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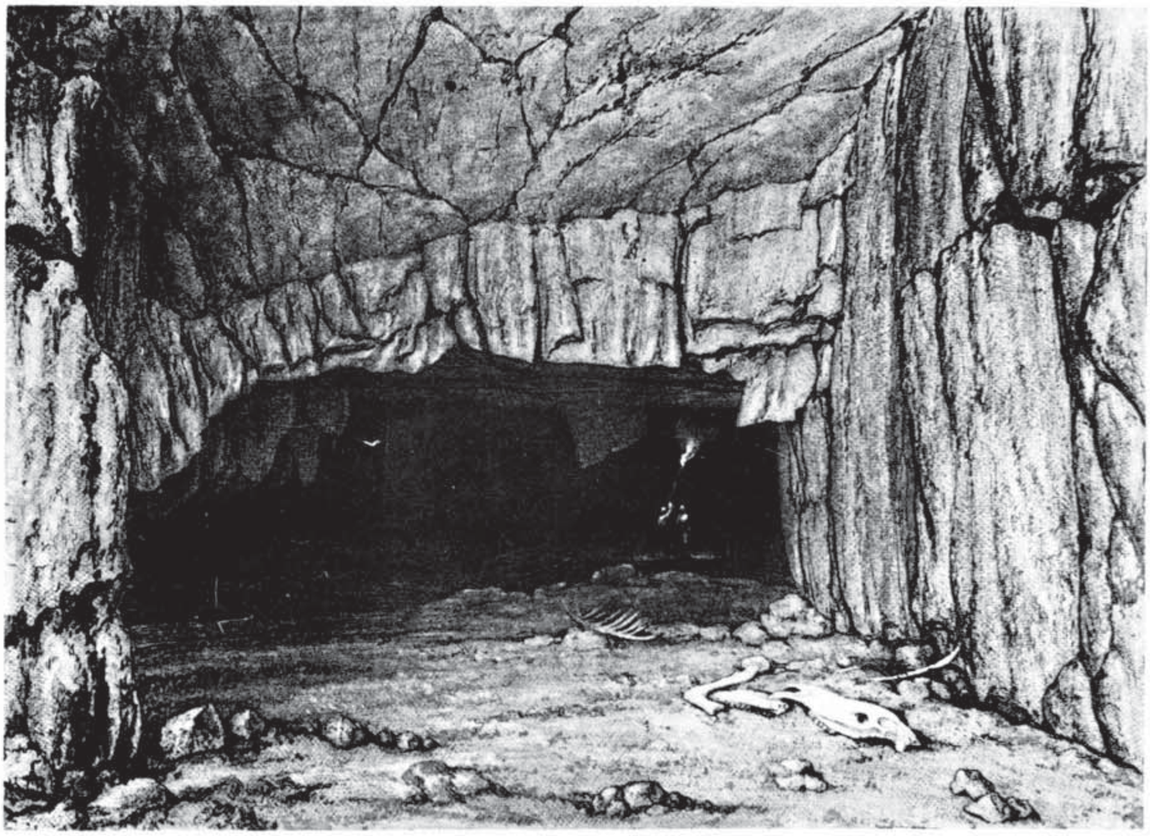

Drawn & Etchd by Wm Westall A.R.A.

Entrance to Yordas Cave

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Yordas Cave

I.S.C. 1977
Brightgate Caves
Rope Lengths
Palaeolithic Art
Solutional Erosion
Lichenometry
Polished Limestone
Yorkshire Hydrology

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Cover picture: Entrance to Yordas Cave, by W. Westoll, 1816.

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BRIGHTGATE CAVE, SNITTERTON, DERBYSHIRE

by Peter F. Ryder

ABSTRACT

A little known cave system lies in dolomites between two lava horizons in the Carboniferous Limestone, west of Matlock. The system is partly a labyrinth developed along joints, and partly a steeply dipping bedding cave. Smoked initials imply visits by lead miners in the 16th century.

The initial fact that aroused interest in Brightgate Cave amongst members of the Moldywarps Speleological Group was that it appeared in 'Caves of Derbyshire' (Ford, 1974, p. 28) without a length being ascribed to it. In the course of three visits the system was thoroughly examined and surveyed, proving to be an extensive and in placed intricate phreatic cave, unusual for the area in that it is all "natural", unmodified by mining.

The cave was first entered in modern times in December 1965 by a party of cavers including L. Hurt (1968) who chronicled the initial exploration. The Entrance Chamber was entered after a little boulder moving, but entry to the Labyrinth Series beneath, and the remainder of the cave, only came after another thirteen months of sporadic digging by L. Hurt and his colleagues.

Situation

The cave entrance is situated at SK 265599 amongst boulders at the foot of a low crag at the head of Northern Dale, about one mile due south of the village of Wensley. It is best approached, with permission, from Brightgate Farm on Bonsall Lane, by crossing one field to the head of the narrow dry valley and contouring round to the east below a small wooded crag, to the cave entrance at the same level a few hundred feet beyond at about 920 ft (276 m) above sea level.

The cave system is developed in dolomitized limestones of the Matlock Group, Carboniferous Limestone. These lie between the Upper and Lower Lavas (locally called toadstones) and they dip northwards at about 20°. Bedding planes in the cave probably represent washed-out wayboard clays (thin volcanic ash layers). The geological situation is thus similar to the Jug Holes system about a mile to the east.

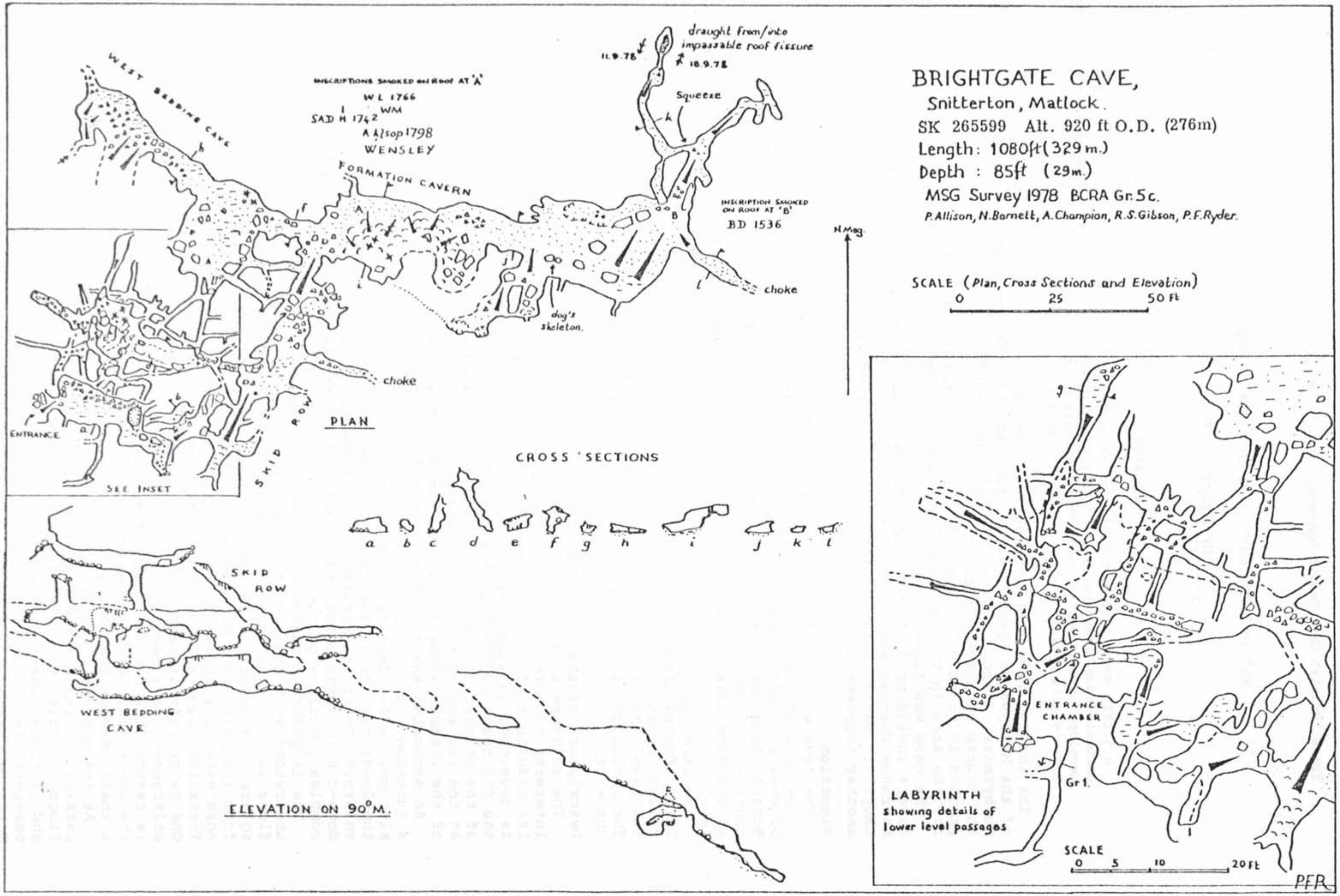
Description of the Cave (Fig. 1)

The entrance is a drop through loose boulders, recently rearranged in the interests of safety, into the Entrance Chamber, 20 ft long and 8 ft wide, with its bedding roof slanting down from right to left (northwards). The whole cave is developed in limestones dipping northwards at around 30°, the influence of the dip being apparent in the passage cross-sections everywhere. On the right of the chamber a narrow joint passage runs up-dip for 20 ft, ending too tight. At the far end of the chamber a few feet of bedding passage continue the line of the chamber along the strike, to end in a choke.

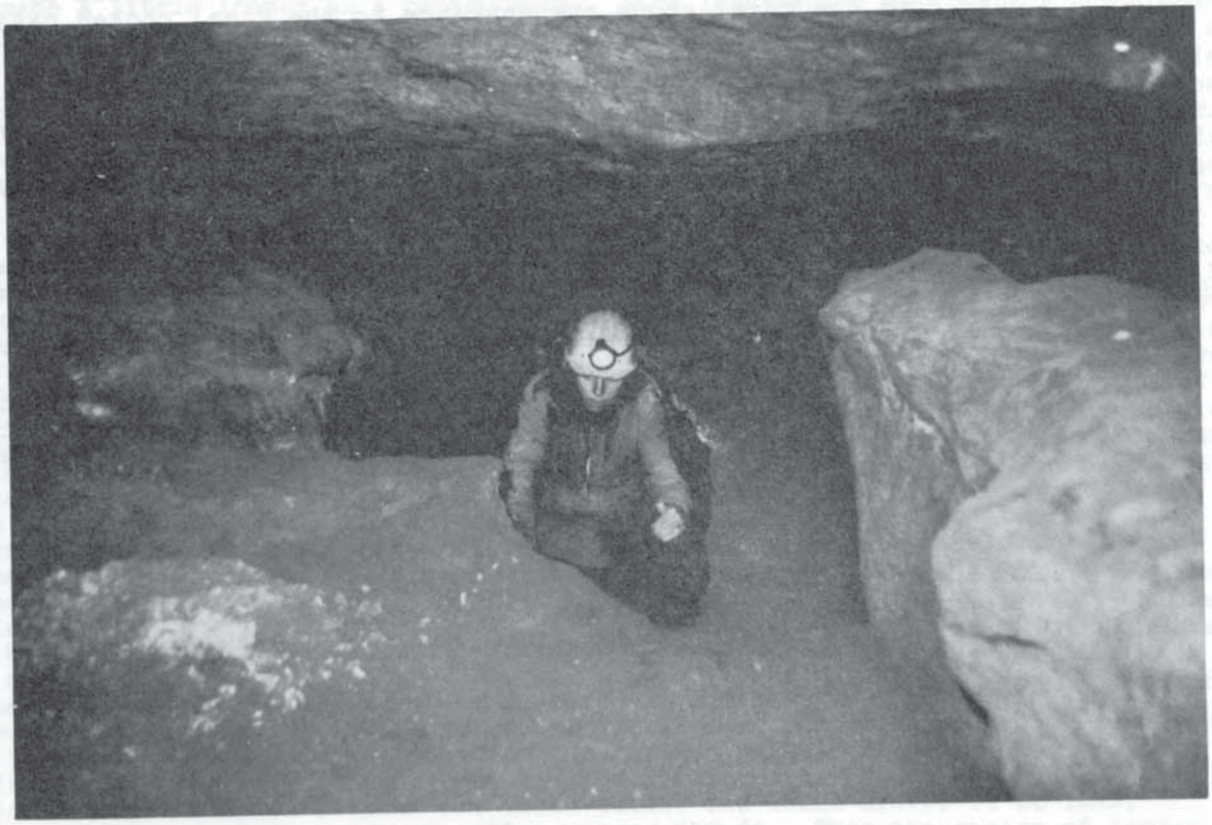
An excavated shaft in the chamber floor drops 12 ft and is an easy climb to a junction. To the right a low tubular passage descends to end in an impassable slot only a few feet from the decorated grottoes at the head of Skid Row, in the lower reaches of the cave. To the left a tall but narrow, phreatically-enlarged joint only passable as a sideways crawl at floor level, runs away down-dip to a sharp left turn, and another narrow section, to the first of the complex junctions of the Labyrinth.

The Labyrinth consists of a complex of intersecting tilted rifts, best understood with the aid of the survey (which shows a plan of the passages at floor level). The whole maze is contained within an area approximately 50 ft square, but despite this contains over 300 ft of passage. The series, apart from its being in a dipping bed of limestone, bears a close resemblance to the more extensive phreatic cross rift systems in the Yoredale limestones of North Yorkshire, such as Devis Hole Mine Cave and Windegg Mine Caverns (Ryder, 1975). One major rift passage running east-west across the Labyrinth shows a pronounced enlargement on a bedding plane 12 ft above floor level. The same bedding plane is responsible for the roofs of the Entrance Chamber and most of the cave below the Labyrinth. At its western end the upper section of this rift enlarges into a small chamber containing some large stalagmite bosses.

At its opposite, eastern, end this rift ends in a 'T'-junction with a larger passage running up- and down-dip, named Skid Row from its slippery stalagmite floor. Up-dip, to the right, the passage ends in a series of small passages and grottoes, heavily encrusted with rather "dead" formations. These passages terminate only a few feet from the choked bedding plane at the end of the Entrance Chamber.


BRIGHTGATE CAVE,
Snitterton, Matlock.
SK 265599 Alt. 920 ft O.D. (276m)
Length: 1080ft (329 m.)
Depth : 85ft (29m.)
MSG Survey 1978 BCRA Gr. 5c.
P. Allison, N. Barnett, A. Champion, R. S. Gibson, P. F. Ryder.
N Mag.
SCALE (Plan, Cross Sections and Elevation)
0 25 50 Ft
WEST BEDDING CAVE
INSCRIPTIONS SMOKED ON ROOF AT 'A'
W L 1766
SAD H 1742 WM
A Alsop 1798
WENSLEY
FORMATION CAVERN
draught from/into impassable roof fissure
11.9.78
18.9.78
Squeeze
INSCRIPTION SMOKED ON ROOF AT 'B'
BD 1536
choke
dog's skeleton.
choke
ENTRANCE
SEE INSET
SKID ROW
PLAN
CROSS SECTIONS
a b c d e f g h i j k l
SKID ROW
WEST BEDDING CAVE
ELEVATION ON 90°M.
ENTRANCE CHAMBER
Gr 1.
LABYRINTH
showing details of lower level passages
SCALE
0 5 10 20 Ft
PFR

1. Formation Cavern, looking east, with 18th century miners' inscriptions on the roof.



2. The final passage just below the 1538 inscription showing the sandy fill.

Going down-dip, Skid Row enlarges into a wide bouldery passage, showing collapse modification, before dropping through boulders into Formation Cavern, a wide and well-decorated chamber developed on the inclined bedding. To the west here a tubular passage runs back along the strike and opens into an 8 ft high chamber, with several narrow rifts to the left running back into the Labyrinth. Straight ahead the passage lowers to the West Bedding Cave, a low crawl in the main bedding plane. Beyond a constriction this enlarges a little, the bedding continuing up-dip to the left, but apparently impassably low, with a solid rock floor. The passage ends in a little soily chamber with a good draught which indicates its proximity to the surface. This seems the most likely point for miners to have entered the cave, although the earthy collapse is not obviously recent.

The main cave beyond Formation Cavern runs north-east, diagonally down-dip, past massive stalagmite flows on the right into a wide sandy cavern where sandy fill is much in evidence. Up-dip from here an ascending crawl ends where the bedding closes amongst calcite flows and dried up crystal pools. Positive evidence of a previous explorer is found here in the form of a blackened skeleton, partly calcited over, apparently that of a dog, which reposes between two boulders in the centre of the chamber floor.

At its lower end the cavern contracts to a descending passage, ending in a squeeze down into constricted choked fissures, where the fill takes on a more clayey consistency. The heavy calciting of the upper sections of the system is noticeably absent in this region. On the left of this passage, 3 ft above floor level, a very narrow tube leads off, which on the afternoon of 11.9.78 was issuing a powerful draught, but at the same time of day a week later was draughting inwards quite noticeably. The first few feet of this tube are very tight and awkward, but beyond this it enlarges, to end in a constriction through which a pool, with a small aven above, could be glimpsed; this aven breaks up through the bedding which controls so much of the cave development, so that this is stratigraphically the highest point in the system. Hammering here allowed a better look at the aven, which proved to close upwards to an impassable slot, though taking the draught; this is another point which must be very close to the surface, or perhaps to old mine workings.

Miners' Inscriptions

The system below the dug-out shaft from the Entrance Chamber has been examined in the past by lead miners, as two smoked inscriptions on the sloping bedding roof show. In Formation Cavern are a group of initials, some with dates: 'W L 1766', 'WM', 'SAD H 1742', and 'A. Alsop, 1798', the last being accompanied by 'WENSLEY'. Lower down the cave, above the entrance to the final choked passage, is the rather faint inscription 'B.D. 1536'. At first sight this seems rather unlikely, but comparison with nearby recent smokings suggests that it is in fact of some antiquity. The use of arabic numerals in this country did become widespread in the 16th century, appearing in the dates of English coins from 1551 onwards. Documentary sources which refer to mines in the area working in the later 16th century were quoted by Kirkham (1962), therefore the date may in fact be authentic.

The miners do not seem to have made any actual modifications to the cave, which shows no evidence of mineralisation. Some excavation of small amounts of fill from choked passages at the lower end of the system probably results from the attention of cavers in recent years. The dog's skeleton appears to be of considerable age, and may be associated with miners' visits to the cave between the 16th and 18th centuries.

The total length of passage surveyed in the cave is 1,080 ft (329 m), descending to a depth of 85 ft (29 m) below the entrance. The position of the cave, at the head of a valley side, and only just below the local plateau surface, suggests that it is of considerable age.

REFERENCES

Ford, T.D. 1974 *Caves of Derbyshire,* Dalesman, Clapham, Yorks.

Hurt, L. 1968 Brightgate Caverns. *British Caver,* vol. 48, pp. 19-21.

Kirkham, N. 1962 Tearsall and Dalefield Soughs. *Bull. Peak Dist. Mines Hist. Soc.,* vol. 1, no. 6, pp. 3-14.

Ryder, P.F. 1975 Phreatic network caves in the Swaledale area. *Trans. Brit. Cave Res. Assoc.,* vol. 2, no. 4, pp. 177-192.

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OPTIMUM LENGTHS FOR CAVING LADDERS AND ROPES

by Brian Paul Hindle

ABSTRACT

Analysis of pitch lengths in the northern Pennines can be used to determine the optimum length for caving ladders, with a view to reducing the amount of waste ladder carried, whether more than one length of ladder is needed, and, if so, what proportions of different lengths are required. Similar techniques can be applied to the choice of rope lengths.

A. LADDERS

It is still generally accepted that 25 feet is the standard length for caving ladders. This length was presumably used originally as it was a convenient imperial length (i.e. ¼ of 100 ft) and was the largest length of rope ladder that could be coiled easily and carried comfortably. Nowadays there would appear to be no particular justification for the 25 ft ladder and this length may well be an anachronism. Furthermore, although the present writer is no lover of metrication, it is at least logical that we should think about metric ladder lengths. This whole topic is of some importance to those who make ladders, whether they are individual clubs or commercial firms, as well as being important to cavers who carry around underground substantial lengths of ladder which are not used on a particular trip.

The first question to be asked is whether it is possible to standardise on a single most useful ladder length, or whether two lengths or more are needed. In a previous article on the subject, D.P. Creedy (1970) looked at the distribution of pitch lengths in the northern Pennines in order to see how many of each of his standard ladder lengths (15, 30 and 50 feet) would be needed for a basic tackle store. It is perhaps more useful to look again at the pitch lengths in order to decide first what ladder length (or lengths) to adopt, and second if more than one length is contemplated, what proportions of different ladder lengths are needed. The question of rung spacing is irrelevant; the choice between 10 and 12 inches (25 cm and 30 cm) is based on a mixture of personal preference and club tradition (and cost!) and any length of ladder (metric or imperial) can be made with either spacing even if the ladder has to be made a little longer as a consequence. Such lengthening may prove a positive advantage as will be seen later. A so-called 10 metre ladder with 10 inches spacing is 33 ft 4 inches (40 rungs) and with 12 inches spacing, exactly 33 ft. In all calculations here it is assumed that a 10 m ladder is 33 ft, and a 5 m ladder exactly half that length (though it would be 16 ft 8 inches with 10 inches spacing or 17 ft with 12 inches spacing).

We are now more fortunate in having the fuller lists of pitch lengths in D. Brooks *et al.*'s *Northern Caves* and volumes 1-4 have been used to compile Figure 1 and Table 1 below. The whole exercise has been carried out in imperial units, as the guidebooks almost always use a vertical interval in multiples of 5 feet. All potholes requiring a total of less than an arbitrary limit of 100 ft of ladder have been ignored, thus concentrating on the distribution of pitch lengths in potholes requiring more tackle: smaller holes can be laddered without having to worry too much about being over-burdened. There are only nine pitches of over 200 ft and these are omitted from the graph.

Creedy noted a high frequency of 30 ft pitches from his more limited data - but in Figure 1 and Table 1, it is clear that the peak is 25 ft, with 30 ft pitches being very little more common than would be expected. On the other hand, there are far more 50 and 60 ft pitches and far fewer 45, 55 and 65 ft pitches than would be expected; the four point running mean gives some idea of the pitch lengths that ought to occur if the distribution of pitch lengths was more 'normal' (not using that word in the strict statistical sense). One must immediately ask whether the data themselves are reliable - or have pitches lengths been rounded up to the nearest 10 ft interval? From personal knowledge, this seems unlikely, for one does not often find oneself at the bottom of 50 or 60 ft pitches with substantial lengths of ladder (i.e. in excess of 5 ft) in a heap on the floor. We must assume, however, that pitch lengths have been rounded up to the next 5 ft, and that very few pitches are longer than stated, though many are shorter. This rounding process also occurs on many cave surveys; in the guidebooks a 25 ft pitch means one between perhaps 22 and 26 ft.

It is clear that even in these potholes requiring over 100 ft of ladder, the majority of individual pitches are quite small: one-third are 25 ft or less, half are 35 ft or less, and only 10% are over 100 ft. Thus the choice of ladder lengths becomes important: if one uses only 25 ft ladders, it is necessary to carry two ladders to rig all pitches from 30 ft to 50 ft (36% of pitches) with varying amounts of waste ladder which has to be carried but not used. Similarly,

TABLE 1

Pitch Length (ft)	Total Pitches (Multiplier) M	25 ft Ladders: Number Required	25 ft Ladders: Waste (ft) W_1	25 ft Ladders: Waste Index MxW_1	5 m and 10 m Ladders: Number Required 5 m	5 m and 10 m Ladders: Number Required 10 m	5 m and 10 m Ladders: Waste (ft) W_2	5 m and 10 m Ladders: Waste Index MxW_2
10	13	1	15	195	1	0	6.5	85
15	50	1	10	500	1	0	1.5	75
20	54	1	5	270	1	0	-3.5	-189
25	70	1	0	0	0	0	8	560
30	57	2	20	1140	0	1	3	171
35	38	2	15	570	0	1	-2	-76
40	38	2	10	380	1	1	9.5	361
45	20	2	5	100	1	1	4.5	90
50	38	2	0	0	1	1	-0.5	-19
55	12	3	20	240	0	2	11	132
60	26	3	15	390	0	2	6	156
65	6	3	10	60	0	2	1	6
70	15	3	5	75	0	2	-4	-60
75	11	3	0	0	1	2	7.5	83
80	9	4	20	180	1	2	2.5	22
85	4	4	15	60	1	2	-2.5	-10
90	11	4	10	110	0	3	9	99
95	4	4	5	20	0	3	4	16
100	8	4	0	0	0	3	-1	-8
>100	55	-	-	-	-	-	-	-
TOTAL	539	-	-	4290	-	-	-	1494

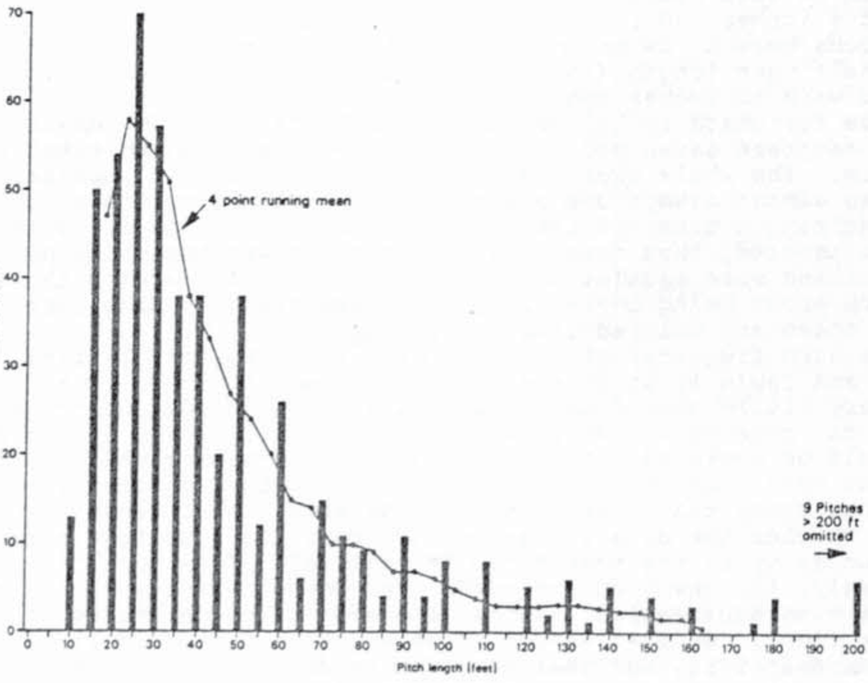

Figure 1 : Pitch lengths in potholes requiring 100 ft of ladder or more
[Source : Northern Caves, Vols 1-4]

if one standardises at 10 metres (33 ft); one can rig 52% of pitches with one ladder (assuming one such ladder will suffice for 35 ft pitches), but there will be even larger amounts of waste ladder for pitches between 40 ft and 70 ft.

This problem can be quantified by looking at the number of ladders needed for each pitch length, working out the length of waste ladder, and multiplying this by the number of pitches of that length which occur in our set of deeper potholes; this is an index of the amount of ladder not used, or wasted. Table 1 ignores pitches over 100 ft, for they account for only 10% of the total, and this exclusion will not materially affect the calculation, and certainly not for the purposes of comparing one set of ladder lengths with another. We see that using only 25 ft ladders gives a 'waste index' of 4290 whereas using only 10 m ladders raises the index to 5983. Our aim must be to get this index as low as possible although there are a number of other considerations.

It is clear therefore that standardising on a single ladder length, although convenient, is very wasteful, and that a combination of two ladder lengths will be better. Any more than two would lead to confusion; of the two lengths chosen, one should be half the length of the other, and both will thus be immediately distinguishable. If this is not the case, chaos can result. The present writer's club is currently using a mixture of 25 ft and 10 m ladders, and for those who do not recognise the difference, there is always the danger, and indeed the strong possibility of ending up at the final 35 ft pitch with only a 25 ft ladder, and having to gaze wistfully at the unreachable passage below.

A number of possible combinations of ladder length are possible, viz: 20 ft and 40 ft, 5 m and 10 m or 15 ft and 30 ft. It is of course clearly possible to continue down to ladder lengths of 5 ft and 10 ft which will have no wastage at all, but this would be wasteful in its own way, as this would require a vast number of ladders, and in any case there are no 5 ft pitches. Indeed, the smallest ladder size should be available for *more than* the shortest pitch length, and as there are so few 10 ft pitches, a 15 ft ladder is the absolute minimum. There is much to be said for the 5 metre (16.5 ft) ladder, for it can be used at a pinch for 20 ft pitches just as two 10 m ladders can be used for a 70 ft pitch. The wastage indices for these combinations are as follows:

TABLE 2

	Waste Index
20 ft and 40 ft	3415
5 m and 10 m (2 ft short on 35 ft and 80 ft pitches)	2632
5 m and 10 m (also 4 ft short on 20 ft and 70 ft pitches)	1494
15 ft and 30 ft	2310

Clearly the amount of wastage is reduced as the ladder size is decreased. The 20/40 ft combination suffers from having most of its waste where there are most pitches (e.g. 25 ft, 50 ft). The clearest gain, however, is made by using 5 m and 10 m ladders and by leaving them about 4 ft short on pitches of 20 and 70 ft (Table 1). As was stated above, pitches are very unlikely to be longer than stated, and quite likely to be shorter; furthermore a tape loop can be fastened to the bottom of the ladder to provide an extra rung if needed. Alternatively one could make each ladder one rung longer, as was suggested earlier.

In the event of there being several 40 - 50 ft pitches in a particular pothole, it will be much simpler to fasten together a 5 and a 10 metre ladder outside the cave to make carrying easier for a small party. A further advantage of this choice of lengths is that, although metric, it converts readily to imperial lengths with which most British cavers are familiar; three 10 m ladders make 100 ft (more or less) and a 5 + 10 m ladder is 50 ft.

If we accept that the adoption of 5 and 10 metre ladders is the optimum solution, the next step is to determine how many of each are needed. This can be done by looking at the required ladders for every pitch length from 10 ft to 100 ft (for the moment omitting longer pitches) and assuming that ladder requirements are proportional to the number of pitches of each length given above. The ratio is one 5 m ladder to every 2.1 10 m ladders. The correct ratio for all pitches up to 200 ft is 1:2.6, and for pitches of all lengths (up to 360 ft) 1:2.9. One might settle for a ratio of two 5 m ladders to every five 10 m ladders giving a total ladder length in this unit of 60 metres or 200 ft. Two or three such units should meet the needs of most clubs caving in the northern Pennines.

A few examples drawn at random from all four volumes of Northern Caves will show that this system works fairly well, reducing both the number of ladders and the length of waste ladder. We assume that all the pitches listed are laddered.

TABLE 3

Pothole	25 ft Ladders		5 m & 10 m Ladders		
	Number Required	Waste (ft)	Number Required 5 m	Number Required 10 m	Waste (ft)
Penyghent Pot	18	70	4	11	49
Lost Johns NRT	15	78	3	8	16.5
Meregill Hole	13	25	1	9	13.5
Pasture Gill Pot	16	65	3	9	11.9

B ROPES

Some of these techniques can be used to determine the optimum lengths of rope - whether it be for single or double lifelining or for SRT. Wastage (i.e. unused rope) is much less of a problem than with ladders. For simplicity it would be helpful to have ropes of similar lengths to the ladders in use. It might be thought that a little extra is useful for tying on or for belaying the lifeliner: however, in the first instance no more than 2 ft extra is needed (bearing in mind that the rope is tied on at waist level) and in the second there ought to be a separate belay for the lifeliner, and certainly so if a double lifeline is to be used. Thus for use with 25 ft ladders, a minimum rope length of 50 ft (100 ft for double lifeline) will suffice for 70% of all pitches and 100 ft (200 ft) for another 20% of pitches. This is rather a long gap between rope lengths (especially as a 100 ft (200 ft) rope has to be used for a 60 ft pitch). A 75 ft (150 ft) rope could be inserted, but would only be used for 13% of pitches, and the 100 ft (200 ft) then used for only 7%. The main problem here is not wastage, but the over-use of the shortest rope length: this can be prevented by using a shorter rope; at 40 ft (80 ft) the rope can still be used on 59% of all pitches and at 10 metres (20 m) on 52% (assuming it can be used for 35 ft pitches). Thus the following is suggested:

TABLE 4

Rope Length (m) Single	Double	% of pitches on which length can be used	Ratio of rope lengths required
10	20	52	8.7
20	40	26	4.3
30	60	12	2.0

Thus an appropriate ratio of lengths would be 9 : 4 : 2. Longer ropes can be cut as needed.

This ratio of short lengths seems rather high, but one has only to look at the potholes listed above to see that large numbers of short ropes are in fact required (assuming that all pitches are lifelined if SRT is not being used).

TABLE 5

	Single (Double) Rope Lengths required (m)			
	10(20)	20(40)	30(60)	Over 30(60)
Penyghent Pot	7	3	1	-
Lost Johns NRT	6	1	1	-
Meregill Hole	3	1	3	-
Pasture Gill Pot	4	2	-	1

Two final points are worth making; the first is that ropes shrink quite appreciably after their first few trips: 10 - 12% shrinkage is common (especially in plaited or braided ropes) and 18% has been observed in a nylon braided rope used by the present writer. It is thus vital to ascertain the shrinkage of whatever rope is to be used *before* all the lengths are cut. With 18% shrinkage a 100 ft rope becomes 82 ft; it is no joke abseiling down what was thought to be a 100 ft rope only to run out 18 ft above the floor.

Second, it should always be borne in mind that most pitches were measured from the lip of the pitch, and not from any bolts or beams which may have been inserted later; these are usually higher and may cause shortage of rope (and ladder for that matter). The solution here is to use a longer belay, or where that is not possible, to make sure that rope and ladder do in fact reach the foot of the pitch, which is what this article has been all about.

ACKNOWLEDGEMENTS

The author would like to thank Mr. Gustav Dobrzynski, cartographer in the Department of Geography, University of Salford, for re-drawing the diagram.

REFERENCES

Brook, D., *et al.* 1975 *Northern Caves.* 5 vols., Dalesman, Clapham, Yorkshire.
Creedy, D.P. 1970 in *Cave Research Group Newsletter.* No. 24, pp. 16 & 18-19.

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THE AGE OF EXPOSURE OF LIMESTONE PAVEMENTS - A PILOT LICHENOMETRIC STUDY IN CO. CLARE, EIRE

by Stephen T. Trudgill, Robert W. Crabtree and Peter J.C. Walker

ABSTRACT

Pilot studies using lichenometry suggest that some limestone pavements have been exposed in the last few decades while others have been exposed for at least several hundred years.

Much of the debate about the geomorphology and soils of limestone pavements hinge around whether bare limestone surfaces have always been soil-free since the last glaciation or whether soil covers have been eroded during the Post-Glacial (see, for example, Jones, 1966; Trudgill, 1972; Williams, 1966). Geomorphological observations of highly eroded, fretted and runnelled bare surfaces have been used as evidence for the existence of a former acid soil cover while striated surfaces have been preserved since glacial times under calcareous covers (Trudgill, 1973; Atkinson & Smith, 1976, p. 168-9). However, the geomorphological argument is based upon the observation of dissected limestone surfaces existing under acid drift and of similar forms under subaerial conditions. The argument is that the latter represent exhumed surfaces. This is a reasonable argument but if there were a method of dating the subaerial surfaces then the argument would be a more concrete one. It is possible that lichenometry can provide such an independent line of dating evidence.

LICHENOMETRY AND THE ESTABLISHMENT OF A CALIBRATION CURVE

The principle of lichenometry is that, within given, similar conditions, the size distribution of lichen populations will be comparable. The measurement of the diameters of lichens on a known, dated surface can be compared to the sizes of lichens on surfaces of unknown date. Assuming that similar growth conditions exist on both surfaces the dates of the unknown surfaces can be assessed. The procedure is best carried out using a lichen growth curve derived from as many comparable dated surfaces as possible, spanning as wide a time scale as possible. Gravestones, walls of dated buildings and monuments usually provide such surfaces.

In Co. Clare two main sites were used to establish a growth curve. These were the dated gravestones in Kilfenora chapel and in Killeany chapel, near Lisdoonvarna (Fig. 1). Only limestone gravestones were used. The species measured were the white lichen *Lecanora calcarea* which is a foliose, surface-living species and a crustose (partially embedded in the surface) species which has so far not been identified but is also in the genus *Lecanora*. The former species occurs widely on walls and large glacial erratic blocks; unfortunately it does not occur widely on the flat bare pavements of interest. Here, moisture retention is minimal and exposure is great. However, while the latter (crustose) species appears to be slower to establish itself and is absent from the younger gravestones, it is widespread on the exposed pavements, though it is scarce where other lichens are present. The orange lichen *Caloplaca heppiana* is common on erratic boulders but was scarce on gravestones and so was not used in the present study.

The calibration curves for the lichens on the gravestones at Kilfenora chapel and Killeany chapel are shown in Figs. 2a and 2b. As can be expected, there is a wide scatter of data and, for example, an individual of 9 cm diameter at Kilfenora can be of a date from 1880 to 1920. However, taking the data bodies overall, lines of definite trends can be drawn and it is these trend lines which have been used in the dating exercise. As can be seen the two trend lines are not dissimilar for the two sites and therefore these have been amalgamated for the purposes of dating.

In the case of the crustose lichens, the curve is far from complete and reference has to be made to walls and other objects where the dates are less precisely known. However, assuming that the walls can be dated using the *Lecanora calcarea* curve, then the crustose lichen curve can be extrapolated. Clearly, this is far from satisfactory and further work is planned to improve the validity of this curve.

The use of the curves in their present form must be heavily qualified. Gravestones and walls present a variety of surfaces where water retention may be encouraged (horizontal) or discouraged (vertical). The walls and boulders also present a variety of surfaces and are also creviced to a variable extent. The aspects of the surfaces varies markedly. In this paper all the data are lumped together because of the low number of observed sites. In future work it is hoped that standardisation may be made for each aspect and for creviced,

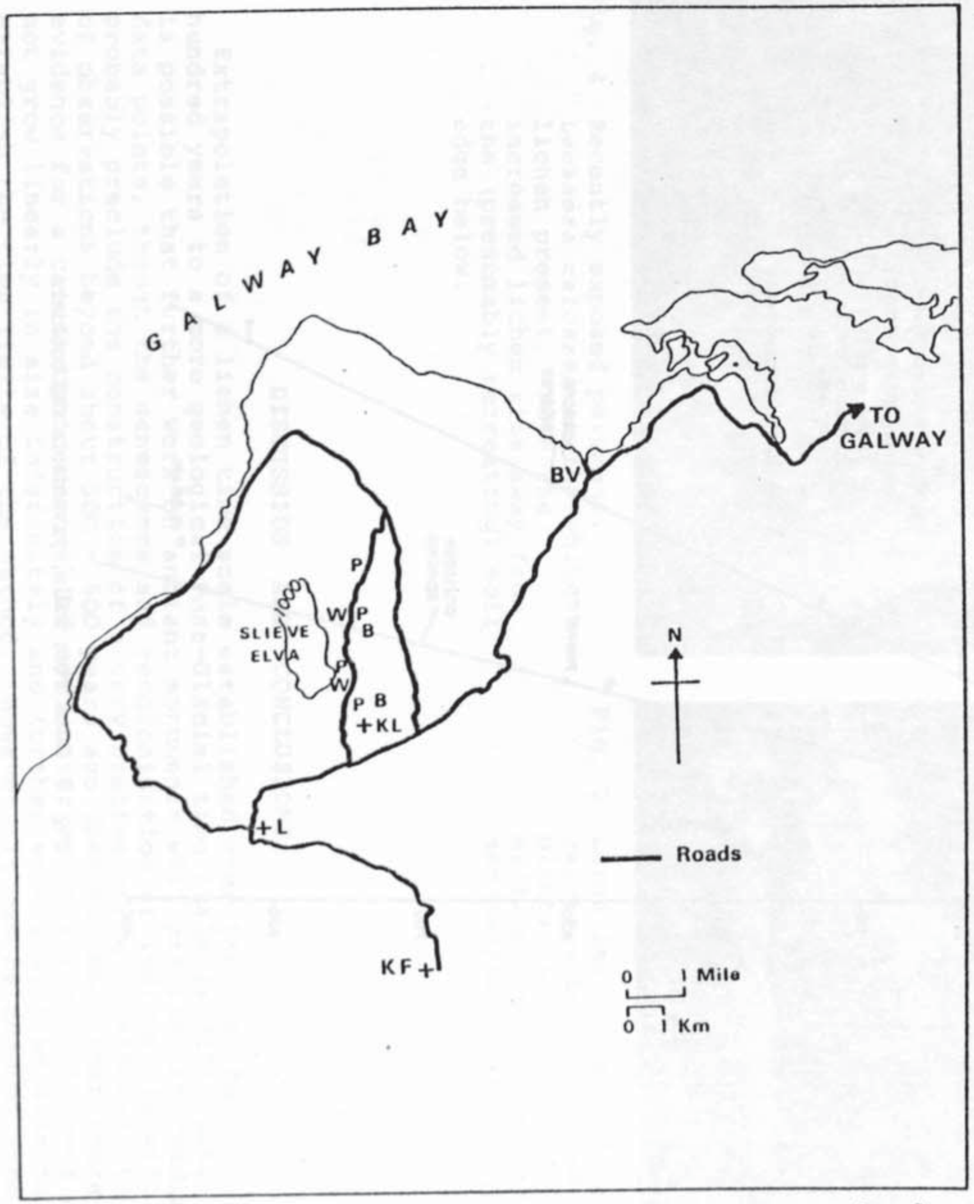

Fig. 1. The area of study: BV = Ballyvaghan; KF = Kilfenora chapel;
KL = Kileany chapel; L = Lisdoonvarna;
P = pavement sites; W = wall sites; B = erratic block sites.

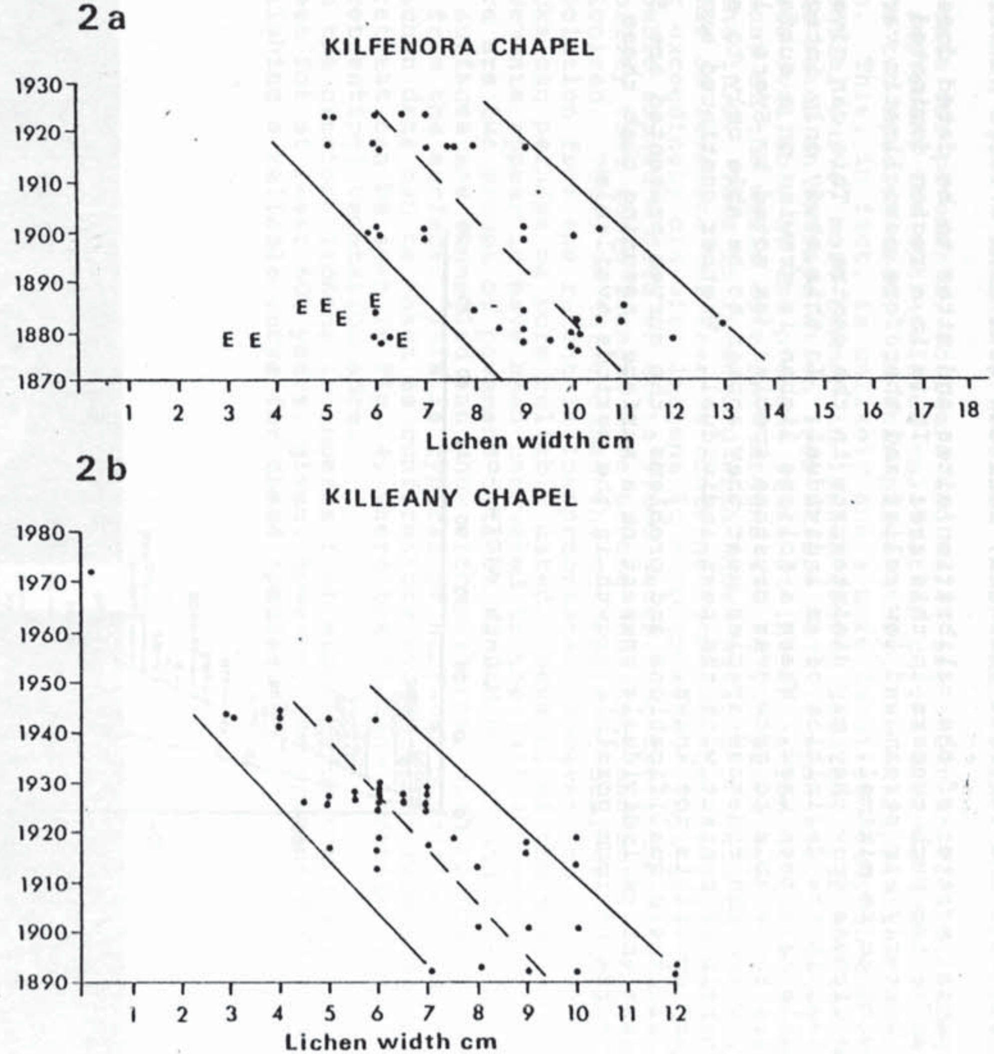

Fig. 2, Calibration curves from chapel gravestones.

flat, horizontal and vertical surfaces, deriving data from a large number of sites.

The spatial scatter of the calibration sites and sites to be dated does not give rise to too much concern in this area. It is in a region dominated by a moist westerly air stream and low relief and therefore mesoclimatic variations are thought to be minimal.

As the lichens grow they may disintegrate in the centre. This can give rise to problems in the definition of an individual. In this study only integral individuals have been used. Where a foliose lichen is growing on a surface, it appears to be able to grow over crustose species (as noted by Syers, 1964). However, where the crustose species meet they appear to be able only to expand to the margin of contact with the next individual. Whether continued expansion and piracy occurs is not known.

Given all these qualifications and problems, the curves presented are for the largest entire individuals present on a surface, assuming that these represent the maximum possible growth in the periods available.

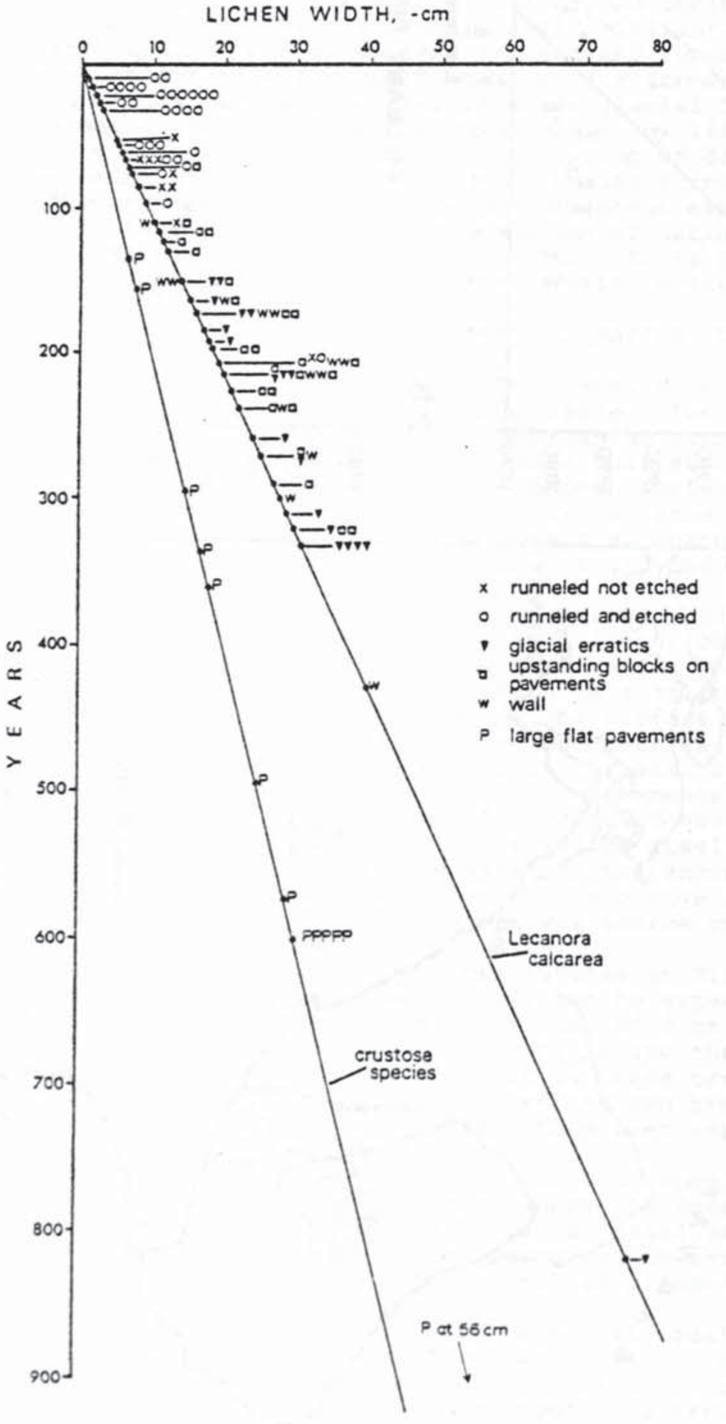

Fig. 3. Data from walls, pavements and boulders.

PAVEMENT, BOULDER AND WALL DATA

The data for pavements, boulders and walls are shown in Fig. 3. The solid lines represent the extrapolated calibration curves derived from the gravestones for the two species used. In this pilot study, the extrapolation assumes linear growth. This, in fact, is unlikely and a more detailed study should reveal an exponential curve, more common in lichen growth studies. Further study should also be based on extrapolation from before 1870 if possible. However, from the data available at the present stage of investigation it can be suggested that most of the walls date from around 150 to 250 years ago, i.e. between 1730 and 1830. This is in accord with known periods of wall building in Ireland.

As far as *Lecanora calcarea* is concerned some of the glacial erratic boulders appear exceedingly old with lichens 50 - 70 cm wide. This is in accord with a probable exposure date of up to 9,000 years. However, there is every possibility that these lichens have become senescent and open, and have been re-colonised. Thus, in these cases the method is of dubious value and extrapolation from the recent is inappropriate. However, more recently exposed bedrocks can perhaps be more reliably dated. Several of the upstanding blocks on pavements appear to have been uncovered in the last 400 years.

There are two groups of pavement data at around 0 - 30 and 50 - 90 years ago. These surfaces are runnelled and show etch patterns, with crinoid fossils standing proud from the surface. This is typical of surfaces occurring under acid soils. The lichen data can be taken as confirmatory evidence for recent soil retreat. Such retreat can be seen in Fig. 4, where the lichens increase in size away from the (retreating) vegetation edge.

With the crustose lichens it appears that exposure of the large flat pavements has been for at least 600 years, given, however, the present difficulties of establishing a reliable curve for these species.

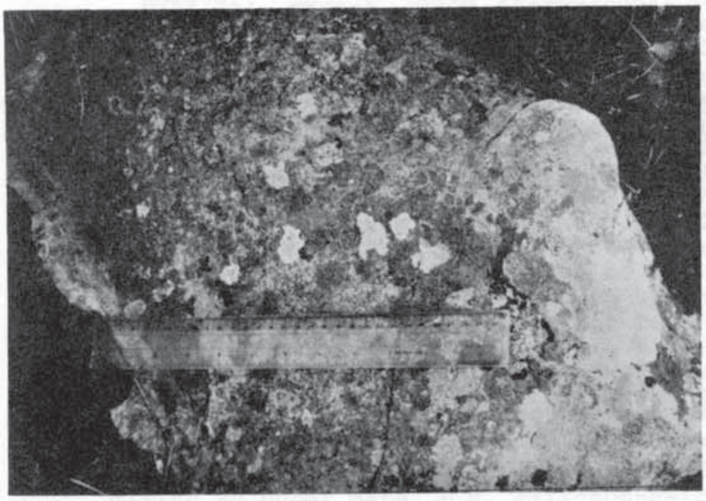

Fig. 4 Recently exposed pavement. *Lecanora calcarea* is the whitest lichen present. Note the increased lichen size away from the (presumably retreating) soil edge below.

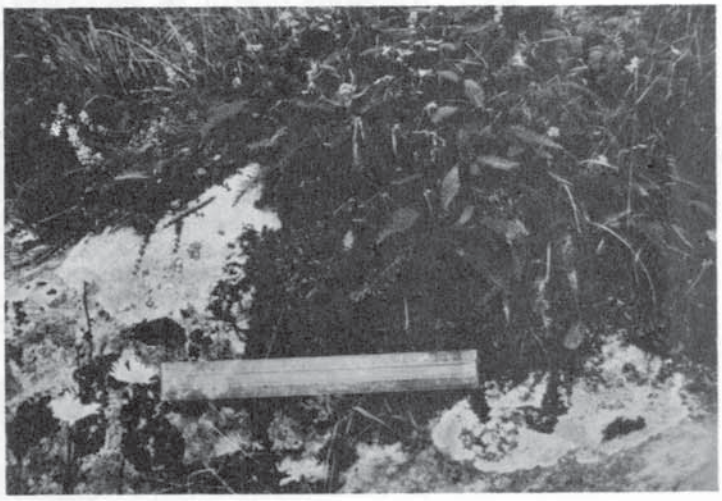

Fig. 5 Large individuals of *Lecanora calcarea* being covered by higher plants, notably *Achillea millefolium, Lotus corniculatus* and *Galium verum*.

DISCUSSION AND CONCLUSIONS

Extrapolation of a lichen time scale established over the last few hundred years to a more geological Post-Glacial time scale is difficult. It is possible that further work on ancient monuments will provide intermediate data points, though the senescence and recolonisation of individuals will probably preclude the construction of a very precise curve. Certainly the lack of observations beyond about 500 - 600 years ago does not mean that there is evidence for a catastrophic removal of soil cover at this time. Lichens do not grow linearly in size indefinitely and further work should be able to establish the time limits of the method. However, it can be deduced from the present evidence that the extensive flat pavements have been bare for at least 600 years; glacial erratics have been bare for at least 600 - 800 years. The walls and chapel building itself at Killeany can be dated at 150 - 300 years ago. Perhaps the most interesting facet of this work is that corroborative evidence is provided for the runnelled and etched pavements which, on geomorphological evidence, appear to have been exhumed. Some runnelled pavements appear to date from 150 - 300 years ago and runnelled and etched pavements from around 80 and around 20 years ago. The former period coincides with the periods of wall building and such development could have been a causative factor in exhumation. In more recent times there is certainly a hearsay memory of people, who are now aged between 60 and 80, of large herds of goats in the region when they were children. Such herds are now largely feral and disbanded, and limited in population size, but larger herds in former times could certainly have contributed to devegetation. It should also be noted that some large lichens are presently being covered by higher plants (Fig. 5), and this is probably evidence of decreased grazing pressure at the present day.

Further work on more comparable sites and older sites, together with some archive work, may provide some of the answers to the remaining questions about the history of the development of the limestone pavements in the Burren.

ACKNOWLEDGEMENTS

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REFERENCES

Atkinson, T.C. & D.I. Smith 1976 The erosion of limestones. Ch. 5 IN: Ford, T.D. & C.H.D. Cullingford, *The Science of Speleology*, pp. 151-177, Academic Press, London.

Jones, R.J. 1965 Aspects of the biological weathering of limestone pavements. *Proc. Geol. Assoc.*, vol. 76, pp. 421-434.

Syers, J.K. 1964 *A study of soil formation on Carboniferous Limestone*. Unpub. Ph.D. thesis, University of Durham.

Trudgill, S.T. 1972 The influence of drifts and soils on limestone weathering. *Proc. Univ. Bristol Speleol. Soc.*, vol. 13 (1), pp. 113-118.

Trudgill, S.T. 1973 Limestone erosion under soil. *Proc. VIth Int. Speleol Congr., Olomouc*, Ba, pp. 409-422.

Williams, P.W. 1966 Limestone pavements with special reference to Western Ireland. *Trans. Inst. Brit. Geogr.*, vol. 40, pp. 155-172.

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METHODS FOR DATING PALAEOLITHIC CAVE ART

by Alex Hooper

ABSTRACT

No Palaeolithic cave art is known in the British Isles, despite the occurrence at several sites in Great Britain of mobile art of this period and the recent extension northwards, as far as Rouen in France, of the range of decorated caves. Traditional and experimental methods of dating art in caves are described.

There are currently nearly two hundred known caves containing art thought to originate in the Upper Palaeolithic period. Cave art of this date (approximately 35,000 - 10,000 years BP) usually depicts animals, human beings or signs of unknown significance in engraving, painting, carving or, rarely, clay modelling (see Breuil (1952); Leroi-Gourhan (1968); Sieveking and Sieveking (1962); and Ucko and Rosenfeld (1967): references to all caves mentioned below may be found in these works unless otherwise stated).

Most of these decorated caves are in south-western France or north-western Spain, but there are also sites in Portugal, Italy, Sicily, Turkey and southern Russia. No decorated caves of this date are known in the British Isles, although in 1912 Breuil and Sollas (who has recently been posthumously implicated in the Piltdown Man hoax of earlier this century (see Halstead, 1978)) investigated a possibility at Paviland on the Gower Peninsula that turned out to be disappointing: "In western England we know of the research undertaken by Professor Sollas and myself in 1912 to the north of the Bristol Channel. The only discovery was of some wide red parallel bands in a coastal cave to the east of Paviland; the age of these cannot be fixed", (Breuil, 1952, p. 25). Molleson (1976) has reviewed the history of research in Paviland Cave.

However, "mobile" Upper Palaeolithic art, engraved on pieces of stone, bone or ivory, has been found at several archaeological sites in Great Britain, e.g. Robin Hood's Cave and Pin Hole Cave at Creswell Crags, and Kendrick's Cave, North Wales (Sieveking, 1972). In addition, the known range of prehistoric decorated caves has in recent years spread northwards - La Grotte Mayenne-Sciences at Saulges, Mayenne (Dams, Dams and Bouillon, 1974), and Gouy near Rouen (Graindor, 1972) were both found in the last ten years - so it does not seem impossible that a happy discovery might one day take place on this side of the Channel.

The dating of art found on cave walls and floors is a more complicated procedure than archaeological dating generally. It is rare for any particular work of cave art to be precisely dateable; therefore, some combination of the following methods is normally used by prehistorians to put art believed to be of the Upper Palaeolithic into its relevant chronological context.

(a) The mouth of a cave or of a gallery within a cave may be sealed by an accumulation of debris containing dateable archaeological material. This material gives an "upper" (i.e. latest possible) date to the art inside the cave or gallery, provided that there is only one entrance, e.g. Marsoulas, Haute-Garonne.

(b) Dateable archaeological deposits may sometimes cover the decorated walls, giving an upper date, e.g. Pair-non-Pair, Gironde.

(c) Pieces of rock still holding paint or engraved lines may have fallen from the cave wall into dateable archaeological deposits, giving an upper date to the art, e.g. Angles-sur-l'Anglin, Vienne.

(d) At many caves there are dateable archaeological sites that are close to the decorations, but this does not necessarily mean that the people who caused the archaeological layers were also responsible for the art. It may have been by artists who did not inhabit the site, or, as at Ussat-les-Eglises, Ariège, there may be evidence of human occupation of the cave from very ancient to very recent times and there may be little or nothing to link the art to any one of the periods of occupation.

(e) Sometimes dateable artefacts are found in close association with the art. For example, carbonized wood, probably the remains of a torch, dated by radio-carbon methods to 11,860 BC $\pm$ 740, was found in the newly discovered decorated cave of Fontanet, Ariège (Clottes and Simonnet, 1974). Another example of dating by artefact is given by the two flint blades found, one on a rock ledge, the other on the floor, near to wall engravings of animals in the cave of Le Tuc d'Audoubert, Ariège. The tools were compatible in size with the engraved lines and were of an Upper Palaeolithic style of manufacture.

(f) Calcite dripstone may cover the art or parts of it, e.g. Lascaux, Dordogne. The extent to which this has taken place may give a rough indication of the art's antiquity.

(g) Associated with this last point is the case of Cougnac, Lot, where stalagmites and stalactites were broken off in antiquity so that the paintings on the walls might be viewed more easily. The speleothems have been reforming over the broken pieces, thus giving an impression of the passage of time since the breakage.

(h) Extinct species of animals are depicted in some caves, e.g. mammoth at Bernifal, Dordogne. Where it is certain that the picture is not a modern forgery, this indicates that the artist was practising at the time when the species was in evidence.

(i) Sometimes one or more pictures have been superimposed on another and it is possible to tell which is prior, e.g. Les Combarelles, Dordogne. Breuil developed his ideas of stylistic evolution of the art partly from using this method and partly from comparing the styles, techniques and contents of dated works of art with those of undated examples.

(j) Comparison between archaeologically dated mobile art and cave art, especially if the relevant sites are close to each other, e.g. Altamira and El Castillo, Santander, where animal engravings on dated bones resemble each other and also pictures on the walls of both caves, thus giving a probable period, i.e. from the Upper Solutrean to the Lower Magdalenian phases of the Palaeolithic. Another good example of this method is the close similarity between mobile art from layers dated by radio-carbon to approximately 10,900 BC at the cave of La Vache and wall art in the nearby cave of Niaux, Ariège (Nougier and Robert, 1976).

(k) Leroi-Gourhan (1968) formulated a hypothesis, to some extent confirmed by other dating methods, that the artists progressively penetrated the caves throughout the millenia of the Upper Palaeolithic, i.e. using the cave thresholds early in the epoch, later placing the art deeper in the caves and so on until the Middle Magdelenian (approximately 15,000 BP). This process may have been associated with the gradual development of more efficient lighting methods, or, perhaps, with some changing religious requirement.

(l) In 1975 at the cave of Les Fieux, near Miers, Lot, extraneous pieces of manganese dioxide (a black pigment) were found in an Upper Palaeolithic layer in excavations at the cave mouth. This pigment is currently being chemically and spectrographically compared with black paintings on the walls inside the cave (F. Champagne - pers. comm.; see Champagne and Espitalié, 1972). It may eventually be possible to draw useful information concerning the date of the wall art from this comparison.

(m) Almost no experimental work has been published on the pigments of the paintings in the French and Spanish caves (this is partly due to the authorities' wish to conserve the art). However, for southern African rock art, Denninger (1971) reports that, by using a method known as "paper chromatography", it is possible to separate out amino acids from paints containing albuminous binders (i.e. paint binders derived from blood or blood serum). The various amino acids disintegrate at constant rates until, after 1,800 years, the last one disappears. Obviously, the effective time range of this method is too restricted for the European Upper Palaeolithic paintings, but it does, perhaps, offer possibilities for future research, especially as the amount of pigment destroyed is very small compared to that needed for radio-isotope methods of dating.

(n) It is well known that for relatively recent paintings on canvas or wood it is sometimes possible, with the aid of infra-red or ultra-violet lighting, to see pigments that may not be seen in the "visible" spectrum. This method has been tried, notably by Marshack (1975), Collison (1974) and by Collison and Hooper (1976), for cave art, without conclusive results for the dating of the art. Fournier was able to photograph fluorescence induced by ultra-violet light on the limestone walls at La Grotte Mayenne-Sciences near Saulges; where the pigment of a painted animal outline occurred on the limestone, the fluorescence was inhibited, thus showing an "aura" around the animal image (Hooper, 1977, Fig. 23). This result holds out promise for future work, which might have implications for the dating of paintings on limestone.

(o) The paintings at the cave of Tito Bustillo, Asturias, have been tentatively ascribed to 11,300 - 11,200 BP by Creer and Kopper (1972), using a method known as "palaeomagnetic dating". Certain geomagnetic variations recorded in the human habitation deposits at the cave mouth, which is some way from the paintings in the interior, were correlated with part of the geomagnetic record established for Lake Windermere, England. Of course, the same restrictions as in (d) (see above) apply in associating the date ascribed to the threshold habitation deposits with the art deeper in the cave.

Thus, none of the methods currently in use for fixing the general time range for Upper Palaeolithic art can give an absolute date for its execution. The approach used by Denninger, in (m) above, offers the one that is perhaps most likely to lead to this end, within the needs of conservation of the art inside the caves. However, in any given case, the hypothesis that the art falls within a stated age range may be sustained, provided that the results of all available methods of age assessment point towards this conclusion and that none positively counters it.

REFERENCES

Breuil, H. 1952 *Four Hundred Centuries of Cave Art*, Montignac.

Champagne, F. and Espitalié, R. 1972 Note sur une datation du Sauveterrien de la grotte des Fieux, à Miers (Lot), *Bull. Soc. Préhist. Fr.*, t. 69, pp. 55 - 58.

Clottes, J. and Simonnet, R. 1974 Une datation radiocarbone dans la grotte ornée de Fontanet (Ornolac-Ussat-les-Bains, Ariège), *Bull. Soc. Préhist. Fr.*, t. 71, No. 4.

Collison, D. 1974 The Photography of Cave Art, *British Journal of Photography*, vol. 121, pp. 456-458.

Collison, D. and Hooper, A. 1976 L'art paléolithique de la grotte des Eglises à Ussat (Ariège), *Gallia Préhistoire*, t. 19, pp. 221-238.

Creer, K.M. and Kopper, J.S. 1974 Paleomagnetic Dating of Cave Paintings in Tito Bustillo Cave, Asturias, Spain, *Science*, vol. 186, pp. 348-350.

Dams, M., Dams, L. and Bouillon, R. 1974 Les figurations rupestres paléolithiques de la Grotte Mayenne-Sciences à Saulges (Mayenne), *Préhistoire Ariégeoise*, vol. XXIX, pp. 65-87.

Denninger, E. 1971 The use of paper chromatography to determine the age of albuminous binders and its application to rock paintings, IN Schoonraad, M. (ed.), *Rock Paintings in Southern Africa*, Spec. Pub. no. 2, South African Assoc. for the Advancement of Science.

Graindor, M.J. 1972 Upper Palaeolithic Rock Engravings at Gouy (France), *World Archaeology*, vol. 3, no. 3, pp. 243-251.

Halstead, L.B. 1978 New light on the Piltdown hoax?, *Nature*, vol. 276, pp. 11-13.

Hooper, A. 1977 *Problems of Interpretation in Palaeolithic Cave Art* (unpub. M.Phil. thesis), Institute of Archaeology, University of London.

Leroi-Gourhan, A. 1968 *The Art of Prehistoric Man in Western Europe*, Thames and Hudson, London.

Marshack, A. 1975 Exploring the Mind of Ice Age Man, *National Geographic*, vol. 147, pp. 62-89.

Mólleson, T. 1976 Remains of Pleistocene man in Paviland and Pontnewydd Caves, Wales, *Trans. B.C.R.A.*, vol. 3, no. 2, pp. 112-116.

Nougier, L.-R. and Robert, R. 1976 Contributions à l'étude de la frise dans l'art mobilier du magdalénien terminal, *Préhistoire Ariégeoise*, vol. XXXI, pp. 31-45.

Sieveking, A. and Sieveking, G. 1962 *The Caves of France and Northern Spain: A Guide*, Vista Books, London.

Sieveking, G. 1972 Mobile Art in Great Britain, *Santander Symposium*, Actas del Symposium Internacional de Arte Prehistórico, pp. 385-388.

Ucko, P.J. and Rosenfield, A. 1967 *Palaeolithic Cave Art*, Weidenfeld and Nicolson, London.

MS Received December 1978

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AN INVESTIGATION INTO THE RELATIONSHIP BETWEEN SOLVENT MOTION AND THE SOLUTIONAL EROSION OF AN INCLINED LIMESTONE SURFACE

by Stephen T. Watts and Stephen T. Trudgill

ABSTRACT

Theories and previous work on solvent motion are reviewed. Dilute acid was dribbled down an inclined limestone surface and it was found that solvent motion was the limiting factor affecting solution for all slope angles. Rill flow started to occur above 15° slope and was pronounced above 40°.

It is well recognised that solvent motion is an important determining factor as regards the rate of solution of a substance, in that, for example, stirring increases the rate of solution. This work is an attempt to establish the relationship between the motion of a solvent over a limestone surface and the consequent solution of that surface.

If the solubilities of different chemicals are to be compared in the laboratory, the solvent motion factor is usually kept constant so that it can be excluded from the calculations. However, in the natural world, different landforms may be created by different flow velocities, and so this factor can not be excluded, (Kaye, 1957, p. 35).

The work arises from an apparent conflict between different authors in the literature, which will be evident in the following account. Basically, some think that solvent motion is an important limiting factor affecting the rate of solution of limestone, whilst others do not think that it is of importance.

THE LAW OF LIMITING FACTORS

The law of limiting factors states that when a chemical process depends on more than one essential condition being favourable, its rate is limited by that factor which is nearest its minimum value. Thus in Fig. 1, during the rising part of the graph factor x is limiting, but when the curve flattens out, another factor is limiting, because this new factor is relatively nearer its minimum level.

The essential conditions or possible limiting factors associated with the solution of limestones have been reviewed by a number of authors. The factors of greatest concern are:

(a) The rate at which individual chemical reactions can take place.
(b) The rate at which the diffusion of products away from, or diffusion of reactants towards the solute face can take place.

There are numerous important parameters affecting both (a) and (b) above, such as temperature. A temperature increase encourages both an increase in reaction rate and an increase in diffusion rate. In most cases, the temperature is held constant to save complication, but it should be remembered that it too can be a limiting factor, for example, upon the solution of limestones in arctic areas.

Solvent motion is a parameter associated with the rate at which diffusion can take place. It is the main aim of this paper to illustrate the extent to which solvent motion is a limiting factor in the solution of limestones.

It should be noted that in the present paper, the solution of limestone is considered at the scale of a single limestone exposure, such as the side of a clint. The limiting factors controlling the solutional erosion of a whole limestone basin are much more complex, due to the larger scale of study. For example, Atkinson and Smith (1976, p. 155) stated that "there are only four factors which affect the rate at which a limestone is eroded, if the erosion is measured as an average rate over the whole of the drainage basin. They are the composition and resistance of the rock itself (the lithological factor), the amount of runoff from the basin, the temperature and the prevailing levels of carbon dioxide". In this example, solvent motion is only one of many parameters associated with the much more complex factor, the amount of runoff from the basin.

LITERATURE INCORPORATING SIMILAR STUDIES

Whilst it is acknowledged in much of the literature that solvent motion is of importance in determining the solution of limestone, only one or two studies have concentrated on this topic in detail. Sometimes the factor is only indirectly inferred as being of importance, and in other cases it is not considered at all.

Kaye (1957) wrote specifically on the "effect of solvent motion on limestone solution". Four experiments were carried out to show the effect of increasing flow velocity on solution rates:-

(a) Experiment 1

A simple experiment to show the effect of bubbles of carbon dioxide splashing solvent, and so increasing the rate of reaction. A calcite crystal was placed in hydrochloric acid, and it was observed that bubbles of carbon dioxide rose to the surface, where they clung on to the rock before eventually bursting, and splashing the acid over the crystal surface. This caused a notch to develop around the surface of the acid, rather like the motion of a larger scale associated with limestone coasts. The effect of the bubbles was proved by adding a wetting agent to the acid, making the bubbles last longer by increasing the surface tension. Thus they floated away from the surface of the crystal before bursting and no surface notch was observed.

(b) Experiment 2

This experiment utilised the fact that slope angle is a parameter influencing flow velocity. Dilute acid was allowed to flow down smooth limestone surfaces inclined at different angles, and then the depth of solution was measured by cutting the block into two, producing a cross-section of the channel which could then be measured. The Chezy equation (equation 1) was used to estimate the velocity of the acid from the slope angle, and so a relationship could be established between a velocity factor and the depth of solution. Two relationships were obtained, one assuming laminar flow and the other assuming turbulent flow (Fig. 2).

The Chezy Equation:-

$$v = \sqrt{Rs}.\ C. \qquad \text{(Equation 1)}$$

v = the mean velocity s = the slope
R = the hydraulic radius C = the Chezy coefficient

(c) Experiment 3

Hydrochloric acid was piped through holes of known mean diameter in marble blocks at different velocities. As in experiment 2, a positive relationship between the amount of solution and the mean velocity was obtained (solution measured by the mean diameter of the hole).

(d) Experiment 4

The depth of a pit in a rock surface formed by a jet of acid of known velocity was measured. The depth was found to increase with velocity.

Weyl (1958) followed up Kaye's work by interpreting data from a similar sort of experiment in terms of limiting factors. Weyl noted that there were four possible limiting factors in the solution reaction system when the natural solvent of carbonic acid was used:-

(a) The dissociation of calcite at the solid liquid interface into calcium and carbonate ions;

$$CaCO_3 = Ca^{++} + CO_3^{--} \qquad \text{(Equation 2)}$$

(b) The reaction between carbonate ions and dissolved carbon dioxide to form bicarbonate ions;

$$CO_3^{--} + CO_2(aq) + H_2O = 2HCO_3^- \qquad \text{(Equation 3)}$$

This is actually the result of 3 separate equations;

$$CO_3^{--} + CO_2(aq) + H_2O = 2HCO_3^- \qquad \text{(Equation 4)}$$

$$H_2CO_3 = H^+ + HCO_3^- \qquad \text{(Equation 5)}$$

$$CO_2(aq) + H_2O = H_2CO_3 \qquad \text{(Equation 6)}$$

(c) If the solution is in contact with a gas phase containing carbon dioxide, there is an additional reaction;

$$CO_2(g) + H_2O(l) = CO_2(aq) \qquad \text{(Equation 7)}$$

(d) The transport of the various species through the solution by diffusion and fluid motion to equalise concentration gradients.

A jet of carbonic acid was applied to limestone, and the rate of solution was measured by the depth of the resulting depression in the rock (results shown

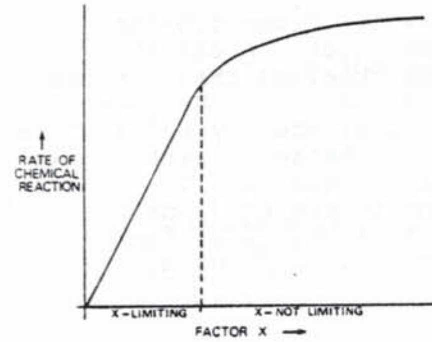

FIG. 1 DIAGRAM TO SHOW THE LAW OF LIMITING FACTORS.

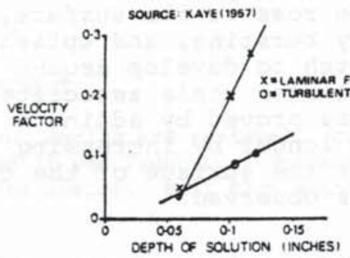

FIG. 2 THE RELATIONSHIP BETWEEN VELOCITY FACTOR AND DEPTH OF SOLUTION IN KAYE'S SECOND EXPERIMENT.

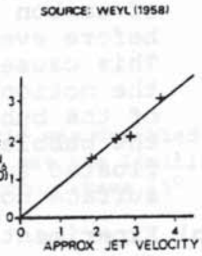

FIG. 3 THE RELATIONSHIP BETWEEN JET VELOCITY OF H_2CO_3 AND RATE OF SOLUTION IN WEYL'S EXPERIMENT.

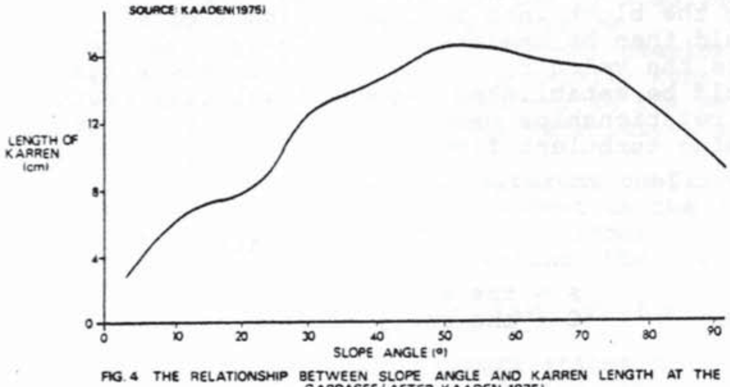

FIG. 4 THE RELATIONSHIP BETWEEN SLOPE ANGLE AND KARREN LENGTH AT THE GARDASEE (AFTER KAADEN 1975)

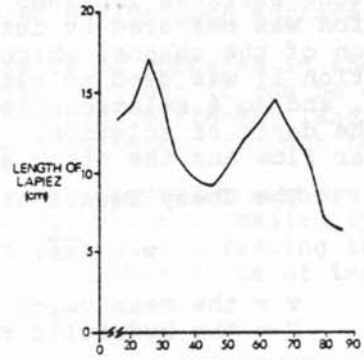

FIG. 5 THE RELATIONSHIP BETWEEN SLOPE ANGLE AND LENGTH OF LAPIEZ IN DACHSTEIN (AFTER HEINEMANN 1977)

KEY

DIVIDES, RIDGES ETC. (GENERALLY NO MORE THAN 1mm HIGH).

----- BOUNDARY OF VERY FLAT AREA ONTO WHICH SOLVENT COULD FLOW.

→ MAJOR SOLVENT ROUTEWAYS (USED IN CALCULATING AVERAGE CHANNEL LENGTH).

X SOLVENT STARTING PLACE (BELOW BURETTE)

FIG. 6 SURFACE PLAN OF ROCK USED IN EXPERIMENT

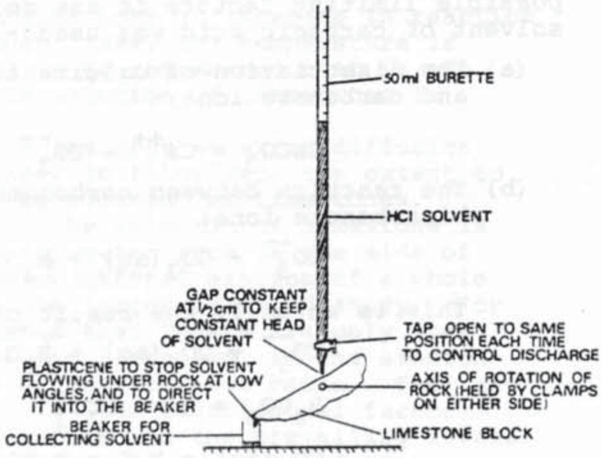

FIG. 7 EXPERIMENTAL APPARATUS USED

in Fig. 3. This demonstrates that the rate of solution of calcite, even at the high flow velocities used (up to 3.7 m/s) is not limited by the rate of dissociation at the solid-liquid interface. To make sure that the removal of material was all by solution, the experiment was repeated using distilled water. The amount removed decreased proportionally to the decrease in solubility associated with distilled water. Experiments of similar logic were carried out to show that steps (b) and (c) above were also non-limiting at the velocities used, and thus it was concluded that "the rate of solution of calcite depends only on the rate of transport of the solute through the solution to equalise concentration gradients".

Weyl also considered the work of Gartikov and Pantelva (1937). They rotated calcite crystals in various solvents at high speeds, and found that whilst for the most part there was a positive relationship between the velocity and the amount of solution, the rate of solution eventually levelled off. This was attributed to the slow rate of interaction between water and carbon dioxide being a limiting factor at this point, but no evidence was presented to suggest that it was indeed this step that was limiting. It could equally well have been one of the other two steps ((a)&(b)).

Picknett (1976) stated that the "rate of solution or deposition depends on two main processes:-

(a) Surface reaction - the release and recombination of calcium and carbonate ions at the solid surface.

(b) Diffusion - the migration of ions and molecules through the solution towards or away from the solid surface".

(Picknett considered Weyl's steps (b) and (c) to proceed at a sufficiently faster rate than step (a) for them to be of little importance in terms of limiting factors). To determine which of these two processes limited the rate of solution (or deposition) of calcite, two equations were compared, one for the surface reaction rate and one for the diffusion rate. The equation for diffusion rate has a transfer coefficient (Kt) and varies for different types of flow. For a given set of conditions, Picknett compared the rates obtained using the equations for surface reaction rate, and diffusion rate. Three different values for the diffusion rate were obtained, each assuming different values of Kt (still water, streamline flow and turbulent flow). In all cases it was found that the surface reaction rate was lower than the diffusion rate, and thus it was concluded that solution was limited by the surface reaction rate. This is clearly in conflict with the results obtained by Kaye and Weyl.

Kaaden (1975), working near the Gardasee, related the length of rillenkarren to slope angle (Fig. 4). There is clearly a maximum length in the region of 50 - 60 degrees.

Heinemann (1977) related the length of lapiez to slope angle at Dachstein (Fig. 5). He found that there were two peaks in the distribution, one at about 25 degrees, and the other at about 65 degrees. These were attributed to two different modes of lapiez formation. The lower peak (25°) represents lapiez formed on knoll features, while the upper one (65°) represents lapiez formed on rock ledges, edges, etc.

Heinemann, Kaaden and Pfeffer (1977), in reviewing the works of Kaaden and Heinemann mentioned above, concluded that if the longer, or better developed karren/lapiez are the result of more intensive solution, then the results show that the optimal conditions for solution do not coincide with the steepest slope angle. Since the velocity of solvents on the surface is controlled to a large extent by the slope of the surface (Kaye, 1957) then presumably, other limiting factors are of importance in determining solution of limestone in the areas studied.

Newson (1971) noted that, maximum solution in Mendip underground water systems was not related to the velocity of flow. The highest flow velocities were to be found in swallet water, whilst the greatest amount of solution was by the percolation water, which moved very slowly indeed. This apparent conflict with the work of Weyl and Kaye was attributed to a higher initial aggressiveness, and much greater surface area of contact in the percolation system.

LIMITATIONS OF PREVIOUS WORK

It is suggested that three groups of work can be identified that arrive at different conclusions as to the effect of solvent motion on solution:-

(a) Kaye, Weyl

Solvent motion is the limiting factor, and solution is proportional to the amount of solvent motion.

This work suffers from the small nature of the samples used in determining relationships. The logic is fine, but one can not really make sweeping statements on the basis of 3 sample points (in the case of Weyl) or 4 sample points (in the case of Kaye). The significance of this criticism will be illustrated in section 6 when the results of the experiment described in section 5 are discussed.

(b) Picknett

Solvent motion is not a limiting factor, and the surface reaction rate limits the rate of solution.

This work is purely theoretical, and in this respect it suffers, because it does not take into account the many complicating factors present in natural systems. Parameters such as foreign ion content, temperature, solutional disintegration and others are highly variable in natural systems and their effect may not be apparent in a theoretical model. Note, however, that Roques (1969) developed a method of including the complicating factors of common ion effects, ionic complexes and salts.

(c) Heinemann, Kaaden

Solvent motion is a limiting factor, but there is not a simple relationship between solution and motion, as indicated by their graphs with maxima. The observed relationship is probably due to there being other limiting factors as well. This work, unlike the previous two groups, is concerned with natural limestone environments. In this respect, the authors were concerned with the landforms resulting from different levels of solvent motion, but could not explain the results obtained from a theoretical point of view.

Whilst it is accepted that empirical laboratory studies and theoretical studies may be limited in their application to the real world, the studies of Heinemann and Kaaden suffered because of the lack of control available. Discharge of solvents varies considerably in natural systems, especially between different climatic zones. From the basic lays of hydraulic geometry, as outlined by Leopold and Maddock (1953), it is evident that the velocity of the solvent will vary by a simple power function of the discharge ($v = kQ^m$), and so they may have been concerned with a varying range of velocities. Another important defect in this work is that it assumes karren and lapiez to be the only landforms representative of solution. In fact solution may be occurring where there are no karren or lapiez. This could be due perhaps to the nature of flow being different, for example, there may be sheet flow instead of rill-like flow. The nature of the flow solvent over the rock face will be dependent to a large extent on the nature of the solvent application to the surface. If it is supplied by rainfall, falling evenly over the whole surface, then sheet flow could result. If on the other hand, the solvent reaches the surface, for example, after dripping from a pointed rock, then channelled flow will probably result. Thus the greater presence of karren in the middle slope angle range may reflect the fact that there are means whereby channelled flow can be initiated on such slopes, sheet flow being more common on slopes of small or large angle.

There are numerous other small limitations with such studies of natural systems, all stemming from the fundamental lack of control. For example, mechanical erosion may predominate at certain slope angles in the environment being studied, or there may be particular mineral assemblages associated with certain slope angle ranges. The proportion of laminar and turbulent flow can not be studied easily in such small flows.

Not withstanding these criticisms, such studies are valuable in that they show relationships between micro-landforms and slope angle on limestone slopes. However, it is the conclusion implying that longer and deeper karren/lapiez are indicative of greater solution that may be at fault.

THE EXPERIMENT

The following experiment was designed to overcome some of the problems noted to be present in previous work in the last section:-

(a) Discharge was controlled
(b) A large number of samples was taken
(c) Solution was measured by the concentration of calcium in runoff, rather than as the development of a landform.

One of the independent variables affecting the velocity of water passing over a limestone surface is the slope angle, and on the basis of this relationship it was decided to use slope angle as a surrogate measure for velocity.

A block of limestone approximately 13 x 22 cm with a relatively flat surface was chosen for the experiment. The rock came from the Carboniferous Limestone Series near Peveril Castle, Castleton, Derbyshire, and had no irregular mineral accumulations which may have affected the results of the experiment. Although a rock with a relatively flat surface was chosen, there were inevitably a few irregularities, and these are indicated on the map of the rock surface in Fig. 6.

The map was compiled by laying a piece of glass over the rock and tracing the outlines of features using a chinagraph pencil.

Using two clamp stands and bosses, the rock was held in such a way that it could be rotated to different surface angles. Solvent was run onto the rock from a burette held above the point X on Fig. 6, and the slope angle of the solvent path was measured with an Abney Level to the nearest half-degree.

The solvent used in the experiment was 1% HCl. This concentration was chosen after a few initial experiments on the reverse side of the limestone block, dripping different concentrations of acid onto it. The concentration required was the one which gave the highest reaction rate, without causing any physically visible bubbling of CO_2. As noted above, Kaye found that bubbling of solvent accentuates the reaction rate due to splashing when the bubbles burst. The basic chemical reaction involved, in simplified form, is given by equation 8:

$$HCl + CaCO_3 = Ca^{++} + HCO_3^- + Cl^- \qquad \text{(Equation 8)}$$

Due to the readiness of HCl to dissociate in solution, the system is not likely to be limited by the availability of H^+ ions which may well be limiting in natural systems where H_2CO_3 is the usual solvent - (see steps (a) and (b) of Weyl). The limitations of this chemical substitution are discussed below in the Problems section.

At the bottom end of the limestone slope, some plasticene was molded into a point. This was for two reasons: firstly, to prevent solvent running underneath the rock which it would have done at the lower slope angles, and, secondly, to direct the acid into a beaker; (otherwise a beaker of 12 cm diameter would have been used). A 50 ml beaker was used to collect the solvent. Fig. 7 shows the experimental apparatus used.

To measure the amount of solution, a standard EDTA titration technique was used, testing for calcium concentrations in 50 ml samples. It is recognised that solution of other minerals such as dolomite may also be of importance, but these were not tested for in case they complicated the picture.

For each run, 50 ml of acid was run over the limestone. Although discharge decreased from the beginning to the end of the run, due to the lowering head of acid in the burette, the rate of change of discharge and the initial discharge were kept constant by ensuring that:

(a) the burette tap was open to exactly the same position for each run,

& (b) the end of the burette was the same height above the surface of the rock in each run (0.5 cm).

A range of slope angles was selected for study, such that data was collected for each 5^o class between 0^o and 90^o (i.e. 18 different slope angles were used). For each slope angle, 10 runs were made, and the mean calcium content was determined for each slope angle. Thus, in total, 180 titrations were carried out.

It was recognised that the surface area for reaction varied considerably between different angle categories, mainly in terms of channel width variations between different runs. For this reason, a record of channel shape was made for each slope angle. The channel shape did not vary significantly between different runs of the same slope angle, and it was recorded by tracing onto a piece of glass laid over the rock, supported by plasticene pedestals. The channel plans for each slope angle are illustrated in Fig. 16. The area of each channel pattern was estimated using a square-counting technique.

EXPERIMENTAL RESULTS

Table 1 shows the calcium concentration in millimoles per litre, and the surface area for reaction at each of the slope angles studied.

The average velocity of the solvent was to be used as an indication of solvent motion. As Kaye points out, it is very difficult actually to measure the velocity in such small channels. He used the Chezy equation (Equation 1) to estimate a velocity factor, but in the present study, Manning's Equation (Equation 9) was used because this is more widely used:

Manning's Equation:-

$$v = 4.875 \, \frac{R^{0.667} \, s^{0.5}}{n} \qquad \text{(Equation 9)}$$

v = mean velocity

v = mean velocity s = slope

R = hydraulic radius n = Manning's n

Clearly, before this equation can be used for estimating the average velocity, the hydraulic radius and Manning's n have to be estimated. Note, due to the very high slope angles used, the sine of the angle was used for s rather than the conventional tangent used for low slope angles. For R, the hydraulic radius to be obtained, the average width and depth of the channel must be estimated (see Table 1) by the length of the channel. The length of the channel varied

TABLE 1

Slope angle (^{o})	Calcium concentration (millimoles/litre)	Surface area (cm^{2})
4	979	61.03
8	1003	60.71
12.5	983	60.71
17	850	27.22
22	747	23.16
27.5	896	28.39
32.5	850	30.97
38	871	26.97
43	747	18.58
47.5	753	15.42
53	760	14.71
57.5	744	14.71
63	805	14.65
69	662	13.55
72	797	12.77
78.5	784	12.32
83	796	11.68
89.5	976	9.55

between different slope angles and between different parts of the same channel at low slope angles. The length of such channels was estimated by taking the average length of the major routeways in the channel. The depth of the channel was estimated to be 0.1 cm in all cases. This is clearly a rash assumption, since it will certainly vary slightly between different channels. However, on the basis of experimental work done for a different project, applying Leopold and Maddock-type hydraulic geometry equations, the channel depth was found to be fairly constant at different slope angles, and approximated 0.1 cm for the discharge levels used in the present experiment. Changes of velocity are more likely to be accommodated by width adjustment than by depth adjustment in such unconfined channels, and thus the depth will depend more on properties such as the surface tension of the solvent.

Experimental values of Manning's n vary from about 0.01 for smooth metal surfaces to 0.06 for natural channels with many rocks and protuberances or irregular alignment. A value of 0.02 was assumed for this experiment. This is a slightly subjective estimation, but such estimations have to be used whenever Manning's equation is utilised.

Table 2 shows values of slope length, stream width, hydraulic radius, and velocity as estimated using Manning's equation for each sample slope angle.

TABLE 2

Slope angle (^{o})	Slope length (cm)	Stream width (cm)	Hydraulic Radius	Velocity (cm/s)
4	15.48	3.95	0.095	13.400
8	15.48	3.92	0.095	18.930
12.5	15.48	3.92	0.095	23.606
17	15.50	1.76	0.090	26.458
22	15.50	1.49	0.088	29.502
27.5	15.10	1.88	0.090	33.253
32.5	15.10	2.05	0.091	36.127
38	15.10	1.79	0.090	38.393
43	14.70	1.26	0.086	39.198
47.5	14.70	1.05	0.084	40.123
53	14.70	1.00	0.083	41.415
57.5	14.70	1.00	0.083	42.559
63	14.70	1.00	0.083	43.753
69	14.00	0.97	0.083	44.802
72	14.00	0.91	0.082	44.851
78.5	14.00	0.88	0.082	45.509
83	14.00	0.83	0.081	45.433
89.5	14.00	0.68	0.077	44.096

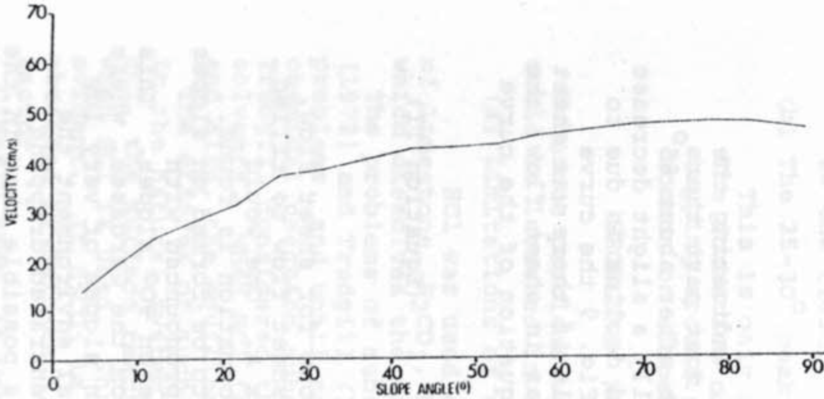

Fig. 8 THE RELATIONSHIP BETWEEN SLOPE ANGLE AND VELOCITY

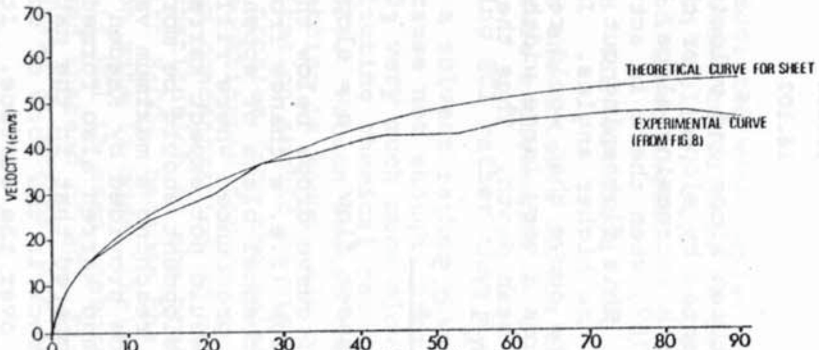

FIG. 9 RELATIONSHIP BETWEEN SLOPE ANGLE AND VELOCITY IN THE EXPERIMENTAL DATA AND WITH SHEET FLOW

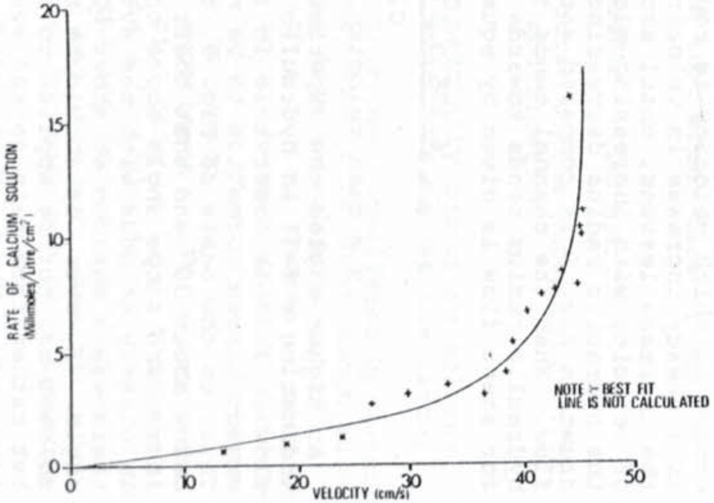

FIG. 10 RELATIONSHIP BETWEEN VELOCITY OF SOLVENT AND SOLUTION RATE

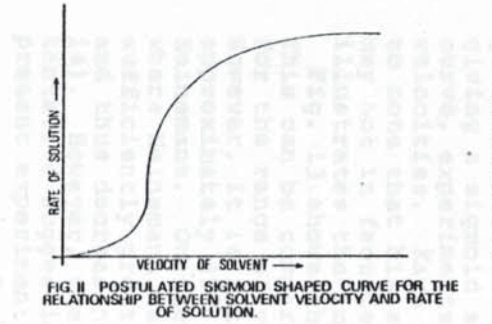

FIG. 11 POSTULATED SIGMOID SHAPED CURVE FOR THE RELATIONSHIP BETWEEN SOLVENT VELOCITY AND RATE OF SOLUTION.

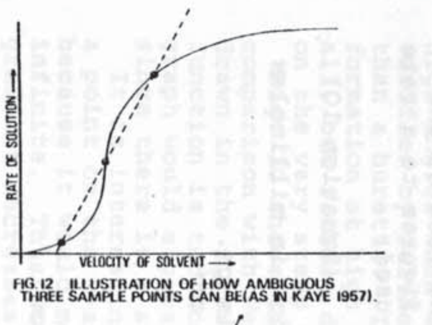

FIG. 12 ILLUSTRATION OF HOW AMBIGUOUS THREE SAMPLE POINTS CAN BE (AS IN KAYE 1957).

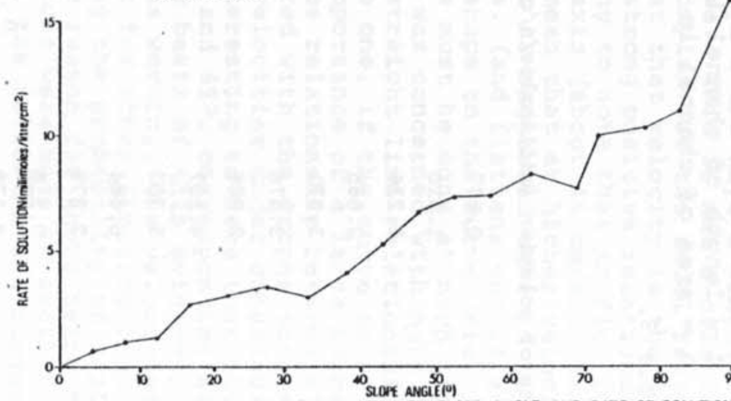

FIG. 13 EXPERIMENTAL RELATIONSHIP BETWEEN SLOPE ANGLE AND RATE OF SOLUTION.

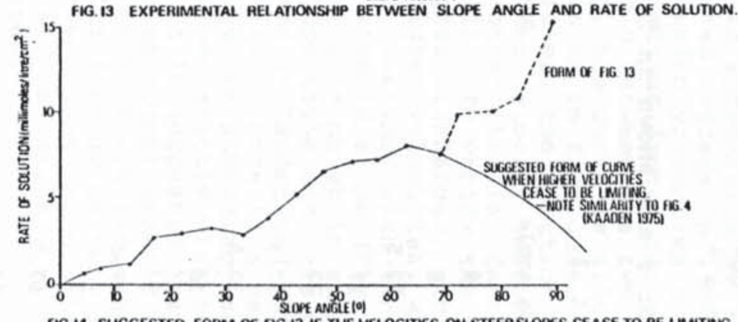

FIG. 14 SUGGESTED FORM OF FIG. 13 IF THE VELOCITIES ON STEEP SLOPES CEASE TO BE LIMITING. (FOR EXAMPLE, WHEN HCl IS REPLACED BY H_2CO_3)

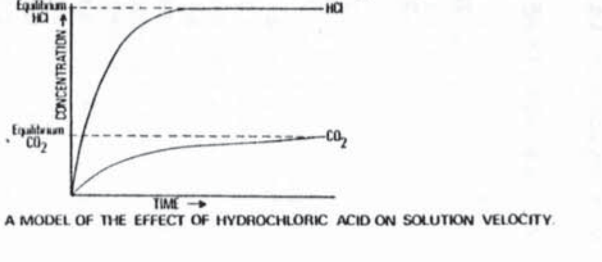

FIG. 15 A MODEL OF THE EFFECT OF HYDROCHLORIC ACID ON SOLUTION VELOCITY.

The calcium concentrations obtained in Table 1 show the amount of calcium dissolved during the time taken for the solvent to pass over the rock at the velocity of the particular run in question. To convert these figures to a rate of solution in millimoles per second per cm^2, equation 10 was used:

$$r = \frac{v.C.}{20.\ l.\ A.} \qquad \text{(Equation 10)}$$

r = rate of solution in millimoles per second per cm^2
v = velocity in $cm.s^{-1}$
C = calcium concentration in millimoles per litre
l = length of channel in cm.
A = area of channel in cm^2

Values obtained for r are shown in Table 3.

TABLE 3

Slope angle (°)	Rate of solution (millimoles/s/cm^2)
4	0.697
8	1.010
12.5	1.236
17	2.665
22	3.071
27.5	3.476
32.5	2.986
38	4.107
43	5.363
47.5	6.664
53	7.276
57.5	7.318
63	8.178
69	7.819
72	9.993
78.5	10.340
83	11.056
89.5	16.102

Fig. 8 shows the relationship between slope and velocity, indicating the extent to which velocity is represented by slope. For the most part there is a steady increase in velocity with increasing slope, but after about 65° the increase lessens, until about 78°, when there is actually a slight decrease of velocity with increasing slope. This flattening out and decline is due to the hydraulic radius decreasing at the higher angles. In Fig. 9 the curve drawn in Fig. 8 is compared with the curve that would result if there was sheet flow. When the channel tends towards a very large width, as in sheet flow, the hydraulic radius tends towards the mean depth. Thus the equation of the curve for sheet flow is given by equation 11:

$$v = \frac{4.875\ 0.1^{0.667}\ s^{0.5}}{0.02} \qquad \text{(Equation 11)}$$

v = mean velocity of sheet flow $\quad$ s = slope

At higher angles the experimental curve drops below the one for sheet flow, indicating a fall in hydraulic radius (i.e. a change from sheet flow to rilled flow). This is observable in the channel plans of appendix A. One would expect karren formation to be more pronounced where rill formation is found. Thus, on the basis of Fig. 9, one would not expect karren to be formed on slopes below about 30° and that their development should be more pronounced with increasing slope angle above this, reaching a maximum value on 90° slopes. This is clearly at odds with the evidence provided by Kaaden from the Gardasee, where there was a maximum at about 60°, and karren also formed on slopes of very low angle. However, it should be remembered that in the natural environment the solvent may not be applied to the rock in the form of concentrated dripping, but rather from rain spread evenly over the surface. It is possible that in the latter case the hydraulic radius may rise again at very high angles at the Gardasee, to give Kaaden's maximum at 60°. The presence of sheet flow at very high angles when the solvent is spread evenly over the surface can only be verified by further experiment, perhaps using a spray to apply the acid, rather than a burette. It should be remembered, however, that the lower karren formation at high angles might not be due to changes in hydraulic radius at all, but rather, due to velocity ceasing to be a limiting factor for solution on the very steep slopes.

Fig. 10 shows the relationship between velocity and the rate of solution, for comparison with Weyl's and Kaye's graphs. An approximate best-fit curve is drawn in the figure. This is not a calculated regression line because the function is too complex for the usual regression procedures to be used. The graph would suggest that velocity is the limiting factor for solution rate, since there is a strong positive relationship between the two variables.

It is interesting to note that in Fig. 10, the curve is almost asymptotic to a point on the x-axis (about 46 cm/s). This is in fact quite impossible, because it would mean that at higher velocities, the solution rate would be infinite. Thus it is suggested that at higher velocity values the curve's gradient decreases, (and flattens out if another limiting factor appears), giving a sigmoid shape to the curve (Fig. 11). To verify the nature of this curve, experiments must be done at much higher discharges, giving higher velocities. Kaye was concerned with much higher velocities, and it is interesting to note that his straight line relationship, obtained with three sample points, may not in fact be one, if the curve is of sigmoid shape (Fig. 12). This illustrates the importance of a large number of samples in such an analysis.

Fig. 13 shows the relationship between slope angle and rate of solution. This can be compared with the graphs obtained by Kaaden and Heinemann. Clearly, for the range of velocities under consideration, there is a maximum at 90°. However, it is interesting to note that there are subsidiary maxima at approximately 25° and 65°, corresponding almost exactly with those obtained by Heinemann. On the basis of this evidence, it is suggested that at Dachstein, where Heinemann was working, the velocities on slopes steeper than 72° were sufficiently great for other limiting factors to start influencing the system, and thus decreasing the probability of lapiez forming on very steep slopes (Fig. 14). However, the reason for there being two maxima is not clear. Some tentative suggestions were made in section 4(c) above, but on the basis of the present experiment the following are suggested:

(a) The 60-65° peak

This could result from a tendancy for the solvent to form rills in this range of slope angles, for which, some evidence is provided by Fig. 9 (for karren and lapiez). Also, above a critical slope angle, velocity may cease to be limiting at the discharge levels experienced in the field.

(b) The 25-30° peak

This is only associated with lapiez formed on knoll-like features. The formation of these could well be better when there is sheet flow, lapping around such knolls. Fig. 9 suggests that sheet flow is more common on slopes of lower angle.

PROBLEMS WITH THE APPROACH AND POSSIBLE MODIFICATIONS

Numerous problems were encountered during the course of the experiment which could be lessened in future experiments by slight modification.

(a) Limitations of using HCl rather than H_2CO_3

HCl was used as a solvent rather than the naturally occurring solvent of limestone, H_2CO_3, because not enough time was available to use the latter, which dissolves the $CaCO_3$ very much more slowly.

The problems of substituting chemical reactions have been considered by Watson (1972) and Trudgill (1976). Watson stated that very little is known about such problems, and until something is known, all results from experiments using chemical reaction substitution should be viewed with a certain degree of scepticism. Trudgill considered the problem from the relative solution velocities of different solvents. When HCl is substituted for H_2CO_3, the solution velocity is increased, and also, the equilibrium concentration of calcium is raised (Fig. 15).

The effects of such substitution in the present experiment could be important. In the natural system with H_2CO_3, because the solution rate is lower than with HCl, the surface reaction rate is more likely to be a limiting factor than it is when HCl is used. Thus if HCl is used, natural limiting factors may not be evident. If H_2CO_3 is used instead of HCl, Fig. 13 may look more like the graph obtained by Heinemann, where at steeper angles, reaction rate may be a limiting factor.

Clearly then, it would be very desirable to use the chemical reactions found in natural limestone environments, rather than substituted reactions, but this would require much more time and solvent.

(b) Small range of solvent velocities

It is apparent from Fig. 10 that it is necessary to consider a larger range of solvent velocities to establish the complete relationship. (The sigmoid curve of Fig. 11 is only postulated). Higher velocities could be obtained by using a pump or a greater head of solvent to increase the discharge.

(c) Use of burette to apply the solvent

In natural systems it is probable that the solvent is distributed more evenly over the surface by rainfall. In such situations, the relationship found in Fig. 8 may not hold true. This needs to be investigated further using a spray to apply the solvent. It would be very significant if rilled flow is found to have a maximum occurrence in the middle slope angle range, around 60^{o}. However, in certain natural situations, it may be that the solvent is applied in the form of concentrated dripping, perhaps from a rock promontory on the edge of a ledge, or from vegetation leaves.

(d) Inconsistent channel geometry

Certain inaccuracies may have resulted from the inconsistent nature of the stream channel geometry. Because the channel shape is not held constant between runs, one has to compute the hydraulic radius in order to use Manning's equation. The use of the hydraulic radius in such calculations is not strictly valid anyway, because the stream does not flow in a proper channel. Thus it would be desirable to control the channel shape, perhaps by cutting a groove in the rock, down which the solvent could flow. Of course, it would be desirable to be able to measure the velocity directly, perhaps by the timing of the passage of dye, or use of a micro-velocity meter, rather than using Manning's equation. Subjective judgement was required at several stages in the use of Manning's equation, but the biggest error is probably in the estimation of average channel depth, because a small change in channel depth could cause a bigger change in the hydraulic radius.

(e) Angle measurement

Even though the rock chosen for the experiment was relatively flat, small irregularities could have caused inaccuracies in the measurement of slope angle. This problem could be solved by flattening the surface properly, using a rock saw and polisher.

(f) Temperature control

Throughout the experiment there was no control on temperature, which could have influenced the reaction and diffusion rates. This problem could have been solved by working in a room with a controlled temperature.

CONCLUSIONS

Using the experimental results obtained, it is possible to suggest tentatively that:

(a) for the range of flow velocities used, solvent motion was the limiting factor throughout all slope angles when the solvent was HCl. At higher velocities, such as may occur in the natural environment, and with the natural solvent, H_2CO_3, reaction rate may become a limiting factor on steep slopes. This might be one explanation why Kaaden and Heinemann did not obtain the best microform development on the steepest slopes;

(b) the solvent may flow in a rill-like pattern at intermediate and high angles of slope, and in a sheet-like pattern at lower angles. The predominance of rill flow at higher angles (Fig. 16) might explain why karren formation is most pronounced on slopes of angle 60-65^{o}, above which, other factors may be limiting. If lapiez formation is favoured by sheet flow of a solvent around a knoll, then it may predominate at lower slope angles around 25-30^{o}.

REFERENCES

Atkinson, T.C. & Smith, D.I. 1976 *The erosion of limestones* IN *The science of speleology* eds. Ford, T.D. & Cullingford, C.H.D., Academic Press, London.

Gartikov, V.M. & Pantelva, L.I. 1937 Kinetics of solvation of calcium carbonate. *J. Gen. Chem. U.S.S.R.*, 7, pp. 56-64.

Heinemann, U. 1977 *Untersuchungen zum Karrensphänomen am Dachstein*, Unveröffentl. Staatsarbeit, Köln.

Heinemann, U., Kaaden, K. & Pfeffer, K-H. 1977 Neue Aspekte zum Phänomen der Rillenkarren, *Abhandlungen zur Karst und Höhlenkunde; Reihe A - Speläologie*, Heft 15. - Festschrift fur A. Bögli, pp. 56-80.

Kaaden, K. 1975 *Untersuchungen zum Problem des Karrenphänpmens am nördl Gardasee*, Unveroffentl Examensarbeit, Frankfurt.

Kaye, C.A. 1957 The effect of solvent motion on limestone solution, *J. Geol.*, 65, pp. 35-46.
Leopold, L.B. & Maddock, T. Jr. 1953 *The hydraulic geometry of stream channels and some physiographic implications*, U.S.G.S. Prof. Paper 252.
Leopold, L.B., Wolman, M.G. & Miller, J.P. 1964 *Fluvial processes in geomorphology*, Freeman. Esp. pp. 156-160.
Newson, M.D. 1971 A model of subterranean limestone erosion in the British Isles, based on hydrology, *Trans. Inst. Brit. Geog.*, 54, pp. 55-70.
Picknett, R.G. 1976 *The chemistry of cave waters*, parts I & II IN *The science of speleology*, eds. Ford, T.D. & Cullingford, C.H.D., Academic Press, London.
Roques, H. 1969 A review of the present day problems in the physical chemistry of carbonates in solution, *Trans. Cave Res. Group, G.B.*, 11(3), pp. 139-163.
Trudgill, S.T. 1976 *Rock weathering and climate: Quantitative and experimental aspects* IN *Geomorphology and climate*, ed. Derbyshire, E., Wiley.
Watson, R.A. 1972 Limitations on substituting chemical reactions in model experiments, *Zeit. Für Geomorph.*, 16, pp. 103-108.
Weyl, P.K. 1958 The solution kinetics of calcite, *J. Geol.*, 66, pp. 163-176.

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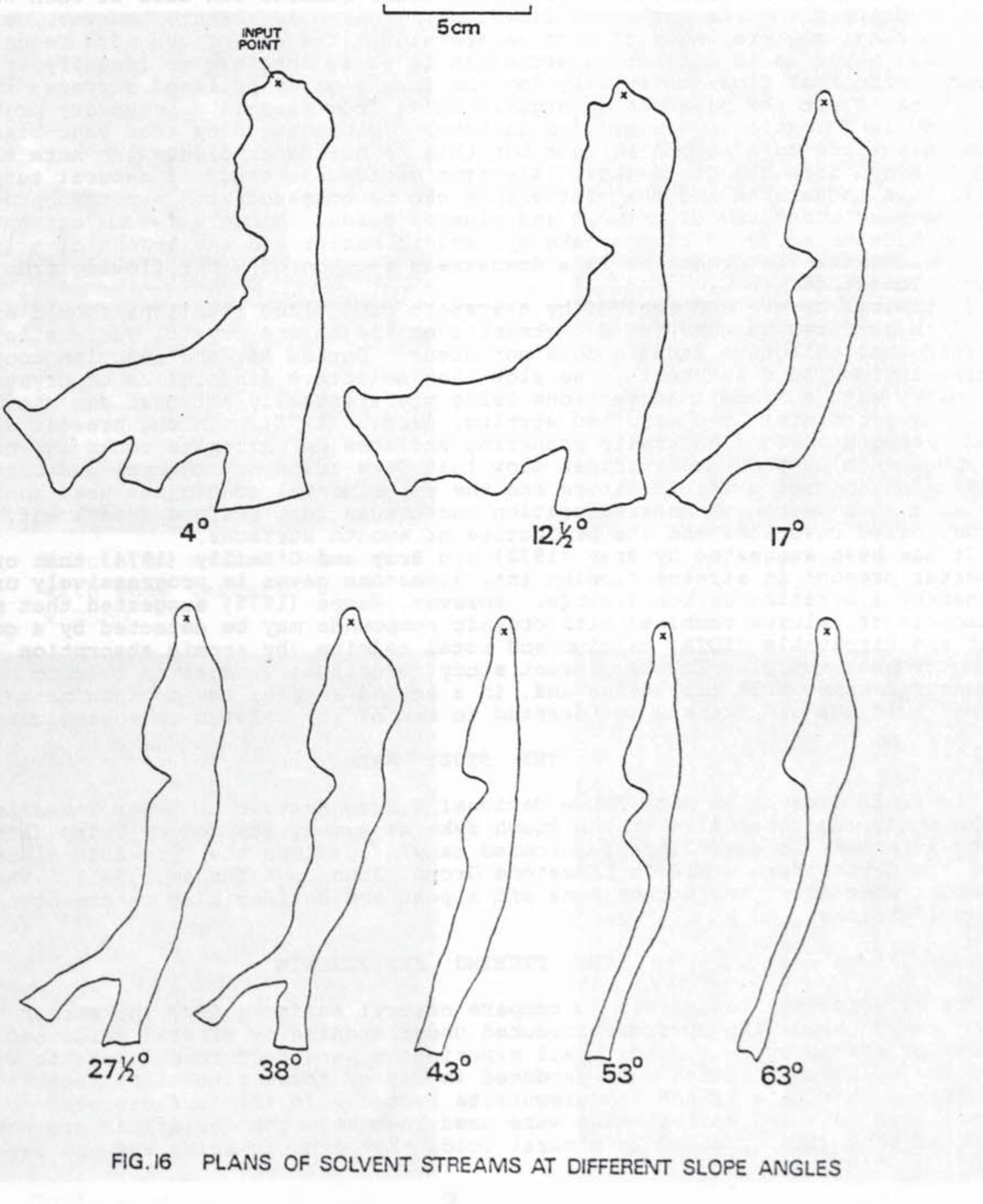

FIG.16 PLANS OF SOLVENT STREAMS AT DIFFERENT SLOPE ANGLES

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CHEMICAL POLISH OF LIMESTONE AND INTERACTIONS BETWEEN CALCIUM AND ORGANIC MATTER IN PEAT DRAINAGE WATERS

by Stephen T. Trudgill

ABSTRACT

Chemical polish occurs in ograni-rich drainage waters but laboratory experimentation and electron microscope work suggested that the presence of organic acids was not a prerequisite for its formation. In the waters studied there was little evidence for the presence of calcium in organic compounds. The results point to the importance of dissolution by dissociated organic acids and carbon dioxide released during decay of ogranic matter rather than to chelation by organic acids. A fast surface ion detachment, transport controlled reaction is implicated in the production of smooth surfaces.

It is known that organic acids are effective agents of dissolution (Trudgill, 1978; Williams, 1963) but their relationship with micro-morphology is unclear. Glassy, polished limestone surfaces can be observed where waters drain from peat over limestone and polished surfaces and micro-runnels can also be seen where water drips from tree bark over limestone. Polish is absent, however, under organic soils where water flow rates are slow. The aim of the work described in this paper is to attempt to establish if it is possible to identify critical combinations of flow and acidity for the formation of polished surfaces and whether or not the presence of organic acids from peat is a necessary prerequisite for their formation. Observation in other regions suggests that sand-blasting may give rise to a smooth surface but this is not under discussion here as sand was absent from the field site. Electron microscope study of natural surfaces has been undertaken and the photographs can be compared with surfaces produced by varying strengths of organic and mineral acids. Moreover, some attempt has been made to study calcium uptake by organic matter and the trends of calcium-organic matter interactions in a downstream section of water flowing from peat over limestone.

In theory, crystals dissolved by transport controlled reactions should exhibit smooth surfaces because ion detachment over the entire crystal surface is so rapid that selective etching does not occur. During surface reaction controlled dissolution ion detachment is so slow that selective dissolution of crystal surfaces occurs, with surface intersections being preferentially attached and showing crystallographically controlled etching, Berner (1978). In the present study SEM observations of naturally occurring surfaces on carbonate rocks and of experimentally produced surfaces show that both transport control and surface reaction control exist in nature and the experimental conditions used confirm that a high degree of undersaturation encourages fast surface detachment, transport controlled reactions and the production of smooth surfaces.

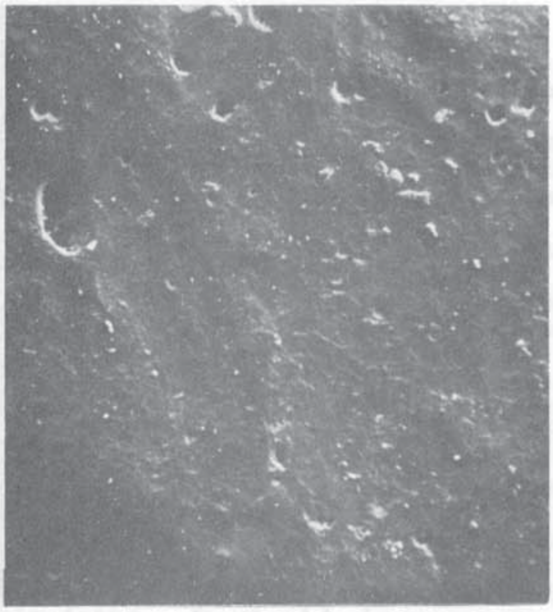
It has been suggested by Bray (1972) and Bray and O'Reilly (1974) that organic matter present in streams flowing into limestone caves is progressively oxidized, thereby liberating carbon dioxide. However, Kempe (1975) suggested that measurable amounts of calcium combined with organic compounds may be detected by a comparison of the titratable (EDTA) calcium and total calcium (by atomic absorption spectrophotometry). In the present study downstream changes in calcium have been measured using EDTA titrations and, in a second sample, the organic matter has been oxidized and the sample titrated to see if any calcium release occurred.

THE STUDY AREA

The field area is in Moor House National Nature Reserve in Upper Teesdale and the study was undertaken on the Rough Syke streamway studied by Crisp (1966). The streamway is a scalloped, unroofed canyon cut into the Tyne Bottom Limestone of the Carboniferous Middle Limestone Group (Johnson & Dunham, 1963). The canyon occurs soon after the stream runs off a peat and boulder clay catchment on to the limestone.

THE ETCHING EXPERIMENTS

The experimental design was to compare natural surfaces from the stream bed near the canyon head with surfaces produced under etching by mineral acids and by weak or strong organic acids. All experiments were performed in static water. If the polished surfaces were produced in any of these situations then it canbe inferred that flow is not a prerequisite factor. If the surfaces were produced when both weak and strong acids were used then strength variations are not important and if they were produced in mineral acids then organic acids are not essential.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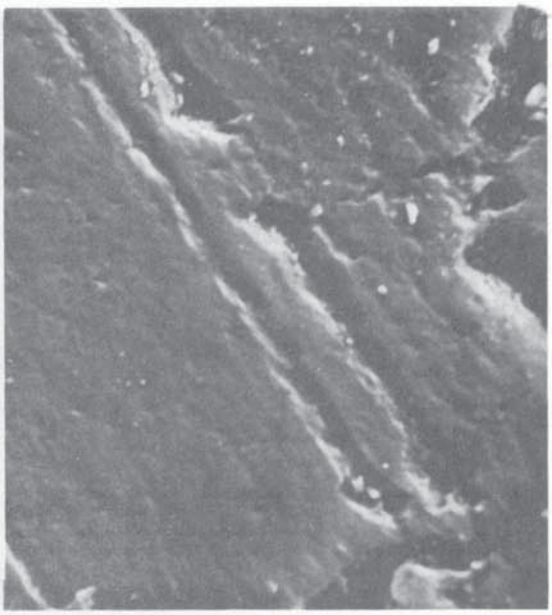
Naturally occurring polished surface Rough Sike streamway x 20.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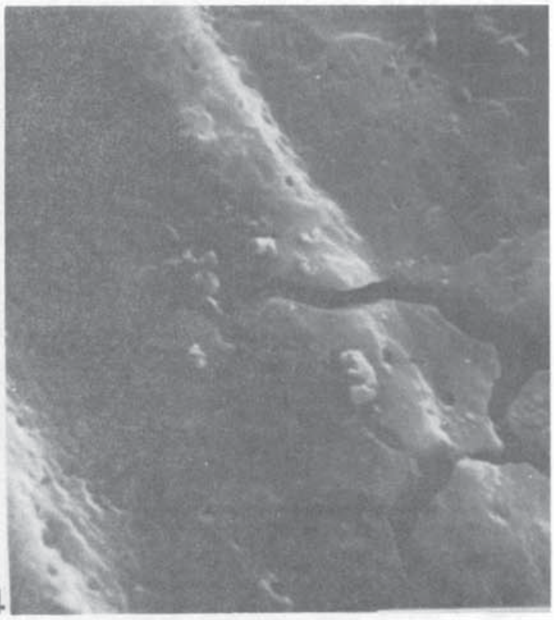
As Fig. 1, x 2500.


3

Fractured surface etched with weak tartaric acid, x 2500.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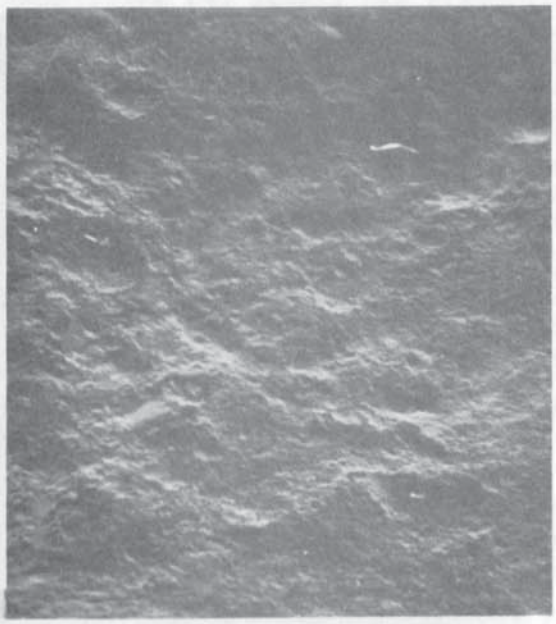
Surface etched with strong tartaric acid, x 2500.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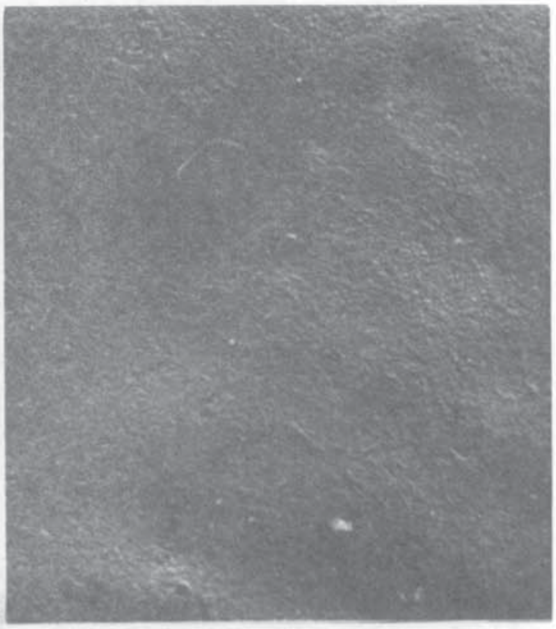
Surface etched with weak lactic acid, x 20.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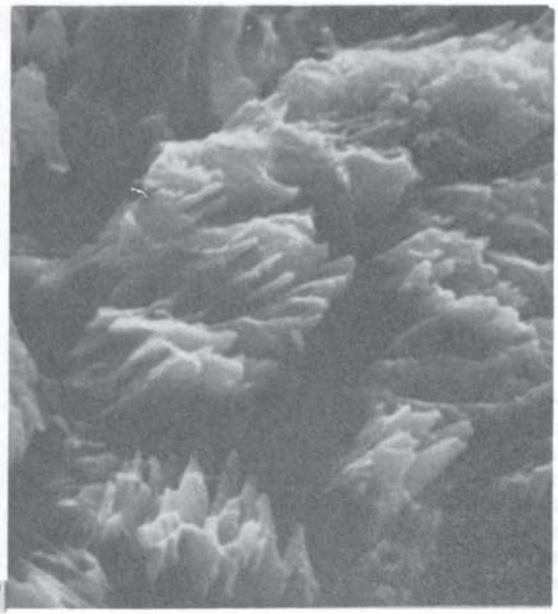
Surface etched with strong lactic acid, x 20.



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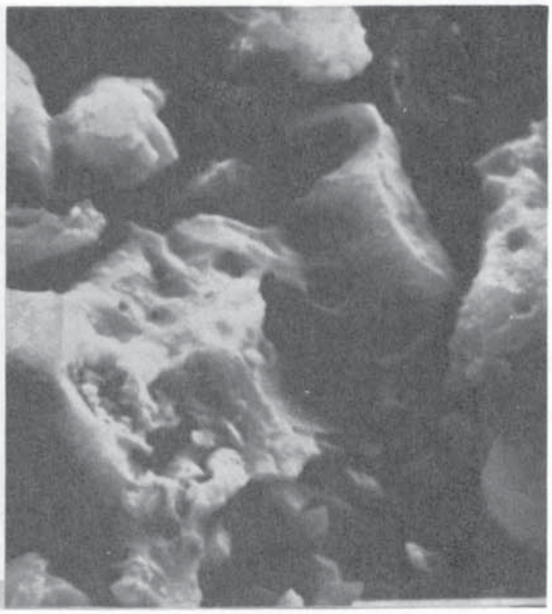
Surface etched with weak lactic acid, x 2500.



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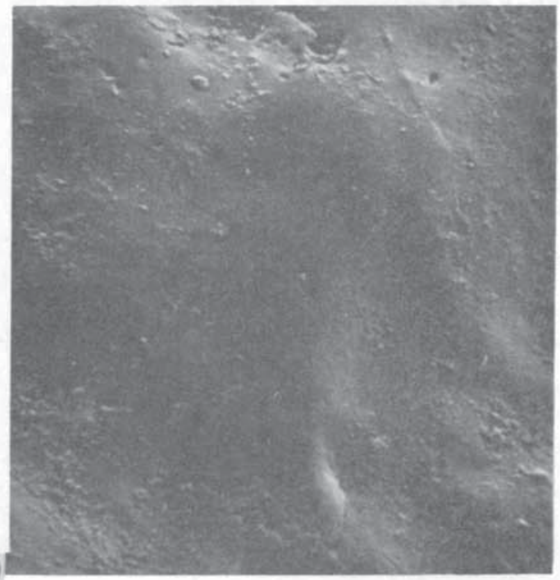
Surface etched with strong lactic acid, x 2500.



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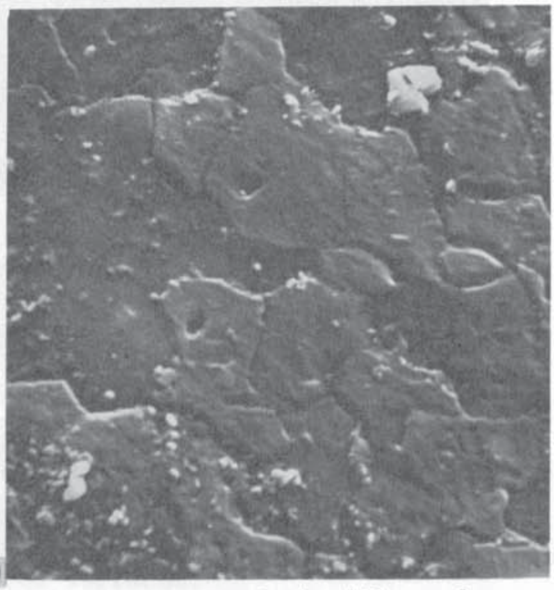
Surface etched with weak hydrochloric acid, x 20.



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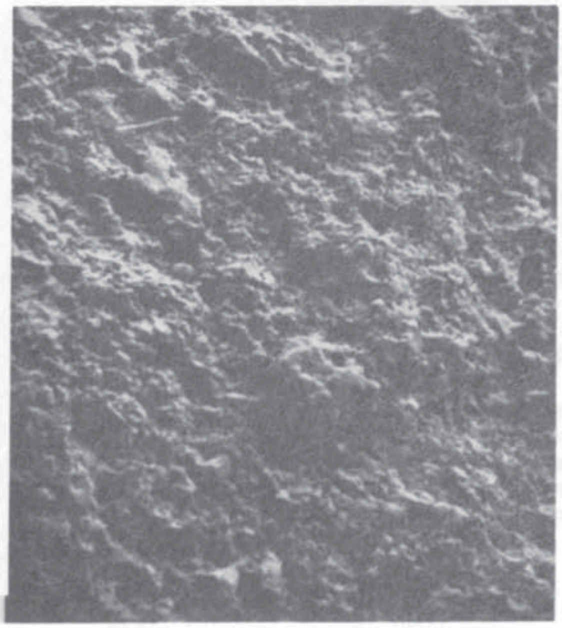
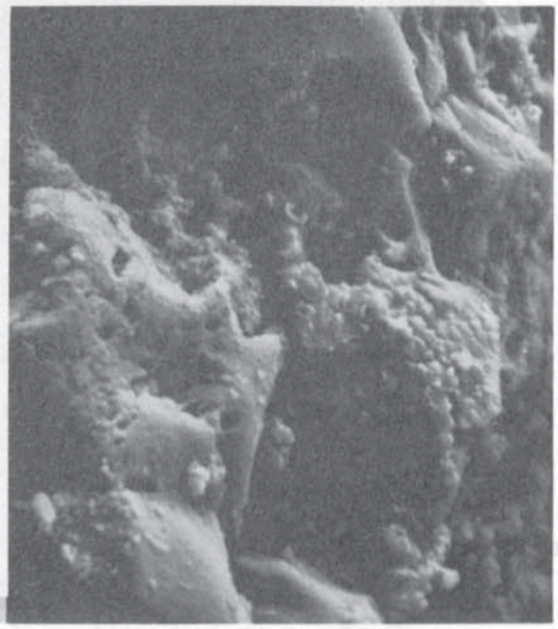
Surface etched with weak hydrochloric acid, x 2500.



11

Naturally occurring subsoil surface, x 20.



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Naturally occurring subsoil surface, x 640.

All surfaces were examined by electron microscopy at x20, x640 and x2500 scale. The mineral acid used was hydrochloric acid and the organic acids used were tartaric, salicylic, lactic and oxalic. The concentrations used were chosen to give a contrast between strong and weak acids and were 0.2 M and 0.02 M. The surfaces used in the experiments started as simple fractured surfaces (not ground in any way) and were derived from one large rock sample. The rock type used had a sparite texture.

The results showed the remarkable smoothness of the natural surface from the stream bed, even at x2500 magnification (Figs. 1 & 2). This smoothness was not completely reproduced in any of the experiments. Tartaric, citric and salicyclic acids showed deep etching, for example as shown for weak tartaric in Fig. 3. In general, an increase in the strength of acid destroyed the delicacy of etching, as shown by Fig. 4 for concentrated tartaric acid. For lactic acid there appeared to be a polish at x20 scale for both weak and concentrated acid (Figs. 5 & 6) but higher magnification showed etching to be present, although in the strong acid it was, again, less marked (Figs. 7 & 8). Only in hydrochloric acid was the polish at all approached and shown at both high and low magnification (Figs. 9 & 10). Some of the etched organic acid surfaces bear some resemblance to the visibility etched naturally occurring subsoil rock surfaces (Figs. 11 & 12).

Three deductions may be made from the observations; firstly, some polished surfaces were produced under static conditions and therefore that flow is not a prerequisite. It should, however, be immediately cautioned that where the smoothest surfaces occurred (i.e. concentrated tartaric (Fig. 4), and hydrochloric acid (Figs. 9 & 10) bubble trains could be observed as the reaction proceeded, thus increasing the action of solvent motion. Not only is this evidence of rapid carbon dioxide production during reaction but also it will mean that ion diffusion from the rock surface will be mechanically encouraged. Thus the results are not as conclusive as they might have been as motion is not entirely excluded. Secondly, the surfaces were generally more subdued in strong acids, though this was by no means always the case: strong hydrochloric acid tended to produce slightly deeper etching than weak. Third, polishing was evident in mineral acids and thus the presence of organic acids is not a prerequisite.

These conclusions suggest that chemical polish is not unique to the presence of organic acids, though it should be cautioned that only pure 'Analar' organic acids were used and naturally occurring humic substances may have a different effect. Experimentation with 'Analar' acids means that the precise strength and composition of the acids is known but the replication of nature is limited; using naturally occurring humus would overcome this latter problem but its nature and stability is largely unknown. It is possible that further experiments might be devised using naturally occurring humus extracts in flowing and static conditions. The evidence presented above suggests that a dissociated acid under flowing conditions is involved in the formation of polished surfaces. In addition, the evidence of increased smoothness with strength of acid reinforces the model of Berner (1978) that rapid surface detachment of ions is correlated with the production of a smooth surface.

WATER CHEMISTRY

Replicate pairs of water samples were taken at five stations downstream from the peat-limestone contact in September, 1978, during a period of very low flow of around 0.1 m^3/s. At each site the first sample was titrated with EDTA for calcium and the second was allowed to stand for about 4 hours, after adding hydrogen peroxide. The peroxide cleared the solution of all organic colour and after this stage the sample was titrated, the result calculated with an allowance for dilution by the addition of peroxide. Aggressiveness, pH carbonate and acid strength were also measured. The measurements were undertaken on two days and the results are shown in Fig. 13. They show a clear trend of increased pH and calcium and decreased acid strength downstream, together with a maintained or temporarily increased aggressiveness. The latter is in accord with Bray's work on the liberation of carbon dioxide by organic matter decay. The evidence of ion balance (Table 1) suggests that calcium excess is present, but this cannot be equated with organically bound calcium as anions other than HCO_3^- were not measured and this could account for the imbalance, moreover if the work of Kempe is correct EDTA will not titrate organically bound calcium. There is no systematic trend in peroxide release of calcium although some appears to be present at station 2 on day 1 but the evidence for large quantities of calcium in chelate form in organic compounds in solution is not overwhelming. Crisp (1966) recorded less than 1 mg/g calcium present in particulate peat, but no visible particulate peat was present in the samples and so this is not under discussion here, nor is adsorption on to particulate peat surfaces.

The evidence from the data presented is that chelated calcium in organic compounds in solution is not of great importance. Interactions with larger peat particles may occur but they are not investigated here. It appears that dissociated organic acids and more likely, carbon dioxide liberated from organic matter decay form the primary sources of chemical erosion of the stream bed. The results of the etching experiments and of the water chemical analyses both tend to minimise the importance of the chelatory properties of organic acids.

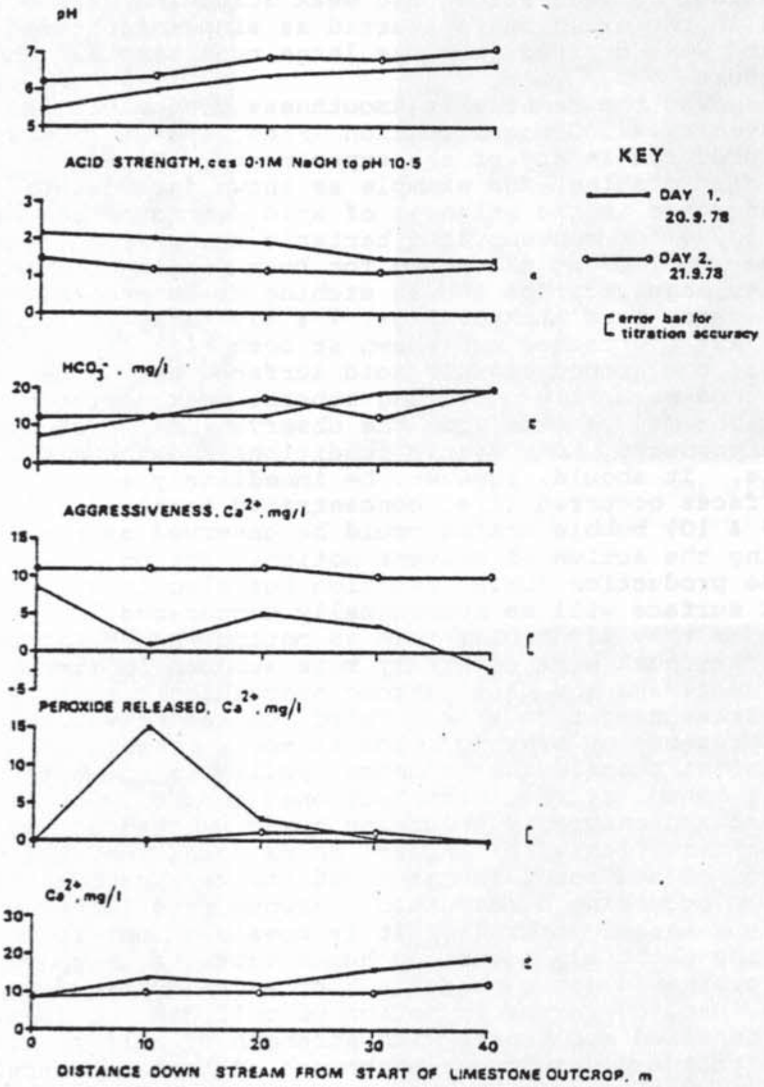

Fig. 13. Downstream changes in water chemistry

TABLE 1 Ion Balance between Ca^{2+} and HCO_3^-, meq/l^{-1}

Site	Day 1 Ca^{2+}	Day 1 HCO_3^-	Day 2 Ca^{2+}	Day 2 HCO_3^-
1	.499	.120	.499	.200
2	.699	.200	.499	.200
3	.599	.200	.499	.280
4	.798	.280	.499	.200
5	1.198	.320	.599	.320

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REFERENCES

Berner, R.A. 1978 Rate control of mineral dissolution under earth surface conditions. *American Journal of Science*, vol. 278, pp. 1235-1252.

Bray, L.G. 1972 Preliminary oxidation studies on some cave waters from South Wales. *Trans. Cave Res. Gp. G.B.*, vol. 14, no. 2, pp. 59-66.

Bray, L.G. & P.M. O'Reilly 1974 Preliminary oxidation studies of some waters from the Ogof Ffynnon Ddu System, Breconshire. *Trans. B.C.R.A.*, vol. 1, no. 2, pp. 75-84.

Crisp, D.T. 1966 Input and output of minerals for an area of Pennine moorland: the importance of precipitation, drainage, peat erosion and animals. *J. Appl. Ecol.*, vol. 3, pp. 327-348.

Kempe, S. 1975 Ca and Mg organic complexes in the water (illustrated by water analysis from the River Alster, Hamburg, Fed. Rep. of Germany). *Annales Spéléologie*, vol. 30, pp. 695-698.

Johnson, G.A.L. & K.C. Dunham 1963 *The Geology of Moor House*, Nature Conservancy Monograph, HMSO.

Trudgill, S.T. 1978 Reaction rates and equilibrium levels in the dissolution of limestones in organic acids. *Proc. 7th Int. Speleol. Conf., Sheffield*, pp. 399-401.

Williams, V.H. 1963 *A study of the solutional processes and phenomena in limestone with special reference ot the North Avonian outcrop of the South Wales Coalfield.* Unpub. Ph.D. thesis, University College, Swansea.

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GRADUAL CHANGES IN THE HYDROLOGY OF THE YORKSHIRE DALES DEMONSTRATED BY TOURIST DESCRIPTIONS

by R.A. Halliwell

SUMMARY

Tourist descriptions and travelogues are used to trace gradually changing hydrological conditions through the last one to two hundred years at a series of sites in the Yorkshire Dales.

Much work has been published by historical geographers on changes in climatic conditions through historical time and on the effect of man on the landscape. However, with the exception of coastal changes, little appears to have been written on the gradual changes in the landscape due to natural processes. This is probably because these natural changes are usually either single catastrophic events, and therefore outside the scope of this paper, or are too gradual to excite comment at the time.

As a background to a process orientated study of the limestone hydrology of part of the Yorkshire Dales (Halliwell, 1977), an attempt was made to collect as many historical descriptions of the landscape of the area as possible. In many cases the major reason for visiting the area was to see the caves and much of the interest was linked with the water in the caves. Using these descriptions it has proved possible to plot changes in the water regime of the caves in particular and the area in general. It must be admitted that there are problems with plagiarism and this point has been studied in detail by Shaw (1971) with reference to the works of Hutton. The concept of tracing historically gradual but geologically rapid changes is illustrated by a series of case studies.

MALHAM

The Malham area has for a long time been a popular place for tourists to visit and numerous descriptions of visits by early tourists may be found. The earliest detailed description of the hydrology of the area appears to be Pococke (1751):

> "Malham Ptarne, a piece of water which may be near two miles in circumference; there are very good perch and other fish in it, and the water runs out in a rivulet, which soon divides into two parts, and which is lost among the stones, going underground by what they call two swallows".

Pococke continued to describe the correct hydrology of the area with the Malham Tarn water basically flowing to Aire Head springs whilst the Smelt Mill sink waters rise at the foot of the Cove. Bray (1783), although disparaging about the Tarn which "... has nothing beautiful in its shape or borders, being bare of trees and everything else to ornament it ..." goes into more detail about the response of the Tarn outflow to precipitation: "... At the foot of it (Malham Cove), a current of water issues out, which is probably the same as is lost near the Tarn; but in floods, the subterranean passage is not able to give vent to all the water; and, it is said, that a cataract then pours down from the top of the rock ...".

This response to rainfall was also described in detail by Hurtley (1786): "... From the Apex of this Cove, after what is in this part of the country called a RUGG, or a succession of rainy and tempestuous weather, when the water-sink at the southern extremity of the Tarn is unable to receive the overflux of the lake there falls a large and heavy torrent, making a more grand and magnificent cascade than imagination can form an idea of ... . This vast and precipitate Cascade, so generally enquired after, and so seldom seen by travellers in the summer months hath been so much admired, as to leave it equally a subject of wonder and concern, that the Inlets of the stream which might easily be done, have not been stopt, and this lofty and imperious Cataract thereby rendered a perpetual object of gratification and astonishment ...".

This general concept of the tarn sinks overflowing and producing a waterfall over the Cove in wet weather was repeated in several later descriptions including Murray (1799), Housman (1808), Whitaker (1812), Westall (1818) and Bigland (1819). However Phillips (1835) made no mention of the water coming over the Cove and White (1838) stated that it is only " ... in time of floods ..." that "... this vomitary is too small to discharge the waters, which rise up to the summit of the rock, and pour down in a cataract, superior in depth and but little inferior in grandeur to the falls of Niagara ...". This period in the early nineteenth century appears to mark an intermediate stage between the waters regularly flowing over the Cove after heavy rainfall and the need for an extreme flood before the waterfall occurred.

Howson (1850) stated that "... twice within the last forty years the swollen waters of the Tarn have made their way over the Cove. ... In Flood the Tarn water not infrequently rushes over here (Comb Scar) and forms a second Gordale, but it is commonly prevented from reaching the Cove by sinking at the foot of this pass through the shattered and fissured stratum". The rare nature of the occurrence of the waterfall in the latter half of the nineteenth century is also stressed by Brown (1896) who after quoting Hurtley's description of the cataract stated that "... there has only been one such case within the memory of anyone now living. And as there are sometimes floods as great as there were a century ago the underground passage must have been worn much larger within recent times ...

Martel (1897) also stressed the rarity of the occurrence of the waterfall although the two dates he quoted of 1775 and 1824 do not agree with the descriptions of Howson and Brown. No record of a cascade flowing over the Cove since the mid-19th century has been traced.

Thus it is possible using the historical descriptions of the hydrology of the Tarn/Cove system to trace the change from frequent flow over the Cove in wet weather, to rare flow over the Cove but frequent flow over Comb Scar, to total cessation of flow over the Cove. O'Connor (1974) suggested that at present "... springtime flooding at least once a decade is adequate to send a surface flow right down a normally dry waterfall near the head of the Watlowes valley, but rarely further ...". When this is compared with Howson it indicates a further decrease in the length of surface flow in flood of the Tarn outflows.

THE EBBING AND FLOWING WELL, GIGGLESWICK

Like Malham, the Ebbing and Flowing Well at Giggleswick was a well known natural curiosity and as such formed part of the itinerary for the majority of visitors to the area. The earliest located mention of the well is in Drayton's *Poly-olbion* (1613-22):

> "At Giggleswick, where I a fountain can you show
> That eight times a day is said to ebb and flow!"

The descriptions of the well in the late eighteenth century (Bray, 1783; Byng, 1792) speak of the well "... ebbing and flowing very suddenly and frequently ..." (Pococke, 1751). However the well was already no longer continuously ebbing and flowing and Hutton (1781) notes "We were informed that if the weather was either very droughty or very wet, the phenomena ceased ...".

This lack of continuity of ebb and flow was also stressed by Housman (1808): "Its reciprocations seem very irregular, and are said almost to cease in times of very great rain or long continued drought ...", and by Whitaker (1812), Howson (1850) and Black (1886) who confided "... but the tourist will sometimes, to his disappointment and disgust, find that it does not ebb and flow ...".

It was Speight (1892) who first considered that the well might be changing and suggested that "... the question not unnaturally arises: Has the Giggleswick Well maintained its 'tidal character' since Saxon times ... ?". In his very detailed pamphlet on the well Brown (1903) implied that the ebbing and flowing was becoming less frequent than in earlier days although it was still reasonably common with the well ebbing and flowing continuously over periods of up to a month.

More recently Myers (1962) suggested that the well now only ebbs and flows very infrequently and stated that he has only seen it in operation twice in ten years. During many visits to the well between 1970 and 1975 under varying conditions of flow, the well was only seen to ebb and flow on four occasions.

Thus it is obvious that the frequency of ebbing and flowing has decreased considerably over the last 300 years. The rate of change cannot be gauged as accurately as at Malham because the effects are of a lesser magnitude and therefore the gradual change is less noticeable. It is interesting to note that both Gough (1813) and Brown (1903) mentioned wells at Tideswell and near Torbay which had previously been ebbing and flowing wells but had become ordinary springs.

WEATHERCOTE CAVE

Like Malham and the well at Giggleswick, Weathercote Cave was one of the natural curiosities visited by many early tourists. Indeed Weathercote was one of the first show caves in Yorkshire although it has never been highly commercialised (North, 1959). The change which appears to have taken place at Weathercote is an increase in the frequency of flooding but this is a difficult change to document because many of the descriptions of the cave make no mention of flooding; for example Pococke (1751), Byng (1792), Murray (1799), Wakefield (1808) and Westall (1818) all described the cave in detail without mentioning flooding.

However an equal number of visitors do report on the occurrence of floods at the site, the earliest report being in Hutton (1781) "After a little rain another cascade similar to the former falls nearly from the same height on the west side of the cave, appearing and disappearing with great variety amongst the rocks, as if it fell down the chimney of a ruinous building, where several holes were made into it in the gable-end. If the rain still increases a large stream lets it out of the room by the side of the little cave; and in great floods a vast river falls into the great cave down the precipice on the eastern side. With their united streams they are sometimes able to fill the whole capacity of the cavern and make it overflow; the subterranean crannies and passages of this leaky vessel not being able with the increased pressure from above, to carry off the water as fast as it is poured in; but this happens only once in seven or ten years ...".

In a later edition of his book Hutton (1784) provided more information on the flooding stating that "The owner of the cave says that it run over in the back end of the year 1757 before Christmas, in 1759, in 1771 two or three times, and all in the backend of the year; and in February 1782 and November 1783. But during this interval, the water has been several times near the top of the cave ...".

The flooding of the cave was also described by Housman (1808) "During long continued, heavy rains, this gaping wonder of nature is sometimes unable to contain the water received into its rocky jaws, then it discharges itself copiously at its mouth...". The occurrence of flooding is also described by Howson (1850), Boyd-Dawkins (1874), Brown (1885), Balderston (1888), Speight (1892) and Martel (1897) and is illustrated in J.M. Turner's painting (1818). Martel stated "The heavier the rain, the more lateral streams discharge the water; six times in twenty years it appears, when Dale Beck flowed above ground, the bottom cavern was not able to take all the water, and Weathercote Cave overflowed: this is just what occurred at the end of July 1895, eight hours before my visit. It was then Dale Beck passed over the mouth of the hole and flowed along its surface thalweg, continuing its course on the other side of Weathercote Cave ...".

Recent discussions with local people have revealed that the cave now frequently overflows; Mr. Chapman of Beezley Farm tells of commonly having to wade through water flowing across the drive to Weathercote House, whilst Mr. Bazeley, the present owner of the house, stated that the cave overflowed approximately twice a year (pers. comm., 1976).

This increase in the frequency of overflowing shown by the notes of Hutton, Martel and present day conditions, may be linked to the blocking up of the passages leading from the cave. Hutton (1784) stated "The owner of the cave and others have been in the passage beneath, halfway to Ginglepot: they have no doubt but it leads thither; they did not get so far, owing to the water deepening, more than the height lessening. Another subterranean river, that from Gatekirk above, meets this cascade directly underneath it, along which there is a passage, and which the above party in some measure through mistake explored, by missing their way in their return, by getting far beyond the cascade before they were convinced of their error, by the noise of the cascade gradually decreasing ...".

The existence of this passage is also mentioned by Housman (1808) but the great similarity with the Hutton report suggests he may be quoting this. However, both Boyd-Dawkins (1874) and Martel (1897) reported that Mr. Metcalfe entered the caves below Weathercote and reached this river junction. There is little reason to doubt the truth of this because Metcalfe was an adventurous cave explorer having been in the first party to descend Alum Pot via Long Churn in 1847 and via the main shaft in 1870. The existence of these two independent accounts of the caves makes it appear very likely that the caves exist but currently the passages cannot be reached because they are filled with silt and water (Hinchcliffe, 1964; Brook *et al.*, 1975). Thus there is ample evidence of a possible mechanism which could have caused the increase in flood frequency.

The existence of an increase in surface flow in the area is also suggested by the new road bridge by St. Leonard's Church. During the last few years the tarmac was stripped off the bridge by flooding on several occasions and the bridge was finally replaced by a considerably higher bridge in late 1974.

MEREGILL SKIT

Unlike the sites described above, Meregill Skit was not a site which was frequently visited by tourists. It is, however, possible to provide evidence of a change in hydrology since the beginning of the century although it is not known whether this change was sudden or gradual.

When the Yorkshire Geological Society were undertaking their series of dyetests around Ingleborough they placed fluorescein in Meregill at 1pm on July 4th, 1903 and it was seen issuing from Meregill Skit the following morning. Although no specific mention is made of the water conditions when the test was undertaken, as a part of a previous test on the Great Douk waters whilst looking for the dye from June 30 to July 3 they noted that "... the stream was low at the time and there was little water above God's Bridge ...". There is also a further less specific comment referring to the whole summer and stating that "Tatham Wife Hole, at Falls Foot, was visited several times during the investigation, but was always dry and consequently could not be tested ...". The implication of both these remarks is that water levels were generally low at the time the dye was seen issuing from Meregill Skit (Carter & Dwerryhouse, 1905).

The test was repeated by University of Leeds Speleological Association (Brook *et al.*, 1969) and in this test the water issued from the risings at God's Bridge under conditions of moderate flood. At the present time Meregill Skit only flows in time of flood and under average weather conditions the rising is dry, indeed the guidebook (Brook *et al.*, 1975) states that the cave is "... at head of normally dry side channel just upvalley from God's Bridge ...". Thus it may be seen that there has been a considerable decrease in the frequency of flow from Meregill Skit, almost certainly as a result of the enlargement of the sub-surface connection between Meregill Skit and God's Bridge.

A second less definite indication of change in this locality is provided by the name *God's Bridge*. Unless in earlier days there was water flowing upstream of God's Bridge and sinking to flow under the bridge, there would have been nothing to differentiate God's Bridge from the rest of the dry stream bed. Thus in earlier times there probably was water flowing above God's Bridge although the risings must have been only a short distance above the bridge because many of the historical descriptions speak of springs by the bridge. This, therefore, is a second line of evidence which suggests that Meregill Skit may have been a more active rising in the past.

CONCLUSION

The above examples were deliberately chosen because they illustrate gradual changes in the landscape. There are descriptions from the area of sudden changes, such as the storm and associated landslip of 1817 which totally changed Yordas Cave (Westall, 1818). However, such catastrophic events can be seen from many landscapes whilst limestone appears to be one of the few non-coastal landforms where long term gradual changes can be traced. It would be useful to attempt to trace similar changes in the other limestone areas of Britain although in some areas this would not be possible because of the influence of mining.

ACKNOWLEDGEMENTS

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REFERENCES

Balderston, R.R. & M. 1888 *Ingleton bygone and present.* Simpkin, Marshall & Co. , London. 368pp.

Bigland, J. 1819 *A Topographical and Historical Description of the County of York.* Sherwood, Neely and Jones, London. 958pp.

Black, A. 1886 *Black's Guide to Yorkshire.* 12th edition. Adam & Charles Black, Edinburgh. 386pp.

Bray, W. 1783 *Sketch of a Tour into Derbyshire and Yorkshire.* 2nd edition. B. White, London. 402pp.

Brook, D. & H. Crabtree 1969 *The Explorations Journal of ULSA.* Univ. Leeds Speleological Assoc., Leeds. 72pp.

Brook, D. *et al.* 1975 *Northern Caves, Vol. 3: Ingleborough.* Dalesman, Clapham, North Yorkshire. 144pp.

Brown, G.H. 1896 *On foot around Settle.* J.W. Lambert, Settle. 246pp.

Brown, G.H. 1903 *The Ebbing and Flowing Well, Giggleswick.* J.W. Lambert, Settle. 20pp.

Brown, J. 1885 *Tourist Rambles in the Northern and Midland Counties.* Second Series. Simpkin, Marshall & Co., London. 307pp.

Byng, J. 1792 *The Torrington Diaries. Vol 3: A Tour to the North.* Eyre and Spottiswoode, London. (1936. edition)

Carter, W.L. & A.R. Dwerryhouse 1905 The underground waters of N.W. Yorkshire. Part 2: The underground waters of Ingleborough. *Proc. Yorks. geol. Soc.*, 15, pp. 248-304.

Dawkins, W.B. 1871 On the formation of the caves around Ingleborough. *Manchester Geol. Soc. Trans.*, 11 (2), pp. 106-114.

Drayton, M. 1613-22 *Poly-olbion or a Chorographicall Description of Tracts, Rivers and Mountains ... of Great Britain.* 2 vols., London.

Gough, J. 1813 Observations on the ebbing and flowing well at Giggleswick. *Manchester Lit. & Phil. Soc. Mem.* 2nd series, 2, pp. 354-383.

Halliwell, R.A. 1977 *Aspects of limestone waters near Ingleton, North Yorkshire.* Unpub. Ph.D. thesis, University of Hull.

Hinchcliffe, N.H. 1964 Weathercote Cave. *North Ribblesdale Caving Group News Journal*, 1 (1), 10pp.

Housman, J. 1808 *A descriptive tour and guide to the lakes, caves and mountains ...* 3rd edition. F. Jollie & Sons, Carlisle. 323pp.

Howson, W. 1850 *An illustrated Guide to the curiosities of Craven.* Whittaker & Co., London & Settle. 134pp.

Hurtley, T. 1786 *A concise account of some natural curiosities in the environs of Malham, in Craven, Yorkshire.* J. Robson & T. Longman, London. 68pp.

Hutton, J. 1781 *A tour to the caves.* 2nd edition. Richardson & Urquhart, London. (Reprinted by SR Publishers, Wakefield, 1970). 100pp.

Hutton, J. 1784 A tour to the caves. 4th edition IN T. West, *A Guide to the Lakes ...* 7th edition, W.J. Richardson, London. 311pp.

Martel, E.A. 1897 *Irland et cavernes Anglaises.* Delagrave, Paris. 403pp.

Murray, S. 1799-1803 *A companion and useful Guide to the beauties of Scotland, the Lakes of Cumberland, Westmorland, Lancashire; and to the curiosities of the West Riding of Yorkshire; particularly the district called Craven in Yorkshire.* George Nicol, London. 2 vols.

Myers, J.O. 1962 Cave Physics. IN C.H.D. Cullingford (Ed.), *British Caving.* 2nd edition. Routledge & Kegan, London, Chapter 7, pp. 226-251.

North, J. 1959 Early tourists at a Yorkshire cave. *Country Life,* pp. 956-7.

O'Connor, J. *et al.,* 1974 Karst features of Malham and the Craven Fault zone. IN A.C. Waltham (Ed.), *Limestones and caves of N.W. England.* David & Charles, Newton Abbot, Devon. pp. 395-409.

Phillips, J. 1835 *Illustrations of the geology of Yorkshire. Part 2: The Mountain limestones.* Murray, London.

Pococke, R. 1751 *The travels through England of Dr. Richard Pococke during 1750, 1751 and later years.* Reprinted by the Camden Society, NS42 (1888).

Shaw, T.R. 1971 John Hutton 1740?-1806. His "Tour to the Caves ..." and his place in the History of Speleology. *Studies in Speleology,* 2, pp. 109-128.

Speight, H. 1892 *The Craven and north west Yorkshire Highlands.* Elliot Stock, London. 470pp.

Turner, J.M. 1818 *Weathercote Cave when half-filled with water.* Water colour 301 x 423 mm. BM1910-2-12-281. (British Museum).

Wakefield, P. 1808 *A family tour through the British Empire containing some account of its natural and artificial curiosities.* 4th edition. Darton & Harvey, London. 454pp.

Westall, W. 1818 *Views of the caves near Ingleton, Gordale Scar and Malham Cove in Yorkshire.* J. Murray, London.

Whitaker, T.D. 1812 *The history and antiquities of the Deanery of Craven.* 2nd edition. J. Nichols & Son, London. 530pp.

White, W. 1838 *History, Gazetteer and Directory of the West Riding of Yorkshire ...* 2 volumes. Robert Leader, Sheffield. 852pp.

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A SHORT HISTORY OF THE 7TH INTERNATIONAL SPELEOLOGICAL CONGRESS

by Malcolm Newson and John Wilmut

Whilst Speleology often makes huge progress by the activities of individuals or small groups of researchers or explorers and whilst any larger grouping is sometimes anathema because it will involve bureaucracy, the international dimension has now come to Britain to stay, thanks to a very successful staging of the four-yearly International Speleological Congress here in 1977. Motivated intially by Europeans, previous hosts have been France, Belgium, Italy, West Germany, Yugoslavia and Czechoslovakia. Whilst there exists an International Union of Speleology, which is now recognised by UNESCO, it is a coordinating body only and plays little part in organising each Congress. Speleology in the host country must be flourishing, coherent and be able to spend a great deal of time and money in organising the event; a successful Congress therefore says as much about the national status of Speleology in the host country as anything else. The 7th Congress took 7 years to prepare, three weeks to hold and two more years to digest! The present account is a shortened form of the Completion Report.

The first phase

During Autumn 1969 the dissatisfaction of British delegates to the 5th Congress and encouragement from abroad led a number of people to speculate on the remote possibilities of Britain acting as hosts to the 7th Congress. The late E.K. Tratman became most determined to see the Congress here before his boots were hung up! He prepared a memorandum on April 22nd 1970 which became the first working document of the 7th Congress. Reaction was slow, perhaps daunted by the enormous task which 'Trat' had delimited - carefully planning meetings, a paid secretariat and a reduced emphasis on excursions ('Britain is a small island'). The Cave Research Group (CRG) discussed the matter at its Southern area meeting in June 1970. Trat was too impatient and, over an excess of Yugoslav reisling in a Bristol restaurant persuaded an unfortunate member of the 'Karst Police' to start pushing things along. A circular from Dr. Tratman dated 1.7.70, asked the CRG, British Speleological Association (BSA), National Caving Association (NCA) and the Pengelly Cave Studies Trust to contact him in an attempt to make any further moves broadly-based and non-factional.

Both the scientific bodies (CRG & BSA) and the NCA took positive steps by autumn 1970. An early attempt to get the matter made an exclusively NCA one was defeated and that body agreed at its AGM of 31.10.70 to cooperate in any independent meeting which might be organised. CRG, BSA and the Pengelly Cave Studies Trust also nominated representatives to attend the first meeting.

The first meeting was held in Leicester on 23rd January, 1971. Minutes were produced and circulated and a Feasibility Committee formed.

By February 1971 the first of the moves towards a more unified structure for speleological organisation in Britain, a vital necessity for the organisation of a Congress, had taken place. The National Caving Association was recognised by the Sports Council as 'the governing body' of the sport of caving. Whilst this was viewed as a possible avenue to government funding for the Congress, the scientific bias to Speleology made it necessary to approach the Royal Society for backing. A proposal for grant-aid was submitted to them in February 1972 but the Feasibility Committee were advised that it needed re-submitting and a meeting was organised with the Society's Executive Secretary in October 1972. His advice proved very helpful.

The new Royal Society document was submitted in April 1973, with the full approval and joint authorship of the Feasibility Committee. It tried to make clear the dual sporting and scientific content of Speleology. As J. Sweeting said, "It's a bit like a lunar landing - you must know what you're doing and be fit!".

The Royal Society had let it be known that one obstacle to recognising the Congress proposals was the ambiguous position of having both CRG and BSA concerned with scientific Speleology in Britain. They favoured a single organisation and fortunately the two bodies had been planning to merge for some time. This merger, to form the British Cave Research Association (BCRA), occurred on 1st July 1973. On the 13th July the Committee were notified that the Travelling Expenses Committee of the Royal Society had awarded the Congress a loan of £500 as a contribution to anticipated net costs of £4000 to £5000.

In July, too, correspondence was begun with the University of Sheffield since the city had been selected as the most likely venue for the core of the Congress and the University's conference facilties had received high praise in the National Press.

On the 10th September 1973 Dr. Warwick informed the Feasibility Committee by wine-stained post-card from Czechoslovakia that Britain's candidature to host the 7th Congress had been approved by the plenary session of the 6th Congress. The first phase was therefore drawn to a hectic close.

The second phase

Prior to knowing that the U.K. had definitely been chosen as hosts to the 7th Congress the Committee had been known as 'the ad hoc Feasibility Committee'. The re-named Executive Committee of the 7th International Speleological Congress was formed on 3rd November 1973.

Already a number of decisions had been taken. Sheffield was to be the main venue, with Bristol as reserve. Prior publication of the papers would be attempted for the first time in the history of the Congress, with a strict control on the standard of papers. The anticipated attendance was 400-600, income £4,500, expenditure £7,700. (Estimated attendance rose to 1000 after a good attendance at Olomouc for the 6th Congress and financial estimates were to alter drastically with a steep rise in inflation. For example, the cost of full board in Ranmoor House conference centre, Sheffield in 1971 was a mere £2.55 per day!).

Three meetings of the Executive Committee were held during 1974. During January the Chairman and Secretary toured a short list of university conference offices; that at Sheffield was by far the most dynamic and undertook to provide free assistance with routine secretarial duties, circulation, collection of fees, etc. A nagging doubt about Sheffield at the time was that there was no active karst research at the University, but this was later to alter with the move of Dr. Trudgill to the Geography Department. Thus Sheffield became fixed as the venue for the central core week of paper sessions, the dates: 10th - 17th September 1977. A suggestion was made that post-Congress events should not include excursions but consist of academic Symposia. Dr. Panos, Hon. Secretary of the 6th Congress was asked for help with mailing lists for the First Circular, but funds could not be found to bring him to the U.K. to give detailed help. Apart from receiving the mailing list in due course there was little continuity between Congresses and little coordination from the International Union of Speleology, a fact which produced a revolutionary mood amongst the members of the Committee.

In April 1974 the Committee listed the topics for paper sessions and set a limit on the length of papers at 1200 words. In August of that year the University of Sheffield was officially booked, a Civic Reception promised by the Lord Mayor and a public liability insurance policy taken out to cover losses through cancellation. The programme of regional events was discussed and a draft of the First Circular drawn up.

Four meetings were held during 1975. At the January one the Executive Committee received a set-back in that the Royal Family had revealed that they would be at Balmoral during the Congress, recuperating from the Jubilee, and Prince Philip would therefore be unable to open the Congress, although there was still hope that Prince Charles would be available; this hope only became dashed in 1977. Two local Sheffield cavers volunteered their services as a result of a short talk about Congress plans delivered to the BCRA Conference in Leeds on September 15th 1974. They provided a document on Sheffield entertainment as early as the January 1975 meeting. At that meeting a motif, depicting a silhouetted caver on an outline of Britain, was accepted as the official badge of the 7th Congress. This has recently been accepted as the badge of the BCRA. At the April meeting a typed draft of the First Circular was ready. The Executive Committee had received a two-thirds response from Chairman of IUS Commissions in reply to a request for their programme requirements at Sheffield. It became clear that Excursions, Camps and Symposia would require a great deal of coordination and an Excursions Secretary was appointed.

In early 1975 Mr. Terry Stoddart resigned from his position as Conference Officer with the University of Sheffield. He was now running a firm called British Educational Conference Travel Ltd. which was based in Sheffield and would be happy to handle the Congress. A contract was discussed and accepted which left all the printing, postage and acceptance of bookings to B.E.C. Travel, thus freeing the Committee from the need to recruit paid secretarial assistance. B.E.C. reserved the right to make profit from accommodation in exchange for this considerable aid.

At the September 1975 meeting the Finance Officer was able to report a grant of between £1500 and £2000 from the Sports Council, to support half the Congress' costs (in fact 40% of half as the result of an estimate of a 40% sporting content for the Congress). British Tourist Authority would supply a free loan to cover advertising publicity and the British Council would fund individual cavers from East Europe to £100 each. The September meeting also received the First Circulars and the Congress poster for rapid dissemination to the BCRA Conference during which the meeting was held. First Circulars were posted abroad during the month. Circulars and posters widely distributed to Information Offices in limestone areas, as well as to Dr. Panos' mailing list from the previous Congress (1754 were sent to 77 countries). A single sheet news release was also distributed and sent in bulk to Australia, New Zealand, Canada and the U.S.A.

By November 1975 there were 120 replies to the First Circular, a sub-committee on exhibitions had been set up and specialist advice sought on book sales at the Congress.

By the first of the four 1976 meetings it was clear that mailing circulars to East Europe would be very troublesome and costly re-mailings had to be adopted, e.g. for Czechoslovakia. The Foreign Office was approached on protocol matters concerning visas, etc. From then on all likely delegates from 'problem' countries were notified to try to ensure their smooth attendance at the Congress. There were only 275 replies to the First Circular by April 3rd 1976 and the estimate of final numbers was reduced from 800 to 500. Already it was time for material to be collected for the Second Circular. Money matters discussed at the meeting were the avoidance of tax on the Congress and the insurance of caving activities on the Congress. These were also on the Agenda for the June meeting and, for instance the Cave Diving Camp was cancelled because of the difficulty of insuring the participants. Some other events were dropped in the light of preferences expressed by First Circular returns, now numbering 823. A paper was presented on book sales suggesting the running of an official shop for BCRA and the Congress Executive Committee. At the June meeting, too, the idea of forming a limited company for loss avoidance was mooted for the first time; it took almost a year to kill the idea.

A developing preoccupation with precise practical problems led the September meeting to Ranmoor House, Sheffield, the Congress centre, for a tour of inspection. The Second Circular was behind schedule as a result of the long vacation and the severe difficulty of estimating costs for events, the result of spiralling inflation. In Ireland a new representative was appointed and he submitted excursions and camps for addition to the Circular. A day ticket system was proposed for the Sheffield week to get more working British cavers in to the Congress.

The Second Circular was not ready for inspection until the November meeting at Thornbridge Hall, thus putting it two months late and clashing its mailing with the Christmas rush (abroad at least). The full analysis of First Circular returns showed up three facts of interest: many of the delegates would have accompanying members, camping was over-subscribed and University accommodation under-subscribed but there appeared to be no major translation problem. Nearly 450 papers had been promised and this would result in a more expensive volume of Proceedings. Commercial approaches were discussed including the sale of a 'T' shirt, a commercial venture for exhibition stand space and the sale of advertising in the Sheffield handbook. Press and information outlets were tied up for the run-in period to the Congress by appointing a local representative. Rather bitter discussions took place on the topic of the I.U.S. and its relationship with cavers and the Congress.

Four meetings were held prior to the Congress in 1977. At the first, in February, only 300 bookings had been received, partly due to the mailing difficulties of the Second Circular. A postcard was designed to approach those who had replied to the First Circular but not the Second and a new deadline for bookings set. The delay in receiving firm bookings and cash was, however, to remain one of the major difficulties of the whole Congress. The Programme and Proceedings appeared threatened now by the poor response. Company formation was again discussed. Expenses such as simultaneous translation (£600) and the commercial stand venture were abandoned. BCRA formally agreed to act as book and club publication sales agents at the Congress.

At the April 1977 meeting a loss of £1210 was being anticipated. After voting 'yes' to company formation a postal vote of absent Committee members reversed the decision, expecially when it was known that this threatened all business links, with BEC Travel, the University of Sheffield, etc. A camp site had been provided through the actions of a Sheffield local committee set up on the 31st March. A British Karst Abstracts volume was adopted as a Congress publication. Three events in the Second Circular were cancelled due to poor returns and an excursion was merged with a Symposium. Keeping provincial organisers up to date with bookings proved hard work. One event, the Cave Biology Symposium, became over-subscribed and letters were dispatched to the unlucky late bookers. Only brief French translations were included in the draft of the Third Circular (1st and 2nd were fully translated). A resolution was approved asking the IUS to obtain better funding for itself so that future Congresses could be spared the uncertainties currently rife with the 7th Congress.

By the July 1977 meeting problems with the Sheffield camp site were looming - surveillance, cleaning, etc. - and the prospect of having to employ someone was not welcome. The high proportion of non-payment of deposits was found to be mainly due to delegates from East Europe. However, these people would not threaten the viability of regional events if they did not turn up. Another blow to regional events was, however, the use of all papers submitted in the detailed programme for Sheffield, leaving no papers for the Symposia. Administration of the programme was left to grand chairmen and session chairmen who would need to meet the Congress Secretary before each session to check room and visual-aids allocation, missing speakers, etc. A proof of the Northern area excursion Guidebook, the model for the others, was available for the meeting.

By the meeting of 20th August, held at Ranmoor House, the approximate numbers for the Congress were 495, but with 20 to 30 changes or new bookings coming in each day, worst fears about the lateness of booking were confirmed but it was too late to panic. Two welcome and sudden developments were the allocation of a new supervised, cleaned camp site by Sheffield City, and the offer of four linguists for Registration day from FANY, a voluntary army corps of ladies concerned with language and communications. The Sheffield programme was considered in detail prior to the printing of the Sheffield Handbook. Detailed standing orders for the Ranmoor week were considered.

The Congress

Following the BCRA Conference in Ranmoor House the Congress Finance Officer and Secretary took up residence at BEC Travel to make final preparations and to coordinate the pre-Congress excursions centrally. Little of this coordination was eventually required, a fortunate outcome since the time was very busily employed getting ready for Registration on Saturday, 10th September, completing the Sheffield Handbook and working out the last minute programme. This involved working until 2 a.m. every morning!

Registration was arranged at three desks, subdividing the alphabet and providing a 'problems' desk with interpreters on hand. The 'problems' desk became overloaded at times but even so it was as smooth a Registration as our interpreter helpers could remember. Again, our delegates' lateness, this time in their arrival at Ranmoor, forced Registration facilities to be open on both Sunday and Monday. A large number of delegates simply did not turn up but a large number of new delegates took their places.

The programme organisation and financial control were maintained by two Committee Officers throughout the week but they were superbly backed up by student volunteers from Sheffield, the staff of BEC Travel and by the rest of the Committee 'out front', trouble shooting as problems arose. 'Trat' was very heavily involved in this work and though the week must have tired him, he also organised a post-Congress Symposium, and was clearly elated at the success of the Congress. One of the main commitments was to visual aids; the persistence of the French delegates in calling for a film festival forced a series of panics over projectors, projectionists, and so on.

Although the allocation of lecture rooms did not bode well for delegates' comfort, black-out, location finding, etc. the paper programme ran very smoothly, planned to the last minute by posting it late each night for the following day and meeting all the chairmen before a session. Pre-publication of papers was a key item, allowing purposeful selection of sessions by delegates.

On the social side, the cooperation of the Ranmoor staff to ensure good food, a good bar, a shoulder to cry on, etc. ensured an excellent spirit. The Civic Reception will remain unequalled in excellence for many Congresses. The film festival, evening talks and slide shows and a lively last night, plus a good day excursion programme combined to make the Sheffield week an exhilarating one.

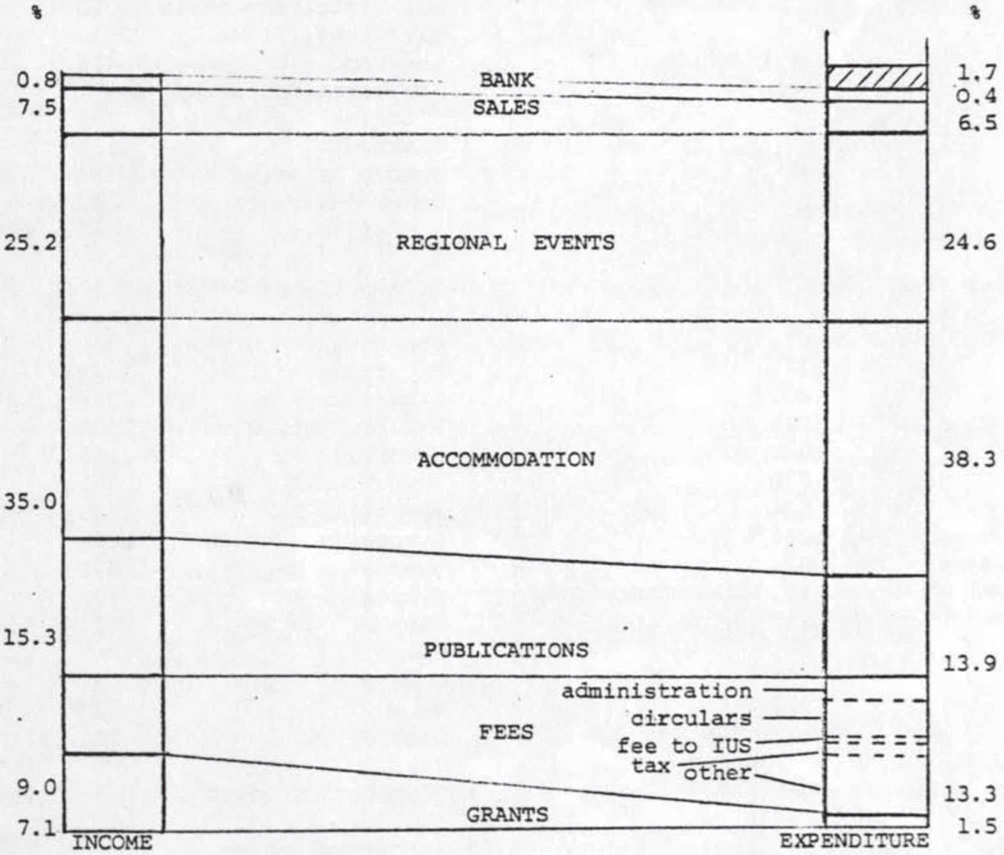
Post-Congress activities ran as smoothly as pre-Congress ones, requiring no central coordination.

Financing the Congress

The Income and Expenditure Account is appended to this report. It shows that, despite the difficulties caused by inflation, last minute cancellations and uncertainties over some regional events, the Congress made a small surplus. The assets of the Congress are now all in the form of unsold publications. It can be seen that over £2000 has already come in through post-Congress sales, and the face value of the remaining stock is a little less than £3000, of which we may reasonably expect to sell £2000 worth.

The total turnover of the Congress exceeded £50,000, and this is almost an order of magnitude greater than the estimate that the committee first made. This reflects both an increasing awareness of the real costs of mounting an enterprise of this size, and the ravages of inflation which hit the later stages of the planning.

An appreciation of the alloeation of funds within the Congress can be gained from the diagram below, which shows the percentages of the turnover allocated to the major cost components. It is clear from this analysis that the accommodation (at Ranmoor House), the publications (Proceedings and Handbooks), and the Regional Events account for about three-quarters of the turnover, and it was fortunate that the losses on the accommodation were offset by small gains on both publications and regional events.



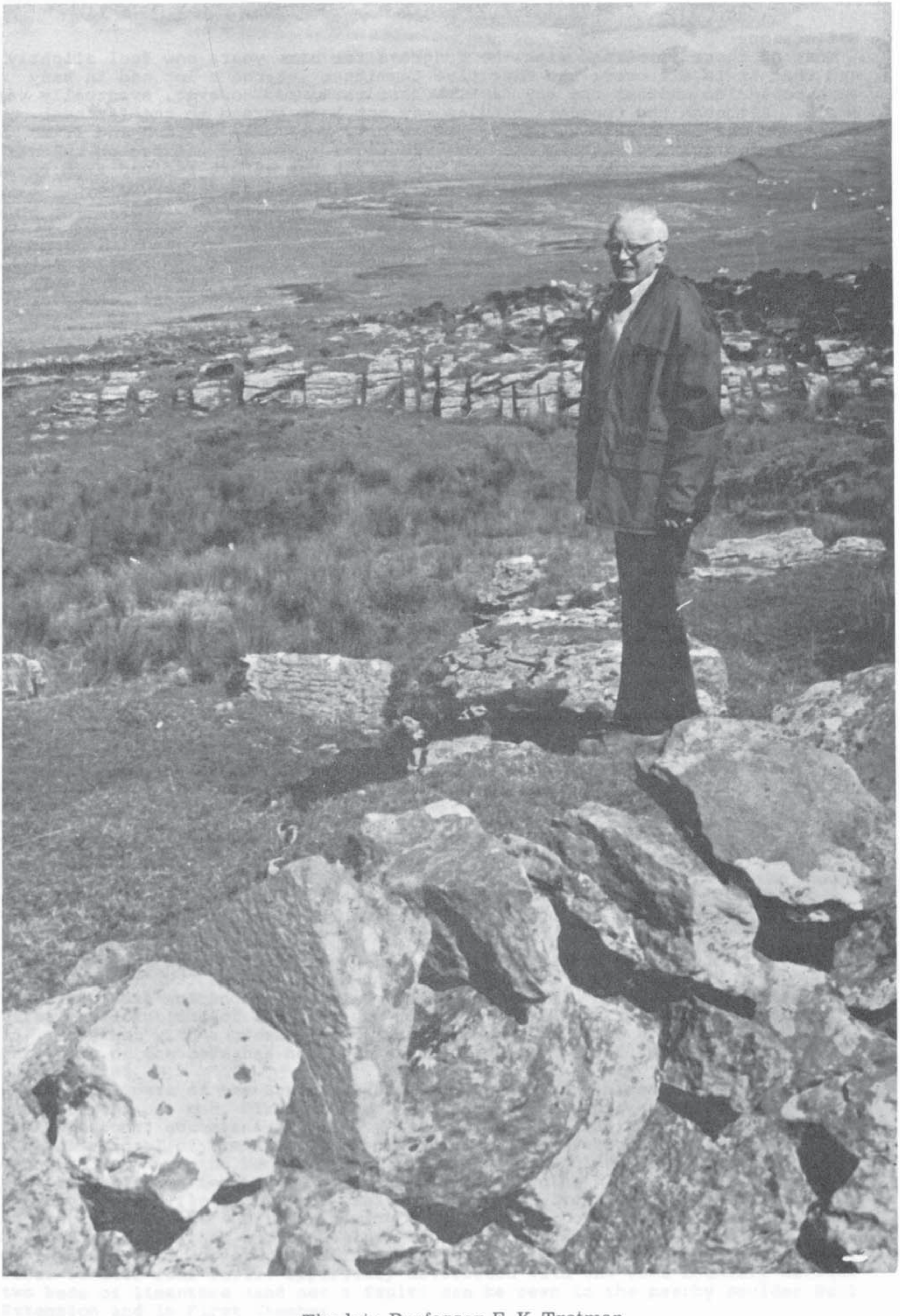
PROVISIONAL FINAL ACCOUNT MARCH 1979

INCOME

	£	£
GRANTS, LOANS, ETC.		
Grants & Gifts	2318	
Loan	500	
Special Grant	800	3618
GENERAL FEES & TICKET SALES		
General Fees	4495	
Sundry Sales/Fees	128	4623
SPECIAL EVENT FEES		
Sheffield Excursions	645	
Excursion A	1147	
Excursion B	2402	
Exc. C/Symp. H	1129	
Excursion F	2935	
Symposium J	270	
Symposium K	884	
Symposium M	1094	
Symposium N	824	
Symposium P	662	
Camp R	241	
Camp T	266	
Camp U	22	
Camp V	273	
Camp W	122	12916
ACCOMMODATION FEES		17938
PUBLICATIONS		
Income from fees	5690	
Sales	2162	7852
GENERAL SALES		
Tee Shirts	326	
Bookshop	3112	
Exhibition Space	408	3846
BANK INTEREST		392
		£51185

EXPENDITURE

	£	£
REPAYMENTS		
Loan Repayment	500	
Special Grant Refund	255	755
COSTS AGAINST FEES		
Fee Refunds	101	
Administration costs	1060	
Circulars (3)	2542	
Insurance	475	
Registration costs/ Losses	701	
Coaches	185	
Sundry Printing	450	
Other Costs at Sheffield	630	6144
SPECIAL EVENT COSTS		
Sheffield Excursion	791	
Excursion A	1224	
Excursion B	2208	
Exc. C/Symp. H	1365	
Excursion F	3196	
Symposium J	303	
Symposium K	425	
Symposium M	1029	
Symposium N	671	
Symposium P	578	
Camp R	104	
Camp T	363	
Camp U	22	
Camp V	127	
Camp W	200	12606
ACCOMMODATION COSTS		19589
PUBLICATION COSTS		7093
GENERAL COSTS		
Tee Shirts	296	
Bookshop Purchases	2891	
Exhibition Facilities	155	3342
BANK CHARGES		217
FEE TO IUS		338
VALUE ADDED TAX		236
SURPLUS OF INCOME OVER EXPENDITURE		865
		£51185



The late Professor E. K. Tratman

President of the International Speleological Congress

Sheffield 1977

Seen on his favourite limestone, the Burren, Co. Clare.

Reflections

Most of those concerned with the Congress for nine years now feel slightly sad that it is all over; the Executive Committee learned a lot and in many ways could 'do another one any day'! Their part was, however, eventually very small. Although the Congress ripples may not have spread to the farthest corner of the farthest club hut or public bar, very many British and Irish helpers came forward with crucial contributions. New and unexpected talents appeared at every stage and the high praise for the effort recived from those who visited us during September 1977 is justly spread over the whole of Speleology in the British Isles, giving it a new maturity and coherence.

The modest financial surplus (around 5% of turnover) is a triumph of planning and allows the spirit of the Congress to be perpetuated in awards through the Ghar Parau Foundation. One of these will bear the name of E.K. Tratman, who did so much to get us all moving and saw it through in a very active capacity. The United States is to host the 1981 Congress. However much bigger and better the reputation of that country foretells the Congress will be, they will labour with the tremendous disadvantage of distance and they do not possess a Sheffield!

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LETTERS TO THE EDITOR

THE PERI - GLACIAL VADOSE EFFECT

Dear Sir,

As someone who has been interested in the formation of the Devon caves for over 20 years I read the recent paper by T.M. Bailey on the above subject (1) with disbelief. The majority of Devon Caves were formed under phreatic conditions, usually with contemporaneous heavy silt deposition which confined solution to the roof and led, in places, to very deeply incised half tubes. Vadose action, where it has occurred, has been confined to the washing out of the silt infill, except in a very few places where the original phreatic floor of the cave has been reached (2).

Mr. Bailey's thesis is that "the peri-glacial vadose effect" is a way of explaining the "extensive vadose entrenchment extending ... downwards as much as 20 metres". His paper does not include the criteria by which he judged a particular site as being vadose, nor does it include a description of any site in sufficient detail for the reader to judge for himself. No maps are included to show how his "vadose" features can be related to a consistent flow pattern controlled by gravity. The purpose of this letter is to describe some of the sites mentioned by Mr. Bailey and show that there are alternative, much simpler explanations for each.

1. The Stalactites of Pridhamsleigh Lake

It is stated that there are stalactites at -12 metres in Pridhamsleigh Lake, but no reference is given. The original, and only sighting, of these elusive formations was made in 1952. Two naval cadets from Plymouth wanted to try out their diving kit in a cave. Following the trip one of them wrote to John Hooper, who subsequently reprinted the letter (3). It is clear that the visit was far from being successful. The first person to dive started out of control, stopping his descent at 70 feet, when he touched the wall. This disturbed so much mud that he was blinded and returned immediately to the surface. All subsequent attempts to dive were blind because of the large quantities of suspended matter. The letter contains the sentence "I saw some stalactites at 40 ft".

About ten years ago a series of dives were made in the lake and significant underwater discoveries were made (4). Work was hampered by extensive "formations" at all levels which disintegrated at a touch to give a cloud of very fine mud. These formations clearly resulted from long standing still water phreatic solution which had left the insoluble components of the limestone as a tracery decorating the walls. (Similar formations can be seen, above water level, in other caves in the area). No calcite formations of any kind were seen below the water table.

In the circumstances it seems likely that the naval diver mistook some of the insoluble residue "formations" as being stalactites. If this is the case the recent evidence of the extreme fragility of these residues can be used to argue that the water level has never been significantly lower than it is now.

2) The Slabs, Baker's Pit Cave

In suggesting that the Crystal Corridor has vadose features concealed by "later infill" Mr. Bailey argues that it "shows its real nature at 'The Slabs' where a vadose entrenchment extends downward following the tilt of the fault ...". Verbal descriptions of the area now known as "The Slabs" have been published (5), together with a cross-section and a photograph. The speleogenesis of this part of the cave has not been documented and a brief summary seems appropriate.

The outer part of the Baker's Pit cave system is organised around a large chamber. At one end, First Chamber, there has been almost total solution of the limestone, accompanied by heavy silt deposition. This was followed by partial removal of the silt by a small vadose stream which has not yet excavated down to the bedrock. At the other end, Boulder Hall, the original phreatic solution took place along joints and bedding planes (*vide* the passages in the roof and floor of nearby Easter Chamber). Eventually these blocks became detached and subsided, giving what is now a boulder ruckle of phreatic boulders. While this was happening, or shortly afterwards, a large section of the wall/roof detached itself, ending up on top of part of the boulder pile. Other similar roof falls, apparently associated with the same boundary between two beds of limestone (and not a fault) can be seen in the nearby Boulder Hall Extension and in First Chamber.

The tiny stream, that has washed the silt infill from parts of First Chamber, has washed out a passage beneath the boulder ruckle which can be followed down to a phreatic chamber which can also be reached by climbing down The Slabs. It is not until it reaches this chamber that the stream runs on bedrock limestone. The corrosive water has cut a vadose trench, about two feet deep and too narrow to enter, across the floor of the chamber. It cannot be followed as the roof of the chamber descends to the silt-filled bedding plane out of which the original chamber developed phreatically. This clearly vadose trench, the biggest I am aware of in the whole cave system, appears to be the feature described as a "pro-phreatic conduit" by Bailey.

3) Judge's Chamber, Baker's Pit Cave

Mr. Bailey states "the Drain comes out in what would have been a 6 metre pot, now the Judge's Chamber". The Drain is a comparatively restricted horizontal phreatic tube linking two separate parts of the cave. Its restricted nature may well be because it runs through the bed of limestone which, in general, does not support cave development - possibly because of lower solubility. Normal solution has taken place in the Judge's Chamber - and there is even a rather robust example of a solutional formation of the type found in the Lake at Pridhamsleigh. (There are many more such formations in some of the other passages nearby.) The floor of the Judge's Chamber is a phreatic boulder ruckle similar to, but smaller than, the one found in Boulder Hall. The boulders show no sign of water having fallen on them from above, the roof of the chamber is pristine - so they didn't get there as a result of a roof fall, and the boulders are an order of magnitude too big to have come down the Drain itself. There is no way in which a vadose theory can explain the presence of these boulders in the chamber.

4) Joint Mitnor Cave

The 'water level marks' of Joint Mitnor Cave are calcite deposits that have been formed round the edge of a large pool with a static water level. Mr. Bailey neither describes the nature of these marks or gives a reason for suggesting that "these may be interglacial invasion marks".

I do not want to comment on Mr. Bailey's theory. However, the cave systems which he chooses to illustrate his theory are almost totally lacking in vadose features and for this reason the "periglacial vadose effect" cannot apply to these caves.

March 19th 1979

From: Dr. C.F. Reynolds,
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(1) Bailey, T.M. 1978 The Peri-Glacial Vadose Effect; Evidence from Devon Caves, *Trans. Brit. Cave Res. Assoc.*, Vol. 5, No. 3, pp. 143-151.
(2) Reynolds, C.F. In preparation.
(3) Hooper, J.H.D. 1964 The Pridhamsleigh Caverns, Devon, *Cave Science*, Vol. 5, No. 35, pp. 138-149.
(4) Lang, G. Private Communications.
(5) Hooper, J.H.D. 1956 The Buckfastleigh Caverns, Devon, *Cave Science*, Vol. 4, No. 27, pp. 96-121. (see p. 104 bottom, p. 109-110, p. 123 section m-m' and photograph opposite p. 147 of following number).

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