BCRA TRANSACTIONS

BRITISH CAVE RESEARCH ASSOCIATION

Volume 8 Number 4 December 1981

INSERTING THE DYE IN P8 -AND OUT IT COMES AT RUSSET WELL!

CASTLETON WATER TRACING
LIMESTONE PAVEMENTS
EXPLORATION MEDICINE
RADIATION IN TRANSVAAL CAVES

BRITISH CAVE RESEARCH ASSOCIATION

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A HYDROLOGICAL STUDY OF THE CASTLETON AREA, DERBYSHIRE

by: N.S.J. Christopher, S.T. Trudgill, R.W.Crabtree,
A.M.Pickles and S.M.Culshaw.

ABSTRACT

Water tracing has been carried out in the Castleton area, Derbyshire, using fluorescent dyes and chemical tracers; pH, conductivity and water flow levels were also recorded at one output site.

The dye results show that the principal input in Speedwell Cavern for most of the Rushup Edge swallets is Whirlpool Rising and this is linked to the Bathing Pool. The results also show that Peak Cavern is also linked to the allogenic Speedwell system in low flow. Giants Hole water was not detected at the main inlets and only detected downstream from the Assault Course. Slop Moll sough resurgence has a greater proportion of swallet water than Russett Well which is thought to be an immature karst resurgence. First time of arrival and peak concentration times for dyes and chemicals are presented.

The results broadly confirm previous dye tests, but suggest the aquifer behaves like a fractured rock aquifer with diffuse flow or there exists a large volume of phreatic ground water within the aquifer. These results are supported by the flood pulse results.

It is suggested that prior to the making of Slop Moll, Peak Cavern was a more important resurgence. The development of the hydrology of the area appears to be related to the retreat of the shale cover.

The Castleton area is the premier caving area of Derbyshire containing more penetrable cave than any other part of Derbyshire. It is also the classic example in Derbyshire, of a multiple allogenic sink to resurgence system.

The outlines of the system have been known in considerable detail for over 20 years, but there has been no serious or systematic attempt to apply modern hydrological study methods to the area prior to the work of the authors.

The general geology and hydrology has been summarized by Ford (1966) and the geomorphology examined in greater detail by Ford (1977).

The area consists of an east-west belt of Lower Carboniferous Limestone reef knolls, lying to the north of a plateau composed of back reef lagoonal limestones. To the north and east the lower slopes of the fore reef area are flanked by younger Upper Carboniferous (Namurian) shales and sandstones of the Millstone Grit which originally extended over the present outcrop of the limestone, but have been progressively removed by erosion in the Tertiary and Pleistocene so that they are now only present along Rushup Edge. To the east the River Noe, a tributary of the River Derwent has cut the broad Hope Valley in the less resistant shales, leaving the limestone plateau and reef crests at an elevation of 150-280m above the valley floor.

Rushup Edge is a south-facing escarpment that overlooks the limestone by 150-200m and which has been formed by the northward slope retreat of the shales and sandstones. The total allogenic catchment area for the swallets is 2.75 km^2, out of a total catchment for the Castleton resurgences of about 7.3km^2.

The hydrological pattern deduced by Ford (1966) is based principally on the structural geology and the results of dye tests in 1952 carried out by the Derwent Valley Water Board (now absorbed in the Severn Trent Water Authority). Details of these tests were given by Ford (1955) and are summarized together with one more recent dye test, in Table 1.

The water flowing off Rushup Edge is engulfed in a series of eleven sinks numbered from west to east P1 to P12. The prefix 'P' is thought to stand for "Point of Engulfment"; P11, Giants Cave, is a point of engulfment but not a "sink" as the stream resurges within a few metres and sinks again at P10 (Snelslow). The sink points have been excavated and some have led to penetrable caves. The most extensive of these are Giants Hole (P12) and P8 (Jack Pot) at 3130 m and 822 m lengths respectively. All the caves end in sumps that have received prolonged attention from the Cave Diving Group with varied success (Ford and Murland 1980). A generalised version of the geology and caves is presented in Figure 1.

The cave streams are next found in Peak Cavern and within Speedwell Cavern where there are two principal resurgences, Main Rising and Whirlpool Rising, and several smaller inlets, e.g. Cliff Cavern, Bathing Pool and Assault Course, all of which combine to flow down the Bunghole series and resurge at Russett Well and Slop Moll in Peak Cavern Gorge, some 200 metres north of the resurgence of the Peak Cavern stream which is also interrelated at certain high flow stages.

Ford has proposed (1966) that the eleven sinks form three separate hydrological units, P1-P4, flowing via the mineralised fault of Coalpithole vein to Speedwell Main Rising, whilst P5-P8 form a separate unit flowing southwards to intersect New Rake to reappear in Speedwell Main Rising. The remaining sinks, P9-P12, flow via Faucet Rake to Whirlpool Rising (Figure 1). The nearby Peak Cavern system, apart from flood overflow into the Speedwell, is completely separate, collecting percolation water alone from the south and flowing mainly along Dirtlow Rake. The response of Peak Cavern to a flood in Speedwell has three stages. First the static pool in Lumbago Walk in Peak Cavern overflows to connect with Slop Moll. Then, Speedwell Pot becomes active and overflows into the lower end of the Peak Cavern stream. Finally, in extreme flood, Speedwell water backs up through Treasury sump and flows down Victoria passage to join the Peak Cavern stream.

TABLE 1

Summary of Previous Dye Tracing in the Castleton area
(After Ford 1955 and Smith and Waltham 1971)

Sink	Dye Used	First Time of Arrival (hours)	Peak Concentration Reached (hours)	Comments
No.3 Shaft Perryfoot	Fluorescein	156	180	Slop Moll cleared first in 9 days, Russett Well in 21 days.
Giants Hole (P12)	"	120	168	Dye cleared in 13 days
Little Bull Pit (P6)	"	72	-	High flow.
Jackpot (P8)	Optical Brightener	not known	not known	Only positive at Goosehill Bridge. Peak Cavern inlets negative. Time period not stated.

The flood pulse work of Christopher (1980) was principally intended to study chemical variability during a flood event, but conclusions were also drawn that supported Ford's (1966) concept of the hydrology. It should be mentioned that since this work was carried out the hydrology of the Slop Moll and Russett Well system has been significantly altered by the lowering of the outfall channel of Slop Moll by approximately one metre to its apparent level during lead mining days. This was carried out by local cavers seeking to re-enter the sough. The result has been a considerable reduction in the discharge of Russett Well to the extent that in very dry weather it ceases to flow and Slop Moll now flows at all times.

The technique of simultaneous dye traces to one or more resurgences has been developed by Smart and Laidlaw (1977). Only three dyes can be used simultaneously because it is necessary for the dyes to have distinctive detection wavelengths to avoid spectral overlap. Quantitative information is obtained by taking frequent samples over the study period (0.5 - 4hr intervals) and by

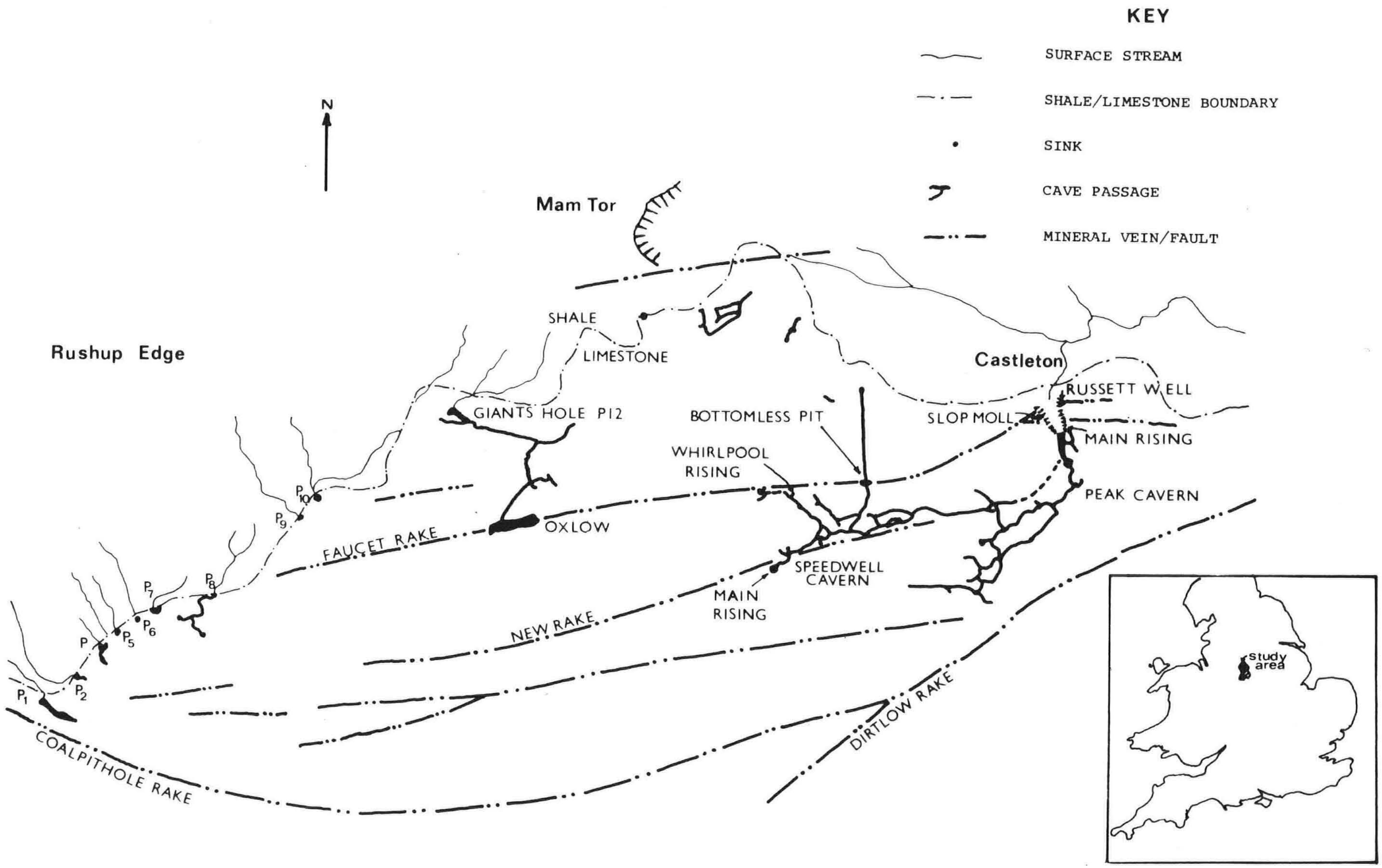


FIGURE 1

GENERALISED GEOLOGY, HYDROLOGY AND CAVES OF CASTLETON AREA, DERBYSHIRE measuring the concentration of fluorescent dye present in the sample, on a filter fluorometer. If the site is suitable the discharge can also be measured and from a quantitative knowledge of the dye inputs versus dye recovery with calculations performed to yield additional information. The interpretation of resultant dye concentration versus time graphs is not easy, but much more information can be obtained than from a straightforward point to point dye trace (Brown and Ford 1971; Crabtree 1979).

METHODS

Dyes and Chemical traces

Based on the hydrology proposed by Ford (1966) it was decided to place dye into one sink of each hydrological group and P_1,P_8 (Jack Pot) and P_{12} (Giants Hole) were selected as the most appropriate. The tests were carried out during September and October 1980, with first inputs on 22nd September.

The three dyes used in this work were Rhodamine WT, Lissamine FF and Amino G Acid, based on the recommendations of Smart and Laidlaw (1977). Rhodamine WT suffers from adsorption onto sediments but is of use, since background fluorescence is low at Rhodamine WT wavelengths and therefore it is easily detected in very low concentrations in natural waters. Lissamine is not so readily adsorbed, but there is a higher background fluorescence at its characteristic wavelength. Amino G Acid has intermediate absorptive properties and a variable, but often higher, background fluorescence.

In addition, it was decided to tag three further sinks with chemical tracers. The choice of tracer was limited by analytical technique, cost, availability and the necessity to avoid ionic species overlap. Sodium chloride, potassium nitrate and ammonium sulphate were selected and P5,P6 and P10 (Snelslow) were selected for the input points respectively. Input quantities and times are given in Table 2 for dyes and chemicals.

Table 2

Dye & Chemical Input Quantities & Times on 22nd October 1980

DYE INPUTS

Site		Dye	Time
P1 swallet	100 ml	Rhodamine WT	14.15
P8 swallet	200 g	Lissamine FF	14.45
Giants Hole	400 g	Amino G. Acid	15.30

CHEMICAL INPUTS

Site	Chemical	Time
P5	21 kg of 100% sodium chloride	14.30
P6	12 kg of potassium nitrate	14.40
P10 (Snelslow)	12 kg of ammonium sulphate	15.55

Background fluorescence

Prior to the dye tests water samples were taken to assess background fluorescence values; samples were taken at both low and high flow conditions as background values frequently increase during high flows. This is largely due to the entrainment of organic matter in surface wash during rainfall events. Agricultural sources, especially organic wastes from farm livestock, can also be entrained during high flow and lead to increased backgrounds, especially at Amino G Acid wavelengths and, to a lesser extent, at the Lissamine FF wavelengths. Background fluorescence values for Russett Well are presented in Table 3.

TABLE 3

Background Fluorescence Values at Russett Well

		RHODAMINE WT		LISSAMINE FF		AMINO G ACID	
Sample Date	Flow Conditions	Fluorescence*	Dye Equiv. (μg/l)	Fluorescence*	Dye Equiv. (μg/l)	Fluorescence	Dye Equiv. (μg/l)
22.6.80	Low	8 x 30	0.05	58.5 x 30	6.2	73 x 10	130
25.6.80	Very low	8 x 30	0.05	54 x 30	4.8	66 x 10	120
30.6.80	Medium rising stage	7 x 30	0.05	61 x 30	6.6	73 x 10	130
1.7.80	High, falling stage	9 x 30	0.05	76 x 30	10.6	84 x 10	170
10.7.80	Low	7 x 30	0.05	60 x 30	6.3	68 x 10	127

* Readings direct from fluorometer; x30, x10, x3, x1, refer to amount of light passed through a control slit to the primary filter; x30 allows 30 times more light through than x1 and is the most sensitive scale; a calibration of these values is in μg/l standard dye solutions.

Sampling

The sampling strategy adopted was to place automatic water samplers inside Peak Cavern, on Russett Well and Slop Moll. Activated charcoal detectors were used for the detection of Rhodamine WT and Lissamine FF and cotton wool detectors for Amino G Acid. The charcoal detectors were made of approximately 40 g of 8-10 mesh granular charcoal dried at 110°C overnight contained in fine mesh nylon. The cotton detectors were about 10 g of surgical cotton wool similarly enclosed in nylon or within tubular bandage. These were placed at Russett Well, Slop Moll Peak Cavern resurgence and in the stream along the Five Arches section of Peak Cavern Show Cave. These were initially changed every two days, but later every four days. Usually two of each type of detector was placed at each site and upon collection placed in separate, labelled, polythene bags to avoid cross contamination. All detectors used at the resurgences were recovered.

Additionally, charcoal and cotton detectors were placed within Speedwell Cavern. Three of each type at Main Rising and Whirlpool Rising; two of each type in the Bathing Pool overflow and the Cliff Cavern stream close to its junction with Main Passage, and a single detector of each type was placed at the "Pit Props" downstream of all the other inlets and downstream of the probable intersection of the Assault Course inlet with Far Canal. These detectors were left in for two weeks until the completion of the main programme of dye tests. All these detectors were recovered, except one cotton detector from the Bathing Pool.

At Russett Well the detectors were placed in the main resurgence pool and a Rock and Taylor peristaltic pump 48 interval sampler was used with a two day clock and an hourly sampling interval. This sampler functioned perfectly until day 12 (October 4). It was also possible to install a stage recorder between the outflow lip and the bridge at the junction of the resurgence outflow and the main stream. The flow was very unsteady and turbulent and the cross-section was not controlled. Stage records were calibrated for discharge by current metering under the bridge. However, due to the nature of the channel (irregular cross-section and flow disturbance by large stones) the relationship between flow and stage is irregular. The record is therefore only of relative water level and not of absolute discharge.

A continuous record of pH was made from an EIL 3050 pH meter coupled remotely to a Pye Ingold LOT 401 combination pH electrode mounted on a float system in the resurgence pool and buffered periodically at 7.06. Conductivity was measured by a WPA CM25 conductivity bridge coupled to an EIL EBA/01 Sproule flow-through conductivity cell with a cell constant of 0.1 fixed in the sump pool. The low cell constant was chosen to improve the signal to noise ratio. All lead wires were individually screened and earthed to an earthing rod in the sump pool. This precaution was found to be essential during a preliminary study in June 1980.

The output of both measuring instruments was recorded on a Smiths Industries RE571.2 twin channel potentiometer recorder set on its slowest chart speed of 30 mm per hour. This system worked perfectly until the flood of 6-8th October when the well side terminal box was flooded and the pH trace was lost. Conductivity recording continued until 14th October, a period of twenty five days. The meters and recorder were kept in a weatherproof garden shed 25 m from the resurgence.

At Slop Moll a Northants Engineering vacuum sampler was used with a sampling interval of 3.3 hours. It was not possible to measure discharge, principally due to a lack of available equipment, and also due to the irregular nature of the channel and the diffuse nature of the resurgence point. This sampler functioned perfectly until day 19 (11th October) when sampling was suspended.

The sampler within Peak Cavern was an Automatic Liquid Co Ltd vacuum sampler with a sampling interval of 4 hours. The installation site was in the show cave section along Five Arches. Stage measurements were not attempted.

Dark brown water sampler bottles were used at Slop Moll and both this sampler and that at Russett Well were covered with black polythene sheeting to prevent photochemical decay of stored dyes between sampler servicing; this is an especially important precaution with Amino G Acid, which shows photo-decomposition (Smart & Laidlaw, 1977).

Laboratory Evaluation

The sampler on Russett Well produced 245 samples in 12 days. The sampler on Slop Moll functioned perfectly throughout, producing 121 samples. The Peak Cavern sampler functioned erratically in the conditions within the cave and at some time during the flood of 6th-8th October was completely immersed in muddy water. This had a detrimental effect on the clockwork mechanism and therefore only partial records are available from this site with only 46 samples. Additionally, 150 detectors were used at all sites.

The dye concentration measurements were performed on a Turner II filter fluorometer; the excitation and emission peaks of the three dyes used are given in Table 4, together with the filter combinations recommended by Smart and Laidlaw (1977).

TABLE 4

Dye and filter characteristics
(After Smart & Laidlaw, 1977)

Dye	Excitation Peak nm	Emission Peak nm	Primary Filter	Secondary Filter
Rhodamine WT	555	580	2x1-60*+61+	4-97*+3-66
Lissamine FF	420	515	98+	55+
Amino G Acid	355	445	7-37[2]	98+

* Corning Filter

\+ Kodak Wratten Filter

Dye analysis was performed on all samples for Lissamine FF and Amino G Acid; however, due to analytical error, meaningful results were not obtained for Rhodamine WT for water samples. Detector analysis was satisfactorily performed on all detectors recovered for all three dyes. The extraction was by elution with a mixture of equal volumes of acetone and 10% aqueous potassium hydroxide solution. The elutant was made up to a standard volume and the fluorescence measured at the three dye wavelengths. Background fluorescence for blank detectors was subtracted from the results. However, no background measurements were made on detectors placed in the streams for specified periods prior to introducing dye to the system because of access restrictions.

In the absence of a complete discharge record quantitative dye recovery was not possible. However, time of travel can be assessed from the first time of arrival above background fluorescence and the shape of the recovery curve can be shown.

Calcium, magnesium, sodium and potassium were measured on every water sample by atomic absorption spectrophotometry, using a Pye Unicam SP90 Series 2 instrument. An air-acetylene flame was used throughout and the standards were matched to the samples for concentration of major components to allow for inter-species interference and to eliminate any sample preparation.

Chloride, nitrate and ammonia were determined on alternate Russett Well samples and on all other samples. However, if an anomaly was discovered in the Russett Well samples, the intermediate results were obtained. Chloride was determined by titration with standard silver nitrate solution using potassium chromate indicator (Mohr's method). Nitrate was measured by direct spectrophotometry at 210 nm and ammonia was measured by direct nesselerisation and comparisation with standard disks.

CHRONOLOGY

Friday,19th September 1980 (Evening)	pH and conductivity recording began
Saturday 20th September	Detectors placed in Speedwell Cavern.
Monday 22nd September A.M.	All samplers and stage recorders set up.
P.M.	(See Table 2) Dyes and chemicals introduced.
22nd September - 4th October	Every two days collected samples, re-set samplers, changed resurgence detectors.
Saturday, 4th October	Detectors removed from Speedwell Cavern.
Monday 6th October - Wednesday, 8th October.	Heavy rain at Castleton (c 70mm in 3 days. Major flood event.
Sunday, 12th October	Removed all samplers and stage records from resurgences.
Wednesday, 15th October	Removed pH and conductivity recording equipment.

RESULTS

Weather and Flow Conditions during the Trace

Daily (9.30 am - 9.30am) rainfall data was obtained from the Buxton Weather Station. These represent only total rainfall and no attempt has been made to assess effective precipitation. The figures are presented in Table 5. It was essentially dry during the study period, with some rain before, and a heavy storm on 6th-8th October.

TABLE 5

Rainfall Data Recorded at Buxton Weather Station
(9.30 am - 9.30 am)

Date	Rainfall mm	Date	Rainfall mm	Date	Rainfall mm
7	0	19	14.7	1	3.5
8	0.6	20	4.2	2	0
9	2.8	21	1.9	3	6.9
10	7.7	22	2.6	4	0
11	4.2	23	1.4	5	5.0
12	17.1	24	0	6	29.8
13	1.0	25	0	7	14.2
14	0.8	26	0.9	8	27.6
15	0.5	27	1.3	9	1.2
16	20.5	28	0	10	2.2
17	0.2	29	0.4	11	0
18	0.4	30	0.5	12	0

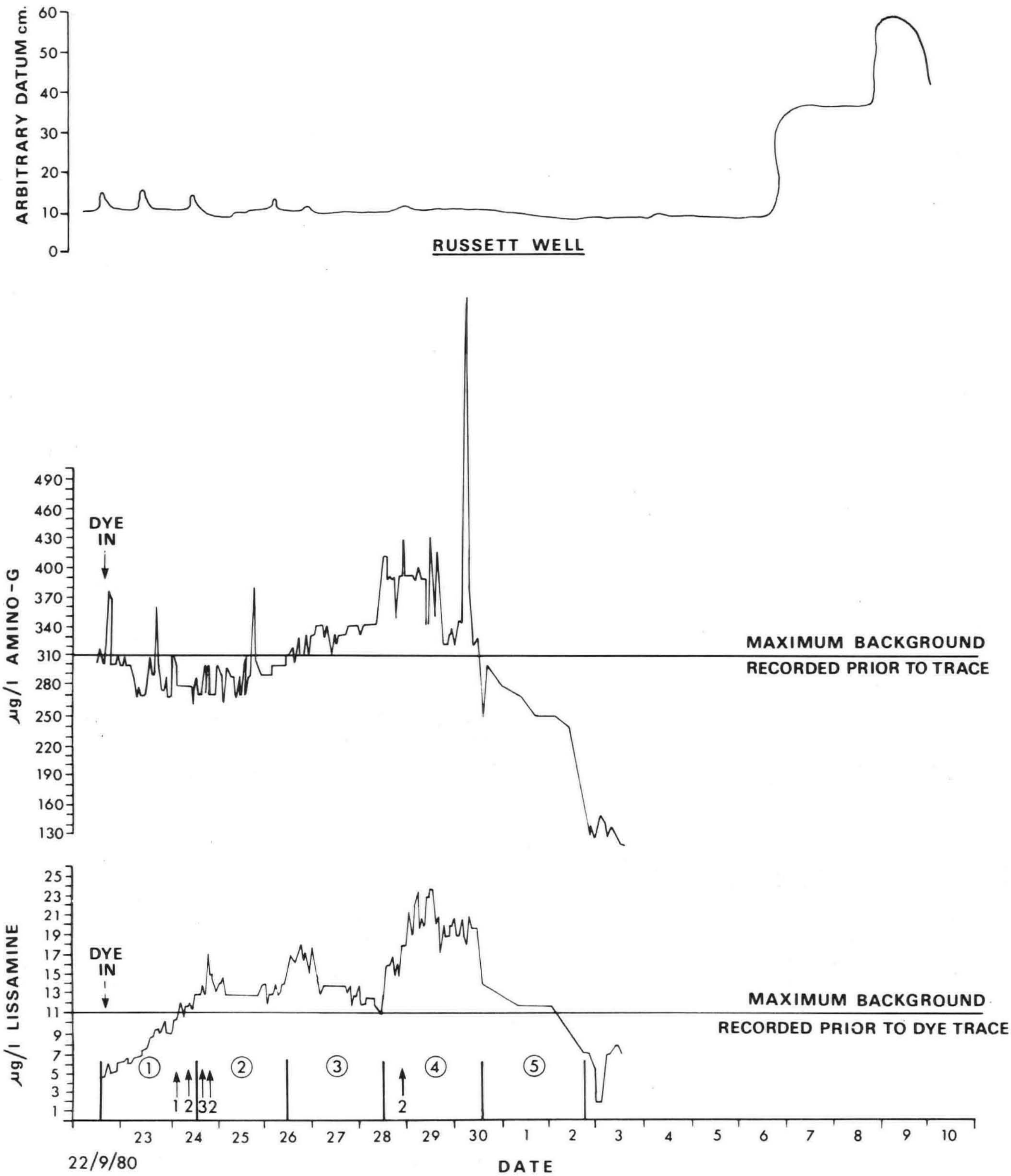


Fig. 2. The arrowed figures, 1, 2 & 3, represent arrival times of the chemical tracers. 1 = NaCl; 2= KNO_3; 3 = $(NH_4)_2SO_4$. The circled numbers, 1 - 5 , indicate sample periods discussed in the text.

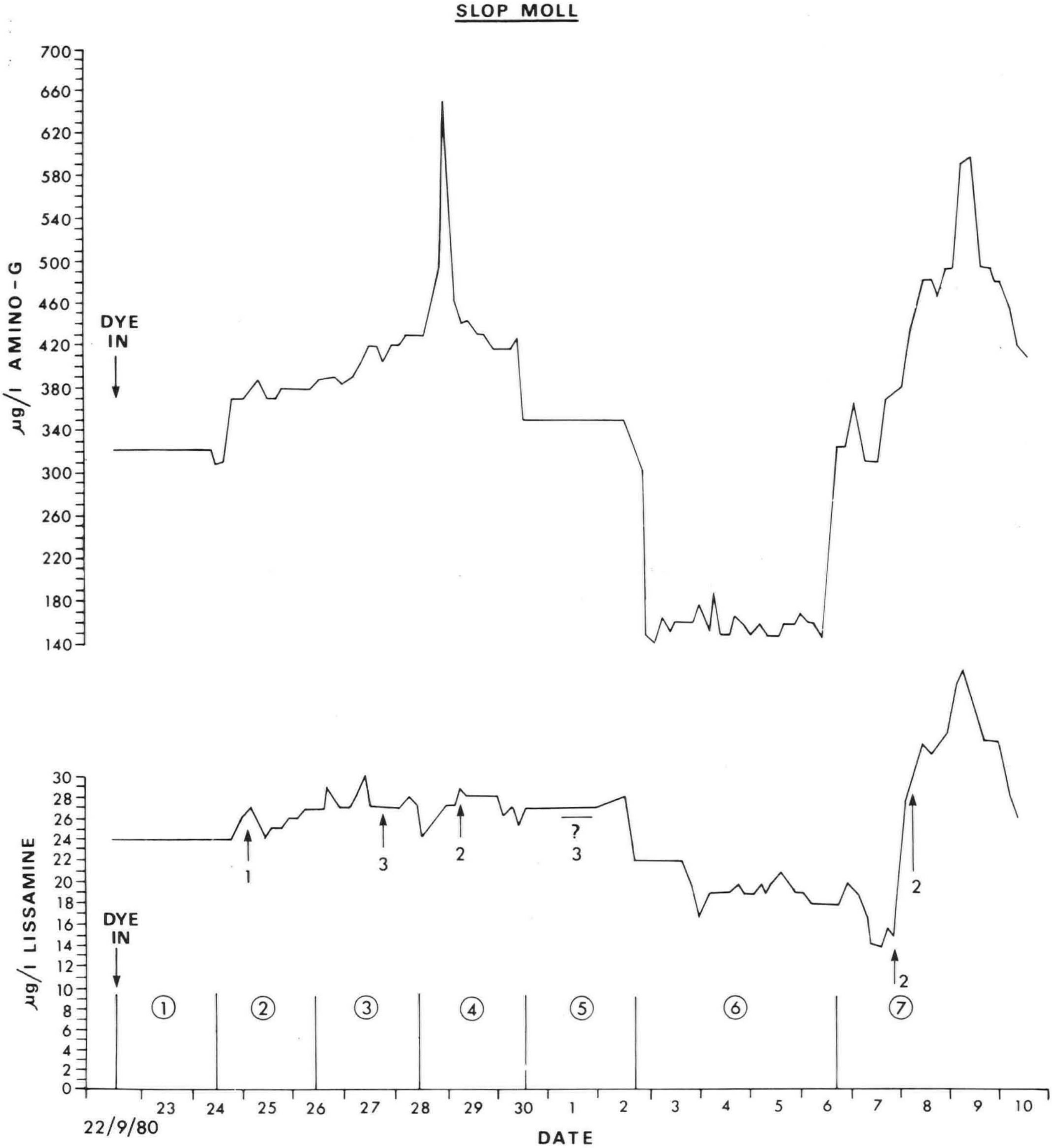


Fig. 3. The arrowed figures, 1,2 & 3, represent arrival times of the chemical tracers. 1 = NaCl; 2 = KNO_3; 3 = $(NH_4)_2SO_4$. The circled numbers, 1 - 5 , indicate sample periods discussed in the text.

The rainfall pattern is reflected in the flow conditions at Russett Well. During the trace a base flow of 0.06 - 0.08 m^3/sec. was recorded. Reference to Figure 2 shows that the hydrograph at Russett Well recorded three small flow peaks in response to rainfall events. As rain was recorded on only two of these days, either rainfall occurred at Castleton and not Buxton or these pulses relate to previous rainfall. If the former is true then rapid flow for some proportion of the input swallet water or percolation water must be occurring and this possibility will be considered further when the flood event of 6th-8th October is discussed. During the storm of 6th-8th October 71.6mm of rainfall fell at Buxton (Table 5). During the main part of the trace stage remained approximately constant and thus dye peaks during that period can be interpreted in terms of arrival of labelled bodies of ground water at steady flow rather than flushing effects in response to rainfall.

TABLE 6

DETECTORS

	PEAK CAVERN 5 Arches			PEAK CAVERN Resurgence		
DAY	RWT	LISS	A-G	RWT	LISS	A-G
1-3	-	-	-	-	-	-
3-5	-	+	-	-	-	-
5-7	-	+	-	-	-	-
7-9	-	+	-	-	-	+
9-11	-	+	-	-	-	+
11-15	+	+	+	+	-	(-)
15-19	+	+	+	+	+	+

SPEEDWELL CAVERN

		RWT	LISS	A-G
Cliff Cavern	CC	(+)	++	-
Main Rising	MR	-	+	-
Bathing Pool	BP	++	++	-
Whirlpool Rising	WP	+	+	-
Pit Props	PP	+	+++	+

++ very strong positive trace
+ positive trace
- negative
() doubtful

Dye Recovery: Detectors

The data shown in Table 6 give point to point traces with a 2 day time base for Peak Cavern stream at the Five Arches and at the Peak Cavern Resurgence and for the whole period for Speedwell Cavern. Rhodamine WT from P1 was detectable at Peak Cavern Resurgence on days 12-14; Lissamine from P8 was detectable in Peak Cavern Five Arches on days 3-4, but not at the Resurgence until days 12-15. This suggests that there is some independent flow between the two points, acting to dilute the Resurgence below detectable levels or an unusually high and variable background is present at the Five Arches site. As the Peak Cavern waters undoubtedly flow to the Resurgence, divergence from the Cavern is not a possible explanation. However, dilution would have to be massive to cause complete loss of tracer detectability.

Further evidence for this does, however, come from the Amino G Acid trace; detection of this from Giants Hole at the Resurgence being on days 7-9, but not till days 11-15 at the Five Arches. This result again suggests an independence of the water bodies and also that Giants Hole water appears in the system between the Five Arches and the Resurgence in the gorge.

The Speedwell detectors show that the P8 water (Lissamine) was present at all sites; the P1 water (Rhodamine) was positively detected at Whirlpool Rising, Bathing Pool and at the "Pit Props" in the Far Canal; it was not detected at Main Rising and the Cliff Cavern result is doubtful.

The rather surprising detection of Lissamine FF in the Cliff Cavern water should be viewed with caution, as no detector background results are available to discriminate between high background fluorescence and dye presence. It is also known (John Back, personal comm.) that the sumps in P8 are at a lower altitude than the Cliff Cavern inlets!

Amino G Acid from Giants Hole (P12) was only detected at the Pit Props and this is a most surprising result. It suggests that the Giants Hole water must therefore flow, at least in part, via the small Assault Course and inlet stream and also possibly via a more northerly route along Faucet Rake to Bottomless Pit and thence to the resurgences of Russett Well and Slop Moll where the dye was also positively detected.

Dye Recovery: Water Samples

The results for Lissamine and Amino G are shown in Figure 2 for Russett Well and Figure 3 for Slop Moll. Rhodamine detector values are shown in Table 7 (values for Lissamine and Amino G detectors parallel the dye trace results shown in the figures and need not be discussed).

TABLE 7

Rhodamine WT Detectors at Russett Well & Slop Moll

DAY	Russett Well	Slop Moll
1-3	-	-
3-5	-	-
5-7	-	-
7-9	+	+
9-11	+	+
11-15	+	+
15-19	+	+

Rhodamine arrived at both sites on days 7-9, which agrees with previous results (Table 1). Lissamine from P8 appeared at Russett Well early on day 3 (40 hours after input) and at Slop Moll later on day 3 (56 hours after input). This points to a measure of independence of the two risings. It should also be noted that the background values for Slop Moll (around $\mu g.l^{-1}$at the Lissamine wavelength) are higher than for Russett Well (4-10 $\mu g.l^{-1}$) implying that the former may have a greater input of surface water with a high organic content.

Amino G Acid from Giants Hole appeared at Russett Well in three small peaks on days 1-4, but these apparent traces are discounted as positives despite the fact that they are higher than the recorded background levels prior to the trace. This is because they are related to discharge peaks when more organic-rich water could have been entrained. In addition, the first peak is only some three hours after the dye was put in to Giants Hole, a distance of 2.8 km in a straight line, requiring an unlikely velocity of almost 1 km/hr. Time of arrival is thus taken as being on day 5 (95 hours after input), indicating a slower pathway than from P8. The almost complete lack of Amino G Acid in Speedwell could also be an indication of a difference in flow paths for P8 and Giants Hole. However, Amino G arrived at Slop Moll on day 3 (35 hours after input),again pointing to an inter dependence between Slop Moll and Russett Well and a swifter response of the former. The peak concentrations for Russett and Slop Moll are respectively the middle of day 9 and the end of day 7 for Amino G Acid, again suggesting a more direct flow to the latter which is in line with first time of arrival data. A summary of the dye daca is shown in Table 8 and it can be noted that it is not possible to define a clear peak for Lissamine at Russett Well.

The times of arrival of dye at Slop Moll and Russett Well are shorter than to the two Peak Cavern sites, except for Lissamine (P8) which is the same (Table 8).

TABLE 8 Summary of dye first time of arrival data

	RUSSETT WELL	SLOP MOLL	PEAK CAVERN 5 Arches	PEAK CAVERN Main Resurgence
Rhodamine WT (P1)	Day 7-9	Day 7-9	Day 11-15	Day 11-15
Lissamine FF (P8)	Day 3 (40 hours)	Day 3 (56 hours)	Day 3-5	Day 15-19
Amino G Acid (P12 Giants	Day 5 (95 hours)	Day 3 (55 hours)	Day 11-15	Day 7-9

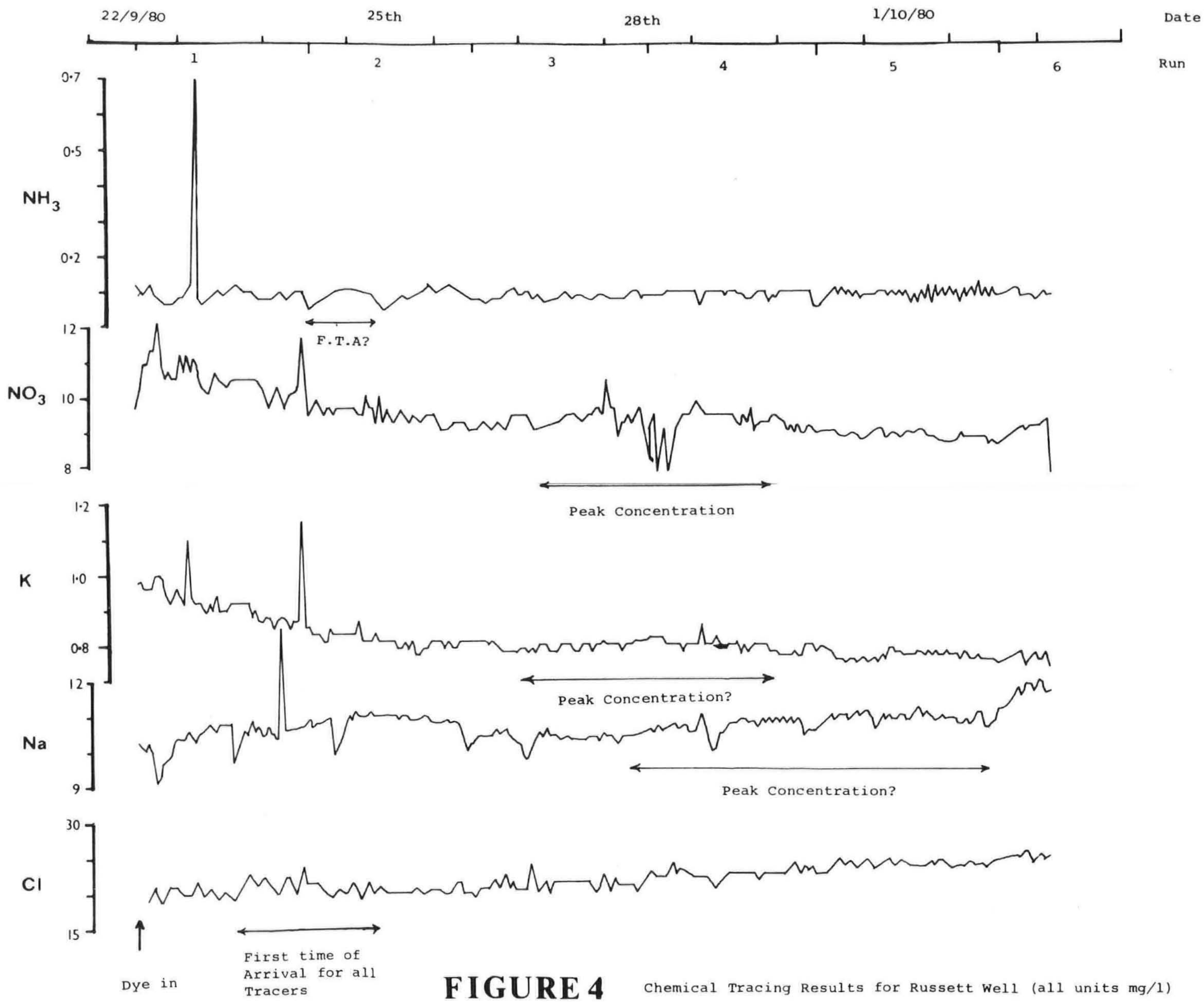


FIGURE 4 Chemical Tracing Results for Russett Well (all units mg/l)

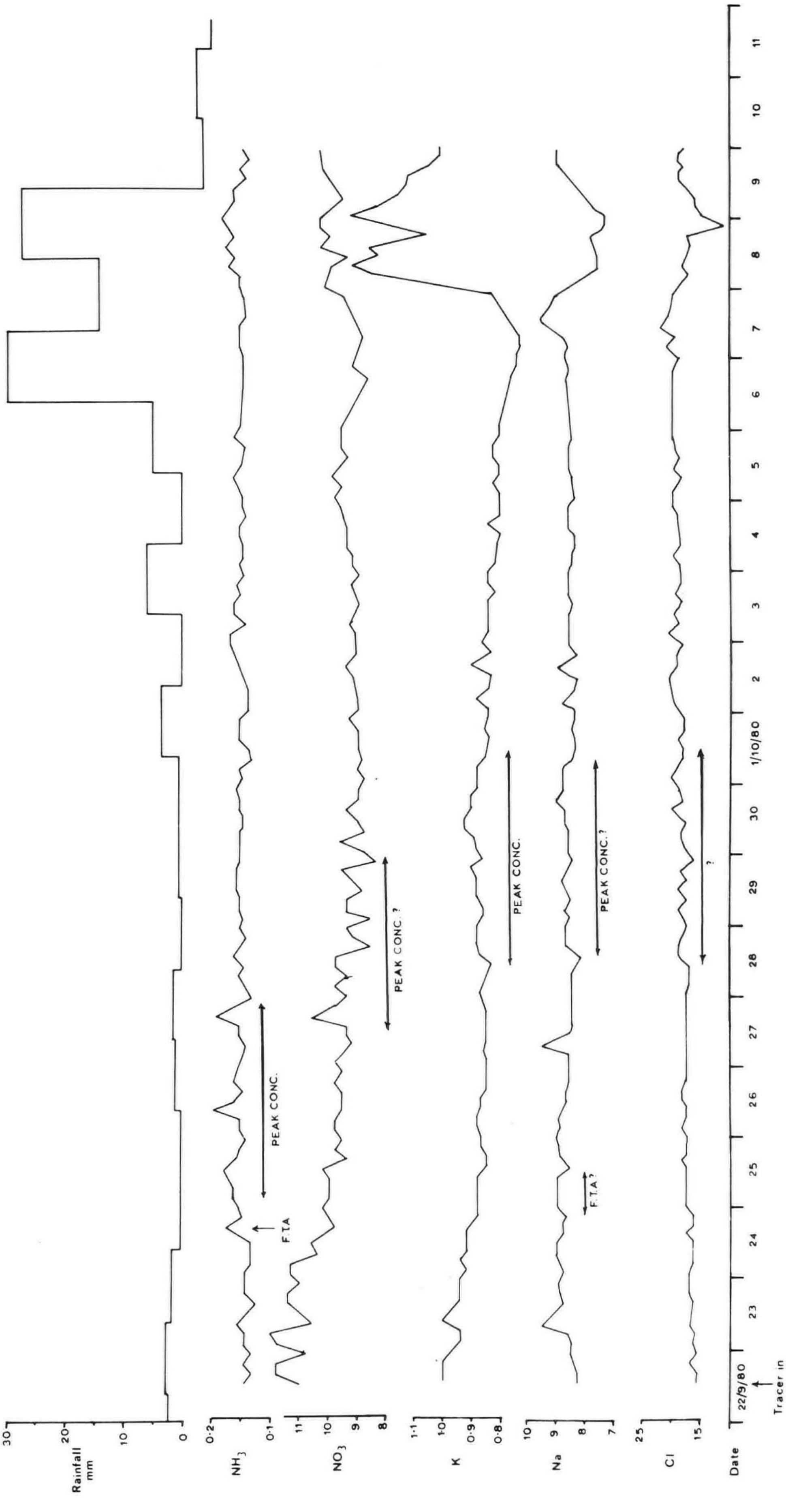
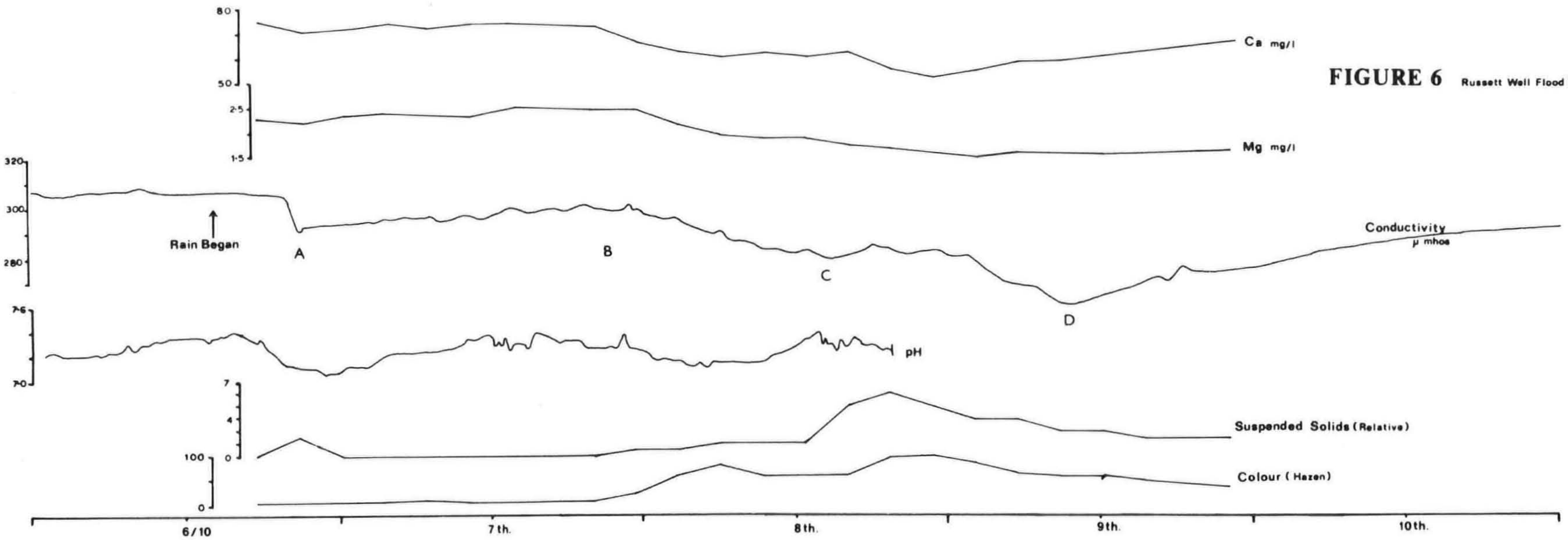


FIGURE 5 Chemical Results for Slop Moll

FIGURE 6 Russett Well Flood Pulse 6-10 October 1980



The shape of the dye breakthrough curves suggests that Slop Moll and Russett Well operate more like a diffuse flow system (e.g. a fractured rock aquifer), than a classic karst aquifer with pipe flow. This interpretation is contrary to what is known about the system from direct exploration. However, this type of breakthrough curve can also be produced when small bodies of dyed water, as, for example, the swallet streams, are mixed with a larger body of undyed water. This latter explanation would suggest that the system upstream of the risings in Speedwell Cavern is mostly flooded. The explanation is also supported by the fact that after an apparent end of the dye trace in Slop Moll after day 11, high flow led to a repeated high dye peak, indicating the presence of a substantial stored mass of dyed water dispersed within the ground water system, rather than the passage of a neatly displaced parcel of water.

Chemical Tracer Results

The results of the chemical analyses for Russett Well and Slop Moll are presented in Figures 4 and 5 respectively.

Generally the results were disappointing, principally because of high background concentration coupled with a large natural variability of the ionic species studied. However, in conjunction with the dye traces some results such as peak concentration have been provisionally assigned; these are summarized in Table 9 for both Russett Well and Slop Moll.

TABLE 9 Summary of Chemical Traces

Input Point	Chemical	First time of Arrival (hours)	Peak Concentration
Russett Well			
P5	Sodium chloride	37	55-95 hrs (?)
P6	Potassium nitrate	35-45	100-170 hrs (?)
P10	Ammonium sulphate	16 or 60	7-10 days (?)
Slop Moll			
P5	Sodium chloride	?	6-9 days
P6	Potassium nitrate	?	6-9 days
P10	Ammonium sulphate	50	85-115 hrs

Little further can be said about these results, except that a higher dosage could have been more effective and that such peaks as are present do not contradict other evidence as to links in the system.

The Flood Event 6-8th October

The pH and conductivity trace for Russett Well over the period 6-8th October is presented in Figure 6, together with a selection of chemical variables recorded from Slop Moll over the same period. (The Russett Well sampler ceased to function on 6th October.)

The patterns of the two traces are similar for both pH and conductivity and so as only the conductivity trace is complete for the whole flood event it will be discussed in preference.

Rain began at Castleton at about 14.00 on 6th October and was intense between 16.00 and 18.00., during this period the conductivity was essentially constant. From 19.30-20.30 there was a sharp drop of 30 micromhos to 280 micromhos in conductivity (Point A). The next 23 hours saw a gradual recovery in conductivity up to 300 micromhos when a further decline began (Point B, 20.00 on 7th October). At this time the water, that had up till now been clear, began to discolour and the increase in colour reached a maximum at 06.00 on 8th October and then declined. A further minimum in conductivity was reached at 14.30 on 8th October and over the succeeding twelve hours a further pulse of high solute water arrived at Russett Well accompanied by a large increase in suspended solids and colour intensity. The conductivity minimum was reached at Point D (9.30 on 9th October), after which a steady recovery began.

The first 36 hours of the trace show that there is some very rapid component of flow that introduces a significant amount of low solute water within six hours of rain beginning. But that after this there is a very subdued

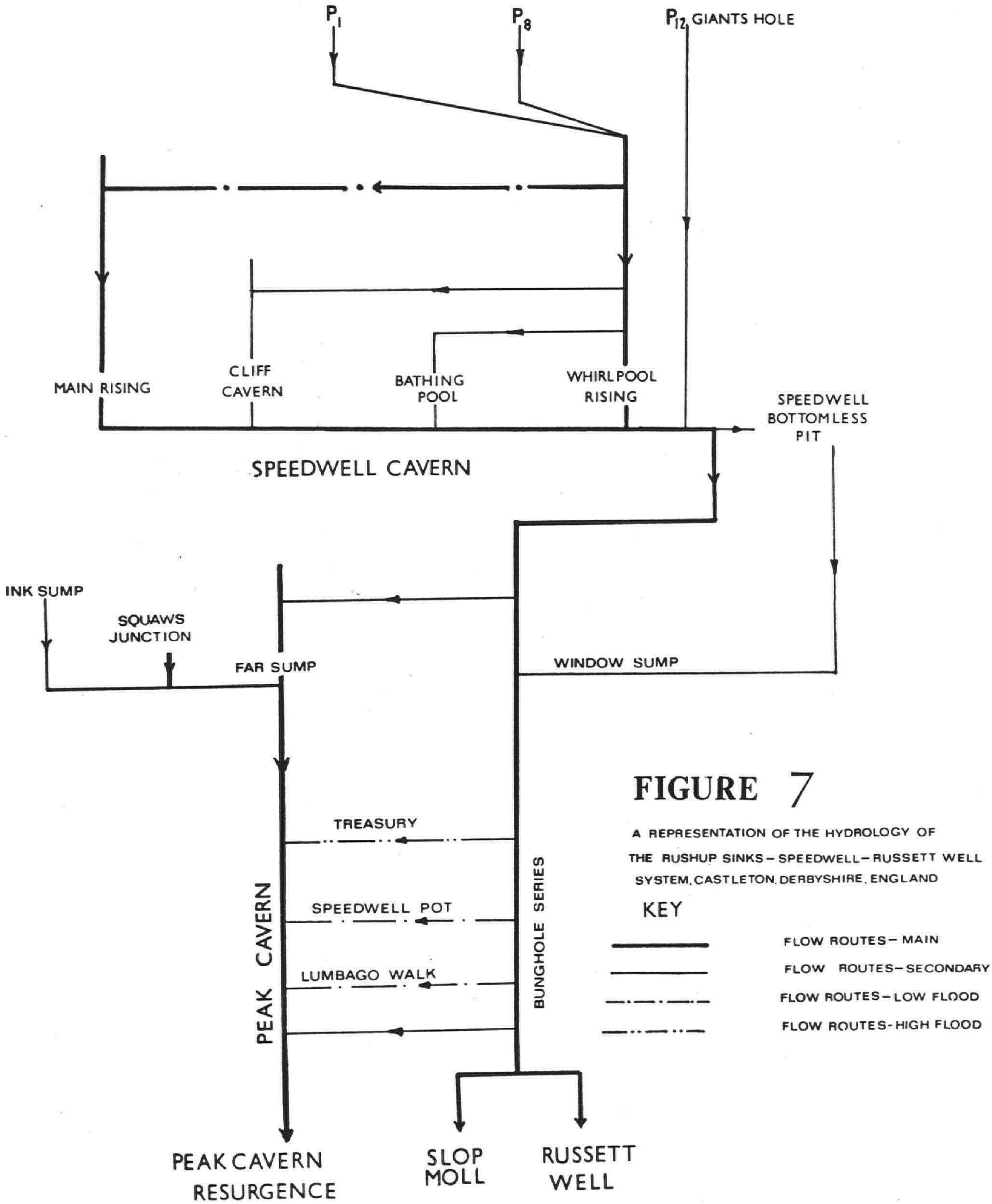


FIGURE 7

A REPRESENTATION OF THE HYDROLOGY OF THE RUSHUP SINKS – SPEEDWELL – RUSSETT WELL SYSTEM, CASTLETON, DERBYSHIRE, ENGLAND response, with the main flood water not arriving at Russett Well until 29 hours after rain began (Point B).

The dye concentration graphs for Slop Moll (Figure 2) confirm this pattern. There is a small peak in Lissamine FF, and a larger one in Amino G coincident with event A, and the two succeeding peaks are coincident with events C and D in the early mornings of 8th and 9th October respectively.

These results are good supporting evidence for the existence of a large body of resident ground water in the aquifer as suggested from the shape of the dye breakthrough curves at low flow. It is the displacement of this water by influent flood water with extensive mixing that has given the conductivity trace its shape.

The subsequent peaks in dye concentration and troughs in conductivity represent similar responses to subsequent rainfall events on 7th and 8th October.

The very large reservoir of water being displaced between events A and B could be provided by the extensive vein cavity, fault and fracture system thought to exist upstream of Speedwell Cavern (Ford 1966). This would support the suggestion that the system upstream of Speedwell is almost totally flooded, which is in accordance with the diving reports from Giants Hole and P8 (Ford and Murland 1980).

An inspection of Figure 6 shows that both the conductivity and more especially the pH traces show fine detail in the form of small rises in conductivity at various points. The meaning of these is unclear despite a careful attempt at a fuller interpretation (Wilcock, pers.comm.). Whether these represent the arrival of small packages of water from individual sinks or groups of sinks cannot be confirmed. There is a marked visual similarity between the pH trace between 10.00 and 18.00 on 7th October and between 12.00 and 19.00 on 9th October, which could represent duplication of response to two rainfall events. However, until more comparative data is available on better known systems no better interpretation of these traces is possible.

These results are in contrast to those reported by Christopher (1980) where a much more rapid response over 19 hours was recorded at Russett Well. This may reflect the changed hydrological conditions with the excavation of Slop Moll. This is now the principal all-weather resurgence and has a much more flashy response than previously. Also, from the evidence of background fluorescence, dye traces and magnesium concentrations, it has a higher proportion of swallet water than Russett Well.

DISCUSSION

The pattern of flow routes and connections proven by these studies is summarized in Fig.7, which shows diagrammatically the main flow routes in "normal" conditions, secondary connections through the phreatic zone between the main routes, and the additional connections which operate in low and high flood conditions. The results permit speculation on the evolution of the feeder systems to Peak Cavern Gorge before the apparent human intervention by excavation of Peakshole Sough (Slop Moll) in the 18th century.

Russett Well cannot cope with the high stage flow of the Rushup Edge swallets, even with the relief provided by Slop Moll; one can therefore presume that the present flood overflow routes of Peak Cavern, notably Speedwell Pot and the Treasury, and other preferred routes of dye travel to the resurgence were more active in the past before Slop Moll existed.

Observations within the Lower Bung Hole series of Speedwell Cavern suggest that the bedding plane controlled phreatic tube below Sand Passage is very young with only minimal vadose down-cutting. Such altitude measurements as are available indicate that the lip of Treasury Pot and the floor of Block Hall are at approximately the same altitude. The vadose downcutting in the Bung Hole series reaches a maximum in the area of Block Hall. Therefore, at an earlier stage the original route for the Rushup Edge water was probably up Treasury Pot and out through Peak Cavern, and at a later date out via Speedwell

Pot. Subsequently, base level lowering in Peak Cavern Gorge allowed the development of the Russett Well route that has been partly pirated by Slop Moll.

Finally, the overall development of the drainage will be considered: there appears to exist a three-phase system:

1. A largely abandoned system on Dirtlow Rake which may have fed Peak Cavern, remote from the allogenic catchment having only weak links with the active Speedwell System.
2. The present active Speedwell System principally on or close to New Rake.
3. A poorly developed Proto-System principally along Faucet Rake, carrying the Giants Hole water.

This three-phase system is consistent with a shale and sandstone escarpment and catchment area (Rushup Edge) retreating progressively northwards during the Pleistocene that provided water of the appropriate chemistry for cave development. As the escarpment retreated it progressively exposed more of the limestone that already contained a well-developed hydraulic system of mineralised faults, joints and vein cavities which directed water towards the Proto Peak Cavern Gorge.

The absence of Giants Hole dye at Speedwell Whirlpool Rising appears to be strong supporting evidence for this model.*

ACKNOWLEDGMENTS

In a project of this size many people have contributed; some may not be mentioned but their services are acknowledged.

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We would also like to thank Mr. R. Elliott for allowing us unlimited access to Russett Well and the use of his garden shed; the Custodian of Peak Cavern, Mr. G. Keaton for similar access to Peak Cavern and Slop Moll; Mr. Fletcher of Buxton Corporation for providing rainfall data; and, finally, Mr. L.H.Dowse of the Severn Trent Water Authority for encouraging the project.

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* Editor's Note.

On visits to Speedwell on 18/7/81 & 16/9/81 after periods of dry weather there was no stream at all flowing out of Whirlpool Rising so that all swallet water entering the Speedwell stream was presumably coming from Main Rising - yet another supporting observation for the concept of a fractured rock aquifer with connected flow.

Trans. British Cave Research Assoc. vol.8, no.4, pp.207-224. December 1981.

MORPHOMETRY OF THE LIMESTONE PAVEMENTS OF FARLETON KNOTT, (CUMBRIA, ENGLAND)

by Helen S. Goldie

ABSTRACT

The results of detailed morphometric studies on the limestone pavements of Farleton Knott, Cumbria, are compared with Yorkshire and two parts of Switzerland. There are widely differing conditions in the different areas and they were graded according to sizes of pavement blocks and joints to indicate the degree of dissection. On the four sub-areas on Farleton Knott, Holme Park Fell ranks second after pavement sites at Sanetsch in Switzerland as relatively undissected ; Newbiggin Crags rank equal to Ingleborough (Yorkshire) and Glattalp (Switzerland); Farleton Fell has a medium grade and Hutton Roof Crags are the most dissected of all the areas sampled.

Statistical tests suggest that, although there are significant differences between some of the areas, there are also considerable similarities in spite of differences in local environmental conditions. This could suggest that there are several factors apart from hard limestone and glacial stripping which affect pavement development.

The impact of man's removal of clint blocks from the pavements is also described.

Morphometric work of a detailed nature has not previously been published for the limestone pavements of Farleton Knott, Cumbria (in that part of Cumbria formerly called Westmorland), nor are there many such details given anywhere in the pavement literature. Williams (1966) gave some morphometric details of the pavements of the Burren, Western Ireland, and the present author published preliminary results of a study of the Craven area of Yorkshire (1973). The pavements of Farleton Knott have been studied in a similar way to those of Craven and the results of these studies are here compared and discussed along with other work on sites in Switzerland.

This article aims, firstly, to present morphometric data for the Farleton Knott pavements, secondly, to compare these data with work for Yorkshire and Switzerland and thereby to present some general observations of pavement form, and, thirdly, to attempt an explanation of these landforms in terms of limestone lithology and other factors affecting their characteristics and development including the influence of man. The comparison between the pavements of N.W. England and Switzerland was made to try to discover whether there are similarities or differences between these features in widely differing conditions (Goldie, 1976).

PREVIOUS LITERATURE

The limestone pavements of N.W. England long ago attracted the attention of scientists, and they have been studied quite extensively in several areas since the end of the 19th century. They were noted as features of special interest before this period and were described in various topographic accounts of the Northern counties. There are far fewer mentions of this type for the Westmorland (Cumbria) pavements than there are for those of Yorkshire.

Important work concerning the pavements appeared occasionally in the 1930s including work by Wager (1931) and Hudson (1933). However, it was not until the 1950s that substantial work on the limestone landforms, as such, was produced for N.W. England. Most published work concerns the pavements of Yorkshire, in particular those of the Ingleborough and Malham areas, but the ideas are also relevant to other pavement areas, and the ideas examined in the present work have grown from the studies of the previous decades.

Sweeting (1950) discussed the erosion cycles of the Ingleborough district, drawing attention to the conspicuous platform at about 390 m O.D (1300 ft), large areas of which consist of limestone pavements. The plateau is erosional, not geological, and where it cuts into beds low in the succession the pavement is more intermittently distributed than in the higher, more massive limestones.

Further north, where the platform is in the less massive Yoredales, pavements occur only in the most massive beds of limestone. Moisley (1953) asked why certain bedding planes are picked out to make pavements and whether solution alone could have stripped these surfaces. To the first question Moisley saw the answer lying in the shale bands which are common in the Great Scar Limestone of Yorkshire. He envisaged these bands protecting the limestone beneath and increasing dissection of overlying beds (Fig. 1). A stripping mechanism to remove the debris is required to form a pavement. Glacial stripping was the suggested mechanism, for various reasons.

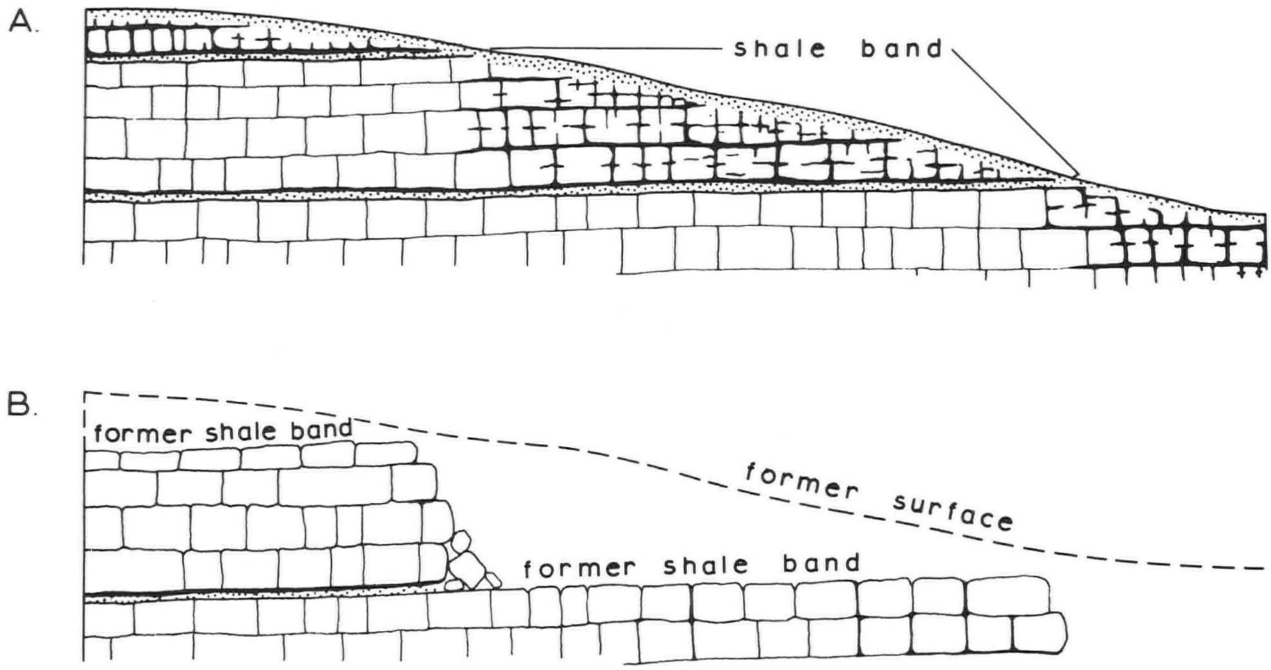


Fig. 1
A Possible Origin of Limestone Pavement (after Moisley, 1953)

Controversial ideas on the pavements of N.W. England were proposed by Parry (1960) concerning the action of snowbank solution. Parry considered this process to be of great importance in pavement evolution, but the evidence given was rather scancy and the idea has not received a great deal of attention since.

Interesting and valuable work on the N.W. England pavements came in the mid-1960s. Jones (1965) gave special attention to the effects of biological weathering. On the evidence that the opposition of ridges in the vertical surfaces in one side of a grike to another is as constant as it is, Jones suggested that grikes have often developed as a series of vertical tubes along joint planes enlarging and opening up laterally. This idea has also been held by Bögli (1960) and others working on the vegetational aspects of the pavements, for plants may be an important agent in the process, occupying and expanding the tubes, or indeed, forming them in the first place. Jones also assessed the role of lichens as indicators of soil retreat from pavements.

Clayton (1966) presented ideas concerned mainly with the formation of the pavements. He acknowledged the importance of glaciation to the pavements, but confused solution beneath soil and drift, producing detail, with creation of the basic pavement form. He also used the spatial sequence of pavement from scar edge to the inner edge of a terrace to illustrate the temporal development of the forms. Near the scar edge the clints, which are generally small and divided by wide grikes, were supposed to have been longest exposed to the air and thereby to have become more dissected than those away from the scar edge. There are serious difficulties in using this sequence to illustrate temporal development of pavement. All parts of the pavement may not have been in a like condition initially. It is possible that the intensity of glacial stripping differed from the scar edge to the inner edge, and also it is now known that limestone covered by soil and vegetation may be more actively eroded than bare limestone. The present form of the terrace may be an amalgam of relics from several sequences of activity from different periods in the past.

Sweeting (1966) gave particular attention to the role of lithology in influencing the character of limestone pavements. Subsequent work by Sweeting and Sweeting in the late 1960s and early 1970s expanded the idea that microscopic properties of limestones are related to the development of limestone scenery. This is the basis for the lithological part of the present article. One of the Sweetings' observations, based on many samples, was that more sparry limestones may be related to relatively undissected pavement. Recent progress in the field of karst morphology in relation to detailed properties of limestones has been discussed by Sweeting (1979).

In his work on limestone pavements Williams was concerned mainly with the Burren of Western Ireland (1966), though he made some comparisons with the Yorkshire pavements. He commented that grikes in N.W. Yorkshire seemed deeper and wider than in Western Ireland. The very small sample of measurements (20) which the present author has for comparison with her figures for Yorkshire shows this to be the case, and also shows the Yorkshire clints to be larger (tables 2a and 2b).

When considering the age of the grikes Williams was of the opinion that some of the deeper, wider grikes of Yorkshire may date from before the Last Glaciation. This idea is quite reasonable for some grikes, but if 49 cm of solution can take place in 12,000 years then a grike could be as wide as 98 cm without dating from before the Last Glaciation. There are, however, grikes wider than this, up to 1.5 m wide, especially in the Sanetsch area of Switzerland.

Also of importance to the present work is Thomas' article (1959) on the South Wales pavements. Thomas believed that closely spaced minor fracture planes were significant to local variation in solution rates and to development of the pavement forms.

It will suffice here to mention the relevant continental literature fairly briefly, as it was well reviewed by Williams (1966). There are ideas and studies which have been useful in the course of the present author's work, especially those of Bögli. Eckert (1900) gave measurements of blocks, clefts and runnels in the karren fields of the German Alps. His figures were as great as 20-22 m deep for some clefts (grikes) and he described some blocks as many metres wide. Eckert mentioned the importance of rock type to these landforms, as did other continental authors including Duparc and Roger (1891). It was Bögli (1960) who made the most important recent European contribution to karren studies. He made a thorough study of the chemistry of the solution process on limestone, and of the resulting landforms. This literature did not, however, contain either detailed measurements of limestone pavement features or of lithology in relation to pavements.

TERMINOLOGY AND HYPOTHESES EXAMINED

A comment on pavement terminology is required before presenting results and analysis. In addition, a brief summary of the hypotheses that have been examined in the study is necessary. A general definition of limestone pavement, which will suffice here, is that given by Williams (1966) : "a roughly horizontal exposure of limestone bedrock and surface of which is (a) approximately parallel to its bedding and (b) is divided into a geometrical pattern of blocks by the intersection of widened fissures" (Plate 1).

The surface blocks of the pavements are termed clints. Grikes are the open fissures which separate the clints from each other. The top surfaces of the clints are generally horizontal and the grikes penetrate the top bed of the rock. A runnel is a groove on the surface of a clint or side of a grike, caused by solution. The French term lapiaz is used to cover the broad range of small limestone surface forms, though it should be restricted to the runnels cut in that surface. The German equivalent is Karren and a range of Karren terms covers differing types of surface runnels and clints and grikes. The German term for clints is Flachkarren, for grikes Kluftkarren.

The main hypothesis examined concerns the lithology of the limestone and springs directly from the work of Sweeting and Sweeting already referred to. This hypothesis is that the sparry calcite content of limestones (expressed as a percentage) is an important factor influencing variation in the size of pavement blocks (clints) and the fissures (grikes) which separate them. Specifically it is proposed that there is a direct relationship between sparry calcite content and clint size. A second hypothesis to be given consideration is that man has had a considerable impact upon the character and distribution of the pavements in the Farleton Knott area. This hypothesis is based on the opinions of other workers who know the area well and upon information available in the press, (e.g. Dalesman Vol.18 No.7, p.341, 1956; and numerous issues of the Craven Herald) as well as on impressions gained from the field.

DESCRIPTION OF STUDY AREA

South and east of the Lake District, and west of the Ingleborough-Malham area are outcrops of Carboniferous Limestone (map, fig.2). Steep craggy areas of the limestone, up to 120m high, are virtually the only solid rock present in the area by the Kent estuary and Morecambe Bay. But further east, west of the Dent Fault a larger area of limestone hills rises to over 225m, culminating in Farleton Knott. The area was studied in four parts: Farleton Fell, Newbiggin Crags, Holme Park Fell and Hutton Roof Crags (map, fig. 3). To the north, near Orton, are outcrops of Carboniferous Limestone which were examined only briefly.

The position and structures of the limestone are related to major structural events in the history of the Lake District. In the north the limestones dip gently northwards away from the centre of the Lake District 'dome'. But in the south, around Morecambe Bay, they are partly sharply folded along well-defined belts, for example, Silverdale-Arnside, and Hutton Roof (Mosely, 1973). The two areas were continuous during deposition and the thickest beds were laid down in Holkerian and Asbian times. The lithology is very similar throughout the whole area with a tendency to less purity, possibly more quartz, in the Eden Valley area (Garwood, 1912). The Dent Fault severed the region after deposition.

The limestone thickness varies and is about 300m in the area around Farleton Knott. The facies is basinal, in contrast with the shelf facies of West Yorkshire. The dips of the strata vary widely, being as steep as 45 to 50^{o}, in contrast with the horizontal and sub-horizontal disposition in Craven. The difference is, of course, accounted for by the different structural histories of the two areas. The extent of outcrop is less in Westmorland than it is in Yorkshire, consequently there is much less interference with surface drainage than there is further east. In other respects the form of the ground is similar to that of the east in Yorkshire, thus typical scars with terraces and screes occur. Many of the dip slopes carry limestone pavement. One difference is that the more pseudobrecciated rocks of Westmorland are apparent due to the weathering out of honeycomb patterns in the rock.

During the Pleistocene ice affected the Farleton Knott area, as it flowed southwards, whilst ice flowing north affected the Orton-Tebay area (King, 1976).

Compared with Yorkshire the Morecambe Bay limestone areas experience a mild climate, owing to their lower altitude and their location entirely west of the Pennine watershed. On Farleton Knott there is a vegetation of lush undergrowth, shrubs and trees, which owes its existence to the mild climate and light grazing pressure. Part of Farleton Knott is managed and protected by the Forestry Commision, which influences the density of vegetation both directly and indirectly. A direct influence has been actual planting. In a wooded pavement area (Dalton Forest) a small experiment was established in 1951 to ascertain whether it was possible to produce tree growth directly and whether the outcrop could support growth sufficiently to assist in the breakdown of the rock formation. The experiment (Crosland, 1956) was, broadly speaking, a success, for the mortality rate of the trees planted was not high.

The Farleton Knott pavement outcrops are quite extensive on the top of the hill, at altitudes between about 210m and 270m. This top is an undulating surface with an overall gentle southward slope. However, there are localized areas of steeply dipping pavement, with a variety of pavement types. The general impression is that the pavement is good in quite extensive patches with large, smooth un-runnelled clints, separated by more broken and denuded areas.

Plate 1. Clints and grikes on Newbiggin Crags, Farleton Knott.

Plate 2. Bedding plane exposed by the removal of overlying clint blocks.

Plate 3. Limestone chip debris from the removal of clint blocks.

Limestone quarrying affects the western side intensely, as the quarries at Holme bite into the hill. There are certain parts where clint tops have been recently removed for garden rockery stone (Plate 2).

Description of sample sites

1. Newbiggin Crags. This is an area of massive clints, composed of very honeycombed limestone. There is little loose flaggy rock. Rough clint surfaces suggest that clint tops have been removed from here not long ago. Indeed it is known that removal did occur recently from parts of Newbiggin Crags. The clints generally make distinctive rectangular and triangular patterns (Plate 1).
2. Farleton Fell. At the northern end of Farleton Knott the area known as Farleton Fell possesses pavement sloping at about 16^{o} as well as horizontally disposed pavement. In places there has been recent removal of clint tops and much sugary debris remains from this activity. The limestones are very pseudobrecciated over part of this area, and this gives a cockled surface to the clints.
3. Holme Park Fell. This very accessible area of pavement west of Newbiggin Crags shows extensive signs of clint block removal. Over the ares the pavements vary from massive with large clints to flaky and patchy. A slope of 2 to 3^{o} in places gives rise to distinct runnel patterns on the down-slope side (Fig. 4). The length of clints in this particular part is high, averaging 5.6m, and the long dimension is downslope.
4. Hutton Roof Crags. Hutton Roof is well-known for its steeply sloping pavement but this is not the only type of pavement to be found in this area. Beyond the eastward sloping pavement are extensive tracts of good, varied pavement at variable dips. A distinctive characteristic of the area is a shrub and tree vegetation which is relatively dense, in spite of some sheep grazing. As at Holme Park Fell there are sites here with a gentle dip and well-developed runnels on the down-dip edge of the clints. In other places there are beautifully smooth large massive clints in rectangular and triangular shapes.

Sampling procedure

The pavement sampling carried out on Farleton Knott was done with the aim of achieving as comprehensive a picture as possible of the variety of pavement forms in the area. Four sites of $100m^2$ were measured at each of four subdivisions (Fig. 3). At five random points within each $100m^2$ square the nearest clint and grike were measured. Measurements taken at each point were clint length (CL), clint width (CW), grike width (GW), grike depth (GD), grike orientation and the dip of the bedrock. In addition, qualitative observations were made of the extent and nature of soil and vegetaion, of the general character of the pavement, of the detailed nature of the limestone surface and of the nature of the runnels present. On a later occasion the solution runnels were examined in more detail and diagrams drawn of the runnel patterns.

Thirty two limestone samples were studied in hand sample and thin section, two from each of the sixteen sample squares. The thin sections were examined under a petrological microscope at magnifications of 44x and 125x. This examination was done in order to assess texture, structure, sparry calcite content, fossil content and associated minerals such as iron, quartz, gypsum and dolomite.

Westmorland thin sections

The thin sections from Farleton Knott show very little variation. Those from Yorkshire showed a greater variety and those from Sanetsch still greater variety. All the Westmorland sections examined are biosparites with a sparry calcite content between 50 and 65% Nearly all are altered and show features of recrystallization; about half contain iron stain and about half are cracked; all are quite fossiliferous.

There is very little quartz in any of the sections. Mosaics of calcite crystals are poor and infrequent except in the few fresher sections. Only in texture does there seem to be any major distinction between the four main areas studied. Medium to coarse limestones are found at Hutton Roof Crags and Holme Park Fell, whereas those examined from Farleton Fell and Newbiggin Crags are mainly fine to medium in texture. In the two latter areas there also tend to be more sections in which quartz is present than in the former two.

Fig. 2 : THE LIMESTONE AREAS OF WESTMORLAND

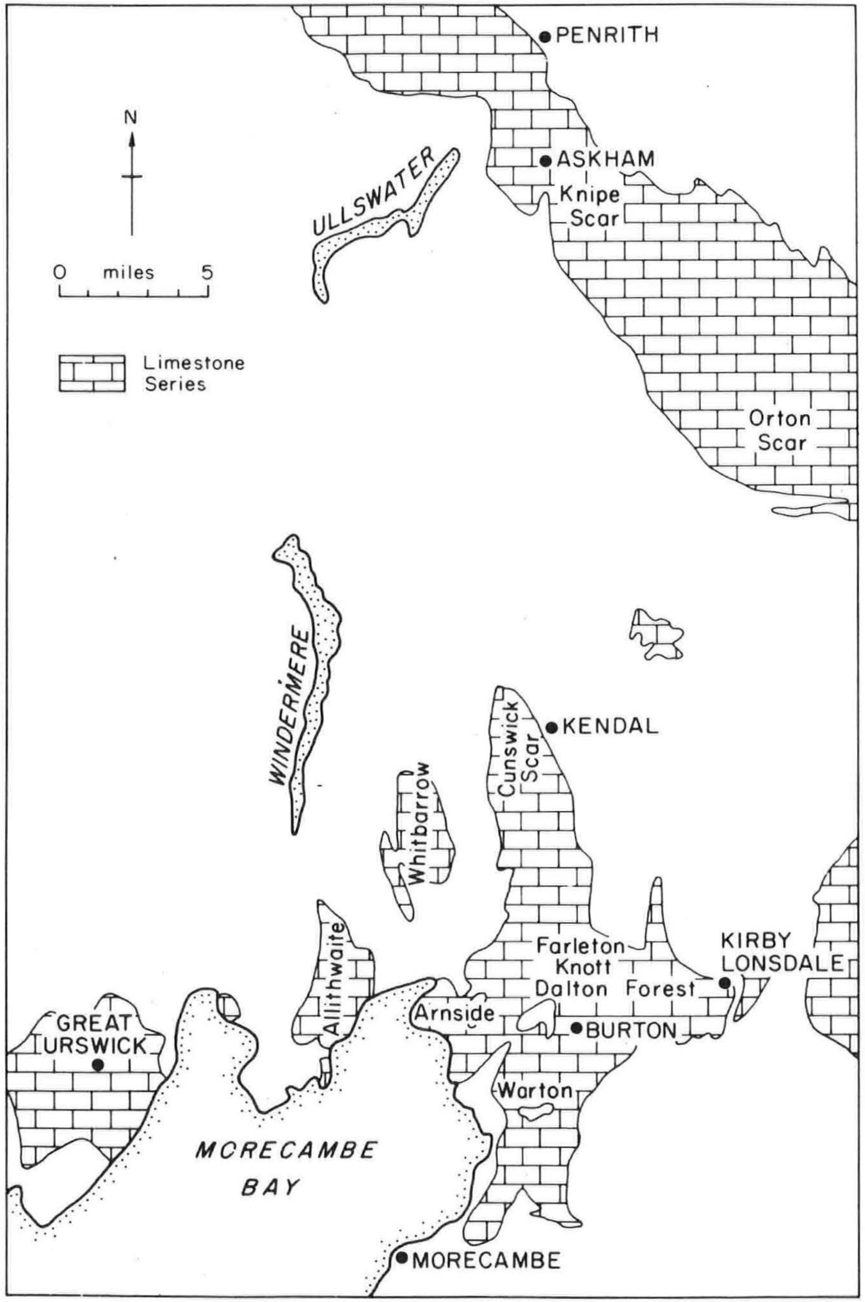
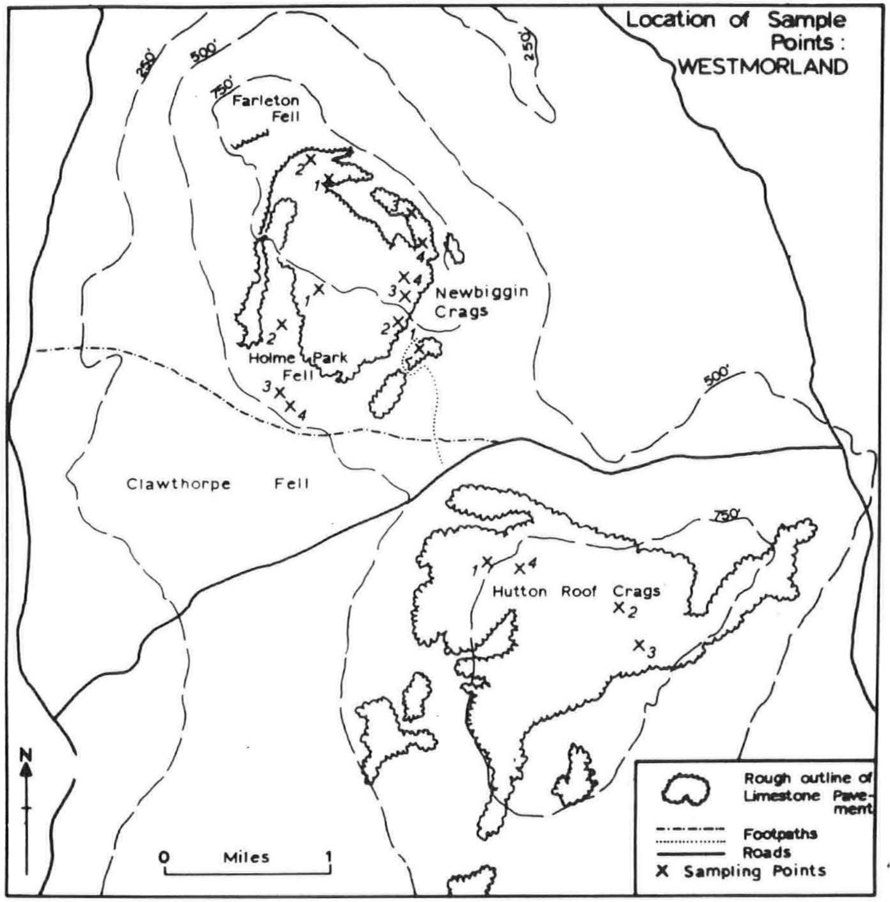


Fig.3.



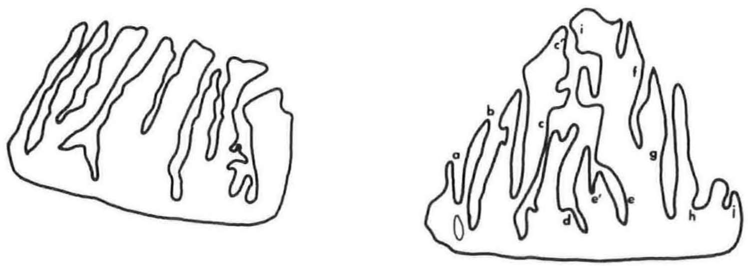


Fig.4. Diagram of typical runnels at Holme Park Fell.
The down-dip direction is at the open end of the runnels.

RESULTS OF MORPHOMETRIC STUDY

Pavement measurements from Westmorland were treated as a 'large group' for the purpose of comparison with five other areas studied: Ingleborough, Malham and Wharfedale in Yorkshire; and Sanetsch and Glattalp in Switzerland. Means and standard deviations were calculated for each of the measures: clint width (CW); clint length (CL); grike width (GW); and grike depth (DG) and are shown in Table 2a. Percentage frequency distribution graphs were drawn for each measure, including one each for the six large groups and one each for the four subdivisions of Farleton Knott. In addition graphs for all the Yorkshire figures and all the Swiss figures were drawn. These graphs are shown in Figs. 5 to 8. The data in the large groups were compared and tested to establish whether any group differed significantly from any other on each measure. The results of this testing are shown in Table 1.

Table 1

Results of tests for significance of difference for large groups : Z values

Wh = Wharfedale
M = Malham
I = Ingleborough
W = Westmorland
S = Sanetsch
G = Glattalp
/ = not significantly different

1. GRIKE DEPTH

	Wh	M	I	W	S	G
Wh						
M	2					
I	17	19				
W	5.4	2.5	/			
S	3.4	4.5	7	7		
G	/	/	2.8	3.5	10	

2. GRIKE WIDTH

	Wh	M	I	W	S	G
Wh						
M	/					
I	3.5	/				
W	/	/	2.9			
S	/	2.1	/	/		
G	4.4	4	4.1	5.6	4.9	

3. CLINT WIDTH

	Wh	M	I	W	S	G
Wh						
M	/					
I	20	2.3				
W	3.2	3.8	/			
S	/	/	2.96	/		
G	/	1.8	/	/	/	

4. CLINT LENGTH

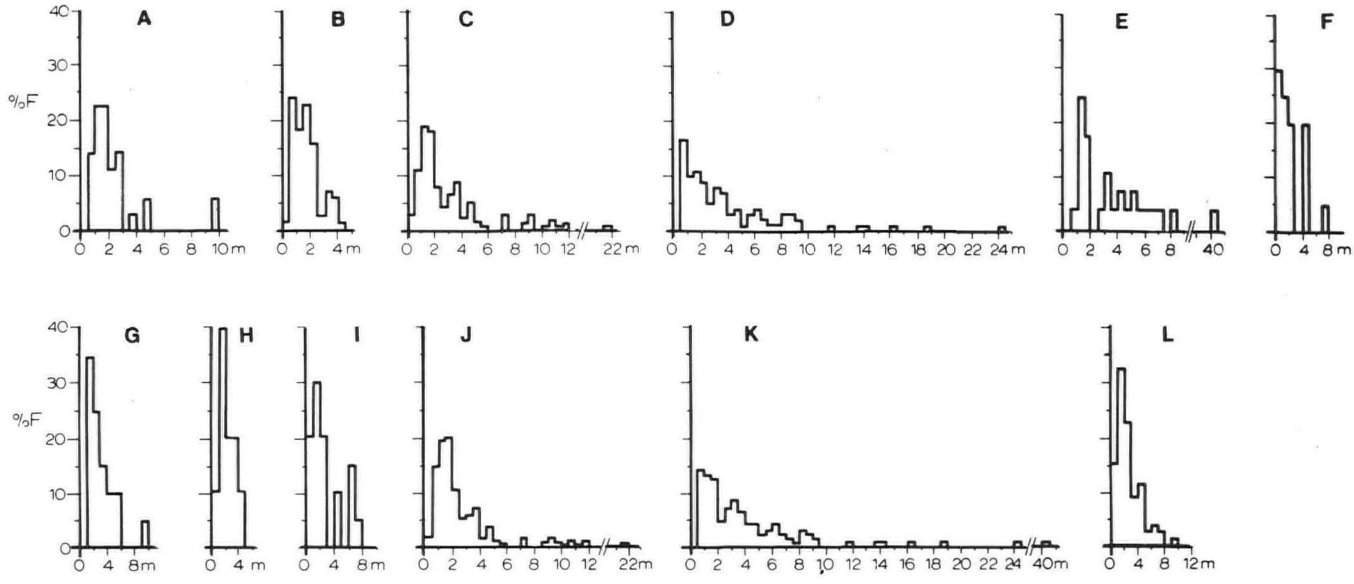
	Wh	M	I	W	S	G
Wh						
M	/					
I	3.4	/				
W	/	/	/			
S	4.1	2.2	2.2	2.2		
G	2.4	1.9	/	/	/	

(The Mann Witney U test for large groups was used to test whether the large groups of pavement morphometric data differed significantly from each other. The level of rejection was 0.05 probability).

Clint length The figures for Westmorland for clint length differed significantly only from those for Sanetsch although the percentage frequency distribution graphs appear very different from those for other areas as well. The graphs F to I show the range of values in the Westmorland area, up to 9m, to be considerably less than for areas such as Sanetsch, Glattalp and Ingleborough. However, the range is similar to that in Wharfedale (B) where clint lengths reach about 10 metres maximum. The means of the four separate Westmorland groups (Table 2a) are 3.15m, 2.3m, 2.75m and 2.2m. These values fall between the mean clint length on Ingleborough, 3.25m, and the mean for Wharfedale, 1.76m. The area with the greatest mean length of clints is the Glattalp area of Switzerland (4.58m).

Clint width Westmorland's clint width figures differ significantly from those

Fig.5. Percentage frquency distributions of clint lengths for each sample area.



A	Malham	D	Sanetsch	G	Holme Park Fell	J	**Yorkshire**
B	Wharfedale	E	Glattalp	H	Newbiggin Crags	K	**Switzerland**
C	Ingleborough	F	Hutton Roof Crags	I	Farleton Fell	L	**Westmorland**

Fig. 6. Percentage frequency distributions of clint widths for each sample area.

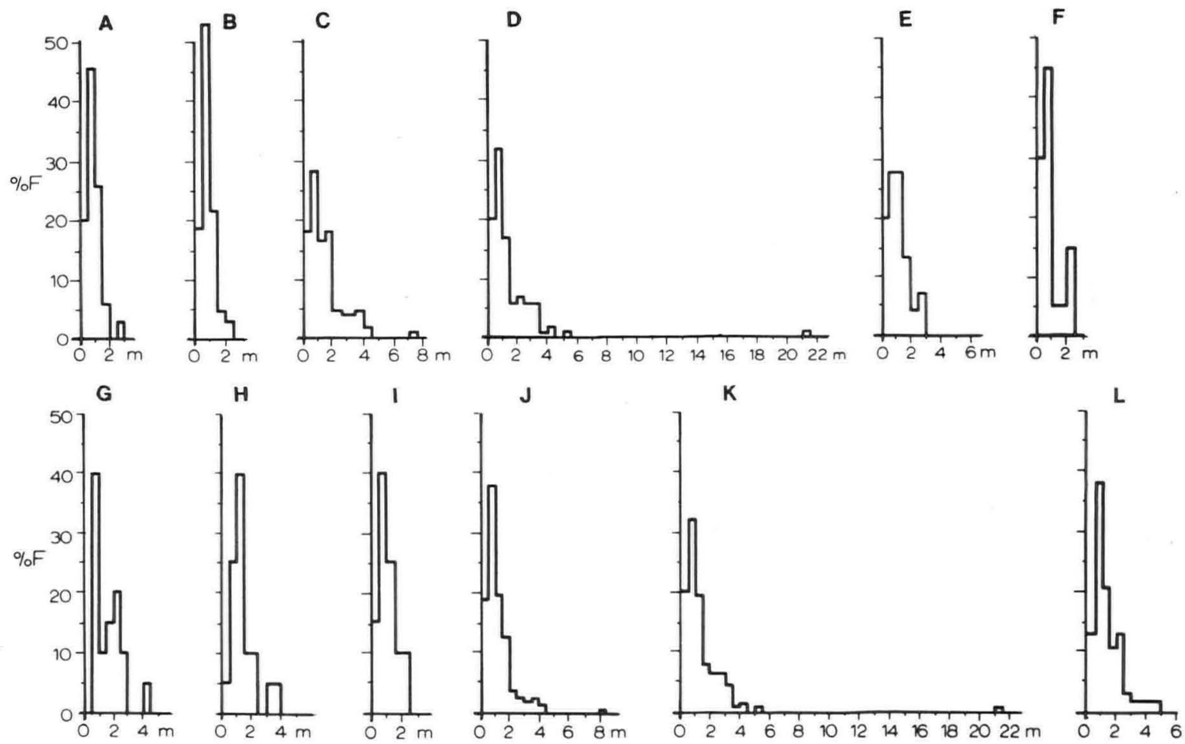


Fig.7. Percentage frequency distributions of grike widths for each sample area.

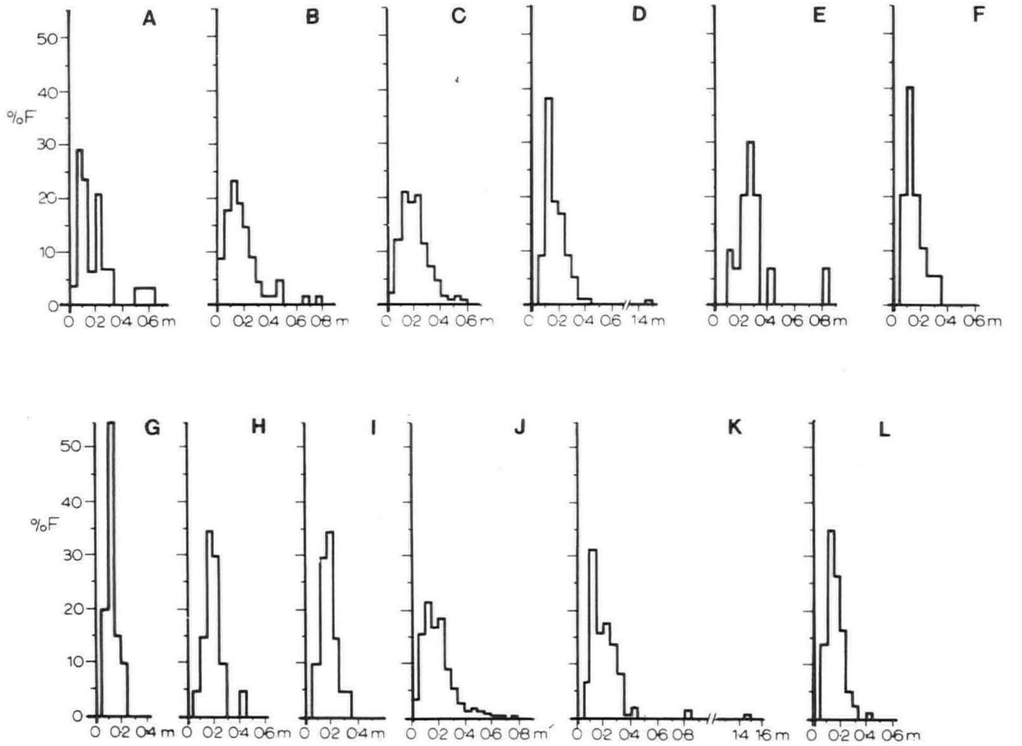
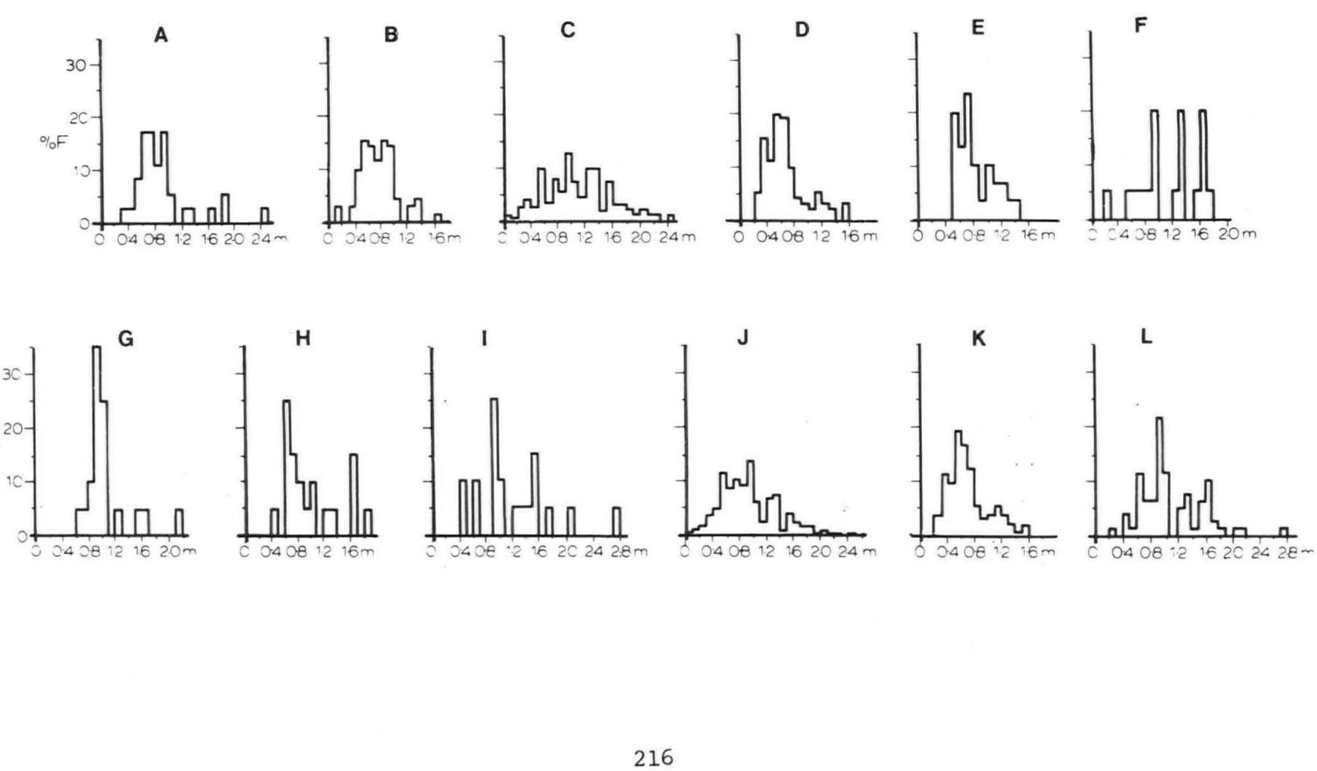


Fig. 8. Percentage frequency distributions of grike depths for each sample area.



for Wharfedale and Malham (Table 1). Examination of the percentage frequency distribution graphs (Fig. 6) shows similar patterns for all areas with the greatest range being at Sanetsch (D), where the highest value is over 20 metres. Apart from this value, and values on Ingleborough (C) of nearly 8m, most clint width values do not exceed 5m. The means for the four Westmorland areas (Table 2a) range from 0.9m at Hutton Roof Crags to 2.32m at Holme Park Fell, compared with the area with the narrowest clints measured, Wharfedale, where the mean is 0.85m, and with 1.52m for Sanetsch, which is the largest mean after Hutton Roof Crags and Holme Park Fell. These figures taken in conjunction with the clint length figures ties in with the field observation of 'squarish' clints at Newbiggin Crags.

Grike Width The grike width figures for Westmorland differ significantly from those for Ingleborough and Glattalp (Table 1). There is a similar narrow range of values for all the four Westmorland sample areas, maximum values being less than 0.5m. This compares with a range of up to 1.5m at Sanetsch (Fig. 6D), 0.8m in Wharfedale and 0.85m at Glattalp. The main pattern of figures for Sanetsch is, however, similar to that for Hutton Roof Crags (F). The averages range from 0.2m to 0.13m in the Westmorland areas, compared with 0.3m at Glattalp, and 0.19m at Sanetsch, Wharfedale and Malham (Table 2).

Table 2a Large Group Means and Standard Deviations (all values in metres)

Area	CL m X	CL m SD	CW m X	CW m SD	GW m X	GW m SD	GD m X	GD m SD
Glattalp	4.58	7.06	1.11	0.69	0.3	0.16	0.95	0.25
Sanetsch	4.17	3.98	1.52	2.25	0.19	0.14	0.66	0.31
Holme Park Fell	3.15	1.96	2.32	0.95	0.13	0.04	1.05	0.34
Hutton Roof Crags	2.3	1.69	0.9	0.86	0.15	0.06	0.17	0.41
Farleton Fell	2.75	2.23	1.05	0.58	0.17	0.14	1.21	0.56
Newbiggin Crags	2.2	1.05	1.59	1.09	0.2	0.07	1.0	0.34
Ingleborough	3.25	3.15	1.41	1.16	0.2	0.15	1.03	0.46
Whafedale	1.76	0.95	0.85	0.44	0.19	0.24	0.76	0.28
Malham	2.44	2.05	1.11	0.74	0.19	0.14	1.07	0.43

Table 2b Means of preliminary measurements in the Burren, Western Ireland

Grike width	0.14 metres
Grike depth	0.65 "
Clint width	2.03 "
Clint length	5.85 "

Grike depth The percentage frequency distribution graphs of grike depths show greater differences on first impression than the other measures do. This impression is confirmed by the tests for significance of difference which show that all possible combinations are significantly different from each other except Westmorland-Ingleborough, Glattalp-Wharfedale and Glattalp-Malham. The Westmorland graphs show disjointed distributions. The range of values in Westmorland is up to 2.8m whilst on Ingleborough it is 2.5m (Fig. 7). The means for the four sub-divisions of Farleton Knott (Table 2a) range from 1m to 1.21m. The shallowest grikes are at Sanetsch where the mean depth is 0.66m. Those on Farleton Fell are on average the deepest of the areas sampled (Table 2a)

Grading When the average measurements of clints and grikes are used to grade the several sample areas it is found that the pavements on Farleton Knott are very varied in their degree of dissection (Table 3). In the grading procedure large clints and narrow, shallow grikes indicate pavements with little dissection. Thus clint width and clint length values are graded with the largest values having the highest grades, whist for grike widths and depths the lowest sizes have the highest grade number. The grades for all four measures are added together to give the overall grading which indicates degree of dissection.

Table 3 Large Area Grading

I: Clint Length

Area	CL(m)	Grade
Glattalp	4.58	4
Sanetsch	4.17	
Ingleborough	3.25	3
Holme Park Fell	3.15	
Farleton Fell	2.75	
Malham	2.44	2
Hutton Roof	2.3	
Newbiggin	2.2	

II: Clint Width

Area	CW(m)	Grade
Holme Park	2.32	4
Newbiggin	1.59	3
Sanetsch	1.52	
Ingleborough	1.41	
Glattalp	1.11	2
Malham	1.11	
Farleton Fell	1.05	
Hutton Roof	0.9	1
Wharfedale	0.85	

III: Grike Width

Area	GW(m)	Grade
Glattalp	0.3	1
Newbiggin	0.2	2
Ingleborough	0.2	
Sanetsch	0.19.	
Wharfedale	0.19	
Malham	0.19	
Farleton Fell	0.17	3
Hutton Roof	0.15	
Holme Park	0.13	

IV: Grike Depth

Area	GD(m)	Grade
Farleton Fell	1.21	1
Hutton Roof Crags	1.17	
Malham	1.07	2
Holme Park Fell	1.05	
Ingleborough	1.03	
Newbiggin Crags	1.00	3
Glattalp	0.95	
Wharfedale	0.76	4
Sanetsch	0.66	

V: Final Grading

Sanetsch	13
Holme Park Fell	12
Ingleborough)	
Newbiggin)	10
Glattalp)	
Farleton Fell	9
Malham)	8
Wharfedale)	
Hutton Roof	7

Table 3 shows that the pavements at Home Park Fell are relatively undissected. They are more dissected on average than those at Sanetsch, a relatively recently deglaciated pavement, and they are on average less dissected than pavement on the rest of Farleton Knott and sites in Yorkshire. The Newbiggin Crags pavements have a similar degree of dissection to the Ingleborough and Glattalp pavements, all three having a grade of 10. Farleton Fell is slightly more dissected, with a grade of 9, whilst the pavements at Hutton Roof are on average the most dissected of all the areas sampled, with a grade of 7. The Holme Park Fell pavements attain their high grade by having narrow grikes and wide clints. The high degree of dissection at Hutton Roof Crags is the result of both small clints and deep grikes.

Significance of difference The significance tests give the justification for comparing the pavement between the different study areas. The results of these tests suggest that much of the variation found in the data between different areas is not the fortuitous result of sampling. Clint length is the measure showing most difference, 7 pairs showing significantly different results (Table 1). At the same time the lack of significant differences between some areas for some measures does suggest that there are general similarities in pavement morphometry between pavements in quite widely differing environments. This is of great interest as it could mean that there is some underlying explanation of these features in spite of differences in climate, vegetation, soil, age of exposure, lithology and topography. The immediate factor which springs to mind is jointing. Are there similar patterns of jointing latent in the limestones that compose the pavements of these very different areas? However, the stated hypotheses should be examined before looking to fresh ideas.

FACTORS AFFECTING THE CHARACTERISTICS OF LIMESTONE PAVEMENTS

Whilst not forgetting that these landforms are influenced by many factors including the changing circumstances of climate and vegetation, the effects of structure, glaciation and topographic position, and the possible ways in which solution takes place, this study of Farleton Knott has concentrated in particular on the effect of lithology and also upon man's influence as a geomorphic agent. Before considering these last two factors it is worth looking briefly at the effects of glacial erosion and deposition. It must be borne in mind, when trying to account for variations in morphometry of the pavements in terms of lithological factors, that glaciation, particularly glacial erosion, could have produced a very great variety of forms in the first instance before post-glacial weathering got under way.

It has been suggested that the degree and recentness of glacial erosion are very important factors influencing the characteristics of limestone pavement surfaces (Pigott, 1965). The manner in which both the character of the pre-glacial limestone surface, in particular the thickness of debris cover, and the intensity of glacial scouring can produce a variety of pavement surfaces, and thus varied block and joint sizes, is very important. Figure 9 summarises the possibilities which could be produced by the combination of the two factors of pre-glacial conditions and glacial scour. This is in effect a diagrammatic expansion of Pigott's idea of the importance of glaciation to varying pavement morphometry. Applying these figures in the field, it is interesting to observe that there are good undissected pavements near Chapel-le-Dale in Yorkshire which is considered to be an area where the ice in the Last Glaciation was strongly active and highly effective in erosion (Clayton, 1966).

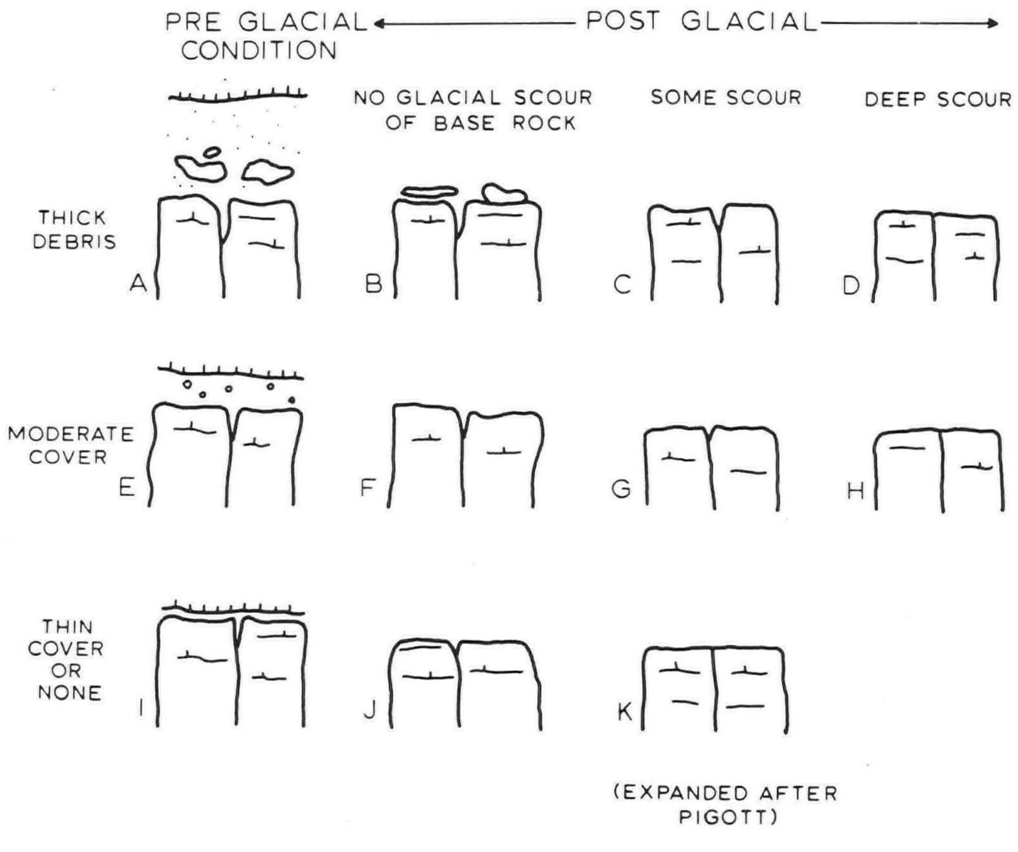


Fig. 9 Pre-glacial and glacial factors influencing pavements.

Sparry calcite content of the limestones

The relationship between the estimated percentage sparry calcite content of the thin sections of the sampled limestones and the measurements of the clints and grikes at the same sampling points has been considered in some detail. The purpose of this exercise was to ascertain whether the sparry calcite content of the limestones is related to the morphometry of the pavements, as was suggested by the Sweetings (1969) and hypothesized at the start of this study.

Overall, the results of this particular analysis do not support the findings of Sweeting for Ireland. Nowhere is the correlation coefficient between the morphometric measures and the sparry calcite content of the thin sections greater than 0.7 (at Malham in Yorkshire), the next closest being 0.53 (Ingleborough), (see Table 4). Nor does inspection of the graphs (Fig. 10) indicate any special relationships in the Westmorland figures. Here the medium length clints (2m to 7m) tend to be associated with fewer low values of sparry calcite than the shorter clints. The clints longer than 7m are also related to rocks with low sparry calcite contents. There is a similar spread of the clint width figures for the Westmorland area. The deepest grikes are generally associated with the sparry calcite range 50 to 60%.

Table 4 Correlation Coefficients : Morphometry and Sparry calcite content of thin sections.

Area	GD/CAL	GW/CAL	CW/CAL	CL/CAL
Malham	0.03	0.24	0.42	0.77
Wharfedale	-0.11	0.13	0.24	0.17
Ingleborough	0.22	0.02	0.04	0.09
Westmorland	0.09	-0.001	0.22	0.17
Twisleton	0.31	-0.06	0.24	0.53
Sanetsch	0.33	0.005	-0.21	-0.05
Yorkshire	0.12	0.09	0.07	0.18

(The 'Regression' programme of the Statistical Package for the Social Sciences (SPSS)-version 6 - was used on the I.B.M. 360 computer at University College London to obtain these correlation coefficients)

For grike depth figures there is again no significant correlation nor is there for the relationship between grike width and sparry calcite content for Westmorland or the other sample areas.

Quartz content

The sample of Westmorland thin sections containing quartz was too small to analyse in order to test the hypothesis that a high quartz content in the limestone is related to undissected pavements. The sections from Farleton Knott in which quartz is present are more from Farleton Fell and Newbiggin Crags than from the other two areas, but there was no particular association of these sections with the larger pavement blocks. In the analysis of the Yorkshire no obvious link between the presence of quartz and larger pavement blocks was found in the present author's studies.

Texture and Fracture

Expressing the texture of thin sections assessed on a graded scale from 1 to 5, it was found for the Yorkshire sample that the coarse-grained limestones could be connected with a greater number of large clints than are the fine-grained limestones. However, the samples for Westmorland were too small to be useful in this analysis. There was no indication from what was available that the same findings as for Yorkshire occurred.

The occurrence of fractures in the thin sections was related to the morphometric results for Yorkshire, but in the Westmorland sample the limestones were all too similar in this respect and so were not analyzed. The results for Yorkshire were not conclusive; 'well-cracked' rocks (many cracks within 1 cm). there seem to give rise to wider grikes than 'less-cracked' (cracks 1 cm or more apart), but the trend is slight.

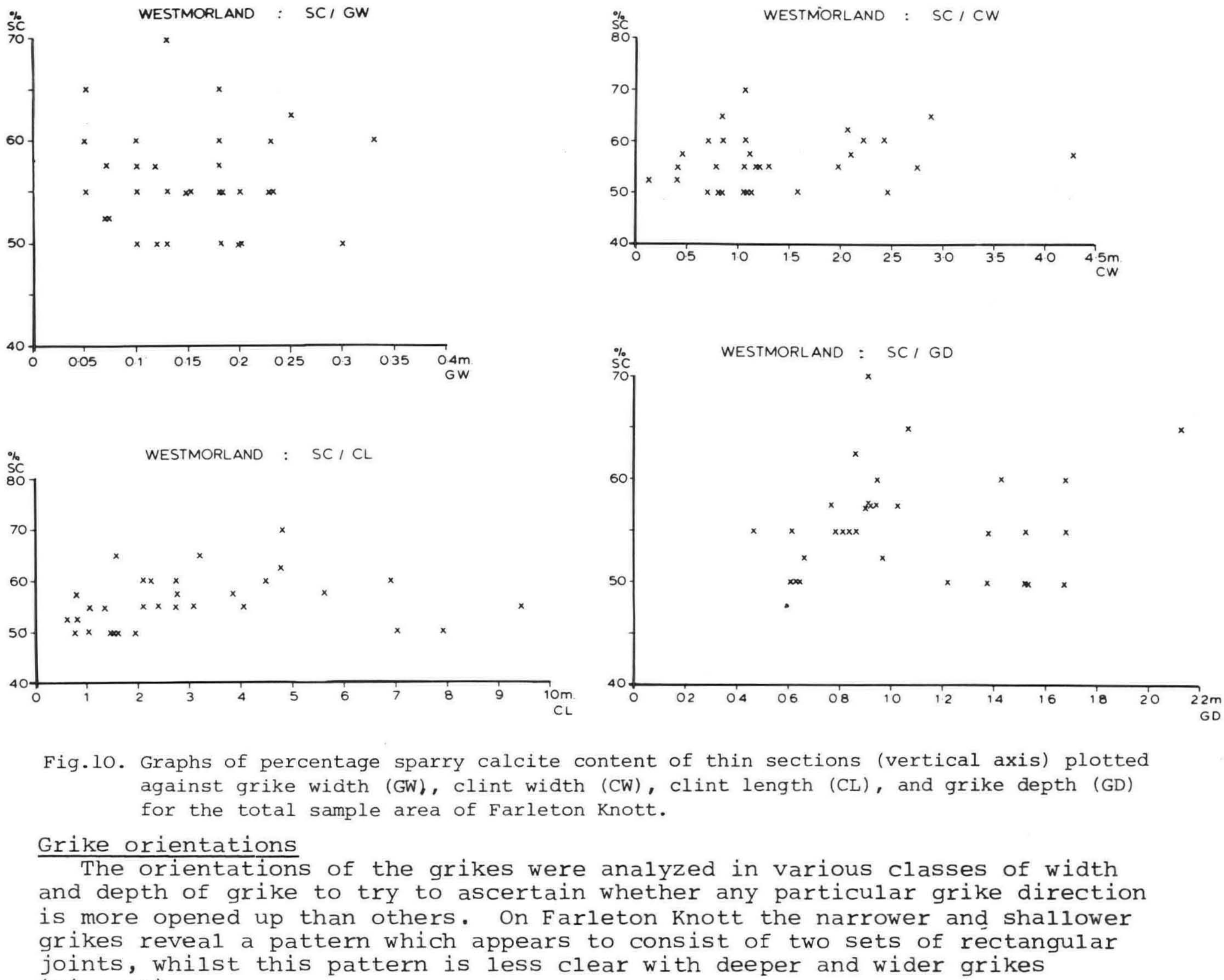


Fig.10. Graphs of percentage sparry calcite content of thin sections (vertical axis) plotted against grike width (GW), clint width (CW), clint length (CL), and grike depth (GD) for the total sample area of Farleton Knott.

Grike orientations

The orientations of the grikes were analyzed in various classes of width and depth of grike to try to ascertain whether any particular grike direction is more opened up than others. On Farleton Knott the narrower and shallower grikes reveal a pattern which appears to consist of two sets of rectangular joints, whilst this pattern is less clear with deeper and wider grikes (Fig. 11).

THE INFLUENCE OF MAN ON THE WESTMORLAND PAVEMENTS

In places the limestone pavements of Farleton Knott show the effects of man's activity as a geomorphological agent. These effects stem from the proximity to settlement and value to agriculture of the areas where pavements occur, and from the direct value of the limestone as a marketable commodity of varying use. They illustrate present-day problems associated with conflicting land-use, for agriculture, quarrying and recreation, in one of the less spoiled areas of Great Britain, and with the need to conserve areas of scientific value.

In the Westmorland pavement areas generally the most important recent influence has been the removal of solution-patterned clint tops for garden rockery stone, and also the quarrying of roadstone. The former affects large areas of pavement superficially, whilst the latter involves deep extraction of limestone over a more restricted area. On Farleton Fell both practices have affected the character and distribution of the pavements (Plate 3). Removal of clint tops leaves a rough limestone surface often with sugary gravel and may permit the complete coverage of the former pavement area by the growth of vegetation. North of Farleton Knott, on the Orton pavements, very large areas have been affected by the removal of superficial limestone.

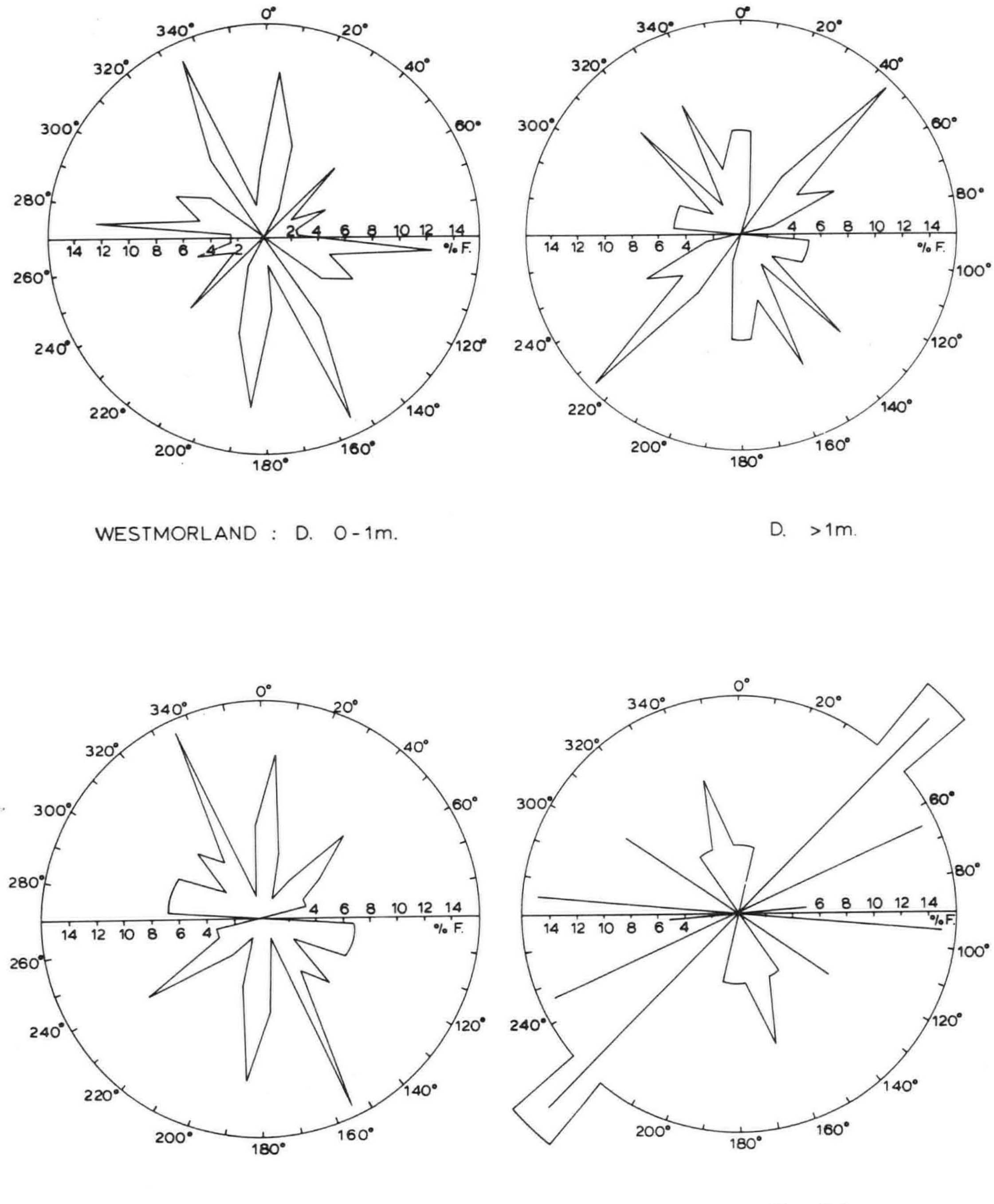


Fig.11. Joint orientations of grikes at Farleton Knott, for grikes with depths less than 1m (D=o-1m), for grikes deeper than 1m (D> 1m), for grikes with widths less than 0.2m (W=O - 0.2m), and for grikes wider than 0.2 m (W>0.2m).

Numerous lines of enquiry have been pursued to obtain details of the extent of man's impact on the pavements, but much of the information available is non-quantitative. Certainly the removal of pavement blocks as garden rockery stone has taken place in recent years, as testified for example around Orton by the lorries and equipment used for the removal actually being seen on the pavements. Furthermore, the blocks are seen at their final destinations, in the garden walls of rockeries all over England. Local newspapers also provide accounts of the controversies concerning this use of pavement blocks.

The Nature Conservancy Council was concerned with removal from Farleton Knott, which was registered as a Site of Special Scientific Interest in 1954. Removal was permitted from a strictly limited area, and removal for the purposes of garden rockery stone was made illegal. At Knott End, Orton, near Tebay, an unscheduled area, an application to remove limestone for rockeries was refused in 1961. Then, on appeal, permission was granted regarding 10 acres of the original 190 acres. Extensive areas of limestone gravel and broken outcrop testify to the removal of large amount of tops from this district.

Within the Farleton Knott pavements the most affected parts have been Newbiggin Crags and the area towards the west near Holme Park Fell, and of course the large quarry at Holme which at present is the most dramatic influence of man on the landscape of Farleton Knott.

The restrictions on clint removal which are supposed to operate in this area have not been strictly followed. They have not been easy to monitor and illegal removal is all too easy. On recent visits (1980 and 1981) areas not damaged in 1973 were seen to have had clint tops removed. The areas most affected are by the access tracks onto Newbiggin Crags and Holme Park Fell. Hutton Roof Crags and Farleton Fell, being less accessible, have not suffered the same fate. On the field below Newbiggin Crags, in an area where there was once pavement, there is now very little outcrop at all, manure has been spread and the area is now pasture.

A landform which has taken centuries to produce can be removed altogether in a few minutes (Plates 2 & 3).

CONCLUSION

This article has presented new data on a relatively little known area of limestone pavement, compared this area with other pavements in Northern England and Switzerland and examined some of the hypotheses concerning pavement features and development which have arisen from the literature of recent years. The morphometric part of the study has established reasonably the range and variety of pavements on Farleton Knott and placed this area in the perspective of other sites, showing similarities and differences according to the measure involved. The lithological work has been less positive for the results in detail do not appear to support the hypothesis that high sparry calcite content of the constituent limestones leads to relatively undissected pavement. However, neither do they completely refute the hypothesis. The range of limestone types on Farleton Knott is really not great enough to support or reject the hypothesis. Other ideas, however, are worth detailed examination, in particular the latent jointing patterns in limestone massifs. Lastly, a brief discussion of the evidence for man's involvement as a geomorphic agent in the limestone landscape of Farleton Knott is a reminder that his influence on the landscape cannot be neglected in geomorphological studies.

ACKNOWLEDGEMENTS

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EXPLORATION MEDICINE FOR CAVERS

Symposium held at Ingleton 14th. March. 1981.

The following papers were presented at the Symposium.

HYPOTHERMIA AND CAVERS

by John C. Frankland

Many cavers will have heard more about hypothermia than they wanted to as it has recently been well publicised as a hazard and possibly over-diagnosed on occasions. Nevertheless the problem remains in the caving environment. It will by considered in two categories - for the general caver and for the cave rescuer, although both must overlap and circumstances can push one group into the other.

An academic definition of hypothermia is a person with a core or inner temperature below 35°C, measured in either the rectum or oesophagus. In a hostile environment this represents an appreciably cooled and very much at risk individual who could rapidly die even though he has only just entered the hypothermic temperature range. We must not ignore those above this limit who may still have lost appreciable heat and can rapidly deteriorate. Dr. Oliver Lloyd's classic paper of 1964 describes the death of two Mendip cavers in one and one and a half hours after showing the first features of hypothermia.

In cold conditions temperature conservation is mainly dependant on body insulation and body heat production. If the former is inadequate bigger demands are placed on the latter and if exhaustion results then as the exercise level falls so inexorably will the core temperature.

The insulation value of the cavers clothing is paramount and is considered by Dave Brook elsewhere in this publication. It has been well documented that the insulation value of conventional clothing can drop to around 5% of its dry value after immersion as all who went caving in pre-wet-suit days will graphically remember. Unlike the mountaineers we are spared the very low air temperatures and the very high wind speeds which are even more threatening. However, all cavers can at times face an increased risk of hypothermia when emerging onto a cold windy winter hillside in wet clothing.

Basically those at risk are those with inadequate clothing, the thinnest, the least fit in a party who cannot maintain the high energy production of their colleagues, the novices as conditioning causes better adaptation to cold and, also, the recently ill, the hungover and those trapped by flood or immobilized through injury.

In cavers the more dangerous exposure exhaustion syndrome is more likely than simple hypothermia. Its onset is insidious - unlike having a broken leg or becoming pregnant. All who cave have felt the first features of just shivering or being uncomfortably cold whilst delayed. This and the other early features of inertia, lethargy and feeling rather miserable can be totally reversed by exercise which will rapidly generate enough heat to restore normal body temperature levels both in the inner core and the outer shell.

The exhausted and the injured caver cannot manage this effective self-rewarming. Nor can those significantly cold for anyone with a core temperature of 35°C or below, i.e. hypothermic, as the academics would define the condition, is unable to rewarm by exercise as this will merely divert warmer core blood to the muscles of the outer body shell and cause a net heat loss (Freeman and Pugh, 1969).

Another important feature is that the hypothermic victim may not be aware that anything is amiss so that when he has reached a core temperature at which exercise is positively harmful he may be subjectively feeling well and continue exertion causing further deterioration. Mountaineers have described a phase of "warm euphoria" where the victims actually shed clothing and following such a trail is often a useful guide to finding where the corpse lies.

As hypothermia develops from its mildest form the further features remain vague and can include fatigue, pallor, shivering lethargy and cramps. As the body temperature falls further violent trembling, unreasonable behaviour, difficulty seeing clearly, slurring of speech, confusion, muscular weakness, lack of co-ordination and inability to walk can develop, associated with a lack of rational thought, poor judgement and progressing rapidly to sleepiness, coma and apparent death. As normal cerebration fails, unreasonable behaviour, truculence and bouts of irrational undirected activity may occur. When these features develop underground the cavers present must cope with only available resources (Frankland 1975). With mild cooling forced exercise will effect a rapid cure particularly if high energy foods can be supplied. If in doubt attempting this and observing the effect seems reasonable if their level of consciousness is normal and their co-ordination and movement not impaired as most will improve. These victims should then be escorted out of the cave immediately with all possible help and meticulous protection on even minor hazards. If such victims begin to deteriorate showing they are excessively cooled or exhausted the evacuation should be stopped immediately and rest and insulation provided. The aim of this is to allow rewarming with on-going body metabolism which should be effective if the insulation is adequate.

Traditional mountain rescue teaching is to remove all wet clothing and replace it with dry clothing being carried. This can hardly be practical advice underground. Removing any top layers of wet clothing and replacing them after ringing them out seems reasonable together with using any clothing other party members can spare without risk to themselves. Placing the victim in a fully curled up position with thighs to chest and calves to the back of the thighs will reduce the body surface area available for heat loss by 30%. Placing him on a bed of ropes or tackle bags should minimise heat loss to cold rock. Digging a pit in sand has been found useful by some in survival situations as has building a wall to shelter from draughts and the driest and most wind-free spot should be sought. Many will forget to insulate the head and hands where heat loss can be considerable.

Perhaps the most effective re-warming measure is for two or more of his companions to lie closely alongside the victim to provide heat from the intimate contact of their own bodies. This is infinitely more valuable than the traditional but useless rubbing of limbs and my feeling is that more cavers are aware of this now than a decade ago and overcoming the natural reluctance of most men to hug other men closely when this is appropriate in a rescue situation. Space blankets and polythene 500 gauge exposure bags are both of value the latter being appreciably more effective than the former. Many would argue that the former are so light as to be carried routinely on all caving trips.

On expedition caving with underground camps sleeping bags may be available, and may be the ideal remedy particularly if shared with a warm caver. Warm drinks (try using a candle or carbide light) and nourishing food are beneficial and should be encouraged. However, the apathy of exposure will make most reluctant to take sustenance and feeding the victim little and often is usually most effective.

With these measures many victims will improve even in the underground environment and self rescue may then be possible. However, help from a rescue team may still be necessary and an early decision about this should be made and a call out sought if in doubt,

The rescue team can provide, hopefully, a very important boost to the victim's morale if showing a modicum of competence, and also provide extra insulation and the stretcher and manpower to effect rescue where injuries or significant cooling make this necessary.

On all but the simplest of rescuesit is usually necessary to assume some cooling to have occurred and so to provide insulation to combat this. For about twelve years the Neoprene Exposure Bag has been standard equipment in the Yorkshire Dales often with space blankets beneath, even if the victim is in a full wet suit. It is close fitting and covers the head; different models allow the arms to be within the bag or loose for self-help and protection, although the hands are still enclosed. For minimal bulk effective insulation is provided even if further immersion during rescue is likely. In such a bag victims will measurably warm up over a few hours and undoubtedly it has saved several lives (Frankland, 1973).

Recently the Flectalon Rescue Blanket has been used underground in South Wales and found very effective by those employing it.

In 1972 Lloyd described airway rewarming as the first on-site method of treating hypothermia and in 1974 it was first used successfully in the field on a cold caver (Lloyd and Frankland, 1974). Since then the method has aroused controversy as some academics have claimed negligible benefit shown on animal experiments (Auld et al 1979) but American coastguards have shown a significant advantage in reducing temperature "afterdrop" in man.

The original commercial equipment, the "Reviva", was bulky and many rescue teams became disenchanted with carrying it to victims who were either dead or did not need it. The Reviva is now slightly less bulky but recently alternative equipment marketed as "The Little Dragon" is available which fits easily into a normal caving ammunition box and is equally effective. Our experience with this suggests it has a bonus use for the non-critically hypothermic where giving warm moist air to breathe will have a beneficial effect on those who have been trapped underground but not injured, after which they can more safely and more rapidly be escorted out.

All airway rewarming is an adjunct to and never a substitute for adequate insulation. The heat supplied is only of the order of $5.0\ K_j/m^2/hr$ but it can also prevent the normal respiratory heat loss of around $35.0\ K_j/m^2hr$ so perhaps "airway insulation" is a better term than airway rewarming.

One difficulty rescuers face is how to monitor the condition of hypothermic patients underground for, if their temperature is falling, they are inexorably dying. Physiologists and academic clinicians claim that only the core temperature as measured in the rectum or oesophagus is relevant. This is impractical initially and undesirable during rescue when the victim should be fully cocooned in adequate insulation. To disturb this periodically to insert a thermometer per rectum would be detrimental and impossible when he is splinted and strapped in a stretcher. A subnormal thermometer kept under the tongue for three minutes will give a temperature level several degrees below the core temperature but by measuring changes in this level in practice one can ascertain if the patient is rewarming or cooling. Standard clinical thermometers are of no value as readings are likely to be off scale but any chemist should be able to supply subnormal thermometers. Do not take measurements within half an hour of giving a warm drink. Carry two such thermometers as your own fingers may well be cold and breakage through fumbling is likely.

The American militia and some European Mountain Rescue teams use chemical heat packs to place on the victim's trunk. Apart from diminutive models sold to warm skiers hands these are not yet on the British market and as yet there is no documented proof of their effectiveness. Perhaps this technique would be worthy of trial in cave rescue as theoretically and practically it looks most promising and simple enough for the difficult circumstances in which we work.

Finally, hypothermia represents the most difficult situation in which to define the point of death. Electrocardiographic evidence of cardiac arrest for up to one hour and survival of children after immersion in cold water for up to forty minutes have both been followed by full recovery without brain damage. For cold victims death can only be defined as failure to resuscitate after all measures have been tried. Obviously in caves such techniques are not feasible but within the constraints of common sense resuscitation on the surface should not be abandoned because of lack of signs of life. Helicopter evacuation of significantly cold victims after evacuation from the cave is totally justifiable if available and if weather conditions permit.

Fortunately most caving victims are fit, resilient and not too profoundly chilled so that with the simple measures outlined will usually improve steadily over a few hours.

Materials referred to:

Flectalon — Manufactured by Porth Textiles Ltd., Flectalon Division, Llwynypia, Rhondda, Mid. Glamorgan.

Little Dragon — Manufactured by M.F. Mitchell, Capplerigg, Kentmere, Kendal, Cumbria.

Reviva — Manufactured by Peter Bell Engineering, "The Slack", Ambleside, Cumbria.

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THE CAUSES OF CAVING ACCIDENTS

by John Forder

INTRODUCTION

This paper is a brief résumé of a talk given to the B.C.R.A. symposium on "Medical Aspects of Caving" in March 1981; since the lecture was based largely on the contents of my article in "Caves & Caving", No. 6 (November 1979) the present paper is intended as a supplement to my previous one, rather than as a transcript of my talk.

Caving accident statistics, from the Cave Rescue Organisation and the Mendip Rescue Organisation have been analysed and categorised as shown in the accompanying tables; it is probably worth repeating the following points with regard to the categories:

Firstly, not all the examples were accidents - incidents would, perhaps, be a better word to describe some of the rescues (particularly those in category 3).

Secondly, not all the accidents happened to cavers - there are, for instance, odd examples of walkers falling down holes.

Thirdly, the categories are not mutually exclusive; consider, for example, the case of a caver with exposure after a fall in a flooded cave - did he fall because of incipient exposure - or because the pitch was too wet ? Or did he succumb to exposure because he was immobilised after his fall ?

Finally, no attempt has been made to classify accidents according to severity (apart from a section on fatalities).

	CATEGORY	C.R.O. No	C.R.O. %	M.R.O. No	M.R.O. %	TOTAL No	TOTAL %
1	FALLS	70	24.6	42	22.3	112	23.7
2	FLOODS	60	21.1	19	10.1	79	16.7
3	OVERDUE	43	15.1	33	17.6	76	16.1
4	EXPOSURE/EXHAUSTION	27	9.5	16	8.5	43	9.1
5	LOST/LIGHT FAILURE	20	7.0	33	17.6	53	11.2
6	ROCK FALLS	14	4.9	7	3.7	21	4.4
7	STUCK	8	2.8	14	7.4	22	4.7
8	UNABLE TO CLIMB OUT/UP ROPE	5	1.8	-	-	5	1.1
9	SUMP DIVING	5	1.8	4	2.1	9	1.9
10	FALLS/ABSEILING	4	1.4	-	-	4	0.8
11	UNABLE TO PRUSIK	3	1.1	-	-	3	0.6
12	LEFT UNDERGROUND	3	1.1	-	-	3	0.6
13	TRAPPED BEYOND ROCK FALL	1	0.35	-	-	1	0.2
14	MISCELLANEOUS	21	7.4	20	10.6	41	8.7
		284	99.95	188	99.9	472	99.8

TABLE 1. Incidents attended by C.R.O. from 1935 - 1980
and M.R.O. from 1951-1980

Table 1 gives a comparison between the rescue statistics for the C.R.O. during the years 1935 to 1980 and the M.R.O. for the period 1951-1980. It has been organised to be in the order of frequency of call-outs for the C.R.O. (compare the original table in "Caves & Caving"; the order has hardly changed with the addition of the statistics for the last two years).

Perhaps not surprisingly, falls account for the largest number of rescue call-outs in both regions - after that, however, there appears to be no great degree of correlation between the two areas. The fact that in the North there are many flood-prone stream-sink caves accounts for the high incidence of flooding in the C.R.O. section of the table, as compared with the M.R.O. section, but there is no very obvious reason for the other differences in the order of frequency for the two regions.

Most of the categorics are self-explanatory, and the lessons to be learnt quite obvious - apart from category 14, miscellaneous, which includes all sorts of odd incidents. Perhaps the most bizarre of these is the case of the school-boy whose helmet fell off - and who then straightened up, impaling his head on a stalactite! On Mendip, there seem to be two main contributory causes to this category - being locked in a cave (!) and being unwilling to dive a sump (usually sump 1 in Swildon's Hole).

	CATEGORY	C.R.O. No.	C.R.O. %	No. of deaths	M.R.O. No.	M.R.O. %	TOTAL No. of deaths	TOTAL %
1	FALLS	8	30.8	8			8	26.7
9	DIVING	5	19.2	7	1	25	6	20.0
6	ROCK FALLS	4	15.4	4			4	13.3
4	EXPOSURE OR EXHAUSTION	3	11.5	3	1	25	4	13.3
2	FLOODS	2	7.7	7	1	25	3	10.0
10	FALLS/ABSEILING	2	7.7	2			2	6.7
7	STUCK	1	3.8	1			1	3.3
14	MISCELLANEOUS	1	3.8	2	1	25	2	6.7
		26	99.9	34	4	100	30	100

TABLE 2. Fatal accidents attended by C.R.O. from 1935-1980 and M.R.O. from 1951-1980

Table 2 gives a comparison of fatal accidents in the two areas for the years in question.

In the Yorkshire Dales area, 34 people have died underground in 26 separate accidents - compared with only four in Mendip. Given that falls are the commonest cause of accidents, it is hardly surprising that this accounts for the largest number of deaths - almost a third, in fact. After this, however, the order of frequency alters from that in Table 1, the second most common cause of caving fatalities being diving accidents. Considering that rock falls caused only about 5% of accidents, the number of deaths is surprisingly high - at 15.4% - implying that rock falls, though not very common, tend to have serious consequences.

SYSTEM	No. of INCIDENTS	% of TOTAL
GAPING GILL	43	15.1
EASEGILL	35	12.3
WEST KINGSDALE	30	10.6
ALUM POT	24	8.5
IREBY FELL CAVERN	17	6.0
TOTAL	149	52.5

TABLE 3. List of most common accident sites in C.R.O. area.

SYSTEM	No. of INCIDENTS	% of TOTAL
SWILDON'S HOLE	67	35.6
EASTWATER	14	7.4
AUGUST/LONGWOOD SYSTEM	11	5.9
STOKE LANE	10	5.3
SIDCOT SWALLET	9	4.8
TOTAL	111	59.0

TABLE 4. List of most common accident sites in M.R.O. area.

Tables 3 and 4 give lists of the most common sites for underground accidents; this is not, of course a list of England's most dangerous caves: rather it is a list of England's most popular ones. In the north, the Gaping Gill, West Kingsdale, and Easegill systems between them account for over a third of all the incidents - in view of the attractive nature and size of these caves, this is hardly surprising. A similar situation obtains on Mendip, where the most popular and longest cave, Swindon's Hole, accounts for 35.6% of all the incidents under consideration.

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CLOTHING FOR CAVING AND RESCUE

by D. Brook

The earliest humans to enter caves probably wore animal skins which helped to make the cool, damp underground environment more bearable. When caves became popular places to visit for scientific study and sport however, mankind had advanced somewhat and ventured into the underworld clad in old but serviceable clothing beneath an outer layer of tweeds or a cast off suit. This form of garb was comfortable when dry but absorbed a great weight of water on wetting and also lost much of its insulation value. Nevertheless quite wet and intimidating potholes such as Meregill and Rowten were bottomed with such attire at the turn of the century. Since those first golden days of the birth of speleology, lighting, tackle and footwear have been improved dramatically and few would enjoy a full return to the old techniques. Where clothing is concerned however the Edwardian type of attire is still very convenient and comfortable. Using the modern belay points to avoid the water it is possible to reach the bottom of many major potholes without a wetting. Should a ducking occur all is not lost although the remedy requires courage - strip off all the clothing and wring it out before donning it again. Wet clothing is quite tolerable for periods of several hours in the coldest caves so long as one is active but long immersion in very cold water soon causes loss of co-ordination and the onset of hypothermia.

Up to 1950 the only improvements in caving clothing were the adoption of woollen underwear to provide more warmth and comfort when wet and a boilersuit to prevent snagging in tortuous caves. With such clothing wet and tight caves could be explored but digging or surveying in such places was not a pleasant occupation. Aircrew survival suits had been developed during the war and these 'goon suits' were pressed into service by cavers seeking protection from water. They were worn over the usual underwear, trousers and pullovers, and under a boilersuit to protect and contain their voluminous folds. The thin rubberised fabric of goon suits had low abrasion and snag resistance and during most arduous caving trips a leak would occur. Since the suits came complete with feet they filled with water pouring in through the leaks or the neck opening and the only way to get rid of it was to perform a handstand or to puncture the feet. Needless to say the suits were soon full of holes through which water swilled in and out with little hindrance. In this state their effectiveness was mainly psychological.

For British cavers the real breakthrough came in the early 1960s with the introduction of the wet suit for caving. Expanded neoprene has only about half the thermal insulation value of an equivalent thickness of clothing because it allows significant losses by conduction but it retains almost all its insulating properties when immersed in water whereas clothing looses most of its thermal resistance. A boilersuit or coverall of tough thin material is best worn over a wet suit since the neoprene (particularly the unlined type) is very easily cut and abraded, although should a cut occur only the body area at the cut is cooled. Even in tatters a wet suit affords some thermal protection and their use had made possible the exploration and survey of extremely wet and arduous caves.

The neoprene suit was originally used for diving and it is most effective and comfortable when the wearer is immersed in water. Out of water strenuous activity leads to overheating since the suit cannot breathe and sweating, skin abrasion and sores are the result. For this reason many cavers only use a neoprene suit in very wet caves and revert to thick underwear (long johns, Damart, Viloft, etc.) and old clothes for normal caving.

A most comfortable alternative is to use a 'furry suit' in all but very wet caves. The originals were one piece pile fabric garments used by aircrews and tankcrews. They or the purpose-made caving suits are worn under a coverall and they are very warm unless completely immersed in water. The pile fabric is a man-made simulation of the animal fur worn by the earlier cave dwellers but the synthetic materials have several advantages over animal fur, which make them very suitable for use in wet/cold environments (Brook and Keighley, 1980).

The synthetic pile fabrics have been shown to have a most useful role in the construction of survival and rescue bags. Other novel materials such as heat-reflective Flectalon also appear promising although their performance under very wet conditions has not been measured (Bates et al, 1980).

Comparative tests were first made on sleeping bags of pile fabric and quilted fillings of down, fibrefil and Holofil in a cold chamber at temperatures down to -20°C. Even when wet the pile fabric bags had an equivalent performance to the other (dry) bags. The study was continued as a field trial in which an Eskimo pile fabric bivouac bag was tested along with three types of mountain rescue bag. The warm-up time of cold subjects was monitored in each bag in turn and although the pile bag was by far the lightest it performed the best (Keighley, 1980).

To evaluate the use of pile bags in low temperature caves two were taken on the Pierre St. Martin Expedition of 1974. Before they were tested however, a real emergency occurred and two members were cut off by flooding just above the last pitches. Thirty six hours later they were found to be making their way out, but very cold. One had reached a chamber above the wet pitches and was put into a pile bag for a couple of hours. Fully warmed up he made his way out unaided. The other victim was found below in a very wet 60m pitch and was very cold and uncoordinated - clearly in no state to tackle the SRT pitch. He was placed in an Eskimo bag under a polythene sheet but there was no way to avoid the spray of cold (4°C) water. After two hours the caver had recovered sufficiently to tackle the pitch followed by a further period of three hours in the damp bivouac bag before he made his way out.

Thick pile fabrics wick away water into the fabric backing where it can drain away so wet clothing is dried in these bags without having to disturb the victim. The fabric is very permeable to air and water vapour which is a decided advantage in normal caving, but could cause heat loss from an inactive person in a draughty situation. The problem is overcome by a wind resistant cover.

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CARE AFTER CAVING ACCIDENTS

by Frank Walker

In the 43 years between its inception in 1935 and 1978, the Cave Rescue Organisation (C.R.O.), based at Clapham, has attended 240 caving incidents. The figures for the last three years have not been analyzed so have not been included, although they show no marked alteration in trends. The breakdown of the callout figures shows :-

	No. of incidents	% of total
Flooding	56	23
Fractures sustained	44	19
Other injuries	42	17
Help needed	43	18
Cavers overdue	30	13
Fatal accident	25 (32 deaths)	10

The causes of the injuries received or death were :-

	No. of incidents	No. of deaths	% of total
Falls	68	9	64
Rock falls	17	4	18
Drowning	7	14	6
Bad air	2	1	1
Others	11	4	11

The bottom figure of 11 "Other causes" contains bizarre incidents such as "Winch failure" and "Caver hit by falling caver". Of the 44 incidents (19% of callouts) where fractures were sustained, the figures shown that the great majority of caving accidents result in lower limb injuries.

		No. of cases	
Fractured:	Tibia or Fibula	11	
	Spine	10	(one permanent paraplegic)
	Femur	8	
	Ankle	8	
	Arm	66	
	Pelvis	6	
	Skull	4	
	Wrist	33	
	Ribs	33	
	Others	3	

44 victims had multiple injuries.

The first point to make is that the care of an injured caver is really basic 'First Aid' and commonsense as in any surface accident, modified by the underground environment and the particular situation of each incident.

When the victim is reached by the first person after the accident, "patient assessment" is the first action - a quick overall general examination for priorities before a more slower detailed examination. The next priority is "Is he breathing?" if unconscious. Then "Is his heart beating?". The brain can stand only about 5 minutes of total oxygen lack before irreversible brain damage takes place and after 10 minutes death occurs. If either or both of these vital functions are absent on the first examination and the time interval not too great, mouth to mouth resuscitation with external cardiac massage should be started. This may have to be continued until the patient can be intubated. Whether anyone could be rescued in this condition from anything more than a simple walk-in cave is debatable.

If unconscious but breathing, and in all other accidents, the patient should then be made safe from further injury, e.g. removed from the path of more falling boulders, from sliding off a ledge or dragged from under a waterfall. This is important. Many people tend to be frightened of moving someone, say with an injured back, in case they hurt the person or make the injury worse. But done carefully this is unlikely and the alternative may be further graver injuries or rapid hypothermia. It may be justifiable leaving a victim lying in the stream at the foot of the pitch in Kingsdale's Master Cave with a fractured femur, as happened two years ago. The C.R.O. can have them on the surface within two hours of the accident. But it would be a different matter if the accident had happened at the bottom of Meregill Hole where it would be many hours before help arrived. It has been estimated that an unprotected immobile victim would survive two hours immersed in water. A wetsuit would slow the process down but not stop the cooling.

When made safe, the individual injuries should then receive attention. If unconscious, the patient should be placed in the 3/4 prone position to keep the tongue from obstructing the airway, and to allow the drainage of saliva, blood and often vomit. Watch out for false teeth! Cavers must be getting older. This was illustrated by a recent rescue, where a caver sustained a nasty compound fractured ankle and a dislocated elbow but was mainly concerned his teeth weren't mislaid. We have also met contact lenses on a rescue but in a conscious patient so far. These may have to be removed as false teeth should be in an unconscious person. Keep a check on the pulse rate, size and reaction to light of the pupils, respiration rate and level of consciousness. Subsequent alteration in these will give an indication of his state during the rescue. There is really very little else one can do for an unconscious patient, except remove him as quickly as possible to a hospital with a neurosurgical unit.

The treatment of fractures and dislocations is the same. Firm splintage that immobilizes the joint above and below the injury. With most cavers wearing tight fitting wetsuits or bulky layers of clothing, precise diagnosis is often impossible and there is no justification in cutting away large areas of insulation to facilitate greater accuracy. It will not affect the immediate treatment. The definitive treatment will be carried out in hospital after X-rays have been taken. When properly splinted the pain should stop or at least diminish in intensity. Once pain is eased, shock and morale will improve.

In lower leg fractures, strapping the injured leg to the other in as many places as possible is the standard treatment. If the femur is broken the patient should be laid flat as they may be shocked through blood loss into the thigh muscles, and could need intravenous transfusion before being moved. Happily this has not been necessary yet.

Pelvic injury pain can be relieved by lying the patient flat and wedging each wing of the pelvis to give support, or by tying slings around the pelvic girdle to give the same effect. Broken ribs can be supported with strapping around the chest. This is essential if enough ribs have been broken to cause a flail chest wall and respiratory difficulty. Arm and shoulder injuries should have the arm strapped across the front of the chest and supported by a sling. In back or neck injuries if there is any doubt as to its severity, it is better to treat for a suspected fracture and forbid all movement, except as mentioned above, and wait for evacuation on a rigid stretcher. A well-fitting cervical collar will splint the neck. The worry with back injuries is that, with movement, you will convert a stable fracture into an unstable one and percipitate a paraplegia. Luckily, as the injuries are usually caused by falls, most are compression fractures and very stable. There has been only one permanent paraplegic and this was from a fall of only 15 ft but he fell backwards horizontally onto a projecting stone.

If the fracture is compound, i.e. the skin over the fracture is broken, any obvious large foreign matter should be removed with clean fingers and if there is clean water nearby, gently washing it will do no harm. Otherwise, it is better to leave things alone until proper medical help arrives. If there is gross deformity, such as a foot facing backwards, try to rectify the anatomy as the blood supply may well be impaired and if left too long gangrene may follow. Gently apply traction to the limb end and turn the deformed part to UNDO the twisting of the fracture. When there is any prolonged bleeding from cuts direct firm pressure over the bleeding point will usually stop it. If the bleeding is arterial use the pressure points; if you don't know these, an intermittent tourniquet. Head wounds tend to ooze blood profusely and again firm pressure is used. If there is an obvious fracture or brain matter exposed, don't press too hard.

If the party has any pain-killing drugs with them, such as Codeine or Fortral these should be given, preferably 10-15 minutes before any movement. Also food can be given if available. After only a very short time a totally immobile injured person will soon cool and become hypothermic. People do not often die from a broken leg but can die from hypothermia in a few hours. Any spare clothing, or extra wetsuits should be put around the victim. A spaceblanket will do no harm and body contact preferably by two people will help to cut down heat loss.

The C.R.O.'s standard management of lower leg injuries is the Hey's splint. This gives support to the whole leg and can be supplemented by Kramer wire splints for ankle injuries if necessary. We do have available other splints, such as pneumatic splints and polyurethane foam casts. However, the pneumatic splints are not 'puncture proof' enough for routine underground use and to use the polyurethane entails carrying two extra ammo boxes underground. The Hey's splint is light, non-bulky and fits easily into the modified Neil Robertson stretcher that is invariably used, when being taken underground. The new Bayer cast splints that have recently come on the market may prove an excellent alternative, for below-knee and forearm injuries.

The patient is placed inside a neoprene exposure bag before being placed in the stretcher. Sometimes, if thought necessary, they are wrapped in a space-blanket as well. They are often sweating by the end of the rescue. Walking cases are put in a parachute harness for pulling up pitches. Major fractures invariably need strong analgesic drugs for the rescue and particularly before the limb is manipulated prior to splinting. Morphine or pethidine are equally effective, but both may cause vomiting, which, if not looked for, may be disastrous with the patient firmly fixed flat on his back. Little and often is the best way to give it, to avoid a totally drugged patient who is unable to help himself. Antibiotics may have to be given when there is a grossly contaminated compound fracture and the rescue likely to be a long one.

The question whether the patient is fit to make his own way out with help is often very difficult to answer. In a very long system it would probably be greatly to the person's advantage to start towards the surface. In upper body and chest injuries there is no great danger. A friend of mine got himself out of the bottom of Birks Fell Pot with a broken humerus without calling out a rescue team. Needless to say he is now an Underground Controller with the C.R.O. This is in contrast to some callouts we get to people who are sat at the bottom of the entrance pitch with superficial lacerations to their hands! If the patient is just concussed he can probably still walk out slowly if safeguarded at every point. Obvious fractures have to wait for a stretcher, the main problem is in deciding whether they have a broken or badly sprained ankle. There is probably no harm in trying to hobble if it is not too painful. In all cases one must be prepared to stop if the patient becomes exhausted, hypothermic or deteriorates and wait for help. The C.R.O. has the facilities for 'prolonged stay' underground with an injured patient if the need should arise because of the impossibility of immediate rescue or to improve the patient's condition before moving him. I prefer the expression 'long stay' to 'hospitalization' as the latter has a ring of some permancy about it, and any stay longer than about 48 hours, in my opinion, is likely to run into logistic problems, apart from the medical complications that occur even in the best run hospitals, such as pressure sores or chest infections. These can occur with frightening rapidity in an immobile person, even with good nursing. A delay in evacuation whilst some obstruction is removed or whilst some blood volume expanding transfusion is given is time well spent but delay longer and you may merely watch the patient's state deteriorate inexorably due to some undiagnosed injury.

This briefly, in outline, is the standard care of the commonest caving injuries attended by the C.R.O. After any caving accident, the hallmarks of a good rescue are competent First Aid often backed up by more specialized medical help - followed by a quick, smooth evacuation to a hospital for definitive treatment.

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PROBLEMS WITH FEET AFTER COLD IMMERSION

by Howard Oakley

Non-freezing cold injury (which used to be called trench or immersion foot) normally affects the foot which gets cold and wet in constricting clothing and footwear, and remains immobile and inactive. It normally takes over 12 hours of such exposure to develop. When affected, it first goes numb, weak, clumsy, swells and may go red. The second stage occurs when the foot is rewarmed: it then goes pale and blue, the pulses fade and there may be numbness lasting for two to five hours. Stage three may last for up to 14 weeks - in this, it goes red, swells, and is painful. Blistering may develop, and the foot feels hot with strong pulses, although there may be damage to nerves (numbness and/or pain), and blood vessels (even leading to gangrene). Finally, the foot gradually returns to normal, or may have one of a number of long-term complications. These may affect the skin (loss of nails, tender dry and cracking skin, or chronic infection), the nerves (leading to excessive sweating, persistent pain, or loss of feeling) the blood vessels (which may become over-sensitive to the cold, or produce Raynaud's disease in which the toes go white in the cold and are very slow to warm up) and the bones and joints (resulting in contractures, bone loss, or arthritis).

First Aid treatment requires the removal of the feet from the cold and wet, protecting them and elevating them (to help the swelling go down) and keeping them clean and warm. Direct heat, alcohol and trauma must be avoided. Expert medical care should then be sought, particularly if there is any blistering, tissue damage, or severe pain. Even very powerful painkillers are useless to deal with some of the pain which results from this, but quinine (in 300 milligramme doses, at first only at night, but up to three times daily if necessary) seems to be almost ideal.

Prevention is most important: dry footwear should always be available when long trips are undertaken, and every opportunity taken to clean and dry the feet and change into warm dry footwear. The importance of comfortable footwear (not too tight), good loopstitch or fibre-pile socks, and good foot care cannot be overemphasised. The danger of using wet wetsuits for long periods must be recognised - these constrict at the ankles in particular, and increase the likelihood of non-freezing cold injury.

Whilst severe injury is rare, mild degrees are quite common. Under-reporting is a major factor, as many people seem to expect red, swollen and painful feet after prolonged trips, or when 'on the hills'. It is important to be aware of this problem, though, as whilst the initial attack may be trivial, the pain and 'cold feet' of the future may be quite disabling. Those who also go to snowy climes must beware that it predisposes to more severe problems such as frostbite.

I welcome personal experiences, case reports or discussion about non-freezing cold injury sustained in any activity. Please contact me at: 3, Hunton Close, Lympstone, Near Exmouth, Devon EX8 5JG (telephone Exmouth 79653).

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MEDICINE ON BIG EXPEDITIONS

by J. Buchan

You have heard about big caves in a remote corner of the globe. There is obviously not much point in one or two men disappearing into the wilderness to try and tackle a project like that, so you have a large expedition. If you are taking a lot of men and/or women and the country is as difficult as they say, best take a doctor with you. You never know, he may be some help. Thank goodness expeditions like to have doctors along - a wonderful opportunity for those of us who are normally desk-bound.

The hardest part is the months before - the preparation. You have to try to imagine every conceivable mishap and prepare yourself to cope with it, both mentally and in terms of the equipment you have. Clearly, you cannot plan for what you expect to happen - essentially nothing - but for every mortal thing that might happen. Anything from a cut finger to an outbreak of botulism from the tinned tuna.

Drug Companies are the suppliers of most of the medical gear. They have both my sympathy and gratitude. They are regularly inundated with requests for samples of their products by doctors off on their ego trips abroad. In my experience a third to a half respond favourably. Some are very generous indeed, and it is difficult to steer a sensible line between accepting stuff just because it is offered and getting things you think will be really useful. Do you really need fifty doses of female hormone ?

Drugs

You will all have seen lists of drugs and equipment recommended by professional expedition doctors, for example Dr. R. Illingworth in the British Medical Journal (1981). These lists are a helpful guide but can only give a general outline. Everyone has his own favourites, his own ideas of what may be appropriate, and anyway, you are severely limited by what you can beg.

The aim is to find out as much about the area as you can, conjure up visions of sick and wounded lying in inaccessible subcamps, and then work out what you think you might need to cope. Be careful of official publications. I have found that, presumably for political reasons, officials are reluctant to tell you about the diseases you may encounter. The best way I think is to talk to someone who has been there before. For the Borneo trip I went to see Dr. David Giles, Medical Officer of the 1978 Royal Geographical Society trip. He lent me his expedition medical report and gave me the names of the local doctors in Sarawak who had cared for patients. One of them, Dr. Mosko Reuben, wrote me a very helpful letter. I also took advice from Dr. David Warrell, an ex-University acquaintance who now works in Bangkok. My thanks to all of them.

Dressings, Bandages

These are rather harder to come by than drugs. Johnson and Johnson, makers of Band-Aids, NA dressings and so on, were my major suppliers of dressings. The headquarters at Slough probably don't know it but I am the local medical officer for the factory in Earby. Some of the managers come to me for medicals - it's as well none of them ever fails. Seton, makers of Tubigrip and other dressings, were very helpful indeed and I should like to recommend cotton crepe bandages as a useful all-purpose bandage which are made by STD and normally sold for varicose vein clinics. They are tougher and more resilient than ordinary crepe, less likely to snag, and they can be wound on very firmly to provide considerable pressure over a wound if necessary. We use this type of bandage in the practice now. It's just a shame they're such a funny colour.

The Chemist

My friendly neighbourhood pharmacist has now retired. He has sponsored more expeditions than I dare think. Not only has he given me enormous quantities of stuff, but he has spent lots of time looking things up, and 'phoning round for me for those items I needed yesterday. He it was who prepared the insect repellent which was invaluable in Sarawak.

Prophylaxis

Everyone knows you have to have injections before you go abroad. As expedition M.O. I had to decide which ones people should have. I looked at Professor Dick's (1978) famous book on immunisation, found it unhelpful, and plumped for TAB, cholera, polio., tetanus, hepatitis and rabies. All these are readily available except rabies. I'm sorry to say that I didn't make out a good enough case to the public health laboratories for them to supply free vaccine and so I had to buy it. At £18.50 per ml. it is a good job you can use two doses of 0.1 ml. given intradermally. The makers (Servier Laboratories) say you should use a 1 ml. dose but are prepared to concede that, given carefully, an 0.1 intradermal dose will do. The main difficulty is to collect all the expedition members together at the same time to given them their injections.

Policy

Once abroad the expedition doctor has to decide in his own mind what he is there for. It is of course as much a matter of temperament and personality as a conscious decision. Clearly illness and trauma are the doctor's responsibility, but what about these questions ? "Is this water safe to drink?" "I've just been stung, do you think it will be alright?" "I have this pain - will I be able to go caving?" "Why do the glands swell in my armpit when I have been stung on my hand?" You could just disappear underground, or laugh the questions off, or you could be earnest and serious. You could encourage questions or the opposite.

Many questions go unasked. I found that out when my wife, who is a nurse, came to my aid in Sarawak after I had been ill. She dealt with lots of problems which people perceived as too trivial for the doctor's attention. Perhaps I am more intimidating than I imagine.

Handling the local population is also a matter for personality and temperament. I was disheartened by the queues of local people for whom I could do little, especially the babies for whom I had no medication. Perhaps others would be stimulated by the challenge.

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CAVE DIVING MEDICINE

by Peter Glanvill

There is no difference between medicine for cave divers and that for open water divers although actual techniques vary considerably. Interestingly, in a recent paper on cave diving accidents, little emphasis was placed on medical causes for accidents and I hope to provide some food for thought about this. A bibliography is provided for those interested, although most of you who take up cave diving will find virtually all you need in the CDG training manual.

The law of physics always affecting one when diving is Boyle's Law, which lays down the relationship between pressure and volume. Figure 1 illustrates the consequences of the law clearly. As one descends each 10m the pressure on one is increased by one atmosphere. One can see that the greatest changes in gas volume occur relatively near the surface - which is why I will be spending much of this paper describing the problems of shallow water diving - arbitrarily chosen as anywhere above 30m. The development of the demand valve, which supplies air at the pressure of the surrounding water, enables the diver to become an independent unit free from any links to the surface. It is diving with such a system of Self Contained Underwater Breathing Apparatus (acronym SCUBA) to which I will be referring.

As the diver with SCUBA descends his body is largely unaware of the increasing pressure because the pressure is being distributed equally over the body which is largely composed of incompressible tissues. The pressure is there even if you don't notice it as anyone who has seen his ammo-box implode at depth will testify. However, those organs in the body which are air-filled will be affected. Problems arise when failure occurs in the pressure equalisation systems in these spaces and the external pressure rises above the internal pressure.

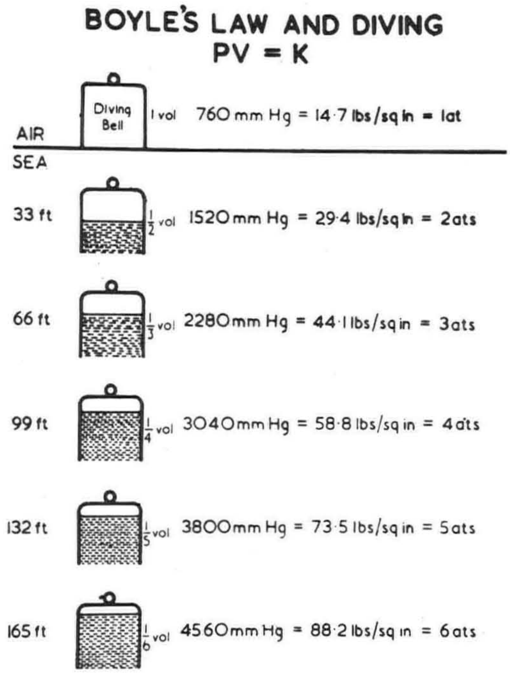
The main regions affected are in the head, the ear, the sinuses and the teeth, in the chest, the lungs, and finally there is the gut comprising the stomach and intestine.

Firstly, consider the ear. There are three sections - the outer, middle and inner ear. The outer opening known as the external auditory meatus communicates by a skin-lined tube (canal) with the ear drum, a thin but tough and sensitive fibrous membrane: behind this is the middle ear. Three tiny bones, the hammer, anvil and stirrup, cross it linking the ear drum and the oval window of the inner ear. Entering the middle ear is the Eustacian tube, a semi-collapsible tube which is normally closed at the lower end where it opens into the area behind the nose and above the back of the throat, the nasopharynx. This tube has the same sort of lining as the nose and is probably the cause of more problems for divers than anything else I will mention. The inner ear consists of the sound reception apparatus, the cochlea, and the balance apparatus, the vestubular system. There are two openings to the middle ear and these are sealed by membranes to retain the perilymph fluid which surrounds the structures I have just mentioned.

The external canal is subject to obstruction by wax, debris, earplugs (if you are misguided enough to put them in) or boils. It can be dangerous to dive with obstructed canals, for pressure is not easily transmitted to the drum and during a dive the middle ear pressure may rise forcing the drum out. This condition is known as reversed ear. It used to be associated with the tight-fitting hoods worn by the old style dry-suit divers. Neoprene hoods don't usually cause such difficulties.

Normally pressure in the middle ear is equalised by air passing in to it through the Eustacian tube from the throat. This sensation is felt as the popping of the ears when one ascends or descends a hill in a car. Ears can be induced to 'pop' by forcibly breathing out through the closed nose whilst the mouth also is closed. This is known as the Valsalva manoeuvre. As a diver descends he will be breathing air at the pressure of the water around him and he must communicate that pressure to his middle ear to equalise pressures either side of the ear drum. To do this the diver either uses the above manoeuvre or some other trick such as yawning, wiggling his jaw or swallowing to open his Eustacian tube. If the ears are not cleared the result will be increasing pain the deeper he goes until, if he has managed to ignore the pain that far, the diver's ear drum will perforate and cold water will pour into the middle ear. This will cause severe vertigo with a sensation of falling to the affected side. Even if the diver aborts the dive before actually perforating

Fig. 1.



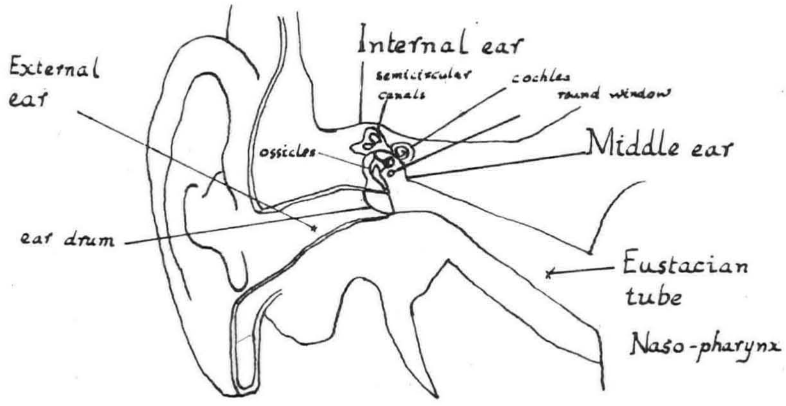
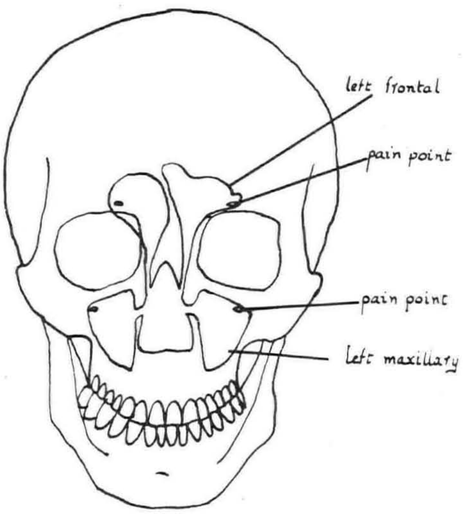


Fig. 2. Right ear viewed from in front.



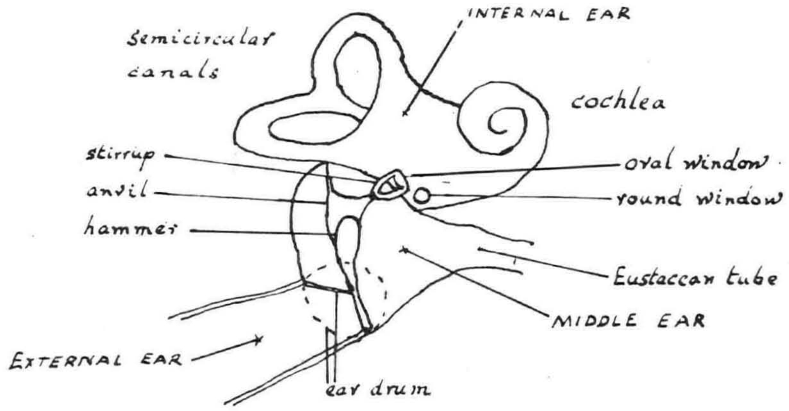


Fig. 4. Enlargement of middle and internal ears.

Fig.3. The para-nasal air sinuses.

his drum he may still have pain for some hours after his dive. My father, a fellow diver, once spent a sleepless night taking quantities of analgesics after sustaining an otic barotrauma, as injuries such as this are described.

The diver who has difficulty in clearing his ears has a big problem. Sometimes the cause is just nasal congestion after a cold and then a nasal decongestant spray such as Afrazine is helpful. However, some divers have days when for no apparent reason they just can't clear their ears. The answer must lie in the idiosyncracies of their individual Eustacian tubes. A friend of mine frequently has trouble with one ear, always the same one, and usually only in winter.

We now come to the inner ear. This rarely gets damaged in diving - if it does it usually means the diver has ignored some of the previous warnings. Recently one or two interesting syndromes have been noted with regard to inner ear function. These are of practical importance to the cave diver. Firstly, there is evidence to show that excessive middle ear pressures such as might occur during over-enthusiastic efforts to clear the ears can cause a rupture of the round window and leakage of the perilymph into the middle ear. The symptoms are sudden vertigo, roaring in the ears (known as tinnitus) and deafness. It may well be painless. It is important to seek medical aid relatively quickly if this problem is suspected, for surgical repair of the round window may be necessary. If the damage is not repaired then the vertigo will eventually settle down but deafness remains. One diver I know has stopped diving because he sustained a round window rupture and is now deaf in one ear. He does not wish to hazard his other ear.

Alternobaric vertigo is another condition not as well known as some of those described. It is thought to be a result of inequal pressurisation between the ears and can cause dizziness of varying degree and duration during ascent. In a recent CDG newsletter I found a description of what sounds like alternobaric vertigo experienced by a diver exploring in Peak Cavern. I'd certainly be interested to hear from any other cave divers who have had dizzy spells. I would like to close this section by quoting from the book Diving Medicine on the subject of alternobaric vertigo: "The occurrence of vertigo during shallow underwater exposures can be quite hazardous. The resulting spatial disorientation with possible nausea and vomiting may explain some of the previously unexplained deaths of experienced scuba divers. The best treatment is prevention. First individuals should not dive if difficulties with ear clearing exist or if a Valsalva manoeuvre at 1 ata (atmosphere absolute) produces vertigo. Second, if a diver notices any ear fullness or blockage or vertigo during compression further descent should be stopped and the diver should ascend until the ears can be cleared. Third, if such symptoms are noted during ascent, the ascent should be stopped abruptly and the diver should descent until the symptoms disappear if gas supplies and other conditions permit. Fourth, diving with a companion is always a safe precaution." All but the last remark is relevant to cave diving.

Leaving the ear we move on to the sinuses which are air spaces in the bones of the skull linked to the nose by tiny holes called ostia. Pressure is normally equalised with these without the diver having to think about it but if he has a congested nose or descends too fast then trouble may start. The relative low pressure in the sinuses means that to equalise pressure something has to fill them; if it isn't air then it will be blood oozing from the membranes lining the sinuses. The end result is a nose bleed - unpleasant but not serious. This condition is known as a squeeze. Squeeze can occur elsewhere such as inside a face mask if the diver does not equalise pressure through his nose as he descends A good description of a sinus squeeze can be read in the Northern Caving Club Journal No. 4, page 37.

Teeth are important. Firstly, because they may get holes in them which will act like sealed sinuses and can therefore cause pain on both descent and ascent and, secondly, they must be able to hold a mouthpiece comfortably and securely. A friend had to have major oral surgery because he couldn't dive in comfort any more. So if you are taking up diving get your teeth checked.

The contents of the chest are next. The chest cavity contains the lungs surrounded by a double-sided membrane, the pleura, which seals them from the rest of the cavity. Beyond, the muscles and ribs form a semi-collapsible cage. At the base of the cavity is the diaphragm, a large flat muscle responsible for the act of breathing. Lowering the diaphragm results in a drop in pressure around the lungs and they expand, being naturally elastic. The converse happens on breathing in. At depth the work done in breathing is increased because the air is more viscous, and it is possible to exercise violently enough that one cannot draw enough air out of one's demand valve. This is known as 'beating the lung' and can result in blackout. The point is that violent exercise underwater to beat the lung is much less than what would be considered violent exercise on dry land. I have got puffed carrying a large heavy kitbag up the underwater slope to Chamber 19 in Wookey Hole. One particular hazard is burst lung. This occurs if one ascends from depth (as shallow as 3 metres) on a lung full of compressed air. As one ascends the gas in the lung expands to occupy a volume much larger than that of the lung. The result is a burst lung which can be fatal. The moral is never hold your breath when ascending from a scuba dive - even in a swimming pool.

The guts are rarely discussed but can give trouble. Normally the air in a diver's gut is compressed on descent and causes no problems. However, if you gulp your food rapidly, and hence swallow air, you are liable to find yourself

Hazards in cave diving!   Cartoons by Bingham.

in trouble if you dive after a heavy meal. The consequent gas bubble in the stomach may be fine when compressed but on surfacing can become so unmanageable as to split the diaphragm and prevent breathing. There are cases of divers surfacing blue in the face and in extremes until a fortuitous and gargantuan belch has restored normality. If the worst comes to the worst one can always try recompressing and belching. Another risk of pre-dive dietary over-indulgence is vomiting underwater - very serious indeed.

Lastly, I would like to mention some problems in deep diving. I will start with nitrogen narcosis or "L'ivresse des grandes profondes" translated into English as "Rapture of the deeps". We call it the "narks" in this country. It is a result of the fact that under pressure the normally inert gas nitrogen acts as a form of anaesthetic. This usually starts to happen with compressed air at around a depth of 30m. The effect is that of slowly getting drunk, for the deeper you get the worse it gets until the end result is death. At the depths cave divers are now reaching the main symptoms are likely to be euphoria, a sense of well-being, and self confidence, which are all very well provided you are aware of the situation. One can develop a tolerance to the narks with repeated exposure as one can develop a tolerance to alcohol by regular drinking. It is interesting to note that tolerance to alcohol increases tolerance to the narks. Narcosis is definitely something to be kept in mind now that cave divers are pushing deeper.

Finally we come to the most dangerous complication of deep diving - the bends, otherwise known as caisson disease or more properly as decompression sickness. Over a period of time at depth, nitrogen gas dissolves in the tissues of the body. A too rapid ascent by a diver after being at depth for any length of time will result in the gas dissolved in the tissues coming out of solution too fast to diffuse gently into the bloodstream. The end result is the formation of gas bubbles in the tissues and blood vessels. The physical consequences are multiple, from, in the milder form, skin rashes and joint pains to, in their most serious manifestation, paralysis due to nervous system involvement. The only treatment is immediate recompression best effected in a decompression chamber where medical aid is available. To avoid the bends decompression tables have been evolved over the years: these give guide lines to divers as to the longest period they can safely remain at any depth without having to decompress on the way back to the surface. My advice is to avoid getting into decompression time if you possibly can.

Some of you may want to know why I have not mentioned oxygen diving. This is because the technique is nowadays considered dangerous and unnecessary. Pure oxygen is poisonous if breathed at a pressure of more than 2 ata (it causes convulsions) and even at 1 ata it can cause trouble if breathed for long periods.

Finally the question of fitness to dive must be considered. The CDG application form states "I am over 18, I am physically fit and I am not suffering from epilepsy". It assumes cave divers are going to be fit if they have managed to cave for several years (one of the criteria for acceptance as a CDG member). In marked contrast to the above sentence is the form given to doctors examining sport divers for the BS-AC. This involves a list covering a complete side of foolscap for the guidance of the examining doctor. Many of the exclusions need not concern us, for the infirmities detailed are likely to prevent one from caving let alone diving. However, a few points should be kept in mind. Firstly, middle ear disease, e.g. a perforated ear-drum or history of vertigo really should disqualify someone from diving. Secondly, sufferers from or with a history of, asthma or smokers with chronic bronchitis should think very carefully about diving. Some medical authorities would say anybody with a history of wheeziness should not dive. Thirdly, diabetics, however fit they feel, would be ill-advised to go in for cave-diving - they are excluded from open water diving within the confines of the BS-AC.

The above exclusions are not exhaustive and my advice to would-be cave-divers is that if you are in any doubt consult a doctor who knows something about caving and diving medicine before attempting it.

Lastly I would like to comment that I have never met a good diver who was not acutely aware of the physiological effects of diving. In a strange medium one needs all the information one can obtain. Dive cautiously.

My thanks to the following for their assistance in the preparation of this paper Dr. Michael Glanvill for his criticism of the manuscript, Christopher 'Bingham' Jones for the cartoons, Dr. Oliver Lloyd for preparing some of the diagrams and my wife for preparing the drawings.

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SYNTHETIC CAST SPLINTS - ADDENDUM (see pages 245-253)

When rigid splints are put on fractures "in the field" a risk exists that due to further swelling around the injury the cast may become too tight and the circulation impeded. In rescue situations without hospital equipment available to splint the cast immediately this can have serious consequences.

A new technique allows a wire to be incorporated beneath the cast which can be pulled by rotation round a metal bar to split the cast and relieve the pressure. The technique can be used on both plaster and plastic casts. Those considering plastic casts for cave rescue might find this an appropriate safety device to incorporate in the cast.

The UK distributors are:

ATHRODAX ORTHOPAEDIC
Athrodax House
High Street
HADDENHAM
AYLESBURY
BUCKS HD17 8ER
TEL (0844) 291056

who publish a booklet giving details of the technique. The wires cost well under £1 each and the rotating lever about £25. (With minimal ingenuity a lever could be improvised from a strip of metal).

JOHN FRANKLAND

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THE USE OF ALTERNATIVE CASTING MATERIALS UNDERGROUND

by Alison Stone, M. Borroff, P. Matthews,
A. Boycott and B. Jopling

INTRODUCTION

Immobilisation of broken limbs sustained in caving accidents has always presented difficulties for two main reasons, the first being that of negotiation of a rigidly immobile and stretcher-bound victim through tight passages, boulder chokes or small streamways; and the second due to the length of time the victim may have to spend underground prior to hospitalisation.

Plaster of Paris has been used underground to immobilise fractured limbs on prior occasions, particularly in two notable incidents (1,2). Unfortunately plaster has a number of drawbacks for use in the underground environment:

(i) A finished plaster cast is unable to take the patient's weight without cracking for at least 48 hours under normal conditions above ground. In the high humidity encountered underground, it is doubtful if the cast would dry out sufficiently to bear weight at all.

(ii) Plaster casts are rapidly broken down by water.

(iii) Plaster casts are heavy, bulky and have a poor impact resistance.

Over the past few years several new casting materials have been developed to overcome the drawbacks of plaster. One of these was recently used in the incident in Agen Allwedd by Mizrahi, who has also had considerable experience of the use of Baycast both in the cave rescue training sessions above ground and underground with the Gloucestershire Cave Rescue Group (3). It was therefore decided to try the full range of available materials in an underground environment, to evaluate their suitability for cave rescue purposes.

MATERIALS AND METHOD

The complete exercise was conducted underground in the entrance series of Ogof Ffynnon Ddu I.

The air temperature, humidity and water temperature were recorded in the area that was used for the application of the casts.

Five casting materials were evaluated :

(i) BAYCAST (Bayer UK)
A moisture curing polyurethane prepolymer coated onto a cotton gauze.

(ii) CRYSTONA (Smith & Nephew Limited)
Polyacrylic acid and an alumino-silicate glass coated onto a cotton gauze.

(iii) HEXCELITE (Hexcel UK)
A polycaprolactone (thermoplastic) coated onto cotton gauze which becomes pliable at 80^{o}C.

(iv) SCOTCHCAST (3M Company)
A moisture curing polyurethane prepolymer coated onto a knitted fibre-glass backing.

(v) ZOROC (Johnson & Johnson Ltd)
Plaster of Paris and a melamine-formaldehyde resin coated onto a cotton gauze.

Each of these materials was applied as a long leg walking cast with the exception of Hexcelite, which was applied as a below knee walking cast, since insufficient material was available for a full leg cast. Finally, a type of cast called a femoral functional brace was applied, to evaluate the performance of the knee hinge in comparison with the long leg casts. The types of casts are illustrated in Figure 1.

The five volunteers were of similar weight and fitness and had casts applied as follows:

The leg was first wrapped with a layer of undercast padding which was applied directly over the neoprene of the volunteer's wet suit. Water shedding paddings were used, i.e. Soffban (Smith & Nephew) or Softexe (Cuxton Gerrard), or polypropylene stockinette and webwrap (3M Company).

Each casting material was applied following the manufacturers instructions as closely as possible with regard to the number of layers, moulding techniques and the time required before weight bearing. The materials requiring immersion in cold water were dipped in water drawn from an adjacent pool at ambient cave temperature. These details are summarised in Table 1. In order to permit observation of peripheral circulation during the caving exercise, the toes were not enclosed in the casts but the foot of the cast was enclosed in a removable canvas or leather 'cast-boot' with a thin rubber sole.

The casts were left on for the manufacturer's recommended time before weight-bearing was allowed, followed by a pre-arranged caving trip in the entrance series of OFDI (accompanied by numerous helpers!)

This was planned to include the following features:

a wide, high passage with irregular floor (20 metres);
a low, narrow rift passage (50 metres);
a high, wide, steeply ascending passage (75 metres);
a tight tube with right angle bend, directed sharply downwards (15 metres);
a long section of fairly low, rough abrasive passage, necessitating crawling on all fours with several wet sections (125 metres);
a 10m ladder pitch;
a river passage varying from knee to waist depth (125 metres);
a wet uphill crawl on rough floor (15 metres).

Along the route (which took about two hours to complete) observations were made after each 'obstacle' with the plaster boot removed. The victims were asked about comfort, pain, cold and were examined for any impairment of skin circulation or chaffing areas. The plaster was inspected for cracks, areas of softness, any delamination and any other salient features.

At the completion of the trial the casts were, if possible, taken off underground using a pair of standard shears.

RESULTS

The air temperature was 12°C with 100% humidity. Ambient water temperature was 9°C.

BAYCAST

The first cast of 6 rolls and 1 slab started to soften within 10 minutes of setting off with loosening at the top end of the plaster. After the wet crawl (30 minutes) the cast was quite soft and by one hour had separated into layers at the ankle. The volunteer complained of a cold foot but this was thought to be due to the hole in the boot as his circulation was unimpaired. Otherwise he found the cast comfortable.

In view of the initial problems, a second cast was afterwards applied to the same volunteer but using considerably more material. This cast stood up well and in fact was worn around a longer section of cave (as the ladder pitch by this time had been derigged). After the trip down the mainstream the volunteer reported that he felt 'bendy below the knee' and slight softening at the top of the cast was noted.

Neither of these casts presented any problems in removal. Some delamination of the individual layers of the cast was discernible.

CRYSTONA

This was found to be easy to apply and mould and it set in stated time. The cast stood up well to weight-bearing, crawling and full immersion in the stream passage. After about 90 mins a fine crack was noticed in the front of the ankle and a soft patch on the sole but the overall strength of the cast was not materially impaired. There was virtually no softening around the top of the cast and the volunteer did not complain of any discomfort. Removal of the cast was easily accomplished.

HEXCELITE

This was slightly difficult to apply as it involved removal of a backing strip while holding a hot roll of the material. It set very quickly and was probably ready for weight bearing after 15 minutes. The cast stood up well to the conditions with no softening. The open weave construction, however, did collect

TABLE I Casting Materials and Conditions Used

Product	Manufacturers Recommended Parameters						Underground Parameters	
	Dip Water Temperature	Activation Procedure	Setting Time	Weight Bearing Time	Number of Layers Required	Shelf Time	Dip Water Temperature	Amount Applied
BAYCAST	Room Temperature (20°C)	Dip 5-10sec Squeeze roll while under water	5-10 mins	30 mins	9 - 12	6 months	9°C	(i) 4x4" rolls 2x6" rolls 1x6" slab (ii) 9x4" rolls 2x6" rolls 3x6" slabs
CRYSTONA	Room Temperature (20°C)	Dip 5-10sec Excess water shaken off	9-12 mins	1 hour	8 - 10	Up to 2 years	9°C	16 x 4" rolls (3 applied as slabs)
*HEXCELITE	80°C	Immerse for 4-5 mins Water allowed to drain off	3 - 6 mins	30 mins	4 - 5	Indefinite	80°C	5 x 4" rolls*
SCOTCHCAST	Room Temperature (18-24°C)	Dip 10-15 sec. Excess water shaken off	6 mins	30 mins	5 - 6	At least 1 year	9°C	6 x 4" rolls
**ZOROC	Warm water 30°C	Dip 5 sec Firm squeeze	5 - 8 min	1 hour	6 - 8	3 years	30°C	5 x 4" rolls 6 x 6" ** Gypsona

* Below knee walking cast only

** See results

some mud and sand (washed out in the stream) and the cut ends of the open weave abraded the skin of the foot. Removal was not difficult with shears.

SCOTCHCAST

This was easy to apply and the cast set in the stated time, becoming absolutely rigid. After the exercise the cast was unscathed and there was no sign of cracks, softening, delamination or other deterioration. The volunteer reported that the cast was comfortable but that his toes had been cold.

It was only when it came to removing the cast that difficulties were encountered. Using the large shears the leg portion could be cut but this required considerable strength. The ankle part resisted all such efforts and the volunteer was sent out of the cave with his half removed cast to have it removed by means of a mains-operated reciprocating plaster saw!

ZOROC

This material took longer than the recommended time to set due to the very humid and cold conditions. Some ordinary plaster (Gypsona) was applied over the resin plaster and after one hour the cast was enclosed in plastic bags prior to starting on the route. Application of the roll was more difficult than plaster due to the lack of creaminess. The plaster remained more or less intact although the Zoroc had softened and cracked around the foot.

In contrast to the other materials, immersion in water is not recommended for Zoroc casts as they are plaster-based. It was included in the trial for completeness and in view of the composite nature of the cast it will not be discussed further.

DISCUSSION

The application of cast splintage underground for limbs which have been injured in caving accidents may play a crucial role in facilitating the victims evacuation to the surface. Ideally, such a cast would enable the caver to assist himself through obstacles such as boulder chokes, crawls, rift passages and thus cut hours off the rescue time. In the preparation of a cast it has long been realised that traditional plaster of Paris has distinct limitations. This study has attempted to evaluate the potential of some of the newer synthetic casting materials for use in cave rescue.

It is fully appreciated that a study of this nature over-simplifies the problems which might be encountered in a real rescue. Our volunteers did not have broken legs; were in no danger of exposure and probably enjoyed themselves! While one must be cautious interpreting the results, it is felt nevertheless that the trial has provided information useful for those involved in cave rescue organisations.

On the whole, we were favourably impressed by the synthetic casting materials. They are, of course, marketed primarily for use in hospitals and very different criteria of suitability have to be taken into account when emergency treatment underground is being considered. It is hardly surprising that in this situation some of the products should have appeared more applicable than others.

Ease of application of the casts was an important consideration. It was generally agreed that the Crystona was the easiest to apply and mould, probably because of its close similarity in application to Plaster of Paris. Scotchcast was also easy to put on and one had to make the conscious effort to avoid using too much. Baycast was thought to be less easy to apply, being somewhat tacky and difficult to mould. Residual tackiness of the cast even after curing is common to both Scotchcast and Baycast and can readily be overcome by rubbing in a silicone or paraffin-wax based hand cream. The disadvantage of this, however, is that further layers of the material will no longer adhere, so that later reinforcement of a weakened area is not practicable. Hexcelite being a thermoplastic, has to be melted in hot water before being applied. While this is not an insurmountable task in a rescue situation it is hardly a point in its favour when comparison is being made with cold-curing alternatives. The risk of burns through accidental contact of hot casting material or water with the victim's skin is perhaps more apparent than real but merits precaution.

Wide variation was noted in the amount of different materials needed to produce casts of comparable strength, e.g. 16 rolls of crystona were used as opposed to just six of Scotchcast. In comparing the suitability of these materials for cave rescue, bulk is certainly of some importance both with regard to transport and surface storage. It is not, however, an overriding factor since there is not usually any shortage of willing porters on rescues.

All of the casts made up from the four materials on trial were regarded as superior to Plaster of Paris under the same conditions. The Scotchcast,

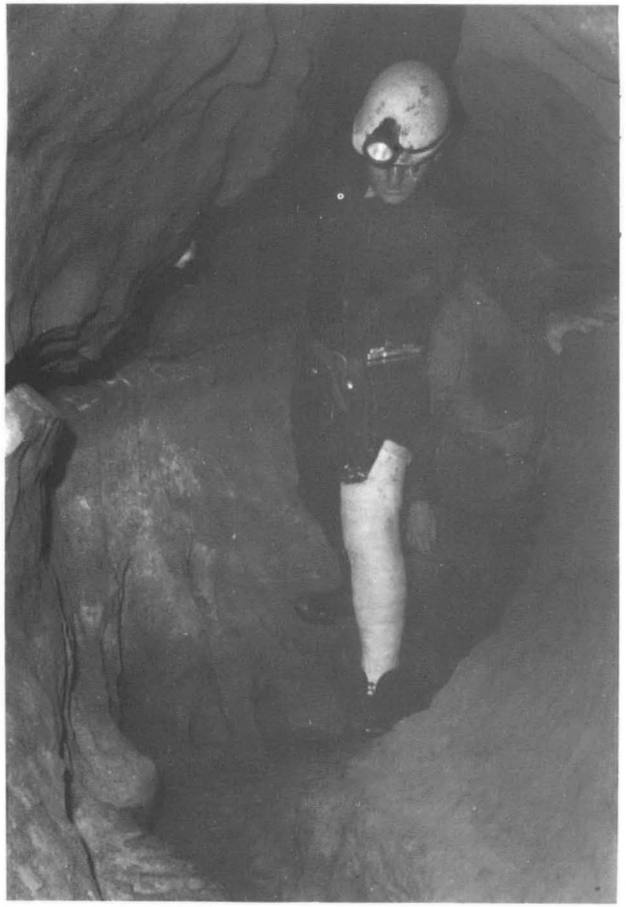
PLATE 1.

1.Application of Baycast over water-shedding padding.

2. Application of Scotchcast.

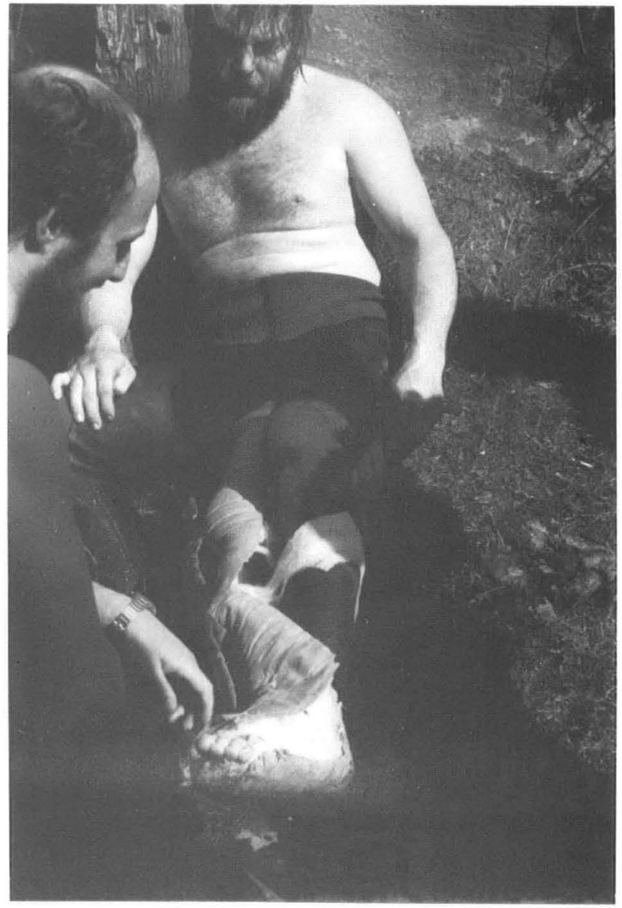
3. Application of Hexcelite showing removal of backing strip.

4. Completed Hexcelite cast.



1.Scotchcast leg in action

2. Removal of leg part of Scotchcast.



3. Removal of the second Baycast splint.

PLATE 2.

Crystona and Hexcelite casts stood up well to being dragged in flat-out crawls and wet passages. They withstood bumps and knocks associated with movement along constricted passages and were all strong, light in weight, water resistant and possessed excellent impact resistance. We were impressed at how well the materials stood up to the stream passage. The first of the casts prepared from Baycast was less impressive and in retrospect there may have been some over-confidence in the mechanical strength of the material. The second splint, employing several more layers was much more satisfactory, though even then, some separation and softening was demonstrable after total immersion.

If ease of application of the cast is of obvious importance, the simplicity of removal may be less significant to the layman. The explanation is that in all limb fractures the presence of a complete encircling cast carries a distinct risk of constriction and circulatory embarrassment. It follows that it is absolutely imperative that any casts applied should be capable of immediate removal, even if the injured person is still in the cave. All but one of the casts were taken off very easily with simple plaster shears; the exception being Scotchcast. It was generally agreed that only rescue personnel thoroughly confident in the use of this material should apply this in a cave rescue situation because of the danger of making too thick a cast.

The shelf life of the splintage materials is worthy of close attention since hopefully the rescue supplies will not be taken out from the rescue stores for use too frequently. The tendency to slow deterioration shown by Plaster of Paris is also exhibited by some of the newer materials (see Table 1). Baycast probably has the shortest shelf life and although supplies can be exchanged at local hospitals this should not be necessary if materials with longer shelf lives are used. Hexcelite has an indefinite shelf life and would probably be very suitable for use in hot, humid conditions.

These materials are all very expensive (see Table II).

Table II Approximate Costs of Materials used in Trial

BAYCAST	cast (i)	£10.35
	cast (ii)	£20.20
CRYSTONA		£23.52
HEXCELITE	short leg cast	£15.90
	long leg cast	£31.80
SCOTCHCAST		£37.56
ZOROC		£7.70
	+ Gypsona	£2.10
GYPSONA	(for comparison)	£3.10

Scotchcast is about eight times the price of plaster but in a cave rescue situation this comparison is not really applicable as plaster just wouldn't perform the same functions and the extra cost is justified for the extra benefits.

The cast boots used in this trial were of a design commonly used in hospitals and were less than ideal for use underground having hardly been designed for the rigors of caving! For rescue purposes, a cast boot needs to be strong enough to prevent stubbing the toes, warm enough to insulate the victims toes during immersion in water and be suitably abrasion resistant. At the same time the boot should allow easy access to the toes in order to check peripheral circulation and be adjustable to fit a range of foot sizes comfortably. There is clearly an opportunity for some useful development to take place in this area.

In conclusion, we felt that the trial served a useful purpose and gave us the opportunity to try the new materials out in extremely adverse circumstances. Various drawbacks were encountered which are discussed above and these should be considered when choosing which of these casting materials to use in a cave rescue. Of those tested Scotchcast stood up best to the rigors of use underground but might be difficult to remove quickly. Crystona most adequately met our requirements.

Footnote

Whilst the above trial was proceeding the opportunity was also taken of assessing the technique of functional cast bracing (for use underground). This is a relatively new method of splinting fractures and combines circumferential casts with hinges incorporated in the plaster enabling full knee flexion. In hospitals it is generally employed for fractures which have reached a stage of union where they are 'sticky' and it has proved to be a definite advance in fracture management.

One volunteer was "plastered" with 5 x 4" rolls of Crystona below the knee and 5 x 4" above the knee with plastic hinges embedded in slabs to each side of the knee. A roll of 4" Scotchcast was used as a final reinforcement. After one hour the volunteer was allowed to weight bear and followed the same route as the other five with considerably less trouble. Although knee flexion was possible the ladder pitch proved difficult owing to the ends of the rungs catching on the hinges.

Our impression was that the place of cast-bracing underground is likely to be very limited, especially as its use with fresh fractures allows slight movement and could cause considerable pain. It is conceded however, that very occasionally, employment of the technique could make all the difference between success and failure of a rescue. The facility of having knee flexion might allow an injured caver with a broken leg to be extricated from a tight constricted cave whereas with a rigid plaster this would have been totally impossible.

ACKNOWLEDGEMENTS

Our thanks are due to the six victims who hobbled in the casts, all the cavers who sat around and helped them, John Howes and Dave Mager for their photographic help, the companies who donated their products and showed such keen interest, 3M, Johnson & Johnson Ltd., Smith & Nephew, Cuxton Gerrard and Bayer (especially to Chris Sandy of Bayer who came underground and helped), Morriston Hospital plaster room staff and Anne Davies for secretarial help.

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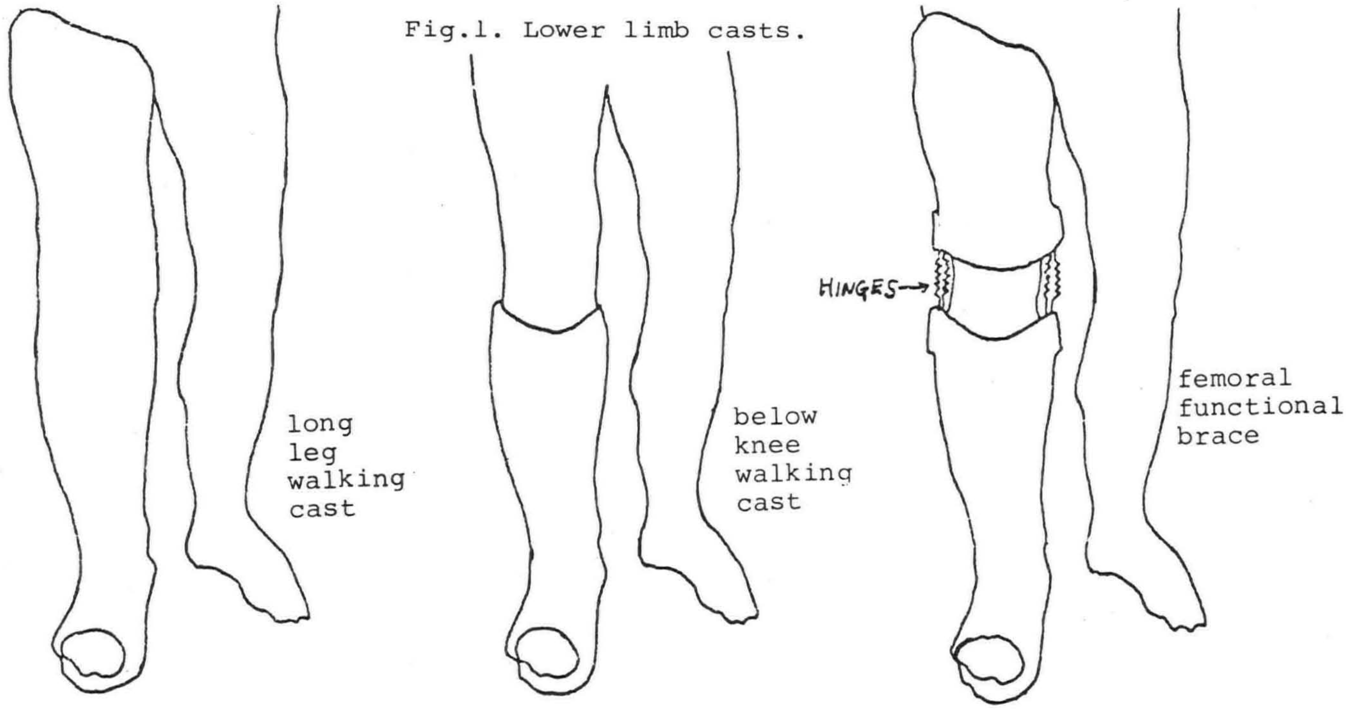
Fig.1. Lower limb casts.



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CASTS FOR SPLINTING CAVING INJURIES

by N. Mizrahi

Experience has shown that limb fractures are the most common significant injury to be met in a cave rescue situation. Adequate splintage will go far to minimise pain, blood loss and shock. This is especially important in cave rescue where extraction of the casualty can take many hours. Unfortunately, conventional methods of splinting - fracture boards, inflatable splints, etc. - are not really up to the extraordinary demands placed when a casualty has to be manoeuvred often in tight and/or wet passages.

The only really satisfactory way of splinting a leg or ankle injury is by applying a full plaster cast. Unfortunately, plaster of Paris is heavy and readily disintegrates in wet conditions. For the past year Gloucestershire Cave Rescue Group have been evaluating various types of splint material. A technique using polyurethane foam was considered by J. Frankland et al (The Practitioner, Vol. 209, pp. 831-834, 1972) but this involved mixing chemicals under fairly well controlled conditions and was found to be practically unsuitable for use in underground conditions.

Recently several manufacturers have introduced splinting material comprising woven bandages impregnated with a self-polymerising polyurethane activated by water. The first of these to be available in this country and therefore evaluated by us was Baycast. We have used this on many occasions during training sessions both on the surface and underground, and we have found it fairly straightforward to apply with a little practice. At cave temperatures the cast sets sufficiently to give good support within thirty minutes. Within 45 minutes the cast is strong enough to allow weight bearing. The latter aspect can be vitally important in a cave rescue situation as a weight-bearing cast would enable a casualty, who is in good general condition, to help himself with a little assistance. Not only is this far quicker than laboriously carrying a stretcher, but, recent experience has shown that keeping a casualty moving can ward off hypothermia for a considerable time.

We have found the cast to be a fraction of the weight of conventional plaster and virtually unaffected by long periods of soaking and abrasion.

We feel that cave rescue organisations should now seriously consider becoming familiar with the use of this casting material so that they would be in a position to apply it when confronted with a casualty with a suitable fracture where a long or difficult extraction may be involved.

Apart from the cost, i.e. £10 to £14 for a full cast, the main difficulty seems to be the limited shelf life. We have an arrangement with our local casualty hospital to change over our stock every six months. It may be a satisfactory arrangement merely to ensure that Baycast is available at local casualty hospitals and then ask them for a supply if and when needed. A suggested requirement that would cope with most situations would be :

4 x 15 cms. rolls
6 x 10 cms. rolls
1 x 15 cm. back slab
1 x 10 cm. back slab
3 rolls Lyoband foam bandage (for applying next to skin).

All of the above will just fit into a standard ammunition box. The other requirements of course, being at least two pints of water - not usually a problem underground!

Many of the above points were well demonstrated at a recent incident where a caver had sustained fractures to his lower leg whilst well into a long and difficult cave system. An inflatable splint soon came adrift; a plaster cast had then been applied but had soon disintegrated in the wet conditions. This was the first time that a Baycast splint had been used in a cave rescue situation in this country. A full - toe to groin - weight-bearing cast was applied after which the casualty was able to leave the stretcher and, with assistance, help himself for a large part of the way. The cast was unaffected by the prolonged abrasion and soaking and many hours were saved in his extraction from the cave.

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ALPHA-RADIATION IN KARST CAVES OF THE TRANSVAAL, SOUTH AFRICA

by Frances M. Gamble

ABSTRACT

During Spring, 1980, a preliminary investigation was conducted into α-radiation concentrations in karst caves of the Transvaal, South Africa. Results indicate that further monitoring is necessary, particularly during summer when ventilation is outwards and at a minimum. In addition, it appears that cave personnel should be rotated with surface occupations in some instances in order to reduce exposures. In these cases, regular monitoring of α-radiation should be instigated as a standard procedure.

An awareness of the interaction between Man and karst caves developed particularly as a consequence of an increasing recreational demand, and of the destruction of a finite resource. As caves are the last and possibly best of the remaining wilderness areas (Wilmut, 1972), their correct management is essential. The great tourist caves of the United States, through the National Parks Service, have been the sites of considerable management policy and technique research (Yarborough, 1977).

The first work on natural radiation in caves was published during the early 1960s (Yarborough, 1978). It was only in 1975 that serious investigations of the situation in Carlsbad Caverns, New Mexico (Wilkening and Watkins, 1976; Ahlstrand, 1977), and in Akiyoshi Cavern, Japan (Ikeya, 1976), were initiated. The increased occurrence of respiratory-tract and lung cancer amongst uranium miners prompted concern about other rock-enclosed spaces such as caves.

The intention of the present paper is to examine the occurrence of α-radiation in selected Transvaal caves, and their implications for personnel in both tourist and wild caves. This paper forms the report on a preliminary study of the local situation conducted during August-September (Spring), 1980. It is not conclusive, but serves to provide some guidelines for future action and research.

ALPHA-RADIATION IN ROCK-ENCLOSED SPACES

Small quantities of uranium and thorium are widely distributed in rock, sand and soil (Evans, 1969). During their initial radioactive decay, the chemically inert gases radon and thoron are diffused from the surface into adjacent water or air. They decay through alpha, beta and gamma radiation emission by daughter products to the stable nuclide, lead. The daughter products take the form of particles which adhere to condensation nuclei and other surfaces, and which may be inhaled or ingested. Of particular significance are the daughters, RaA, RaB and RaC to RaC′ in the radon chain, and ThA, ThB and ThC to ThC′ in the thoron chain. The half-life decay times of the radon daughters are approximately 3, 27 and 20 minutes respectively, whereas those for the thoron daughters are based on an initial decay of ThA of 0.16 seconds. Decay continues in situ, and, particularly through α-radiation, causes cumulative damage to respiratory-tract and lung tissue. The radon daughters are more hazardous than those of thoron by virtue of their longer half-lives. However, thoron daughters are actually more dangerous and therefore cannot be ignored in consideration of total α-radiation concentrations.

Concentrations of daughter products are determined initially by the amount of uranium and thorium in the host rock. They are particularly high in rock-enclosed spaces (Knutsen, 1977) in accordance with porosity, fresh rock faces, silt, shale, water and limited ventilation. The most important of these determinants is the ventilation rate, being inversely related to the concentration of α-radiation.

The α-radiation concentration during decay is expressed in terms of Working Levels (WL). The Working Level is defined as the concentration of decay products in one litre of air which ultimately results in the emission of 1.3×10^5 MeV of α-radiation (Evans, 1969). The cumulative exposure of visitors to α-radiation is time dependent, being expressed as Working Level Months (WLM) in accordance with months of 173 hours[1].

Definite adverse health impacts of α-radiation on uranium miners have been established. Consequently, exposure limits corresponding with those for radiation workers have been defined. (International Commission on Radiological Protection, 1976). These are presently:

- 4 WLM per annum
- an absolute maximum of 2 WLM per 3-month period, with a total exposure not exceeding 4 WLM per annum.
- a cumulative total exposure of 120 WLM in any 30-year period.

These limits are likely to be lowered quite substantially, mainly as a consequence of Swedish research (Young, 1979). Such mine standards do not apply to caves, but are regarded as being indicative of possible problems in some caves where high α-radiation levels are monitored (Yarborough, 1977). These limits must be reduced by a factor of 10 for smokers (Knutsen, 1977), and by a factor of at least 7 for respiratory infection (Creasia, et al, 1972). Members of the general public are permitted much reduced exposures (International Atomic Energy Agency, 1962).

- 1.5 rem to a single organ per annum
- 0.5 rem to the whole body per annum

Persons under 16 years are permitted no exposure above the general background radiation levels.

A number of guidelines relevant to the cave situation may be extracted from the uranium mines recommendations (Yarborough, 1977):

1. In general, public exposure should be limited to 10% of occupational exposure, and to 3% for a large population sample.

2. 0.1 WL = no problem, requiring no cavern monitoring
   0.2 WL = monitoring of cave annually
   0.2 - 0.3 WL = semi-annual to quarterly monitoring of cave
   More than 0.3 WL = problem
   1.0 WL upwards = medical supervision of exposure (Young, 1979).

To date investigation of cave radiation levels has been very limited. It has been confined mainly to National Parks Service caves, especially Carlsbad Caverns, in the United States. The major reported findings of these studies are that:

- there are strong diurnal and seasonal fluctuations in concentration (Ahlstrand, 1977; Yarborough, 1977; Seymore et al, 1980);
- these fluctuations are dependent on temperature, ventilation and, to a lesser extent, pressure (Ahlstrand and Fry, 1978);
- the average levels of α-radiation in the monitored caves vary from traces to 2.5 WL (Yarborough, 1978);
- concentrations of up to 18 WL have been monitored in caves (Knutsen, 1977).

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[1] 1 WLM of exposure is accumulated at concentrations of 1 WL for 173 hours - the average monthly exposure for a 40-hour week. 1 WLM is approximately equal to 1 .25 rems.

Mammoth Cave has revealed a major, but not insurmountable, problem (Yarborough, 1978). Due to the temperature-maintenance attempts of winter sealing of the cave, alpha-radiation levels are high. It is only by solicitous rotation of personnel between the cave and surface areas that exposure can be maintained at levels below 4 WLM per annum.

As these α-radiation levels monitored in caves may be regarded as potentially hazardous, concern has been expressed about implications for both visitors and employees. The general conclusion at this stage is that there is no danger to visitors, because of the very limited duration of their exposure, but that in certain instances, there may be a problem for cave guides and other underground personnel (Oldham, 1976). Such a situation requires co-ordination of the monitoring programme, as for example the National Parks Service does in the United States.

In South Africa, the concentrations of α-radiation emitted by daughters of Radon have been monitored in the gold and uranium mines. It has been concluded that due to the good ventilation throughout the mines, there is no need for concern about the exposure of miners in the area (Rapson, 1971). It was in this light and that of overseas experience that a brief preliminary investigation of the situation in Transvaal caves was undertaken. During this study emphasis was placed on those caves visited frequently as tourist or educational sites.

THE TRANSVAAL STUDY

During August-September (Spring) 1980 a preliminary investigation of the α-radiation concentrations in Transvaal karst caves was undertaken.

Fig. 1. Distribution of caves in which α-radiation was monitored in the Transvaal.

Twelve caves (Fig. 1) were monitored to provide:

- distribution throughout most of the Transvaal karst cave areas;
- coverage of existing tourist and wild caves, indluding those with potential high intensity recreational usage, by both tourists and speleologists;
- sack, or single-entrance caves, and transit, or multiple-entrance caves.

Monitoring was undertaken using a precision vacuum pump with 8μ filter papers, and a scintillation scaler with digital display (Rolle, 1972). This instrument provides a single count of total α-radiation activity over a 15-minute period, thereby giving a measure of the total human hazard. The monitoring programme involved a variety of conditions and situations in the caves (Table 1). The number and detail of sites within each cave was determined by the characteristics of the cave and by its use. In all cases, sites were selected to show the transition from entrance to deep cave zones, and variations from constricted passages to large chambers as appropriate to individual caves. Throughout the monitoring period, and in all cases, cave ventilation was slight and inwards.

TABLE 1 : Details of α-radiation monitoring in Transvaal caves, Spring 1980.

Cave	Date	No. of Samples	Average α-radiation value (WL)	Minimum α-radiation value (WL)	Maximum α-radiation value (WL)	Cave Nature	Cave Use
Sterkfontein	23.8	6	0.006	0.003	0.01	Transit	Tourist
Wolkberg	30.8	6	0.100	0.060	0.16	Sack	Tourist***
Mimosa	1.9	2	0.010	0.009	0.01	Sack	Wild
Peppercorn	1.9	1	0.030	-	-	Sack	Water supply
Ficus	1.9	3	0.012	0.007	0.02	Sack	Wild
Van Rooys	21.9*	5	0.050	0.002	0.03	Transit	Wild
Yom Tov	7.9	2	0.060	0.050	0.06	Sack**	Wild
Echo	13.9	8	0.160	0.020	0.62	Transit	Tourist
Sudwala	14.9	11	0.084	0.0007	0.15	Sack	Tourist
Abe Bailey	20.9	5	0.017	0.004	0.03	Sack	Educational***
Dripkelder	20.9	7	0.120	0.050	0.16	Sack	Wild
Bolts	21.9	7	0.040	0.030	0.05	Sack	Wild

* One reading in the entrance passage on 6.9.1980 included

** Cave gated - very little ventilation

*** Potential cave use

The ambient external α-radiation values, in both dolomite and quartzite areas, were 0.0001 WL, which may be regarded as normal atmospheric concentrations (Rolle, 1981). The average background total ionising radiation level in the Johannesburg region is 0.13 rem per annum (Atomic Energy Board, 1978). The cave concentrations therefore are regarded as being considerably higher than those of normal background α- radiation. The highest cave values recorded were in the remote sections of Echo Cave, beyond the tourist section, where 0.25 and 0.62 WL were measured. In the remote sections of both Dripkelder (wild) and Wolkberg (potential tourist) Caves 0.16 WL were recorded. In the First Chamber of the

Wolkberg Cave and in the Devil's Workshop of the Sudwala tourist cave 0.15 WL was measured. These high α-radiation values corresponded in all cases, except the Wolkberg First Chamber, with areas of poor ventilation. Caves in the Transvaal are of limited dimension, of phreatic origin and are generally dry except for occasional small lakes of water-table origin. These features contribute to the limited air exchanges experienced, and frequently to accumulations of silt and rock break-down. The Wolkberg First Chamber is dominated by large, old and inactive speleothems as well as by extensive silt and rock breakdown deposits. By contrast, most of the low α-radiation concentrations were measured in the entrance zones of the caves. They were particularly associated with marked inward ventilation implying dilution by the external atmosphere. It is most likely that during summer, with air flow reversed and reduced, levels would be considerably higher.

EXPOSURE TO ALPHA-RADIATION IN TRANSVAAL CAVES

Exposure to cave atmospheres and thereby to α-radiation in the Transvaal occurs on three levels: the occasional tourist visiting a commercial cave; the speleologist or research scientist exposed for between 16 and 40 hours per month; and the cave personnel exposed to approximately 170 hours per month. Some committed research scientists may also fall into this latter group on an intermittent basis according to the nature of individual research projects.

The nature of the exposure varies. The average tourist is exposed only to easily accessible and congenial sections of a cave where dust levels are usually fairly low. The cave guide is exposed to similar conditions for lengthy periods, and usually has additional limited exposure to conditions more severe in terms of accessibility and inhalation. The active speleologist and research scientist are probably the most severely exposed visitors to cave systems though visits are usually of less duration than guides. As the Transvaal karst caves, formed in the Malma dolomite, tend to be of limited dimensions and to contain substantial silt deposits, accessibility frequently demands crawling and/or swimming, with associated ingestion of dust and water respectively. In addition, activities in which these persons engage frequently generate dust. High atmospheric humidities (averaging 98%) also generate ideal conditions for the plating out of radioactive daughters on condensation nuclei.

IMPLICATIONS FOR MANAGEMENT

The observations of Transvaal caves in Spring 1980 indicate that α-radiation is present in the cave atmospheres of the area to a greater or lesser extent. However, a definite pattern is not yet established. It appears that poor ventilation is the main control, but that the occurrence of silt, dust, recent water and rock breakdown are all contributory factors. It is possible that shale inclusions and/or banded-ironstone may also contribute to the very high values.

It is obvious that caves in the same vicinity vary quite considerably, and also that individual caves may vary daily. On all occasions during the observation period ventilation was inwards being conducive to dilution of α-radiation concentrations. It is possible that values may be increased during summer with minimum and outward air movement. Conversely, during winter values may be slightly lower. In addition, other caves may demonstrate quite different characteristics.

It is apparent that under these conditions :

1. there is no danger to the casual visitor (tourist);
2. there is no proven danger to speleologists or scientists depending upon actual length of exposure;
3. there may be some danger to cave guides where they are continuously exposed to high levels of α-radiation, such as at Echo and Wolkberg caves;
4. there may be some danger if prolonged exposure is experienced in certain caves, particularly as there is some likelihood that concentrations would be higher in summer.

It is therefore essential that the monitoring should be extended to other caves and to a longer time period in order to obtain a more definite picture of the situation in the Transvaal. In addition it is essential that a number of problems are borne in mind when assessing the hazardousness of particular exposure. These include the complications of smoking and respiratory infection both of which affect the cilia in the lungs. The increased ingestion of α-radiation by speleologists must also be considered. This latter occurs during the movement of speleologists through a cave system, and particularly when moving close to the surface in dusty regions frequently with mouths open. It is also ingested when radon-rich water is consumed (infrequently), although this ingestion is not a great hazard (Somela and Kahlos, 1972).

The likelihood is that exposures of cave personnel, speleologists and scientists to α-radiation would exceed 1 WLM per annum. In limited cases it may be considerably higher than this and may warrant rotation of working areas in order to reduce the dose. In any case, where exposure limits are likely to be reduced and one is dealing essentially with members of the general public, a policy of minimising exposure as far as possible is essential. The cumulative effects of exposure must also be considered.

CONCLUSION

The present study of the α-radiation concentrations in Transvaal caves is a starting point - a preliminary study in order to provide some indication of the necessity for further work in this field. It is apparent that in view of the fairly high readings obtained, the fact that many occur in high intensity recreational caves, and the fact that concentrations are likely to be higher at other times of year, further investigation should be undertaken.

In the interim it is essential that the exposure of personnel should be limited. For example, where at least one high concentration has already been monitored, rotation to surface occupations should be practised with cave guides. In addition, other persons such as scientists and speleologists must be alerted to the possible problem to which they may be exposed. It is essential that there should be co-ordination of the monitoring programme, through the Provincial Nature Conservation Division as this body is already legislatively protective of caves in the Transvaal.

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ERRATA IN VOLUME 8 NUMBER 2 (Matienzo)

Plate 1, photo credit should be to A.C.Waltham
p.87. Part (i)(c) of the Abstract 2nd line, the scale should read 1:5000
p.88. Alpine Cough Pot should read Alpine Chough Pot.
pp.58,84,86 correct spelling is J.C.Fernández Gutiérrez.

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