effects of the first process are predominant, while in a long stream passage the effects of the second process become predominant.

Table 5

Solute concentration changes at Grönligrotta, 20.6.72

	Surface sink	Stream in cave
Temperature, °C	12.7	9.4
Alkaline hardness (10^5 xM)	15	17
Calcium (10^5 xM)	11.3	13.4
Magnesium (10^5 xM)	5.2	5.2
Aggressiveness (10^5 xMCa)	8.7	16.3
Limestone solution (10^5 xM) (Δ Total hardness)	-	+2.1
Change of total CO_2 (10^5 xMCa) (Δ Sat. Total hardness)	-	+9.7
C.O.D. (4 hr 28°C $KMnO_4$ demand, mg l^{-1} O_2)	1.9	1.7
C.O.D. ($K_2Cr_2O_7$ demand, mg l^{-1} O_2)	5.1	5.1

Acknowledgements

The author would like to thank the Royal Society for making this research possible, and the University of Bristol for making available the necessary laboratory space and equipment. The author particularly wishes to thank Dr. G. Nickless and Dr. R.G. Picknett for advice and criticism during the work and the preparation of this paper.

References

Atkinson, T.; 1971. Ph.D. Thesis (unpublished), University of Bristol.

Bray, L.G.; 1975. Recent Chemical work in the Ogof Ffynnon Ddu system; further oxidation studies, *Trans. Brit, Cave Res. Assoc.* Vol 2, (3) pp, 127-132;

1972 Preliminary oxidation studies on some cave waters from South Wales. *Trans Cave Res. Group. G.B.,* vol 14 (2) pp.59-66.

Picknett, R.G.; 1973. Saturated calcite solutions from 10°C to 40° C a theoretical study evaluating the solubility product and other constants, *Trans. Cave Res Group G.B.,* vol 15 (2), pp 67-80

Stenner, R.D.; 1968. Water tracing in St. Cuthbert's Swallet, Priddy, Somerset. *Trans. Cave Res. Group G.B.,* vol 10(2), pp.49-60.

1970. Preliminary results of an application of the procedure for the measurement of aggressiveness of water to Calcium Carbonate, *Trans. Cave Res. Group G.B.,* vol 12(4), pp. 283-289.

1971. The measurement of aggressiveness of water to Calcium Carbonate, Parts II and III. *Trans. Cave Res. Group G.B.,* vol 13(4) pp.283-295.

1973. A study of the hydrology of G.B. Cave, Charterhouse-on-Mendip, Somerset, *Proc. University Bristol Speleo Soc.* vol 13(2), pp.171-226.

1977. Some investigations in European Caves. In "Cave Notes 1975-77", Bristol Exploration Club, Caving Report No. 21, pp.29-34.

Dept. of Inorganic Chemistry,
University of Bristol,
Bristol.

Trans. British Cave Research Assoc. Vol. 4, No. 3, pp 361-365 August 1977

A SURVEY OF CARLSWARK CAVERN, STONEY MIDDLETON, DERBYSHIRE, WITH GEOLOGICAL AND HYDROLOGICAL NOTES

Noel Christopher and John Beck.

(a) The Survey

The survey was begun on 25.11.73 when the connection between Carlswalk Cavern and Gimlis' Dream was about to be blocked, and having surveyed, that day, as far as the crawl half-way along the new extension, we decided to survey the rest of the cave!

Work proceeded at a steady pace until Easter 1974, when it languished until the Autumn, with apparently only a few trips necessary to complete the work, but the pace was not pushed until the following year when after a mere 17 trips the field work was apparently completed. A few short trips to survey parts of the cave found since the original survey work were made later.

The survey was carried out with a hand-held Suunto compass, a Suunto clinometer or calibrated Abney level, and a Fibron tape. The compass was checked for gross errors, but individual daily calibrations were not carried out. The method of using the instruments and the precisions obtained conform to a poor BCRA Grade 5 for the centre line. The passage detail was measured or estimated, if warranted, at the survey stations and wherever else necessary to ensure a reasonably detailed outline to conform to BCRA Grade C. The cave contains only one closed internal traverse, but this unfortunately can only be made through the lower sump which even during the exceptionally dry summer of 1975 remained flooded so the traverse could not be closed.

There are three entrances to the system and these were closed by P.R. Deakin using a theodolite and conventional land surveying techniques to give National grid references accurate to one metre. These were taken as accurate and the cave survey was closed to these points. A level survey was not carried out and the only vertical closure possible was from altitudes given in a previous survey (King, 1962) which were checked for gross errors from Ordnance Survey maps, and used to assess the vertical misclosure.

The survey was calculated by coordinates using initially a Hewlett Packard HP 35 pocket calculator, and subsequently a Texas Instrument SR 51A calculator. These considerably reduced the tedium of this method, and the internal computation to 13 significant figures was more than sufficiently accurate for the purpose. A magnetic declination of 8° was incorporated. The main closed loops were calculated twice to check for mechanical errors, which proved to be few. The major side passages were also double-checked. Traverse misclosure information is given in Table 1. The survey was plotted on 0.5 x 0.8 metre sheets of graph paper, at a scale of 1: 500 (2mm = 1metre) using the Gin entrance as base point. A permanent tracing was made on one sheet of permatrace 1.2m x 0.75m using Rotring Variant pens of 0.5mm thickness for the main outline and 0.3 or 0.25mm for the detail. For parts of Dynamite series and some side passages a 0.4mm pen was used for the outline to improve the appearance.

Contrary to present recommendations (Ellis 1976) it was decided not to Grid the final tracing as it was already sufficiently cluttered, but grid marks are provided around the margin of the plan for anyone who so desires to draw in a plan grid.

Extended elevations of the whole cave were drawn in three sections and, due to its complexity, a projected elevation insert of the Falls Chamber Porth Crawl was added as an insert at a scale of 1 to 200 (5mm = 1m).

The survey was primarily carried out by four persons, Noel Christopher, Paul Deakin, Dave Gill and John Beck, NC was present on 15 of the 17 trips accompanied by one or more of the principal surveyors; in addition, 6 people helped with one trip each, these were, Jim Burton, Joe Cooper, N. Smith, H Mares, O C Lloyd and Ron Bridger, all of these people were/are or have subsequently become members of the Eldon Pothole Club.

Tables 1 and 2 give details of traverse misclosures and passage lengths respectively.

Table 1

A. Horizontal Misclosures of Principal Traverses

Traverse	Misclosure in Metres. Easting	Northing	$\sqrt{E^2+N^2}$	Traverse Length	% Error
Entrance on Gin to Eyam Dale Shaft	-3	-8	8.5	354.8	2.4
Entrance on Gin to Merlin's Entrance	-8	-13	15.3	586.9	2.6
Eyam Dale Shaft to Merlin's Entrance	-5	-5	7.1	154.4	2.8

B. Vertical Misclosure

	Underground Survey	Surface Difference	Error
Lower Entrance to Eyam Dale Shaft	25.2 m	26.5 m	- 1.3 m
Lower Entrance to Merlin's Entrance	35.5 m	36.9 m	- 1.4 m

Lower Sump at End of Stalactite passage	- 16.7 m below Gin Entrance
Lower Sump at Downstream Side	- 22.8 m below Gin Entrance
Misclosure =	6.1 m or 0.93%
Traverse Length =	655.1 m

Table 2

Passage Lengths

	Length in Metres	
Carlswark Cavern		
Gin Entrance to Eyam Dale Shaft	354.5	
New Series from Junction with Northwest passage to Lower Sump	323.8	
Dynamite Series	322.2	
Lower Entrance Series	76.8	
Side Passages	749.1	
	1826.4	= 5992 ft
Merlin Mine		
Merlin Entrance to End of Gimli's Dream	234.0	
Streamway from Junction with Gimli's Dream	171.1	
Minor other side passages	462.9	
	868.0	2848 ft
Total Carlswark + Merlin	2694.4 m	8840 ft

(b) Geological and Hydrological Notes

It has been shown (Beck, 1975) that the underground drainage system of the Stoney Middleton – Foolow area has developed in response to a series of erosional events, which progressively lowered the base level in the Derwent Valley. Four principal cave levels have so far been recognised within a 40 m thickness of the Upper Monsale Dale Beds. They are defined as the First Remnant Complex, the Second Remnant Complex, the Carlswark Complex, and the Lower Complex. Each of the four levels has been recognised in Carlswark Cavern, and it is here that their relationships can best be studied.

The majority of the cave passages belong to the Carlswark Complex, a network of phreatic tubes developed by solution at the base of a band of silicified *Gigantoproductus spp.* (Lower Giganteus Bed of Morris, 1929; the Lower Shell Bed of Stevenson and Gaunt, 1971).

The known cave, including the natural passages of the Merlin Mine, represents the eastern end of what is undoubtedly a large system, which carries both allogenic swallet water and accumulated percolation water eastwards along the strike of the Carboniferous Limestone to a now-abandoned resurgence, in the vicinity of Stoney Middleton. The position of this resurgence is not clear, for the water is now carried over the last part of its underground course by Moorwood Sough whose tail (= outfall) lies in the grounds of Stoney Middleton Hall at an altitude of roughly 465 ft O.D.

It has been shown by dye tests that there are two parallel and separate stream courses. The more northerly carries water from the Millstone grit shales eastwards via the allogenic swallets of Eyam Edge and the more southerly carries the underground overflow from the reservoir of the Wardlow Basin along a parallel strike-oriented course. An analogy may be drawn with the Peak-Speedwell system at Castleton, where New Rake Acts as a barrier to separate allogenic from autochthonous stream passages. In the case of the Stoney Middleton system, Middlefield Rake may perform the same function, though there is as yet no direct supporting evidence.

The two streams enter Glebe Mine, Eyam, as one, and must unite in the region beyond the second sump downstream in Merlin Mine. The Merlin Streamway turns to the North between Eyam Dale and The Delf, to flow along the axis of a shallow Northward plunging syncline.

It is convenient to describe the four cave levels in reverse order of development, for none of the Remnant passages open to surface in Carlswark Cavern.

The Lower Complex

The Lower Complex is very little known. The lowest entrance to Carlswark Cavern lies at the foot of a cliff, just above road level, half a mile west of Stoney Middleton. The entrance passage was described by Short whose account (1734) shows that the level of the Lower Sump has not changed since that time. There are two passages leading from the entrance chamber. The smaller tube closes quickly, but a larger passage can be followed for 58 metres to the Lower Sump. The large phreatic passage has been followed into the sump in times of drought, and disappears into a boulder choke in a rift chamber in the middle of the sump. It could never be followed beyond here, for even in drought the northward dip carries the choked continuation below water level. The passage has been located by divers in the rift sump below Aladdin's Crawl, where it is again choked. The inner end of the Lower Sump is a joint-oriented fissure enlarged by miners.

The Carlswark Complex

Above the entrance end of the Lower Sump is a rift on a joint of a set bearing 320°, This can be climbed, passing tubes at levels intermediate between the Lower Complex and the Carlswark Complex. The highest tube opens into the floor of the large Oyster Chamber, from which Carlswark Complex Passages, their roofs covered with etched out silicified fossil brachiopods, radiate. To the east, the passage soon diminishes in size, and chokes of flowstone prevent further progress, though the tube beyond the choke opens into the cliff face above and to the east of the Lower Entrance. The reason for the diminution in size is the capture of water flowing eastwards through the Carlswark Complex by the open joints which connect it to the Lower Complex.

To the west of Oyster Chamber, the large Eyam Passage can be followed for roughly 200 metres to Noughts and Crosses Chamber, where the passage divides into three. This region lies on the axis of a low amplitude north-south anticline, which plunges to the north, and small inlets from the stream in Eyam Dale join to flow via North West Passage, roughly parallel to the plunging axis. North West Passage can be followed down dip to join Cockle Passage, where another small stream enters. The water used to leave via Big Dig, a heavily silted northwest-trending passage, but has been diverted into a sump during efforts to clear the silt. During flood conditions, water rises in Big Dig until a large stream flows out into the known cave. Once over the crest of the anticline, the watershed of the cave is crossed, and the stream is free-flowing eastwards to the inner end of the Lower Sump. The sump rises up to the entrance passage in times of flood and the Lower Entrance may then become a powerful resurgence.

Cockle Passage may be followed eastwards to intersect the much larger Stalactite Passage. This junction is again on the axis of the anticline, and beyond this point, the water flows eastwards to the Lower Sump. The connection between Carlswark Complex and Lower Complex is again made by way of an open joint of the 320° set, and by a tube on the same intermediate bedding plane as that leading into the floor of the Oyster Chamber. Beyond the capture point, the Carlswark Complex passage continues, but soon becomes silted to the roof.

Dynamite Passage is an obvious northward branch of Stalactite Passage. It appears at first sight to be a phreatic tube with a vadose trench incised into the floor. However, although percolation streams are in places cutting such trenches, none are incised to this degree. Close inspection reveals that the trench is an artificial cut-through fluvio-glacial fill: comparison of levels suggests that the miner drove it in order to lower the water level in the passages on the far side. Were the trench excavated to its original depth, it would be impossible for silt to settle in Big Dig, and it is thought that the purpose of their work was to pass Big Dig and investigate the vein of Stub Scrin, which lies a short distance to the west. The floodwater flowing from Dynamite Passage emerges from the downstream end of the sump near Big Dig, into which the small percolation stream has been diverted.

Eyam Passage and Stalactite Passage are large strike-oriented conduits which carried phreatic flow from west to east, and during the later stages of their development lost their water to the Lower Complex by way of the connecting rifts at the eastern end. Eyam Passage, higher up the dip slope, shows evidence of vadose modification at the eastern end, while Stalactite Passage, probably still paraphreatic in character at the time of capture, does not. The smaller passages running north-south are down dip connections, carrying percolation water down dip to the phreas, and carrying floodwater into the higher vadose conduits.

Carlswark Complex passages to the west of the Eyam Dale Shaft can only be reached from Merlin Mine. Eyam Dale shaft is a convenient western entrance to Carlswark Cavern through an enlarged natural fissure. The Carlswark Complex continues westwards as Gimli's Dream, a stretch of passage with an extensive fill of glacial debris, partly reworked, and extensively flowstoned. The area at the base of the shaft has become complicated by extensive cavern breakdown, and it is probable that the thick deposits of silt beyond have built up behind the piles of blocks.

The access point to this western portion of the Carlswark Complex is by a squeeze at the bottom of the deepest stope in shaft S 3, on Stub Scrin, in the Merlin Mine. Below the squeeze, a small passage on the east side leads back to Gimli's Dream. To the west, the large stream can usually be heard, but on reaching the streamway, all that can be seen is a swirling pool in Sump Pool Chamber. The downstream sump, although small, is free-diveable with care except in flood, when its length increases to about 4 metres, and the current would prevent a return. Beyond the sump, the stream crosses a wide bedding chamber, and plunges over a short pitch. Climbing and squeezing through boulders with the stream leads shortly to 'Shag's Sump'. This was passed in the 1976 drought to a cross rift, where there would normally be an air space, after 8 metres. The passage is very restricted, with small stubby projecting stalactites and stalagmites. The passage turns through a right angle at the cross rift, and was followed, in places with minimal air space, for a further 8 metres until it again sumped. The stream flows down dip from here, to reappear in Glebe Mine, Eyam, from a deep sump. Between Shag's Sump and Glebe Mine, the Waterfall Swallet Stream must join the Merlin Stream. Dye testing in 1973 showed that the Waterfall Swallet stream, although it appears at Glebe, does not flow through the Merlin Streamway.

The upstream Sump 1 must not be free-dived. It is 20 metres long, and is often silted amost to the roof. It is restricted at the upstream end. The stream passage was followed in the 1975 drought to the rather evil Sump Five, after 130 metres. This was passed by pumping in the 1976 drought to Sump Six, which followed almost immediately and was too tight for further progress. There is a slim possibility that when the stream is flowing, enough silt may be removed to make the passage penetrable. When the water stops or slows down, silt slumps back down the slope, hopelessly blocking the sump.

Sumps Five and Six lie in the vicinity of Mossley Scrin, on which vein there are extensive workings in Nicker Grove Mine. The vein may have acted as a dam, causing the stream to sump. The effect of a vein, acting as a dam can be seen on the upstream side of Sump Two, where a small stringer of fluorspar and barytes crosses the passage.

The total drop throughout the Carlswark Complex, from Sump Five in Merlin to the opening in the cliff near the Resurgence Entrance, is in the order of 6 metres, a low gradient considering the long stretches of passage that are penetrable.

The Remnant Complexes

Remnant Complex passages are seen in the system in two areas. There are high level tubes and chambers in the Merlin Mine, and there are many high level fragments in the Dynamite Series of Carlswark Cavern. The entrance to the Merlin Mine lies high on the west side of Eyam Dale, south of the Eyam Dale Shaft. Natural cavities are reached by turning left after 12 metres, along the vein of Sycamore Scrin. A tube leads to the head of a 17 metre pitch, which may have acted as a capture point of Remnant Complex water by the developing Carlswark Complex below. The remaining tubes and chambers are heavily silted, and blocked by flowstone.

Continuing along the main level on Merlin Pipe, a short climb leads to a further chamber. The tubes leaving this chamber are also soon blocked by silt. They lie on a bedding plane 24.75 metres above the base of the Lower Shell Bed.

Stub Scrin is reached, crossing the pipe, 60 metres from the entrance. To the left at the junction are more natural cavities, principally open joints. To the right, two shafts descend to lower levels. The second shaft provides the access to the Merlin Streamway and Gimli's Dream. A third shaft can be reached, and digging is in progress here. A level continues along the pipe to a shaft on Cowlishaw Vein. The shaft is blind in solid rock, and the base of this shaft is known to lie only 5 metres above the streamway, where there is a short upward trial on the vein.

The Remnant Complex passages of the Dynamite Series are more extensive. Dynamite Chamber is entered from the north end of Dynamite Passage, via an upward squeeze among boulders. Dynamite Chamber is a large cavity developed on a joint of the 320° set. The Carlswark Complex passage is thought to continue beyond the boulder choke, but may be silted for a long distance. The continuing passage lies on a bedding plane 5.1 metres above the base of the Lower Shell Bed. A small joint-oriented chamber follows, and the continuation again lies on the + 5.1m bedding plane. The third chamber (Midnight Chamber) is larger, and the continuing crawl again lies at + 5.1m.

The fourth chamber is Prospect Chamber, and is the largest. Several prominent bedding planes can be followed along its walls, and at the north end, a bedding plane at + 12.80 m forms the roof. A tube leads off at roof level on this parting to a fifth joint chamber, Fall Chamber. Fall Chamber can again be followed northwards, and climbing between jammed boulders, and traversing in the roof, leads to two passages lying on a bedding plane at + 26.48 m. These highest tubes lie directly below the road in Eyam Dale, and the chokes which block them should not be touched. Traffic can be clearly heard. The tube on the west side shows evidence of vadose modification, while that on the east, where there is more extensive cavern breakdown, does not. This suggests that water flowing at this level was captured by the joint-oriented cavities, and carried down to the Carlswark Complex. The western tube was therefore modified and enlarged, while the eastern one deteriorated.

Returning to Prospect Chamber, a tube can be followed by the determined caver on a bedding plane lying at + 8.70 m. This is the notorious Porth Crawl, partly a joint controlled rift, partly a bedding controlled tube. It is only just penetrable. A tight climb at the northern end of Porth Crawl opens into the floor of a large phreatic tube at the + 12.80 m level. The passage has been reduced to its present uncomfortable size by the dumping of miners' deads during excavation of the continuation by cavers. In the downstream (southerly) direction, the tube ends at a choke of large boulders, where prospects for digging seem remote. To the north, the tube is again lost among boulders (though here the choke is of miners' debris) and access can be gained through loose boulders to a mine level. This is Clog Passage, and lies on Stub Scrin. Choked shafts from surface can be seen.

Isolated fragments of the + 12.80 tube can be reached by climbing down shafts in the floor of Clog Passage, and the final descent leads into a small chamber from which two passages lead on. The right-hand (east) passage again ends at a choke, but that to the north follows the vein, and its fill has been excavated by the miner to gain access to the vein continuation. Two shafts in the floor lead nowhere; they are unstable, and should be carefully passed. The tube is finally lost in more chokes at the base of a large joint-oriented aven, and a small feeder system can be followed to the north west. An awkward keyhole-shaped passage leads to yet another joint-oriented cavity. Two tubes continue from here. The right fork is soon impassable due to silt and flowstone, although there is an air space. The left fork is very small and awkward to pass, but leads into the Final Aven, which is well named, for it is impossible that the tiny tubes beyond this point could ever be followed by cavers. The silted right fork could be excavated, but the nature of this feeder system suggests that it will eventually become too tight. The journey from the Eyam Dale Shaft to the end of the Dynamite Series is so arduous that digging is almost out of the question.

The principal levels of the system are thus as follows;

1)	First Remnant System;	+26.48 m	Top of White Bed?
	1 a;	+19.83 m	
2)	Second Remnant System;	+12.80 m	Bedding plane below Upper Shell Bed.
	2 a;	+ 8.70 m	
	2 b;	+ 5.10 m	Base of unit with isolated *Lithostrotion* sp.
3)	Carlswark Complex;	0.00 m	Bedding plane/wayboard at the base of Lower Shell Bed.
	3 a;	- 6.00 m (app).	
4)	Lower Complex;	- 12.63 m	Prominent Bedding plane in lowest crinoidal limestones.

The four cave levels appear to be directly related to terrace levels in the valleys, and further work will clarify the correlation of these terraces in different areas of the limestone outcrop.

Prospects for further exploration from the Merlin Streamway seem remote, but the Remnant Complexes are obviously far more extensive than is known. The westward trending "dry" tubes of Carlswark Cavern are silted, but the stilt is of recent origin, and is now being slowly removed.

Acknowledgement

The studies reported herein were carried out during the tenure of a N.E.R.C. research studentship by one of us (J.S.B.)

References

Beck, J.S. 1975. The caves of the Foolow-Eyam-Stoney Middleton area, Derbyshire, and their genesis. *Trans. Brit. Cave Res. Assoc.* vol. 2, pp. 1-11.

Ellis, B.M. 1976. *Surveying Caves.* Brit. Cave Res. Assoc. Publn.

King, B. 1962. Carlswark and the cave system of the Foolow-Stoney Middleton area *Cave Science,* vol. 4 no. 32, pp.377-383.

Morris, T.O. 1929. The Carboniferous Limestone and Millstone Grit Series of Stoney Middleton and Eyam, Derbyshire. *Proc. Sorby Sci. Soc.* (Sheffield) vol. 1. pp.37-67.

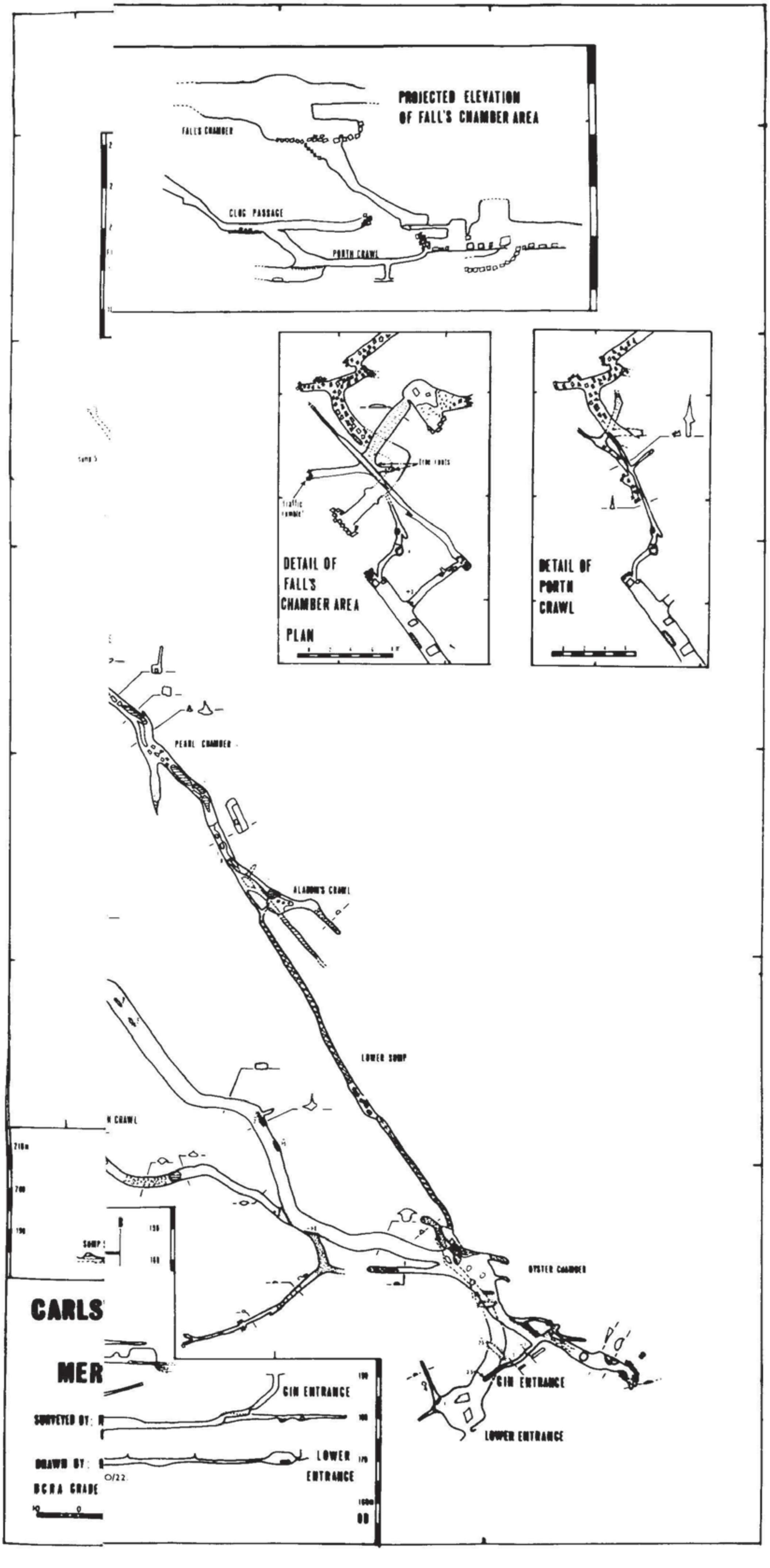
Short, T. 1734. *The Natural History of Mineral Waters* (of Derbyshire etc). London 359pp.

Stevenson, I.P. & Gaunt, G.D. 1971. *Geology of the Country around Chapel-en-le-Frith.* Mem. Geol. Surv. U.K.

March 1977

Noel Christopher
22 Deva Close,
Poynton, Cheshire.

John Beck
Glebe Cottage,
Eyam,
near Sheffield.



to the follow-
ocation on
ı care in using

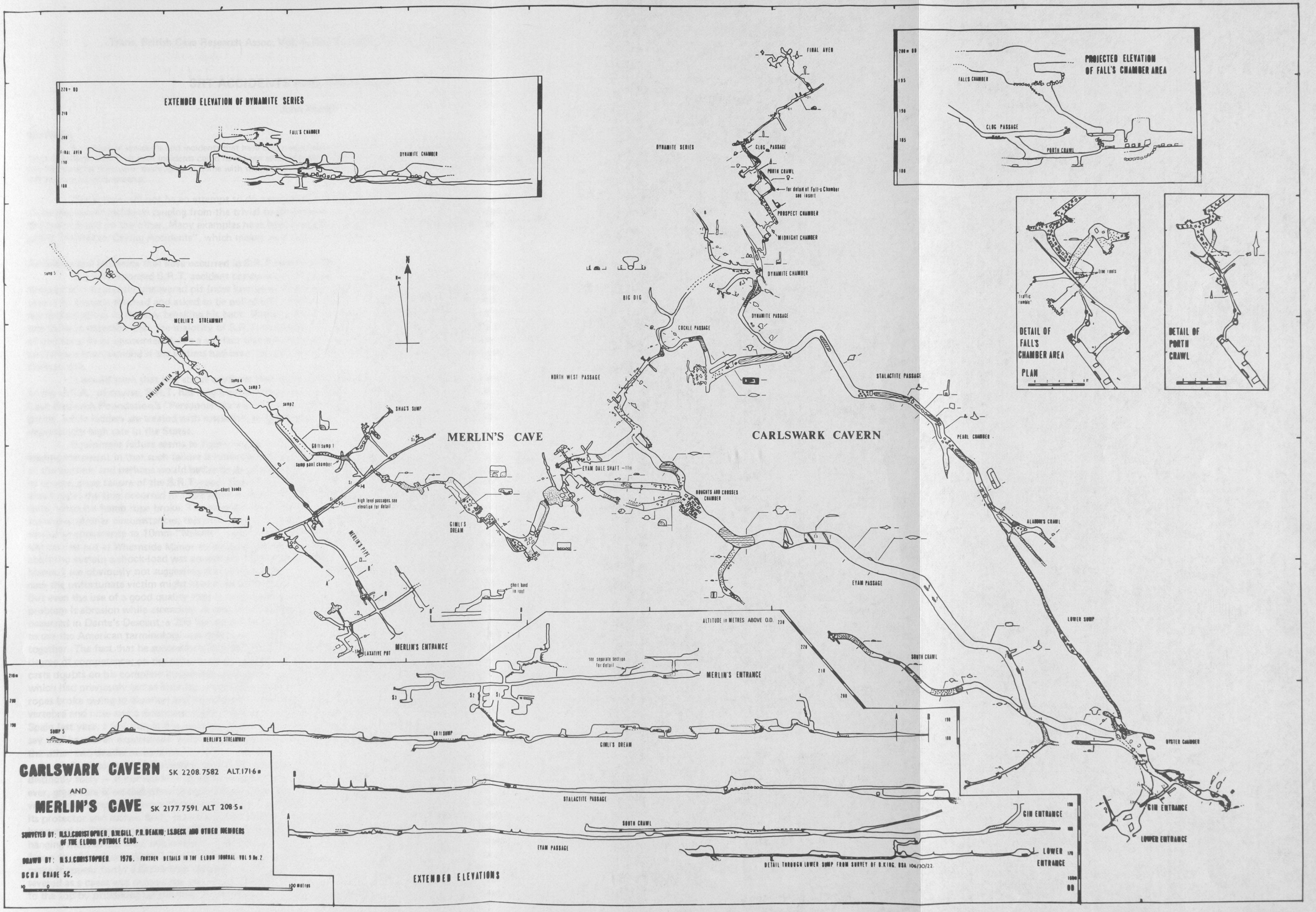
a catalogue
ɔrtunate to
y the N.S.S.

tury, was
ıe unexplained
ssure and he
it does have
with the sort
/ attention
rse, excep-

me or another.
that the
ormal way to
ıen at a

s a mis-
re on the part
sibility is,
e of an
Gloucester-
died in
awserlaid one
de drop
ofar as its
ıe was to
ıt in this
er quality.
se, the
lent which
ed the pit—
d
ggests a
erlaid,
of rock,
, one of the
ıe, a broken
aver in
ıan to
rast with

up with a
ion. How-
has a
ımp off
ıich has
s free-
ıooth
asion to
ts sheath
ıt got
as responsible


EXTENDED ELEVATION OF DYNAMITE SERIES
FALL'S CHAMBER
FINAL AVEN
DYNAMITE CHAMBER
PROJECTED ELEVATION OF FALL'S CHAMBER AREA
FALL'S CHAMBER
CLOG PASSAGE
PORTH CRAWL
DETAIL OF FALL'S CHAMBER AREA
PLAN
DETAIL OF PORTH CRAWL
FINAL AVEN
DYNAMITE SERIES
CLOG PASSAGE
PORTH CRAWL
for detail of Fall's Chamber see insert
PROSPECT CHAMBER
MIDNIGHT CHAMBER
DYNAMITE CHAMBER
DYNAMITE PASSAGE
BIG DIG
COCKLE PASSAGE
NORTH WEST PASSAGE
STALACTITE PASSAGE
PEARL CHAMBER
N
MERLIN'S STREAMWAY
SHAG'S SUMP
60 ft sump
sump pool chamber
high level passages, see elevation for detail
MERLIN'S PIPE
GIMLI'S DREAM
EYAM DALE SHAFT - 11m
NOUGHTS AND CROSSES CHAMBER
MERLIN'S CAVE
CARLSWARK CAVERN
ALADDIN'S CRAWL
EYAM PASSAGE
LAXATIVE POT
MERLIN'S ENTRANCE
ALTITUDE in METRES ABOVE O.D.
see separate section for detail
MERLIN'S ENTRANCE
LOWER SUMP
SOUTH CRAWL
OYSTER CHAMBER
GIN ENTRANCE
LOWER ENTRANCE
SUMP 5
MERLIN'S STREAMWAY
60 ft SUMP
GIMLI'S DREAM
STALACTITE PASSAGE
SOUTH CRAWL
EYAM PASSAGE
GIN ENTRANCE
LOWER ENTRANCE
DETAIL THROUGH LOWER SUMP FROM SURVEY OF D.KING. BSA 106/30/22.
EXTENDED ELEVATIONS
CARLSWARK CAVERN SK 2208.7582 ALT.171·6 m
AND
MERLIN'S CAVE SK 2177.7591. ALT 208·5 m
SURVEYED BY: N.S.J.CHRISTOPHER, D.W.GILL, P.R.DEAKIN; I.S.BECK AND OTHER MEMBERS OF THE ELDON POTHOLE CLUB.
DRAWN BY: N.S.J.CHRISTOPHER. 1976. FURTHER DETAILS IN THE ELDON JOURNAL VOL 9 No.2.
BCRA GRADE 5C.
10 0 100 metres

Trans. British Cave Research Assoc. Vol. 4, No. 3, pp 367-372 August 1977

SRT ACCIDENTS AND INCIDENTS

John Forder

Summary

A number of accidents and incidents that have occurred to cavers using SRT, if examined in detail, lead to the following conclusions: nearly all such incidents could have been avoided if the people concerned had practised in a safe location on the surface until they were thoroughly at home with their equipment and techniques and if they had taken enough care in using the techniques underground.

This article will not be an attempt to do a statistical analysis of scores of accidents, rather a catalogue of accidents and incidents ranging from the trivial to the serious on the one hand, and from the unfortunate to the plain stupid on the other. Many examples have been culled from a booklet published annually by the N.S.S. called "American Caving Accidents", which makes very interesting reading.

Accidents and incidents that have occurred in S.R.T./Self-lifelining

The first recorded S.R.T. accident concerns one Plumley who, about the middle of last century, was lowered into a recently uncovered pit (now known as Plumley's Den) in Burrington Combe; for some unexplained reason he became alarmed and asked to be pulled out. Unfortunately, the rope had slipped into a fissure and he was pulled across it, thereby breaking his back. Rather a trivial example in the present context, but it does have one thing in common with the majority of S.R.T. incidents – the people concerned were unfamiliar with the sort of problems to be encountered. It's a sad fact that the majority of accidents which have come to my attention could have been avoided if the victims had been "au fait" with the scene, although there are, of course, exceptions to this.

It would seem that just about anything that could go wrong, has, in fact, done so, at one time or another. In the U.S.A., of course, S.R.T. has long been the favoured method of "vertical caving", so much so that the Cave Research Foundation's "Personnel Manual" reads in such a way as to suggest that rope is the normal way to get by, while ladders are treated with suspicion; in spite of this, however, incidents continue to happen at a depressingly high rate in the States.

Equipment failure seems to figure largely in S.R.T. accidents, but generally speaking, this is a misleading statement in that such failure is normally due to misuse of tackle or lack of knowledge or care on the part of the victims, and perhaps would better be described as personnel failure. The most frightening possibility is, of course, gross failure of the S.R.T. rope. There have been two deaths in Britain caused by breakage of an abseil rope; the first occurred in 1967 when a caver fell 60 ft from the top of a 300 ft mine-shaft in Gloucestershire, when his hemp rope broke. The second was, of course, the Gaping Gill accident where a caver died in somewhat similar circumstances, this time using polypropylene. This latter rope was a staple-spun hawserlaid one similar in appearance to 10mm "Nelson", a sort of synthetic analogue of sisal; however a rather crude drop test carried out at Whernside Manor to indicate that the rope used was very inferior to "Nelson" insofar as its ability to sustain a shock-load was concerned. Thus in both these cases, use of totally unsuitable rope was to blame. I am obviously not suggesting that polypropylene be used for S.R.T. but it is conceivable that in this case the unfortunate victim might have lived had the party been using even polypropylene of a higher quality. But even the use of a good quality rope is no guarantee of absolute safety; with such a rope, of course, the problem is abrasion while ascending. A case in point which has some peculiarities, concerns an accident which occurred in Dante's Descent, a 256 feet deep hole in Arizona, when a member of the N.S.S. "dropped the pit– to use the American terminology–on two ropes – 125 feet of Goldline and 150 feet of Perlon – tied together. The fact that he successfully abseiled in and was prepared to prussik out over the knot suggests a degree of competence; on the other hand, his use of two stretchy climbing ropes, one of them hawserlaid, casts doubts on his complete knowledge, as does the fact that the rope was hung over a sharp edge of rock, which had previously cut at least two other ropes without protection. When he was some 60 feet up, one of the ropes broke owing to abrasion and he landed feet first, sustaining a compression fracture of the spine, a broken vertebra and nose and a dislocated ankle. Probably most of you are aware of the death of a British caver in Spain last year; I feel that at this juncture, it would be inappropriate to make any comment other than to say that he was an experienced caver, who seems to have been a genuine victim of bad luck, in contrast with the other two deaths mentioned.

Probably many who have tried S.R.T. can remember incidents in which their rope finished up with a distinctly furry – if not worse – appearance, and one tends to get a bit neurotic about edge protection. However, great care is needed when using protectors, as witness a recent happening in Vulcan Pot, which has a very awkward take-off and is difficult to protect. The Blue Water rope used somehow managed to jump off its protector and sustain fairly severe abrasion. Perhaps the most spectacular incident of this sort which has happened in Britain involved a braidline rope in use on the 130 feet pit in Dale Head Hole; the pit is free-hanging most of the way, but if rigged in the obvious way the rope will rub against an apparently smooth face a few feet down. When I "did" this hole, we were using Blue Water, which suffered enough abrasion to make it appear furry; a Cambridge University party were less fortunate, as their braidline rope had its sheath severed as a caver was nearing the top of the pitch. He fell 30 feet before the sheath bunched up, but got to the top by prussiking up the core. It would appear that a small, sharp edge in this smooth face was responsible for cutting the sheath and it is thought that this bunching up only occurred because there was a knot in the end of the rope. Tests have indicated that the sheath-slippage is likely to be much less of a problem with Blue

Editor's Note: This and the four following articles are the texts of talks presented at the BCRA Symposium on S.R.T. held at Buxton in March 1976. The other speakers did not produce any written version of their talks so that the planned S.R.T. publication could not be prepared by BCRA. The delay in publication may mean that a few remarks are now obsolete but it is hoped that the present format of publication is better than none at all.

Water and Marlow 16 plait matt terylene. One might think that if the only thing between oneself and eternity is a bit of string, you'd make sure it was tied off fairly securely, but failure of the main belay has figured in the accident statistics. Where it has happened human error has certainly compounded – if not actually caused – such affairs. One such incident occurred when a prussiker – in Puerto Rico – had reached a breakover about half-way up a 50 foot shaft. Unable to negotiate it – presumably on account of inexperience – she asked those below to pull the rope away from the edge. This they did, and the so-called knot a "variation of a hitch on a bight around a tree", whatever that may amount to, came undone, the climber being badly bruised on her arm in the subsequent fall. Another such incident occurred in Yorkshire not in British Columbia when the rope simply flicked off a sloping rock projection, sending the abseiler 50 feet to the bottom and fracturing three vertebra. The people in the party were not experienced cavers, although they had some climbing experience; the victim was using a spare light, his two primary sources having already failed so doubtless the lack of visibility failed to show up the details or defects of the belay.

Most people would trust a good big lump of rock as a belay point, and three years ago in a cave in Tennessee such a rock, estimated at 500 lb was used for this purpose. As you may know, rocks are becoming quite popular as 'pets' in the States, so possibly this particular one, having had its lead fixed thought it was time for "walkies" and so joined the abseiler on his descent. Fortunately for him, he was in a chimney and was able to jam himself across it, sustaining a broken arm, dislocated shoulder and gashed foot as the boulder struck him.

The prospect of going out of control while rappeling is a rather unsettling one, and I have come across several references to it occurring in practice. Probably the best easily-obtainable abseiling device from the point of view of ease of control is the rappel rack, but even these can cause problems. For examples, in Ellison's Cave, Georgia (1969) the second man to descent a 510 foot pitch had trouble in moving with five bars so he unclipped a bar. Part way down he speeded up to try and avoid a shower, but went out of control in spite of attempts to push the bars together and wrap the rope round his hip. He shouted for the first man down to pull on the rope, a procedure which met with only partial success, and the last 300 foot of descent was covered in an essentially uncontrolled fashion, as a result of which he received a cracked vertebra and pubic bone in addition to cuts and bruises. Subsequent inspection of his equipment showed that the 4th bar on his rack did not slide very easily, but whether this was a cause or effect of the accident is open to conjecture. The victim had only been caving four months, but was judged to be ready for a big drop. It's difficult in this accident to know what extent his compa, ative lack of experience contributed to the accident, but the victim admits that when he started to go out of control, he momentarily "froze. . ." One of the things to be wary of when using a rack is that without one's full weight on it – especially on a long pitch with the rope taut – one often has to feed the rope through to get over a lip where the belay is such as not to allow a free-hang. Removing a bar to facilitate the manoeuvre can lead to an unpleasantly fast descent when one's weight finally does come onto the rope. Most experience "S.R.T.ists" could probably cope with such a situation, but one example concerns a caver who failed to do so and went out of control on a 185 foot pitch in Natural Well, Alabama, and was lucky, in the circumstances, to escape with cuts and bruises. The accident could probably have been prevented by the first person down keeping an eye on the rope and pulling when it became apparent that she was in trouble. Even the use of six bars is not a talisman to guard against disaster; an "amusing" case occurred when the N.S.S. held a convention at Big Horn Caverns, Wyoming a few years ago, having rigged several ropes and a ladder on a 64 foot pitch. Many people were milling about down below when an abseiler had trouble with a 6-bar rack; spreading the bars apart, he took off, showering debris over the crowd at the bottom and eventually smashing into a ladder climber, causing the rungs to slip several feet before stopping. Luckily, no-one was badly hurt. Obviously the circumstances were rather unusual, but it would appear that general laxity about who did what, in addition to the capacity of the rappeler, were contributory causes. Other abseiling devices are, probably, more likely to cause accidents of this sort, and I would guess that the comparative lack of such incidents in the States is largely due to the fact that such devices are in less general use over there. The only such incident I have been able to find in recent years happened when a novice caver – said to be "nervous and shaky" before the descent – was abseiling a 65 foot pitch on a krab and brake bar. She slipped and let go of the rope 20 foot down. She was controlled by a man below and the incident had no severe consequences. Nothing much can be done for the first man down in such circumstances, but it is probably a good idea to stick around the bottom of the rope for the next man's descent on any abseil trip.

On the face of it, this problem of going out of control is the one most amenable to solving by the use of a lifeline. My personal opinion is that a lifeline takes away a great deal of the fun of the business – which, when all's said and done, is the main reason for going underground – and I would not advocate their use except for novices or people who appear ill-at-ease, who shouldn't be there anyway. An interesting case in point occurred about 8 years ago in a West Virginian cave where two people had successfully "dropped" a 180 foot pit with a lifeline. However, when the third person was on her way down, the two ropes got entangled and a mini-epic ensued. The caver was held round her chest by the lifeline, and to add to the fun, a waterfall made communication difficult. A fourth person went down on another rope, struggled for an hour or two, but failed to sort her out and finally – for reasons best known to herself – prussiked to the bottom. One of the first two down then ascended, managed to free her lifeline and prussiked in tandem with her for — allegedly — a couple of hours. It's not at all clear why two hours were insufficient for the pit, presumably the ropes twisted up made progress difficult, but the ropes again became entangled and stopped their progression. Eventually, after hanging around for five hours, she was somehow freed and lowered to the bottom by rappel controlled from below, and pulled out with the aid of cavers called in by those on the surface. The reason for this botch-up is the total incompetence of the participants, who obviously had no business attempting such a big drop. The three women in the party had, in fact, only been underground two or three times.

Rappeling off the end of a rope sounds — in abstract — a bit of a joke, but has in fact happened. Apparently, this is not very rare in mountain accidents, but — so far — there seems to have been relatively few such incidents underground. One such occurred in the (perhaps aptly named) Gory Hole in Indiana, where a group of experienced cavers had rigged the 140 foot entrance pit for the purpose of taking pictures for a guide book. One line was rigged all the way down, but the other was belayed so as to enable a photographer to reach a ledge 30 foot off the floor. Having taken his pictures, he asked if the rope he'd just descended reached the floor and when he received an affirmative reply he abseiled off the end, cracking a vertebra, fracturing a wrist, and spraining his ankle. Here, it would appear that human error was the cause, but it perhaps points to the fact that one should always tie a knot in the end of ones rope.

Rather similar to the above incident were two cases of people getting stuck on ropes through incompetence while rappeling; in Elkhorn Mountain Pit, four people — having been told it was 90 feet deep — went to abseil on a 90 foot rope. Unfortunately, the hole is 140 foot deep. The first one down managed to stop and tie himself off (burning his hands in the process) but having no ascending gear on him was unable to get out. His friends couldn't get any gear down to him owing to ledges, and so he had to be hauled out bodily by a rescue team. The second such incident involved a caver rappeling onto a knot in a 180 foot pit, and being unable to extricate himself. He, too, was pulled to safety by a rescue team, after hanging around for 3 - 4 hours. In this case — Cass Cave, W. Virginia — he would, if water level had been normal, have been hanging under an ice-cold shower (time of year, late winter). These and similar cases could have been avoided if the people concerned — all inexperienced — had practised changing over from rappel to prussik, in safety on the surface, before venturing underground.

Other manoeuvres which should be practised in the same way include swapping from rope to rope both while descending and ascending. This business of manoeuvring while hanging from a rope has probably led to several near accidents and possibly to several actual ones. One which comes to mind concerns a French caver prussiking in a Pyrenean hole in 1975. The shaft was rigged in several stages, the bottom of one rope being belayed to the same point as the top of the next. At one such change-over point the victim apparently removed both his Jumars from the lower rope without first attaching himself to the upper, possibly because the presence of a ledge gave him a false sense of security, and he fell to his death.

Apropos of which, all ropes show an alarming tendency to shrink after a few uses, so it is possible that you might "know" full well that your rope is long enough for a particular pitch and find it several feet short. One such case was brought to our notice recently when a party were using a 100 foot rope (nylon braidline, I think) to abseil through Swinsto, and found it a bit short on the 45 foot pitches. Subsequent measurement showed it to have shrunk by 16 feet, not by any means an unusual phemomenon; virtually all the ropes in use at Whernside Manor have shrunk by anything up to 20%. A simple soaking of brand new Blue Water Rope in cold water, followed by slow drying, showed a decrease from a 319feet to 303 feet. Subsequently after fair usage it had to be chopped where abrasion had occurred, and yielded a 210 feet and a 75 feet length — thus total shrinkage was 34 feet or more than 10%.

Most of the incidents so far quoted have occurred to people descending; ascending is, generally speaking, safer inasmuch as one can ensure that one is securely fastened to the rope, but probably is more open to bungling by the incompetent, and, of course, abrasion becomes of more importance. One of the most absurd incidents imaginable occurred in Lost John's Hole, where in 1972 a caver was rescued when he abseiled down the Battle Axe pitch and was unable to prussik back out.

Another such incident which took place in Britain could well be ascribed to bad luck. In 1973, three climbers with little caving experience abseiled into Eldon Hole but were unable to re-ascend their 11mm perlon-rope owing to rain which had washed mud onto it, rendering it too slippery for their ascenders to grip. A fourth person left on the surface went for help and they were extricated safely. It is said that prussik knots can be made to grip on any rope, by adding an extra turn (or turns) as necessary, so if these people had been equipped with knots and known how to use them they might have been able to get out. The use of knots is, of course, a tedious business compared with that of mechanical ascenders, but in such circumstances could save a lot of trouble.

Perhaps on the borderline between the silliness of the penultimate case and the bad luck (?) of the last, was an incident in New York where a group of cavers failed to get out of Shell Cave owing to the fact that their Gibbs ascenders would not work on ¾ inch manila (presumably ¾ inch diameter). A second group who saw them in the cave said they appeared to be well-equipped — but, had they tried their equipment on the surface prior to going underground, presumably their systems' shortcomings would have been shown up.

In similar vein, an utter shambles occurred in Elkhorn Mountain Cave, West Virginia in 1968 when sever cavers descended the 140 foot entrance pit. The first man up took rather a long time, but made it, the second reached a breakover a mere 10 feet up, which he was unable to surmount, so he decided to go back down but only managed to free one of his Jumars. Finally he adopted a body rappel position, cut the sling to the stuck ascender, and descended. A third person got out in 35 minutes, followed by a fourth, who although he made it safely had a bit of a problem when one of his slings broke. The three on the surface decided to try to pull out those left below (one of whom had, by this time, cut his knee badly and was unable to help himself).

This attempt failed, so those on the surface went for help. While waiting, those below tried to get out using Backmann knots, but that failed too. In the end all four were hauled out by a rescue party. In the circumstances, they got away lightly in view of their total incompetence, which was in all probability due to not having practised previously.

Water on pitches can, of course, be a potential hazard; personally, in high water conditions I would prefer to be securely fastened to a single rope than trying to cling to a ladder, and think that – if one is reasonably well sorted out – S.R.T. is no more dangerous than ladders under such conditions. However I have a brief note from an American caver who states "we have lost two people in New York owing to over-exposure to cold water when prussiking (less than 80 feet)". Unfortunately I have no details of this (or these) incident(s). A rather bizarre case involving a water-hazard occurred in 1970 in West Virginia when a moderately-experienced caver dropped a 96 foot entrance pit in spite of an abnormally large stream going down. He was unable to prussik out but, amazingly enough, his friend on the surface did not go for assistance but communicated by passing notes up and down tied to a piece of rope. The following day, a party of cavers just happened by, found the surface man still sitting there, lowered a dry suit and hauled out the victim.

I regard competence in the use of knots as an essential pre-requisite for safe 'SRT-eeing' but look upon it as an emergency device, while in the States, vertical cavers frequently use knots as a matter of course. Probably knots are more prone to slipping on clean ropes than are mechanical devices, though, as mentioned previously, they can be made to grip under adverse conditions. Two incidents where knots slipped with near disastrous consequences, make the point. The more spectacular of the two involved an "experienced pit caver" ascending a 180 foot pit in Tennessee in 1971; getting over the lip, his knots slipped on the muddy rope, so he clutched tightly in panic at them, thus preventing their gripping. Near the bottom, he threw out his hands in panic to stop himself, letting go the knots which then gripped the rope. However, the rope stretched sufficiently for him to hit the bottom, thereby sustaining a broken ankle and bruised chin. The report states that had he not grabbed the knots, left to themselves they would have gripped without trouble – a proposition which seems to have been borne out by the fact that he did stop when he did let go. I'm not altogether convinced that this would always happen, however. The caver was wet and tired at the time, presumably a contributory fact to the incident. Rather less spectacularly, a novice caver in Freeman's Pit, Indiana, using borrowed manila slings, got into a mess with a restricting harness; in desperation, while trying to sort himself out, he unloosened the knots so that he virtually free-fell 45 feet to within 5 feet of the floor, at which point the chest harness knot gripped – yet another silly incident where luck prevented a tragedy.

There are several recorded instances of cavers' harnesses and slings coming apart, generally owing to lack of care or foresight by those concerned. One such incident occurred in the Devil's Sink Hole in Texas, where 40 people (7 experienced) were practising vertical techniques in a 130 foot pit. A novice who had previously twice prussiked 50 foot on the surface, rigged into the Texas Prussik system using Jumars, the upper one attached to her sit harness with 1" tubular tape, 2 lengths of which were tied with a "double carrick bend" (a carrick bend being somewhat similar to a reef knot), while the lower one was fastened to a foot loop. Her rig was checked by an experienced caver before her ascent, but after 100 ft the carrick knot came undone and she fell to her death. A rather similar incident occurred when a solo caver – also using the Texas Prussik – had got to near the top of a 75 foot pit in West Virginia when a screw-gate krab holding his sit sling together somehow flexed and came undone, releasing him to hang, momentarily, upside down by his feet. The foot loop then came off and he fell nearly 70 feet to the bottom more or less head first – sustaining relatively minor injuries in the circumstances. When he regained consciousness, he found in addition to cuts and bruises that he had a suspected broken foot and ribs and a sprained neck. His equipment – including his lamp – had got scattered around the foot of the shaft, but in spite of his injuries and the fact that he had to work in the ½-light filtering down the pit, he re-rigged his system using a jumar and his belt-tape, getting out safely. He subsequently found he'd broken his foot and merely bruised his ribs, and his neck was stiff for the next three months. In his position I'd have kept the following snippet of information to myself but he was sufficiently ingenuous to let slip the fact that the krab had already failed him twice before, but he had a sentimental attachment to it – a pity that this feeling wasn't reciprocated.

A similar incident in Shaft Cave, Indiana, had a happier ending for the (experienced caver, using "bowline-backed ascender knots" – whatever they may be – whose top knot came undone when he was 50 feet up. He flipped over, to be held upside down by his foot-loops, and with assistance from above, he was able to right himself and proceed. The obvious moral here is to be certain that ones krabs and knots are fastened properly, but in addition such accidents as these could possibly be prevented if one had a connection between ones sit harness and foot ascender.

A final case of this ilk concerns a prussiker climbing a 230 foot shaft in Alabama. 30 feet from the top one strand of his seat-to-jumar rope – said to be old, worn-looking 5/16 inch nylon – broke. Having descended a few feet to a small ledge, he attempted to replace it but his Swiss-seat krab did not lock properly and when he re-started, the krab came undone and left him in a very dangerous position. His friend on top lowered him a rope with a chest loop and left him clinging to a precarious, sloping ledge for about 3½ hours till assistance was available and he could be pulled out. Although an experienced caver, he was not carrying enough equipment to help himself.

Other examples of equipment failure include a near tragedy in Echo Pot when an abseiler's sling-to-rack krab came undone, the caver saving himself by hanging on to the rope. The Orpheus Caving Club Journal (Vol. II No. 5 May 1975) contains an interesting account of a caver getting into trouble in the 240 foot shaft of Rowter Hole. It seems that the stitching on his shoulder harness pulled out, the fastening on his Mitchell Box came undone and the harness got entangled round his upper Jumar some 140 feet up. The situation was not exactly helped by the rope's being weighted with tackle, but the person concerned, fortunately an experienced caver, was able to extricate himself. In a sense not strictly relevant, but nevertheless a horrifying incident which, one hopes, will not be repeated concerns the criminally-irresponsible idiot who stole a karabiner from the top of an 180 foot shaft in Derbyshire, "rebelaying" the rope to the bolt by a couple of half-hitches, a fact only discovered by the first man up, when he reached the top.

Probably many people could contribute their own stories of incidents of one sort or another, such as, for instance, cavers using a 195 foot pitch (the top 60 feet at any rate) for S.R.T. training, the people concerned passing tackle up and down from the top to crumbling ledge; not to mention the individual who, his mate having sent down a couple of Jumars, got stuck fast a few feet up the second pitch in Sell Gill Hole (the fact that his light had gone out contributing to his discomfiture).

Of the 32 incidents recorded here, 13 involved abseiling while 19 involved prussiking (or not being able to prussik). I don't think personally that these figures reflect the relative dangers of going down against going up for the experienced, it seems more likely that for the unwary more things can go wrong while ascending than while descending. With such a diversity of incidents, statistical methods of analysis are hardly applicable, but certain trends can be detected. Being unable to prussik, going out of control while descending, rope breakage and harnesses falling apart each account for four instances and between them for 50%. Failure of the belay is surprisingly popular with three incidents, next slipping prussik knots and too much water tie with two each, while I have included a single example of each of the following:- sheath breakage, twisted lifeline, abseiling off the end of a rope, reaching the end of a too short rope and sitting there for a few hours, abseiling onto a knot with the same result, prussik knot coming undone, krab-to-rack opening while descending, krab-stealing and difficulty while rope changing. Eleven incidents definitely involved experienced cavers, but of those several in effect brought the accident on themselves; four through some part of their harness coming undone, one through not checking his harness-to-descender krab, one through lack of care in rigging the pitch, one by the simple human error of abseiling on the wrong (short) rope. At least one was tired and wet at the time of the incident, which leaves only two cases to be ascribed to bad luck – the fatal accident in Spain, and the case of sheath slipping in D.H.H.; the last of these 11 being the case of intervention by an outside agency in the shape of a krab-stealer.

As far as self-lifelining is concerned, I've come across very few references to untoward incidents. Abseiling down and self-lifelining out has been very widely used on the Continent, with – it would seem – a fair degree of safety and success. Probably most of you are aware of the accident which occurred in the Berger last year, when two French cavers died. It appears that one of them set off up a 100 foot pitch when the cave was in flood, but did not notice that his "safety" device was not running through the rope, rather, it was pulling the rope up with it. Part way up, the evidence suggests, he came off the ladder and fell onto the man at the bottom, as a result of which both drowned. Such an accident is, of course, avoidable. In most circumstances if one were to fall off a ladder it probably wouldn't matter very much how one's safety device were rigged – the worst that would happen would be to dangle in some discomfort for a short period. Two possibilities present themselves though, as traps for the unwary. If one has a jammer fastened to ones belt – a fairly common practice – and one is knocked out by a falling rock one could quickly die hanging from the belt. Similarly, if the ladder broke, one would be in rather dire straits with such a "safety" system; the answer to this would seem to be to rig some sort of sit-sling-safety device, so that one could dangle in –relative-comfort till one regained consciousness in the former case, or while thinking about what to do in the latter. (And if one didn't have the means to, or the knowledge of how to prussik, the hanging around period would be rather long).

The conclusion to be drawn from this melancholy series of events is so obvious as not to need me to point it out; however, for the sake of completeness, I will do so. S.R.T. is a potentially hazardous business, and people are jumping on the band-wagon without regard for this fact – even in the States, where people have been at it for 20-odd years, the lessons do not seem to have sunk home. It is recommended that people taking up S.R.T. should be reasonably experienced cavers, preferably used to handling tackle (though there are several instances on record of people in the States being rescued after a crash-course in prussiking underground; one worth quoting involved seven individuals, the youngest being 13 years old and including a certain Hector – essaying a 1½ mile through trip starting at Sloan's Valley Cave, Kentucky. En route they had problems with several of them getting tired, and two becoming claustrophobic and hysterical, so their relief must have been considerable when they eventually arrrived within sight of daylight. However, this relief must have turned to consternation when they found themselves at the foot of the 56 foot shaft of Screaming Willy Hole. Their leader couldn't have been totally incompetent for he managed to free-climb out and find some cavers on the surface, from whom he borrowed some ascending gear, and a hastily organised mini-course enabled five – some frightened and tired – of the remaining six to get out. Poor old Hector had to be tied on a rope and pulled out; it's just conceivable that his inability to prussik might have had something to do with the fact that Hector was a dog!. Further recommendations are that everyone should have his own equipment, to be carried at all times – i.e. prussiking gear when descending, and vice-versa; that one should practise rope-swapping, knot-crossing, changing from abseil to prussik and vice versa before going anywhere near a cave. Such manoeuvres are rarely needed, but when they are it's likely to be in adverse circumstances where it would be difficult if not impossible to learn; in any case, such exercises develop a facility in the use of equipment which is very useful to possess. All equipment should be regularly checked and one should have some sort of safety device while prussiking – either an extra ascender or having one's seat-harness connected to two separate ascenders in such a way that failure of the main one doesn't shock load the other. Also one should have and know how to use prussik loops. Finally to finish on a personal note. I'm firmly of the opinion that S.R.T. opens up new possibilities and makes caving more fun; I certainly won't let the contents of this talk drive me back to using ladders.

March 1976

John Forder
Whernside Manor,
Dent, Sedbergh,
Cumbria LA10 5RE.

Trans. British Cave Research Assoc. Vol. 4, No. 3, pp 373-375 August 1977

SECURITY FOR THE ABSEILER/PRUSSIKER

B. J. Smith

"Security" means peace of mind, as well as safety. If you are not confident in the techniques you are using, or have no confidence in the equipment, then you are not secure. To be confident about the techniques under discussion one must practise them until such confidence is achieved, above ground whenever necessary, and in complete safety. To have confidence in one's equipment means acquiring the knowledge (a) to obtain the correct equipment in the first place, (b) to look after it well, (c) to use it within the limits of its design and strength, and (d) to replace it when necessary. With regard to "personal" equipment i.e.. descendeur, ascendeurs, harnesses, slings, safety devices (if any) etc., to obtain the knowledge to buy suitable equipment and look after it is not too difficult. To use it within its limits and replace it when necessary requires knowledge of the relevant facts and perhaps manufacturers should be more forthcoming in this respect, e.g. if ascendeurs are to be used as self-lining devices to what extent are they constructed and tested with regard to loading, including shock-loading. Thrun (1971) reported a Zedel Jammer as opening completely at 800-900lbs. No such figure seems to be available for Jumars or Cloggers, whereas Gibbs bear the legend "tested to 1000 lbs" when purchased. I feel that it is important for all manufacturers to state such figures if and whenever possible. A more difficult problem is that of the expected life of the equipment. When should harnesses, descendeurs, and ascendeurs be replaced? When they show signs of wear is, I suppose, the obvious but unsatisfactory answer. I once sent a Clog figure-of-8 descendeur back to the manufacturers via the climbing shop where it was purchased, with as I thought, grooves worn in it deeply enough to condemn it. I was eventually informed that it still had considerable life in it and could be used, if I remember rightly until the metal thickness was down to 8mm. This refers to the old i.e. larger Clog. If substantiated such information should be made generally known. On the other hand, my first pair of Cloggers, with the original soft alloy cam, began to slip after only a few months use, the top corner of the cam having worn smooth even though all the remaining teeth were hardly worn at all. I would not have dreamt of throwing them away after such little use had they not ceased to function safely. (The two more recent designs seem considerably more hard-wearing, I should add.).

The ropes we use, which may be personally or club owned, are another matter. As there is still at present to my knowledge only one rope specifically made for SRT caving (Blue Water), it is not entirely fair to expect rope manufacturers in this country to be able to give anything but general information i.e. nominal strength when new, on the ropes we choose to use. Their suitability for the purpose we put them to and the life expectancy of them under these conditions are factors we must ascertain for ourselves, with the help of the manufacturers where possible. Ultimately, with the co-operation of technical experts, rope manufacturers and cavers it should be possible to produce better ropes specifically designed for SRT caving, displaying known properties. Until such a time we must acquaint ourselves with the properties of the ropes we do use. Are the ropes we use safe for our purposes? An example:- Many people these days shun the use of kernmantel ropes for SRT on the grounds that the sheath when abraded through can slip down the core; a case of this happening was reported by Solari (1968). The most commonly used type of rope in this country today for SRT is a braided construction, which commonly consists of a plaited or braided core, or even a virtually straight core as in Kernmantel, with one or two braided sheaths i.e. very little difference in principle so far as the type of incident referred to above is concerned. Is *your* rope safe in this respect? Try the following simple test. Hang a few feet above the ground on a length of your SRT rope, in a sit-sling attached to an ascendeur (Jumar or Clogger etc.) on the rope. (I suggest using Jumars as Gibbs can sometimes hold under these circumstances. Thrun says Hieblers will hold in this situation but it is surely better if the rope does not display this property). Cut carefully round the outer sheath until it is completely severed; it may tear the last few fibres. Certain types of rope, in particular Super Braidline, display the property that you will now *fall* as sheath and Jumar will slip rapidly down the core. On other ropes, such as Marlow 16 plait, you may find, as I did, that you can cut through the outer sheath, the inner sheath and even four or five of the core yarns (out of six) before any undue slipping takes place.

This test, and several others, have been carried out by myself and many other club members in an attempt to familiarise ourselves with the properties and limits of the rope we are using.

Other tests include simply logging the use of each rope length and periodic testing of samples to obtain a long term picture of the wear rate of the ropes under caving conditions. The effect of certain devices (a variety of descendeurs and ascendeurs) on new clean rope i.e. not underground, was also tested and found to be in general agreement with Thrun's comment:- "Jumars have been used for a period of time with only slight, if any, increase in rope wear." i.e. *all* devices cause wear, but there is little difference between that caused by different devices. Also, the wear rate on new, clean rope is insignificant in comparison with that when ropes are used underground. We observed a very rapid *initial* wear on ropes used underground, although there was a levelling off after further use. In other words it seems that the conditions under which we use the ropes have a more serious effect on rope life than the devices themselves. The abrasion test, pioneered by A. Eavis (1974) was also repeated, and although not directly comparable, did provide us with useful information. (Smith 1976) Whilst not claiming any startling breakthrough in rope technology, nor advocating that every caver should embark on an ambitious testing programme we do feel that our series of tests, which are still continuing, have been useful to *us* in that we feel more confident in using a rope whose limitation we are coming to terms with.

Trans. British Cave Research Assoc. Vol. 4, No. 3, pp 377-379 August 1977

16 PLAIT MATT TERYLENE/POLYESTER ROPES FOR S.R.T.

E. G. Hawkins (Marlow Ropes Ltd.,)

Marlow Ropes Limited is a member of the Hawkins & Tipson Group, a Public Company quoted on the stock market since 1973. Marlow Ropes was formed in 1961 by Hawkins & Tipson, to concentrate on synthetic fibre ropes which were then virtually in their infancy although Nylon ropes had been manufactured since the war.

Our particular involvement was with Terylene/Polyester which seemed at the time to have characteristics which were in many cases more valuable and versatile than Nylon, especially its low controlled stretch characteristics.

The first major market was yachting as at this time prices were so high that all products met with considerable sales resistance elsewhere. Since then, although yachting is Marlow's prime concern as a single market, we are active in the general industrial field which in some cases shows the confidence users feel in Terylene as a fibre — for example, Fire Brigades, Coastguards.

History of 16 plait

We are for caving particulary concerned with 16 plait because of its special qualities, but we should point out that this is only one of a range of several types of Terylene/Polyester ropes and ropes of other fibres which we currently manufacture and stock. It is clearly the most suitable for this purpose. It was originally designed for yacht winching operations and this is still its biggest use.

The first type of 16 plait (circa 1959) had parallel filament cores with a single 16 plait outer in continuous filament yarn (shiny). Yatchsmen's complaints about the slippery surface and the stiffness of the rope first made us change the outside fibres to matt finish yarns. The next improvement was again in response to yatchtsmen's requests, to make the rope softer. This was achieved by covering the parallel core with a loose plait so that there was a parallel core and two plaited covers. This is the rope currently in operation, although there have been marginal improvements in strength over the years due to improved Polyester yarns. Four years ago we introduced colours — red, blue and gold and although these were much appreciated they are rather harder and in some cases weaken the overall strength of the rope.

We are currently working on two developments:-

1. **Type 3 White**

This is already on sale in 16mm dia. upwards and we are actively considering it for 10-14mm as well. It consists of a long laid 3 strand continuous filament core covered with a single 16 plait matt cover. The advantage of this rope is the considerable increase in strength, especially in bigger sizes, although there is some improvement in 10-14mm as well (see chart below).

2. **Type 3 Coloured**

We shall in due course be bringing out new shades of red, blue and gold which is in fact a new type of yarn, being stronger and softer. The colours are also better, especially the red which is redder rather than orange. The chart below shows the differences and improvements and it is as well to note that the core strength of current manufacture is 80% and the new manufacture 100%.

	White	Coloured
Current 16 plait matt *10mm*	2000kg.	1600kg.
New Colours	-	2000kg.
Type 3 16 Plait matt	2250kg.	?
Current 16 plait matt *12mm*	3000kg.	3000kg.
New Colours	-	3000kg.
Type 3 16 plait matt	3000kg. ?	?

16 Plait Matt for S.R.T. - Advantages

1. *Matt finish* — for better grip, friction, adhesion between inner and outer plaits.
2. The 16 plait construction makes the rope virtually un-kinkable and more important non-twist under load (we have an instance of a 500 ft length of rope on a block and tackle on a gantry having no twist at all under load).
3. Protected strength (80% core 20% cover). Most other plaited or braided products are 50/50.
4. Non-rucking. 16 plait will not concertina over ledges etc., and will suffer less damage as a result.
5. The round shape of 16 plait will be kept through working. This prevents flattening around sharp bends which could cause damage due to excessive friction.

Disadvantages

1. Loss of strength after relatively few uses. The reason for this cannot yet be proved but we do suspect it is due to grit particles washing in and out of the rope core and abrading the internal fibres. Microscopic examinations have failed to show any grit or damage but we are not particularly happy with the tests.

2. Lack of energy absorption in cases of free fall dropping on extensive heavy shock loading (see appendix below "The Energy Absorption Potential of Marlow 16 plait Polyester Ropes").

Work Progress

We would like to produce as a supplementary to our retail price list a "guide to cavers" which could give guidance to cavers on care and protection of ropes, a list of do's and don'ts and most important of all if possible establish length of life recommendations. This will have to be established with the recommendation of B.C.R.A. on work carried out by Brian Smith of the Bradford Pothole Club.

Experimental Work Currently in Progress and Activities Considered

1. Current type 16 plait and new type is with a climbing expedition to be used as a fixed rope.
2. Current type 16 plait and new type with Brian Smith to compare one with the other.
3. Once we have established the answer to (2) a sample length of the chosen type in new colours on the outer plait to be sent to Brian Smith for evaluation.

Note:

If Type 3 proves unsuitable (but we may decide to go ahead anyway with Type 3 for yachting) we will carry a range of the present 16 plait for cavers. In this situation we may or may not decide to stock all colours in 10 and 12mm but would like to seek guidance at this stage to which colours would be preferred.

4. Proofing of external fibres to close the pores (see sample). The work so far done experimentally on proofing has been encouraging but not wholly successful.

Reasons for above Work

1. (Climbers – To widen the market.
2. (Type 3) – Greater initial strength to counteract strength loss due to grit. (Better resistance to grit "flow" due to solid strand core?).
3. (Colours) – Identification.
4. (Proofing) – To protect the core from strength loss due to grit, by closing the pores.

We welcome questions and criticism.

Postscript

I should add that the *Type 3* 16 plait as referred to in my article has subsequently been eliminated from our programme for *cavers,* since its outer cover would slide down the core in a potentially fatal manner if it were completely severed. We heard at the SRT symposium from B. Smith that this is an undesirable quality in an SRT Rope and for this reason, for the present we do not intend to stick to our current design of 16 plait matt.

Appendix

The Energy Absorption Potential of Marlow 16 Plait Polyester Ropes – A.E. Willis (Marlow Ropes) Limited

Marlow 16 plait polyester rope in 10mm dia. size has been proved highly successful in caving operations.

When this success first became evident, we immediately began extensive research work, as the result of which we think it desirable that all cavers should be made aware of certain facts about the ropes when they are subjected to shock loads in an emergency.

This is not in any way to introduce an alarmist element but purely to explain, for the benefit of all, the facts as they exist.

Nobody, not even a mountaineer, falls on a rope deliberately, but it must be pointed out that if in emergency a rope is called upon satisfactorily to arrest a falling body the rope must be technically capable of absorbing that load. It is, we think, correct to say that in caving, the chances of a fall are not anywhere near so great as in mountaineering and in the rare event of a fall, the distance is considerably less.

The energy absorption of 16 plait polyester rope is of the order of 6,000 foot pounds per pound weight of rope. Calculated as figures applying to 10mm and 12mm 16 plait ropes, this means an energy absorption rate of 325 foot pounds per foot of rope for 10mm rope and 466 foot pounds per foot for 12mm rope.

If, for the purposes of illustration, we assume lengths of 10, 15, 20 and 25 feet of rope, we have energy absorption capacity of 3,250; 4,878; 6,500 and 8,130 foot pounds respectively for 10mm rope and 4,665; 7,000; 9,300; and 11,650 for 12mm rope. If we now look at the effect of a man falling these distances, the figures that follow presume that a man is falling an equal distance to the length of the rope – that is, for a 10 foot length of rope the man falls 10 feet; for 20 ft. of rope a fall of 20 feet and so on. This is the way that the shock-absorbency of ropes is determined in laboratory testing and represents the worst possible conditions that could exist. In fact, they are worse conditions than are likely to happen in most actual usages of the rope, excepting possibly industrial and yachting safety harnesses.

Firstly then, let us assume that a fully dressed and equipped man weighs 200lb. The energy produced by a falling body is the multiple of the static weight of the body and the length of fall so that at a free fall of 10 feet he will have developed 2,000 foot pounds of energy and at 15, 20 and 25 feet the figures will be 3,000; 4,000 and 5,000; respectively.

When we compare these energy figures to the energy absorption potential of the rope we see that there is a margin of about 1½ : 1. For 12mm rope the margin is around 2¼ : 1.

These figures are for *new* rope and are highly satisfactory but account must be taken of the reduction in strength of ropes through use. It is known that after a reasonable period of use, the strength of ropes used in potholing applications depreciates by up to 50% – even though ropes are invariably washed after use. Extensive research in our laboratory has not so far been able to account for the cause of this but, although examination of used ropes has never defined to any great extent the presence of silt that has penetrated into the rope, this seems the most likely cause. The abrasive nature of silt will, of course, produce some permanent rupture of the fibres from which the rope is made . We know that the reduction in strength is not caused by any tendency to acidic conditions either in cave water or the environs. Neither do the clamps used in descending or prussiking appear to be the cause of damage.

To return to the energy absorption capacity of the ropes, it is essential then, that we look at what is available in them when they have reduced in strength by 50%. Obivously, their absorption capacity is also reduced by 50% — from 6,000 ft. pound per pound weight of rope to 3,000. If we now look again at the figures given for new rope, where we see that for 10mm rope a factor of approx. 1½ : 1 exists between the rope absorption capacity and the energy developed by the falling man, this will reduce to ¾ : 1 for a rope of 50% strength reduction. This means of course that the rope will break.

I repeat that this is, however, when tested under deliberately hazardous laboratory testing conditions and hasten to add that actual conditions encountered in caving operations are not likely to be anywhere near so stringent. If the figures for 12mm rope are examined, a rope of 50% reduction will have an energy absorption factor of approximately $1\frac{1}{8}$: 1 — not a very great margin of safety, but at least the rope should not break.

We have set out our figures in this way to highlight the worst conditions that could occur, but since it is not likely that a potholer will fall without some (possibly quite considerable) length of rope above him the actual shock load transmitted to a rope should be very considerably less than in laboratory testing. The longer the length of rope already out above a caver the greater is the ability of the rope to absorb the load.

To illustrate this, let us say that there is 40 feet of rope above the potholer and that he slips off a ledge. The capacity to absorb energy of a used 10mm rope of 50% strength is 6,500 foot pounds. There will therefore be ample margin to arrest the falling man safely because, since he is in contact with the rope he cannot fall very far even if the rope is lying slack at the start of the fall.

In conclusion, let us repeat that whilst conditions in caving are unlikely to be so serious as to cause a rope to fail, even allowing for a 50% drop in strength due to circumstances of usage, it is always as well to be acquainted with performance under extreme conditions.

Under the terms of the Health & Safety Act it is the duty of a supplier to acquaint the user with all information relating to his product to ensure safe usage. I feel that we are conforming with the requirements of this Act in providing the information given in this paper.

March 1976

Marlow Ropes Ltd.
South Road,
Hailsham,
Sussex BN27 3JS.

Trans. British Cave Research Assoc. Vol. 4, No. 3, pp 381-385 August 1977

SELF-RESCUE FOR THE SMALL S.R.T. PARTY

Paul Ramsden

Summary

Anyone having an accident using S.R.T. may find themselves stuck in the middle of the rope. This situation presents unusual difficulties for the remainder of the party. It will normally be best to get the victim off the pitch as quickly as possible and this article suggests some possible methods.

Since S.R.T. has become popular, cavers now travel around in small number. If someone gets stuck in the middle of a rope, other cavers, if there are any nearby, will not be able to lower them off, as might have been the case using a ladder and lifeline system. Thus rescue for a small S.R.T. party is likely to be a difficult proposition.

Obviously there are many possibilities for the causes of accidents. The following situations give some idea of what could cause trouble:-

Stonefall causing injury or loss of consciousness.
Exhaustion – caused by bad technique or wet pitch.
Light failure – especially with carbides on wet pitches.
Knots in the rope.
The rope re-belayed part way down a pitch.
Harness disintegration.
Ascender or descender gets stuck or fails.
Rope too short.
Sheath slips on core of rope.
Self-lifelining with just a single ascender.
Normal lifelining on ladders using an ascender for belaying.
Rope sticks on a crevice in the rock.

Study of such situations and the appropriate escape procedure should reduce the chances of a rescue situation developing. The following recommendations are made as a basis for safety:- Have a harness system which allows you to rest safely even if unconscious; have each ascender tied off independently to your body harness. Be thoroughly proficient in the following techniques:- locking off a descender; changing abseil to prussik; prussik to abseil; cross over knots (both upwards and downwards); changing ropes when tied off part way down a pitch.

Rescue If someone is hanging part way down a pitch there are two possible courses of action. You can try to pull him up or to let him down. Pulling up can either be done from the top, or by a person going down the rope to do this. Lowering someone down from the top can only be done if there is a separate rope available. Alternatively someone can go down the rope, free the victim's ascender and abseil off with him.

If the victim is at the base of the pitch you have more options open; circumstances will dictate your course of action. You may be able to get the victim out by yourselves. Generally, it will be important to get the victim off the pitch quickly, especially if it is a wet pitch. This means that descending or lowering off are likely to prove easiest. Once the victim is in a safe place the C.R.O. (if any locally) may be called out.

The equipment required to perform a self rescue should not be in excess of what you might reasonably be expected to take with you. If it is, perhaps you ought to think again!

The Pitch head situation The best hang for the rope for rescue purposes has a high anchor point, so the victim can be lifted off the top easily, or prussik loops can be used as belays on the main rope, if subsidiary anchor points are absent. It should be free hanging to avoid friction, but only just, otherwise the rescuer will have to perform while dangling in space. A solid beam is useful, but additional belays near at hand are advantageous.

Operating from the rop of a pitch has the advantage of not exposing the rescuer to as great a risk as if he descended and operated from the middle of the rope.

In the following illustrations prussik knots and ascenders are usually interchangeable.

Hoisting from the pitch head

The Direct Life Method (Fig 1) involves the use of an inverted ascender or prussik knot which is fastened to the body harness or to a sling over one's shoulder. Lifting is done with the powerful leg muscles, the back being kept straight, otherewise you may damage it. As the rope is pulled, a pre-tied knot is slid down and the weight transferred to the knot. After the initial lift, sliding a knot or ascender down the rope requires two hands. If an ascender is used, it may be possible to weight or anchor the lower end, so that it jams automatically as the rope is pulled through. (Fig 2).

The Pulley Lift with slings (Fig 3a) A locking prussik knot or inverted ascender is fixed at the top. Using a long sling anchored at the top, going through a krab or pulley on an inverted ascender, a hoist with theoretical two to one advantage is gained. The lower ascender or knot is pushed down after each lift ready to repeat the procedure. Similar alternatives using just slings and prussik knots may be used. (Fig 3b, Fig 3c).

Counterbalance lift (Yosemite Lift) (Fig 4) A lock prussik knot or inverted ascender is fixed on the main rope. A karabiner is used as a pulley (in this case a short prussik on the main rope provides the anchorage – though obviously this could not be used if you wished to untie the main rope later), through which a sling is attached to an inverted ascender. Bodyweight is applied via the footloop. A variation is to fasten the footloop to the body harness and use full bodyweight as a counterbalance. In either case an upward pull on the

Trans. British Cave Research Assoc. Vol. 4, No. 3, pp 381-385 August 1977

SELF-RESCUE FOR THE SMALL S.R.T. PARTY

Paul Ramsden

Summary

Anyone having an accident using S.R.T. may find themselves stuck in the middle of the rope. This situation presents unusual difficulties for the remainder of the party. It will normally be best to get the victim off the pitch as quickly as possible and this article suggests some possible methods.

Since S.R.T. has become popular, cavers now travel around in small number. If someone gets stuck in the middle of a rope, other cavers, if there are any nearby, will not be able to lower them off, as might have been the case using a ladder and lifeline system. Thus rescue for a small S.R.T. party is likely to be a difficult proposition.

Obviously there are many possibilities for the causes of accidents. The following situations give some idea of what could cause trouble:-

Stonefall causing injury or loss of consciousness.
Exhaustion – caused by bad technique or wet pitch.
Light failure – especially with carbides on wet pitches.
Knots in the rope.
The rope re-belayed part way down a pitch.
Harness disintegration.
Ascender or descender gets stuck or fails.
Rope too short.
Sheath slips on core of rope.
Self-lifelining with just a single ascender.
Normal lifelining on ladders using an ascender for belaying.
Rope sticks on a crevice in the rock.

Study of such situations and the appropriate escape procedure should reduce the chances of a rescue situation developing. The following recommendations are made as a basis for safety:- Have a harness system which allows you to rest safely even if unconscious; have each ascender tied off independently to your body harness. Be thoroughly proficient in the following techniques:- locking off a descender; changing abseil to prussik; prussik to abseil; cross over knots (both upwards and downwards); changing ropes when tied off part way down a pitch.

Rescue If someone is hanging part way down a pitch there are two possible courses of action. You can try to pull him up or to let him down. Pulling up can either be done from the top, or by a person going down the rope to do this. Lowering someone down from the top can only be done if there is a separate rope available. Alternatively someone can go down the rope, free the victim's ascender and abseil off with him.

If the victim is at the base of the pitch you have more options open; circumstances will dictate your course of action. You may be able to get the victim out by yourselves. Generally, it will be important to get the victim off the pitch quickly, especially if it is a wet pitch. This means that descending or lowering off are likely to prove easiest. Once the victim is in a safe place the C.R.O. (if any locally) may be called out.

The equipment required to perform a self rescue should not be in excess of what you might reasonably be expected to take with you. If it is, perhaps you ought to think again!

The Pitch head situation The best hang for the rope for rescue purposes has a high anchor point, so the victim can be lifted off the top easily, or prussik loops can be used as belays on the main rope, if subsidiary anchor points are absent. It should be free hanging to avoid friction, but only just, otherwise the rescuer will have to perform while dangling in space. A solid beam is useful, but additional belays near at hand are advantageous.

Operating from the rop of a pitch has the advantage of not exposing the rescuer to as great a risk as if he descended and operated from the middle of the rope.

In the following illustrations prussik knots and ascenders are usually interchangeable.

Hoisting from the pitch head

The Direct Life Method (Fig 1) involves the use of an inverted ascender or prussik knot which is fastened to the body harness or to a sling over one's shoulder. Lifting is done with the powerful leg muscles, the back being kept straight, otherewise you may damage it. As the rope is pulled, a pre-tied knot is slid down and the weight transferred to the knot. After the initial lift, sliding a knot or ascender down the rope requires two hands. If an ascender is used, it may be possible to weight or anchor the lower end, so that it jams automatically as the rope is pulled through. (Fig 2).

The Pulley Lift with slings (Fig 3a) A locking prussik knot or inverted ascender is fixed at the top. Using a long sling anchored at the top, going through a krab or pulley on an inverted ascender, a hoist with theoretical two to one advantage is gained. The lower ascender or knot is pushed down after each lift ready to repeat the procedure. Similar alternatives using just slings and prussik knots may be used. (Fig 3b, Fig 3c).

Counterbalance lift (Yosemite Lift) (Fig 4) A lock prussik knot or inverted ascender is fixed on the main rope. A karabiner is used as a pulley (in this case a short prussik on the main rope provides the anchorage – though obviously this could not be used if you wished to untie the main rope later), through which a sling is attached to an inverted ascender. Bodyweight is applied via the footloop. A variation is to fasten the footloop to the body harness and use full bodyweight as a counterbalance. In either case an upward pull on the

DIRECT LIFT METHOD

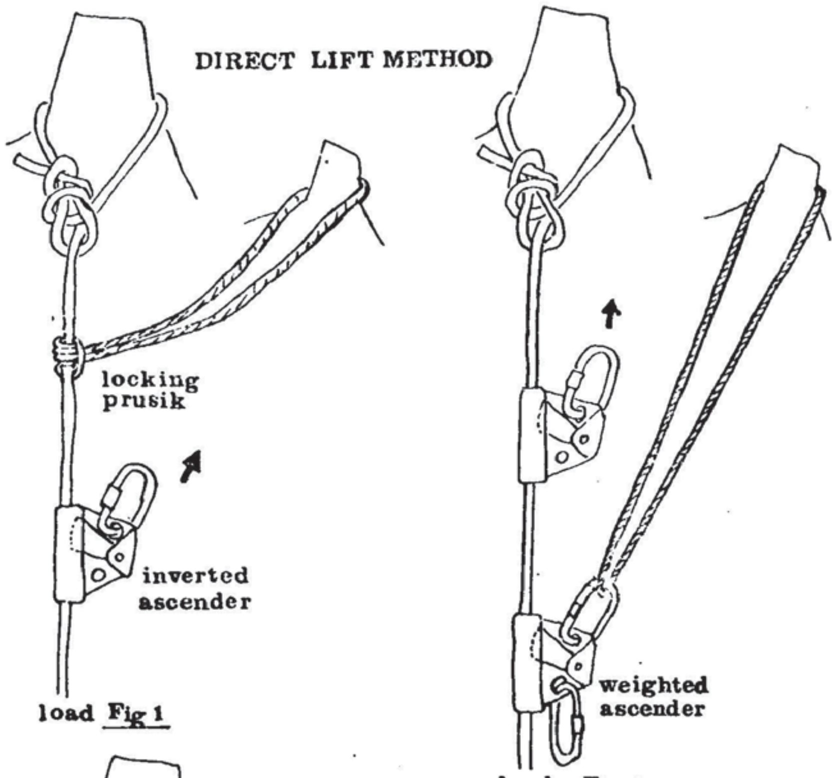
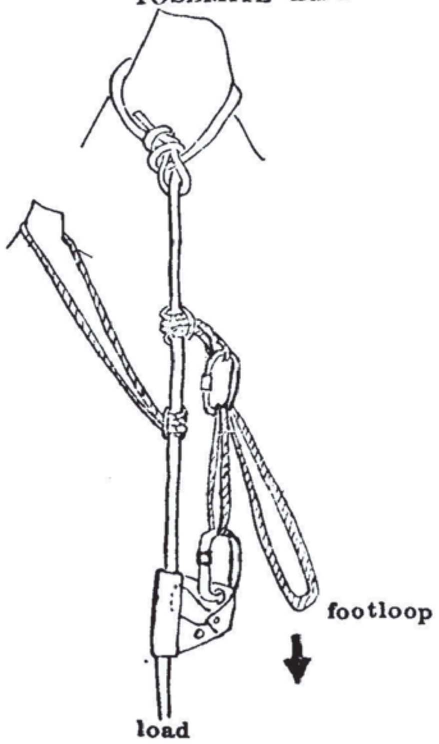


Fig 1 Fig 2

Fig 4 COUNTERBALANCE OR YOSEMITE LIFT



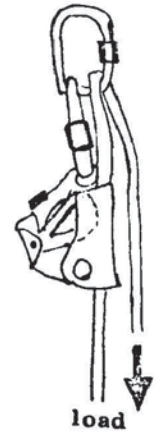


Fig 5

Fig 6

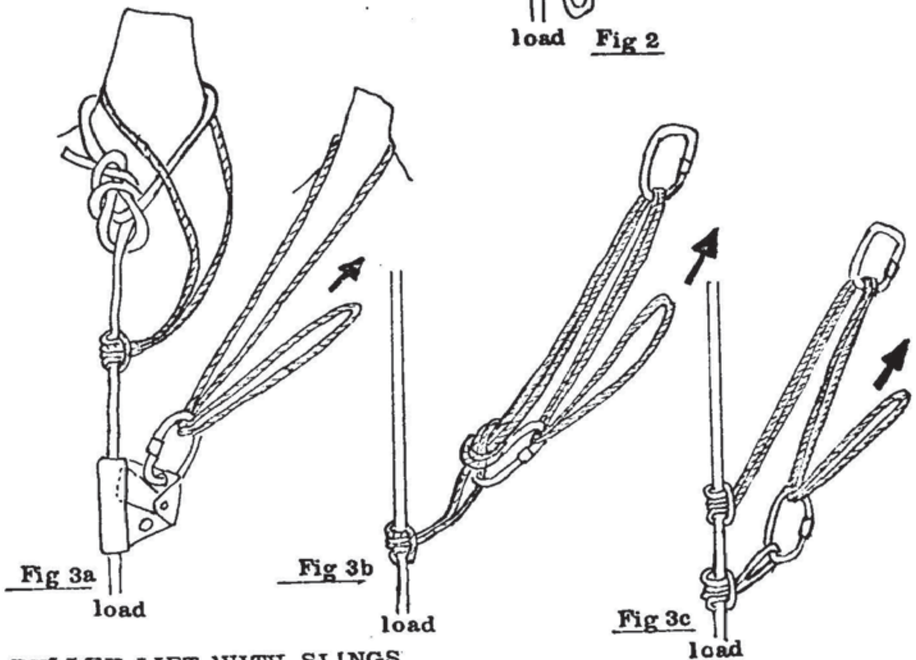


Fig 3a Fig 3b Fig 3c

PULLEY LIFT WITH SLINGS

Fig 7

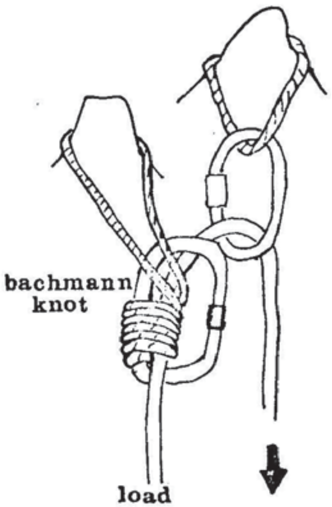


Fig 8

Petzl Gibbon

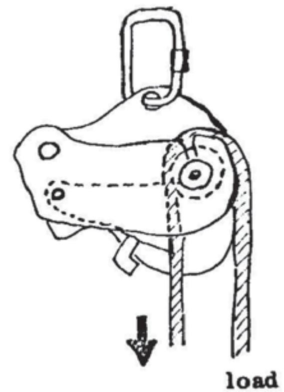


Fig 9

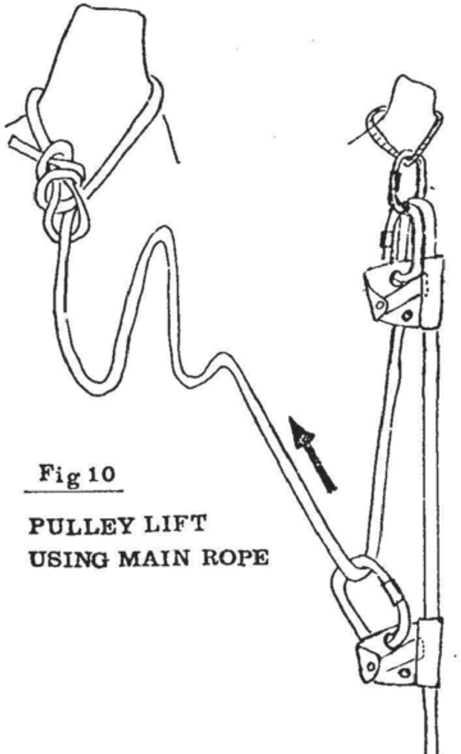


Fig 10

PULLEY LIFT
USING MAIN ROPE

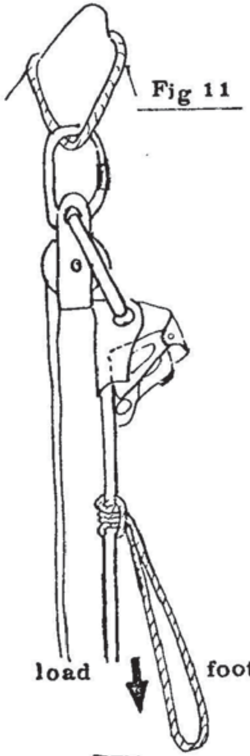


Fig 11

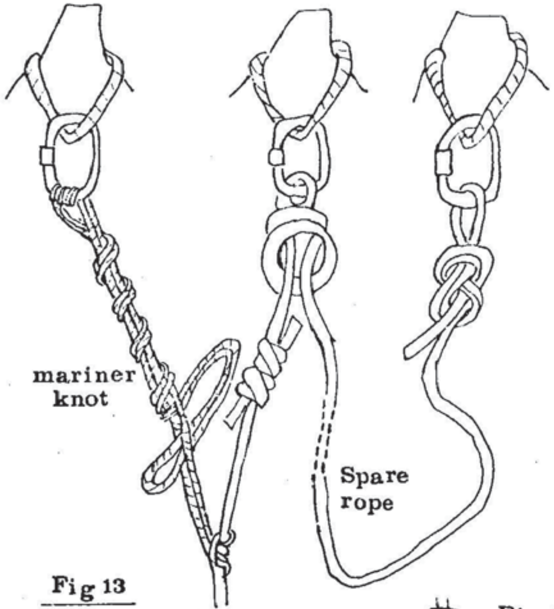


Fig 13

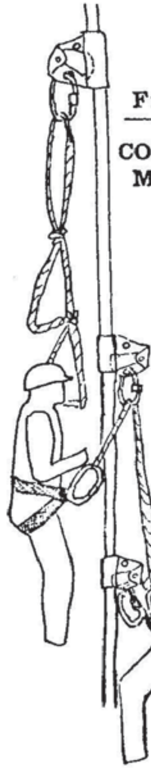


Fig 14

COUNTERBALANCE.
METHOD

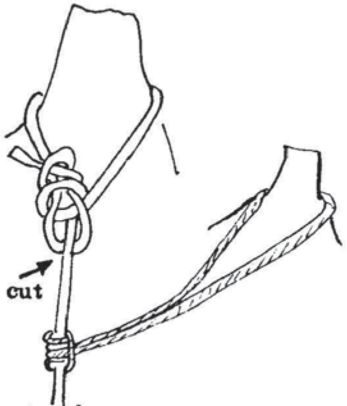


Fig 12a

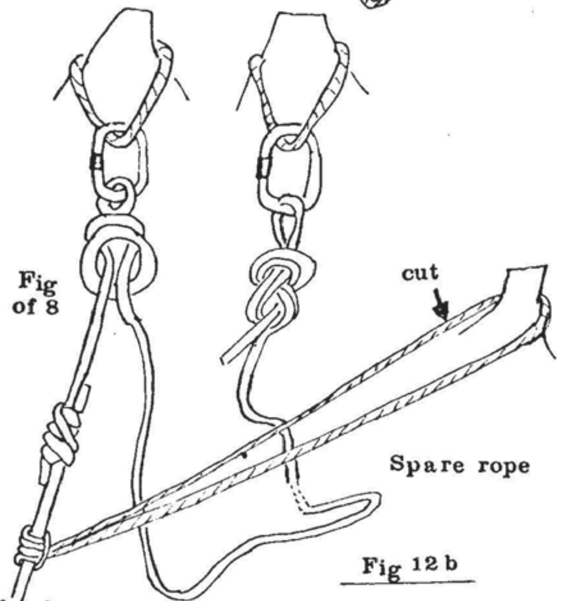


Fig 12 b

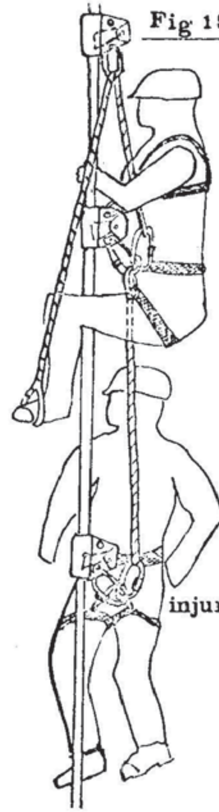


Fig 15

main rope with the hands (or an inverted ascender) will help considerably. As slack is produced on the main rope – the locking prussik is slid down.

Methods described above all deal with the main rope in tension. Once slack is introduced into the system, self locking pulleys may be used, which allow greater freedom of movement.

Various combinations of ascenders, krabs, and knots may be used. In Fig.5 a karabiner is used as a pulley and is locked by an inverted ascender. The system works better with a chain of two karabiners, rather than just a single one, as the rope is then pulled in a straight line through the ascender.

The Petzl pulley and Petzl ascender were designed to fit together (Fig.6) so other types of ascender are not really interchangeable. A note on special equipment perhaps is appropriate. These small pulleys weigh only 100g, but can usefully reduce friction over karabiners.

The knot in Fig.7 is extracted from Techniques de la Speleologie Alpine as are some other techniques in this paper. The two karabiners should be of equal shape and size to prevent the rope slipping. The way to remember how to tie the knot is "The load rope goes over two karabiners then over the first one".

The locking Bachmann Knot (Fig 8) is useful because it doesn't require use of ascenders. It is important that the Bachmann karabiner should be larger than the pulley karabiner – otherwise it might slip through. The knot should be tied off very short, to prevent loss of gain on the transfer of load as this means wasted effort.

The Petzl Gibbon (Fig 9) is perhaps the most sophisticated jammer of this type – though is very uncommon. It is designed to fit between sit and chest harness. It incorporates a pulley wheel and jamming cam and works very efficiently.

The Pulley Lift with the Main Rope (Fig 10) has advantages over the system using a sling (Fig 3a), in that a longer pull with sustained momentum is possible and a self-locking pulley incorporated.

Counterbalance or Yosemite Lift with the main rope (Fig 11) is just a more refined version of Fig 4, with a self-locking pulley incorporated.

Summary of Hoisting methods

Time trials over 20 ft with 160 lb load showed little difference between methods in Fig 2, 10 and 11. The Direct Lift (Fig 2) though convenient for short sections would be tiring on a longer distance. The Pulley lift with a sling (Fig 3a) was shown to be slower than any of the three methods noted above (Figs 2, 10 or 11).

Lowering from the pitch head

Lowering is only possible if a spare rope is available. Normally slack must be introduced into the system (as described above) so the main rope can be untied, another rope attached and fed through a descender.

Alternatively, the *Knife Technique* (Fig 12a) may be used. A prussik knot is tightened as much as possible, then the main rope cut, leaving enough rope to join onto another, which has been fed through a descender and locked off. After joining the two ropes, the prussik sling is cut transferring the load to the descender (Fig 12b).

The prussik knot may be attached by a "Mariner Knot" which can be released under load (Fig 13). This involves two turns on the karabiner, several turns around itself and finished with a bight of the sling going through between the two taut strands coming from the prussik knot. (NOTE it is important to keep the knot in tension otherwise it may slip).

Alternatively, the weight could be taken by one of the hoisting methods described previously, then the prussik knot or inverted ascender is released, then the load transferred to the locked off descender.

If the victim is able to help himself, many other techniques, such as crevasse rescue methods could be used. Another variation suggested is to use a lightweight block and tackle as advertised for removing car engines!

Methods involving descent or ascent of the rope to reach the victim

After reaching the victim there are two possibilities: to abseil off with the victim or to lift him up to the top. If it is necessary to prussik down the loaded rope, care should be taken, as ascender or knots may not grip as well as normal. A ladder or second rope will make the operation considerably easier and thus safer.

Counterbalance Method (Fig 14)

The rescuer firstly attaches a long etrier (two normal etrier footloops fastened together) above the victim. He clips onto the etrier (shortened for clarity in Fig 14) with a cows tail and then unfastens his body ascender. A sling goes from the victim over a karabiner or pulley, which is attached to an ascender, then down to the rescuer. By pulling upwards on the loadside and using his bodyweight as a counterbalance, the rescuer lifts the victim and the rope becomes slack between the victims karabiner and the pulley karabiner. To move up with the victim, the rope is pulled through his ascender. The rescuer then moves up the etrier slings (or spare rope or ladder) taking the pulley ascender with him and repeats the procedure.

To abseil off, a descender is inserted below the victim and locked off. Using the counterbalance the victim can be lifted sufficiently to free his ascender, and then lowered onto the descender. The rescuer unfastens his etriers and attaches himself to the descender and abseils off. More friction than normal is required with two people, so a full turn around a karabiner after the rope leaves the descender is advised, or 6 bars on a rack.

Towing the victim by the rescuer (Fig 15)

A short sling is used to link the victim and rescuer. Another rope goes from the rescuer's body harness over a pulley and down to a footloop. As the rescuer steps down, his body moves up towing the victim as well. The load is transferred to the body ascender, and the pulley ascender raised to repeat the cycle. Extra security is given by pulling the rope through the victim's body ascender. Using this method it is possible to tow an injured person upwards more quickly than using the counterbalance method (Fig 14), since it is not necessary to keep moving up and down the etriers. There is also the advantage of being attached to the rope at all times. Once up to the head of the pitch, difficulty is generally experienced getting the victim off the rope, unless it has a really high belay point. At such times it is better not to have the victim attached to the rescuer as in Fig 15, but it is a relatively easy matter to transfer the victim's weight back to his ascender, and then the rescuer is free to move about as necessary.

To abseil off, a sling is attached to the victim, fed over the pulley directly rather than being fastened to the rescuer and ends in a footloop. A descender is attached to the victim and locked off. The rescuer counterbalances the victim up using the footloop, then releases the victim's body ascender. He then lowers him onto the descender, which is tied off as close as possible to eliminate the possibility of the rescuer's foot being pulled through the pulley! The rescuer removes his body ascender, then the pulley ascender, and attaches himself to the descender and abseils off.

Conclusion

There are many different methods with many more variables of equipment, harness rigs etc., Only by practice using different techniques in varied situations (preferably on the surface) will any fluency be achieved. Ultimately this may help with the decision over "what to do" if a real incident happens underground.

References:

Dobrilla, J.C. & G. Marbach. 1973. *Techniques de la Spéléologie Alpine.* Published by Nabeyrat, Paris.

March, W. *Improvised techniques in mountain rescue.* Jacobean Press, Edinburgh. Revised edition by Cicerone Press, Manchester 1976.

March 1976

Whernside Manor,
Dent, Sedbergh,
Cumbria LA10 5RE.

Trans. British Cave Research Assoc. Vol. 4, No. 3, pp 387-388 August 1977

THE SMALL S.R.T. PARTY – EXPEDITION LOGISTICS

T. Faulkner

Telling readers how to plan an expedition seems rather like showing Granny how to suck eggs, so one or two actual trips are outlined so that the reader may draw his own conclusions.

Needles Pit, 1973

In 1973 we decided to take a look at the bottom of Chourum des Aiguilles in the traditional way. We had no intention of underground camping since we understood that once the hole was rigged the return trip could be done in about 20 hours. After making about four successive trips pushing a mountain of tackle downwards and now feeling like a recovery day between trips we realized that we just did not have time.

Whilst we were de-tackling a small party of French cavers came along and simply slid down the gritty ropes we had noticed hanging on each pitch. They bottomed the hole and prussiked out with such ease that even I could no longer pretend that S.R.T. was an Indian rope trick !

Practice Prussiks & Needles Pit 1974

We spent the next year dangling from cliffs, beams, trees, lamp-posts and sometimes in caves and, in 1974, ten cavers plus about 1,500 ft of rope arrived back at Chourum des Aiguilles. Our first trip took us and the tackle as far as we had previously reached. We then formed into a team of three, and a team of four. The first team's job was to rig the bottom half of the hole and prussik out without the encumbrance of tackle. The second team's job was simply to slide to the bottom two hours behind the first team and de-rig the bottom half of the hole.

This system worked very well and, speaking as a member of the second team we arrived at the bottom feeling as if we had only just left the surface and almost looking forward to the long prussik out. We managed to de-rig more of the hole than planned leaving us with only a six hour trip to finish the job.

If we were to repeat this kind of operation I think we would let the second bottoming party carry a spare rope long enough to deal with the biggest pitch. This would have been of use on the way down, when the way on looked a little dangerous, to line the first man who confirmed it was alright. It would also have been of use when one rope suffered some damage near the bottom of the hole. One thing we might revise was to take the ropes for some pitches in long lengths and cut to suit in place.

Shortly after we emerged from the hole a second British party turned up and showed that with good, almost military planning, underground camping, red teams, blue teams, red and perhaps green arm bands, you could do the hole the traditional way and spend about 800 man hours getting nine men to the bottom against our 243 man hours getting 7 to the bottom.

Reduction of Large Tackle Burden

These two trips are a clear demonstration of the effect of cutting a long tackle burden, S.R.T. makes successive trips to avoid camping and camping tackle well worth considering as the time saved in not ferrying tackle many times along each passage is probably worse than that taken to nip out and camp in comfort. It also can be quite easy to slide down to the tackle and use this point as a spring board to the bottom. Another advantage of making an extra trip out is that it gives one some measure of the hole and helps avoid the obvious damage of overreaching onself.

Since planning is very much a matter of timing, let's look at the time-consuming disadvantages of S.R.T.:

1. Alleged slower rate of climbing. This is not really true except when the climber is being extended by the life-line which will hardly ever take place on a long expedition.
2. Time wasted clipping on. This is compensated for by not having to return a life-line to each climber.
3. Problems on tight pitches. This seems to affect me but I find that sometimes the advantage of not having to bend the knee as much makes up for the extra gear one is wearing.

So this leaves the following advantages:

1. Quicker and easier descent.
2. Less tackle. This is the biggest advantage and we find that a bloke can carry a bag containing 250 ft of rope with little trouble, against this a ladder man would have to carry 10 x 25 ft. ladders and 500 ft of rope.
3. Pitches in quick succession can be climbed simultaneously without waiting to be on to life-line.
4. Less interference by lightning.

This last advantage may seem farfetched, but I am speaking from bitter experience. This was when we were tackling a long surface shaft at Provatina in Greece when on four afternoons operations had to be suspended because we were getting shocks from the 570 ft. ladder. These shocks were of course not the results of direct strikes but merely caused by the ladder straddling the voltage gradient set up by strikes in the area. On looking back to that shocking expedition it seems that a couple of lads could have packed a mule with rope

Trans. British Cave Research Assoc. Vol. 4, No. 3, pp 387-388 August 1977

THE SMALL S.R.T. PARTY – EXPEDITION LOGISTICS

T. Faulkner

Telling readers how to plan an expedition seems rather like showing Granny how to suck eggs, so one or two actual trips are outlined so that the reader may draw his own conclusions.

Needles Pit, 1973

In 1973 we decided to take a look at the bottom of Chourum des Aiguilles in the traditional way. We had no intention of underground camping since we understood that once the hole was rigged the return trip could be done in about 20 hours. After making about four successive trips pushing a mountain of tackle downwards and now feeling like a recovery day between trips we realized that we just did not have time.

Whilst we were de-tackling a small party of French cavers came along and simply slid down the gritty ropes we had noticed hanging on each pitch. They bottomed the hole and prussiked out with such ease that even I could no longer pretend that S.R.T. was an Indian rope trick !

Practice Prussiks & Needles Pit 1974

We spent the next year dangling from cliffs, beams, trees, lamp-posts and sometimes in caves and, in 1974, ten cavers plus about 1,500 ft of rope arrived back at Chourum des Aiguilles. Our first trip took us and the tackle as far as we had previously reached. We then formed into a team of three, and a team of four. The first team's job was to rig the bottom half of the hole and prussik out without the encumbrance of tackle. The second team's job was simply to slide to the bottom two hours behind the first team and de-rig the bottom half of the hole.

This system worked very well and, speaking as a member of the second team we arrived at the bottom feeling as if we had only just left the surface and almost looking forward to the long prussik out. We managed to de-rig more of the hole than planned leaving us with only a six hour trip to finish the job.

If we were to repeat this kind of operation I think we would let the second bottoming party carry a spare rope long enough to deal with the biggest pitch. This would have been of use on the way down, when the way on looked a little dangerous, to line the first man who confirmed it was alright. It would also have been of use when one rope suffered some damage near the bottom of the hole. One thing we might revise was to take the ropes for some pitches in long lengths and cut to suit in place.

Shortly after we emerged from the hole a second British party turned up and showed that with good, almost military planning, underground camping, red teams, blue teams, red and perhaps green arm bands, you could do the hole the traditional way and spend about 800 man hours getting nine men to the bottom against our 243 man hours getting 7 to the bottom.

Reduction of Large Tackle Burden

These two trips are a clear demonstration of the effect of cutting a long tackle burden, S.R.T. makes successive trips to avoid camping and camping tackle well worth considering as the time saved in not ferrying tackle many times along each passage is probably worse than that taken to nip out and camp in comfort. It also can be quite easy to slide down to the tackle and use this point as a spring board to the bottom. Another advantage of making an extra trip out is that it gives one some measure of the hole and helps avoid the obvious damage of overreaching onself.

Since planning is very much a matter of timing, let's look at the time-consuming disadvantages of S.R.T.:

1. Alleged slower rate of climbing. This is not really true except when the climber is being extended by the life-line which will hardly ever take place on a long expedition.
2. Time wasted clipping on. This is compensated for by not having to return a life-line to each climber.
3. Problems on tight pitches. This seems to affect me but I find that sometimes the advantage of not having to bend the knee as much makes up for the extra gear one is wearing.

So this leaves the following advantages:

1. Quicker and easier descent.
2. Less tackle. This is the biggest advantage and we find that a bloke can carry a bag containing 250 ft of rope with little trouble, against this a ladder man would have to carry 10 x 25 ft. ladders and 500 ft of rope.
3. Pitches in quick succession can be climbed simultaneously without waiting to be on to life-line.
4. Less interference by lightning.

This last advantage may seem farfetched, but I am speaking from bitter experience. This was when we were tackling a long surface shaft at Provatina in Greece when on four afternoons operations had to be suspended because we were getting shocks from the 570 ft. ladder. These shocks were of course not the results of direct strikes but merely caused by the ladder straddling the voltage gradient set up by strikes in the area. On looking back to that shocking expedition it seems that a couple of lads could have packed a mule with rope and by S.R.T. done more in a day than we did in six days with or without lightning!

Conclusion

We should, obviously, plan to get further by S.R.T. but it is as well to use some of the time saved to take extra care.

March 1976

Paul Ramsden
Whernside Manor,
Dent, Sedbergh,
Cumbria. LA10 5RE.

Trans. British Cave Research Assoc. Vol. 4, No. 3, pp 389-401 August 1977

THE GEOLOGICAL EVOLUTION OF THE JUGHOLES CAVES, MATLOCK, DERBYSHIRE

N.E. Worley and D.A. Nash

Abstract

The Jugholes caves form part of a typical Derbyshire pipe vein system and a survey of the caves is presented for the first time together with a brief history of the early explorations. Detailed stratigraphical and petrographical work has demonstrated that development of the caves was controlled by the occurrence of lavas, clay wayboards, and pseudobrecciated limestones. Preliminary analysis of cave sediments has shown that they were derived from erosion of a fluorite replacement deposit, basalt lava, and clay wayboards. The evolution of the system is considered to have taken place from the Upper Carboniferous to the present day.

Jugholes caves lie 1¼ miles west of Matlock, Derbyshire (SK 279596). Access to the system may be gained from a footpath leading from Salters Lane which connects with the main A6 in Matlock (fig 1). The entrance is situated on the steep north-facing limestone slopes of a plateau at about 900 ft, O.D. which contains two prominent hills, Blakelow Hill, 1203 feet, and Masson Hill, 1111 feet. The plateau is bordered in the east by Matlock Dale, a north-south gorge produced by the incision of the river Derwent, and to the south by an east-west dry valley, the Via Gellia, dividing the plateau from its former southern extension towards Middleton Moor. A number of smaller dry valleys arranged in a radial pattern dissect the plateau and are partially filled by glacial drift (Smith et. al 1967). The Jugholes system lies beneath one of these valleys and trends north-south.

History and Previous Research

Little is known about the pre-20th century history of the Jugholes, however, a number of early plans have appeared notably one by J. Nuttal dated 1763. This plan notes the position of the Jugholes lying adjacent to Noon Nick Vein (fig 1) and probably represents one of the earliest references establishing the existence of the cave in the 18th century. Other important plans occur in the records kept by the Barmaster who is the Crown Agent in administering lead mining laws in the Mining Field of the High Peak.

The 1899 2nd edition of the 1:2500 Ordanance Survey maps indicates that all of the shafts had been sunk onto the veins by that date. It was probably during this early period that the exaggerated accounts and legends concerning murders, ghosts, underground lakes, and packs of wild dogs arose (Nash 1956).

During the early 20th century accounts of explorations appeared in the High Peak News of 1912, recalling earlier Nottingham Guardian reports of 1906, describing descents of the Jugholes by the Kyndwr Club. It is from their descriptions that the tales of a vast underground lake lying beneath the ground at Jugholes grew up. Further explorations were carried out by the Derbyshire Pennine Club 1907-9 who described the system much as it is today giving accurate dimensions of the magnificent stalagmite cascade (= the Beehives) in the Upper Series (fig 2) thought at that time to be the largest in Britain. They suggested that the system was formed partly by mining and partly by natural agencies. Less accurate accounts were reported by the Matlock New Field Naturalists Club who depicted Jugholes as "a cavern of threefold character; Cavern, Lead Mine and Water Swallet". They also noted the occurrence of the Beehive slopes and the streamway and were the first to recognise that the cave possibly owed its present shape to the stoping of limestone by collapse with later cementation by speleothems, but their suggestions that the cave extended for over half a mile are probably exaggerated. All these early accounts constantly refer to the Upper Series of caves and the entrance cave known as Jugholes (fig 2) indicating that they have changed little since the early 20th century. Unfortunately no reports of the Lower Series have been found suggesting that this was only more recently re-discovered by mining operations.

Other literature concerning Jugholes occurred in a fictional article by Brindley (1945) who wrote disreputable descriptions about the caves, he portrayed how the lead miners stopped mining due to the presence of made dogs and how explorers encountered lakes of hot water from which scalded bodies were washed into the river Derwent !

Latterly, the mineral deposits at Jugholes have received attention in a number of geological publications and theses. Dunham (1952, p. 101) gave the first section of strata exposed, depicting the Jughole as a partly collapsed cave 35 feet high and noted that a fluorspar replacement deposit was being worked by Messrs Constable adjacent to Noon Nick Vein (Fig 1). More recently Smith et al. (1967) described the geology of the Matlock area establishing the stratigraphy (fig 5) and recorded that a fluorite replacement ore-body was worked at Jugholes. The latest work concerns description of the mineral deposits by Ixer (1973) who described a paragenetic sequence for the deposit, recognising the occurrence of the rare nickel mineral Bravoite as inclusions in fluorite crystals.

A complete record of the caves by Nash (1956) remains the only full account of the system and the first attempt to explain their origin. However, after nearly a century of research and documentation no survey of the caves has been published, the stratigraphy, and structure have not been clearly deduced and the origin of the caves has remained a puzzle.

Description of the Caves and Mine Workings

The name Jughole generally refers to the main entrance cavers (SK 27975959) named the Second Water Cavern by Nash (1956), but when used in the plural Jugholes generally refers to the whole cave-cum-mine

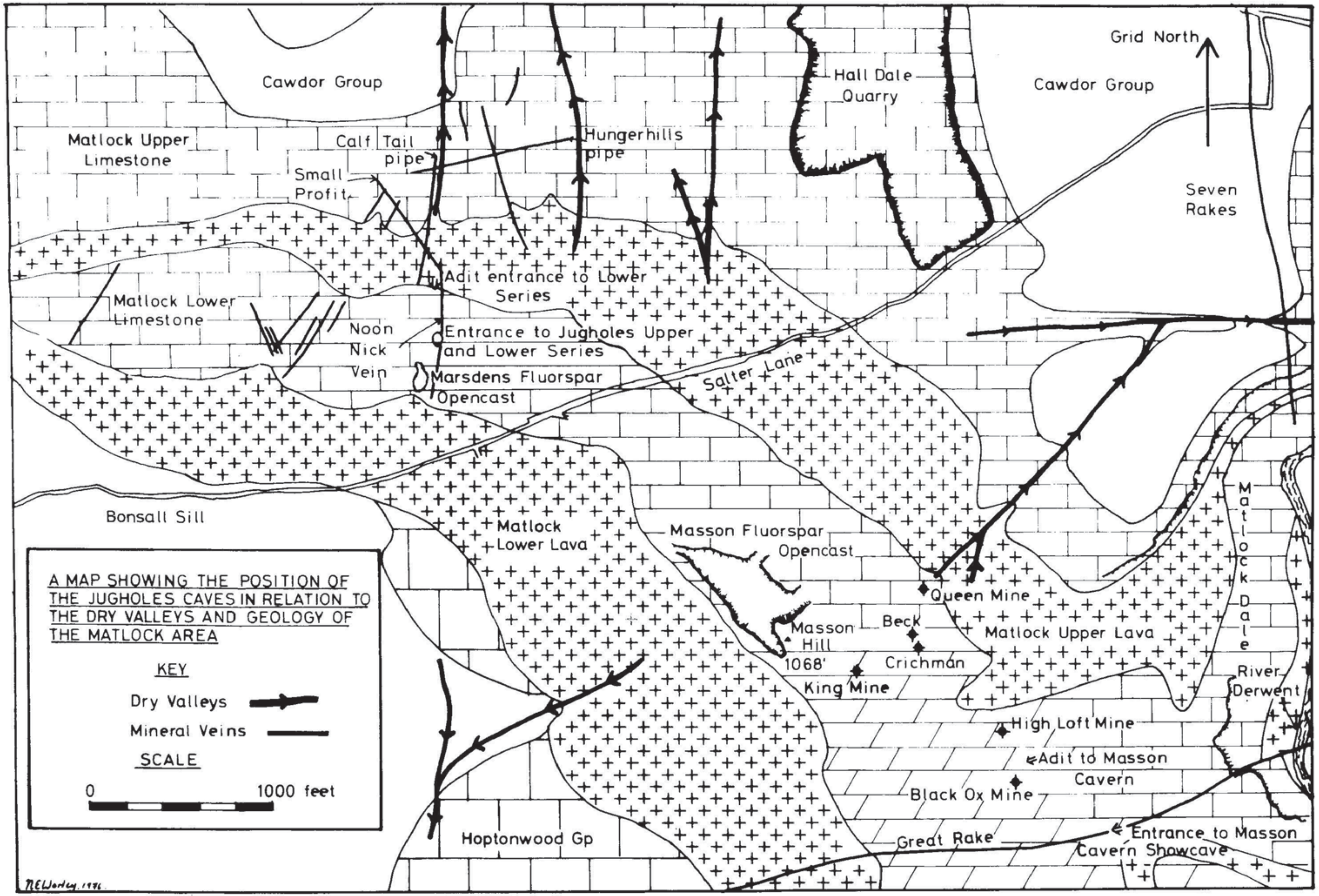
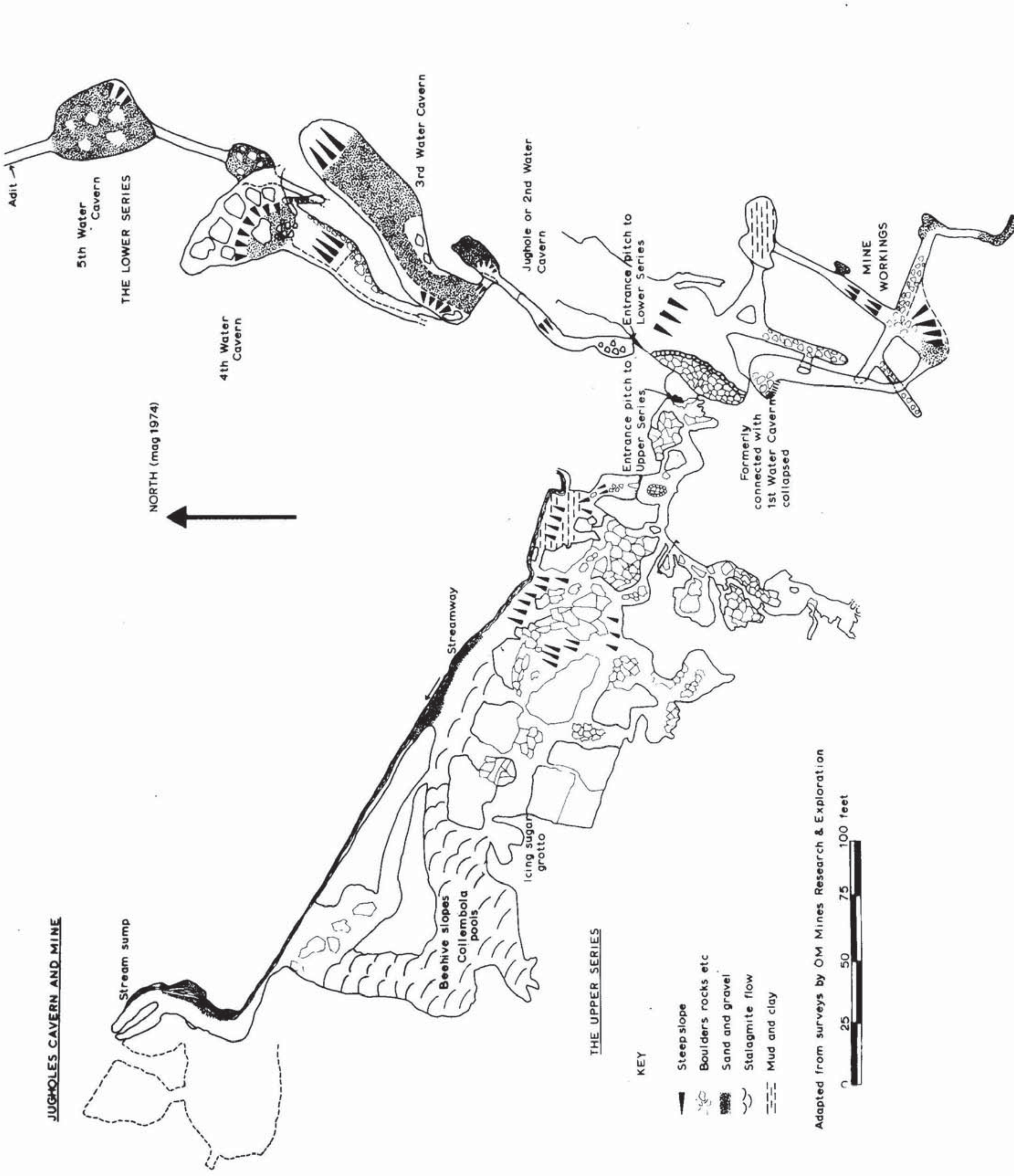

A MAP SHOWING THE POSITION OF THE JUGHOLES CAVES IN RELATION TO THE DRY VALLEYS AND GEOLOGY OF THE MATLOCK AREA
KEY
Dry Valleys
Mineral Veins
SCALE
0
1000 feet
Cawdor Group
Matlock Upper Limestone
Calf Tail pipe
Small Profit
Hungerhills pipe
Hall Dale Quarry
Cawdor Group
Grid North
Seven Rakes
Adit entrance to Lower Series
Matlock Lower Limestone
Noon Nick Vein
Entrance to Jugholes Upper and Lower Series
Marsdens Fluorspar Opencast
Salter Lane
Bonsall Sill
Matlock Lower Lava
Masson Fluorspar Opencast
Queen Mine
Masson Hill 1068'
Beck
Crichman
King Mine
Matlock Upper Lava
Matlock Dale
River Derwent
High Loft Mine
Adit to Masson Cavern
Black Ox Mine
Hoptonwood Gp
Great Rake
Entrance to Masson Cavern Showcave

Fig. 1.



JUGHOLES CAVERN AND MINE
Stream sump
Streamway
Beehive slopes
Collembola pools
Icing sugar grotto
THE UPPER SERIES
KEY
Steep slope
Boulders rocks etc
Sand and gravel
Stalagmite flow
Mud and clay
Adapted from surveys by OM Mines Research & Exploration
0
25
50
75
100 feet
NORTH (mag 1974)
Entrance pitch to Upper Series
Formerly connected with 1st Water Cavern collapsed
Entrance pitch to Lower Series
Jughole or 2nd Water Cavern
MINE WORKINGS
4th Water Cavern
THE LOWER SERIES
5th Water Cavern
Adit
3rd Water Cavern

Fig. 2.

complex. The Second Water Cavern provides access to all the cave and mine systems and is a convenient starting point for description. It appears at first sight to be a miniature Peak Cavern entrance reaching 50 feet high in places and over 25 feet wide; extending about 100 feet south into the hillside. In the roof of the cave are some good examples of stalactites covering phreatic pockets in the walls. The steeply inclined floor is largely formed from coarse reddish brown muddy gravels which contain economic amounts of fluorite. During the late 1950s mining by Messrs. Marsden removed large quantities of this fluorite-bearing sediment. An old narrow gauge rail bears testimony to these later periods of working. At the base of the cavern a mined passage may be followed east into the latest (1939-45) in underground workings, which extend up dip for about 90 feet.

The Upper or Second Series is entered via a shaft 16 ft deep in the southwestern corner of the Second Water Cavern which leads west into a small cave.

After scrambling for 40 feet through a succession of ill-defined partially collapsed chambers three alternative routes can be followed. A low passage leading downdip to the north is recommended but the passage to the south is a sporting crawl leading progressively updip through a maze of collapsed boulders for some 100 feet until it becomes too tight. The main route continues north downdip into a small chamber about 10 feet high with a clay floor representing the weathered top of the Matlock Lower Lava. The stream emerges here and flows to the west connecting after a short crawl with the main bedding plane chamber. This is a magnificent cavern extending for about 200 feet along the strike to the west and 80 feet south updip. Large blocks of limestone have been stoped from the roof and now rest on the steeply inclined floor of the chamber. Many of these have been cemented by a splendid cascade of flowstone which a one time must have covered most of the floor. Passing further west along the streamway the full flowstone cascade is seen; it was called the Beehive Slopes by Nash (1956) on account of the shape of the stalagmites. These slopes can be climbed to a series of pools which before pollution by cavers contained colonies of Collembola. In the southern extremity of the chamber are a series of grottos, notably Icing Sugar Grotto which consists of a series of delightful calcited pools that remain largely unvandalized. Returning to the streamway at the base of the Beehive Slopes good sections of rather coarse clayey sediments have been exposed by entrenchment of the vadose stream beneath the flowstone floor. The route continues along the stream through a low muddy crawl to a sump where the stream disappears. Digging here has not revealed any continuing passages. A tight joint above the streamway can be climbed and leads into a well decorated ill-defined bedding plane cave up to 3 feet high.

The Lower or First Series is also entered from the western side of the Second Water Cavern (fig 2) via a 21 foot pitch down a half-concealed fissure. This series was described by Nash (1956) who noticed that five individual chambers lay in an NNE – SSW line, and named them in order one to five. The prefix Water Cavern was added in order to make a clear distinction from mined passages and passages produced by mineralization processes known locally as pipe veins. During the late 1950s and early 1960s mining operations caused collapse of the First Water Cavern into the lower parts of the Second Water Cavern. At the base of the 21 foot entrance pitch to the Lower Series a muddy chamber with a prominent bedding plane roof and fluorite gravel floor connects with a low passage. Good phreatic solutional features covered by stalactite are present on the roof of the passage which follows a solutionally enlarged master joint heading west and trending north – south (fig 2). After 70 feet the passage intersects a small chamber the floor of which is covered by muddy gravels containing fluorite and calcite. A hole in the western wall passes through the north – south joint and emerges in the southern end of the impressive Third Water Cavern, over 100 feet in length and 20 feet wide reaching over 30 feet in height. Large phreatic pockets are present in the roof and the floor is covered by a coarse, reddish-brown gravel consisting of calcite, fluorite, baryte, and a little galena. A number of pits and depressions in the floor of this chamber probably represent attempts by miners to extract the small amounts of galena present in the sediment. Crossing another solutionally enlarged joint in the south-western part of the Third Water Cavern a low bedding plane cave is entered, developed on the western side of the master joint. The east wall of the chamber is formed by a boulder choke filling the joint. whilst the western wall falls about 20 feet into a parallel rift trending north-northeast – south-southwest. A short crawl downdip leads after 60 feet into a boulder choke beneath the entrance to the Fourth Water Cavern. This is perhaps the most attractive chamber in the system with a roof of interconnecting phreatic pockets coated with a fine tracery of white stalactite. The floor of the chamber has largely collapsed but this has exposed a fine section showing a stalagmite floor bonding a coarse angular fill of limestone blocks and gravels. A climb through a boulder choke to the east passes through a vertical pitch of 10 feet and connecting with a driven level. The level follows a partly natural passage called the High Miners Pipe as it intersects a large natural cavern after 20 feet. Digging in the western part of this cavern failed to extend the system to any significant degree. The level also intersects the Fifth Water Cavern after a further 20 feet; it is somewhat smaller than the others and is principally developed beneath the fourth clay wayboard (fig 3) which is about 3 feet thick at this point. The level continues to the northwest beneath Adit shaft (SK 27975964) and cuts through the base of the Matlock Upper Lava before emerging to the surface via a tight unpleasant collapse hole near the former adit entrance.

Geology of the Caves

Geological mapping on surface and underground has established a detailed stratigraphical section for the Jugholes Caves (fig 5). This has shown that 92 feet of D_2 age Matlock Lower Limestone is sandwiched between two thick basalt lavas, the Matlock Upper and Lower Lavas. When compared with the section exposed to the east around Masson Hill and in Matlock Dale, where the Matlock Lower Limestone reaches 120 feet (Smith et. al. 1967) considerable thinning must have occurred. Field mapping throughout the area has demonstrated that this is generally consistent with westward thinning of the limestones over quite a large area. The succession is characterised by a number of clayey tuff bands known locally as clay-wayboards representing weathered volcanic ashes. Six clay-wayboards have been recognised but only the thicker ones, number 1 and 4, are laterally persistent.

Insoluble residue and petrographic analyses have been carried out on the limestone to determine major compositional variations and relate them to mineralization and cave development. Over 100 samples have been analysed following the techniques described by Folk (1959), R.K. Dunham (1962), and Ireland (1950).

The lowest limestones beneath clay-wayboard 1 consist of extremely coarse shelly crinoidal biomicrudites, the allochems reaching over 5 cms in length. Above this the limestones are generally more fine-grained with allochems consisting of broken brachiopod and crinoidal debris of fine calcirudite size. The lowest 50 feet are strongly pseudobrecciated having a clotted texture in freshly cut hand specimens. This pseudobrecciated was probably caused by burrowing animals and indicates that the limestones were deposited in very shallow water conditions associated with the regression cycles of the Lower Carboniferous described by Ramsbottom (1973). The upper 40 feet or so of the Matlock Lower Limestone is mainly exposed in the adit and appears to be rather thinly-bedded, sparsely fossiliferous and fine-grained.

Fossils are common in the lower limestones and consist of *Lithostrotion sp. Dibunophyllum sp.,* tabulate corals including *Syringopora sp.,* and *Chaetetes sp.* with bands of thick-shelled productids.

The results of insoluble residue analysis obtained by dissolving the limestones in dilute acetic acid showed that the rocks are extremely pure with respect to calcium carbonate with values varying from 0.5 to 5% by weight of acid insoluble residue. The residues consist largely of minute bipyramidal quartz crystals which vary in size from 30μ to 6μ. Organic material was the next most abundant insoluble component and it was generally found that it was responsible for the pigment of the darker limestones. Those limestones with high insoluble residue contents occurred adjacent to mineral veins and have suffered from silica metasomatism associated with the mineralization processes. Otherwise there is little variation in insoluble residues throughout the succession, the limestones with little cave development having similar values to those without. The significance of the principal cave horizons lying beneath clay wayboard 4 in the pseudobrecciated limestones illustrates how the wallrocks can control the development of caves. Microstylolite contacts in the pseudobrecciated limestones cause an overall increase in porosity and reducing the mechanical strength of the limestones, thus rendering them more susceptible to chemical and mechanical erosion.

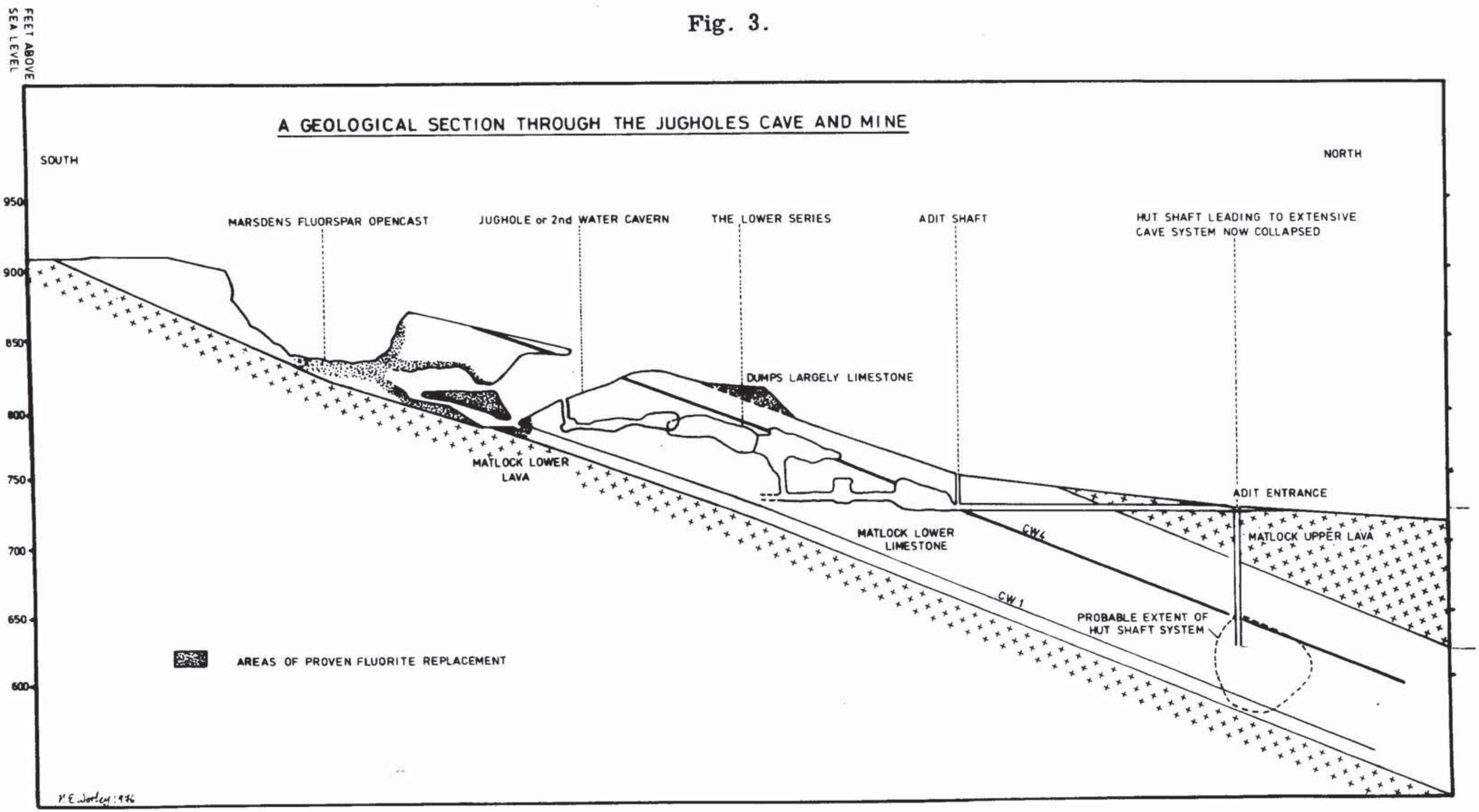
The influence of lava and clay-wayboard horizons acting as hydrological barriers has been discussed at length in terms of their effects on mineral deposition (Firman and Bagshawe 1975; Mackay 1952). It is clear from the study of the Jugholes that the lavas and wayboards acted in a similar way controlling the circulation of phreatic ground water where flow would tend to occur along strike selecting the most prominent bedding planes and clay-wayboard horizons. The soft clays are readily removed and dissolution of the limestones adjacent to the wayboards would soon occur and initiate cave development. The abundance of pyrite in many of the clay-wayboards upon weathering produces areas of low pH and tends to increase the rate of dissolution of the limestone. Similar processes probably operated at the lava/limestone contacts where thick pyrite-rich tuff bands are also common.

The structure of the Matlock area has been described by Shirley (1958) and Smith et al (1967) who established that a complex faulted asymmetric anticline trends east west across the area. Further work has shown that a number of minor folds and faults cut the anticline generally trending north-south and are occupied by dry valleys filled with glacial drift. The Jugholes system lies on the steeply dipping northern limb of this anticline beneath a shallow north-south dry valley and occupies a shallow synclinal structure. A number of master joints (Price 1966) shown in fig.4 exerted a strong control over the development of the caves with a set of enlarged joints trending NNE – SSW extending for about 300 feet. In the Upper Series areas adjacent to these joints have collapsed preventing reconstruction of the original cave form. The influence of joints in the Lower Series is clearer where each of the main chambers steps down adjacent to a solutionally enlarged master joint.

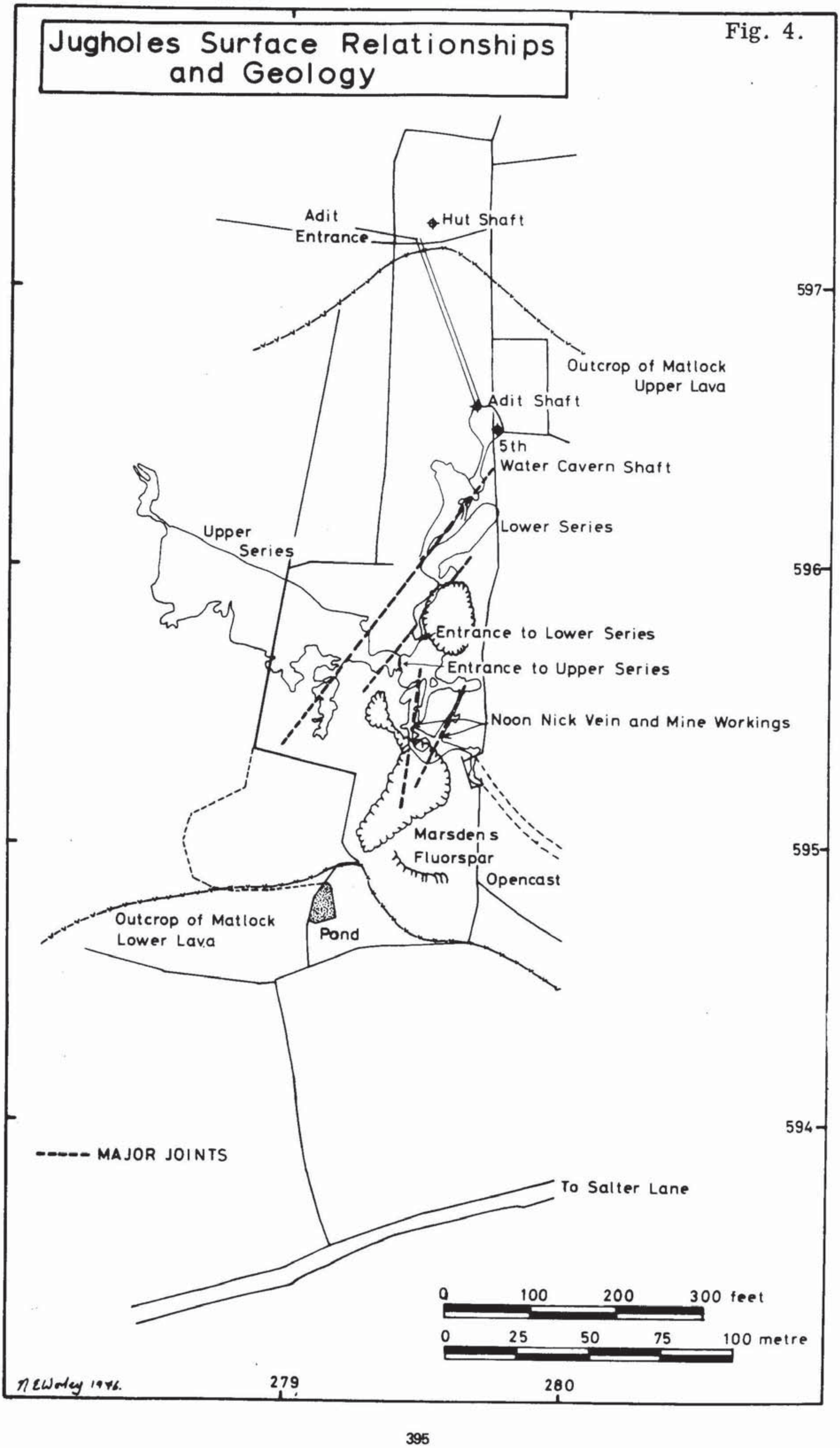
Cave Sediments

One of the most prominent features of the Jugholes caves is the amount of sediment which partially fills many of the chambers. The provenance of these sediments is an important part of any study of the evolution of caves in the Matlock area. Most of the sediments occur beneath a thick well-developed speleothem floor and have been exposed by downcutting of vadose streams and by mining activity. Examination of the sediments in the field shows that they reach considerable thicknesses probably attaining 10 feet and are not well bedded but appear to be rather poorly sorted varying from fine reddish brown laminated silts and clays to extremely coarse subangular gravels. In hand specimen the sediments consist largely of angular clasts of fluorite, calcite, limestone, baryte, and dolomite with smaller amounts of galena. In the Upper Series corroded basalt contributes significantly to the composition of the sediments. Samples were collected in the Upper Series from beneath the speleothem floor adjacent to the streamway and care was taken to avoid sediments disturbed by mining and cavers. These were analysed in the laboratory following techniques described by Folk (1968). Approximately 0.7 kg. of sample was used in each case.. After weighing, the clays (greater than 230 mesh) were washed out using 1% Calgon solution and dried. The samples were then reweighed to calculate the clay fraction before seiving in the ¼ ϕ seive sets for twenty minutes using a Rotap seiver. All the various size fractions were weighed then stored in glass bottles and clearly labelled for later microscopic examination. The clay fraction was retained and small samples were pipetted onto glass slides for X-Ray Diffraction analysis. Results of the size fraction analysis have shown that the sediments are muddy

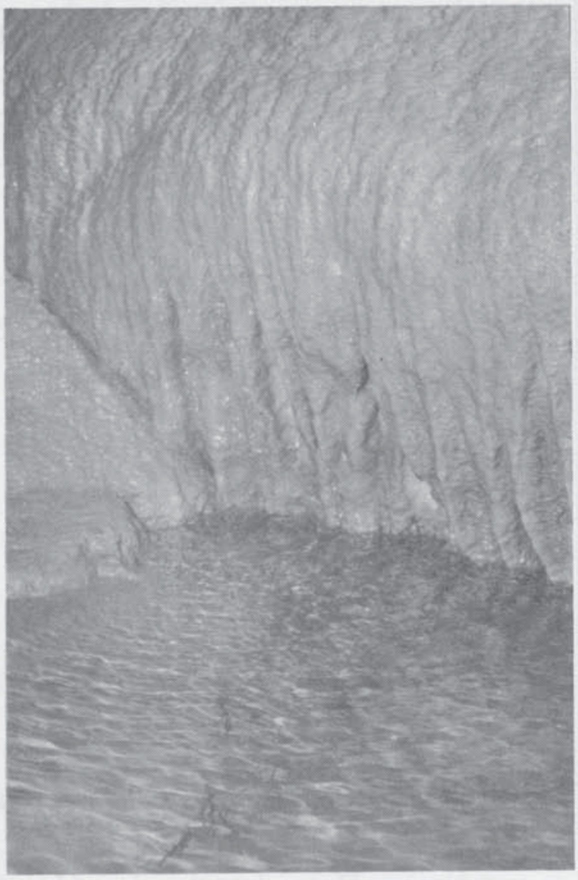
Fig. 3.



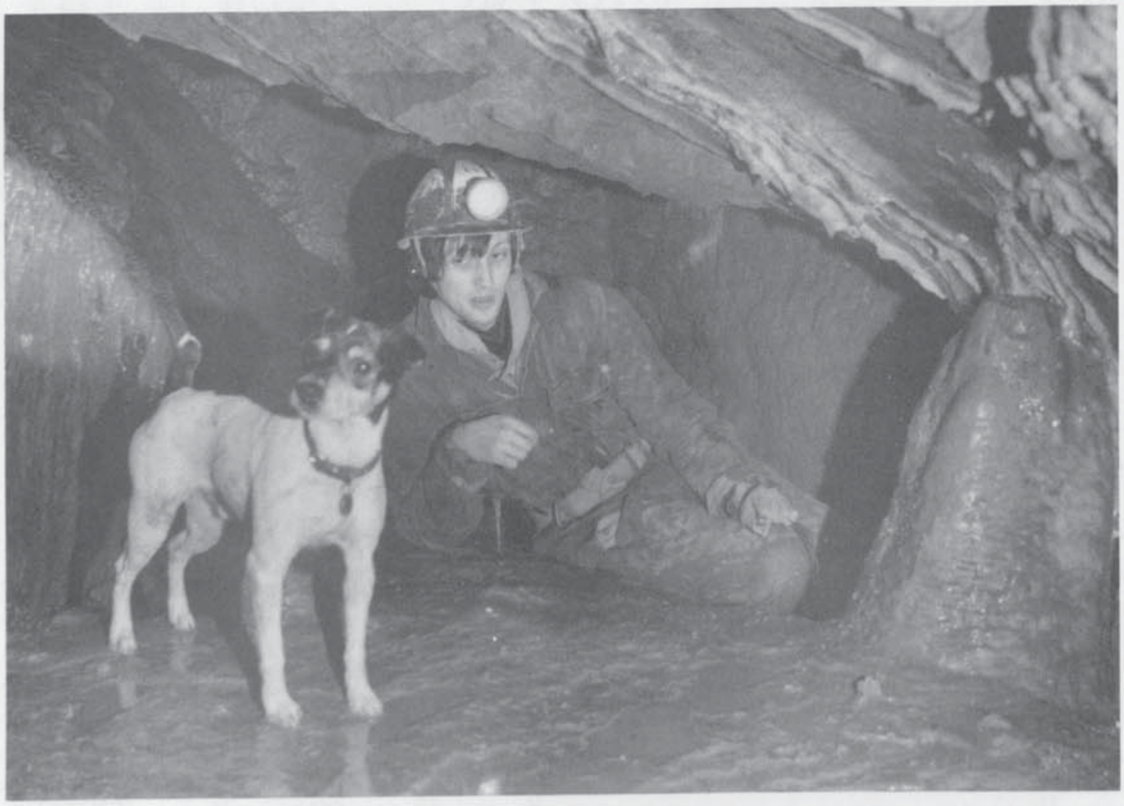
FEET ABOVE SEA LEVEL
A GEOLOGICAL SECTION THROUGH THE JUGHOLES CAVE AND MINE
SOUTH
NORTH
950
900
850
800
750
700
650
600
MARSDENS FLUORSPAR OPENCAST
JUGHOLE or 2nd WATER CAVERN
THE LOWER SERIES
ADIT SHAFT
HUT SHAFT LEADING TO EXTENSIVE CAVE SYSTEM NOW COLLAPSED
DUMPS LARGELY LIMESTONE
MATLOCK LOWER LAVA
ADIT ENTRANCE
MATLOCK UPPER LAVA
MATLOCK LOWER LIMESTONE
CW4
CW1
PROBABLE EXTENT OF HUT SHAFT SYSTEM
AREAS OF PROVEN FLUORITE REPLACEMENT


Jugholes Surface Relationships and Geology
Fig. 4.
Adit Entrance
Hut Shaft
597
596
595
594
Outcrop of Matlock Upper Lava
Adit Shaft
5th Water Cavern Shaft
Lower Series
Upper Series
Entrance to Lower Series
Entrance to Upper Series
Noon Nick Vein and Mine Workings
Marsdens Fluorspar Opencast
Outcrop of Matlock Lower Lava
Pond
MAJOR JOINTS
To Salter Lane
0 100 200 300 feet
0 25 50 75 100 metre
279
280

1. Curtains on the steeply sloping roof above the 'canyon' cut into toadstone.



2. Detail of the Beehive stalagmite slope and Collembolan pools.



3. Author and caving friend demonstrating the inclined bedding.

Photos by Paul Deakin.

gravels having bimodal size frequency distributions. They are moderately well sorted ($\sigma = 0.73$), positively strongly fine skewed and being bimodal, very platykurtic.

Microscopic analysis of the various size fractions has shown that the samples contain up to 40% fluorite as angular fragments, well-rounded vesicular basalt fragments, dolomite, corroded calcite, large clasts of limestone, and baryte. X-Ray diffraction analysis of the clays was carried out in the X-Ray Laboratory, University of Leicester by Mr. R.N. Wilson using a Cu X-Ray source and Ni filter with a scanning rate of ½ °/minute. This enabled the indentification of a number of minerals which include, quartz, feldspar, kaolinite, and iron-rich chlorites.

For comparative purposes a sample was analysed from the Nickergrove Mine, Eyam (Beck 1974) which is developed in a pipe vein system with similar sediment infills. Analysis has shown similar results to those obtained in Jugholes with high concentrations of baryte and fluorite in the coarser size fractions. However, in the case of the cave sediments in the Eyam area some material was derived from erosion of the Upper Carboniferous gritstone-shale escarpment and deposited in the caves in the form of gritstone pebbles, quartz, muscovite, and kaolinite. The absence of this suite of pebbles and muscovite flakes in the Jugholes sediments suggests that the provenance was more localized and that glacial erosion of the gritstone escarpments to the east of Matlock did not contribute sediment to the caves. Most of the sediments were derived from underground erosion of the basaltic rocks which are exposed in the floor of the caves and surface erosion of the dolerite Bonsall Sill (fig.1) which occupies most of the high ground to the south. Weathering of these igneous rocks also produced all of the clay mineral fractions, the kaolinite, feldspar, and iron-rich chlorite.

This study of the sediments cannot be regarded as exhaustive and there is scope for further work but important conclusions may be reached on the origin of the sediments. The bimodal size frequency distribution suggests that the sediments were derived from two sources; — (1) weathering of the basalt lavas and (2) mechanical erosion of the fluorite orebody. Evidence that the cave sediments may have been derived from erosion of the Upper Carboniferous gritstone escarpment lying 2 miles to the east is not forthcoming and it seems that the river Derwent effectively drained all the obsequent streams flowing west from the gritstone at this stage.

Mineralization

The mineral deposits worked from the Jugholes have been briefly described by Dunham (1952) and Ixer (1973). Dunham established that a fluorite replacement orebody was developed above the Matlock Lower Lava associated with the Noon Nick Vein. More detailed examination by Ixer (1973) identified the nickel sulphide, Bravoite, and found that it was widespread in the fluorite crystals. Neither recognised that the Jugholes system is a typical Derbyshire pipe vein, a flat-lying mineral deposit whose length greatly exceeds breadth and often contains caverns (Varvill 1937; Ford 1969). A study of the mineral deposits has been carried out in order to establish the stratigraphical and structural position of the orebody. The replacement deposit is developed above the Matlock Lower Lava partly exposed at the base of the oreshoot in the mine workings (fig 3) in coarse crinoidal biosparrudite limestones. The texture of the orebody consists of a series of closely spaced mineralized joints which intersect each other at right angles. The intervening spaces formerly occupied by limestone have been either completely replaced by colourless to purple fluorite or removed by concurrent solution during the mineralization process producing an open boxwork texture. Calcite, quartz, baryte, and galena are frequently associated with the fluorite mineralization.

A grey fine-grained laminated rock consisting entirely of fluorite is also common.. The laminae are produced by alternate light and dark grey coloration and are about 2 ins. apart. This type of texture is typical of many of the Derbyshire pipe veins and its origin is difficult to interpret. Two hypotheses are suggested:- (a) that the laminations result from a series of metasomatic replacement fronts, each layer representing a successive advance in replacement, or (b) that the layering is produced as a result of sedimentary processes, fluorite being eroded at some early stage from the main orebody and re-deposited as a laminated sedimentary deposit in nearby cavities. The first hypothesis seems to be the most plausible in this case as similar features are common in other pipe veins where the layering is clearly of a metasomatic origin. It is postulated that the lamina are developed by a series of advancing replacement fronts and frequently contain 'ghost' sedimentary features such as crinoid ossicles, stylolite seams, and brachiopod shells.

Cave Fauna

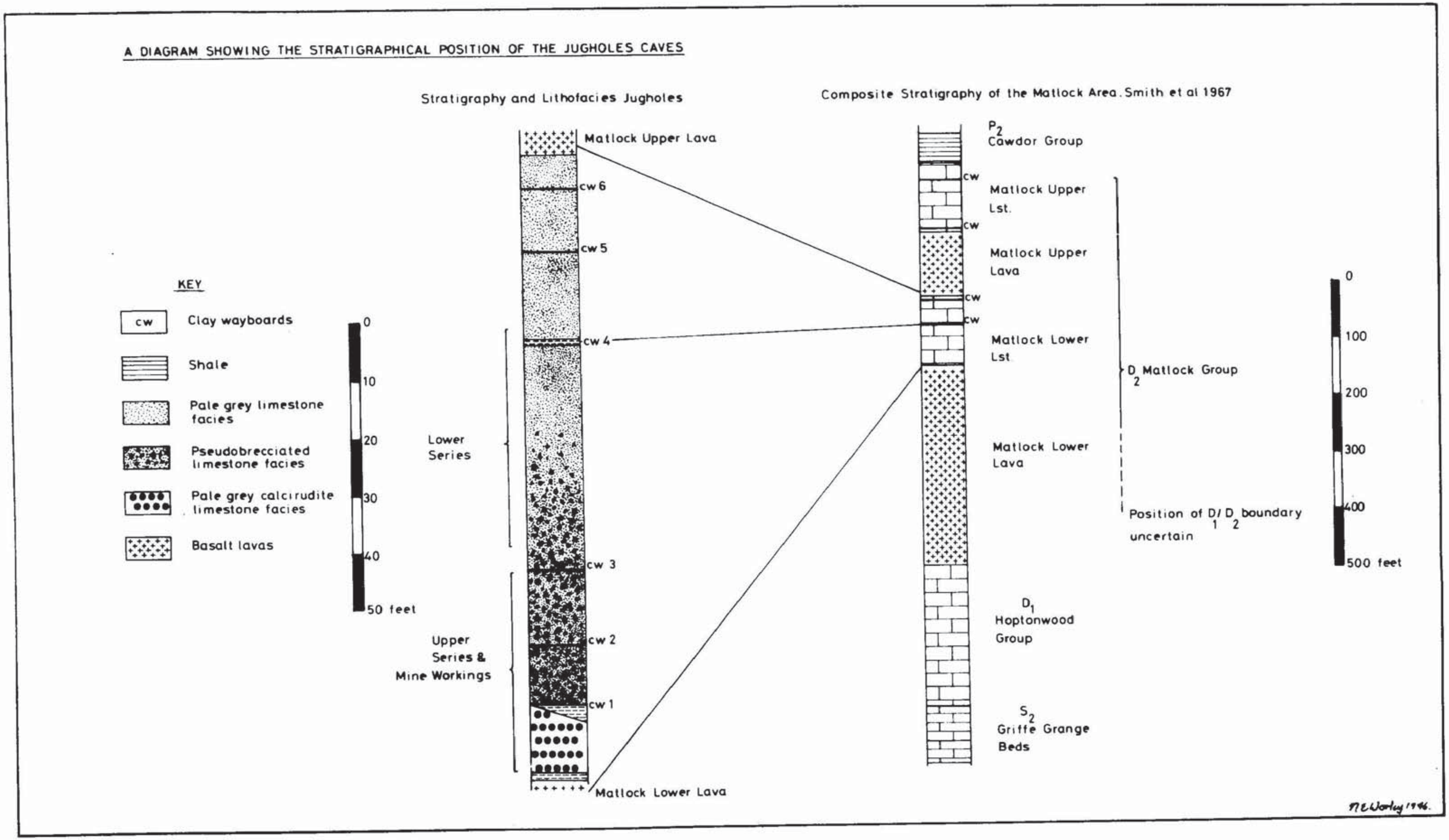
No description of the Jugholes caves would be complete without a mention of its famous bat colonies. Colonies numbering about six of the Whiskered Bat *Myotis mystacinus* are common in the Upper Series and mine workings usually found resting in small phreatic roof pockets. No bats have been seen in the Lower Series presumably as they are less readily penetrated.

Colonies of the Tissue Moth, *Triphosa dubitata* have been noted again in the Upper Series. *Scoliopteryx libratrix,* the Herald Moth, has been found in the entrance pitch to the Upper Series. A colony of Collembolans, *Onychiurus fimitarius,* was formerly abundant in the flowstone pools in the Upper Series but pollution by cavers and the drying up of the gentle trickle of water down the Beehive Slopes have meant the disappearance of this colony.

Conclusions

The analysis of the geology, geomorphology, and cave sediments allows a reconstruction of the evolution of the Jugholes Caves, which is summarised in fig 6. During the late Carboniferous to Permian

Fig. 5.


A DIAGRAM SHOWING THE STRATIGRAPHICAL POSITION OF THE JUGHOLES CAVES
Stratigraphy and Lithofacies Jugholes
Composite Stratigraphy of the Matlock Area. Smith et al 1967
KEY
cw
Clay wayboards
Shale
Pale grey limestone facies
Pseudobrecciated limestone facies
Pale grey calcirudite limestone facies
Basalt lavas
0
10
20
30
40
50 feet
Matlock Upper Lava
cw 6
cw 5
cw 4
cw 3
cw 2
cw 1
Matlock Lower Lava
Lower Series
Upper Series & Mine Workings
P2 Cawdor Group
cw
Matlock Upper Lst.
cw
Matlock Upper Lava
cw
cw
Matlock Lower Lst.
Matlock Lower Lava
D1 Hoptonwood Group
S2 Griffe Grange Beds
D2 Matlock Group
Position of D1/D2 boundary uncertain
0
100
200
300
400
500 feet
N.E.Worley 1996.

A DIAGRAM ILLUSTRATING THE EVOLUTION OF THE CAVES IN THE MATLOCK AREA

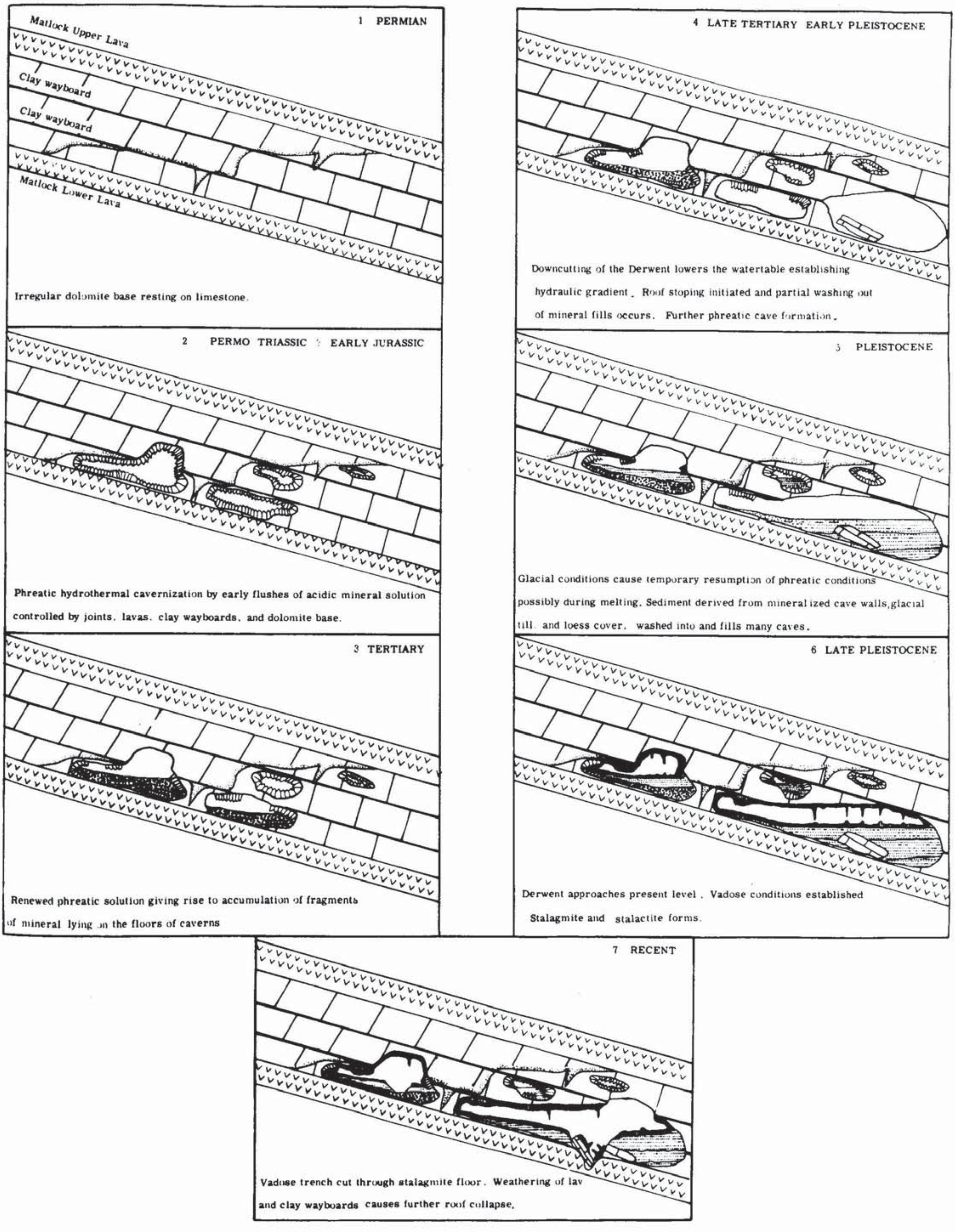


Fig. 6.

periods partial dolomitization of the limestones occurred. This was controlled by the distribution of joints and impervious horizons such as clay-wayboards and lavas. Mineralization occurred during Permo-Triassic times (Ineson and Mitchell 1972) and consisted of fluorite replacement of the limestone walls and partial filling of cavities produced by concurrent dissolution of the wallrocks in what can be described as phreatic hydrothermal cavernization. Fluorite replacement occurred between lavas and clay way-boards in coarse biosparrudite type limestones. The low mechanical strength of fluorite, its open texture, and presence of sulphide inclusions promoted partial mechanical erosion of the mineral deposits under phreatic conditions. Some cave sediments consisting of accumulated mineral fragments were deposited by this process during the Tertiary era.

Pleistocene downcutting of Matlock Dale established a hydraulic gradient with water sinking on the Masson – Blakelow area and rising in the Dale to the east. The water table was probably considerably higher then as the extensive phreatic caves following the strike in the Upper Series suggest that water, once it reached base level flowed west along the strike of the Matlock Lower Lava and may have resurged in Northern Dale half a mile to the west. Some roof stoping may have occurred at this time as the lavas and wayboards decomposed. Progressive downcutting by the Derwent lowered the base level still further and water was pirated to successively lower levels downdip suggesting that the Lower Series and now impenetrable Hut Shaft system (fig 3) were formed at a later period.

Melting of ice or permafrost during the Pleistocene would produce large volumes of water causing temporary rises in the level of the water table, particularly if resurgences were blocked by ice or sediment. Phreatic conditions would therefore be temporarily established in the caves. Sediments derived from erosion of the lavas, limestone, and mineral veins from the Masson – Blakelow Hill area and within the existing cave system were rapidly washed into and partially filled many of the caves. These cave sediments in many cases are natural concentrates or placer deposits containing high percentages of fluorite, baryte, and galena.

When the ice had melted and the water table reached its normal level, vadose conditions were re-established with small streams cutting small trenches through the sediment fills. Sometimes speleothems formed a floor covering the sediments. The development of flowstone was enhanced by the low pH of the water flowing over the pyrite-rich tuffaceous top of the Matlock Lower Lava increasing the amount of dissolved calcium carbonate in the water, only for it to be re-deposited on neutralization further down the system.

The geological history outlined above illustrates how karst processes in the Lower Carboniferous Limestones of Derbyshire have been taking place almost since deposition of the limestones began. Evidence concerning the history of these processes is contained in the Derbyshire pipe vein systems which represent old mineral veins that have acted throughout their history as water courses (Ford 1972). A continuing study of these is being made in order to unravel their complex geological history.

Acknowledgements

The authors acknowledge the permission from Messrs. Tarmac to work on the Jugholes Mines and to S. Hirstwood and J. P. Oakley of Operation Mole for valuable discussions and assistance in compiling the article. Noel Worley acknowledges the receipt of an N.E.R.C. research studentship.

References

Beck J.S. 1974 — The Caves of the Foolow – Eyam – Stoney Middleton area, Derbyshire and their genesis. *Trans. Brit. Cave Res. Assoc.* vol. 2 No. 1 pp 1 – 11.

Brindley F. 1945 — Laying the ghost of Jugholes Caves – a wartime pothole adventure. *Quarry Managers Journal* October.

Clay T. 1960 — Cave Research Group Biological Supp. Pt.V., 1950-1953.

Dunham, K.C. 1952 — *Fluorspar.* Geol. Survey G.B. Spec. Rep. Min. Res. vol. 4 143p.

Dunham, R.J. 1963 — *Classification of carbonate rocks according to depositional texture.* In Ham, W.E. (ed.). *Classification of carbonate rocks; a symposium.* Mem. Am. Ass. Petrol. Geol. No. 1 pp. 108-121.

Firman, R.J. & C. Bagshawe, 1975 — A re-appraisal of the controls of non-metallic gangue mineral distribution in Derbyshire. *Mercian Geol.* vol. 5, pp.145-162.

Folk, R.L., 1959 — A practical petrographic classification of limestone. *Bull. Am. Ass. Petrol. Geol.* 43, pp 1-38.

Folk, R.L., 1968 — *Petrology of Sedimentary Rocks.* Univ. of Texas, Austin, Texas. 170p.

Ford, T.D., 1964. — *The stratiform ore deposits of Derbyshire.* In *Sedimentary Ores Ancient and Modern, revised* ed. C.H. James, Proc. 15th Inter-Univ. Geol. Cong. Leicester (1967) pp. 73-96

Ford, T.D. 1972 — Evidence of Early Stages in the Evolution of the Derbyshire Karst. *Trans. Brit. Cave Res. Assoc.* vol. 14 no 2 pp 73-77

Ineson P.R. & J.G. Mitchell 1972 — Isotopic age determinations on clay minerals from lavas and tuffs of the Derbyshire orefield. *Geol. Mag.* vol. 109 pp. 501-512

Ireland H.A., 1950 — *Insoluble residues.* In Leroy L.W. (ed.). *Subsurface Geologic Methods.* 2nd edition, Colorado School of Mines, Golden, Colorado. pp 140-156.

Ixer R.A. 1972 — *Controls of Mineralisation in Derbyshire.* PhD thesis Univ. Manchester. 117p.

Mackay R.A. 1952 — *Contrasts in rock permeability as a major cause in ore deposition.* Rep. 18th Internat. Geol. Congr. London, pt 13 pp 165-171.

Nash D.A. 1956 — "Jug Holes and the Nature of the Matlock Mines" *Trans. Cave Res. Grp. G.B.* Vol. 5. No. 1. pp.13-22

Price N.J. 1966 — *Fault and joint development in brittle and semi-brittle rock,* Pergamon, Oxford. 176p.

Ramsbottom W.H.C. 1973 — Transgressions and regressions in the Dinantian a new synthesis of British Dinantian stratigraphy. *Proc. Yorks. Geol. Soc.* vol 39, pp 567-607.

Shirley J. 1958 — The Carboniferous Limestone of the area between Monyash and Wirksworth, Derbyshire. *Quart. J. Geol. Soc. London.* vol. 114, pp 411-425.

Smith, E.G., G.H. Rhys, & R.A. Eden, 1967 — *Geology of the Country around Chesterfield, Matlock, and Mansfield.* Mem. Geol. Surv. G.B. 430p.

Varvill W.W. 1937 — A study of the shapes and distribution of the lead deposits in the Pennine limestone in relation to economic mining. *Trans. Instn. Min. Metall.* vol. 46, pp 463-539.

March 1977

N.E. Worley
Geology Dept.
University of Leicester
Leicester LE1 7RH

D.A. Nash
Glebe Cottage
Eyam
near Sheffield.

Trans. British Cave Research Assoc. Vol. 4, No. 3, pp 403-416 August 1977

THE STRATIGRAPHY AND STRUCTURE OF THE OGOF FFYNNON DDU AREA

R.A.P. Charity & N.S.J. Christopher

Summary

Stratigraphic mapping of the limestones above and around the Ogof Ffynnon Ddu cave system have shown that the passages are almost all developed in the Dowlais Limestone of Holkerian (Carboniferous) age (Dinantian S_2), and that individual horizons therein can be recognized both on the surface and in the cave. The mapping has revealed a series of previously undetected north-south folds plunging southwards, and the density and abundance of cave passages can be related to these. Compositional studies of the limestones have shown the presence of a highly variable dolomite content which is reflected in differential solubility, and shown by projecting or undercut beds in the Main Stream Passage.

The area discussed lies on the North Crop of the Carboniferous Limestone associated with the South Wales Coalfield and encompasses an area of 8 km^2 as shown in figure 1.

The work outlined here was commenced to expand the interest of one of the authors in the influence of differential solubility on cave development as outlined in a previous article (Christopher, 1967). Geological interests of the co-author, however, developed the project into a stratigraphic and structural survey of the limestone outcrop around Ogof Ffynnon Ddu. The work is largely independent of other published work. The main themes covered are stratigraphy, structure, geochemistry, acid solution and their implications within Ogof Ffynnon Ddu. The experimental methods utilized together with definition of the petrographic terminology are given in the appendices.

Stratigraphy

The Lower Limestone Shales (the Courceyan Stage of George et. al 1976) formerly the K zone appear to rest conformably on the Grey Grits of the Devonian Old Red Sandstone (George, 1927). Some 30 metres thick at maximum, the beds are fully represented in a river bed exposure at Cwm Byfre and fully described in the Geological Survey Memoir (Strahan, 1932).

Lying unconformably above the Courceyan Stage are beds of the Holkerian (S_2) Stage now known as the Dowlais Limestone (George et. al 1976) reaching a total thickness of 85 – 90 metres in the vicinity of Penwyllt. The strata of this stage are of prime importance, as the major proportion of Ogof Ffynnon Ddu is developed therein. Over 450 thin-sections have been prepared and the conclusions drawn from their examination, combined with geochemical analysis and field observations on the lithology and palaeontology have been used, (though only briefly in this preliminary paper), in producing the succession of beds as detailed below.

The basal beds of 6.1 metres thickness are arenaceous intrasparარenites with biotic and pellagic secondary clasts, capped by a coral biostrome which yields *Lithostrotion martini.* All beds are of medium to thick-bedded character and in places show secondary micritization and stylolitic development. The coral bed is a dolomitic limestone in which many of the skeletal elements of the corals have been effected by secondary dolomitization. Similar bedded cointrasparararenites follow to a thickness of 4.8 metres. The major part of this sequence together with Upper Courceyan stage beds are to be seen in Windy Knoll Quarry (SN 8715 1673). Beds of the lowest sequence are also to be seen at Pwll Byfre, adjacent to the present sink (8744 1666). The *L. martini* coral bed is again met in a high level but small exposure, west of Windy Knoll (8693 1664).

Above the oolites, 5.2 metres of medium to thick bedded intrabiosparararenites with a prominent dolomitized shell bed yielding *Composita ficoides* are found; these also show a moderate stylolitic development. The succeeding beds, originally of similar clastic composition, are extensively dolomitized leaving a ghost fabric. Some of the dolomites are of a cryptocrystalline nature with clasts only evident at lithographic boundaries and these may be of primary origin. Geochemical consideration of the other dolomitized beds shows them to be of secondary (probably hydrothermal) origin. Being thin to thick bedded and 5.2 metres in total thickness, they display all forms of dolomitization from magnesian limestone to pure dolomite and include mottled dolomites similar to those recognised from the South Crop of the South Wales Coalfield (Hatch et. al. 1971). The dolomites are interleaved by occasional high calcium limestones (basally), and centrally by a calcite mudstone which becomes conglomeratic to the south; the bed being of importance stratigraphically. These beds are followed by 15.1 metres of medium to very thick bedded intrabiosparararenite. Some 6 metres from the base, a bed yields numerous specimens of *Syringopora.* Dolomitic beds of some 50 cm thickness lie 2 metres above this coral bed. Only in the uppermost beds of the sequence are stylolites seen once more. Commencing at the *L. martini* coral bed, the described sequence can be seen in Quarry 'B' (8667 1645). Westward, the beds in the exposure for the tramway just below and west of Weighbridge Quarry (8638 1622) correlate with the intrabiosparararenites some 8 metres below the top of Quarry 'B'. In Twyn-y-Ffordd Quarry, (8525 1600) the major part of the described sequence from the base of the Dowlais Limestone to beds some 2 - 3 metres above the dolomitic beds can be seen.

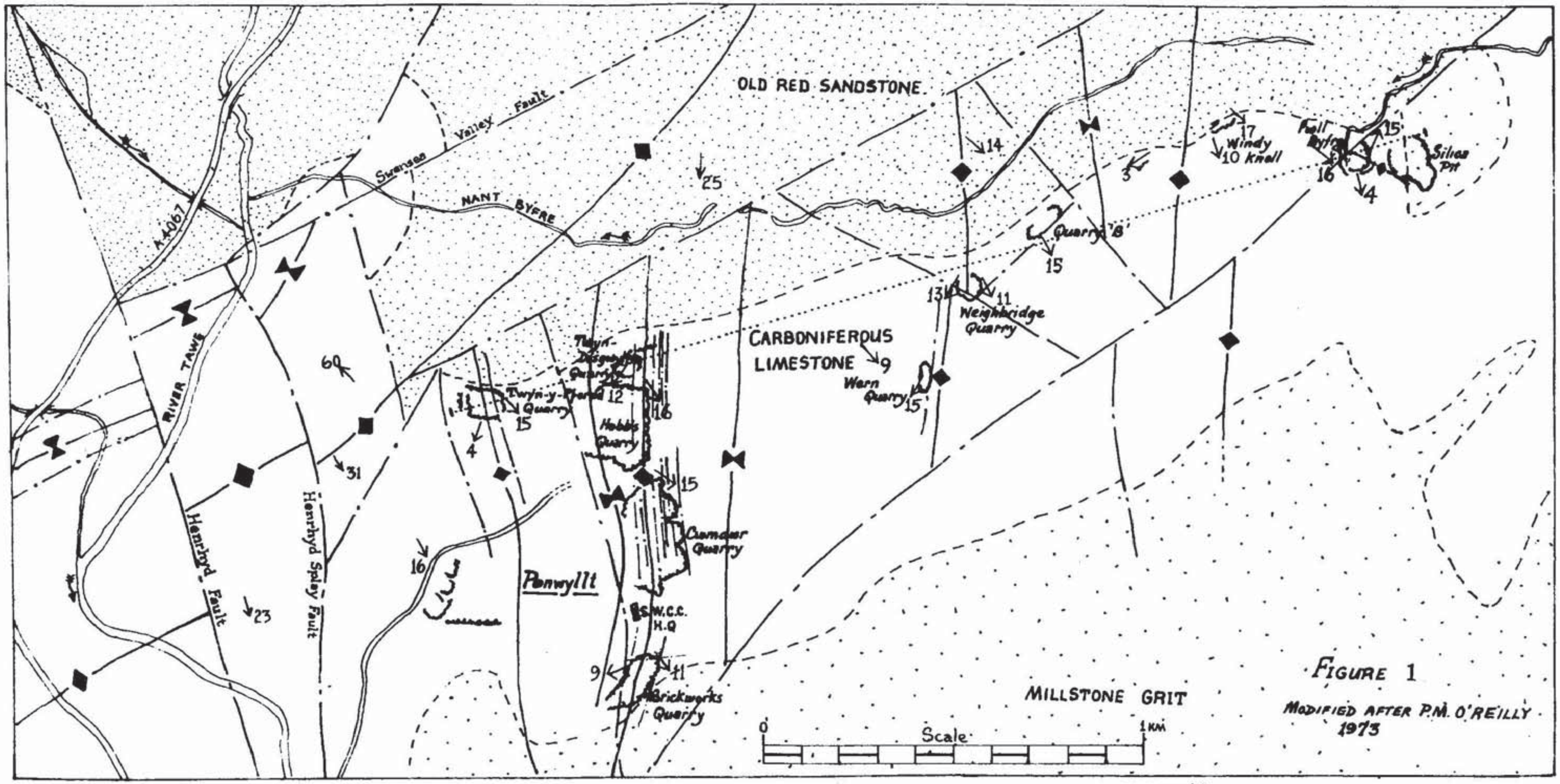
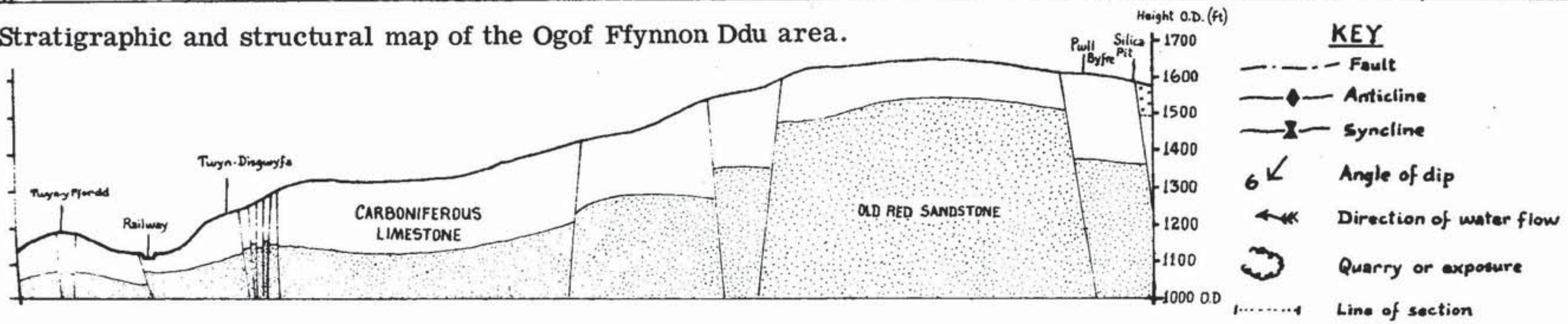


Fig. 1. Stratigraphic and structural map of the Ogof Ffynnon Ddu area.



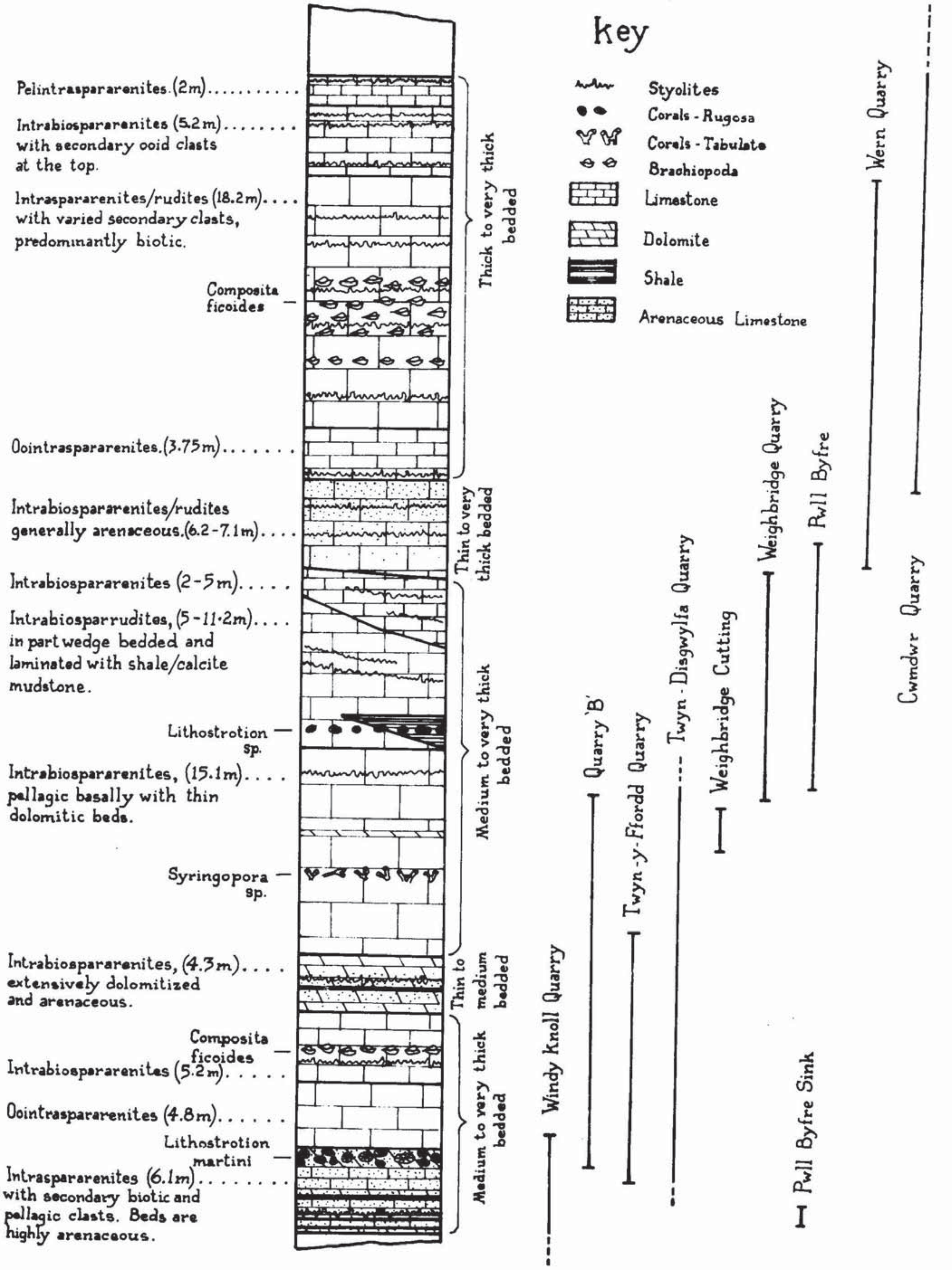


Fig. 2. Composite lithological section of the Dowlai s Limestone (Holkerian stage) Carboniferous Limestone - S_2).

Some 2.2 metres of medium-bedded intrabiosparärenites are interbedded with a series of thin bedded calcite mudstones/shales, in the next part of the sequence. These beds are wedge-bedded basally with 11.2 metres of medium to thick bedded intrabiosparrudites; both sets of beds, close to the base, yield many *Lithostrotion* spp. A further 5 metres of wedge-bedded, medium to very thick-bedded intrabiosparärenites lie above. Most of the beds in the sequence so far described are to be seen in Twyn-Disgwylfa Old Quarry (8560 1605).

The beds just described are overlain by yet further wedge-bedded, thin to very thick-bedded intrabiospararenites and sparrudites to a total thickness of 6.8 – 7.1 metres. The beds described above the intrabiospararenites of Quarry 'B' can be seen in Weighbridge Quarry (8643 1625) and also in the main exposure of Pwll Byfre (8750 1657). These beds, excepting basally, are extensively stylolitic and in upper beds also show secondary micritization.

Above the last described beds are 3.8 metres of thick to very thick-bedded ooïntraspararenites followed by 18.2 metres of thin to very thick-bedded, interbedded intrabiospararenties and sparrudites with varying secondary clasts. A major portion of these beds are of a bioclastic nature; several shell-rich beds following each other and basally yielding Productid shells followed by a profusion of *C. ficoides.* These beds are extremely stylolitic. Wern Quarry (8636 1603) exposes all beds described down to and including the 6.8 – 7.1 metre interbedded intrabiospararenties/rudites. Hobb's Quarry, (8555 1595) probably covers the same sequence as well as lower beds matching in with the upper beds of Twyn-Disgwylfa Old Quarry.

The upper beds of the Holkerian Stage comprise 5.2 metres of thick to very thick-bedded intrabiospararenites with secondary ooid clasts at the top, followed by 2 metres of thick to very thick-bedded pelintraspararenites. These beds together with the 18.2 metres of intrabiospararenites/rudites are seen in Cwmdwr Quarry (8570 1560). At Top Entrance (8637 1590) the uppermost beds may be seen overlain unconformably (George 1927) by the Honeycomb Sandstone of the Asbian Stage (D_1) whilst at old quarry workings (8515 1555), the uppermost beds merge almost undetected except for colour change into the Penderyn Oolite of the Asbian Stage (George 1927; George et al 1976).

Many beds, particularly those of the upper half of the sequence, show signs of compaction, stylolitic development and grain diminution (micritization). Petrographic studies of these beds show a close relationship existing between all three features.

The stratigraphic sequence of the Holkerian Stage as determined by our present studies is shown in figure 2. the Courceyan, Asbian and Brigantian stage beds being omitted at this stage.

We have mentioned the variations in transition to the Asbian Stage which George (1927) considers to represent an unconformity, probably with overstep. The Asbian beds total some 10 metres in this district and where the Honeycomb Sandstone is absent, comprise beds entirely of the Penderyn Oolite (George 1927), the Greenhall Limestone (George et. al 1976) not being differentiated.

Above, beds of darker colour mark transition into the Brigantian Stage some 35 metres thick. Except for colour, the basal beds are hardly distinguishable from the Penderyn Oolite of the Asbian Stage, although a distinct band of shale and sandstone in the Penwyllt areas is thought to mark the boundary. Next, crinoidal limestone, somewhat arenaceous, contains many silicified beds and varied corals and brachiopods. The upper beds are once more oolitic and crinoidal with lamellibranchs and abundant chert. The greater part of these beds can be seen in Brickworks Quarry (8560 1535) and the whole of the Brigantian together with the Asbian and boundary with the Holkerian Stage are seen in exposures southwards along the road from the quarries at 8515 1555.

The highest Lower Carboniferous beds of the area comprise a poorly represented 2 - 3 metres of Upper Limestone Shales (Upper Brigantian [D_{2}-$_{3}$], consisting of shales with impure limestones, generally converted to rottenstone. The exposed rottenstone beds are overlain unconformably by massive quartzites with thin shale partings of the Millstone Grit (Homoceras zone of the Namurian stage).

Geochemistry

The samples collected from the various sites mentioned in the stratigraphy section are being analysed geochemically (Appendix 'A'), as part of the overall project. To date, 77 beds have been analysed and the data so derived is given in table 1, together with comparable results obtained by other workers. The present data involves beds in the lower 24 metres of the Holkerian Stage commencing at the *Lithostrotion martini* coral bed.

The composition of these limestones shows them to be dolomitic, a mean analysis of 4.03% magnesium oxide being obtained. This, however, is a composite figure derived from both surface and cave exposures of the same beds and, as a result, certain features noted over single exposures are lost, e.g. the increase in silica, aluminium, iron and manganese on a proportionate basis with magnesium oxide content or dolomitization as seen in table 2. Using these figures, calculations made on a proportionate basis indicate that de-calcification of high calcium limestone cannot account for these increases and therefore, some addition, possibly via hydrothermal solutions may have occurred. This may in part explain the secondary dolomitization in the area. Atomic absorption and X-ray diffraction analysis of beds have detected arsenic up to a concentration of 1.2% and the sulpho-arsenide, arsenopyrite, appears to be present in several beds, supporting the concept of hydrothermal origin of the dolomites. A link may therefore be forthcoming between the dolomitization in this area and the copper deposits mentioned by George (1927. p.51) lying further west on the North Crop near Horeb Chapel.

A further point worth noting from table 2 which contradicts Steidtmann's (1917) opinion regarding lack of increase in porosity with dolomitization is the clear trend of increased moisture, water of crystallization

TABLE I

Constituent Oxide	H.C.L. n = 46	M.L. n = 6	D.L. n = 15	C.D. n = 8	Dl. n = 2	A n = 77	B n = 31	C	D	E n = 345
SiO_2	0.80	1.97	1.68	1.25	1.28	0.91	1.64	1.14	0.40	5.19
Al_2O_3	0.21	0.65	0.32	0.31	0.69	0.33	0.40	0.41	0.40	0.81
Fe_2O_3	0.08	0.27	0.22	1.20	0.97	0.28	0.53		0.52	0.54[b]
MnO	0.02	0.02	0.02	0.36	0.04	0.05	0.11	-	-	0.05
MgO	0.64	1.40	6.03	16.07	19.97	4.03	8.82	0.26	0.60	7.90
CaO	54.72	53.09	47.69	34.51	31.68	50.23	44.30	54.84	54.70	42.61
Na_2O	-	-	-	-	-	-	-	-	-	0.05
K_2O	0.04	0.09	0.06	0.05	0.08	0.05	0.06	-	-	0.33
H_2O ±	0.54[a]	0.99[a]	0.85[a]	4.10[a]	1.19[a]	1.05[a]	1.74[a]	-	-	0.77[a]
P_2O_5	0.01	0.02	0.01	0.02	0.01	0.01	0.01	-	-	0.04
CO_2	42.22	41.39	42.25	41.02	44.12	42.04	41.88	43.26	41.70	41.58
SO_3	0.14	0.28	0.23	0.14	0.16	0.18	0.21	0.09	0.05	0.05
Cl	-	-	-	-	-	-	-	-	-	0.02
S	-	-	-	-	-	-	-	-	-	0.09
Li_2O	-	-	-	-	-	-	-	-	-	trace
Total %	99.42	100.17	99.36	99.03	100.19	99.16	99.70	100.00	98.37	100.09

KEY: n = number of samples, a = including organic matter, b = includes FeO
H.C.L. = High calcium limestone, M.L. = magnesian limestone, D.L. = Dolomitic limestone,
C.D. = Calcitic dolomite and Dl. = Dolomite.
Column 'A' - Carboniferous limestones, Penwyllt. 'B' - Magnesian rich limestones, Penwyllt.
'C' - Carboniferous limestone, North Wales. 'D' - Salem limestone, Indiana (oolitic calcarenite)
Columns C & D from Hatch et. al. 1971. 'E' - H.N. Stokes, Analyst (Clarke, 1924).

TABLE II

Constituent Oxide	High Calcium Limestone (%)	Magnesian Limestone (%)	Dolomitic Limestone (%)	Calcitic Dolomite (%)	Dolomite (%)
CaO	54.91	54.97	48.56	31.40	32.10
MgO	0.63	1.41	5.23	19.22	19.88
SiO_2	0.67	0.79	1.51	1.02	2.14
Al_2O_3	0.15	0.17	0.26	0.61	0.76
Fe_2O_3	0.07	0.13	0.21	0.39	0.57
MnO	0.02	0.02	0.03	0.03	0.02
H_2O ±	0.39	0.53	0.74	1.32	1.36

and organic matter with MgO content suggesting increased porosity — a finding that will obviously require further study but, even now, lends support to the views of Hall (1895 p.198) and Landes (1946).

Structure

The geological structure of the district around Penwyllt has been discussed in some detail by Weaver (1971 & 1975) and O'Reilly (1973). Our own observations in the field extend this work in an area southward and eastward of 8520 1675 but they have at present been confined to the limestone outcrop.

In figure 1, O'Reilly's structural map (1973 fig 2). has been amended to show the additional features from our survey. This basically comprises the addition of a series of asymmetric, north-south trending, southerly plunging anticlines that appear to have been overlooked by previous workers — probably in the light of the dominance of the Cribarth anticline on the large scale structure.

Commencing at the eastern side of the outcrop, a fault deduced at Pwll Byfre shows a downthrow of the order of 35 metres in beds east of the present swallet. This is partly substantiated by fracturing evident in the exposure and agrees with the findings of previous workers (Weaver, 1975). In addition, dip readings give indication of a minor anticline whose axis lies in a WNW — ENE direction. Westward, Windy Knoll Quarry shows similar anticlinal features, less apparent and having an axis trending ENE — WSW. This however, may be land slipping. Again, the exposure exhibits strike-slip and bedding slip features, both of which are associated with stress relief in folding. Dip readings taken here and westward at 8693 1664 indicate yet a further minor anticline of asymmetric form plunging southwards between these two points and having an axis trending in a general north-south direction. Mapping also shows faulting between the last locality and Quarry 'B' to the west, again agreeing with previous findings. The location of this fault is open to conjecture owing to lack of surface exposure. However, the downthrow of 30 metres deduced from the petrology is similar to the 25m recorded by Weaver (1975). The dip of beds in Quarry 'B' proves basically uniform but the site is broken in the main face by a fault of minor downthrow northward bearing N42°E.

In Weighbridge Quarry, a distinct asymmetric anticline trending south can be seen in the rear face, confirmed by dip readings. Faulting in the western face trends NNE — SSW with downthrow westwards. Passing SSW, into Wern Quarry, dip readings indicate the site to be lying on the western dip slope of the asymmetric anticline mentioned in connection with Weighbridge Quarry. The eastern face exhibits faulting trending slightly west of south in the upper portion but due to slickensiding and travertine deposits from local small scale cave development, downthrow cannot be ascertained. At the base of the eastern face, ripple bedding indicates a current direction S63°E and suggesting the proximity of a landmass or a shoal at the time of deposition.

Due west of this site, Twyn-Disgwylfa Old Quarry shows complex normal step faulting with downthrow generally westward. Within this quarry area, however, reverse, strike slip and bedding slip faulting are also found. South of this exposure, Hobb's Quarry (the only working quarry of the district) reveals the same form of faulting with added visual evidence of synclinal (westward) and asymmetric anticlinal (eastward) features as seen in Plate 1. Yet further southward, Cwmdwr Quarry displays the same series of faults (see Plate 2 and figure 3). Dip readings in this site also confirm the existence of an asymmetric anticlinal structure. Ripple bedding is to be found in the ledges above Cwmdwr Entrance, Ogof Ffynnon Ddu, and this shows a current direction of S87° E not much different from that found in Wern Quarry. Still further southward, Brickworks Quarry provides dip readings over an anticlinal structure with normal faulting downthrown westwards together with strike-slip faulting passing transverse to the long axis of the anticline. These last four quarries all appear to lie along the long axis of a single undulating but generally southward plunging asymmetric anticline trending almost due south. They also appear to lie on the western flank of that structure.

Westward and centrally between Twyn-Disgwylfa Old Quarry and Hobb's Quarry, by the railway cutting, faulting, locally dolomitized, is seen to trend slightly east of south towards the South Wales Caving Club headquarters. This is also visible in aerial photographs to a point some short distance north thereof. Beyond, to the west of the railway cutting, Twyn-y-Ffordd Quarry gives dip readings indicating a further asymmetric anticline crossing this site trending southerly. A fault also passes through the quarry trending NNW — SSE.

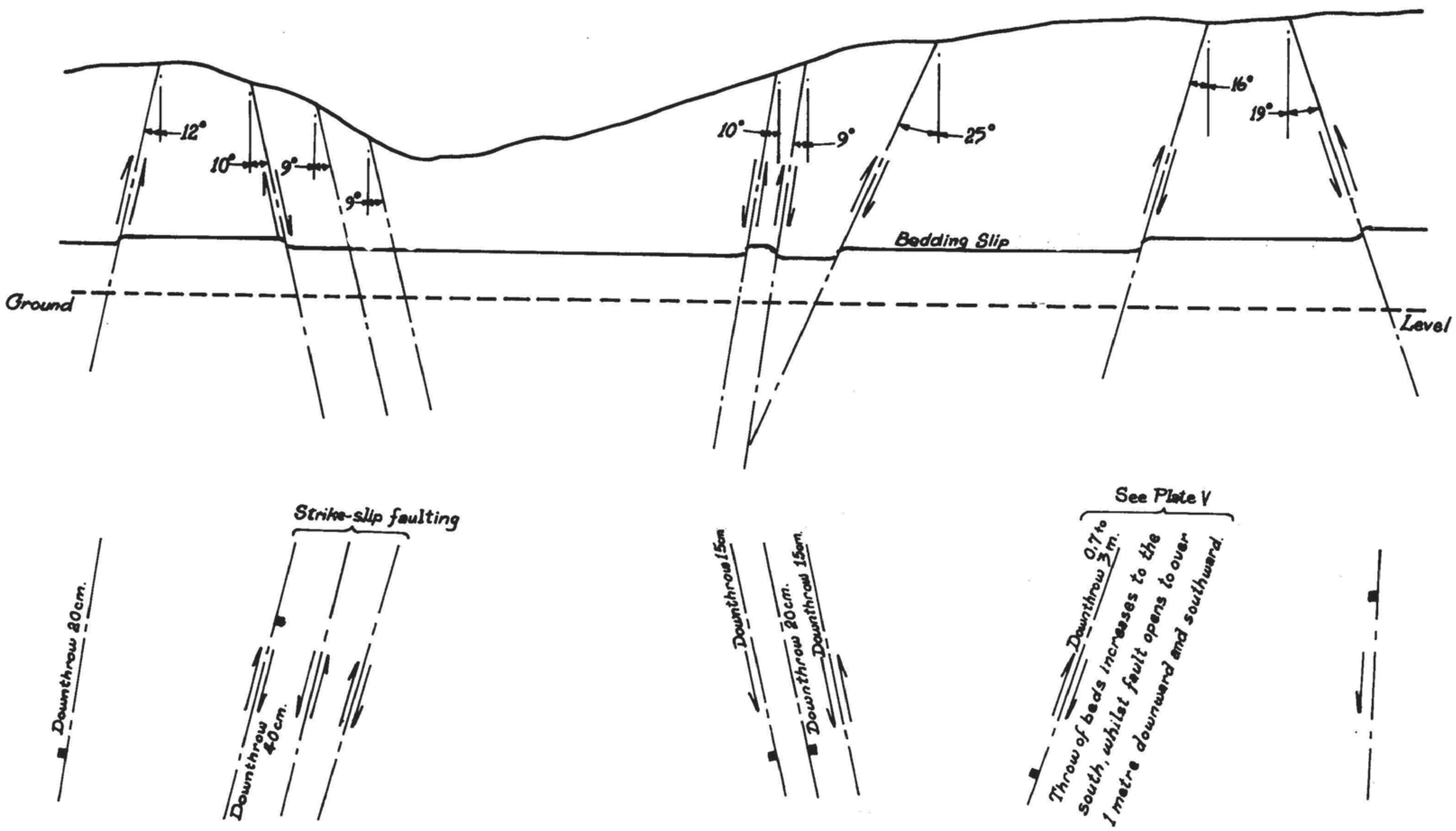
In figure 1, a section is given cutting WSW-ENE through or close to the majority of exposures described. This clearly shows the dominance of normal faulting over reverse faulting. The upthrown horst wedge of the eastern portion, east of Quarry 'B' and up to Pwll Byfre can be clearly seen. The movement, particularly around the latter locality may well warrant further consideration as to the Namurian outlier, eastward, and its existence through faulting as against being a deep seated limestone collapse feature.

The area we have so far surveyed presents a picture of a wave train of minor asymmetric anticlines and synclines or alternatively, repetitive monoclinal structures; in either case, they have a distinct north-south trend and southward plunge. These are quite probably related to one or more similar structures having a WSW-ENE to E-W trend associated with the Cribarth Anticline. The faulting can also be correlated with this structure, with trends comparable with the longitudinal, transverse and shear faults of such a fold.

Acidic Attack on Limestones

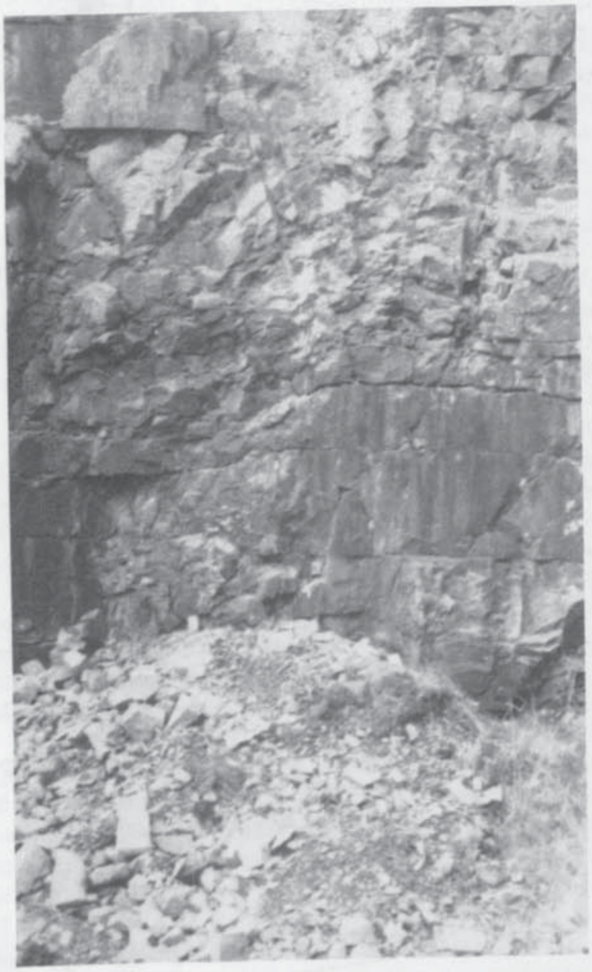
Inside Ogof Ffynnon Ddu, like many other caves, one comes across features of differential corrosion typically represented in Plate 3. Here, the dolomite beds of Quarry 'B', Twyn-y-Fford etc., are met in the Nant Newydd Mainstream Passage below Maypole Inlet, Ogof Ffynnon Ddu II. Our research in connection with such features is to ascertain the lithological factors con-

FIGURE 3: Generalized section and fault plan of the north face, Cwmdwr Quarry.



1. Part of the north face of Hobb's Quarry showing the anticlinal crest and some of the minor faults.

3. The Nant Newydd Mainstream Passage below Maypole inlet showing undercutting beneath dolomitic limestones.



2. Detail of a fault in Cwmdyr Quarry showing crushing, shearing and bedding plane slip. Downthrow to the left is 70 cm.

tributing to differential corrosion. Our work here is in its infancy, comprising simple gravimetric analysis of rock samples from the Mainstream Passage subjected to immersion for a specific period of time in 1 molar hydrochloric acid. The figure obtained for each rock measured in mg/cm^3/ minute weight loss is equated with the MgO content of the sample with the results shown in the graph (figure 4). This indicates an inverse relationship between magnesium oxide content and corrosion rate in rocks classified as dolomitic limestone, calcitic dolomite and dolomite. For high calcium limestone and magnesian limestones however, this relationship breaks down. Limestones falling in these categories would appear to be controlled in their corrosion rate by some other factor still to be located, perhaps grain size, sorting or permeability.

Implications of Structure, Stratigraphy and Geochemistry within Ogof Ffynnon Ddu

Within the confines of the Penwyllt area, Britain's largest cave system with over 40 kilometres of passageway is situated. Many workers have contributed to a knowledge of this cave system – Glennie (1948, 1950), Railton (1953) and O'Reilly (1969, 1973) to name but a few. For the present, our own contribution lies in visual observations within the cave which may be related to the surface geology.

The first and most striking observation is that Top Entrance, Cwmdwr and Ogof Ffynnon Ddu I are all developed within a restricted range of beds forming the uppermost part of the Dowlais Limestone (Holkerian) of the area together with the lower Asbian beds. This has already been mentioned in detail with regard to Ogof Ffynnon Ddu I by Glennie (1948, 1950) and briefly mentioned by Ball (1970) and is clear to the present workers in the light of their field observations.

Within Top Entrance Series, stratigraphic control is exerted by one particular bed which is seen first in the western entrance to Big Chamber near to Top Entrance, extends throughout the whole roof of that locality and down at least to Gnome Pasage near to or at roof level. The bed concerned is the upper *Composita ficoides* shell bed close to the top of the Holkerian sequence. This could also be the shell bed observed by Glennie (1950, p13) close to Ogof Ffynnon Ddu I entrance. In spite of much of the cave developing within a confined sequence of beds, the dolomite beds found in Nant Newydd Mainstream Passage (Ogof Ffynnon Ddu II) lie close to the base of the Dowlais Limestones; the cave therefore ranges through almost all of the available beds.

Below the uppermost passages there is a series of high and moderately narrow passages, e.g. Salubrious Passage and Northern Canyon, which lead into rounded low profile passages such as Selenite Tunnel and Midnight Passage. These latter passages are possibly developed in the oolitic beds some 26 metres down the Holkerian sequence. Whilst the underlying high narrow passages e.g., Maypole Inlet, Swamp Creek and Mainstream Passage are developed in the succeeding thick sequence of intraclastic limestones below the oolite. The relatively smooth corroded surfaces indicate a uniform chemical composition, most probably high calcium limestone, where passage development has proceeded at a relatively rapid rate. This rapid and uniform corrosion is abruptly stopped close to the present base of the cave by the lower dolomitic beds which are well displayed in Second Oxbow, below Maypole Inlet and in Ogof Ffynnon Ddu III close to Smith's Armoury; the dolomite beds represent the base over a considerable proportion of the Ogof Ffynnon Ddu II and III sections. In regions where the dolomite beds are well exposed, their different geochemical character and resistance to corrosion has resulted in local modification of passage shape. The normal high, narrow streamway changes to a modest sized bell-shaped passage., where the inter-relationship of passage shape to geochemistry and petrology is well illustrated (Plate 3); the details of the accompanying fig.5 are taken from Nant Newydd Mainstream Passage below Maypole Inlet, some 50 metres upstream from the area shown in Plate 3. In this area, one can also clearly see the mechanism by which the dolomites are selectively corroded by the stream breaking through to lower beds; these being of higher solubility, are then severely undercut, leaving sharp edged dolomitic ledges above. Taking another area in the upper reaches of Ogof Ffynnon Ddu III, a short bedding plane crawl just below Smith's Armoury is known as the Dolomite Beds. The name is probably derived from studies made by Christopher (1967) which, whilst not mentioning any specific rock type, gave strong indication that they may be of a dolomitic nature. In figure 7, a map of this section of the cave and cross section of the Dolomite Beds is presented. As can be seen from the section, the crawl appears to have been initiated at the interface of a basal dolomitic bed (19) and an upper high calcium limestone bed (18); the latter bed was corroded under phreatic conditions and this was probably stopped by resistance of the upper dolomite bed (17). This upper dolomite cannot be seen in the crawl but is seen beyond the western end as the dip of the strata permits. In view of the depth of the high calcium limestone bed (18), however, it is probable that the upper dolomite is in close proximity to the upper face of the crawl. In contrast, the base of the crawl is partially cut through centrally by the stream, by a vadose mechanism, passing through a total of three dolomitic beds before depth and severe undercutting into lower beds make sampling impossible and so the composition of the lower beds is unknown. It is clear however, that the lower unsampled bed is of higher solubility and chemically it is probably a further high calcium limestone. The individual geochemical composition of each bed in Dolomite Crawl is given in table 3 together with associated corrosion rates.

tributing to differential corrosion. Our work here is in its infancy, comprising simple gravimetric analysis of rock samples from the Mainstream Passage subjected to immersion for a specific period of time in 1 molar hydrochloric acid. The figure obtained for each rock measured in mg/cm^3/minute weight loss is equated with the MgO content of the sample with the results shown in the graph (figure 4). This indicates an inverse relationship between magnesium oxide content and corrosion rate in rocks classified as dolomitic limestone, calcitic dolomite and dolomite. For high calcium limestone and magnesian limestones however, this relationship breaks down. Limestones falling in these categories would appear to be controlled in their corrosion rate by some other factor still to be located, perhaps grain size, sorting or permeability.

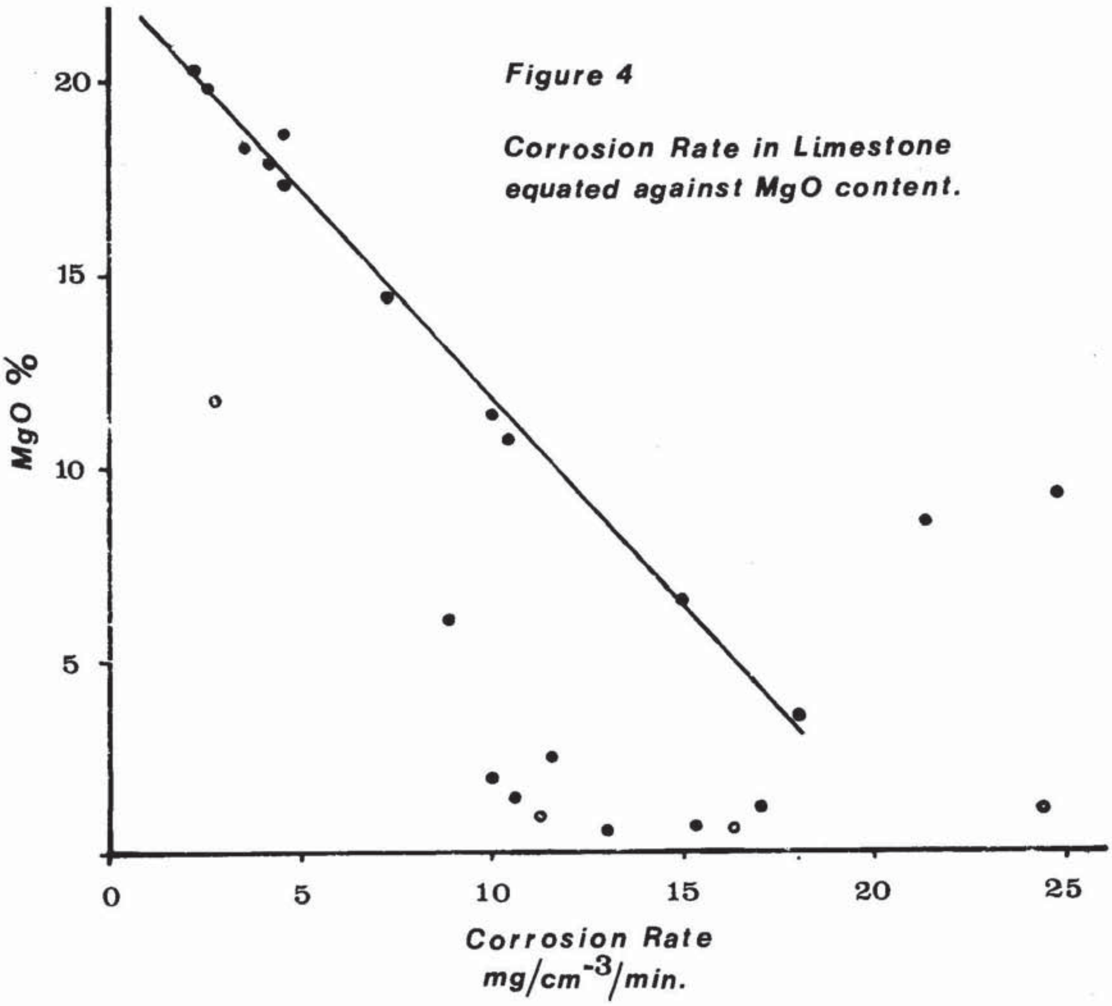
Implications of Structure, Stratigraphy and Geochemistry within Ogof Ffynnon Ddu

Within the confines of the Penwyllt area, Britain's largest cave system with over 40 kilometres of passageway is situated. Many workers have contributed to a knowledge of this cave system — Glennie (1948, 1950), Railton (1953) and O'Reilly (1969, 1973) to name but a few. For the present, our own contribution lies in visual observations within the cave which may be related to the surface geology.

The first and most striking observation is that Top Entrance, Cwmdwr and Ogof Ffynnon Ddu I are all developed within a restricted range of beds forming the uppermost part of the Dowlais Limestone (Holkerian) of the area together with the lower Asbian beds. This has already been mentioned in detail with regard to Ogof Ffynnon Ddu I by Glennie (1948, 1950) and briefly mentioned by Ball (1970) and is clear to the present workers in the light of their field observations.

Within Top Entrance Series, stratigraphic control is exerted by one particular bed which is seen first in the western entrance to Big Chamber near to Top Entrance, extends throughout the whole roof of that locality and down at least to Gnome Pasage near to or at roof level. The bed concerned is the upper *Composita ficoides* shell bed close to the top of the Holkerian sequence. This could also be the shell bed observed by Glennie (1950, p13) close to Ogof Ffynnon Ddu I entrance. In spite of much of the cave developing within a confined sequence of beds, the dolomite beds found in Nant Newydd Mainstream Passage (Ogof Ffynnon Ddu II) lie close to the base of the Dowlais Limestones; the cave therefore ranges through almost all of the available beds.

Below the uppermost passages there is a series of high and moderately narrow passages, e.g. Salubrious Passage and Northern Canyon, which lead into rounded low profile passages such as Selenite Tunnel and Midnight Passage. These latter passages are possibly developed in the oolitic beds some 26 metres down the Holkerian sequence. Whilst the underlying high narrow passages e.g., Maypole Inlet, Swamp Creek and Mainstream Passage are developed in the succeeding thick sequence of intraclastic limestones below the oolite. The relatively smooth corroded surfaces indicate a uniform chemical composition, most probably high calcium limestone, where passage development has proceeded at a relatively rapid rate. This rapid and uniform corrosion is abruptly stopped close to the present base of the cave by the lower dolomitic beds which are well displayed in Second Oxbow, below Maypole Inlet and in Ogof Ffynnon Ddu III close to Smith's Armoury; the dolomite beds represent the base over a considerable proportion of the Ogof Ffynnon Ddu II and III sections. In regions where the dolomite beds are well exposed, their different geochemical character and resistance to corrosion has resulted in local modification of passage shape. The normal high, narrow streamway changes to a modest sized bell-shaped passage., where the inter-relationship of passage shape to geochemistry and petrology is well illustrated (Plate 3); the details of the accompanying fig.5 are taken from Nant Newydd Mainstream Passage below Maypole Inlet, some 50 metres upstream from the area shown in Plate 3. In this area, one can also clearly see the mechanism by which the dolomites are selectively corroded by the stream breaking through to lower beds; these being of higher solubility, are then severely undercut, leaving sharp edged dolomitic ledges above. Taking another area in the upper reaches of Ogof Ffynnon Ddu III, a short bedding plane crawl just below Smith's Armoury is known as the Dolomite Beds. The name is probably derived from studies made by Christopher (1967) which, whilst not mentioning any specific rock type, gave strong indication that they may be of a dolomitic nature. In figure 7, a map of this section of the cave and cross section of the Dolomite Beds is presented. As can be seen from the section, the crawl appears to have been initiated at the interface of a basal dolomitic bed (19) and an upper high calcium limestone bed (18); the latter bed was corroded under phreatic conditions and this was probably stopped by resistance of the upper dolomite bed (17). This upper dolomite cannot be seen in the crawl but is seen beyond the western end as the dip of the strata permits. In view of the depth of the high calcium limestone bed (18), however, it is probable that the upper dolomite is in close proximity to the upper face of the crawl. In contrast, the base of the crawl is partially cut through centrally by the stream, by a vadose mechanism, passing through a total of three dolomitic beds before depth and severe undercutting into lower beds make sampling impossible and so the composition of the lower beds is unknown. It is clear however, that the lower unsampled bed is of higher solubility and chemically it is probably a further high calcium limestone. The individual geochemical composition of each bed in Dolomite Crawl is given in table 3 together with associated corrosion rates.



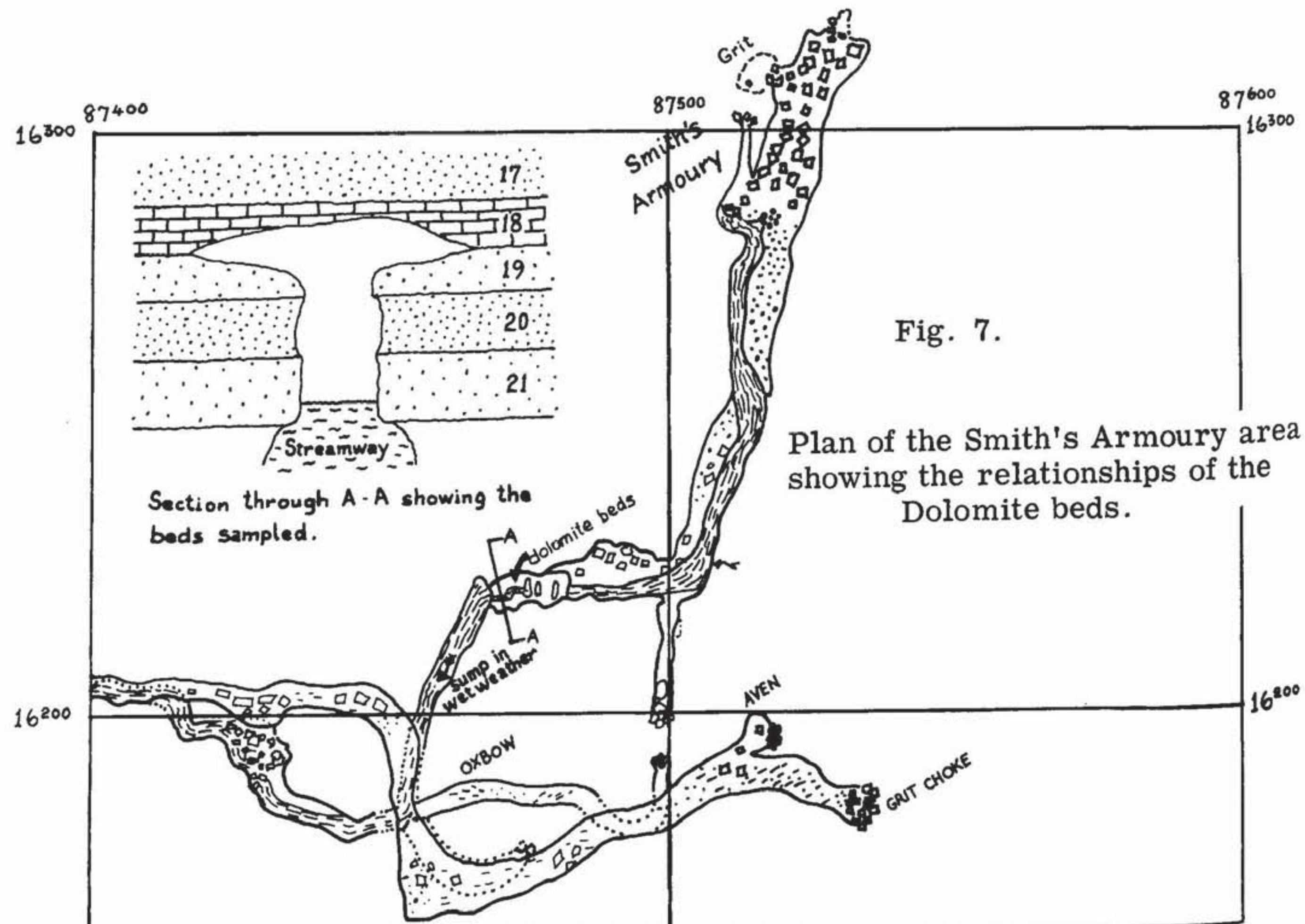


Fig. 7.

Plan of the Smith's Armoury area showing the relationships of the Dolomite beds.

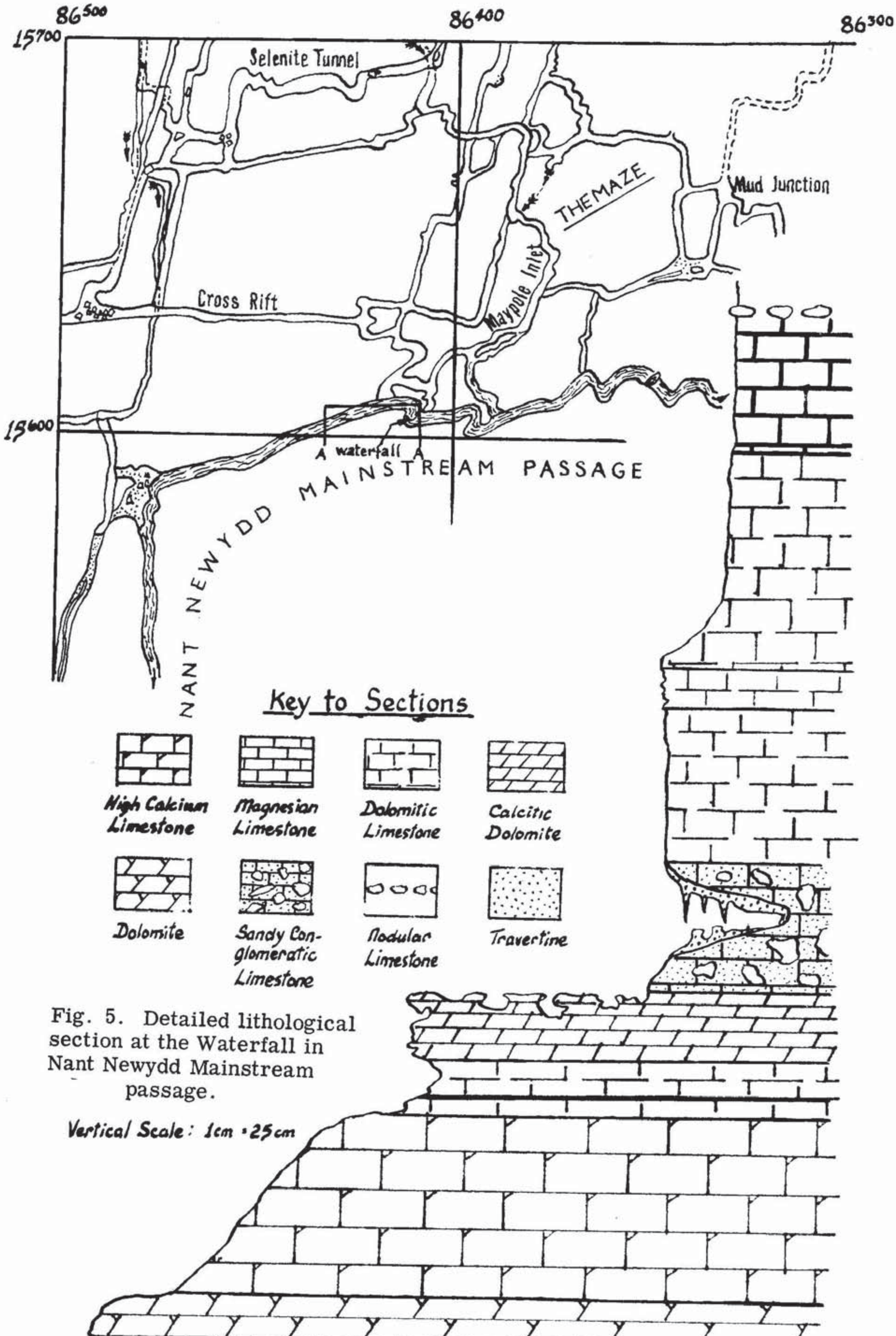


Fig. 5. Detailed lithological section at the Waterfall in Nant Newydd Mainstream passage.

Vertical Scale: 1cm = 25cm

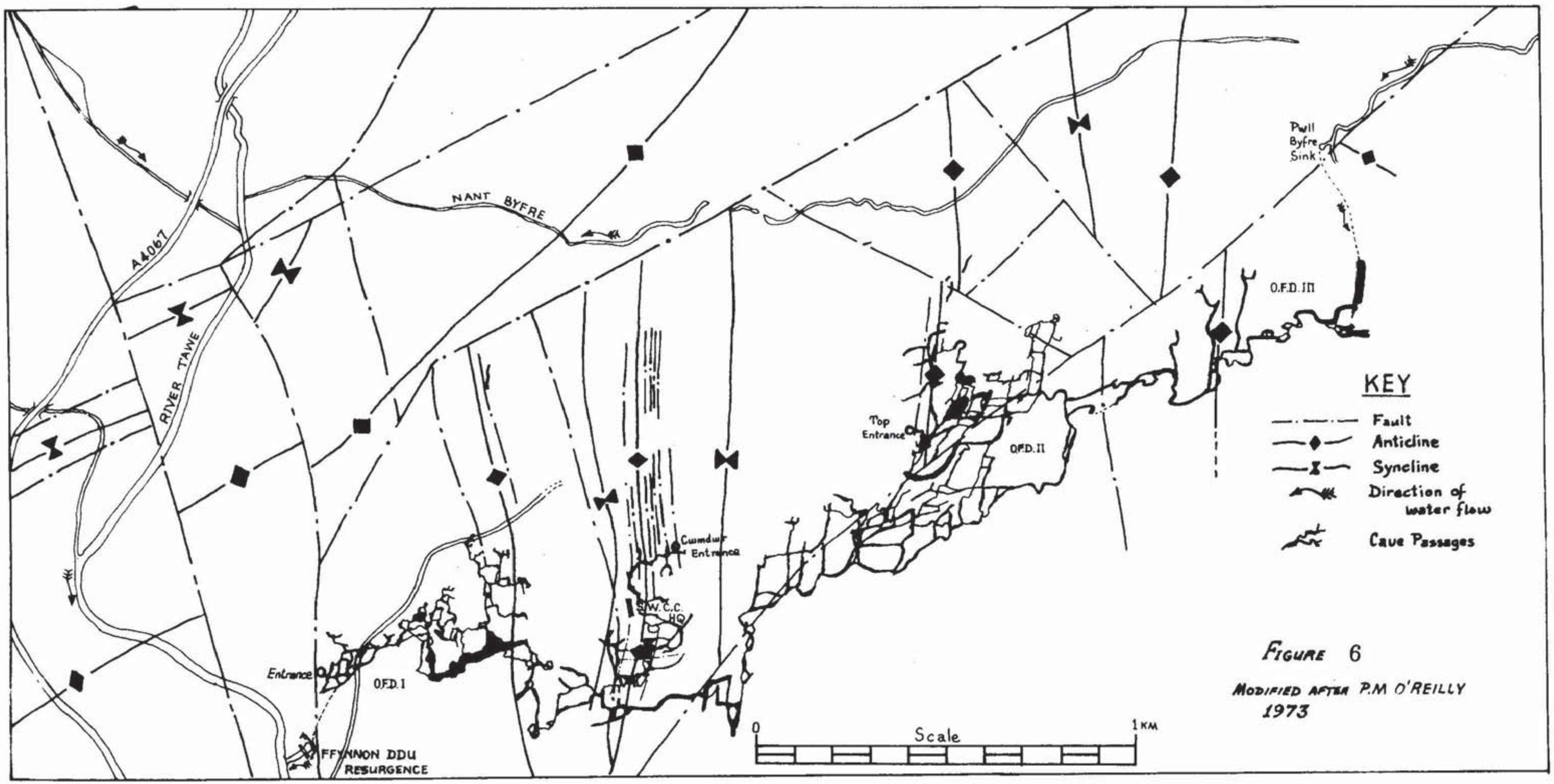


Fig. 6. Plan of Ogof Ffynnon Ddu (after O'Reilly 1973) superimposed on the structural map to show the relationship of passage density and orientation to the folds.

Table 3

Analysis of the Dolomite Beds, Ogof Ffynnon Ddu III

Bed	Approx Depth (cm)	Corrosion Rate mg/cm^3 minute	Organic	CO_2	CaO	MgO	Fe_2O_3	SiO_2	Al_2D_3	K_2O	P_2O_5	SO_3	MnO_2	Total Analysis (%)
17	20-30	3.5	5.88	39.80	32.78	18.26	1.32	0.61	0.09	0.024	0.067	0.021	0.654	99.51
18	30-40	15.3	3.46	39.53	53.28	0.66	0.05	0.36	0.05	0.033	0.003	0.051	0.032	98.26
19	20-25	4.2	6.49	39.47	31.73	17.86	1.57	0.87	0.09	0.024	0.024	0.024	0.768	98.92
20	25-30	4.7	8.95	37.84	29.63	18.59	1.19	1.99	0.09	0.033	0.024	0.062	0.661	99.07
21	25-35	4.6	4.78	38.99	32.25	17.31	1.59	2.11	0.47	0.100	0.029	0.031	0.533	98.19

The elucidation of the structure of the area as a wave train of minor anticlinal and synclinal structures has very important implications if one superimposes a suitably scaled plan of Ogof Ffynnon Ddu onto figure 1 as shown in figure 6. It can be clearly seen that the major series of upper passages coincide with anticlinal structures whilst the synclinal troughs are devoid of any extensive cave development. Moving from west to east, the major upper passages are Waterfall and Railton-Wild Series, Cwmdwr Series, Top Entrance (Clay) Series and the high level passages off Ogof Ffynnon Ddu III.

The alignment of the Mainstream Passage is modified in localised areas by major joints and tension gashes, e.g. the lines of white calcite infill seen in Ogof Ffynnon Ddu I streamway, close to Maypole Inlet in Ogof Ffynnon Ddu II, and in the upper reaches of Ogof Ffynnon Ddu III close to Smith's Armoury. These run principally along a NE – SW direction some 20° to 30° north of the general strike of beds but parallel to the line of the Cribarth Disturbance. This suggests that the Mainstream may be developed along a deep seated synclinal structure to the south east of the cave yet to be proven. This could be similar to that already proven for the Old Series and first parts of the New Series in Dan-yr-Ogof (Coase, 1977).

It is worthy of note at this stage that the major trend of passages throughout Ogof Ffynnon Ddu follows angles complementary to the longitudinal, transverse and shear faults of north – south trending anticlinal structures (see also Weaver, 1973, and O'Reilly, 1973), which indicates a stronger structure control of cave development than envisaged by Glennie (1950, p.8).

In conclusion, whilst the present work has been largely confined to elucidating the stratigraphy and structure as displayed on the surface, important conclusions with regard to the cave and its development are emerging as is the importance of stratigraphic and structural controls.

Acknowledgements

We wish to express our thanks to Dr. T.D. Ford, for his constructive comments and Dr. A.C. Coase for valuable discussions during the course of preparing this paper. Also, to Dr. P.M. O'Reilly for use of his map (1973, fig.2) in construction of figures 1 and 6. We thank Dr. O'Reilly and Mr. W. Little for the many scarce reference papers that have been lent or given. Also, our thanks to the South Wales Caving Club for permission to reproduce, in part, sections of the official survey of Ogof Ffynnon Ddu for figures 5 and 7.

References

Ball K. 1970 — 'Dig This' (or a Child's Guide to Digging) *S. Wales Caving Club Newsl.* 67 p 18-22

Christopher N.S.J. 1967 — Differential Solubility of Limestones *Cave Res. Grp. G.B. Newsl.* 109.

Clarke F.W. 1924 — Data of Geochemistry. *Bull. U.S. Geol. Surv.* 770. 841pp.

Coase A.C. 1977 — Dan-yr-Ogof and Associated Caves. *Trans. Brit. Cave Res. Assoc.* Vol.4. No. 1

Folk R.L. 1959 — Practical Petrographic Classification of Limestones. *Bull. Amer. Assoc. Petrol Geol.* Vol.43, pp1-38

George T.N. 1927 — The Carboniferous Limestone (Avonian) Succession of a portion of the North Crop of the South Wales Coalfield. *Quart. Journ. Geol. Soc. London*, Vol.83. pp.38-95

George T.N., et. al., 1976 — A Correlation of Dinantian Rocks in the British Isles. *Geol. Soc. London.* Special Report No.7

Glennie E.A., 1948 — Some points relating to Ogof Ffynnon Ddu *Trans. Cave Res. Grp. G.B.* Vol. 1 No. 1 pp13-25

Glennie E.A., 1950 — Further Notes on Ogof Ffynnon Ddu *Trans. Cave Res. Grp., G.B.* Vol. 1. No. 3.

Hall C.W., et.al., 1895 — The Magnesian Series of the North West States *Bull. Geol. Soc. Amer.*, Vol.6. pp.167-198.

Hatch F.H. & Rastall R.H., revised by Greensmith J.T. 1971 — *Petrology of the Sedimentary Rocks* London, Murby, 5th Edition. 502 pp.

Landes K.K., 1946 — Porosity through Dolomitization *Bull. Amer. Assoc. Petrol. Geol.* Vol. 30 pp305-318

O'Reilly P.M. et.al. 1969 — *Ogof Ffynnon Ddu.* S. Wales Caving Club, Penwyllt.

O'Reilly P.M., 1973 — Morphology and Hydrology of the Ogof Ffynnon Ddu Karst Area. *Trans. 6th Int. Spel. Cong.* Olomouc, Czech. (Reprinted in S. Wales Caving Club Newsl. 1973).

Pettijohn E.J. 1975 — *Sedimentary Rocks*, New York. Harper & Row. 3rd Edition. 628 pp.

Railton C.L., 1953 — The Ogof Ffynnon Ddu System. *Cave Res. Grp. G.B. Pub* No. 6.

Steidtmann E., 1917 — Origin of Dolomite as disclosed by Stains and other Methods. *Bull. Geol. Soc. Amer.* Vol. 28. pp431-450.

Strahan A.H., et. al., 1932 — *The Geology of the South Wales Coalfield, Pt. V., Merthyr Tydfil.* Geol. Surv. G.B. Memoir, 2nd Edition.

Weaver J.D., 1971 — *The Swansea Valley Disturbance* Unpublished Ph.D. Thesis, University of Wales.

Weaver J.D., 1973 — The relationship between Jointing and Cave Passage Frequency at the Head of the Tawe Valley, S. Wales. *Trans. Cave Res. Grp. G.B.* Vol. 15. No. 3 pp 169-173

Weaver J.D., 1975 — The structure of the Swansea Valley Disturbance between Clydach and Hay-on-Wye, South Wales, *Geol. J. Vol. 10., Pt. 1* pp 75-86.

Appendix 'A' Geochemical Analysis

Samples of rock of 30gm weight were broken into small pieces then ground to pass a 250 micron seive. Bed samples were often composed of equal portions of several samples taken at intervals through the total depth of bed.

Using a four place balance, 0.5 gm of the prepared ground sample was then placed in a clean tared platinum crucible and the weight loss at 120°C, 550°C and 800°C after one hour at each temperature determined. This gave moisture (H_2O-), water of composition including organic matter (H_2O+) and carbon dioxide content respectively. Limestones rich in silica should be ignited at 1050°C for one hour to ensure complete decomposition.

The resultant powder was then dissolved in 1:1 hydrochloric acid, insoluble silica filtered off and weighed and the resultant solution used to determine Calcium (C_a), Magnesium (Mg), soluble Silica (SiO_2), Iron (Fe), Aluminium (A_1), Manganese (Mn), Potassium (K), Phosphate (P_2O_5) and sulphate (SO_3) and in certain cases Titanium (Ti), Sodium (Na) and Arsenic (As_2O_5). The cations were determined by atomic absorbtion, using a Pye Unicam SP90 Series 2 instrument. Calcium, Magnesium, Aluminium and Silica (soluble) were determined using the nitrous oxide flame to overcome sulphate, and in the case of the former two, aluminium interference, with 0.1% added Sodium chloride as an ionization buffer. The remainder of elements were determined in an air/acetylene flame. In all cases, samples and standards were matched for total solids, major components and acid content to minimise matrix effects.

Phosphate was determined colorimetrically using molybdo/vanadate reagent and sulphate gravimetrically on 100 ml of the solution (o.2 gm) as barium sulphate using all the usual precautions.

The geochemical nomenclature utilized in our work for classification of limestones and dolomites is given below (after Pettijohn, 1975, p.361).

Rock Type	MgO Content (%)
High Calcium Limestone	0 – 1.1
Magnesium Limestone	1.1 – 2.1
Dolomitic Limestone	2.1 – 10.8
Calcitic Dolomite	10.8 – 19.5
Dolomite	19.5 – 21.6

Appendix 'B' Corrosion Rate Determination

Small samples of the rock specimens used for determination were ground to a cross-sectional area of approximately 1 1 cm^2, accurately measured. The samples were then potted in polyester resin. ground off to expose the prepared surface, dried and accurately weighed. The whole sample was then immersed in 1 molar hydrochloric acid for 10 minutes at 20°C, washed, dried and reweighed. The resulting weight loss was recorded in mg/cm^{-3}/minute.

Appendix 'C' Petrographic Terminology

The terminology utilized in limestone petrology is diverse and has been discussed in detail by Hatch., et. al. (1971), Pettijohn (1975) and Folk (1959).

For the purposes of our present and intended research programme, a nomenclature incorporating a dual classification, using Folk's method together with the Wentworth's scale of grain sizes has been utilized. This involves the build-up of a nomenclature using up to four components in abbreviated form on the following lines:-

a) The dominant clastic component of the rock

b) The next most dominant clastic component (omitted if variable throughout the bed or beds being considered, and specified separately following the classified name).

c) The nature of the matrix

d) Grain size based on modified abbreviation of the Wentworth scale.

Clastic Components:

These have been split into four categories as in Folk's classification as follows:-

a) Ooids, chemically or mechanically produced and having two or more concentric depositional surfaces. Abbreviation:- Oo-

b) Intraclasts, penecontemporaneous broken and redeposited sediments including false ooids i.e. intraclasts with micritic rims. Abbreviation:- Intra-.

c) Pellets, small (0.03 -0.15 mm) well rounded structureless clasts, often confused with small intraclasts but generally thought to be of fecal origin. Abbreviation:- Pel.

d) Biotic, complete or fragmentary particles of any biotic material. Abbreviation:- Bio.

Matrix:

The matrix or cement between clastic components falls into two categories namely sparite, crystalline calcite not less than 50 microns in size — abbreviated as 'Spar' and, micrite, microcrystalline to cryptocrystalline calcite less than 50 microns in size abbreviated as 'Mic'.

Grain Size — Wentworth scale:

This we have based on the average grain size as observed in the thin-sections prepared as follows:-

a) $<$0.004 mm Calcilutite, abbreviated to Lutite.

b) $<$0.06 mm Calcisiltite, abbreviated to Siltite.

c) $<$2.0 mm Calcarenite, abbreviated to Arenite.

d) $<$8.0 mm Calcirudite, abbreviated to Rudite.

Use of Nomenclature in examples:

Many examples could be used to illustrate use of this nomenclature but here, we give but two. A study of the stratigraphic sequence illustrated in figure 2, page 7, should readily assist in providing further examples.

1. A dominantly intraclastic rock having secondary biotic content set in a sparite matrix with clastic grain size averaging 0.9 mm would be described as an INTRABIOSPARARENITE.

2. An oolitic rock with biotic, pellagic and intraclastic secondary clasts at various stages in the bedding, the clasts set in a sparite matrix and having an average size of 1.3 mm would be classed as an OOSPARARENITE with variable secondary clasts including ooids, pellets and intraclasts (stating the zones in which these are found).

R.A.P. Charity
118 Bradfield Road,
Urmston, Manchester.

N.S.J. Christopher
22 Deva Close,
Poynton, Cheshire.

WHITE SCAR CAVE

Ingleton Yorkshire

The TRANSACTIONS OF THE BRITISH CAVE RESEARCH ASSOCIATION covers all aspects of speleological science, including geology, geomorphology, hydrology, chemistry, physics, archaeology, and biology in their application to caves, as well as technological matters such as exploration, equipment, surveying, photography and documentation. Papers may be read at General Meetings held in various parts of Britain, but they may be submitted for publication without being read. Manuscripts should be sent to the Editor, Dr. T. D. Ford, Geology Dept., University of Leicester, Leicester LE1 7RH, who will be pleased to advise in cases of doubt about the preparation of manuscripts. The Transactions is normally issued four times a year to paid-up members of the British Cave Research Association. Subscriptions are due on January 1st annually.

Full Members £4.50 per annum

Corporate Members Clubs £5 per annum

Back numbers of the Transactions and other publications can be obtained from Bryan Ellis, 30 Main Road, Westonzoyland, Bridgwater, Somerset TA7 0EB.

Printed by Hawthornes of Nottingham Limited