Cave Science

The Transactions of the British Cave Research Association

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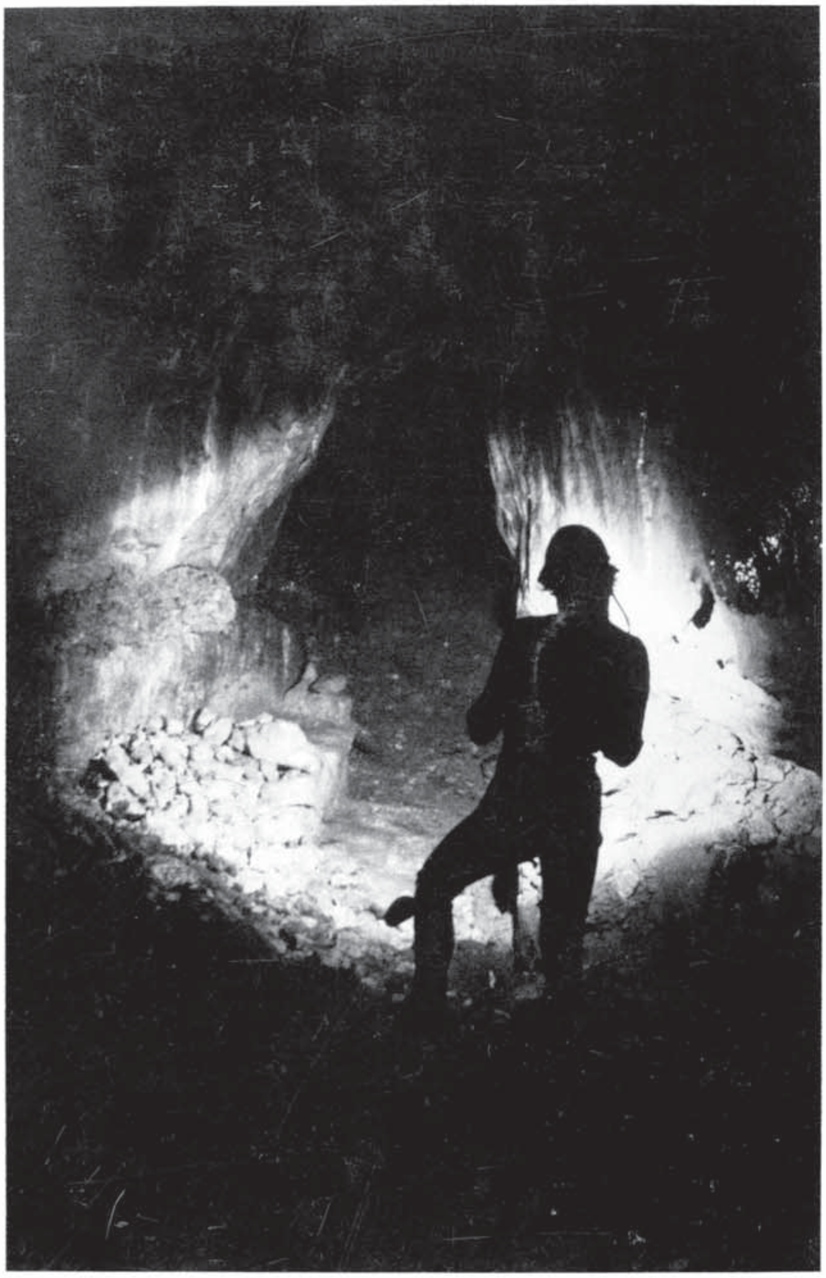

BRITISH CAVE RESEARCH ASSOCIATION

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REDISCOVERY OF THE LOST PILKINGTON'S CAVERN, CASTLETON, DERBYSHIRE

R. P. Shaw

ABSTRACT

Climbs totalling 58 metres, with linking passages totalling 536 metres long, have led into cave passages which fit Pilkington's description of 1789. Originally found by lead miners around 1770-1780, this part of Speedwell Cavern appears to have given access to the stream caves before the canal was driven to intersect the stream system so that a number of mineral veins could be worked. The total vertical range of the Speedwell Cavern System is 182.6 metres, very close to the English depth record.

Speedwell Cavern is a show cave cum mine at the bottom of the Winnats Pass west of Castleton, Derbyshire. The previously known cave has been described by Ford (1956). It consists of a mine level driven as a canal to utilize boat haulage for ore and waste removal which intersects an extensive active and abandoned stream cave system taking swallet water from the Perryfoot/Giants Hole area to Russet Well.

During 1981 a number of pitches were climbed in part of the system using self-drilling bolts. Bolting started in the cavern discovered in the Assault Course part of the system some 100 metres west of the Far Canal by T. D. Ford in 1944. This contained the remains of climbing stemples from which Ford deduced that it might be the bottom of the lost cavern described by Pilkington in 1789.

BRIEF HISTORY

That the "Old Man" knew about the stream cave system of Speedwell Cavern before the canal was driven has been regarded as certain, but hitherto unproven.

The Speedwell Canal, commenced in 1771, was driven to intersect the cave system, which it reached 11 years later, to enable the working of a number of mineral veins therein. Boat haulage was to be used for waste and ore (Rieuwerts and Ford, 1983), though why it did not reach the surface as a level is in doubt. All waste rock (until the Bottomless Pit was reached) was boated back to the bottom of the shaft and then wound to the surface.

The route by which the "Old Man" entered the cave system before the level was driven was described by a number of contemporary tourists. Though most of these accounts were published after the canal reached the stream caves the visits were made before the break-through. The first of these was Sulivan in 1780 (second edition 1785) who described an arduous descent to the stream caves via climbs totalling some 420 feet.

Pilkington (1789) described the descent in a much more detailed account and with a fair degree of accuracy, giving depths of descents and rough lengths traversed but unfortunately no bearings so that it was impossible to work backwards when the presumed bottom was found in 1944.

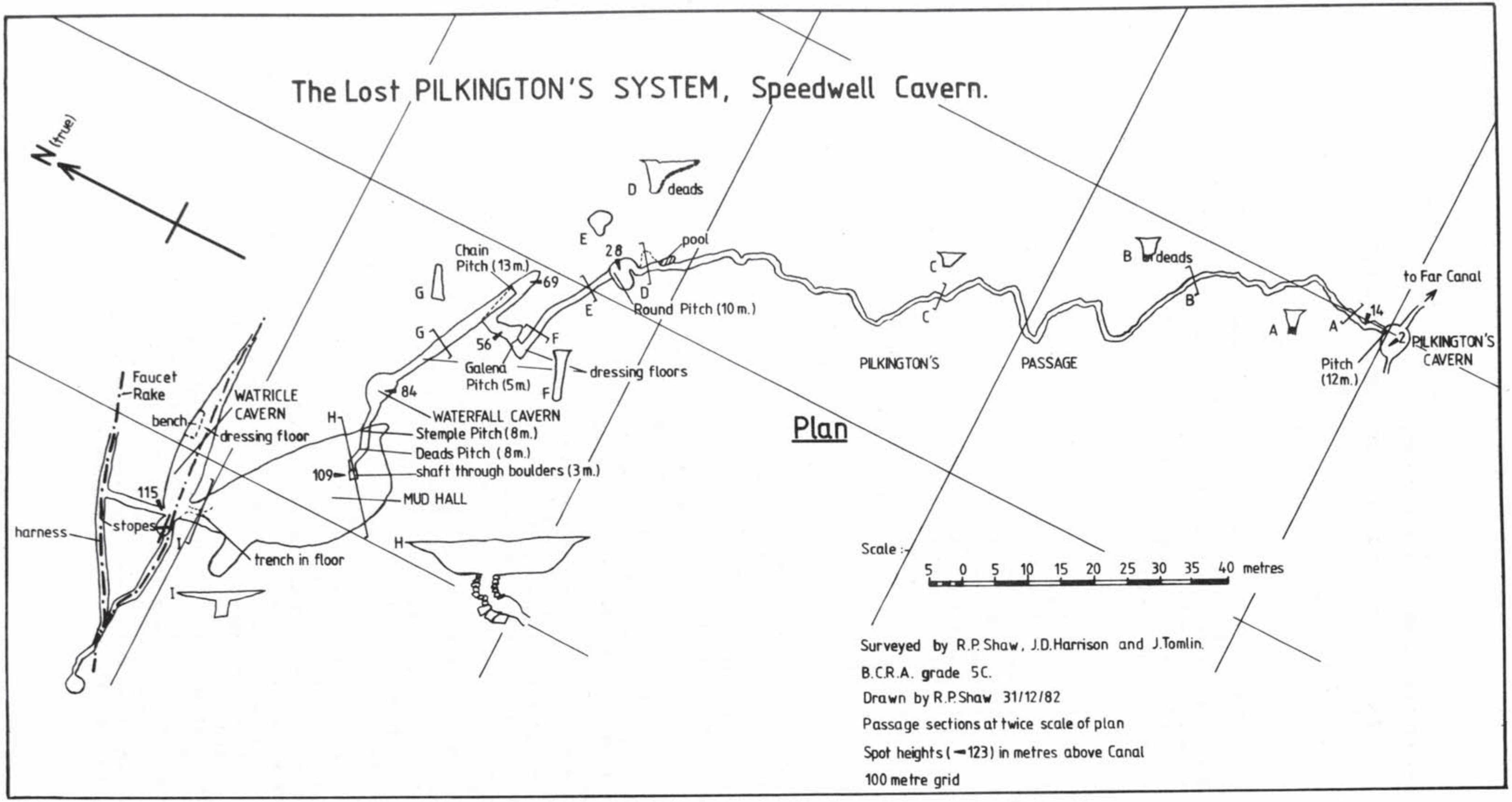
Another description was by Milne (1813) (noted by Anon, 1947) though this is an almost perfect repetition of Pilkington's account without acknowledgement.

From these descriptions several people have tried to locate the lost passages, usually wrongly assuming that they entered the Bottomless Pit Cavern.

The Assault Course series of the Speedwell system was discovered in 1944 by T. D. Ford who dug through a silt-filled passage from the Far Canal (Ford 1956; Simpson, 1953). Some 100 metres from the canal a circular cavern was entered containing stacked deads and the remains of climbing stemples on the floor and a few wedged in the walls. The remains of a wooden platform could be seen above. It was estimated as 50 feet high and this fitted with the last vertical of Pilkington's descent at 16 yards, and so the chamber was provisionally named Pilkington's Cavern.

The last part of Pilkington's account describes a passage "one hundred and twenty yards long, two feet high and two wide and at the end you discover another 150 long, six feet high and two wide". This does not correlate with the present flat-out crawl entrance from the canal, but it does correlate with the downstream end of the Assault Course streamway, which now ends at a sump created when the canal was completed and flooded.

Fig.1.


The Lost PILKINGTON'S SYSTEM, Speedwell Cavern.
N (true)
Plan
deads
D
E
28
pool
Chain Pitch (13 m.)
69
G
E
D
Round Pitch (10 m.)
56
F
Galena Pitch (5 m.)
dressing floors
F
84
WATERFALL CAVERN
Faucet Rake
WATRICLE CAVERN
bench
dressing floor
H
Stemple Pitch (8 m.)
Deads Pitch (8 m.)
109
shaft through boulders (3 m.)
MUD HALL
115
harness
stopes
I
trench in floor
H
I
C
C
B
deads
B
A
A
14
2
to Far Canal
PILKINGTON'S CAVERN
Pitch (12 m.)
PILKINGTON'S
PASSAGE
Scale :-
5 0 5 10 15 20 25 30 35 40 metres
Surveyed by R.P. Shaw, J.D. Harrison and J. Tomlin.
B.C.R.A. grade 5C.
Drawn by R.P. Shaw 31/12/82
Passage sections at twice scale of plan
Spot heights (→123) in metres above Canal
100 metre grid

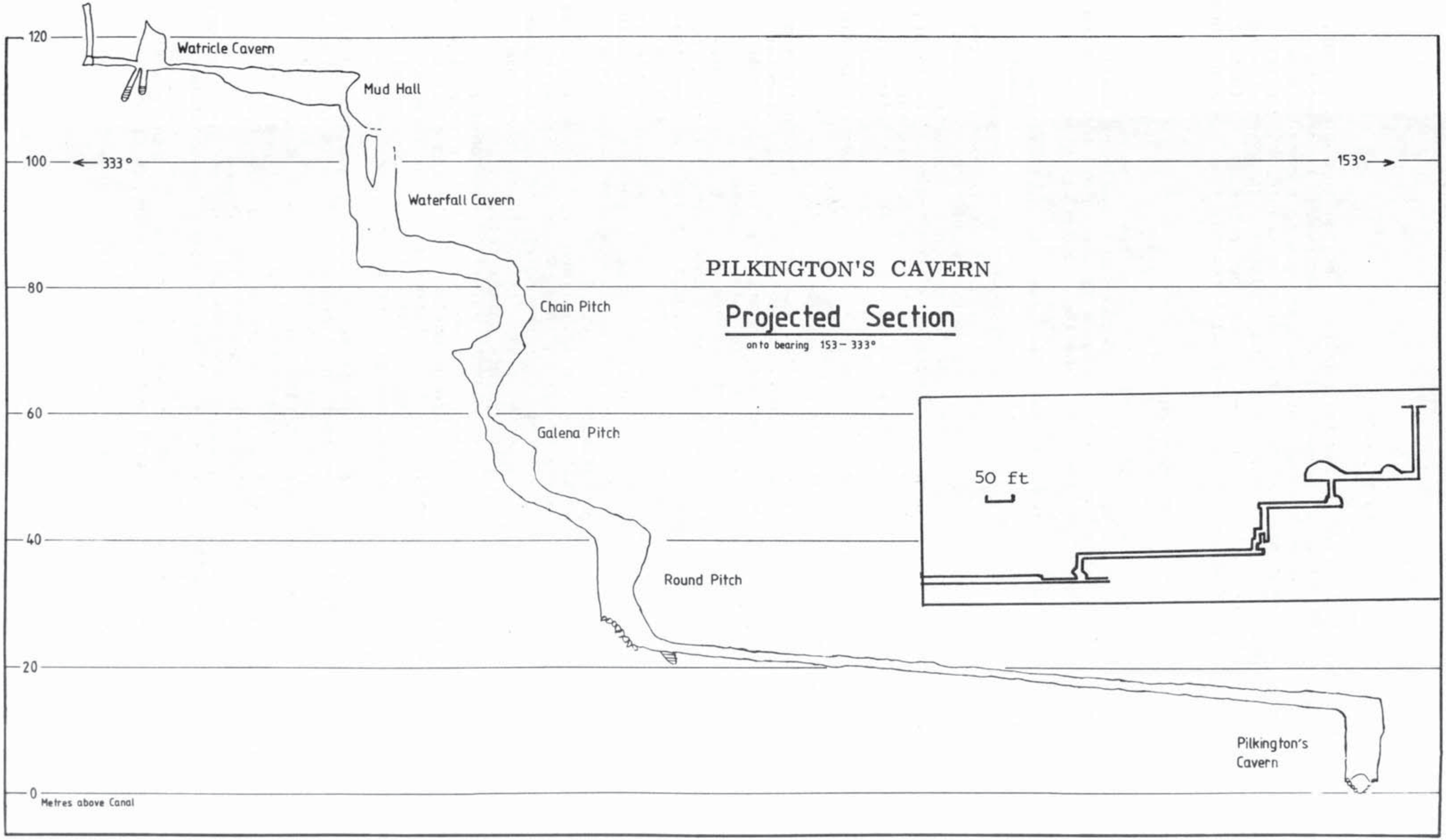


Fig.2. PROJECTED PROFILE OF PILKINGTON'S CAVERN

Inset - Pilkington's Cavern reconstructed from his description.

EXPLORATION

Pilkington's Cavern was climbed, using self-drilling bolts, in January 1981, giving access to about 160 metres of passage trending northwards to a second climb (Round Pitch). This was climbed in late February giving access to some 70 metres of steeply ascending passage including a free climbable third pitch (Galena Pitch) of 7 metres to the fourth pitch (Chain Pitch). This was climbed in November 1981 to a further 250 or so metres of passage including two further pitches (Waterfall Pitch and Boulder Pitch), each of 8 metres, making six pitches in all.

DESCRIPTION

Pilkington's Cavern is circular in plan and about 5 metres in diameter. This first pitch is a climb of 12 metres, the ladder hanging under the small stream that cascades from the passage above. Originally the cavern had climbing stemples and a stemple-supported platform over the top. Deads are stacked at the bottom.

From the head of the climb Pilkington's Passage extends some 160 metres generally northwards. The passage is developed in one bedding plane (probably the same one as the controlling bedding plane of the Peak Cavern streamway) as a vadose canyon. Initially this is 2.1 m high and 0.75 m wide but soon reduces in height and width. In many places it was enlarged by the miners who removed sharp corners to enable them to get the long stemples through. Where the passage height allowed the rubble from this operation was packed onto the floor. The surplus was taken back to the bottom of the Round Pitch. Towards the northern end the passage intersects a number of small scrins and a calcite pipe vein, none of which were investigated by the "Old Man". A number of artifacts were found in the passage including the end of a pick, a brass button and buckle, the remains of a pair of boots, a rope and a number of nails.

The chamber at the north end of Pilkington's Passage and the passage immediately above are partly developed in a calcite pipe vein . Beyond the top of the 11 m Round Pitch the passage is a phreatic tube about 1.5 m in diameter developed in the pipe vein. A short distance beyond this the passage becomes a high vadose rift to a climb of 7 m (Galena Pitch) into a chamber.

Here there is evidence of the presence of the miners in the form of an ore-washing floor of rotten planks with a little galena on them, though there is no evidence of mining. Above the dressing floor is a cluster of large stalagmites.

A series of climbs leads to the bottom of the third pitch (Chain Pitch), a climb of some 12 metres. The pitch is covered with massive flowstone, a hole in which was found to contain a length of iron chain (Pilkington noted that a chain was used on this pitch). Above the pitch the passage is again developed in a calcite pipe vein to a lofty chamber, Waterfall Cavern.

Just before the cavern is reached are the remains of another ore-washing floor, but again no evidence of mining. The cavern is at least 20 metres high with water entering from two points, one in the roof of the cavern and the other down two stempled climbs. The cavern is adorned with stalactitic formations, some of which were broken in mining days but have since partly regrown.

From Waterfall Cavern two difficult free climbs (Waterfall and Boulder Pitches) up a formerly-stempled section, each of 8 metres, led via a short low passage to the bottom of a stempled shaft through boulders. The top of this shaft is in a large chamber named Mud Hall. This chamber is not as large as Pilkington described it but it is certainly impressive. It has a bedding plane roof and a floor of boulders buried in mud, the chamber being up to 5 metres high and 15 metres wide.

At the east end, the chamber reduces in height to a bedding plane about 0.35 metre high but the miners made an easier route by digging a trench in the floor. Beyond this, over a partly collapsed dry-stone wall, which may have marked a property boundary, is another chamber which Pilkington described. Named Watricle Chamber, this was beautifully decorated before being stripped by the miners. The stalactite stumps are starting to regrow but two hundred years is not long enough for total recovery. Pilkington described it thus:-

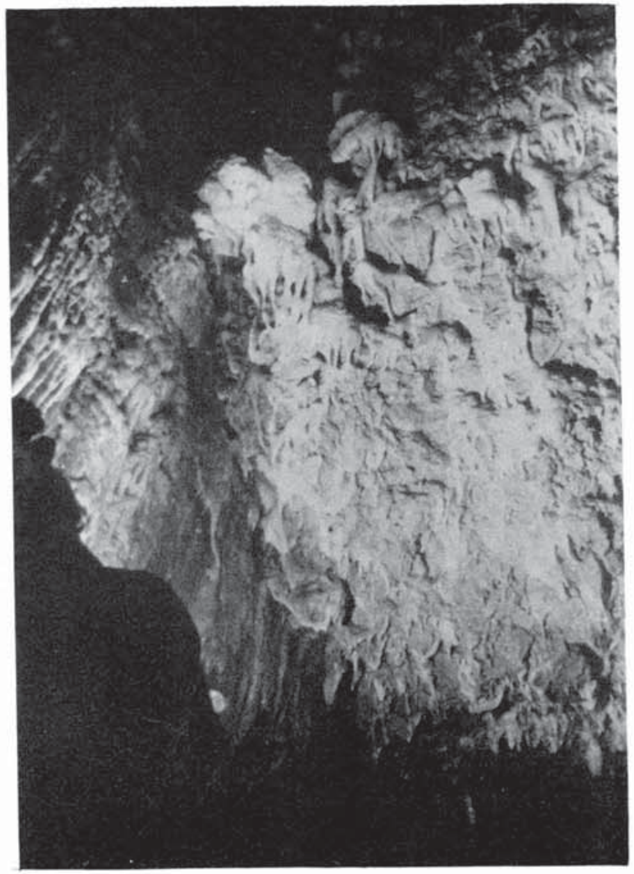
"When the miner first broke into it, it appeared beautiful beyond description. Upon introducing his candle thro' the hole, which he had made, he was struck with astonishment. But when he entered the cavern, it in beauty exceeded his highest expectations. The roof and sides were covered with water icle, almost as white as snow. But now it is in a great measure stripped of its ornament by those who have passed through it".

To the east this chamber extends 20 or so metres to a fall, caused by the

1. Climbing Pilkington's Cavern; remains of miners' wooden platform above.

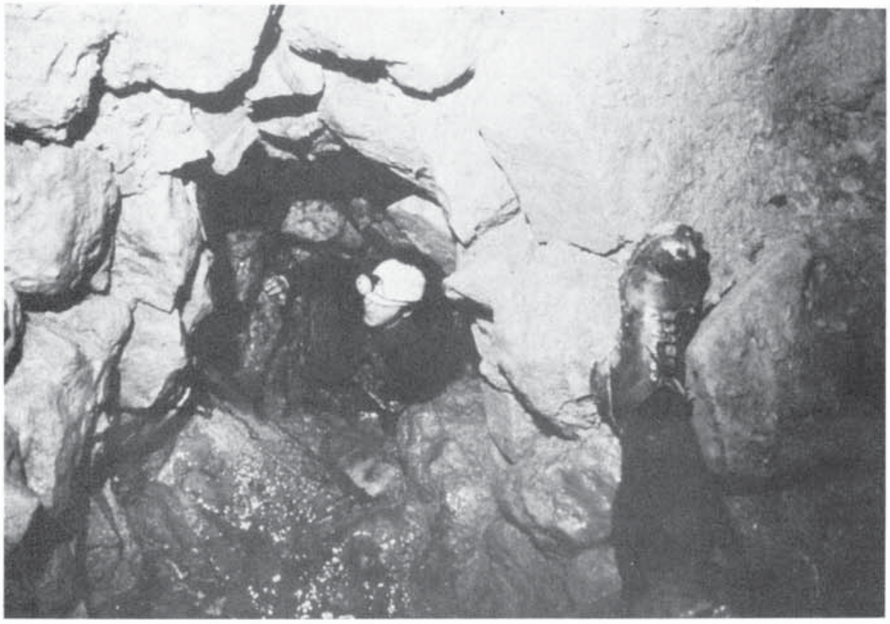
2. Watricle Cavern looking west; ore-dressing bench on right.

PILKINGTON'S CAVERN



3. Broken stalactites in Watricle Cavern.

4. Miners' trench cut in floor from Mud Hall to Watricle Cavern.



5. Climb through boulder shaft into floor of Mud Hall.

6. Remains of washed galena on rotten boards above Galena Pitch.

collapse of sandy gravel fill from a phreatic cavity into the mine workings. The chamber has been extensively used for ore dressing which must have been carried out dry for there is no water available here. The sorted ore was then taken down 3 or 4 pitches, for some 50 m to the bottoms of the wetter pitches for final cleaning, and was then apparently carried back out to the surface via a shaft which appears to be back-filled or totally run-in now.

From Watricle Chamber lead a number of partly natural, partly mined passages and mine workings. Most of these are levels driven in Faucet Rake or branches to the north. Only in two places are the workings continued below the bedding plane controlling the roof of Mud Hall in the form of flooded, partly back-filled stopes. Where present, stopes on the vein above this level are 0.5 to 0.8 m wide extending irregularly upwards for up to 7 m. All shot holes made for mining are about ¾ inch in diameter. To the west a passage mined through sediment fill leads to a small, cleanwashed phreatic chamber with a 10 cm. high bedding plane with solid rock floor and roof being the only exit.

A number of artifacts were found in this section of the system including a wooden kibble with iron bands, tallow dips, a leather harness and chain for dragging corves, iron banding from a corve, a broken wedge and a clay pipe (1750 to 1790 in style).

On the surface above this area, about 50 m above, is a large natural depression close to Faucet Rake which probably represents the surface location of the natural part of the cave system. Any cave between this point and the top of that explored appears to be filled with loess and solifluction sediments.

THE SURVEY

The survey was carried out using Suunto compass and clinometer, read to 0.25^{o} and Fibron tape read to the nearest centimetre. Sections were made at all stations and between where the legs were long. The line survey was initially plotted by computer. A B.C.R.A. grade of 5C is claimed.

In total about 500 metres of new passage was surveyed; of this only about 40 m is mine level. The top of the natural part of the system is some 127.1 m (416 feet) above the canal which is some 55.2 m (180 feet) above the downstream Bung Hole sump in Speedwell cavern. This gives a total altitude range of 182.6 m (596 feet) which is very close to the English depth record for natural cave passage.

GEOLOGY AND EVOLUTION

This part of the Speedwell system is developed in well-bedded limestones of Asbian (D_1) age containing a number of stylolite seams. The limestones are cut by a number of small, less than 1 cm., scrins of baryte and fluorite and irregular calcite pipe veins as well as the large veins of Faucet Rake.

The mineralization in Faucet Rake consists of void fillings in veins of banded fluorite, baryte, calcite and galena up to 0.8 m wide though generally less. In Watricle Chamber there is a sedimentary deposit containing derived fluorite, baryte, calcite and galena which has also been worked.

Pilkington's Passage is a sinuous vadose trench developed from a prominent shale-filled bedding plane with a thin (2 to 3 mm) coal seam which has also been recognised in Speedwell's Cliff Cavern and in Peak Cavern. The passage below the Chain Pitch is developed along a non-mineralized fault of 1.5 m throw down to the south, as shown by upturned limestone beds in the roof. Mud Hall and Watricle Cavern are associated with a prominent bedding plane, probably a clay wayboard. In the case of Mud Hall this horizon forms the roof while in Watricle Cavern it forms the floor. This wayboard may represent the Cave Dale Lava in this locality.

Development of Watricle Cavern has also been controlled by Faucet Rake which runs along its length but has only been worked in the floor at this point.

Most of the system is vadose in origin connecting short sections of formerly phreatic passage developed in Faucet Rake and associated pipe veins. The vadose incision indicates that it formed as an inlet swallet to a system already drained at least to the level of the canal and thus Hope Valley was in existence when this inlet system was last active, though it seems unlikely that the Winnats Pass could have been present so close to such a swallet at that time.

The limited phreatic development at the top of the cave system probably considerably pre-dates the vadose development perhaps representing early cavernization in Faucet Rake and associated pipe veins. Watricle Cavern is partially filled with a silty gravel, similar to that in the entrance series of Giant's Hole, probably of solifluction origin, containing large rounded clasts of Millstone Grit and shale. It is likely that this material was introduced into the cave during a periglacial phase totally blocking the former swallet. As the vadose passages are not very large this cave was an active swallet system only for a limited period of time before the Wolstonian glaciation. Today all water in the system is of percolation origin.

CONCLUSIONS

Pilkington's lost cave system for which cavers have been searching for nearly a century has been found. The early accounts of arduous and long caving expeditions have been shown not to be as exaggerated as some have thought and the route by which the "Old Man" found his way to the stream caves before the canal was driven has been traversed again. Considering that a return trip from the canal to the highest point reached at the bottom of Pilkington's shaft takes at least four hours one has to admire the miners who worked in these passages and shafts fitting stemples on the pitches whilst hanging by ropes under wet condition without the protection of modern clothing. It must surely have been an achievement just to keep their candles burning on some of the pitches.

ACKNOWLEDGMENTS

The exploration and survey described has only been possible due to access to the Speedwell system via the show cave being allowed by the owners, the Harrison family. Especial thanks go to the manager and staff at the shop for changing room and the supply of hot drinks etc., when emerging after a long day underground. Also to the vast amount of willing assistance given by numerous people who helped in bolting, surveying and photography, including John Harrison, Rod Branson, Richard Acton, Jon Reading and John Tomlin. Gratitude must also be extended to Trevor Ford for floor space and continued encouragement as well as for introducing the author to the cave system as a whole.

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RESCUE TECHNIQUES FOR THE SMALL SRT PARTY

Paul Ramsden

Ideally all cavers should be able to help another caver in trouble on a rope. Various techniques of hauling and lowering are described, but unless thoroughly practised the rescuer could find himself in trouble as well!

This article is restricted to techniques, using only the equipment normally carried by the rescuer and victim using a sit stand system such as the Frog rig, with the addition of a couple of pulleys of the type which can be put onto the middle of the rope.

At the outset I recommend practice of a variety of techniques to give familiarity and to see which methods are most appropriate. Often different ascenders can be substituted for one another or even prusik knots used. Try to think through the sequence of moves to see which is the best way to use the equipment available. This applies particularly to hauling systems, where the most efficient systems probably use more gear and cannot easily be put onto a taut rope. You may find you have used an ascender to hold the rope initially, while getting slack into the system, and then find you want to use it elsewhere! Similarly, if you need to remove the body ascender while hanging from a cowstail, this will be awkward or dangerous if it is fastened into the central maillon. With forward planning, a karabiner would be inserted between the body ascender and the central maillon, then the ascender can be removed without unfastening the harness.

There are various reasons why a caver may be suspended part way up a rope (eg. exhaustion, rock fall, etc.). It is essential to GET HIM OFF THE ROPE as quickly as possible, particularly if it is a wet pitch. Even a good harness will restrict his circulation and he may have problems with breathing or bleeding.

You have a choice of either lowering him down, or hauling to the top of the pitch. The particular circumstances will dictate which course of action is most suitable, The following may help you to reach your decision.

1. GENERAL POINTS

1.1. You are looking for a suitable place to give First Aid, etc. If the pitch head is constricted or awkward, lowering may be easiest.

1.2. If there is deep water at the bottom,you cannot safely lower unless there is someone to keep the victim's head out of the water.

1.3. It is difficult to generalize, but in a wet pitch hauling may be better. The rescuer may be hesitant to put himself at risk by performing mid-rope in the water, and once down, the bottom of the pitch is likely to be a hostile place.

1.4. If there are intermediate anchor points, rescue is more difficult. You cannot haul or lower from the pitch head, unless you have unfastened the rope and this needs very careful consideration.

1.5. If you take too long to sort it all out, the victim may be dead, so speed is vital.

Lowering from Mid-rope. This is likely to be the quickest and least strenuous method, but the rescuer has to prusik up or down (you cannot abseil on a taut rope) the rope the victim is hanging on. The rope and belay points must be good. There is potentially more to go wrong than with pitch head operations. The rescuer unfastens the victim's chest ascender and both abseil down together. Extra friction (e.g. a complete turn on a karabiner) is needed on the descender. First Aid and protection can be given to the victim and intermediate belays can be unfastened or passed during the descent. Lowering generally involves going further from the entrance initially, in order to get off the rope quickly.

Hauling from Mid-rope. This has little to commend it unless the victim is near the pitch head and the rescuer is coming from below. The rescuer can give some First Aid and protection to the victim. Rebelays can be passed; but it is strenuous.

Hauling from the Pitch Head. The rescuer is at less personal risk than where two people are hanging on the same rope and belay point. Hauling is slow and strenuous so unless the victim is near the pitch head, this is unlikely to be the quickest method, and getting off at the top may be difficult.

Lowering from the Pitch Head. This is only possible if an extra rope is available, but could be convenient if the rescuer did not want to get on the same rope as the victim.

Once off the rope you can give First Aid and assess the situation. Can you leave the victim and call out the rescue team or must you sit down and wait. Depending on his injuries and the number of people available you may decide to haul him up. With extra people or extra gear, hauling may be quite feasible, where it was inadvisable alone.

Assisted Prusik. If the victim is able to help himself (e.g. damaged arm or leg), a good pull may be all that is necessary. (Fig. 1). The rope can be altered to hauling if necessary. Sliding gear down the rope or shouting advice may even suffice in minor incidents.

MID-ROPE RESCUE

The victim is assumed to have been prusiking.

2. ABSEILING OFF TOGETHER

The rescuer climbs or reverse Prusiks the rope until he is just above the victim.

It is necessary to lift the victim initially to remove his chest jammer, before abseiling off together. Two methods of lifting are described.

2.1. Direct Lift (Fig. 2).

2.1.1. You attach the victim to your central maillon using a karabiner or the victim's short cowstail, a short attachment is best when against a wall so you can use your feet to push away with.

2.1.2. Remove the victim's foot ascender.

2.1.3. Using both feet in your foot loop, take a short step upwards. This is very strenuous as you are taking the weight of two people. It is easier to straighten your legs with a short step than a long one. This should produce slack above his chest ascender.

2.1.4. Remove his chest ascender. He is now hanging below you.

2.1.5. Change to abseil as normal. Lock off the descender immediately below your chest ascender with an extra turn on a karabiner to give extra friction.

2.1.6. Before standing up on your foot loop to release your chest ascender, unfasten the safety back-up/cowstail to the foot jammer. You are quite safe as you are both on the locked descender - but will not be accidentally suspended from the 'safety' as you sit down onto the descender.

2.1.7. Comment. The direct lift method is fairly simple, but has two strenuous moves, so is better for a victim lighter than yourself. Intermediate anchors may be unfastened in some situations, or passed, using the foot loop to unfasten your cow's tail.

2.2. Mid-rope Counterbalance (Fig. 3). This method uses the victim's foot loop and jammer, is less strenuous than the direct lift, but is slightly more complicated.

2.2.1. On reaching the victim, clip your cowstail into his for safety. Your two ascenders are between his chest and foot ascender.

2.2.2. The victim's descender is fastened to his central maillon, the rope fed through with extra friction and locked off.

2.2.3. The victim's footloop is left attached to his central maillon, but is taken out of his foot ascender karabiner and run through this karabiner like a pulley. The foot end of the footloop is clipped into your central maillon. The victim's foot ascender is adjusted so that the foot loop linking the two of you is taut.

2.2.4. Stand in your own footloop and remove your chest ascender. As you sit down onto the footloop, your own weight acts as a counterbalance allowing you to lift him relatively easily with your arms and legs.

2.2.5. Remove his chest ascender, and lower him down to the locked descender by standing in your own footloop.

2.2.6. Re-attach your chest ascender, then remove the upper ascender and victim's footloop.

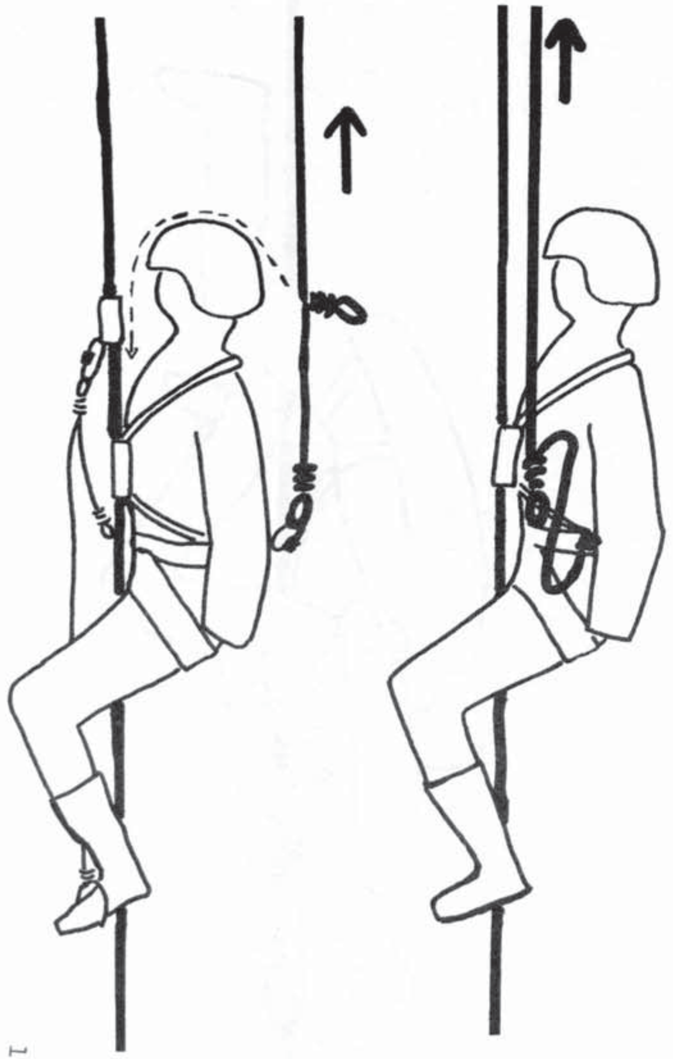

Fig.1. Assisted prusik.

Fig.2. Mid-rope direct lift.

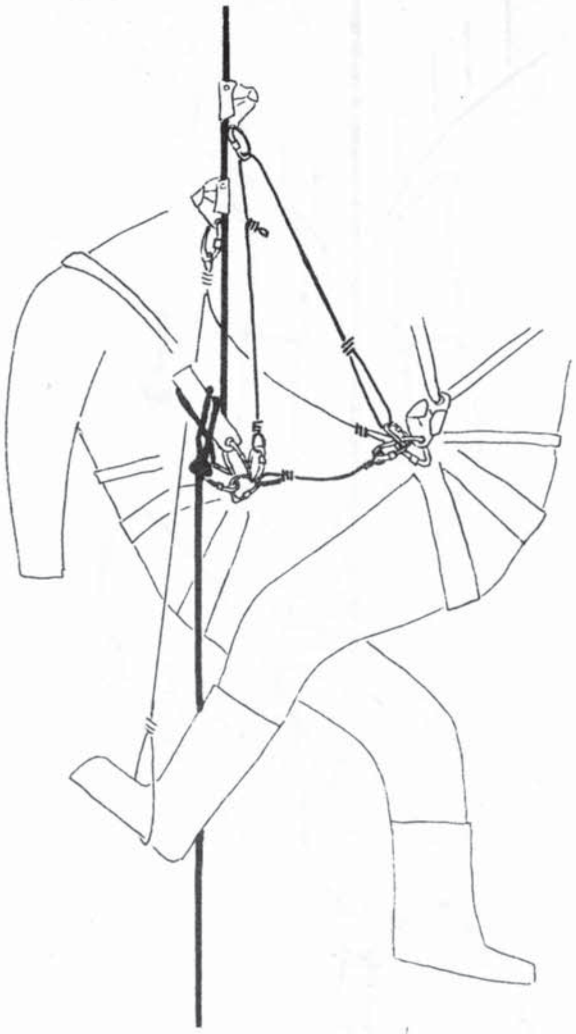

Fig.3. Mid-rope counterbalance.

Fig.4. Pulley foot ascender.

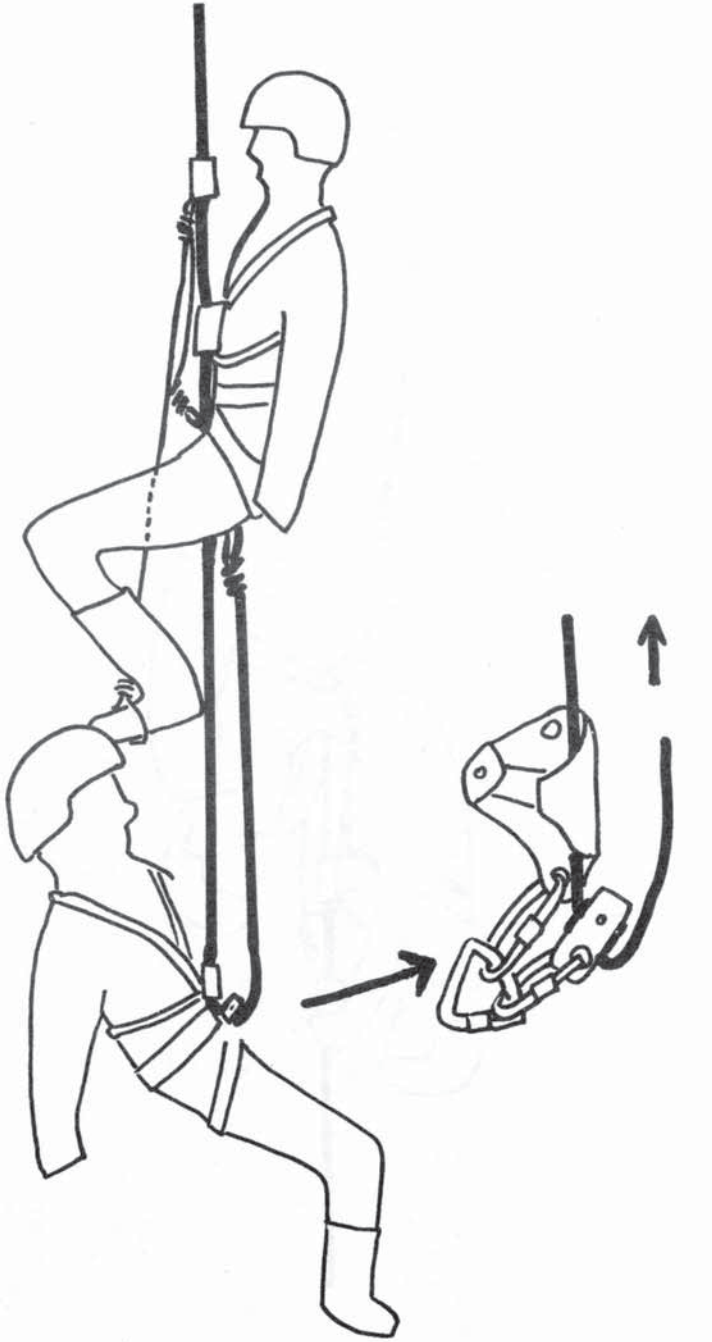

Fig.5. Pulley below victim's chest ascender (2:1 lift).

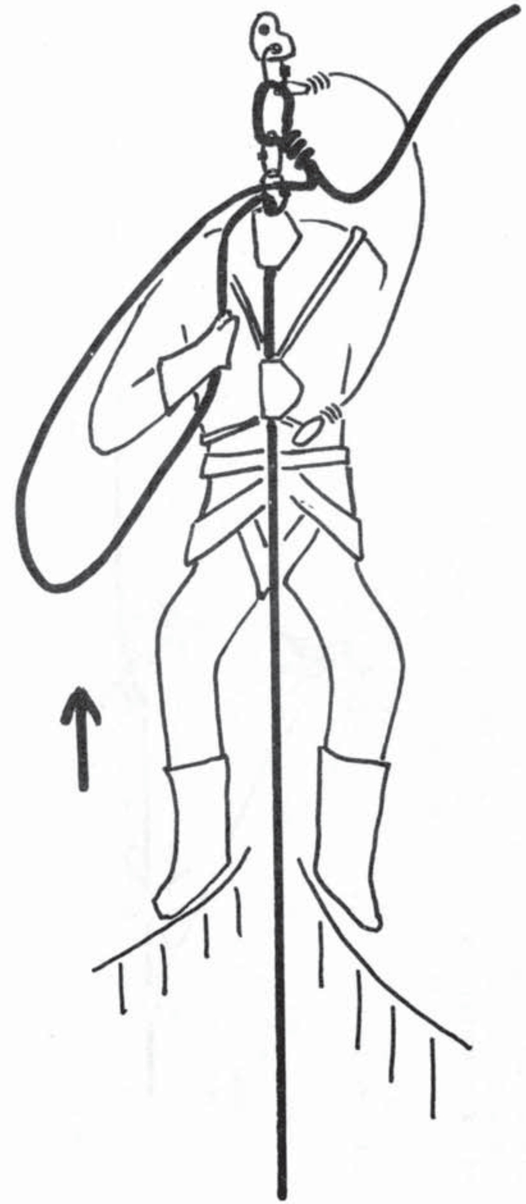

Fig.6. Direct lift.

2.2.7. Prusik down until you can attach yourself to the victim's locked descender with a karabiner, remove your ascenders and abseil down.

2.2.8. Comment. Unless you are lifting a light person this method is preferred because there are no strenuous moves.

3. HAULING FROM MID-ROPE

If you have a good reason for not going down, or perhaps the victim is near the top and you are climbing up, towing is a possibility.

3.1. Direct Lift-Towing. (Fig. 2). Climb above the victim, clip short cows tails together, continue climbing, feeding the rope through his chest ascender.

Comment. Very strenuous and not recommended, unless a very light victim is to be lifted for a short distance. Simplicity is the only advantage, even then getting off the rope will probably be difficult.

3.2. Pulley Foot Ascender-Towing (Fig. 4). A variation to the direct lift (3.1) will make towing easier but slower. Remove your footloop from your foot ascender karabiner and run it over this karabiner (or pulley if available) and attach the end of the footloop to the top of your chest ascender. The footloop will now need altering to get the optimum lift. The long cowstail can be attached to the foot ascender for added security.

3.3. Pulley below Victim's Chest Ascender (2:1 Lift) (Fig. 5). The rope from below the victim is lifted and fed around a pulley inserted immediately below the victim's chest ascender. The rescuer then ties the rope to his harness and continues to climb. The victim's chest ascender grips the rope and the load is halved. Unfortunately the pulley often jams against the chest ascender, so its use is dependent on the particular equipment used by the victim.

4. HAULING FROM THE PITCH HEAD

We assume the rope is taut with the victim's weight, but not attached (or already detached) below. The rope is lifted a short distance with an inverted jammer, and simultaneously pulled through a second inverted jammer, which is attached to the anchor. The hauling can be continued with the slack gained on each lift being held in the anchored jammer. Once slack rope is available, the system can be altered to a different hauling system or to lowering. A high belay is desirable for ease of operation and to facilitate getting the victim off at the top. Three methods of hauling on a taut rope are described.

4.1. Direct Lift. (Fig. 6).

4.1.1. Clip long cowstail into main belay for safety.

4.1.2. Put the foot ascender upside down on the rope below the knot and attach it to the loop of the belay with two karabiners (only one needed with handled ascender).

4.1.3. Rig your chest ascender upside down between chest and sit harness, clip onto rope.

4.1.4. Bend down slightly with a squatting action and stand up, keeping your back straight. The victim is lifted by your strongest muscles.

4.1.5. Pull the slack gained through the inverted foot ascender. The cycle is repeated as necessary.

4.1.6. It is possible to hang from the main belay by a cowstail (Fig. 7) standing up in your footloops, though this may cut into your feet. It is easier to stand up on ledges, but the pull must be vertically in line with the belay, otherwise you will waste effort or get friction on edges. Unused equipment can be used to weight the locking ascender or footloop clipped in directly.

4.1.7. Comment. This is the simplest method, but also the most strenuous. Several short squat lifts are easier than one big one and stand less chance of damaging your back. There is no problem with friction over pulleys, etc. The main disadvantage is the need for a comfortable stance which may not be available with a free hanging rope. The method is best for a very short lift or to get slack before changing to a better hauling system.

4.2. Pulley Lift with Footloop (2:1 Advantage) (Fig. 8).

4.2.1. Attach long cowstail to main belay.

4.2.2. Attach inverted locking ascender to belay as above, with two karabiners.

Fig.7. Direct lift hanging from cowstail.

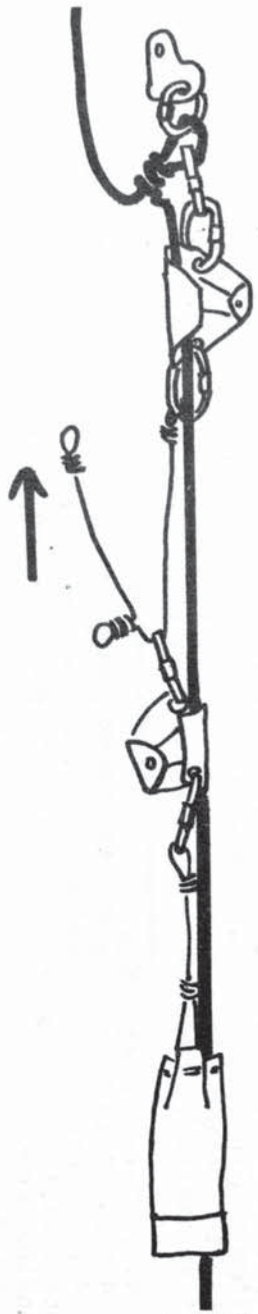

Fig.8. 2 : 1 pulley lift with footloops.

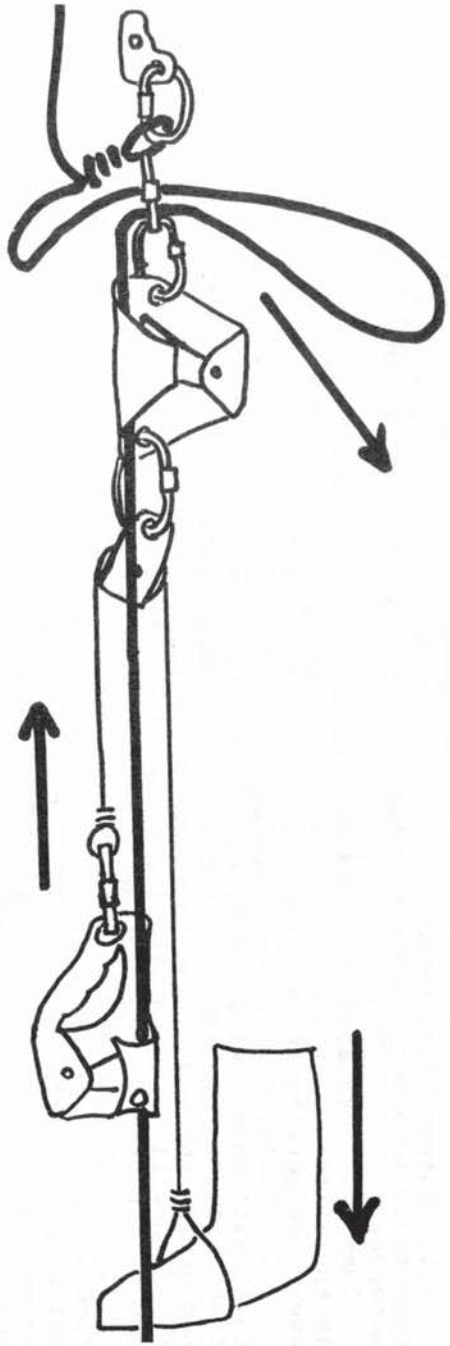

Fig.9. Counterbalance (Yosemite lift).

4.2.3. Clip end of footloop/chest harness etc. to bottom of locking ascender pass down through karabiner (pulley better) on weighted inverted ascender and back up.

4.2.4. Pull on footloop or attach to harness and do squatting lift. The load is theoretically halved. Pull slack rope through locking ascender. The lower ascender will slide down after each lift if weighted and the cycle repeated.

4.2.5. Comment. Suitable to gain initial slack before changing to a better system. Longer hauling is possible, but tedious.

4.3. Counterbalance Lift (Yosemite Lift) (Fig. 9).

4.3.1. Clip your short cowstail into the karabiner holding the rope.

4.3.2. Fix an inverted ascender below the knot with two karabiners linked to the loop of the belay.

4.3.3. Clip a karabiner (and pulley if available) into the lower hole of the locking ascender.

4.3.4. Put the foot ascender on the rope upside down, with the foot loop running over the pulley (karabiner) of the locking ascender.

4.3.5. Standing in the footloop with your full weight, while pulling upwards on the lower ascender (much easier with a handled ascender) will lift the victim. Slack rope is then pulled through the locking ascender.

4.3.6. Comment. This method is the most suitable for hauling as it is simple and less strenuous. It can be done from a ledge or hanging by a cowstail, which incidentally is a sure way of putting all your weight on to the footloop.

4.4. Lifting the Victim off the Rope at the Pitch Head

4.4.1. Clip the victim's long cowstail into the traverse rope at the first opportunity.

4.4.2. Using the counterbalance method, clip your footloop into his central maillon and step down to lift him a little, while you open the cam of the locking ascender.

4.4.3. Lower him until his weight is on the long cowstail, this may take more than one lowering cycle.

4.4.4. Once he is free of the rope, how you get him into a safe place depends on the situation. You can slide him along the traverse rope; use the rope from below to haul him or just grab hold and heave - but make sure you are securely fastened on yourself.

4.5. Intermediate Belay Points

If you are hauling, it is possible to haul from the intermediate belay above the victim. Remember to attach your chest ascender by a karabiner to the central maillon, then you can remove it easily while hanging on the cowstail. Using the counterbalance method, lift the victim level with the belay.

4.5.1. Clip your footloop into his central maillon and lift him as high as possible.

4.5.2. Fasten the victim's foot ascender onto the rope, as high as possible above the rebelay.

4.5.3. Stand on your footloop sufficiently to allow you to open the cam on the locking ascender.

4.5.4. Lower him down until he is hanging by the "safety" rope of his foot ascender. If there is a lot of rope above the rebelay, you may have to repeat the lowering cycle to get rid of the stretch.

4.5.5. The victim is free of the lower section of rope. Clip his cowstail into the belay, before removing his chest ascender and transferring it to the upper rope. Unfasten the rebelay. Transfer the victim's weight back to his chest ascender so that the foot ascender can be used later.

4.5.6. Put your own ascenders on the rope between his ascenders.

4.5.7. Run the footloop from his central maillon over his foot ascender karabiner like a pulley to your foot.

4.5.8. Step in the loop to lift him, so that his weight is transferred to the chest ascender.

4.5.9. Comment. This technique makes such a lift possible, but it takes a long time.

5. HAULING WITH THE MAIN ROPE IN A Z-RIG

The Z-rig can be assembled once slack rope is available, using any of the hauling methods 4.1, 4.2 or 4.3 above. (3:1 Advantage) (Fig. 10).

5.1. The chest ascender is used as the locking ascender and is clipped into the loop of the belay, with two karabiners.

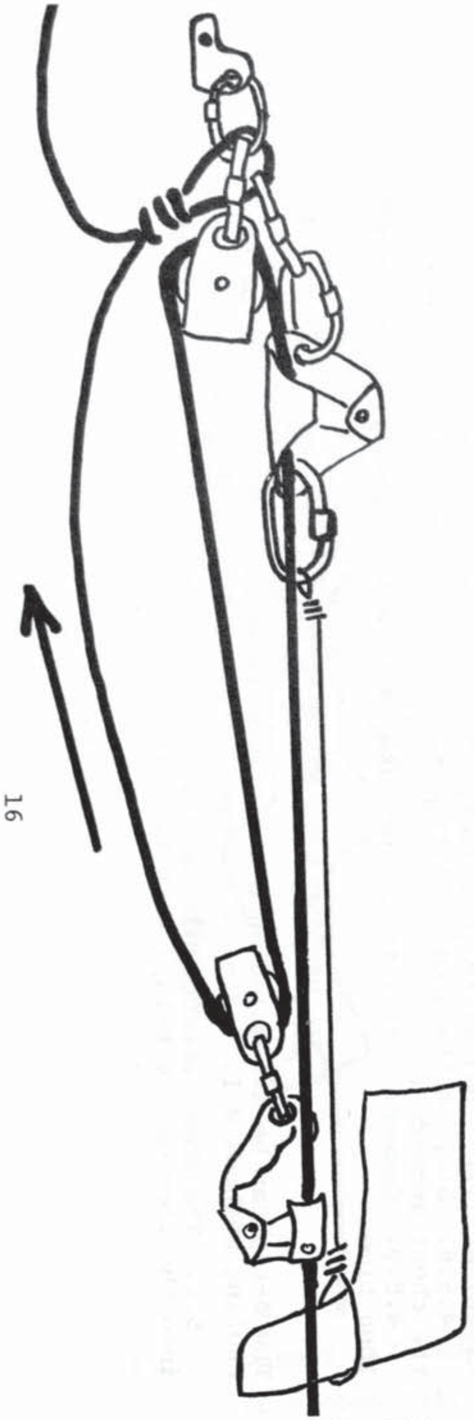

Fig. 10. Z - rig.

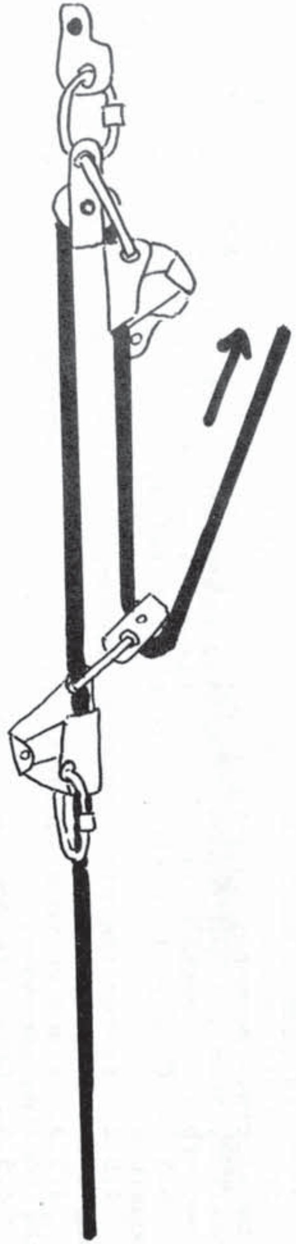

Fig.11. Z - rig.

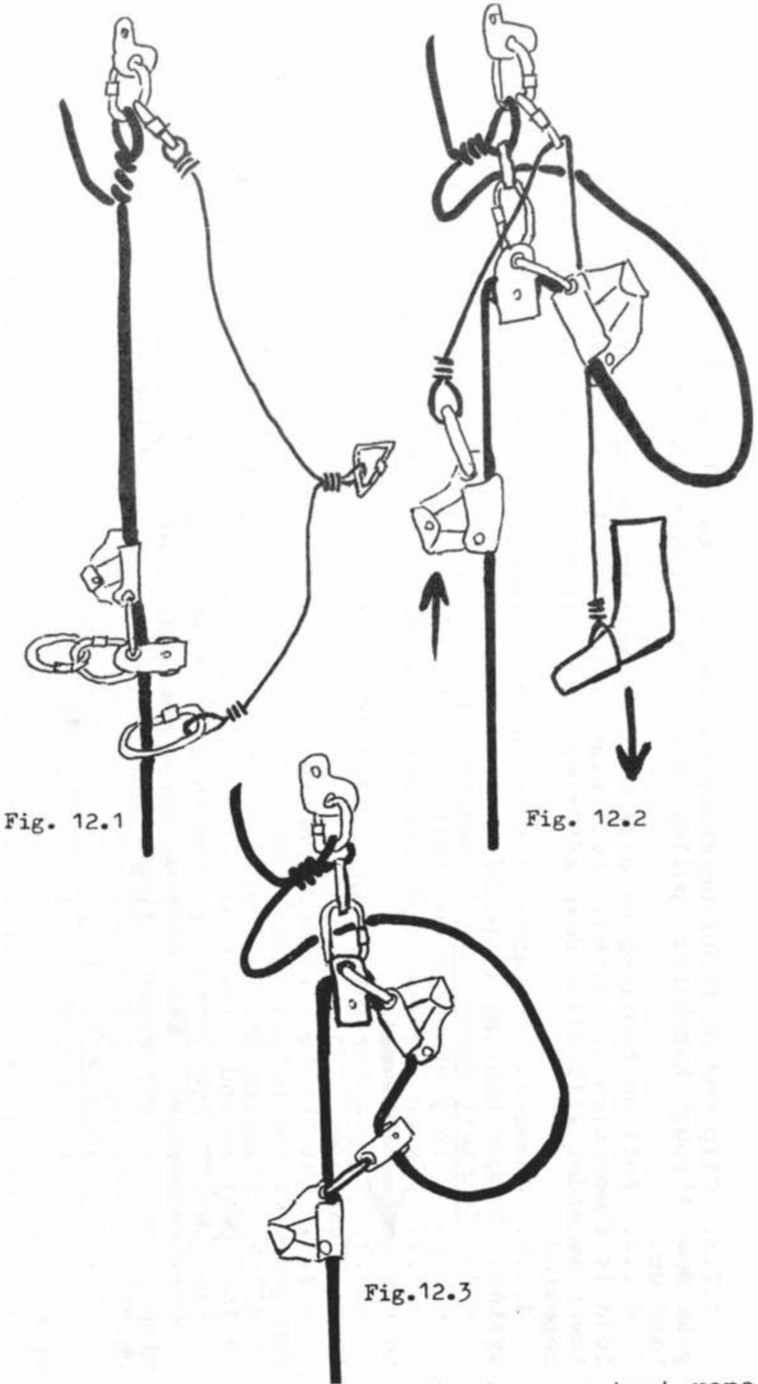

Fig.12. Stages for placing a Z-rig on a taut rope.

5.2. A pulley is clipped to the belay karabiner, the slack rope fed over the pulley and down to the inverted ascender to complete the Z-rig. A pulley wheel on a karabiner is adequate for the lower ascender. In order to prevent the locking ascender from rising with each lift, clip your footloop into the lower hole and stand on it. The moving ascender will slide back down after each lift if weighted.

5.3. A similar but slightly better system is to put a pulley-jammer unit, rather than just a pulley into the belay karabiner (5.2) above. (Fig. 11). This needs a third ascender or prusik loop to lift the loaded rope, while the cam is opened on the locking ascender to transfer the weight to the pulley jammer. The locking ascender is then free to complete the Z-rig. Of course if the rope is slack to start with, assembly of the Z-rig (Fig. 11) is easy, and only needs two ascenders.

5.4. Marbach and Rocourt describe how to put a pulley jammer on a taut rope. (Figs. 12.1, 12.2, 12.3).

5.4.1. The pulley and jammer are put on the rope with a cowstail clipped below them to stop them sliding down. It is very difficult to get the karabiner through both holes of ascender and pulley. You may end up with the karabiner through only three of the four holes - be careful not to drop anything (Fig. 12.1).

5.4.2. The footloop is fastened to the inverted jammer, fed over a karabiner attached to the belay karabiner.

5.4.3. Stand up in the footloop and pull on the inverted ascender as a counter-balance to lift the loaded rope (as method 4.3., Fig. 9).

5.4.4. Clip together the pulley-jammer assembly (if not already done) and attach to the loop of the belay with an extra karabiner (Fig. 12.2).

5.4.5. Repeat the cycle until you have sufficient rope to use the Z-rig (Fig.12.3)

5.5. Comment. The Z-rig is quite efficient, but still not easy enough to contemplate hauling very far by yourself. If you have abseiled off initially, it can be assembled easily on a slack rope and with two or more people can be used as a means of evacuating the victim. Handled ascenders aid hauling on the free rope.

6. COUNTERBALANCE WITH PULLEY-JAMMER

This is a very efficient, not very strenuous hauling method, suitable for evacuating a victim from the bottom of the pitch (Fig. 13). Three ascenders are required, but one can be taken from the victim. The rope is tied directly to the victim at the bottom. It then passes over a pulley jammer at the pitch head. Put both your ascenders on the rope for normal prusiking at the ascender side of the pulley. Lift up on the loaded rope and you will descend as your weight counterbalances the victim. You have two choices:

6.1. Continue to descend until you meet the victim half way up, attach the two long cowstails. Prusik up the rope until the cowstail is tight, sit down and lift on the victim's rope. He will rise as you descend. Repeat the cycle until he is at the top.

6.2. Attach a long cowstail to the main belay and descend/prusik etc. until he is at the top. You will have prusiked twice the pitch length, lifting the difference in weight plus friction.

6.3. Comment. The rope and belay point must be good. The technique will work quite effectively with people of differing weights. The system works with just a pulley at the top, but can cause problems when you get off at the pitch head. An additional hauling rope or life line will make lifting easier if extra assistance is available.

7. LOWERING

7.1. Lowering from the pitch head is only possible if an extra rope is available (Fig. 14). If the rope is loaded initially, it is necessary to haul using one of the methods described, to get sufficient slack to unfasten or cut the rope.

7.2. The rope is then joined to the spare rope, which is locked off through an anchored descender.

7.3. To transfer the load to the descender, haul on the rope again and release the cam on the locking ascender. Do this reverse hauling in short stages, until the descender is loaded.

7.4. The descender is released and the victim lowered.

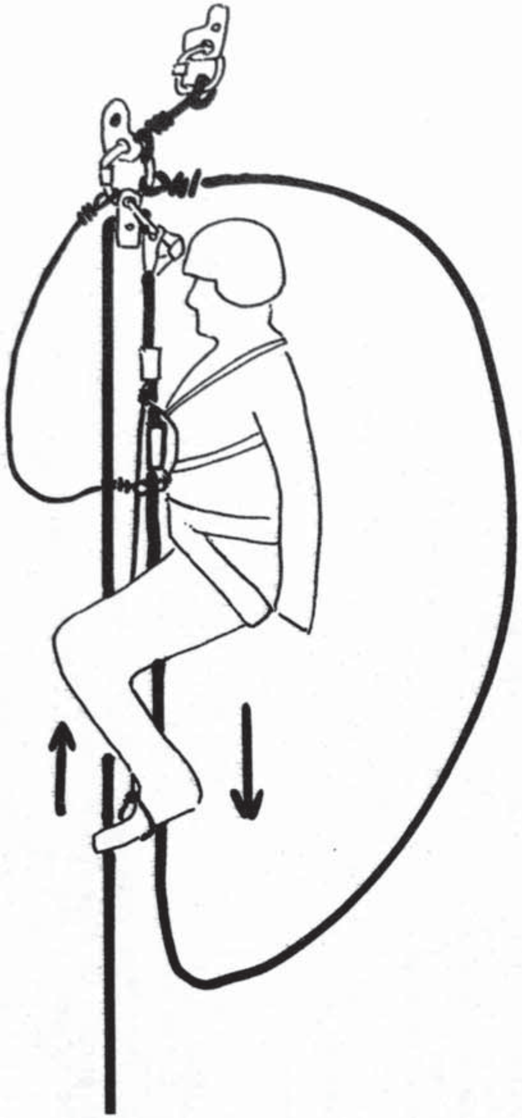

Fig.13. Counterbalance with pulley jammer.

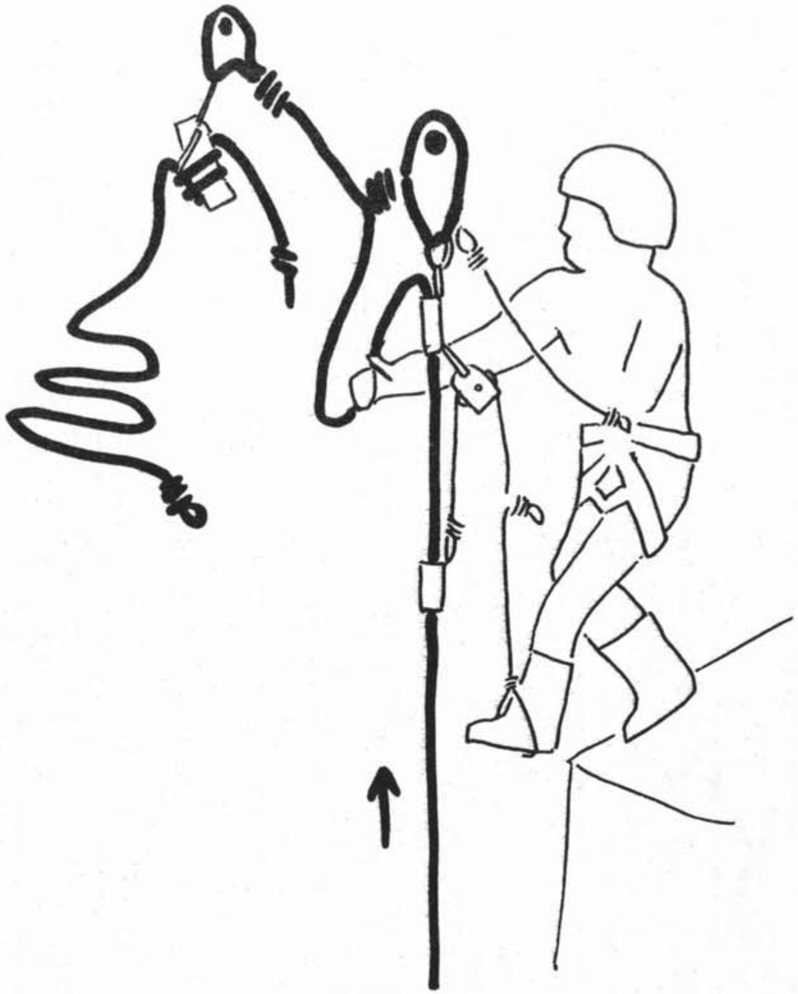

Fig.14. Lowering from pitch head.

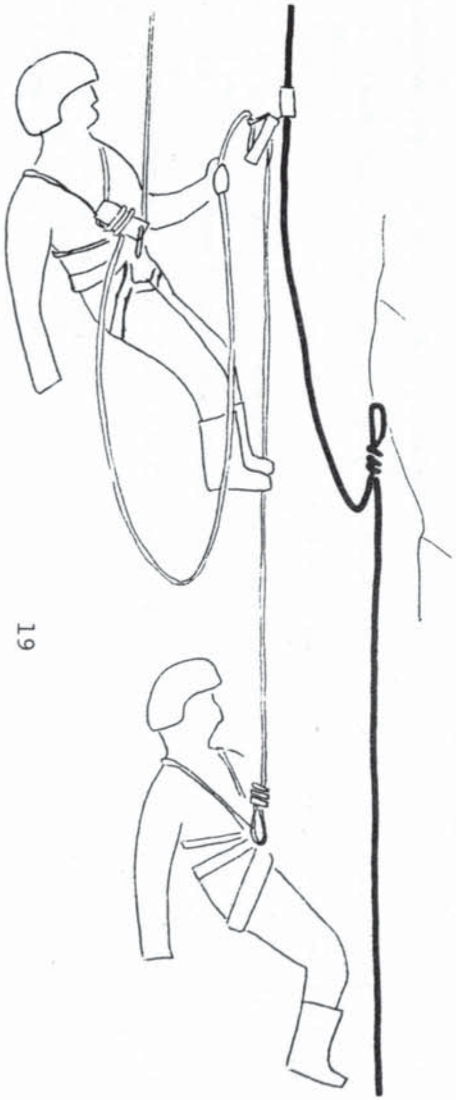

Fig.15. Mid-rope lowering.

Fig.16. Bachmann self-locking knot.

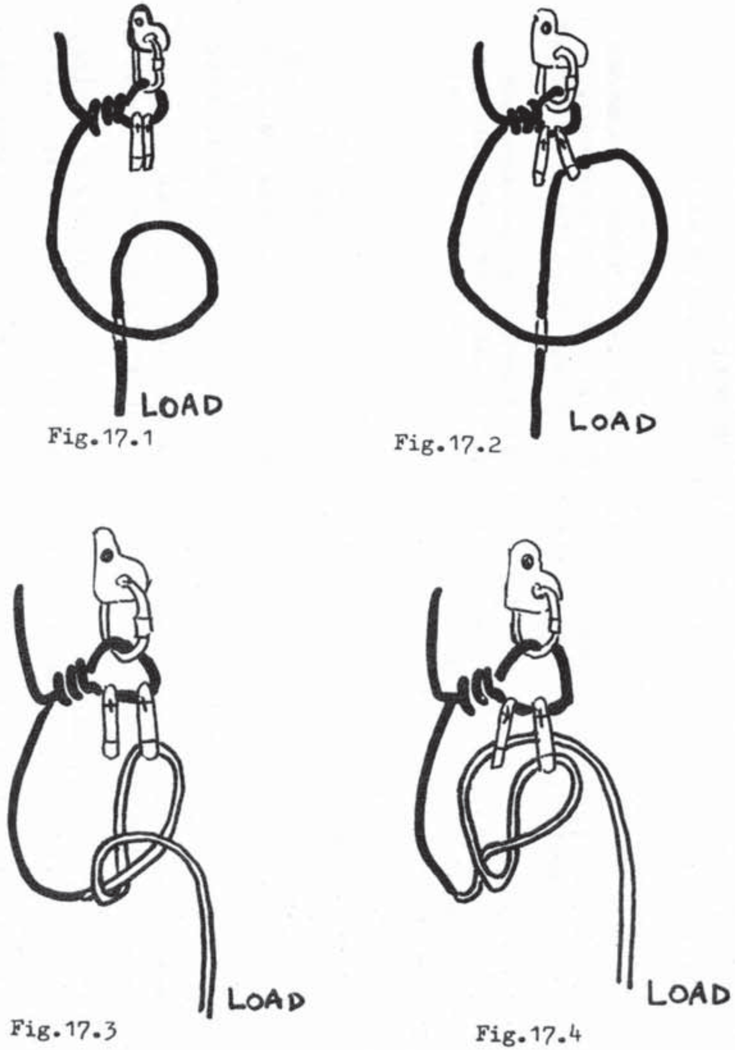

Fig.17. Self-locking knot.

8. MID-ROPE LOWERING

This is a way of dealing with a rope that is rebelayed part way down the pitch (Fig. 15).

8.1. Abseil down the spare rope, which must be as long as the pitch, or at least from the rebelay above the victim to the bottom.
8.2. Lock your descender, and attach yourself to the victim with your cowstail.
8.3. Take the victim's descender, foot ascender and two karabiners. Put the ascender on the pitch rope above the victim and attach the descender.
8.4. The lower end of the spare rope is tied to the victim's harness, threaded through the descender leaving as little slack as possible and locked off.
8.5. Use a footloop over a karabiner (or pulley) attached to an ascender on the pitch rope, to counterbalance the victim sufficiently to release his chest ascender and transfer him to the descender.
8.6. Unlock the descender and lower the victim.

9. IMPROVISATION

If you do not have the necessary equipment improvisation can sometimes provide a substitute, but safety should still be the main consideration.

9.1. Jamming (prusik) knots are probably the most useful but are well described elsewhere.
9.2. A Bachmann knot is a particular jamming knot which can be made into a self-locking knot. (Fig. 16).
9.2.1. The prusik loop is clipped through the karabiner and then wound several times around the rope. It is tied off very short to minimise the distance lost with each lift.
9.2.2. Ideally the Bachmann karabiner is bigger than the pulley karabiner, then it will loosen the knot and allow therope to slide over the pulley, but will not slip through itself.
9.3. Self-locking descenders can be substituted for the locking ascender used in hauling.
9.4. Marbach and Rocourt describe a self-locking knot which is a variation on the relatively common Italian hitch knot. (Figs. 17.1 to 17.4).
9.4.1. Two karabiners are side by side in a loop of the rope with gates towards you and hinges at the top.
9.4.2. The loaded end passes behind the slack rope. (Fig. 17.1 — 17.4).
9.4.3. Put the loaded end into both karabiners. (Fig. 17.4.)
9.4.4. To convert to Italian hitch - remove the left hand karabiner which allows you to lower. Alternatively, tie an Italian hitch and insert an extra karabiner to give a self-locking knot. Remember the loaded rope goes over two karabiners. Insert the extra one behind the Italian Hitch karabiner.

CONCLUSION

The techniques which rely on utilizing the victim's gear may not be possible with a victim using a Ropewalking or Mitchell rig, etc., so flexibility and improvisation may be necessary. The more practice you have with the various methods the more proficient you will be in a real situation.

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ALKALINITY, ITS MEANING AND MEASUREMENT

L. Rose

It is argued that the alkalinity concept has recently been downgraded. The meaning of alkalinity is discussed, including the definition that it is only a measure of how much $CaCO_3$ and $MgCO_3$ has been dissolved. It can be determined accurately by means of a blanked titration. In the experimental part, the standard deviation of such titrations is measured by repeated blind titrations. Two proofs are given that blanking corrects for overshoot in the main titration. The old belief that CO_2 causes error is discarded. Ways in which alkalinity can be used in speleology are described.

Returning to water chemistry in my 70th year, and after a gap of 30 years, I find a remarkable change in the status of alkalinity and its measurement. In 1940 and earlier we were confident that alkalinity was a perfectly straightforward concept, measured to a high precision and accuracy. We measured it on every sample of water, so fundamental was it to us. Today it is not so regarded, or not so universally regarded. Today's workers seem mainly to use it for correlations with items like [Ca] or pH, and do not value it for its own sake. They have changed the method of estimation and in consequence appear to have introduced errors. I cannot avoid the impression that many workers are not as familiar with alkalinity as I and my generation were.

I propose to redescribe alkalinity and its measurement, with the aim of restoring the esteem it once had. I shall demonstrate its precision, and by using two methods, one of which I devised 38 years ago, I shall prove that the results are very accurate. These same proofs also dispose of a common belief that the method I describe suffers from errors introduced into the system by CO_2, errors that depend on Total CO_2.

Now to the meaning of alkalinity: it was a measure of titratable base content, specifically the sum of all entities (ions and molecules) that can be titrated with standard acid, then 0.1 N H_2SO_4. It was carried out on 500 ml of water using Methyl Orange as indicator, and was characterised in that a second titration (the blank) was carried out subsequently on distilled water in a precisely matching way. The effective titration is the first titration minus the second titration. For 500 ml samples, 10 times the blanked titration is the alkalinity in p.p.m., as $CaCO_3$, or M x 10^{-5}. This unit M x 10^{-5} is the modern equivalent of the prewar p.p.m. as $CaCO_3$. Full details are in the Appendix, but the acid is 0.1 M HCl today.

In 1940 we did not know all the minor components calculated by Picknett (1973) for calcite solutions, but we knew accurately the quantity of standard acid it would take to react with them all. We further believed that the result was independent of all CO_2-related equilibria in the water. I have no means of knowing what speleologists believe about this today, but if I may generalise from a few to whom I have submitted my view, this is the nub of the matter. They tell me that Alkalinity is involved in the dynamic equilibria among a number of ionic and molecular reactions. In fact, the connection is tenuous. Unless changes in equilibrium result in precipitation of $CaCO_3$, or in more limestone dissolving, alkalinity is unchanged. The descriptive term for this is "conservative". Alkalinity is a conservative quantity, and in this phraseology it is introduced in Stumm and Morgan (1970, p.129).

I quote from my own war-time lecture notes to textile students: "S.B.V., that is alkalinity, is a German concept of acid-combining power, and it is not affected by CO_2 exchange per se. If CO_2 is lost or gained, alkalinity remains untouched. Only if $CaCO_3$ precipitates does the alkalinity decline, and even then only if $CaCO_3$ is lost to the sample, since solid $CaCO_3$, and $CaCO_3$ in CO_2 solution have equal titration. It therefore follows that a sample of water has its alkalinity preserved indefinitely if the required water is measured out in the field, provided it is subsequently titrated in that same bottle". Compare this with the following: "alkalinity has several sources of error. The true end-point varies slightly with the total CO_2 content". (Mackereth et al., p.52, 1978). It is not true for the alkalinity I describe, and I thought this idea had been abandoned 35 years ago. We then had a dictum: "Alkalinity is not affected by the addition or subtraction of CO_2 in any quantity". Students were quite familiar with these ideas. They were required to show in practical classes that boiling a water containing temporary hardness (driving off CO_2, precipitating $CaCO_3$) left the alkalinity unaffected. To us, alkalinity was no more, and no less than an acid titration of the $CaCO_3$ and $MgCO_3$ dissolved. We demonstrated this: 250 milligrammes of pure $CaCO_3$, suspended in water and dissolved by CO_2 at a Kipps Apparatus, was made up to 1 litre. 500 ml of this had a titration (blanked) of 25.0 ml, and an alkalinity of 250 p.p.m. as $CaCO_3$, if the $CaCO_3$ was pure enough. A titration of 24.9 was usual in class work.

A curious wording is sometimes used as a way of regarding alkalinity, that to me betokens confusion somewhere. Alkalinity is called an "operational" quantity (Mackereth et al. 1978, p.20 and p.50), whereas calcium is called an "analytical" quantity. I will not try to discuss the distinction, but I simply state that alkalinity and Ca stand pari passu. Both of them are the results of analyses; both are the sums of component species. If we refer to Picknett (1973) Table 5 we see that, quantitatively, the following relationships in millimoles hold :-

$$\left[\text{Ca Total}\right] = \left[Ca^{2+}\right] + \left[CaH^{+}CO_3\right] + \left[CaCO_3^{0}\right]$$

$$5.00 = 4.73 + 0.226 + 0.04$$

In that same Table we also see that :-

$$\left[\text{Alk Total}\right] = \tfrac{1}{2}\left[HCO_3^{-}\right] + \left[CO_3^{2-}\right] + \tfrac{1}{2}\left[Ca^{+}HCO_3\right] + \left[CaCO_3^{0}\right]$$

$$= 4.845 + 0.0021 + 0.113 + 0.04$$

$$= 5.00$$

In other words, for this solution, $[Ca] = [Alk]$. This identity is not generally true in karst waters, but it is always true for all solutions of calcite in CO_2 water. The identity is a useful way of proving the accuracy of an alkalinity measurement, by checking it against a calcium analysis on a calcite solution.

It might help us to recall all this if we think of total calcium as $[\Sigma Ca]$, and alkalinity as $[\Sigma Alk]$. Chemists will note that by putting $[Alk]$ in square brackets, I imply a molarity. This is indeed intended. It is the number of gramme moles of carbonate (calcium and magnesium carbonate) dissolved per litre from the limestone. Some people measure it in equivalents today (HCO_3^{-} + 2 CO_3^{2-} + $Ca{+}HCO_3$ + $2CaCO_3^{0}$), and this of course is valid. But it is in the highest degree convenient to have Alk. and Ca and Mg all in the same mode, and since we use molar mode for the metals it should be molar mode for alkalinity. This is the real reason for the traditional use of 500 ml rather than 1 litre for alkalinity analysis.

On the subject of molarities in water chemistry I would like to be allowed a small digression. Scientists today often equate $1 \times 10^{-5}M$ with 1.00089 milligramme of $CaCO_3$ per litre (p.p.m. $CaCO_3$). Quite so, but no one I have found realises that p.p.m. as $CaCO_3$ (which they misquote as p.p.m. $CaCO_3$) does not mean parts per million $CaCO_3$, or even $CaCO_3$ equivalent. The unit p.p.m. as $CaCO_3$, in its prewar definition is in $M \times 10^{-5}$ units precisely. We used it to refer to Ca, to Mg, for both together, for alkalinity and for free CO_2. Pending the day when we all return to molarity we have to know the following:-

1 meq/litre = 50 p.p.m. as $CaCO_3$ = $50 \times 10^{-5}M$ = 0.5mM

= 50.045 p.p.m. $CaCO_3$.

As I have already said, today's alkalinities are in error because the method has been changed. The old method used a blanking procedure. I do not know who invented alkalinity blanks, as it was before my time in industry, but we can easily follow his line of logic. Prewar water chemists knew that CO_2 in any concentration met at alkalinity end-points does not turn the Methyl Orange indicator. So when in an alkalinity test the indicator turns, it is quite certain the titration is overshot. But by how much? The question was answered by some clear-thinking individual who argued that part of the overshoot involves the use of acid to bring pure water to the end-point, and part to titrate the indicator itself. So the proposal was made to carry out a blank, using the same amount of indicator on pure water of the same volume as the sample. This blank would be subtracted from the main titration to yield the true alkalinity titration. Blanks vary with the indicator. For Methyl Orange over my working life I have found the blank to be between 0.35-0.50 ml., i.e. 3.5 to 5.0 p.p.m. as $CaCO_3$. Today, with newer indicators it is different. For example, with BDH 4.5 it is 1.2-2.5 p.p.m. as $CaCO_3$.

I puzzle over why blanked titrations seem to have been forgotten or decisively rejected. It cannot be regarded as too onerous, as the extra work is trifling. I think it has to do with the regrowth of an idea, ill-founded as I believe it to be, that direct titrations to fixed end-points are necessarily prone to a CO_2-induced error, an error related to total CO_2 content of the water. This idea (regarded as a reason for condemning the old titration) has received great support from the emergence of a standard method (anon, 1960; Golterman et al., 1978) in which the titration is taken to an end-point that varies with total CO_2. The pH of this end-point is discovered from a prior rough analysis with indicator to determine the approximate alkalinity, thence to the approximate total CO_2, thence to a pH equal to that of the CO_2 in water at the relevant temperature. A titration to this pH then yields the true alkalinity. I have used this method, and it yields almost exactly the same answer as by my method. I think it is soundly based in theory, but very difficult to apply. It depends on being able to complete the titration with near-zero loss of CO_2. This can be achieved with some difficulty in a laboratory, but is of no interest for field use.

There is such a thing as CO_2 variability, but it is wrong to assume it applies everywhere. It does not occur in my alkalinity method: I proved this in 1941 on the first occasion the CO_2 myth arose. It seems it has to be proved again.

So much is the CO_2 myth evident that I have just a single reference to support my viewpoint. With (for me) perfect timing it appeared as this was being written. Sutcliffe et al. (1982) plot alkalinity by two methods against each other, one a direct titration (no blank) to pH 4.5 using BDH 4.5 indicator, the other a Gran titration result, each pair on the same sample. The Gran plot (Talling, 1973) is a laboratory-based electrochemical method for alkalinities, regarded by those experienced in it (the writer included) to be highly accurate. A plot of 145 pairs shows the Gran figures below the BDH 4.5 figures by 19.9-22.1 micro-equivalents per litre, systematically and quite independently of the alkalinity value. But CO_2 error cannot possibly be the cause of this 20 micro-equivalents discrepancy. If CO_2 influences the end-point of BDH 4.5 titration, it must have slightly taken the place of HCl which would otherwise have had to be used. In other words CO_2 errors are negative, if present at all. There is no way in which CO_2-error can make a BDH 4.5 indicator end-point 20 micro-equivalents per litre more than the true value. But the need for a blank can and does so. Under the conditions used for this BDH 4.5 titration, the blank value is 0.11 ml, or 1.1×10^{-5}M, or 22 micro-equivalents per litre!

In the next section, the Experimental part, I prove some of the things I have asserted here, and also measure the precision.

EXPERIMENTAL SECTION

In this section are given the results of experiments designed to show the validity of the alkalinity method as described in the Appendix. As a preliminary, all the volumetric glassware used was recalibrated. The burette used was of B quality, but when weight-calibrated was converted to a high precision burette. A special sample bottle with plug, volume 560.02 ml at 5^oC was used throughout. In the earliest reported work, HCl of 0.1088 M was used, but later, 0.1 M HCl exactly was available. Some of the studies involved [Ca] determination by the Eriochrome Black T method (Schwarzenbach et al, 1946; and Martell and Calvin, 1952). The EDTA solution (3.992 g of Analar EDTA, disodium salt, dihydrate, plus 0.1 g of magnesium sulphate monohydrate, plus 10.0 ml 1.0 M NaOH, all made to 1 litre) was standardised against a standard calcium solution using ammonium chloride-ammonia buffer and Eriochrome Black T as indicator. The standard calcium was not regarded as the prime standard. The calcium had been repeatedly calibrated in terms of the 1.000 M HCl that was used in dissolving Analar $CaCO_3$. In this way, a well tested link was established between the EDTA used in the work for calcium determination, and the HCl, obtained after 10 fold dilution, that was used for alkalinity. The result of this preparatory work was that if the BDH "Convol"* prepared HCl is taken as exactly 0.1000 M for alkalinities, the EDTA is 0.00999 M.

Two supplies of BDH 4.5 indicator were available, an old and almost completely used bottle, with a 0.6 ml blank in 560 ml of 0.25 ml; and a new bottle with 0.14 ml. Both of these were used.

The burette is marked at 0.1 ml intervals, but with care can be estimated to the nearest 0.01 ml, and this precision is preserved through the calibration process.

The Precision of the Estimation

On 6 days in March-April 1982, 2 polythene winchesters (enough for 8 alkalinities) were filled at Senset Well, Warton, Carnforth, and analysed using "blind" titrations (see Appendix).

In late February and early March, rainfall was high, but later it diminished and virtually stopped on March 15th. As a result the level of alkalinity rose dramatically - but this is of no present interest. We are concerned with the variation in each group of 8 estimations, on each of the 6 days. Table 1 shows the results. The volume of water was 560.02 ml., the acid was 0.1088 M, and 0.6 ml of BDH 4.5 indicator was used.

TABLE 1

Date (1982)	4 Mar.	11 Mar.	18 Mar.	25 Mar.	18 Apl.	21 Apl.
Well Temp. °C	5.0	5.0	5.0	5.0	5.0	5.0
Titrations (1)	21.25	23.55	26.35	26.64	27.15	27.16
(ml) (2)	21.29	23.59	26.28	26.71	27.10	27.12
(3)	21.33	23.56	26.32	26.63	27.12	27.13
(4)	21.36	23.48	26.36	26.69	27.22	27.16
(5)	21.37	23.57	26.29	26.63	27.16	27.20
(6)	21.33	23.59	26.30	26.64	27.09	27.14
(7)	21.26	23.56	26.39	26.69	27.15	27.12
(8)	21.29	23.54	26.37	26.70	27.08	27.18
Blank-ml	0.24	0.23	0.23	0.23	0.23	0.23
$\bar{x}$ of titrations	21.310	23.555	26.333	26.666	27.134	27.151
S.D. of titrations	0.0444	0.0351	0.0406	0.0342	0.0460	0.0290
[Alk] $\times 10^{-5}$M	204.7	226.6	253.6	256.8	261.4	261.5

We have here a group of 6 estimates of the S.D. of the titration, and their mean and S.D. are 0.0382 ± 0.0066 ml. To convert these to M $\times 10^{-5}$ units we multiply by 9.715, or 500/560.02 x 10.881. The final result of this work is a standard deviation 0.371 ± 0.064 p.p.m. as $CaCO_3$.

All the above estimations were carried out on the verbally described BDH 4.5 end-point. However, a further set of 6 8-fold estimates using a master end-point have been carried out. This master was an acetate-acetic buffer brought to neutral grey indicator colour, and used for matching all end-points in the test. Table 2 shows the mean and standard deviations of the second set. However the second set was done with 0.1000 M HCl, and thus the factor converting ml of blanked titration to alkalinity is 8.928, that is 500/560.02 x 10.

* BDH "Convol". Ampoules of chemicals that when diluted to 1 litre or 500 ml yield standard solutions accurate to 0.1%. Essential for making 0.1 M HCl for water analysts having no proper laboratory facilities.

TABLE 2

Date	May 5	May 8	May 9	May 16	May 20	May 25
Blank-ml	0.14	0.14	0.14	0.14	0.14	0.14
$\bar{x}$ titration, ml	28.715	28.632	28.804	28.127	28.306	27.402
S.D. of titration, ml	0.0322	0.0381	0.0331	0.0363	0.0354	0.0390
[Alk.] ppm as $CaCO_3$	255.1	254.4	255.9	249.9	251.5	243.4

The population of 6 estimates of standard deviation have the following characteristics in ml: 0.0357 ± 0.00269, or converted to concentration 0.319 ± 0.024 p.p.m.

These results are somewhat better than with the verbally-described end-point, but the number of results is too few to be satisfied the difference is real. It was largely upon these two tests that I changed from Methyl Orange to the modern BDH 4.5 Prewar results on Methyl Orange had standard deviation 0.85 p.p.m. as $CaCO_3$.

Proof of Accuracy : Method 1

There are several methods that satisfy the critic as to accuracy of alkalinity estimations. One is the measurement of the second derivative of the curve of ml.acid added, plotted against pH. At the true end-point the curve is at an inflection where the second derivative is zero (Hostetter and Roberts, 1919). A second method is the Gran titration, brought to a high performance by Talling (1973). Both of these are essentially laboratory-based methods involving the use of the very best of commercial pH-meters, with a performance much more discriminating than the ordinary laboratory pH meter of precision 0.01-0.02 pH unit. I have used both of these with satisfactory results, satisfactory that is to say for the claims of the old method. However, for several reasons, not least because anyone who can do an alkalinity can check my results, I would like to describe a method I first used in 1944. I find it elegant, and quite convincing.

This method started with a question. Suppose, I asked myself, that I take a water sample and add to it an amount of acid exactly equal to the true alkalinity, and I boil it well and cool it, what will the pH be? Since the solution now has nothing but non-hydrolysing ions, the answer is pH 7. Now suppose I do an ordinary alkalinity measurement and repeat the process. On the understanding we have, it will go acid, and this being pure mineral acid it can be titrated to pH 7 without indicator error. If the ideas are correct, the final titration to pH 7 using 0.1 M NaOH will precisely equal the blank of the ordinary Alk test. The essential point about this sort of test is that in the total absence of CO_2 there is no CO_2 error.

Table 3 shows the results of four such tests. Two water samples were involved on successive days in June 1982, on the first of which after the sample was taken, there was an enormous rainstorm. The waters of Senset Well, Warton fell dramatically in concentration in the next 24 hours by over 10%. Each water sample was analysed in duplicate.

Two sorts of blank were used, the old bottle with 0.25 ml blank, and a new one with 0.14 ml. This was done to check that the method could cope with such discrepancies.

In the first instance blind unblanked titrations were measured on 560.02 ml water, using 0.6 ml of BDH 4.5, and titrating with 0.1000 M HCl. Immediately a second quantity of 560.02 ml was taken, no indicator, and exactly that same amount of HCl added to it, all in a 1500 ml Pyrex beaker. It was slowly heated to its boiling point (covered with a large clock glass) and boiled for 10 minutes. After cooling to room temperature, the beaker and clockglass surfaces were washed down and the contents titrated from a 2 ml burette with 0.1 M NaOH, using 3 drops of Universal Indicator and titrating to pH 7. The results are in Table 3.

TABLE 3

		June 5 (1)	June 5 (2)	June 6 (1)	June 6 (2)
Alkalinity Titration	0.1 M HCl (ml)	28.48	28.38	25.62	25.53
	Blank (ml)	0.25	0.14	0.25	0.14
	Difference (ml)	28.23	28.24	25.37	25.39
	[Alk.] x 10^{-5}M	252.1	252.1	226.5	226.7
Back Titration	Added 0.1 M HCl	28.48	28.38	25.62	25.53
	After boiling, titration with 0.1 M NaOH to pH 7, ml	0.23	0.13	0.22	0.16
	Difference	28.25	28.25	25.40	25.37
	[Alk.] x 10^{-5}M	252.2	252.2	226.8	226.5

These results confirm the claim for accuracy well.

Proof of Accuracy, Method 2

Earlier it has been pointed out that when $CaCO_3$ dissolves in water with the help of CO_2, the resulting solution has [Alk.] exactly equal to [Ca], unlike karst waters in general that not only have dissolved carbonates, but also sulphate. This equivalence between Ca and Alk. on calcite solutions provides a very convenient way of checking the accuracy of [Alk.] estimation because calcium estimation is recognised as of considerable accuracy.

The calcite solution was manufactured with the aid of a Sparklets apparatus, a domestic apparatus for manufacture of "soda water". It was cleaned and in it was placed one litre of distilled water, and about 1½ gr. of Analar $CaCO_3$. Into it was injected one 7½ gramme bulb of CO_2. The apparatus was shaken at intervals, and then left overnight. Next day, it was opened, and the freely gassing, slightly opalescent solution decanted. Approximately 500 ml was diluted to 2 litres in a volumetric flask, and as soon as it could be stoppered without blowing out the plug, the flask was sealed. All traces of opalescence quite quickly disappeared, and after a few hours it was ready for the next step.

I have in the past had trouble with calcium estimation when CO_2 is excessively high, and the ammonia buffer is overwhelmed. So I decided to reduce the still gross over-saturation of CO_2. My work plan called for the use of almost all the 2 litres of solution, so recourse was had to a pH meter. The whole 2 litres of gently gassing solution was emptied into a clean 3 litre beaker and left while the pH meter was buffered and readied for the task. The first reading was 5.8 pH. After a while, when with constant stirring the pH reached 7.1, the whole liquid was returned to the volumetric flask.

It is known that Eriochrome Black T may have an indicator blank. It was estimated on one tablet of BDH total hardness indicator, and it is indeed small. But since I used this blank when standardising the EDTA, I have to use it now. When a tablet is crushed in 100 ml of pure water, together with 15 ml of buffer (molar ammonium chloride plus 5 vols. of molar ammonia) the colour, though mainly blue is not the clear blue of the end-point, but has a touch of red. It takes 0.11 ml of 0.001 M EDTA (the 0.01 M material diluted tenfold) to make it perfectly blue. This quantity, 0.11 ml, 0.001 M, or 0.01 ml of 0.01 M EDTA, is the indicator blank.

Three blind titrations were carried out on 100 ml samples of water, using 0.00999 M EDTA. The results are in Table 4.

Following on this, and using 0.6 ml BDH 4.5indicator, 560.02 ml samples were titrated with 0.1000 M HCl, and BDH 4.5 indicator blanks were redone. The results of the alkalinity tests done in triplicate this way are also in Table 4. Once again, blanked alkalinity titrations are multiplied by 8.928 to calculate Alk., but blanked EDTA titrations need to be multiplied by exactly 10.

TABLE 4

Calcium estimation and Alk. estimation on Calcite solution

		(1)	(2)	(3)
[Calcium] Estimation	EDTA 0.00999 ml	23.82	23.79	23.85
	EDTA blank ml	0.01	0.01	0.01
	Difference	23.81	23.78	23.84
	EDTA consumed, corrected to 0.01 M	23.79	23.76	23.82
	[Ca] x 10^{-5}M	237.9	237.6	238.2
[Alk.] Estimation	0.1 M HCl - ml	26.88	26.86	26.83
	Indicator blank - ml	0.17	0.16	0.17
	Difference	26.71	26.70	26.66
	[Alk.] x 10^{-5}M	238.5	238.4	238.0

The means of these are as follows:

[Ca] = 237.9 x 10^{-5}M

[Alk.] = 238.3 x 10^{-5}M

Discrepancy 0.4 x 10^{-5}, or 0.17%.

This, too confirms the claims for the method.

CONCLUSIONS

The method of the Appendix provides alkalinity figures with a precision and accuracy of approximately 0.4 x 10^{-5}M. A single careful estimation (2 s) is good for ± 0.75 x 10^{-5}M and by replication, the figure can be reduced further.

Alkalinity is independent of changes to water samples until $CaCO_3$ is lost. It is a direct measure of $CaCO_3$ + $MgCO_3$ dissolved, in molar terms.

This most valuable scientific measure is as important as Ca or Mg analyses and perhaps more so, with the advantage that it is easily done.

A change to the esteem in which alkalinity is held may produce several changes in speleological procedures. It may, for example, bring about a change to Stenner's (1969) method for measuring aggressiveness of water. Stenner himself considered whether he might use alkalinity, but chose to use [Ca] estimation to monitor his test, on the grounds of accuracy. I believe the method of the Appendix is at least as accurate as [Ca + Mg] estimation, and definitely superior to [Ca] alone. I currently use Alkalinity in Stenner-type tests with great success and convenience. It also seems clear to me that the relationship between [Ca] and pH, so carefully researched by Picknett (1973) could equally well be expressed as a set of curves between [Alk.] and pH. At the moment I am unsure whether there would be advantage in so doing, but I think so. The [Alk.] versus pH situation is a more basic relationship than that between [Ca] and pH, although they coincide in the case of pure calcite solutions. I prefer to study [Alk.] rather than [Ca + Mg] in my denudation studies on limestone pavement surfaces. Again, it seems more basic to the chemical processes at work.

I shall welcome a debate on the use of alkalinity measurements. The method justifies putting considerable trust in it.

ACKNOWLEDGMENTS

I should like to express my thanks to Dr. J.F. Talling for information relating to Gran end-points and BDH 4.5 end-points. I am especially indebted to Dr. R.G. Picknett for advice on the writing of this report.

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APPENDIX

The Estimation of Alkalinity

In the main, the method here is the old prewar method but two changes (neither due to the author) have been adopted. One is the replacement of 0.1 N H_2SO_4 with 0.1 M HCl. The second is the use of BDH 4.5 indicator instead of Methyl Orange. Methyl Orange is not quite abandoned; it can with care be used by colour-blind persons (details available from the author) but for colour-sighted persons, BDH 4.5 is preferred. Its main advantage is its better discrimination at the end-point.

Apparatus

1 50 ml burette in a clamp-stand.
1 litre beaker, polythene or glass.
1 glass stirring rod (with policeman if glass beaker).
0.1 M HCl solution.
1 1 ml graduated pipette.
BDH 4.5 indicator (BDH Ltd., Poole, Dorset).
500 ml measure.

Method

500 ml of the water under test is placed in the beaker together with ½ ml BDH 4.5, and titrated with 0.1 M HCl in good daylight or under daylight lamp.

Commence the titration stirring rapidly. When the blue is replaced by a grey or pink haze, stop or slow down drastically. Grey or pink drifts back to blue, and when after adding 0.1 ml it takes more than one or two seconds to go blue again, proceed by 1-drop steps, and go slowly, but continue vigorous stirring. The time required for drifting back to blue increases. When it seems to take 20 seconds or so, slow down to ½-drop additions. The end-point is now near, and it is described as a grey colour, neither blue-grey nor pink-grey, that lasts for at least 90 seconds. A clock is useful at first. A 90-second end-point will usually stay at the end-point indefinitely (check). However, very high alkalinity and very low temperature sometimes make 90 seconds insufficient. If colour drifts at all after this time-interval, increase the time without hesitation.

Call the 90-second end-point T_1.

Now measure out 500 ml of distilled water, and add to it ½ ml BDH 4.5. Titrate this very slowly with the 0.1 M HCl, taking some 5-10 minutes. Call this T_2.

Now, if the water measured is exactly 500 ml, and the 0.1 M HCl has f = 1.000, then:

$10 \times (T_1 - T_2)$ = Alkalinity in units of 10^{-5} M <u>or</u> p.p.m. as $CaCO_3$.

In the paper there is a reference to blind titration. This is a technique of avoiding bias by hooding the burette, and only removing the hood to read the burette when the decision about the end-point has been taken. It is a technique always to be used in repetitive work, but is not necessary unless the operator already has an expectation of what the titration will be.

This estimation is sufficiently discriminating to justify measuring out the water rather more accurately than with a measuring cylinder. A bottle with a plug, or even a 500 ml volumetric flask is a valuable piece of equipment.

Less than 500 ml may be used at the sacrifice of a little precision. In some circumstances (e.g. Kamenitza studies) this is essential, and work on 100 ml (S.D. 1.5×10^{-5} M) has been successfully carried out.

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CAVE INVERTEBRATES FROM THE PICOS DE EUROPA, N.SPAIN

Phil Chapman

Recent expeditions by Lancaster University Speleological Society and Oxford University Cave Club to the Picos de Europa, Northern Spain, have uncovered a cave fauna which, though poor in number of species, includes a high proportion of cave-limited species, eight of which are new to science. The poor fauna may reflect a lack of available niches due to an unusually low level of energy input into the caves, except in flood-prone stream passages.

INTRODUCTION

The Lancaster University Speleological Society (LUSS) and Oxford University Cave Club (OUCC) expeditions to the Picos de Europa have brought to light some interesting cave-dwelling animals. Little biological collecting had been done in the High Picos up until the third LUSS visit in 1977, although a rich fauna was known from the warmer lowland caves of Santander and Asturias provinces. In 1977 the author looked briefly at caves and mines in the Andara region of the Sierra de la Corta, eastern Picos de Europa, Santander Province (Chapman, 1977). The following year Nick Airey collected in Cueva del Agua in the Tresviso region (Chapman, 1978), and in 1979 the author made further collections in Agua and in nearby Cueva de la Marniosa. Also in 1979, and again in 1980, members of OUCC, notably Simon Fowler, collected systematically and enthusiastically in caves in the Los Lagos region of the Picos de Cornion, western Picos de Europa, Asturias Province.

The caves explored by Lancaster University Speleological Society and referred to here are described in the LUSS reports of 1977, 1978 and 1979 and elsewhere in this journal. Those explored by Oxford University Cave Club are described in OUCC Proceedings 9 and 10.

Locations of the caves are as follows:

Picos de Cornion

El Hoyo la Madre: Rio Casano gorge near Belbin (43°14'23"N, 01°16'13"W)
Cueva del Osu: 500m south-east of Lago Ercina (43°15'46"N, 01°17'15"W)
Pozu del Xitu: 600m west of Ario refugio, south-east of Los Lagos (43°14'23"N, 01°14'20"W).

Sierra de la Corta

RCA-6 - Lower White House Mine (43°12'40"N, 01°01'10"W)
Cueva de Mazarrasa (43°12'45"N, 01°01'30"W)
Sara (43°12'30"N, 01°01'10"W)
La Cueva del Agua (43°14'50"N, 00°59'30"W)
Cueva de la Marniosa (43°15'12"N, 01°01'20"W)

These caves will subsequently be referred to by the underlined abbreviation of their names.

FAUNA LIST

The following symbols are used after each species' name tentatively to denote its degree of ecological dependence on the caves:

AC = an epigean species which has been accidentally introduced into the hypogean realm.
TX = Trogloxene - a species which spends part of its life-cycle in the hypogean realm, but which is dependent on some resource which can only be found in the epigean realm.
TP = Troglophile - a species which can live and breed in hypogean as well as in epigean habitats.
TB = Troglobite - a species which habitually completes its entire life cycle only in hypogean habitats.

Little is known concerning the distributions of many cavernicoles of the Picos de Europa. It is therefore not possible to be certain of the ecological status of many of the species listed below. Some exhibit morphological features such as eyelessness, depigmentation and attenuation of appendages which are not typical of their taxonomic group and which suggest that they have undergone a long period of genetic isolation in hypogean habitats. Other species belong to groups with known epigean members which are white and eyeless. Uncertainty about the status of such species is reflected in their non-committal classification e.g. as TB/TP.

PHYLUM ANNELIDA
CLASS OLIGOCHAETA
Family Enchythracidae
Enchythraceus vermicularis AC/TP
Agua, on mud-smeared flowstone wall above the Bloody Lake. It was probably washed into the cave through a joint.
PHYLUM MOLLUSCA
CLASS BIVALVIA
ORDER EULAMELLIBRANCHIA
Family Sphaeriidae
Pisidium (Cyclodina) casertanum (Poli) AC/TP
This small freshwater cockle is probably carried into Agua by the stream during floods, but may well maintain a troglophilic population in the streamway. Some troglobitic *Pisidium* species are known (Vandel, 1965). Empty valves of *Pisidium* are washed up on the sand bank at Colin's Climax.
CLASS GASTROPODA
ORDER CTENOBRANCHIATA
Family Hydrobiidae
Bythinella saxatilis (Reynies) TB/TP
The living animal inhabits bedding planes and flooded cracks of the phreas and is seldom seen in caves, but empty shells are washed out into the larger passages and are common on sand banks along the Agua streamway and in Teresa Series in Xitu.
ORDER BASOMMATOPHORA
Family Ancylidae
Ancylus fluviatilis (Müller) AC
Shells of this freshwater limpet are common on the sandbanks at Colin's Climax, Agua.
PHYLUM ARTHROPODA
CLASS CRUSTACEA
ORDER ISOPODA
Family Asellidae
Bragasellus aireyi Henry and Magniez, 1980 TB
First collected by Nick Airey from the Bloody Lake, Agua, in 1979, it has since been found throughout Marniosa. It is a phreatobite which shows close similarities to *B.lagari* from subterranean waters in Cuenca, Guadalajara, Soria and Tenuel Provinces, Spain; to *B.escolai* from la Cueva Calderon (Palencia) and especially to *B.comasi* (Henry and Magniez, 1980). The genus is probably endemic to the Douro catchment.
Bragasellus comasi Henry and Magniez 1976 TB
This species, taken in Osu, is very similar to *B.aireyi* . The type locality of *comasi* is Cova del Infierno (Covadonga, Asturias) and it may well be restricted to the Sella-Dobra river catchment, whilst *aireyi* may be restricted to the adjacent Cares-Deva catchment. It is interesting to note that the larger and more cave-adapted stenasellid, *Stenasellus virei* subsp. *buchneri* Stammer, occurs in the lower altitude (warmer) Pozo de Fresno cave in the Sierra de la Cuera near el Mazuco (Asturias), which is probably in the adjacent catchment of the Rio de las Cabras. High Picos caves may be too cold for *Stenasellus* , which would probably otherwise exclude *Bragasellus* as both genera occupy presumably similar cave niches.
Family Trichoniscidae
Trichoniscoides chapmani Dalens, 1980 TB
This species is quite common on rotted remains of beech leaves and twigs close to the streamway in Agua (Black Hole and Colin's Climax, but not at the entrance as stated by Dalens, 1980), and has also been taken by OUCC members at fresh chicken baits in Pozo de Fresno in the Sierra de Cuera (Asturias). It is very close to *T.arcangeli bouilloni* Vandel, described from a single locality in Ariège, France!

CLASS ARACHNIDA
ORDER PSEUDOSCORPIONIDA
Family Neobisiidae
Neobisium (Blothrus) jeaneli (Ellingsen) TB
This is one of the most cave-adapted pseudoscorpions from Spain. It is eyeless and very large, with greatly elongated appendages. It lives on the banks of the streamway in Marniosa, and is also known from lower altitude caves in Santander, Asturias and Leon (around the Picos de Europa).
ORDER OPILIONES
Family Oligolophidae
Gyas titanus (Simon) : Agua AC/TX
Family Sabaconidae
Sabacon vizcayanus Simon : Agua, Osu TX
Family Ischyropsalidae
Ischyropsalis nodifera Simon : Osu, Madre, Xitu TX/TP
None of these species is of much cavernicolous interest, though the genus *Ischyropsalis* does include some troglobitic species (Vandel, 1965). All three species were taken in shallow passages in the systems indicated.
ORDER ARANEAE
Family Tetragnathidae
Meta sp. taken in Osu AC/TP
CLASS DIPLOPODA
ORDER CRASPEDOSOMIDA
Family Vandeleumidae
Psychrosoma fadriquei Mauriès et Vicente TP
Marniosa, on banks of streamway. The type locality is Cueva del Oro, Macizo del Cornion, Oviedo Province (northern Picos foothills). This is a highly cave-evolved species.
Psychrosoma sp. nov. Mauriès in press. TB
A single male was taken in 1979 on wet rock, near a small stream in Madre.
Family Anthogonidae
Asturasoma chapmani Mauriès 1982 TB/TP
One male and two juveniles were taken in 1979 in Osu on a mud bank close to stream level where they were reported to be fairly common.
Asturasoma fowleri Mauriès 1982 TB/TP
One male was taken in 1980 in Xitu on damp mud in an oxbow above the streamway.
All these millipedes are of great interest and more specimens of the three new species are needed.
CLASS INSECTA
ORDER COLLEMBOLA
Family Entomobryidae
Pseudosinella chapmani Gama, 1979 TB
This is a highly cave-evolved species within the group *vandeli* and is found widely in RCA-6, Mazarrasa, Sara, Agua and Marniosa. *Ps.chapmani* , together with *superoculata* and *duodecimoculata* are probably descended from *Lepidocyrtus pseudosinelloides* Gisin (Gama, 1979).
Pseudosinella goughi Gama : Marniosa TB
Heteromurus hispanicus Bonet : Agua TP
Heteromurus cf. *hispanicus* Bonet : Agua TP
Heteromurus cf. *longicornis* Bonet : Agua ? TP/TB
Family Onychiuridae
Onychiurus ?sp.nov. in *armatus* group : RCA-6 ?TB
Family Hypogastruridae
? *Schoetella* or ? *Mesogastrura* or ? *Mesachorutes* sp. : Agua ?TB/TP
Apart from Entomobryidae, it is at present difficult to obtain precise identifications of cave springtails. There is quite a rich collembolan fauna in Marniosa on the surface and banks of the downstream sump.
ORDER DIPLURA
Family Campodeidae
Gen.nov., sp.nov. Condé in press. TB
A single specimen of this "extraordinary troglobite" (Condé, pers.comm.) was taken in Marniosa on decomposed beech leaves at Colin's Climax.
Plusiocampa espanoli Condé TP/TB
This species was described from a cave in Vizcaya (south of Bilbao). The Picos specimens fall into two groups: those from Agua have shorter antennae than the type group (36-38 segments instead of 47-51), while those from Osu and Xitu (and also Fresno in the Sierra de Cuera) are smaller, and have even

shorter antennae (26-30 segments) (Condé, pers.comm.).
ORDER COLEOPTERA
Family Carabidae
Chrysocarabus lineatus L. : Osu AC
Ceutosphodrus peleus Schauf. : Xitu TP
These beetles were attracted to fresh chicken baits. There is a fairly rich troglobitic carabid and leiodid beetle fauna at lower altitude around the Picos massif (see e.g. Espanol 1953, 1954, 1973), but this does not extend into the cold, high level caves of the Picos.
Family Dytiscidae
Gen. et. sp. indet. AC/TP
Larvae and adults of a dytiscid were taken in pools on the floor of the "spiral staircase" chamber in RCA-6 in 1977 (Chapman, 1977).
Family Staphylinidae
Ancyrophorus aureus (Fauvel) : Marniosa TP
This is a very widespread troglophile found throughout Europe.
ORDER LEPIDOPTERA
Family Noctuidae
Scoliopteryx libatrix (L.) : Madre TX
Family Geometridae
Triphosa dubitata (L.) : Marniosa and Madre TX
Both species are common in European caves, in which they shelter over the winter months.
OTHER TAXA: Unidentified specimens of Thysanura, Trichoptera (Limnophilidae). Hymenoptera (Ichneumonidae), Plecoptera, Diptera (Mycetophilidae) and Tricladida (Planariidae) were taken in various caves. The triclads and Thysanura may be troglophilic, but further undamaged material is required. An elusive amphipod has been reported, but not collected, from Agua (Chapman, 1978).

DISCUSSION

Of 31 species recorded from the caves of the High Picos, 13 are probable troglobites, 8 probable troglophiles, and 4 trogloxenes. 8 new species and 2 new genera are recognised in the collections, and others may be added when all the material has been studied. The fauna described here is not by any means a rich one. This reflects the paucity of collections, the nature of the land surface overlying these caves, and the climate of the area. While further collections should substantially increase the number of known cave-frequenting species of the High Picos, it is unlikely to reveal a fauna of comparable complexity to that of the surrounding low-lying karst areas of Santander and Asturias.

The complexity of a cave fauna is limited by the number of available niches in the cave ecosystem. Caves which receive significant energy inputs in the form of stream-borne detritus, trogloxene bodies and faeces, and organically-rich sediments washed vertically down open joints from the soil are likely to have diverse faunas, as many different niches are available. If the surface fauna is removed by glaciation or other means once the available cave niches have become occupied by troglophiles, then troglobitic evolution is initiated (Barr, 1968). Provided that a diverse and adequate food supply is maintained during the climatic change which initiates troglobitic evolution, and provided conditions thereafter remain favourable, then a diverse troglobitic fauna will appear.

The climate in the Picos results in a relatively low biomass on the surface of the high lapiaz-and-rubble-surfaced mountains which form most of the catchment of the major caves. What plants there are, are covered with snow for more than half of the year and are grazed by sheep and goats for the remainder, resulting in a small food standing crop. Soil cover is patchy and thin, and so it is probable that little organic matter enters the underlying cave systems through vertical seepage. The high summer temperatures probably result in rapid oxidation of organic material in the soil by bacteria, further reducing the energy content of sediments entering the caves. The limestone, though frost-shattered at the surface, is massive and poorly jointed, so that large stretches of cave passages are devoid of life-giving percolation inlets and often appear to be sterile. Cave air temperatures range from $0^{\circ}C$ in the mines and caves of the Andara region up to $6^{\circ}C$ in the Cueva del Agua, so few trogloxenes use the caves and they make little contribution to the cave biomass and its energetics. This leaves only one important source of energy input - the organic matter introduced by floods caused by the spring melt and summer storms. In Agua and Marniosa, flood deposits are evident along the banks of the main stream passages, and it is here or in similar situations in Osu and Xitu that most of the species listed above were taken. Part of both the Agua and Marniosa catchments lies in deciduous woodland dominated by beech, and black, fragmented beech detritus forms the basis of most food chains in these two caves. However, there is a low limit to the number of available niches in an ecosystem thus based, and the life-giving floods occur unpredictably and violently (nearly causing the demise of the author in late July, 1977) thus putting at risk cavernicolous species with an initially low population density inhabiting the stream passages. Apart from the ecological factors involved, the palaeoclimatic history of the region (Obermaier, 1914; Miotke, 1968) suggests that very few cavernicolous populations can have survived the locally severe Pleistocene glaciations to initiate troglobitic evolution. Conditions would have been too harsh for too long a period. Fortunately there are many conveniently close low-lying karst areas which would have retained their cavernicolous faunas during this period. It is likely that a high proportion of the High Picos troglobites are derived from relatively recent immigrants or recolonists from surrounding lowland karst areas. However, many well-represented groups of lowland cavernicoles of adjacent areas (such as beetles of the genus *Speocharis*) have not succeeded in colonizing the cold, energy-poor High Picos caves, which thus have what may be described in biogeographical terms as a disharmonic fauna.

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CAVE SCIENCE

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A METALLURGICAL EXAMINATION OF A SEVERELY CORRODED SECTION OF CAVING LADDER

D. J. Irwin and S. Reid

Metallurgical and chemical examination of a severely corroded section of caving ladder showed that the corrosion attack was the complete removal of the zinc galvanisation without any severe attack on the steel wire strands. Investigation of a number of possible causes of zinc stripping suggested that contact with nitrate-bearing solutions was most likely, and such solutions could have arisen from inflowing dilute fertilizer solutions, or from storage in a disused plastic fertilizer bag. Suggestions for avoiding such problems are put forward.

A section of caving ladder was submitted for examination showing signs of severe corrosion of the wire. It was stated that the ladder had been purchased within the last two years and that this and the remainder of the batch had not been much used. The ladder had also been examined by the NCA Equipment Special Committee who had suggested that the loss of the zinc coating had been due to faulty manufacture, possibly due to the omission of the degreasing operation prior to pickling and plating. There appears to be no technical evidence to substantiate this opinion and, in the view of the authors, highly unlikely to occur in a fully automated process.

Using the facilities and expertise of a well-equipped metallurgical laboratory a full examination of this specimen was carried out by various specialists. The result of this work is given below together with some recommendations for general maintenance of caving ladders and belays using galvanised steel wire.

PROGRAMME OF WORK

The following topics were investigated in order to determine possible causes of the apparently rapid corrosion:

1. Determine the extent of the corrosion on the steel wire and the magnitude of the breakdown of the zinc plating.
2. Determine the level of corrosion upon the aluminium alloy tubular rung.
3. Determine the effectiveness of the galvanising on the steel wire.

The ladder section under examination consisted of one complete rung with approximately 5 inches of cable protruding from each of four cable entry holes. The ladder had been assembled by the pressure-bonded process, now commonly used on ladders obtainable from retail outlets. The galvanised cable diameter was 0.120 inches nominal diameter and was a 7 x 7 strand construction.

Initial examination under a x10 magnifying glass indicated a breakdown of the galvanised coating on all strands of the wire and little corrosion effect could be detected on the aluminium alloy rung. Then examination under a binocular microscope of x25 magnification showed considerable wear and abrasion marks over the surface of the rung, including the surface area adjacent to the cable entry holes. The rung surface was so abraded that little of the original surface of the tube could be observed. The plugged ends of the rung exhibited a well-rounded profile effectively pressing the rung end due to the hammering effect of the ladder against the cave rock.

Examination of the cable revealed a light, even coating of rust on each individual strand of wire, with no evidence of any plating. The rusting was not so extensive as to weaken the wire cable to an unacceptable degree, though visually it would not have created much confidence either! Very slight deformation or wear of the cable was apparent at a point some 0.5 inch away from the rung (at the position where the edge of the boot sole would contact the cable).

The rung was then cut in half, midway along its length and a transverse sample, approximately 0.25 inch long, removed from one half. This was prepared for metallographic examination at magnifications up to x500. The microstructure showed the rung material to be of a aluminium alloy similar to that for specification H30, with a wall thickness of 1/16 inch.

Intergranular corrosion was found on both the inside and outside surfaces to a depth of .0025 and .006 inch respectively. No other defects were observed (PHOTO 1).

One of the pressure-bonded ends was then sectioned longitudinally and a sample removed and prepared for metallographic examination. The pressure-bonded plug was observed to be well crimped with adequate grip to the cable strands (PHOTO 2). Each strand showed a zinc coating approximately 0.0005 inch thick (PHOTOS 3 & 4). Analysis by Scanning Electron Microscope with Energy Dispersive attachment confirmed the coating as zinc; no other chemical anomalies were found. A similar analysis was performed on a sample of cable remote from the rung confirmed the lack of zinc, and again, no other anomalies were found. There is no evidence of faulty manufacture with respect to the galvanising.

DISCUSSION

Although the ladder displays an uncomfortable appearance it is our opinion that the general condition is acceptable to be used for caving provided that regular soaking in lanolin is carried out. The fact that there is no zinc coating present would not reduce the strength of the ladder cable.

<u>The rung</u>

The wear on the rungs, particularly the ends and around the cable-entry holes indicates a good degree of usage, and is not compatible with a little-used ladder.

The intergranular corrosion is not considered significant, as it is not extensive and could have been present wholly, or in part, in the rung material prior to the manufacture of the ladder.

<u>The wire</u>

The wire had been galvanised to the expected standard, but it is difficult to account for its total removal without either or both the steel or aluminium alloy being affected.

What one would expect from the normal corrosion sequence, and this would take a time period of a number of years under normal caving conditions, is that the corrosive breakdown of the galvanizing would take place on the outer strands aided by the tensioning of the wire when a caver is climbing where wear of the zinc surfaces would take place on the inner strands. Thus the outer strands should display a greater extent of the pitting of the steel. Indeed, the inner core of the wire would be expected to show signs of zinc or its oxide. In the case of the ladder under examination this sequence was not present.

In this case it showed that the breakdown was caused by a mechanism that attacked only the zinc. When the zinc and its oxides were removed the steel was then attacked by moisture in the normal way. The mechanism responsible would probably be gradual and be the product of regular exposure to the environment responsible. Further it would be a mechanism that did not attack the aluminium alloy or the steel. The removal of the outer layers of the zinc created a pathway for the mechanism to attack the inner strands bearing in mind that the space between each strand would now be .001 inch wide, an optimum figure for capillary action, once the corrosion products had been leached out. Our examination showed no presence of zinc or its oxide.

Tests on the quality of wire used for caving ladders were carried out by Dickinson for the NCA Equipment Special Committee recently. Each sample from various manufacturers was subjected to the American M.I.L. specification requirements including artificially ageing up to a period of 15 years. All the submitted samples were found to be acceptable and none displayed any serious effects of corrosion.

<u>Debris</u>

Debris and accumulations of cave deposits were searched for in the sample. Small lumps of material were scraped from the cable adjacent to the cable-entry hole on the rung. No unusual material was discovered. A small amount of zinc oxide was found as would be expected (see Fig. 1).

<u>Cause</u>

It was obvious that the ladder had not suffered from the normal corrosive processes in a caving environment as displayed by the condition of both the steel and the aluminium alloy. One agent or a combination of substances could have produced this effect and it is in this field that further investigation must take place. Mixtures of farm chemicals and washing detergents may produce very corrosive substances - but in many cases the aluminium alloy

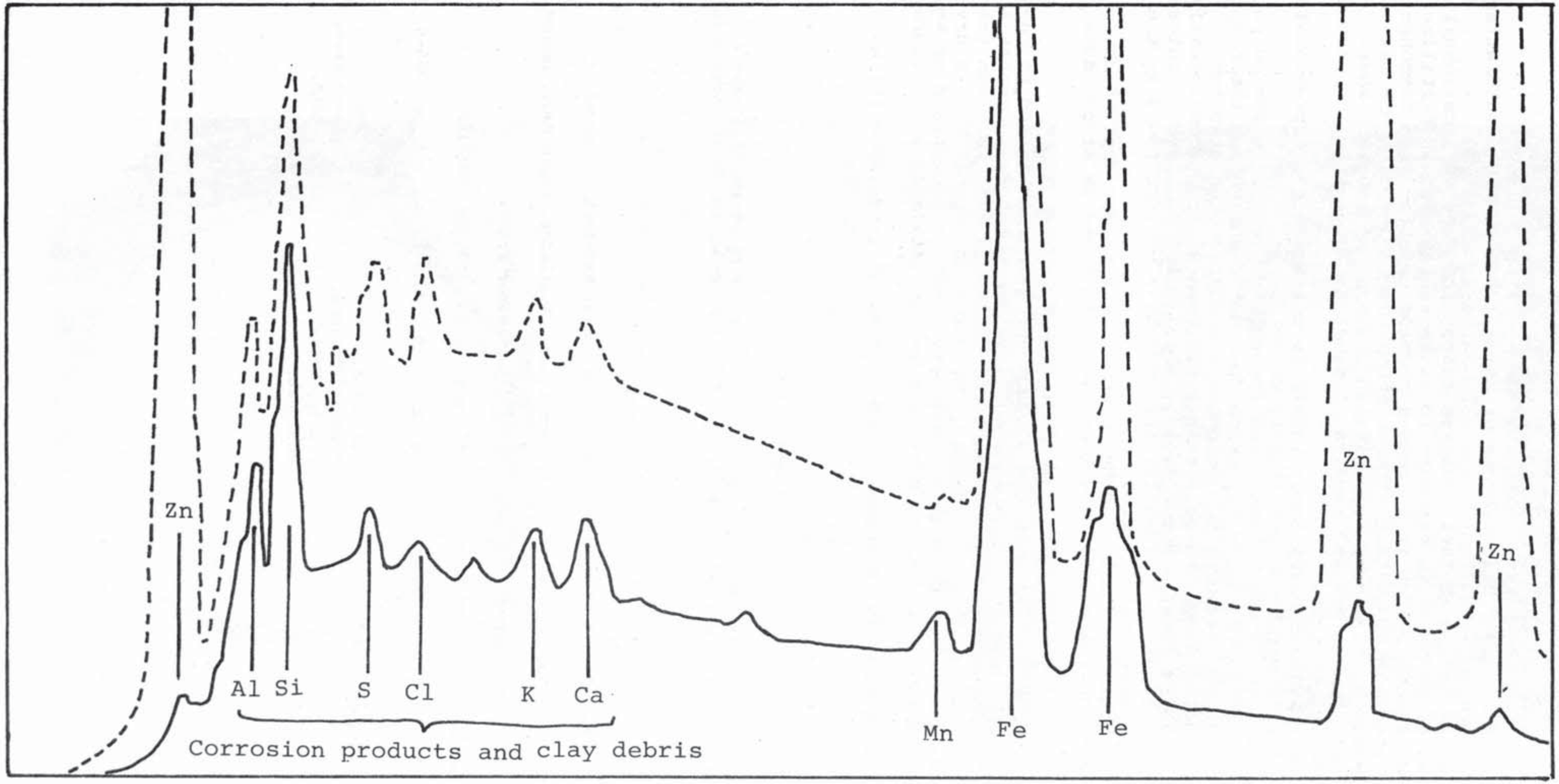

Fig.1. X-ray energy spectrum of centre strand of 7 core wire (250 secs at 20KeV)

dotted line: trace on galvanized surface from within crimp
solid line: trace 10mm away from crimped zone on rusty wire

would have been attacked. Urine (human or animal) and 'Cowsh' would attack the aluminium as well.

One agent or mechanism we feel could be responsible and is occasionally found in a cave environment is exposure to nitrates (as used in fertilizers). Nitrate is also used in industry to remove cadmium and zinc from components made of steel and aluminium alloy without affecting either of these metals. Further work would be necessary to establish those caving regions where nitrates are used by farmers and samples of steel cable left in the cave to study the corrosive effects.

The habit of cavers to carry their tackle in polythene sacks previously used for fertilizers may be a contributory cause.

Cavers should inspect their tackle and report any unusual corrosion points - it is a fact that this excessive corrosion does not occur along the complete length of the wire but at localised points - the sample submitted for examination did not follow this pattern but had been attacked consistently over the entire cable length. Hydrologists should also be asked to enter the field of investigation to identify any corrosive content found in the cave streams including small inlets.

All ladders should be identified by clubs and a record kept of their date of purchase and where they have been used. This can be simply done by means of a tackle log.

Maintenance

There has been much written on the subject and we do not intend to re-write what is easily available in the published literature. But we do emphasise that to keep the equipment in good condition it is essential to clean the equipment by scrubbing after each caving trip and it being allowed to dry in an uncoiled condition in a dry, airy atmosphere - not in a cupboard or small enclosed room. Also, 2 or 3 times a year, soak the tackle in a lanolin/white spirit mix.

A short bibliography is appended giving sources of articles written on the subject.

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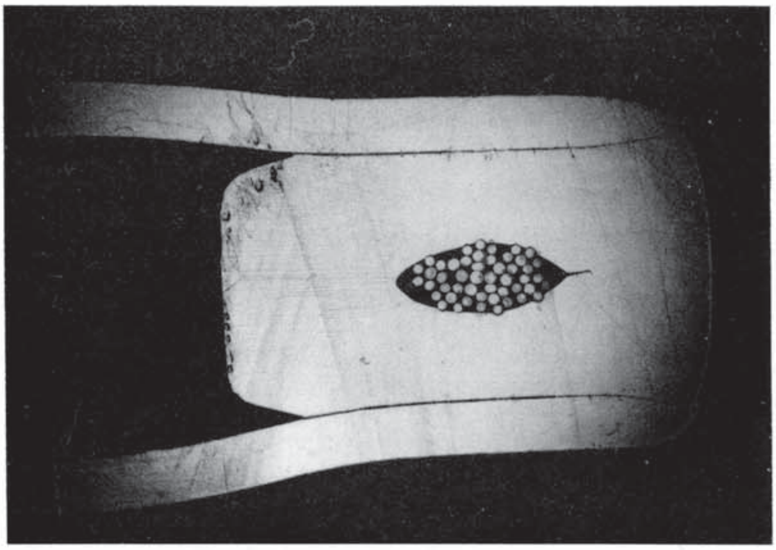
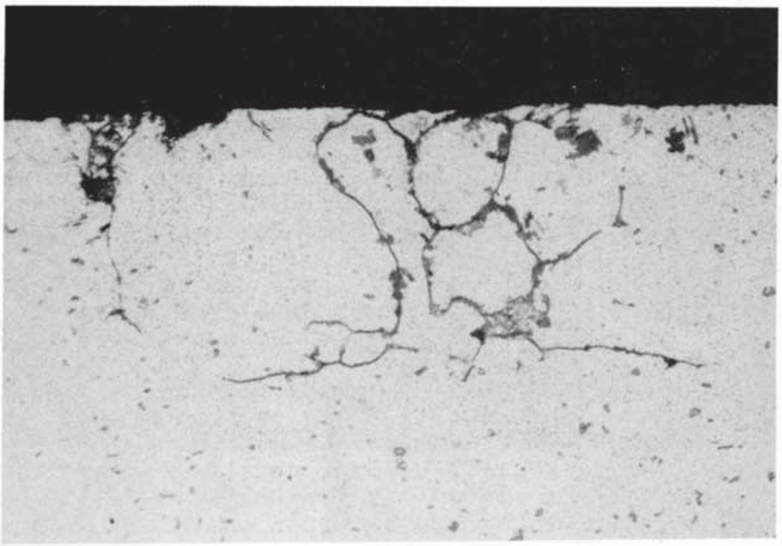
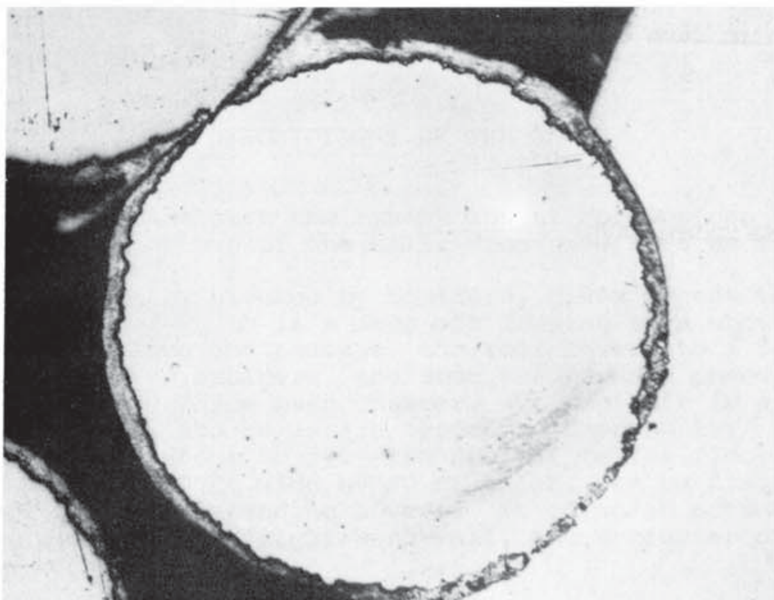


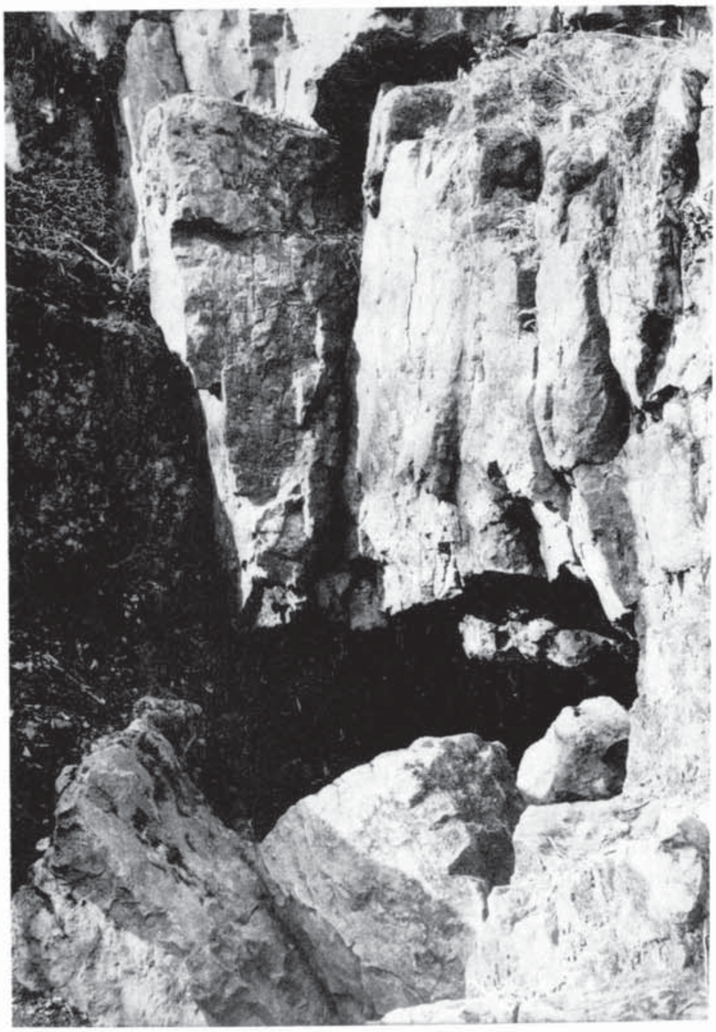
1. General view of section through plugged end, x5, showing acceptable crimping, and rounding due to wear at the end.



2. Detail showing intergranular corrosion to a depth of o.oo6".
Magnification x 400.



3. One strand of wire shows layer of zinc; the black line between zinc and wire denotes a proper bond. Magnification x500.



1. The partly blocked entrance
to Lesser Garth Cave from the south.

2. Straw Grotto, Ogof Pen y Craig.

3. "Eccentric column", Straw Grotto,
Ogof Pen y Craig.

LESSER GARTH CAVES

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THE LESSER GARTH CAVES, near Cardiff, South Wales

by Paul R. Davis

Abstract

Descriptions and surveys of Lesser Garth Cave, Ogof Pen y Craig, Ogof Tynant Fechan and Ogof Grisial are presented. These long-abandoned fragments of phreatic and vadose systems are in danger of destructio by quarrying. Lesser Garth Cave has yielded evidence of intermittent occupation from Bronze Age, Romano-British and Mediaeval times.

Lesser Garth Hill and it's associated caves lie 5½ miles northwest of Cardiff on the western side of a high limestone gorge through which the river Taff runs. This gorge forms part of the southern fringe of the limestone outcrop that encircles the South Wales coalfield, and although there are a few small caves east of the gorge, the main and longest system lies in the western summit. The Lesser Garth cave has been in danger of being quarried away for some time. Excavations in the entrance series have yielded evidence of intermittent use by early man from the Neolithic through to the 12th century. Stratford (1977) noted Lesser Garth cave as having been surveyed by D.H.S.S. (= Dyffrin High Speleological Society).

There are four known caves on Lesser Garth hill; the Lesser Garth Cave itself, which is the longest, Ogof Pen Y Craig, Ogof Tynant Fechan and Ogof Grisial. These caves were probably responsible for draining the uplands, including Lesser Garth hill itself before the glaciers carved out the gorge. As there is little left of the hill above the caves, it is impossible to say whether water entered the system in a large volume via a sinkhole or in smaller quantities over a larger area. It is now also difficult to say where the water resurged. Lesser Garth Cave is probably associated with Ogof Pen Y Craig (although the latter may have been formed by a separate stream) and as the entrance to Lesser Garth Cave has always been open, I suggest that it formed the resurgence.

Both of the above caves show few signs of phreatic action, and appear to have been formed along a bedding plane with vadose downcutting. Since the stream abandoned the system, considerable collapse has taken place, and in places large boulders have formed irregular passages and chambers beneath them, notably in Lesser Garth Cave where, just inside the entrance, collapse has almost blocked the cave to the roof, and has formed a number of lower level 'passages' between the boulders, some of which descend to a considerable depth. In no other part of Lesser Garth Cave is collapse so pronounced, but virtually all of Ogof Pen Y Craig has been affected, and caution is needed when climbing over the boulders. Ogof Tynant Fechan does not appear to be connected with the larger systems, and is probably an old resurgence cave of a small stream. Ogof Grisial may be phreatic in origin, the walls are encrusted with calcite and, as the cave is in the working section of the quarry, it may be quarried away.

DESCRIPTIONS OF THE CAVES

Lesser Garth Cave (ST I25 821) (Fig.2).

A public footpath leads past the Tynant Inn at Morganstown up into the woods and winds up to the top of the hill. The cave lies at the base of some rocks near the top.

The entrance, partially blocked by boulders, gives access to a low, wide chamber, in the floor of which is a deep pit leading to a short descending crawl. About 60 ft. along the passage, the roof lowers to a few feet in height. The way on is over fallen boulders, and soon the passage descends to a boulder platform overlooking the large main chamber. To the left is a deep, narrow rift, and a 30 ft.ladder and belay are needed to descend it; it runs parallel to the main chamber for about 60 ft. The descent to the floor of the main chamber, which is about 10 ft.wide by 40 ft. high, can be free-climbed, but a rope is handy. Before descending however, it is worth noting the large amounts of flowstone down the right-hand wall, and a cluster of small fan-like curtains on the left-hand wall.

Fig. 2.

LESSER GARTH CAVE

LENGTH: 580 ft.

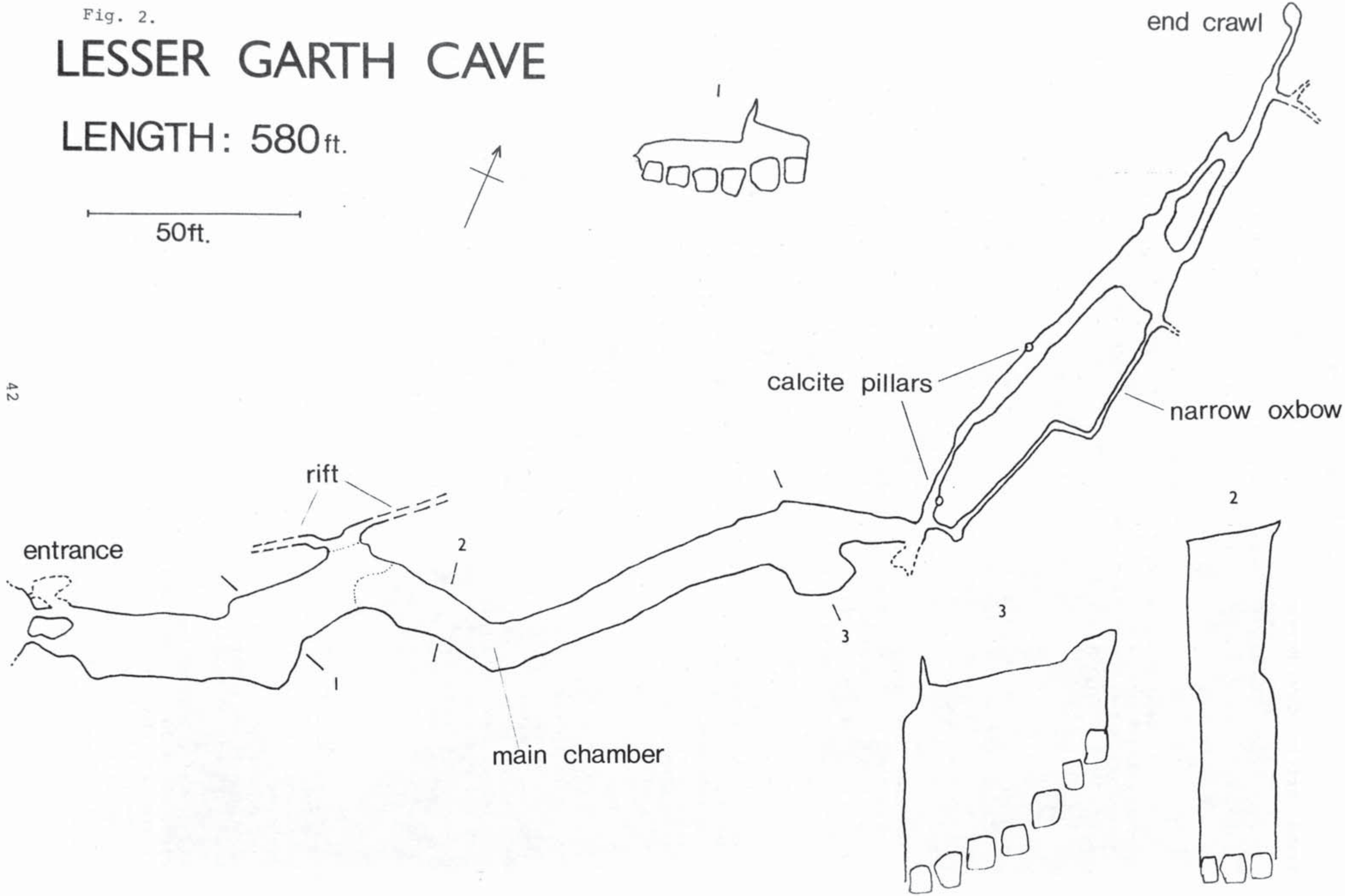
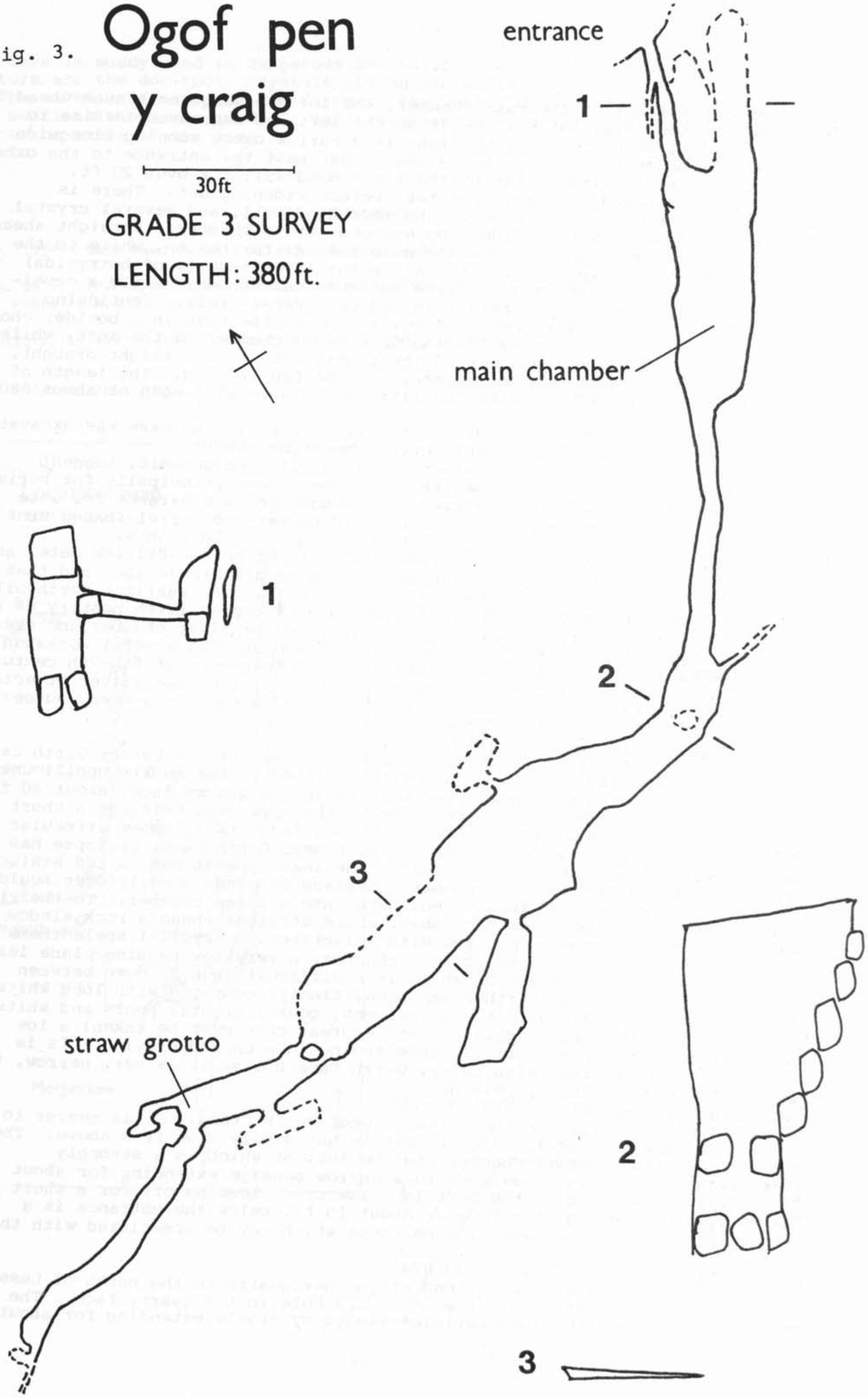


Fig. 3.


Ogof pen y craig
30ft
GRADE 3 SURVEY
LENGTH: 380ft.
entrance
1
main chamber
2
3
straw grotto
1
2
3

Once on the floor of the main chamber, the lofty passage continues ahead over massive boulders, until it bends to the left and decreases in size to only a few feet in width. To the right is a narrow oxbow running alongside the passage and joining up further along. Just past the entrance to the oxbow is a splendid stalactite pillar,by the right hand wall for over 20 ft. Beyond this the passage narrows further, before widening out. There is another dripstone formation here on the left hand wall, and several crystal pools on the floor. The passage then emerges into a chamber; straight ahead is a high level crawl which joins the main passage further on, while to the right the oxbow passage enters. At this point large amounts of botryoidal speleothems decorate the rocks. These bulbous concretions, hardly a centimetre long, are plentiful in both this and Ogof Pen-Y-Craig. Continuing along the main passage the roof soon lowers to end the cave in a boulder choke. There is a squeeze and a crawl leading to a small chamber on the left, while a blocked bedding plane leads off on the right. It emits a slight draught, and possibly links with the end chamber in Ogof Pen-Y-Craig. The length of the main passage is 480 ft. with the rift making a total length of about 580 ft.

Archaeology

In 1912, 1922 and again in 1963-4, the first part of the cave was excavated, providing evidence of intermittent occupation (Anon, 1976).

The earliest finds, a few flints found in a calcited deposit, suggest Neolithic or early bronze age use, which may have been principally for burial; human remains were found in some crevices, suggesting a clearance for late Bronze age domestic occupation. A group of 10 bucket- and barrel-shaped urns from the middle Bronze age were also found along with the flints.

However, it is possible that the skeletons are of Romano-British date, as cremation was the rite usually performed in the middle Bronze age, and that the use of the cave in the Bronze age was funerary only. The earliest worthwhile evidence of domestic occupation are fragments of Romano-British pottery of the late 1st and 3rd centuries, again found mainly in the first chamber and crevices. After the end of the Roman occupation the cave was used as a metal workshop, in association with iron mining on the hill above. Fragments of 5th-7th century pottery, crucibles, clinker and fragments of bronze, iron and silver objects were found near the main chamber. Fragments of 12th century pottery suggest a brief mediaeval use of the cave.

Ogof Pen Y Craig (ST 127 822) (Fig.3).

The cave is situated in an old quarry to the east of the Lesser Garth Cave and can be reached by following the northern flank of the quarry uphill until, looking southeast, several holes can be seen in the quarry face, about 40 ft. below the top. The entrance to the cave is the uppermost hole and a short climb is needed to reach it. A flat-out crawl leads to a larger irregular passage leading to the main chamber. Like Lesser Garth Cave, collapse has formed several lower passages, including one leading east past a red stalactite.

At the far end of the main chamber a passage descends steeply over boulders and then a climb leads up through boulders into a large chamber. To the right a tight crawl leads to a small chamber, while straight ahead a rock window leads to a small chamber decorated with helictites, botryoidal speleothems and dripstones. To the right of this chamber, a very low bedding plane leads to a low chamber, at the end of which is a difficult squeeze down between boulders. This leads to further passages, finely decorated with long white straws and stalactites, dripstones, columns, gours, crystal pools and white helictites. Beyond the formations (where great care must be taken) a low passage leads off for a short distance ending in a choked crevice. It is possible that this links with Lesser Garth Cave but as it is very narrow, the prospect of a dig is not promising.

Ogof Tynant Fechan (ST 126 823) (Fig.4).

This short cave lies to the north of Ogof Pen Y Craig. It is nearer to the top at the base of a small outcrop, but is not easily seen from above. The entrance leads to a small chamber, to the left of which is a strongly draughting slot. This leads down to a narrow passage extending for about 30 ft. Half way along on the left is a low crawl leading off for a short distance before ending at a choke. About 15 ft. below the entrance is a short, low crawl at the base of some rocks which may be associated with the upper cave.

Ogof Grisial (Crystal Cave ST 123 824)

The entrance lies at the far end of the new quarry to the north of Lesser Garth Cave. It is easily visible as a dark hole in the quarry face. The cave is a series of calcite-lined cavities linked by crawls extending for about 80 ft.

The cave is muddy, and is dangerous due to loose rock. An interesting feature are the dog-tooth crystals lining the walls.

The caves were surveyed and drawn by the author during Easter 1982. The sections shown are grade 2, and are drawn looking into the cave at twice the scale of the plan.

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M.S. received June 1982

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Fig. 1.

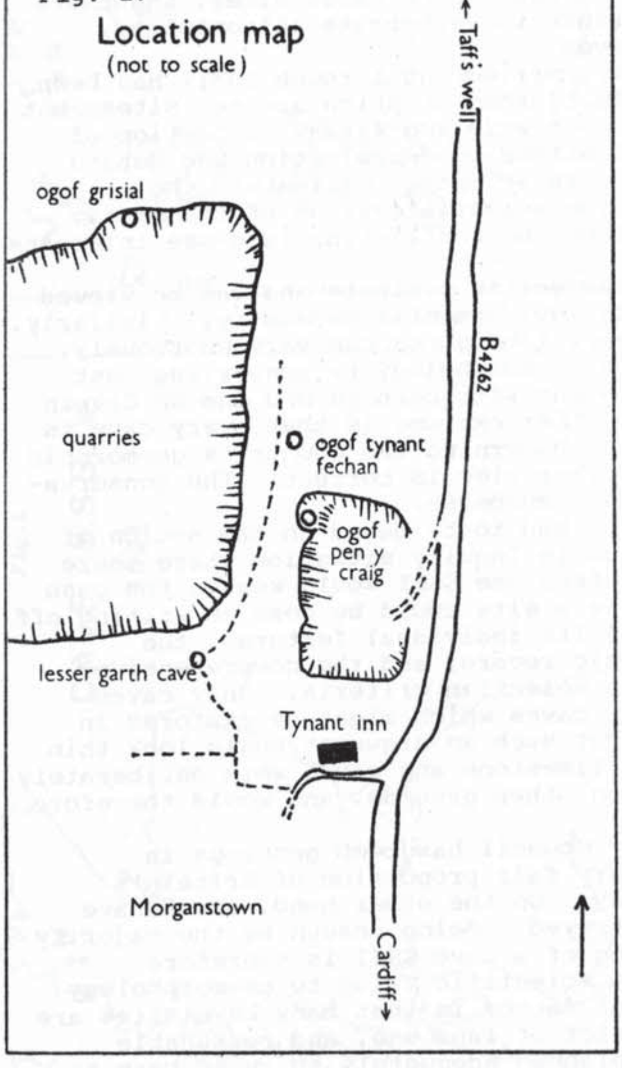
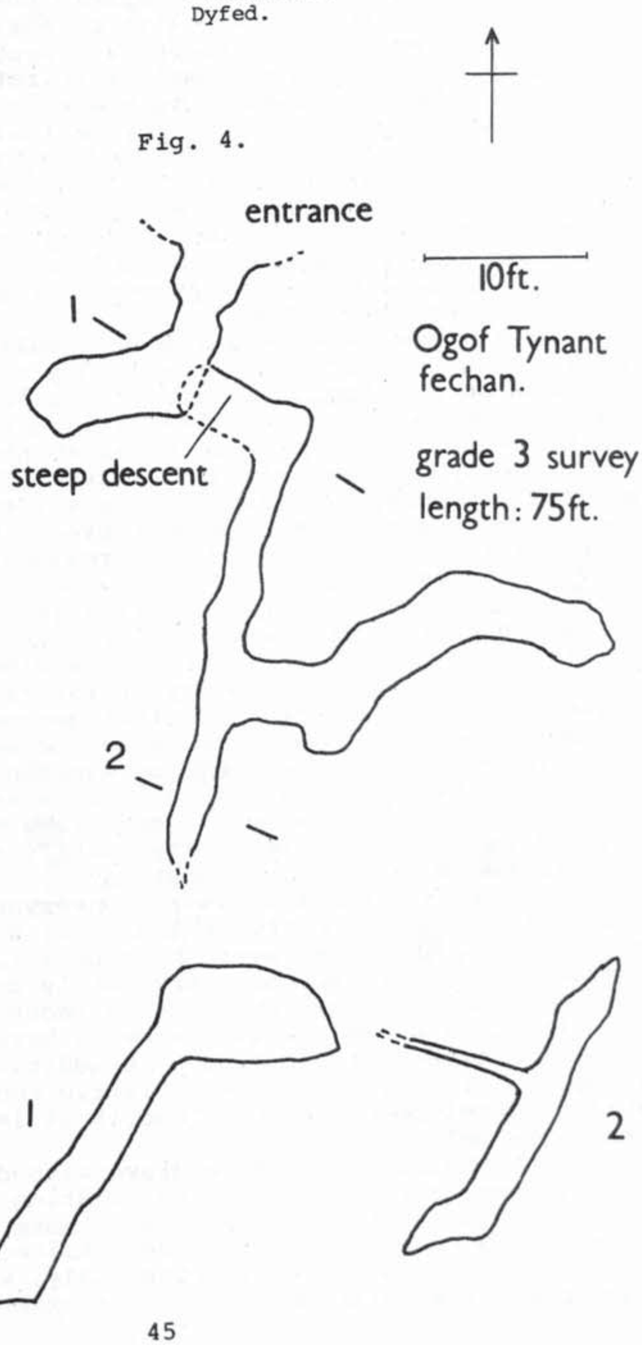


Fig. 4.



CAVE SCIENCE

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A REVIEW OF CAVE CONSERVATION SITES IN BRITAIN

A. C. Waltham

Abstract

The Nature Conservancy Council's current review of its coverage of earth science sites has included a re-assessment of the SSSI's provided for caves. There are now 48 cave sites throughout England, Wales and Scotland. This paper records and briefly outlines the justification behind the selection of these sites.

The Nature Conservancy Council is currently carrying out a comprehensive review of conservation in terms of its earth science Sites of Special Scientific Interest (SSSIs). Within the Geological Conservation Review, one section is concerned purely with cave sites essentially designated for their geomorphological value. There is a separate section on karst sites, and there are other sections, for example with reference to vertebrate paleontology, which have some overlapping interest in caves.

The result of the present review (mainly carried out through 1981) has been the designation of 48 cave SSSIs (see Table 1) some of which are new sites, but others of which are unaltered or modified from existing sites. Selection of these 48 sites has been the end-product of extensive consultation and debate among those interested in both caving and cave science. Ultimately the selection has had to be based entirely on the scientific value of the sites, although in some cases the presence or absence of conflicting land-use interests has had to be considered.

Conservation is of course a difficult subject to evaluate and can be viewed as anything from an uneconomic luxury to an environmental necessity. Similarly, opinions on the justification of cave conservation sites can vary enormously. One extreme is to cover representative cave geomorphology by conserving just the Three Counties caves or Ingleborough, along with perhaps OFD and GB Cavern and a handful of geological oddities. The other extreme is that every cave is a vital and irreplaceable piece of evidence concerning the country's geomorphic evolution, and so cannot be destroyed. Neither view is correct. The conservation effort has to be based on a reasonable compromise.

The final selection of an individual site had to be based on the notion of defending its case for conservation in a Public Inquiry situation where there was a conflict of interests. To fail to defend one SSSI would weaken the case of all other SSSIs, and yet not to designate a site could be seen as writing off its scientific value. Quality or rarity of its individual features, the scientific value of its historical geomorphic record, and the comprehensive value of the site as a whole, were the main selection criteria. Only caves which had been explored could be assessed; caves which might be explored in the future may seem reasonable to a caver but such an argument would look thin to a quarry company lawyer. Some areas of limestone and caves were deliberately omitted as they could be easily justified on other grounds, and would therefore gain protection in a roundabout way.

Some may say that the Nature Conservancy Council has been generous in designating 48 cave SSSIs - which cover a very fair proportion of Britain's major caves. Perhaps cavers have been lucky. On the other hand, caves have a unique fragility and are very easily destroyed. Being unseen by the majority they are easily forgotten, and the recording of a cave SSSI is therefore valuable in its own right. Caves do have a scientific value to geomorphology which far exceeds their size. An additional factor is that many cave sites are in upland areas where there is little conflict of land use, and reasonable surface development can continue if it is planned adequately to avoid harm to the caves below.

Site boundaries have been drawn with due reference to land-use. For a start, they have had to utilise existing surface features, so that they are identifiable on the surface, and in some cases this has accounted for odd shapes when compared to the cave outlines. In some areas of open moorland the boundaries can be drawn generously, whereas in heavily farmed land they have been drawn with more care, for example to avoid individual buildings or

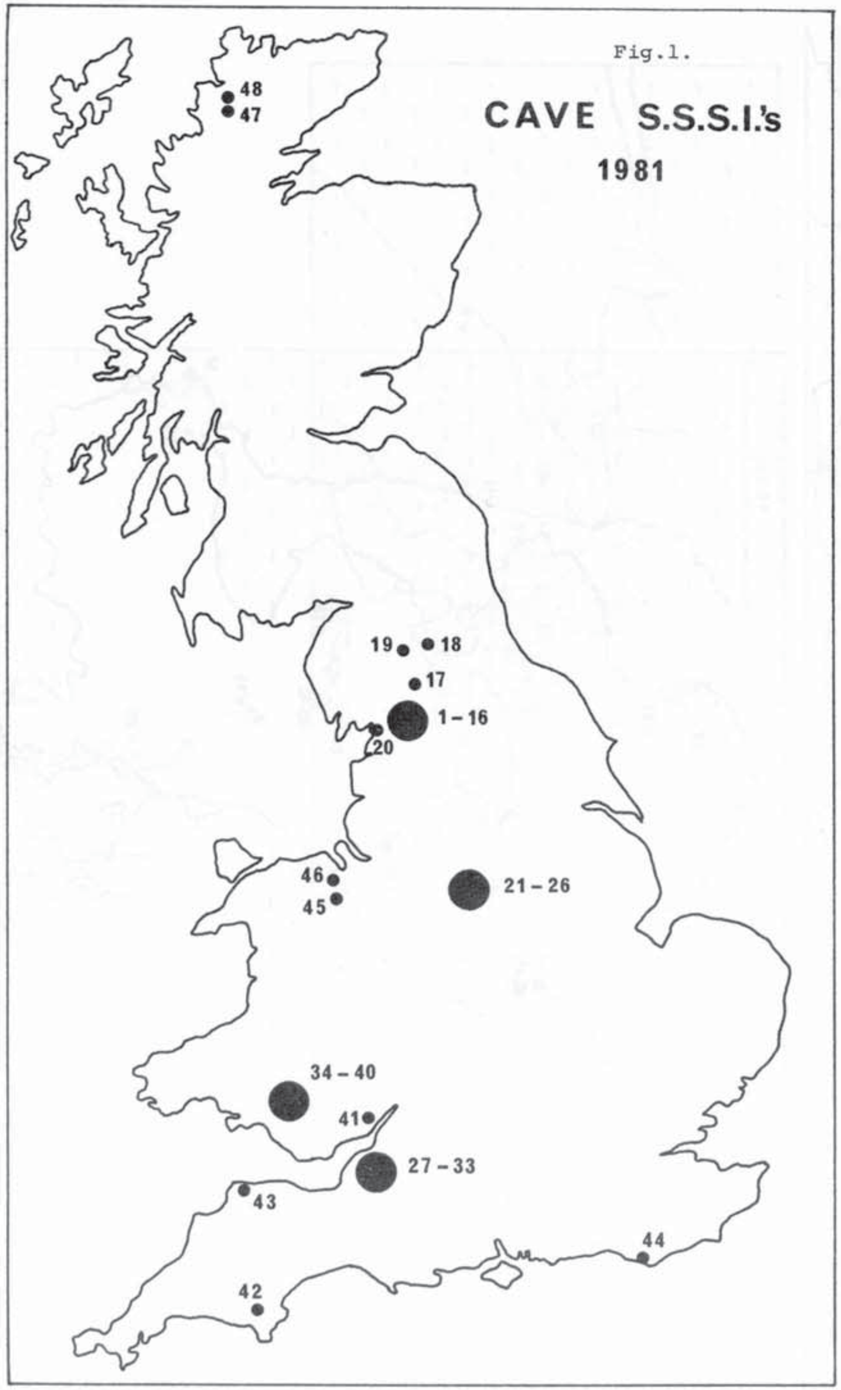


Fig.1.

CAVE S.S.S.I.'s

1981

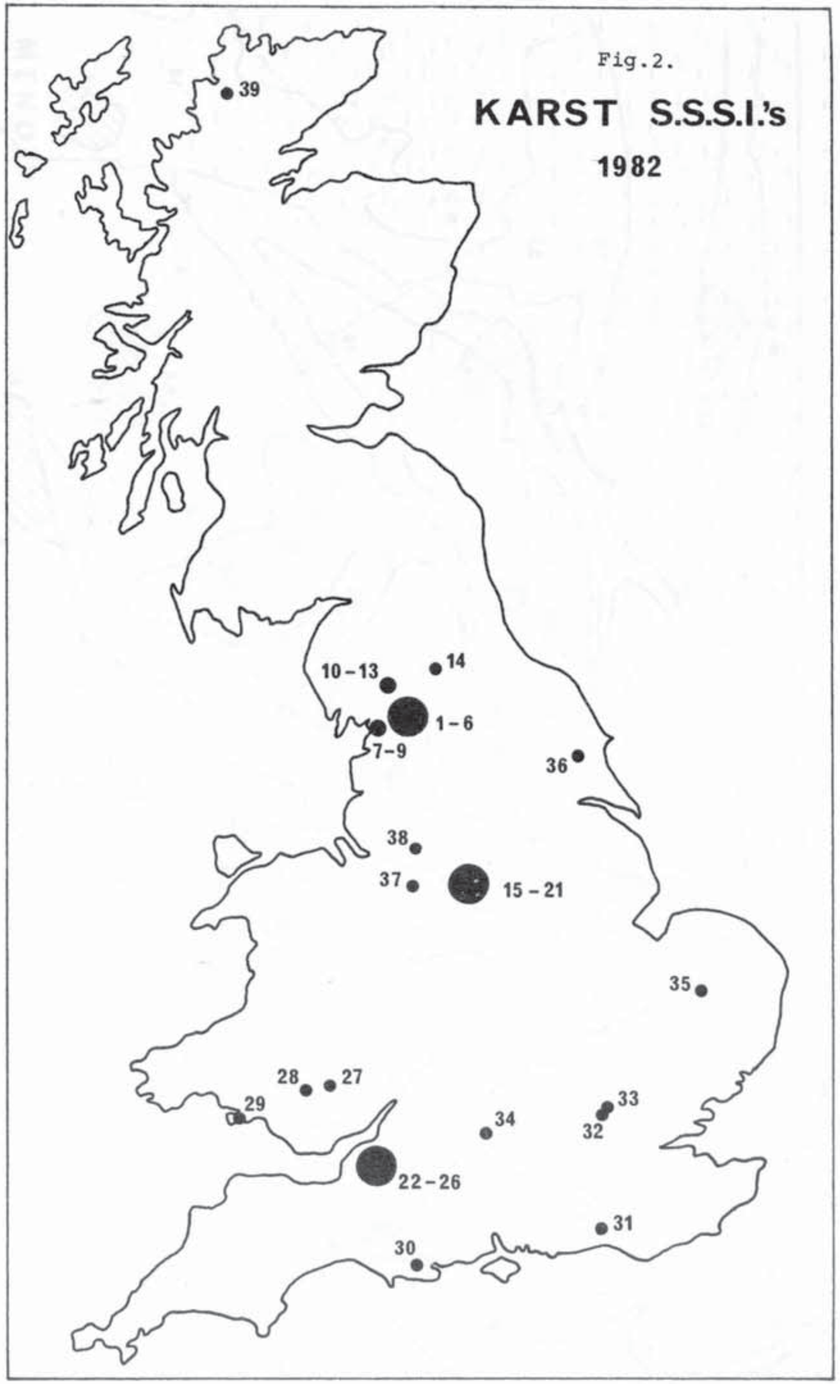
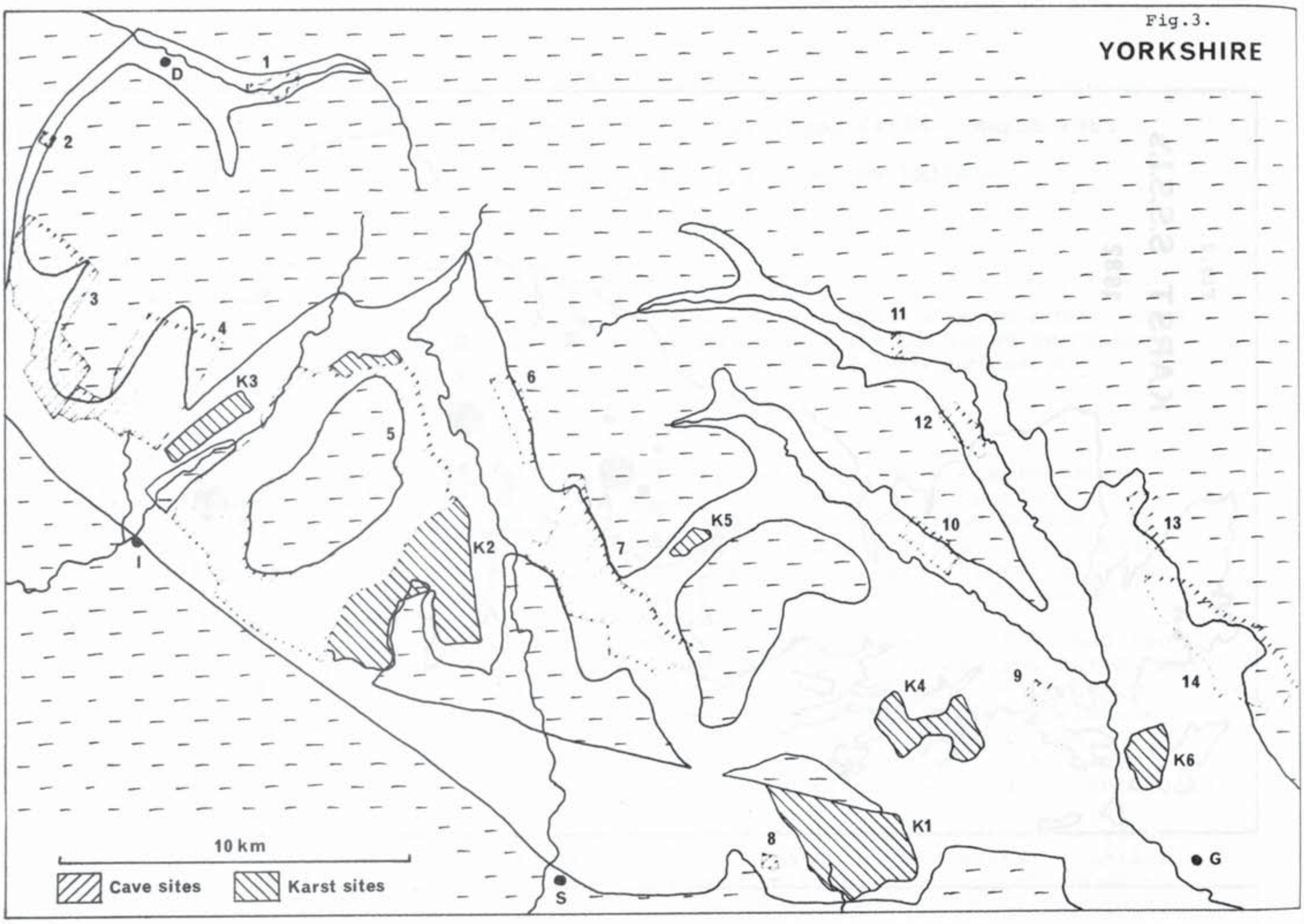


Fig.2.

KARST S.S.S.I.'s

1982

Fig.3.


YORKSHIRE
1
D
2
3
4
K3
5
6
K2
7
K5
11
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10 km
Cave sites
Karst sites
S
G

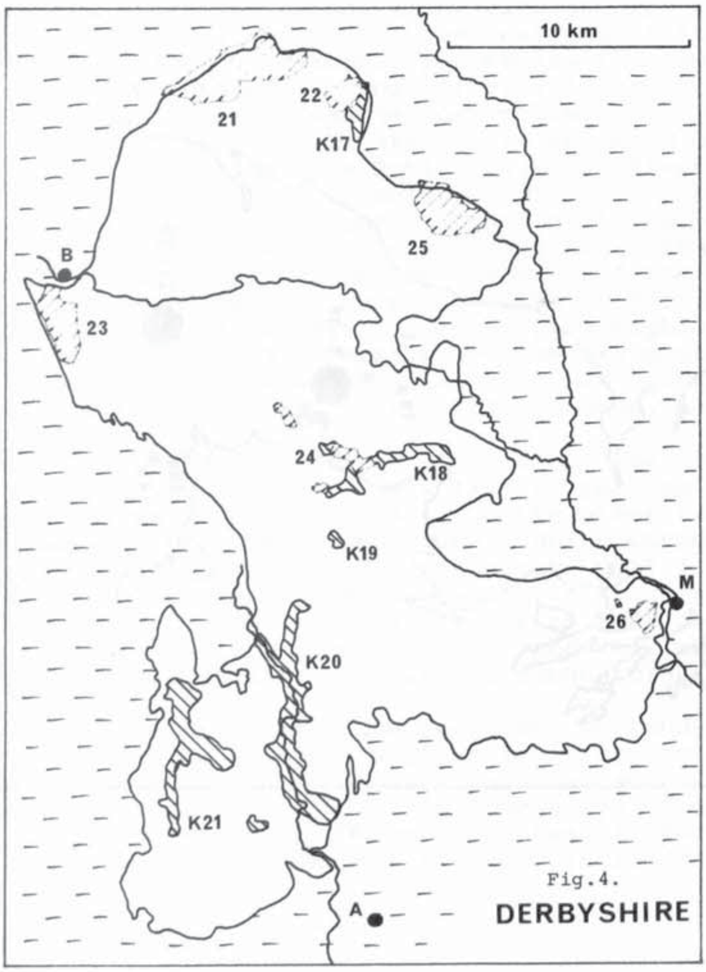
10 km
21
22
K17
25
B
23
24
K18
K19
M
26
K20
K21
A
DERBYSHIRE

Fig.4.

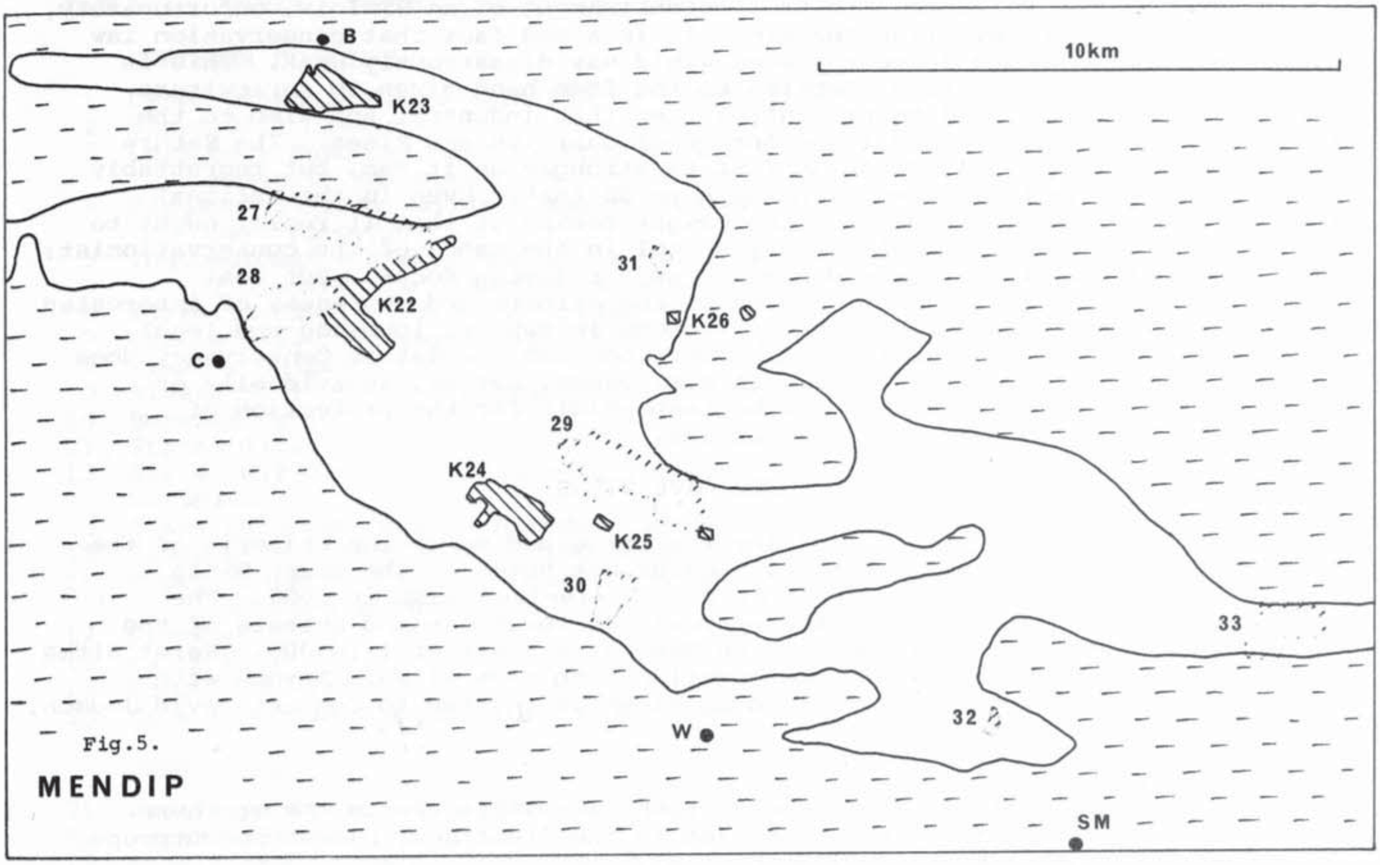

Fig.5.
MENDIP

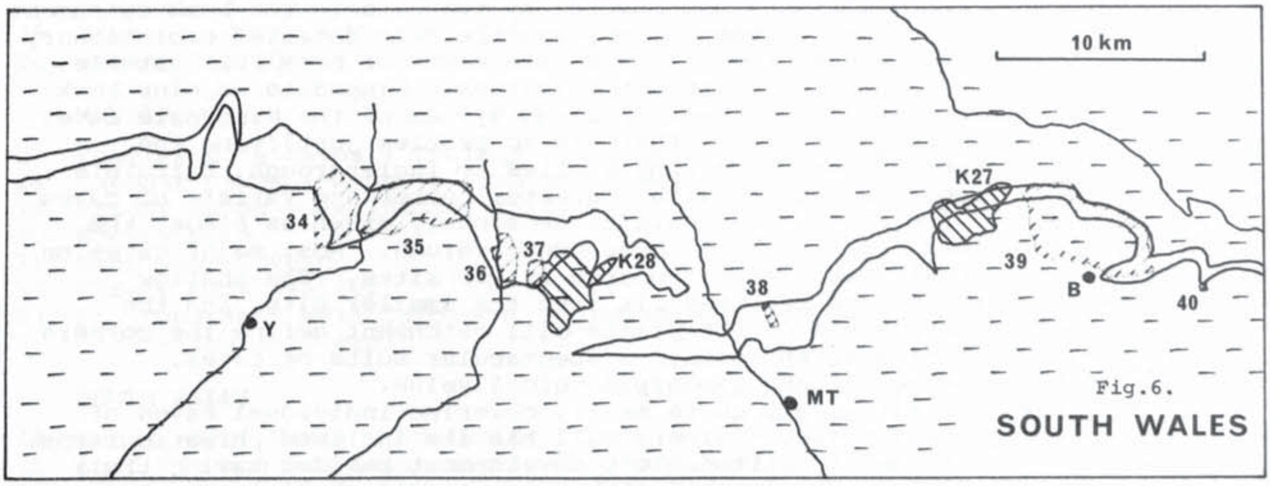

Fig.6.
SOUTH WALES

fields. The benefit of this is to avoid unnecessary conflict and wasted bureaucratic effort. The problem with quarrying is of course more acute. It is easier to take a firm stand over some conflicts of interest if reason can be shown to prevail elsewhere, though it is of course difficult to draw and maintain the thin dividing line.

It is of course vital to note that establishment of an SSSI is, unfortunately, not the ultimate conservation measure. It is a sad fact that conservation law in Britain is pathetically weak - some would say disastrously weak. This is particularly noticeable when compared to the free hand given to agriculture through the negligible planning control over that industry, and also to the enormous powers given to the Inspectorate of Quarries and Mines. The Nature Conservancy Council will defend an SSSI as strongly as it can, but regrettably it has very little real power with which to do that. Even in the National Parks, conservation does not have the weight behind it that it really ought to have. SSSI status is therefore only a tool in the hands of the conservationist; it draws attention to a site and may act as a rallying focus. But real protection of a site must still depend on the efforts and awareness of interested parties, ultimately followed by their success in support lobbying and legal debating. There is no room for complacency, because the Nature Conservancy does not have the power to go it alone. In most cases, cavers, individually or collectively through the BCRA, must be responsible for the protection of Britain's caves from damage or destruction.

THE CAVE SITES

The following notes briefly outline the value and selection criteria of the cave SSSIs now designated (Table 1). Comparable notes on the karst SSSIs (Table 2) are being published in *Studies in Speleology* also in 1983. The accompanying maps can only show the approximate locations and extents of the sites, as the boundaries are defined on maps at a scale of 1:10,000. Karst sites are not shown on the maps where they overlap with cave sites. Anyone with specific enquiries concerning individual sites is invited to contact David Judson, BCRA Conservation Officer.

Northern Pennines.

Not surprisingly, nearly half the British cave SSSIs are in the Northern Pennines, and most of those are clustered in the Great Scar Limestone outcrops around Ingleborough and Wharfedale (Fig. 3).

Five large sites cover the heart of caving land around the Three Peaks. The important Three Counties Caves are covered by two sites. The Leck catchment has Easegill with its immense promise of perhaps the most detailed evolutionary record if only it can be sorted out, and also the caves of Leck Fell notable for their complex active and fossil phreatic systems. Kingsdale adjoins Leck and covers the complete and magnificent drainage system of the Kingsdale caves including the sub-valley floor link. There is no problem justifying the importance of both these sites. The same applies to Ingleborough, Britain's textbook peice of limestone country with a greater number and variety of caves than anywhere else; its boundaries could be generously drawn as almost the whole hill is conserved for a host of independent values. Most major caves on the Penyghent side of Ribblesdale are covered by two sites. The shallow perched caves of Birkwith and Red Moss fit into the smaller site, and the deep and straggling components of the Brants Gill catchment define the corners of the larger. These five sites contain a spectacular suite of caves, undeniably rich in geological and geomorphological value.

Wharfedale has five sites, all quite small, covering individual caves of distinctive or unique morphology. Sleets Gill has its inclined phreatic ramps, and Boreham Cave is the key to Littondale's development besides having truly spectacular calcite deposits. Strans Gill has a splendid shaft system and more very beautiful calcite formations in the Passage of Time. Both the Birks Fell and the Dow sites cover unusual linear caves, the former having the unique double system along with Birks Wood Cave, and the latter constituting a valley to valley drainage system so clearly influenced by geology.

Outlying areas of the Great Scar Limestone account for a handful of small and very varied sites, each included for the value of its morphology in strong contrast to the dominant cave types of the ten sites mentioned above. These therefore cover: the valley floor caves of Dentdale; Short Gill Cavern in its vertical limestone; the peculiar mineralisation of Pikedaw Caverns; the phreatic mazes of the Stump Cross anticline; and out near Morecambe Bay, the

TABLE 1 CAVES SCHEDULED AS SSSIs 1981

NORTHERN PENNINES

1 Upper Dentdale Caves - including Ibbeth Peril, Hackergill, etc.
2 Short Gill Cavern
3 Leck Beck Head Catchment - from Aygill to Ireby, including all Easegill and Leck Fell
4 Kingsdale - from Marble Steps to Vesper, including West and East Kingsdale
5 Ingleborough - almost the entire area inside the roads, but including the Chapel Beck caves and excluding Moughton Scar
6 Birkwith Caves - from Calf Holes to Red Moss
7 Brants Gill Catchment - from Hull Pot area to Hammer Pot
8 Pikedaw Calamine Caverns
9 Sleets Gill Cave - including Dowkabottom
10 Boreham Cave
11 Strans Gill Pot
12 Birks Fell Caves - including Birks Wood system
13 Dow Cave
14 Black Keld Catchment - Mossdale and Langcliffe but not Black Keld
15 Stump Cross Caves - including Mongo Gill
16 Upper Nidderdale Caves - including Goyden, How Stean, Blayshaw Gill and Nidd Heads
17 Crackpot Cave
18 Fairy Hole
19 Knock Fell Caverns
20 Hale Moss Caves - including Hazel Grove

DERBYSHIRE

21 Castleton Caves - Perryfoot to Treak Cliff, Peak, Eldon, etc
22 Bagshaw Cavern
23 Stanley Moor Caves - including Poole's Cavern
24 Upper Lathkilldale Caves - Lathkill Head area, Knotlow area and Water Icicle
25 Stoney Middleton Caves - Carlswark, Streaks, etc
26 Masson Hill Caves - including Jug Holes, Masson, Devonshire etc.

MENDIP

27 Charterhouse Caves - Tynings Farm, GB, Rhino, Longwood, Manor Farm
28 Cheddar Caves - Gough's area and Reservoir
29 Priddy Caves - Swildon's, Eastwater, St. Cuthbert's, Hunter's, etc.
30 Wookey Hole
31 Lamb Leer Cavern
32 Thrupe Lane Swallet
33 St. Dunstan's Well Catchment - including Stoke Lane, Shatter, Withyhill, etc.

SOUTH WALES

34 Dan-yr-Ogof Caves - including Tunnel and Pwll Dwfn
35 Ogof Ffynnon Ddu Area - including Pant Mawr
36 Little Neath River Caves - including White Lady and Town Drain
37 Porth-yr-Ogof
38 Nant Glais Caves - Ogof-y-ci and Rhyd Sych
39 Mynydd Llangattwg Caves - including Agen Allwedd, Craig-a-Ffynnon, etc.
40 Siambre Ddu
41 Otter Hole

OTHER AREAS

42 Buckfastleigh Caves (Devon) - Church Hill, Pridhamsleigh and Potter's Wood
43 Napps Cave (Devon)
44 Beachy Head Cave (East Sussex)
45 Minera Caves (Clwyd) - including Ogof Dydd Byraf
46 Alyn Gorge Caves (Clwyd) - including Hesp Alyn and Hen Ffynnonhau
47 Allt nan Uamh Caves (Highland) - including Claonite
48 Traligill Caves (Highland) - including Glenbain, Cnoc nan Uamh, etc.

TABLE 2 KARST SCHEDULED AS SSSIs 1982

NORTHERN PENNINES

1 Malham and Gordale - including the Watlowes and Janet's Foss
2 Ingleborough - practically the entire hill including Moughton Scar and Norber
3 Scales Moor - including Twistleton Scars
4 High Mark - including Clapham and Proctor High Marks
5 Penyghent Gill - the Giant's Grave area
6 Conistone Old Pasture - including Conistone Dib and Dib Scar
7 Farleton Knott - including Newbiggin Crags and Holmepark Fell
8 Hutton Roof
9 Gait Barrows
10 The Clouds
11 Great Asby Scar
12 Potts Valley
13 Hell Gill (Mallerstang)
14 God's Bridge (Stainmore)

DERBYSHIRE

15 Winnats
16 Cavedale - including the Peak Cavern gorge
17 Bradwell Dale - including Stanlow Dale
18 Lathkill Dale - including Cales Dale
19 Green Lane Pits
20 Dovedale - including Wolfscote and Biggin Dales
21 Manifold Valley - including Hamps Valley

MENDIP

22 Cheddar Gorge - including Velvet Bottom
23 Burrington Combe - including West Twin Valley
24 Brimble Pit and Cross Swallet
25 Sandpit Hole and Bishop's Lot
26 Wurt Pit and Devil's Punch Bowl

SOUTH WALES

27 Mynydd Llangynidr
28 Hepste and Mellte Valleys - including part of Little Neath Valley
29 Llethrid Valley

OTHER AREAS

30 Cull-pepper's Dish (Dorset)
31 Devil's Dyke (West Sussex)
32 Castle Lime Works Quarry (Hertfordshire)
33 Water End Swallowholes (Hertfordshire)
34 The Manger (Oxfordshire)
35 Devil's Punchbowl (Norfolk)
36 Millington Pastures (Humberside)
37 Moston Long Flash (Cheshire)
38 Rostherne Mere (Cheshire)
39 Traligill Valley (Highland)

polje margin caves of Hale Moss. Each cave is the best of its type, unmatched elsewhere in conserved sites.

The remaining Northern cave SSSIs are in Yoredale limestones. Mossdale and Langcliffe determine a large site which includes some caves in the Great Scar Limestone; and perhaps this is the site most likely to expand dramatically in the future. A large Nidderdale site covers both Goyden Pot and How Stean Cave and is currently being increased in value by the divers' activities in Nidd Heads. Further north, Crackpot Cave is only a small site but justified by its key position in the spectacular dale-to-dale drainage. Fairy Cave is both the finest example of a Yoredale linear system and also the saddest example of the inadequacy of conservation law in Britain; limestone resources for the aggregate industry are just too valuable, and part of the cave has already gone. The remote location should ensure a better fate for Knock Fell Caverns, the best developed of the Yoredale maze caves.

Derbyshire

The large area of Peak District Carboniferous Limestone (Fig. 4) is hardly matched by the number of its caves. The handful of large cave systems are such vital components of the karst geomorphology and hydrology that they are nearly all in SSSIs. The largest and most important site is at Castleton, enclosing all the caves which lie below Rushup Edge together with the resurgences at Peak Cavern and the plateau out to Eldon Hole. The nearby and also important resurgence system of Bagshaw Cavern is covered by a separate site.

A complete sink-to-resurgence system, with complex hydrology, is covered by the Stanley Moor site, and the multi-level, valley-floor caves of Stoney Middleton constitute another site. The two remaining Derbyshire sites are small but especially valuable because of their unusual cave morphologies; the Upper Lathkilldale site has the finest of the isolated phreatic cave fragments under the central plateau area, and the Matlock caves are included in another site because of their peculiar geology and mineralogy.

Mendip

The Mendip Hills have seven cave SSSIs (Fig. 5), all quite small and all easily justified because of the enormous amount of scientific study which has been centred on them. The two main groups of sinkhole caves on the plateau are covered by one site each. The Priddy caves, including Swildons, are valuable as large, complex, multi-level phreatic systems, and another site covers their common resurgence at Wookey Hole, now particularly valuable because of the length and morphology of the explored active phreas. The Charterhouse site covers five major cave systems, including G.B. which must be the most intensively studied cave in Britain and has consequently yielded a wealth of scientific data with far-reaching implications; the resurgence end of the system is also covered by the Cheddar site which covers all the caves in the lower end of the gorge.

The fossil system of Lamb Leer and the unusually vertical Thrupe Lane Swallet are each covered by very small sites. Finally, the major caves of eastern Mendip, around Stoke Lane and Fairy Cave Quarry, are covered by one large site which is justifiable on the grounds of the caves' remarkable calcite deposits alone. Conservation in the Fairy Cave Quarry caves is now particularly relevant as the closure of the quarry has left open a variety of options concerning preservation and development of the best decorated passages.

South Wales

The narrow Carboniferous Limestone outcrop along the northern rim of the South Wales coalfield now contains seven cave SSSIs (Fig. 6). The dissected, gently dipping Welsh limestone particularly favours development of small numbers of very long caves. There is no problem therefore in justifying the Dan-yr-Ogof and Ogof Ffynnon Ddu sites, both with large complex cave systems which both contain almost every feature of cave morphology, though added value to the sites also comes from the geologically influenced contrasts between caves on opposite sides of the Swansea Valley. The third and largest site is at Llangattwg, covering both Agen Allwedd and Craig-y-Ffynnon; here the caves are naturally protected by the grit outcrops above them, but they are especially vulnerable in terms of access and pollution through the narrow band of limestone outcrop within the site.

The remaining sites are smaller. Porth-yr-Ogof and Little Neath Cave both have spectacular, active, vadose and phreatic cave, as well as fine related surface features. Nant Glais has geologically-controlled caves associated with a small gorge, while Siambre Ddu is a very small cave of almost no sporting interest but of great value as an example of solution and collapse related to the overlying Millstone Grit. Otter Hole stands isolated from the other sites but is naturally included as a site because of the value of its remarkable calcite deposits on a scale matched nowhere else in the country.

Other Areas

The last seven sites are scattered across the country. Devon has one three-part site covering the major caves of the Buckfastleigh area, and also a second site covering Napps Cave because of the value of its aragonite deposits. Beachy Head Cave warrants inclusion because it is the only significant cave in the Chalk and is a most important insight into the nature of Chalk permeability. Of the two sites in North Wales, Minera includes Ogof Dydd Byraf, subject of an ongoing and still unresolved conservation and access dispute. Nearby, the Alyn Gorge site includes the phreatic caves of the valley, notably the recently drained Hesp Alyn. Two almost adjacent sites in Scotland cover the main caves in the Durness Limstone at Inchnadamph - caves which are especially valuable for their sedimentary record of the glacial and karst erosion.

SECONDARY CAVE CONSERVATION

There are a number of SSSIs included in the recent review which do contain caves but do not appear in the list of cave sites. This is partly due to the difficulties of classifying natural features, and also due to the need to ensure that a site is justified by its strongest features. The obvious examples are Burrington Combe in Mendip and the Manifold Valley in Derbyshire, both of which are classified as karst sites. The caves in both those sites could be dismissed as being of little more than local significance, so they would provide weak justification for cave sites; on the other hand the surface geomorphology of both sites is of high quality and the caves do contribute to the total value of the sites. In this manner a number of caves do receive umbrella protection within the karst sites, and other examples can be identified from Table 2 and the area maps. In South Wales, the caves of the Hepste River and of Llethrid all fall within large karst sites.

Even more caves are included in SSSIs designated for reasons other than their cave or karst value. Notable among these are: Kirkdale Cave in Yorkshire, the Westbury-sub-Mendip fissure, the caves of Creswell Crags on the Derbyshire/ Nottinghamshire boundary, and the Victoria Cave group in Yorkshire, all of which are designated as sites on the basis of their fossiliferous Pleistocene sediments. A number of the smaller caves in Devon are designated because of their value as bat roosts.

In conclusion it is worth noting that while the above lists are long they can never be complete. Additions to the list are always worth considering, particularly where major new cave discoveries may render meaningless existing site boundaries. Anyone with suggestions for new site designations or existing site modifications is invited in the first place to contact the BCRA Conservation Officer. Cavers taking an active interest in conservation matters will always be welcome, as apathy is the greater enemy of conservation when faced with the organisation of conflicting interests.

Acknowledgments

The re-assessment of caves sites was a large operation involving many people. The whole project was greatly eased by the generous co-operation provided by Dr George Black and his colleagues at the Nature Conservancy Council; to all of them, the author and BCRA express their gratitude. Special thanks go to David Judson, BCRA Conservation Officer, who established and co-ordinated the exercise. Thanks are due to the many caves who helped to assess, describe and delimit the individual sites: these include Dave Brook, Harry Long, Martin Davies, Roger Sutcliffe, Trevor Ford, John Beck, Willie Stanton, Graham Price, Bill Gascoine, Alan Jeffreys, Peter Appleton, Bob Cawthorne, Terry Reeve and many others unnamed.

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CAVE SCIENCE

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