Cave Science

The Transactions of the British Cave Research Association

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Volume 9 Number 3 September 1982

BRITISH CAVE RESEARCH ASSOCIATION

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Cover photo: Cross Swallet, Mendip; used tyres partly fill the cross-shaped sinkhole in periglacial lake sediments flooring Mendip's deepest closed basin (Photo by W.I. Stanton).

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Cave Science

By decision of the Council of the British Cave Research Association the Transactions is re-named CAVE SCIENCE from Volume 9 onwards. It will, however, retain the secondary title of Transactions of the British Cave Research Association and the volume numbering will continue unbroken. References in future citations should continue to include Trans. Brit. Cave Res. Assoc. as heretofore. Although bearing the name CAVE SCIENCE, the Transactions is not a direct continuation of the defunct journal of that name published by the British Speleological Association, which merged with the Cave Research Group of Great Britain in 1974. The volume numbering of the present CAVE SCIENCE neither continues the old series, nor does it overlap.

The editorial policy regarding the contents of CAVE SCIENCE remains unchanged.

CAVE SCIENCE

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THE FORMATION OF BLACK DEPOSITS IN SOME CAVES OF SOUTH EAST WALES

W. Gascoine

ABSTRACT

Water tracing done over recent years has shown that streams sinking on the surface of Mynydd Llangynidr do not always enter the cave systems beneath at points close to the position of the sinks; indeed in some cases streams flow considerable distances in the upper strata before entering the caves in the lower limestones and some remain in the upper strata to their resurgence points.

Black deposits are often present on the roofs, walls and floors of caves where such streams enter the systems; the deposits being in the form of soft flows, stalactite or stalagmite structures.

Analysis of these deposits has shown them to be largely iron and manganese oxides in a carbonate encrustation containing fine sand and some clay. The organic matter present, contrary to popular belief, is in very low concentration in spite of the substantial peat deposits present on the surface of these mountains.

As part of the South East Wales Groundwater Study carried out in 1979-80 by consultant engineers working for the Welsh Water Authority, a considerable number of underground water tracings were done in the area of the northern outcrop of limestone on Mynydd Llangattwg and Mynydd Llangynidr in Powys. The main object of the study in that area was to identify the catchment for the large spring near the head of the Clydach Gorge in Gwent known as Ffynnon Gisfaen. The spring is near the top of the limestone sequence well above the level of most known caves in the area, yet it has a continuous flow throughout the year and is only moderately affected by flood or drought.

The chemical composition and temperature of the spring water indicate that it has spent considerable time in the limestone (Welsh Water Authority, 1980).

During the winter of 1979-80 a series of sinks up to 7 km distant from Ffynnon Gisfaen were treated with a water and dyed lycopodium spore slurry and the spring fitted with a plankton net. The net was examined for the presence of dyed spores over a period of days and the successful tests were reported to the Water Authority: a catchment area for the spring was subsequently drawn up (Gascoine, 1980).

Several sinks on Mynydd Llangattwg were noticeably absent from the list of positive traces to the Gisfaen spring and in the following months work has been done on these sinks. One sink near the Beaufort-Llangynidr road (B4560) gave a positive trace using fluorescein dye to the Ace of Spades inlet in Ogof Agen Allwedd after 24 hours (Gascoine, in Humphries 1980). The unusual flow pattern from sink to Ace of Spaces has prompted a close look at the inlet and subsequent analysis of the black deposits that are present on the roof of the cave passage at that point. These deposits also occur in several other passages in Agen Allwedd and in other caves nearby.

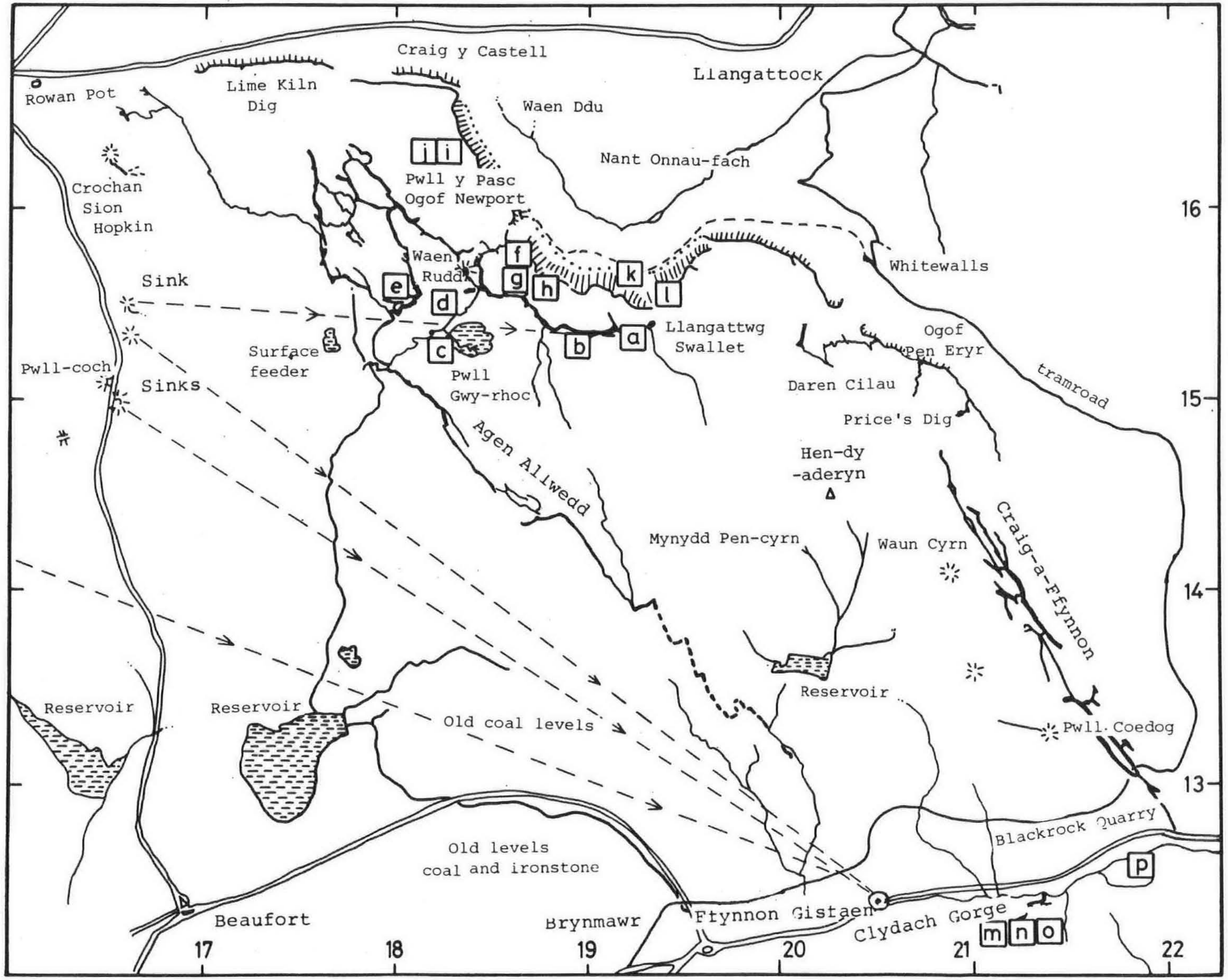
In May 1981 a further dye test from the newly discovered cave Pwll-y-Gwynt in the Dowlais limestone above Agen Allwedd also gave an unusual flow pattern to the lower cave (Gascoine and Millet, 1981) and Pwll-y-Gwynt has also turned out to be a rich source of the black deposits.

THE NATURE AND LOCATION OF THE BLACK DEPOSITS

The locations of the deposits that were analysed are shown by letters on Fig. 1, along with line surveys of the caves in the area and the locations of the sinks associated with Ffynnon Gisfaen; the spring is also identified. The stratigraphic succession is shown on Fig. 2.

The deposits that were sampled for chemical analysis are situated in the following cave locations:

Ogof Agen Allwedd (SO 1876.1579) is a large cave system in the lower Oolite Group nowhere penetrating above the Llanelli Formation which forms the roof of the cave at various points. The deposits sampled were in the areas named below:
(a) Ace of Spades inlet; a small series of phreatic passages at the eastern end of Main Chamber where water enters the cave through a small hole in the roof



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Price's Dig
Agen Allwedd
Hen-dy
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Mynydd Pen-cyrn
Waun Cyrn
Craig-a-Ffynnon
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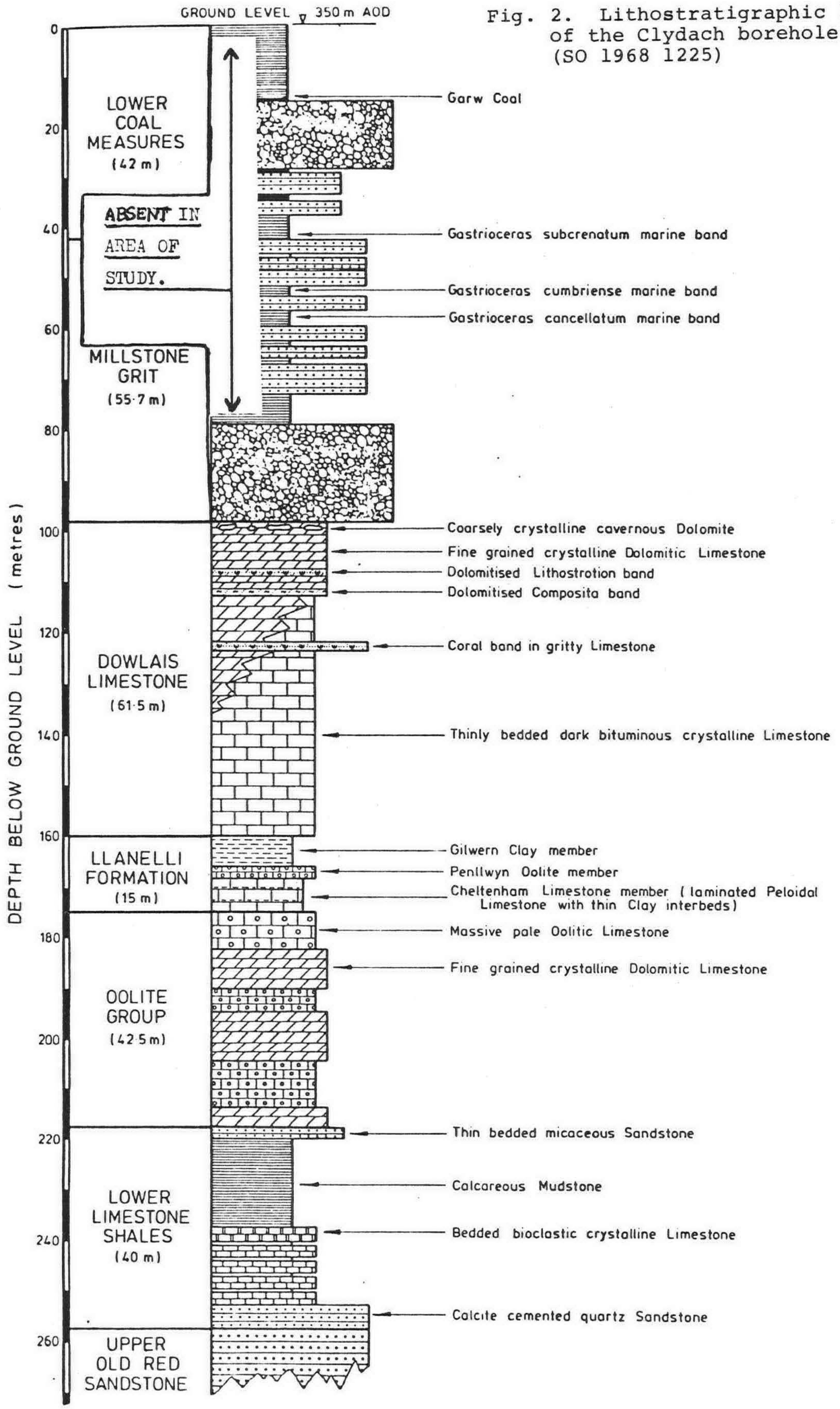
Fig. 2. Lithostratigraphic log of the Clydach borehole (SO 1968 1225)



above a 7 m pot. The deposits in the form of soft flows and short stalactites are on the upper walls of the pot.
(b) Trident Passage: east of Southern Stream passage off the Main Chamber where a stream flows in a tight rift, the black deposits occur on the walls at or near water level as soft flow formations.
(c) Second Boulder Choke: a large area of collapse in the mainstream passage of the cave. Black deposits are present as soft flows on rocks in the stream bed and on the walls of the passages. Deposits are most common near an inlet recently proved to carry water from the cave Pwll-y-Gwynt nearby. (Gascoine and Millet, 1981).
(d) Flood Passage: a small active stream passage just upstream of Second Boulder Choke carrying water of unknown source. Black deposits coat the walls of the passage at various points in both thin and thick layers.
(e) Twin Aven Chamber: a chamber containing fine calcite formations near to the Coal Cellar area of the cave where water enters from Pwll-y-Pasc. Black deposits coat boulders forming a choke at the north end of the chamber.
Pwll-y-Gwynt (SO 1870.1570) in the Dowlais limestone contains a series of shafts, some over 30 m deep, connected by small phreatic tubes near their bases. Black deposits were sampled in the following shafts:
(f) The Entrance shaft: the black flow deposits occur at various levels in the shaft and at its base in small rifts.
(g) The Fourth Aven: a black flow coats the walls of the aven where water continually drips from above.
(h) The Sixth Aven: where the boulder strewn floor of the aven has large amounts of a black soft encrustation on and in-amongst the boulders.
A substantial stream falls down the shaft to disappear in the boulders in wet weather.
(i) Ogof Newport (SO 1826.1613) contains the remnants of a bedding plane developed at the interface between the Dowlais dolomite and the overlying Millstone Grit. Black flow deposits occur in the floor of the bedding plane and in a blocked pot which descends 6 m.
(j) Pwll-y-Pasc (SO 1825.1610) is an extensive bedding plane at the interface of the Dowlais limestone and the Millstone Grit which contains two 18 m pots descending into the Dowlais beds. Black deposits coat the walls and floor in many places as flows and some small black stalactites occur here and there on the bedding plane roof.

Ogof Eglwys Faen (SO 1926.1566) is a cave due East of Ogof Agen Allwedd in the same oolite beds and with many similar features: it has black deposits in two main locations:
(k) The Entrance Chamber: a black film coats the wall of the chamber near the entrance where water trickles from the roof.
(l) The Inner Choke: a large wet boulder choke near the entrance to an extensive series of upper passages. Black flow deposits coat many of the boulders in the choke.
Ogof Clogwyn (SO 2129.1238) is a resurgence cave in the Clydach Gorge lying in the lower Dowlais limestone some 15 m above the Llanelli formation. Black deposits occur in various locations:
(m) Small black stalactites coat the roof around the lip of a small stream inlet.
(n) Earthy black sediments lie on many of the upper phreatic shelves common in the stream passage.
(o) A black granular sediment is present in the floor of a small upper passage where it meets the main stream passage.
Shakespeare's Cave (SO 2170.1249) in a small gorge off the main Clydach Gorge contains a single rift passage with black deposits in small quantities on its upper walls, usually in enlarged joints. The cave lies in the lower oolite beds just above the lower limestone shales.
Siambre Ddu (SO 2509.1145) cave is at Pwll Du 2 km to the South-East of the Clydach Gorge close to the northern edge of the coalfield but lying at the interface of the Dowlais limestone and the overlying Millstone Grit.

The cave contains a single large chamber with a profusion of black stalactites, stalagmites and flowstone, some with yellow or orange crusts in the form of small gours and flows. These formations were sampled for analysis in various parts of the chamber:

(1) the black sediment on the floor of the chamber which coats many of the boulders,
(2) the black flows which coat much of the walls,

(3) the orange crust which is present in places,
(4) the stalactites which hang from various parts of the gritstone roof (some of a large size up to 1 m long).

Searches in other caves in the area failed to yield any samples of the deposit; the caves visited were Ogof-y-Darren Cilau (2050.1520), Ogof Pen Eryr (2070.1523), Prices Dig (2110.1486), Fell Swoop (2000.1586), Blackrock Quarry Cave (2133.1263), Ogof Craig-a-Ffynnon (2201.1286), Blaen Onneu Quarry Caves (1583.1623), Ogof Dwy Sir (2444.1288), Pwll Du Quarry Caves (246.125).

In Pwll-y-Pasc and Ogof Newport a band of grey and orange shale some 15 m thick is visible in the walls of the bedding planes. In Pwll-y-Pasc the shale also contains nodules of an iron-rich mineral which has black and orange-red layers in a concretionary structure. These nodules on analysis proved to have high concentrations of iron as oxide (Table 1).

In Ogof Newport also, iron as the higher oxide is clearly visible as narrow bands of orange within the grey shale. Analysis confirmed its richness in iron (Table 1).

Table 1 Analysis of the Deposits

Location of deposit	Appearance	Ignition loss %	Acid insoluble %	Iron as Fe_2O_3 %	Aluminium as Al_2O_3 %	Manganese as MnO_2 %
Agen Allwedd						
(a) Ace of Spades	Black crust	39.6	26.7	9.5	13.8	6.5
(b) Trident	Black crust	25.4	24.0	6.0	17.4	16.0
(c) 2nd B.C.	Black crust	6.1	87.0	4.0	4.5	0.5
(d) Flood	Black crust	13.2	48.7	23.8	14.7	0.5
(e) Twin Aven	Black film	12.9	75.0	2.5	5.5	1.0
Pwll-y-Gwynt						
(f) 1st shaft	Black crust	17.1	35.3	7.5	11.0	16.0
(g) 4th aven	Black crust	23.8	56.4	10.5	0.6	1.0
(h) 6th aven	Black crust	17.8	48.6	14.0	16.5	3.2
Ogof Newport						
(i) Floor	Black powder	16.6	61.4	14.3	2.9	0.5
Shale band -	orange/grey shale	16.8	30.0	45.7	1.6	1.0
Pwll-y-Pasc						
(j) Wall/floor	Black crust	14.4	55.6	2.9	19.7	4.5
Nodules -	orange/black concentration	14.0	10.0	71.4	0.5	0.5
Siambre Ddu						
Floor	Black crust	33.3	49.6	0.5	17.0	1.5
Wall	Black crust	52.2	26.0	0.5	12.7	9.3
Orange flow	Crust/gours	35.0	5.5	0.5	54.7	1.0
Roof	Black stal	69.8	2.0	4.3	10.2	19.4
Eglwys Faen						
(k) Chamber	Black film	23.2	61.7	0.5	6.0	0.5
(l) Choke	Black flow	32.6	26.1	0.6	6.6	0.5
Ogof Clogwyn						
(m) Roof	Black crust	6.0	79.6	7.1	5.6	0.5
(n) Shelf	Black powder	22.2	53.0	2.8	4.7	0.5
(o) Floor	Black grit	42.0	51.6	3.6	1.0	0.5
Shakespeare's Cave						
(p) Wall	Black powder	16.3	74.0	5.0	8.2	0.5

ANALYSIS

The deposits were analysed for loss on ignition, acid insoluble content, iron content as iron (III) oxide, aluminium content as aluminium oxide, and manganese content as manganese (IV) oxide. The results of the analysis are given in Table 1 and Fig. 3 and the details of the laboratory methods used discussed below.

The black deposits and samples of shale were taken from their locations in the caves in plastic bottles, at least 20 g being sampled in each case. The samples were taken to the laboratories of Ebbw Vale College and dried in an

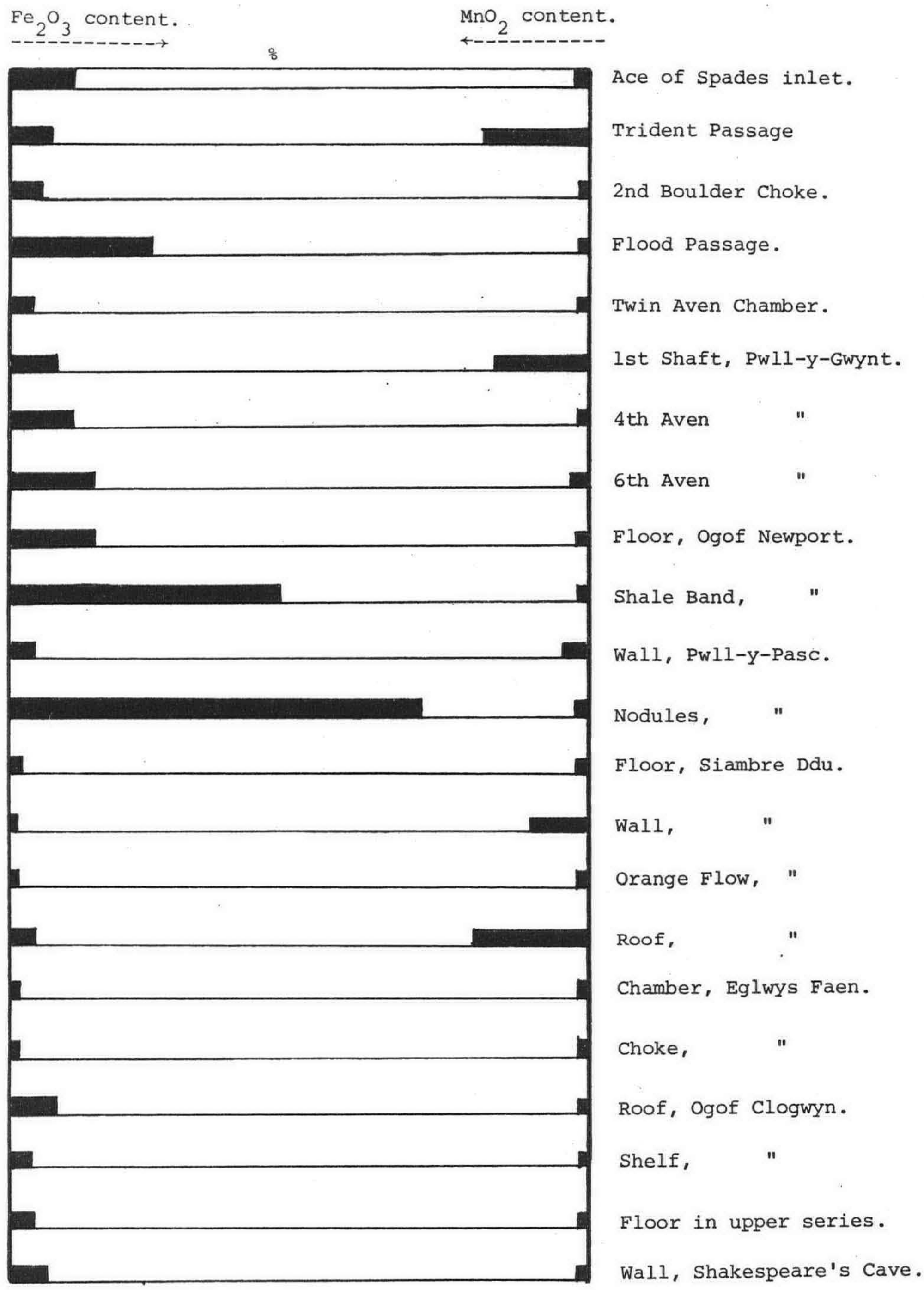


Fig 3. The Fe_2O_3 and MnO_2 content of the deposits.

oven at 110°C before being powdered in a pestle and mortar.

Two 1.0 g samples were taken of the powdered deposit, one to be ignited to constant weight in a silica crucible in a furnace at 1000°C, the other to be dissolved in an aqueous hydrochloric and nitric acid mixture with gentle heating until solution was complete (for a 1.0 g sample 50 cm^3 of water plus 25 cm^3 of each of the concentrated acids was used and found to be satisfactory).

The sample from the furnace was weighed to determine its loss in weight and this was recorded as loss on ignition in Table 1. The partially dissolved sample was filtered through a Whatman No. 41 ashless filter paper and, after washing with water, the paper and residue was ignited to constant weight in a silica crucible over a bunsen burner. The results were recorded as acid insoluble content in Table 1.

The metal ion concentrations in the filtrate from the acid treatment were determined by a wet analysis technique.

The combined filtrate and washings from the acid treatment were neutralized using concentrated ammonium hydroxide solution and then made slightly alkaline with the same solution. The mixed precipitate of iron (III) and aluminium hydroxide was filtered off in a No. 41 ashless paper and ignited to constant weight in a silica crucible over a bunsen burner. The total weight of oxide ash was noted.

The remaining filtrate was then treated with a concentrated solution of sodium hydroxide until the manganese (II) hydroxide precipitate was visible as a pale brown flocculent mass. This was treated with small aliquots of 40 volume hydrogen peroxide solution carefully until oxidation of manganese(II) to manganese(IV) was complete. The oxidised manganese precipitate was filtered off in a No. 41 ashless paper and ignited to constant weight as before. The weight of manganese(IV) oxide being recorded in Table 1.

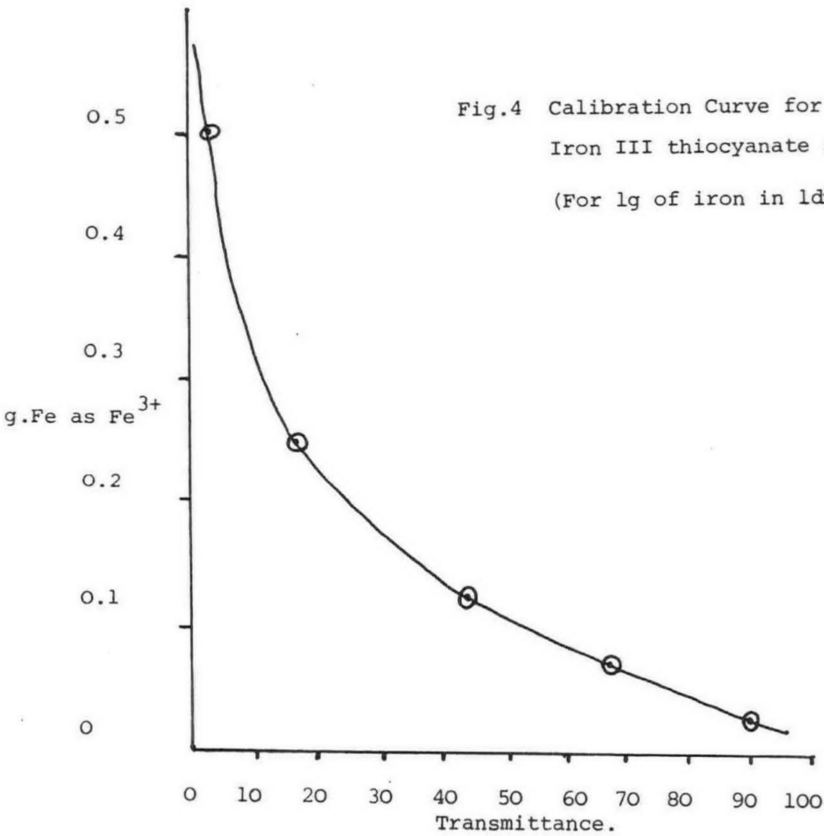


Fig.4 Calibration Curve for Fe^{3+} in Iron III thiocyanate solution (For 1g of iron in 1dm^3 of solution)

To ascertain the relative concentrations of iron and aluminium in the samples of the deposit, a further 1.0 g sample was dissolved in the acid mixture as before and the resulting filtered solution made up to 1 dm^3 with de-ionised water.

A pipetted volume of this was then treated with potassium thiocyanate solution and the blood-red iron(III) thiocyanate solution was put into an EEL Absorptiometer where its colour intensity was measured. Comparison with a graph of the absorption of various known concentrations of iron(III) in solution gave the iron(III) concentration of the solution and hence of the original sample of the black deposit. The results are on Table 1 and the calibration curve for the thiocyanate colour is in Fig. 4.

The concentration of aluminium as oxide was calculated by difference from the iron(III) by absorptiometer and the total weight of oxide by precipitation, see also in Table 1.

One sample taken from the Ace of Spades inlet in Agen Allwedd was analysed more completely by the British Steel Corporation laboratories in Ebbw Vale to ascertain the other elements present in the deposit and their relative concentrations, Table 2.

Table 2 Analysis of the Ace of Spades deposit (done by the British Steel Corporation Laboratory, Ebbw Vale).

Loss on ignition	39.6%	
Acid insoluble	26.7%	
Ca as $CaCO_3$	1.2%	
Fe as Fe_2O_3	9.54%	
Al as Al_2O_3	13.8%	
Mn as MnO_2	6.45%	
Mg as $MgCO_3$	0.61%	
Zn as ZnO	0.53%	
Pb as PbO	0.14%	
Sulphate	0.60%	
Phosphate	0.69%	Total 99.86%

It was not considered relevant subsequently to analyse for calcium and magnesium in all the samples as these metal ions are sure to be present in varying concentrations, the samples being taken from various layers of the limestone strata.

OBSERVATIONS BASED ON THE ANALYSES

The results of analysis shown on Table 1 and represented graphically on Fig. 3 show the large variation in metal content of the samples.

The samples described as being a film of black deposit, e.g. in Eglwys Faen and Twin Aven Chamber, Agen Allwedd proved mainly to be sand and clay with only traces of iron and manganese. This was to be expected as the film was on the surface of laminated clays which were taken as part of the sample. Little real effort was made to scrape off the film to get a more concentrated sample.

The samples that were in the form of black concretionary formations were in the main fairly rich in iron and manganese although the proportions of these two metals varied greatly. The Siambre Ddu samples especially, although often coated with a thin film of iron(III) oxide, proved to be much richer in manganese than iron; indeed the analysis of the orange gour-like material was surprisingly low in both metals in spite of its colour.

The loss of ignition recorded for the samples was concluded to be largely due to decomposition of carbonate, although originally decomposition of organic material derived from peat was suspected as Burke (1970) had noted stalactitic peat deposits in other South Wales caves. However, extraction by ether and benzene proved unsuccessful in separating any organic material from the samples; none of the dried samples gave an infra-red spectrum or a positive result to the test for lignin using phloroglucinol and it was noticeable that addition of the acids to every sample resulted in effervescence and loss of carbon dioxide to varying degrees. Some black shale was found to be present, especially in the Siambre Ddu samples, along with carbonate: this may be due to the proximinity of the Coal Measures to the cave. Although no coal exists directly above the cave, open-cast coal mining was carried out less than 1 km to the south and west.

The acid insoluble material present in varying quantities in the deposits was noticeably sand-like in appearance and microscopic examination showed it to be sand.

Although no quantitative work was done, it is thought that some of the iron in the shale bands and the black cave deposits may be in its reduced form as iron(II). It was noticed that the shale samples and the nodules steadily changed colour becoming more orange as they stood in the laboratory and there was a similar but less marked change in some of the powdered and dried cave deposits.

THE SOURCE OF THE DEPOSITS AND THEIR NATURE

The conclusions as to the source and nature of the black deposits found in the caves in the area of Mynydd Llangattwg are drawn from the following pieces of information which have been collected from personal observations and studies and by reference to literature concerning the geology of the area and its geochemistry (Jones and Owen, 1966).

a) Evidence for water flow in the upper limestones of Mynydd Llangattwg and Mynydd Llangynidr.

The series of water tracing tests done in 1979-80 using dyed lycopodium spores gave results indicating large volumes of water flowing in the upper Dowlais Dolomite or at the interface of the dolomite and the overlying Millstone Grit. All the sinks tested were in collapse features in the Millstone Grit where the grit was not more than 15 m thick and, although several kilometres away to the southeast, all the water resurged at Ffynnon Gisfaen which is itself only 5 m below the top of the Dowlais Dolomite (Welsh Water Authority, 1980).

The water flow to the resurgence was relatively rapid and no evidence was collected of any of the dyed spores entering the caves in the lower Oolite group or resurging at any of the springs in the lower limestone strata in the Clydach Gorge. Furthermore, recent dye tests on a sink close to the Ffynnon Gisfaen catchment using fluorescein has shown water is able to flow over the top of Agen Allwedd to enter the cave only at its far eastern end although the sink is to the west of the known cave.

Evidence of water courses at the interface of the Dowlais Dolomite and the grit is plentiful; Chartist's Cave, Ogof Cynnes, Pwll-y-Pasc, Ogof Newport, and several other smaller caves have bedding plane development in their upper passages with Millstone Grit roofs and in recent studies of the limestone in the area both by borehole and on the outcrop, workers have noted the presence of cavities near the top of the Dowlais beds in places up to 40-50 cm in diameter (Jones and Owen, 1966; Humphries, 1980). Bedding plane development is also present on Pwll Du, to the east of the study area where Siambre Ddu is a classic example of a cave developed at the limestone/gritstone interface. Ogof Hafod Wenog further south is another example.

b) Evidence for the presence of iron- and manganese-rich shales at the limestone gritstone interface.

It is well documented that iron-rich deposits occur amongst the Coal Measures above the Millstone Grit in the area to the south of the study area; however, only a few references have been made to iron deposits at the lower interface of the grit well to the north of the Coal Measures outcrop. Jones and Owen (1966) mentioned the presence of small cavities from 1 mm upwards in size lined with iron oxide deposits whereas the surrounding dolomite is iron free.

As part of this study two shales have been sampled: one in Pwll-y-Pasc where a grey and orange shale band 12-15 cm thick contains nodules of a concretionary iron deposit embedded in the shale and the other in Ogof Newport, a hundred metres or so to the north, where a grey and orange-red shale band also occurs. Both bands are in the upper walls of the bedding planes. Shale bands have proved difficult to identify on the outcropping rocks in the Clydach Gorge or the Llangattwg escarpment owing to extensive weathering and difficulty of access because of scree and other loose material.

c) Evidence for the Black Deposits in the caves being the result of the washing out of the shale bands.

Firstly, it is easily seen that water sinking on the surface of Mynydd Llangattwg and Mynydd Llangynidr is heavily contaminated with peat residues as it enters the gritstone collapses; its pH can be as low as 4.2 in mid-winter.

Secondly, it has been shown by dye testing that several areas of the caves in the lower Oolite group where the black deposits occur are fed by water that has sunk as acidic peaty water into collapses in the grit and in some areas passed through caves at the grit/limestone interface containing the shale on its way to the lower caves, e.g. the sink at SO 166.155 which feeds Ace of Spades in Agen Allwedd; water which flows via Pwll-y-Pasc to Coal Cellar, Agen Allwedd; water passing through Pwll-y-Gwynt, a cave rich in black deposits, enters Agen Allwedd at Second Boulder Choke where black deposits also occur. The sinks for Pwll-y-Gwynt have yet to be located.

Flood Inlet in Agen Allwedd, rich in black deposits, actually runs orange with iron(III) hydroxide as a flocculant precipitate after prolonged heavy rain. The source of water for Flood Inlet is not yet known.

In Siambre Ddu the black deposits are in places stained with red iron hydroxide and, although they are all kept wet with water percolating from the cave roof and upper walls, no sink is situated nearby on the surface which is only 10 m above the level of the cave. The source of the percolating water is not known but rising ground to the south may be a contributor.

CONCLUSIONS

a) The shale band.

It is concluded that the area of study there exists at the interface of the Dowlais Limestones and the Millstone Grit, a thin band of iron- and manganese-rich shale. In the area between the Beaufort- Llangynidr road and the eastern end of Agen Allwedd the shale is rich in limonite (hydrated iron(III) oxide) with some siderite (iron(II) carbonate) and in places nodules of haematite (iron(III) oxide) embedded in it. Wad (manganese(IV) oxide) is also present. The iron-rich shale band is not thought to extend much beyond Eglwys Faen cave for the other caves to the east failed to give evidence of the black deposit which is assumed to be leached from the shale. Indeed the few traces of deposit in Eglwys Faen did not really contain enough iron to show their origin as being in the shale. The shale band is present in the area of the Clydach Gorge although maybe not to such an extent as on Mynydd Llangattwg and is responsible for the iron content of deposits in Ogof Clogwyn and Shakespeare's cave.

The shale band, if it is still in situ, in the Pwll Du area would seem to be much richer in manganese than iron, possibly mostly wad; no exposure of it has been reported but the deposits in Siambre Ddu indicate its presence.

Streaks of the samples from the shales and deposits put onto tiles and compared with streaks of the actual minerals mentioned would seem to confirm these conclusions (R. Machin, pers.comm).

b) The black deposits in the caves.

It is concluded that acidic water from the surface peat is easily able to react with the iron- and manganese- rich shale. Iron(III) salts are 10^5 times more soluble in water at pH 6 than at pH 8.5 and the same trend is followed by manganese salts.

To illustrate the solubility characteristics of iron(III) hydroxide, consider its Solubility Product K_s :

The dissolving process is $Fe(OH)_3 \rightleftharpoons Fe^{3+}_{aq} + 3OH^-_{aq}$

$$Ks = [Fe^{3+}][OH^{-\ 3}]$$ where [ ] is the concentration in dilute solution.

This can be re-written as $K_s = \frac{[Fe^{3+}]\ K_w{}^3}{[H^+]^3}$

as $[H^+]$ is inversely proportional to $[OH^-]$, so a small change in pH which is a function of $[H^+]$ causes a large change in the value of $[Fe^{3+}]$.

The total amount of iron in solution at pH 8.5 can be up to $3 \times 10^{-8} mg/m^3$, at pH 6.0 it can be up to $5 \times 10^{-3} mg/m^3$ (Cooper, 1937).

The iron and manganese salts are thus able to be leached from the shale band and carried by the water while it is still acidic; however, contact with the limestone of the upper dolomite and continued saturation with iron and manganese will cause a rise in pH ultimately to pH 7.6 - 8.0 (the pH of most of the water flowing in caves in the area (Gascoine, 1980)) and as a result precipitation of the salts will occur.

It is known that iron(II) can precipitate from a solution with an acid pH often as iron(II) carbonate, especially in solutions where little or no dissolved oxygen is present, as may be the case in peaty water. This may well happen in the upper limestones but aeration in small cavities which occur in the upper Dowlais beds suggests that the main precipitation will be of iron(III) hydroxide occurring when the water carrying the dissolved salts becomes slightly alkaline.

The precipitation of iron(III) will take place at pH 7 - 7.5 followed at a slightly higher pH by precipitation of manganese as manganese(II) hydroxide or manganese(IV) oxide. This later precipitation of manganese(IV) is also likely to occur as the process needs more oxidising conditions which may only be present when the carrying water enters open cave passage lower in the limestone sequence (Mason, 1966).

Although not conclusive, the evidence from the analysis of the black deposits would seem to indicate that manganese may be carried lower into the limestone than the iron.

The deposits in Ogof Newport and Pwll-y-Pasc are in general richer in iron(III) than manganese(IV) whereas in Pwll-y-Gwynt and Agen Allwedd, lower in the limestone, there are deposits containing substantial amounts of manganese(IV) along with the iron(III).

It is concluded therefore that the black deposits in the caves are formed by precipitation of iron(III) hydroxide and manganese(IV) oxide (on or in clays and sands). These originate from a shale band above the Dowlais limestone and are carried to the lower levels dissolved in water. Their occurrence at or near points where the water enters the cave is due to oxidation by air encouraging precipitation at that point.

The deposits, either as flows or stalactites, are easily dislodged from their positions and can therefore be found also in stream beds and on boulder floors in various parts of the caves.

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MENDIP - PRESSURES ON ITS CAVES AND KARST

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(a talk given at the Cheddar meeting on "Cave Conservation", Summer 1981)

Abstract

Cave scenery is steadily deteriorating. Most of the damage is done by cavers but other culprits include farmers, industrialists, quarrymen and show-cave owners. The causes of damage are examined and examples are given of good conservation practice and theory. Mendip's karst features are threatened by farmers, industrialists, builders and especially quarrymen. The history of the conflict between karst and quarries is recounted and concluded wuth guarded optimism.

Conservationists divide Mendip caves into three classes. The first and by far the largest category is that of uncontrolled caves, which are at the mercy of individual cavers. Experience shows that in all such caves deterioration is a steady, more or less rapid, progression. Even if 95% of cavers visiting them are careful and responsible, the other 5% do the damage.

I began caving in 1941. I have been an active caver throughout the period of mass caving that started after the Second World War. I saw beautiful grottoes in G.B., Stoke Lane, Swildon's and Balch caves during or shortly after their discovery, and I have watched their glories fade. Can you show me any grotto, found recently in an uncontrolled cave, that is surviving? We were well aware of this state of affairs in 1960 when we discovered and named Doomed Grotto in Swildon's. I described it then as "a lovely grotto with a floor of white flowstone, crystal gours, and many glistening pure white formations. Especially attractive were some low mud pillars, each capped with a shiny blob of smooth calcite". Only 14 days later I cleared up a handful of glucose packets and polythene wrappings. Trusting to cavers' good sense is not enough; the few will undo the careful work of the many.

The second category is that of caves with restricted access and a leader system. On Mendip there are four of these: St. Cuthbert's, Shatter, Withyhill and Reservoir. They demand a good deal of dedication on the part of the leaders. Deterioration still occurs, but at a much slower rate.

The third category is show caves. I used to think that a well-run show cave could be the ultimate in cave conservation, but now the drawbacks have become more obvious to me. Stalactite formations - usually the main attraction - can be, and are, broken. Cheddar Caves are still losing individual stalactites to people who lag behind parties and then climb, crawl or wade to get the specimen they want. Wookey Hole (not known for its stalactites thanks to the poet Alexander Pope, who had many of them shot down for his collection) no longer shows the grottoes laboriously opened to the public by Herbert Balch, because of visitor damage. Protection depends on the enthusiasm and watchfulness of the guides, which is not always forthcoming.

Also in show caves the access and control requirements (paths, railings, steps, lighting, etc.) can dominate the scenery, spoiling the effect. Finally, the permanent lighting may cause algae, moss and ferns to grow, obliterating walls and formations and creating a scene which is often pretty, but is not cave scenery. The well being of a show cave depends on efficient and painstaking management, which cannot be guaranteed.

To summarise, the present position is one of steady deterioration in all caves. Access-controlled caves have the best record, because the control is usually exercised for the sake of conservation.

How many Mendip grottoes are still undiscovered? Not all that many, I suspect. From 1940 to 1970 the supply seemed inexhaustible, but is it not true that the last significant discovery of stalactite scenery was made in 1973? Of Mendip's 550 caves, 31 had what I would call fine grottoes when they were discovered, beginning with Lamb Leer in 1674 and ending with Manor Farm in 1973. Now, 17 of those 31 no longer contain significant stalactite scenery. I am thinking of caves like Brownes' Hole, Rod's Pot, Read's Cavern and Balch Cave.

What can be done to improve matters? I can't offer a grand master plan, but I will describe examples of what I have found to be good conservation practice in everyday situations underground.

Obviously it all begins when a cave is discovered. I worked out the other day how much Mendip cave I have been involved in discovering - it comes to about 3.5 kilometres. In the early days of Swildons' Black Hole Series, Luke Devenish, Howard Kenney, Colin Vowles and I took care to do as little damage as possible ourselves and assumed that other visitors (very few in those days) would take equal care. In the Saint Paul's Series we naively laid a guide wire through the lovely grottoes just beyond the Blasted Boss, with a notice asking cavers to stay beside it. It didn't last long, nor did the grottoes. As for the Trouble Series, we were too cynical by then to do more than predict doom. Swildon's was too heavily populated by people who boasted that they were "high-speed cavers" for the grottoes to stand a chance.

Lionel's Hole had few remarkable features beyond its extraordinary layout, but Reservoir Hole was better. Before 1969 the entrance was not effectively gated, and much damage was done. This experience led us to introduce the present leader system, which has worked pretty well.

The Reservoir Hole digging team consisted mainly of old-timers. We were not impatient, and there was no "rush to the end" following a breakthrough. We carefully picked our way along the passages, marking out a path as we went, a path that has been followed ever since.

In subsequent years we pushed ahead, and we never let the digging operations damage the cave. In fact we used them to improve our conservation measures. Excavated rubble, instead of being tipped at random, was used to build paths and steps. Some purists have objected, claiming that they give an unnatural look to the cave. Maybe so, but experience shows that visitors will follow a path, especially if the reason for it is explained to them. Broken or grubby stalactites, crushed gours, mud-smeared walls and trodden mud formations are even less natural.

Sometimes we had to use explosives very close to attractive scenery. We took the trouble to build anti-blast walls (temporary dry stone walls up to 1.5 metres high) to isolate the bang, and they proved effective. I can think of several cases in other caves where such a simple precaution would have saved major damage.

A word about the leader system. It arose partly from necessity (land-owners' requirements) and partly from our wish to ensure that access went hand in hand with maximum conservation. Parties are limited to not more than five persons, because this seems suited to the cave's dimensions and layout. Greater numbers, we found, led to carelessness: for example, someone at the back might want to talk to someone in front and would leave the path to overtake. Novices are not welcome. The standard reply form says "all visitors must be experienced enough to understand the need for conservation and to take the necessary care."

Operating the leader system is a considerable chore that devolves on one person, myself. The motivation springs, I suppose, from a wish and a responsibility to protect my own discovery from damage. Whether any other person or group would have the same feeling for this particular cave, I doubt. Some degree of emotional involvement seems to be required.

In practice, the system depends on the appointment, usually after two guided visits, of one or more trusted leaders from each interested club.

There are people who believe that access to all caves should be free and uncontrolled. This is a kind of ideology with which I have no sympathy because it is opposed to conservation. I have long held the view that, whereas most Mendip caves are best classified as sporting and uncontrollable (for various reasons) it is worth while trying to preserve a very few from the spoliation that results from mass caving. The caves with restricted access and a leader system number only four out of Mendip's total of 28 caves more than 300 metres long. Not too great a proportion, I would suggest.

Now some generalities: there is a simple equation which is highly relevant to conservation. It is: the rate of deterioration of a cave is proportional to the number of cavers visiting it, other things being equal. In other words, the more popular a cave is, the more it will suffer. Some caves can stand up to mass caving because of their nature. Eastwater, Longwood, Thrupe Lane, Sludge Pit, Tynings Barrows, Goatchurch, Lionel's - these are caves with little to lose, except by way of litter and graffiti.

Other popular caves have suffered terribly. The destruction of stalactite scenery in Swildon's, G.B., Stoke Lane, Lamb Leer and smaller caves such as Sidcot, Loxton and Rickford Farm has been colossal. Few people realise ..... etcetera, etcetera. And there lies the rub: if you don't realise what was once there, you don't miss it. So why worry about conservation? Is it merely a Darwinian instinct to ensure the survival of one's own personal values, a curious mixture of philanthropy and selfishness, that kindles this fire in some people to preserve and pass on that which has given them pleasure? Conservation is, after all, a matter of opinion; one caver's grotto may be another caver's racetrack. Perhaps the true conservationist is he who arranges to guide the racetrack through the grotto with minimal damage.

One thing is sure. Human beings are not naturally cave conservationists. In fact the opposite is the case. The average curious human, entering a cave for the first time, will want to familiarise himself with this new environment in the usual way by moving around looking, touching, taking souvenirs. It would be an intellectual effort for him to say "I like this place, therefore I will leave it unspoiled for others to enjoy". Conservation has to be learned, and taught.

Caves have other features that are worth conserving, but they tend to be of specialist rather than universal interest. Cave life - bats, bugs and plants - is an obvious example. So is cave history, ranging from speleogenesis (evidence of the formation of the cave itself, i.e. passage shapes and fillings) to archaeology (evidence of life in and around the cave entrance in more recent times).

Cave deposits are most vulnerable to cave diggers, many of whom, naturally enough, take little interest in the muck and rubble that they are digging out of the promising choked passage. No doubt it's my geological background that makes the deposits in a dig seem highly interesting, and I carefully record them and describe them when reporting on the dig. They always provide clues to the past history of the passage, thus to the likelihood of the dig being a dead end, or just a local choke in a big system.

Some cave deposits yield evidence of conditions on the land surface in Mendip's remote past. Gravels in a cave in Westbury Quarry are a million years or more old, consisting largely of exotic material that accumulated when the Mendip plateau was a broad plain not far above sea level, in a climate warmer than today's. Similar deposits are found in a few other ancient high-level Mendip caves. Many old swallet entrances are blocked by unbedded pebbly mud that sludged in under periglacial conditions. Observation and deduction in a dig at Charterhouse led to the discovery that miners worked lead-bearing solifluction deposits to depths of at least 15 metres.

I therefore regard the recording of cave deposits, whether geological, archaeological or mineralogical, as a necessary offshoot of cave conservation.

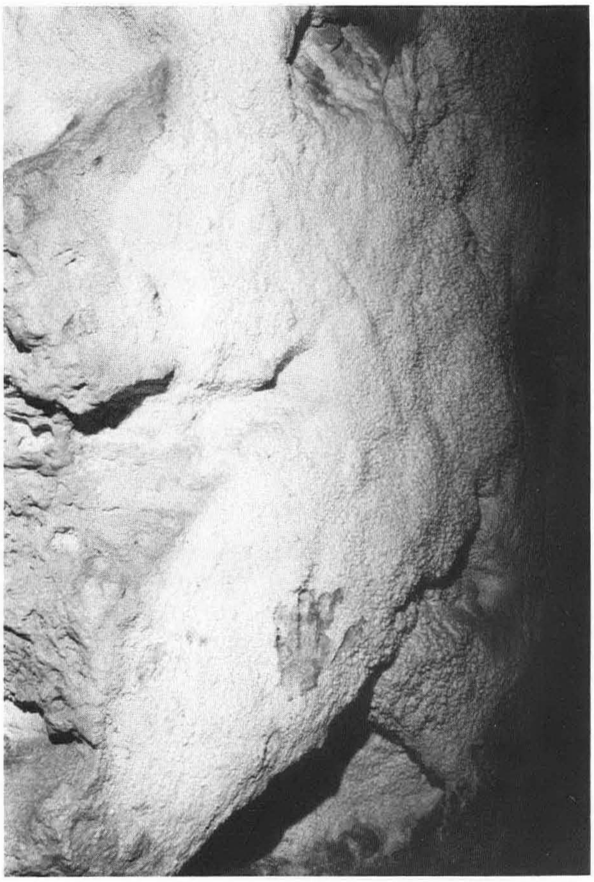
So far I have dealt with the ways in which caves can suffer from the direct attentions of cavers. Damage can also be caused indirectly by individuals who give wide publicity to vulnerable caves. If someone goes around saying or writing how marvellous a particular cave is, and exhibiting surveys and photographs to prove their point, they are really suggesting that everyone should visit it. The result is extra pressure on that cave, and unless it is protected in some way its deterioration will be accelerated. Publicists should be prepared to actively protect the caves that they promote.

There are pressures on caves other than those imposed by cave users. They are applied by what planners call "conflicting interests", that wish to use the space occupied by the caves for their own purposes. On Mendip the conflicting interests are agriculture, waste disposal, quarrying and building.

Farmers, all too often, improve their land by levelling it off. This is done by bulldozing depressions, or by filling them with tree stumps, dismantled stone walls, building or demolition wastes and the like. Several caves opening off swallet depressions have been lost, and in some cases partly filled. The Mendip examples are all fairly small: Cross Swallet (filled with old tyres), Alfie's Hole, Locke's Hole and Tankard Hole (builders' and commercial rubbish), Flower Pot and Hollowfield Swallet (bulldozed), Nedge Hill Hole (old walls) and Plantation Swallet, Bog Hole and Fairy Slatts (excavated material).

The loss in these cases is not great, and in several examples the only damage to the cave has been the blocking of its entrance.

Waste disposal is carried out by agricultural and industrial interests, and its main effect is pollution. Most caves are or should be protected from pollution by Acts of Parliament which various authorities, such as the Planning and Water Authorities, are charged with enforcing. The wastes capable of polluting caves are liquids and leachates, and Mendip has had its share of such pollutions, mostly carried out illegally or in defiance of a code of practice. Silage liquor, generated in badly made clamps, has percolated into Swildon's and Manor Farm, and into many caves still undiscovered. Farmyard washings entering North Hill Swallet exacerbated the augean labours of its heroic



1. Rare large expanse of moonmilk defaced by a handprint (P.Hann).

2. Debris from a dig formed into a pathway across a chamber (P.Hann).

3. Tankard Hole was here! The cave, 165m long and 52 m deep, is buried beneath rubbish filling a doline 8 m deep.

discoverers, and Cowsh Aven in Swildon's owes its name to the same cause. Nancy Camel's Hole was for some years knee-deep in organic slush from a calf-rearing unit.

In Fairy Cave Quarry the plant produced liquid slurry and silt that blocked whole sections of Hillier's and Hillwithy caves, and tar and oil from the same plant can be seen underground. A century ago the lead slaggers at Charterhouse ran the tailings from their buddles down Blackmoor Flood, Blackmoor and Waterwheel swallets, filling long stretches of passage with black mud rich in poisonous lead and zinc.

Industrial waste generally causes the foulest pollutions. Mendip's worst was in 1967 when some 50,000 gallons of waste oil carrying cyanides and toxic metals were illegally discharged into Nedge Hill Hole from tanker lorries. The floor, roof and walls of the cave were thickly coated with oil, and it was impossible to enter. More recently, in 1979, the stream entering Longwood Swallet was mysteriously polluted, possibly by liquids emanating from the glue factory nearby.

So far I have only dealt with cases of damage. The cave contents are affected, or the passages are blocked, but the cave itself remains. However, as we all know, Mendip caves are at risk to a far greater threat, that of total removal by quarrying.

Many Mendip caves were revealed when an advancing quarry face broke into them, and were subsequently destroyed as the face moved through them. Long ago when quarries were still small local affairs the cave might survive, as happened in the case of Loxton Cave, found in 1869, but even before then bone-bearing caves had been found and removed in Uphill Quarry, near Weston-super-Mare. The first sizeable caves to suffer this fate were those of Dulcote Quarry, Wells, from about 1890 onwards, and the process reached a climax in the 1960's and 1970's with the destruction of many quite large caves in Fairy Cave Quarry: Duck's Pot, Plummer's Hole, Balch Cave, Christmas Hole, etc. In 1980 the third or fourth largest Mendip cave chamber, Whopper Cave, was revealed and infilled in Batts Combe Quarry at Cheddar. Much of Stoke Lane Slocker is covered by a valid quarrying consent.

About one mile of known cave, some 3% of Mendip's total, has been destroyed by Mendip quarries. And doubtless there was more cave, never noticed by anyone but the quarrymen.

In 1966 I wrote "it has been said that these caves would never have been known had the quarry not revealed them, and therefore cavers should not grumble at their fate. The argument is invalid ..." and I went on to argue that they would eventually have been dug into. I still hold this view; more strongly than ever, having regard to the determined digging that now characterises the Mendip scene.

What can be done to stop the quarries? Well, much has been and much is being done, but as they threaten other karst features as well as caves I will come back to them later.

Mendip boasts a wide variety of classic karst features, but they are all under pressure from conflicting interests. Many have already been lost. Once again the culprits are farmers, tippers, builders and quarrymen.

I began mapping sinkholes on Mendip about 1948, and I can say confidently that these typical karst features are now much less common than they were. Along with gruffy (mined) ground, of which huge areas have vanished since the Second World War, they have been bulldozed because they are a bit of a nuisance to farmers. Other sinkholes have been used for tipping. Losses have been especially heavy around Priddy. I particularly remember a very deep sinkhole in the field opposite the Queen Victoria Inn, over Sump 12 in Swildon's, which, when the council houses were built, was adapted to take effluent from them, and was mostly filled with rubble at the same time.

The planning laws provide some slight protection for sinkholes. The four biggest Mendip examples (big enough to have their own names) : Wurt Pit, Devil's Punchbowl, Sandpit Hole and Bishop's Lot Swallet are scheduled Sites of Special Scientific Interest (S.S.S.I.'s), and the planners recently refused a formal application to fill Wurt Pit with tip ("and return it to agriculture"!) for that reason. But although Locke's Hole is in the Brimble Pit S.S.S.I. there is no way that the planners can prevent informal agricultural tipping in it, or in any other sinkhole.

There should be something mysterious and beautiful about another typical karst feature, a limestone spring or resurgence. The Early Iron Age Celts worshipped the clear water of springs even more, perhaps, than do today's cave divers. Few of Mendip's springs retain their ancient character, but an exception is the source of the River Axe at Wookey Hole, still magnificent in spite of centuries of service to industry. Inspired landscaping has actually enhanced the beauty of St.Andrew's Well, by Wells Cathedral, but too many Mendip risings are now covered by concrete or steel (in the interests of water supply), hemmed in by uninspired building, or buried under rubble and rubbish from quarries.

A unique spring in East Mendip, Mells River Sink, which reversed in summer to become a sink for the Mells River, no longer "springs" in winter because the deepening of Whatley Quarry, 800 metres away, has permanently lowered the water table. This spring and the nearby Hapsford Spring had the unusual habit of emitting dense swarms of air bubbles when they were active.

Visible pollution spoils the appearance of a spring, as well as killing plant and animal life in it. Fortunately this is fairly uncommon nowadays, because the Water Authorities are empowered to search out and prevent the causes of pollution. A notorious pollution in the recent past was that of the Cheddar resurgence, which ran grey and poisonous to fish during the several decades when lead slaggers were reworking the Charterhouse minery (in spite of several armed attacks on the mine installations by gangs from Cheddar). St. Dunstans Well is still chronically polluted by dust and slurry from quarries at Stoke St. Michael, and Holwell Rising recently suffered a pollution so bad that the Nunney Brook was deoxygenated for 1500 metres downstream of the rising. This was caused by the dumping of whey in a quarry 1100 metres distant from the resurgence. The firm responsible was traced and fined £500. Silage liquor and a leaky sewer at Oakhill were responsible for serious pollution of the Ashwick Grove Risings in the 1970s.

Mendip has limestone gorges and dry valleys as spectacular as any in Europe. It has closed karst basins up to one mile across that contained large lakes in the Ice Age. Some of these features have been and are still being badly damaged by quarrying. Some dry valleys, such as Batts Combe and Chelm's Combe at Cheddar, have been mostly destroyed by quarries that actually took their names from the valleys. Quarries have affected both Cheddar Gorge and Burrington Combe. The former was abandoned in 1906 after a huge landslide had blocked the Gorge and created Canyon Cave, and the latter intersected the cave, Plumley's Hole, in which the first Mendip cave fatality occurred in 1874. Westbury Quarry is eating into the side of the Brimble Pit closed basin, and in 1981 the operators applied for an extension that would remove the overflow channel to the basin. Somerset County Council planners rejected the application because the closed basin is an S.S.S.I. within the Mendip Area of Outstanding Natural Beauty.

In the days before planners ruled, any property owner could open a quarry on his land, and the only way to prevent it was to buy the land. Some of Mendip's finest scenery was saved by people who were prepared to put their money where their mouths were. In 1928, it was proposed to open a quarry at the entrance of Cheddar Gorge, starting with Lion Rock (which in those days, when undergrowth was kept down by grazing animals, did look amazingly leonine), and the Society of Somerset Folk raised the money, bought the land and presented it to the National Trust. In 1931, when Wing Commander Hodgkinson heard of a plan to quarry Ebbor Gorge, he stopped it by buying the Gorge for himself. Thirty-six years later his widow Olive gave it to the National Trust.

In 1948 Somerset County Council took control of quarry development in the county. By 1953 the Council was developing a policy that would give some protection to the Mendip landscape. It was becoming evident that whole hills could be removed by quarries, a process that had happened at Vobster and was well advanced at Dulcote and Sandford. The Somerset Structure Plan (1980) contains a clearly stated policy that should confine major quarry development to the extreme east end of Mendip, beyond Stoke St. Michael, where caves and other karst features are relatively rare.

I will finish with a brief examination of what I consider to be the ultimate threat to Mendip, its caves, and all its karst features - quarrying. Limestone is, of course, a mineral resource, and one of the main failings of Somerset County Council's 1971 quarry study was that it did not deal with the effect that extraction of mineral at the expected rates would have on the reserves, which in this case are the Mendip Hills. Had this been done, the unjustifiable complacency of some of its conclusions might have been realised.

The County's quarry study predicted that by the year 2010 Mendip would be producing 60 million tons of limestone every year. This amount is one sixth of one per cent of the limestone reserves of the actual Mendip Hills, that stand above their surroundings (40,000 million tons). Therefore, at the predicted rate, twelve per cent of the Mendip Hills would vanish during the average human life span. I am sure that if the planners had known this simple fact they would have had second thoughts about the wisdom of quarrying such a small range of hills on such a large scale.

Although Mendip is small, its scenery is unique among Britain's limestone regions. Where else are there gorges as grand as Cheddar, plateaux like Mendip's dotted with Ice Age lakes, conglomerate caves like Wookey Hole or resurgences as beautiful as the Wookey Hole resurgence, stalactite caves finer than the Fairy Cave group, or hills more shapely than Crook Peak and Wavering Down? Yet all these features, and more, are crammed into this one range of hills in Somerset, only 40 km long by 8 km wide. You will not find limestone scenery of this class and variety, above and below ground, nearer than Southern France. Mendip is a national scenic asset of enormous commercial value - a fact which the County planners blithely disregarded when they promoted a policy that would remove it all in 9 human life spans.

Limestone production from Mendip is currently about 10 million tons (one four-thousandth part of the reserves) per year, having fallen slightly from a peak of 12 million tons per year in 1973. It may well increase greatly as gravel deposits in the London area become exhausted, for Mendip is the nearest large source of crushed stone to South East England. Somerset County Council's prediction of a demand for 60 million tons per year from Mendip could still come true, and as we have seen the effect would be catastrophic.

What can protect Mendip from an early doom? First, the County Council's policy of confining major quarry expansion to East Mendip, and encouraging deep sub-water-table working there, will, if it is enforced, provide 8000 million tons of stone from that small area, enough for 130 years' supply even at the 60 million tons per year rate. A second line of defence was erected in 1972 when Central and West Mendip were designated an Area of Outstanding Natural Beauty (A.O.N.B.), to be protected from disfiguring development. But policies can change, as was shown in 1980 when Somerset County Council proposed to expand its own Underwood Quarry at Wells, far from the East Mendip production area and actually breaking into the A.O.N.B. from outside it. Fortunately, the strength of public opposition was such that in 1981 the County withdrew its plan, but we still cannot be confident that the main mass of Mendip is safe.

Accepting that South East England will always generate a huge demand for crushed stone, where can it come from if not from Mendip? There is a fair amount of Carboniferous Limestone north of Bristol in Avon County, and a considerable quantity of igneous rock in Charnwood Forest, Leicestershire, but the nearest really large alternative source area is the Peak District of Derbyshire, significantly farther away and mostly inside a National Park. Derbyshire already produces more limestone per year than Somerset does.

However, the major users of crushed stone, the building and roadmaking trades, do not demand that the stone must be limestone. One possibility now in the planning stage is the shipping of igneous or metamorphic rock down to London from coastal quarries in Scotland - which surely has rock to spare. Bulk carriers seem to offer an economic means of transport.

Considered as a mineral, limestone is essential only to the chemical, cement, metallurgical and allied industries, in quantities much smaller than those currently used for roads and buildings. Chemically pure limestone is preferred, and it may be profitable to work the purest limestones underground, by mining. This is being done now in Derbyshire and elsewhere. Quarrying will always be cheaper than mining, ton for ton, unless the abandoned mine workings can be put to commercial use, and in fact there are signs that such use will be increasingly important in the future. Limestone mines could be located far from exposed karst country, in or near the regions of great demand. I suspect that there is good quality limestone to be found a few hundreds of metres below parts of South East England.

So there is hope that Mendip and its special karst scenery, above and below ground, can survive into the indefinite future. The part we can play in ensuring its survival is to be constantly vigilant, losing no opportunity of emphasising the scientific, social, aesthetic and commercial value of karst scenery to the nation in the corridors of power, recognising and combating bad planning decisions and teaching or preaching conservation to those who have still to understand how important it is.

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HYDROGEOLOGICAL OBSERVATIONS AT THE WATER END SWALLOW HOLE COMPLEX, NORTH MIMMS, HERTFORDSHIRE

by P. T. Walsh and A. C. Ockenden

ABSTRACT

The swallow hole complex in the chalk at Water End, Heterfordshire, has long been of interest to geologists owing to the considerable divergence of surface from subsurface drainage beyond the point where feeder streams enter the complex. A network of boreholes, supplementing an electrical resistivity survey across the complex, has revealed that the site is underlain by a six-layer structure in which Cretaceous, Eocene, Pleistocene (?) and Holocene components can be identified. An attempt is made to trace the history of the site. In contrast with previous opinion, which has emphasised a "Karstic" - type evolution, the present paper regards the complex as an aggradational regime with only subordinate karstic features.

INTRODUCTION

The Water End swallow hole complex, Hertfordshire, is a well-known venue for field excursions in the North London area. Its interest lies in providing some of the largest and most accessible swallow holes in southern England. The holes have received much attention from both geologists and water engineers. Dye-tests carried out in the 1920s (Morris and Fowler 1937) showed that there is a considerable divergence of surface from subsurface drainage from the swallow holes.

During most spring and autumn days the Mimms Hall Brook and Potterells Stream provide a modest flow to the aptly-named swallets at Water End, none of which progresses further by a surface route. During times of drought, no drainage at all reaches the swallow holes, any run-off from the high ground around Potters Bar, Boreham Wood and Barnet being absorbed into the stream beds above the swallow hole complex. At times of high rainfall, mainly in winter and early spring, the complex is not able to absorb the combined discharges of the two feeder streams and a lake forms in the depression occupied by the swallets. The lake discharges through an overflow channel under the A1 trunk road and water thence flows north-westwards to join the upper permanent reaches of the River Colne (Fig. 1). It was found difficult to quantify the volumes of water in the systems described above, but a programme of flow measurements over the period April 1969 to January 1971 indicated that the yearly flow to the complex is of the order of 3 x 10^6 m^3, about 15% of which is "lost" down the overflow channel during the 12 days or so when flood conditions prevail.

Measurements indicate that the complex is able to absorb roughly 1 m^3/sec just before the overflow channel comes into operation: the mean flow, however, is considerably less - about 80 l/sec.

Although this general picture is fairly well known, the authors have found that very little is known of the subsurface structure of the swallow hole complex: such observations as are thought to extend our knowledge are recorded here.

The field surveys on which this paper is based were carried out as the following series of Part III undergraduate projects:

Atkins, J.A. Project on water measurement and site survey (1971), Department of Civil Engineering, The City University, London, Undergraduate project report No.209.
Hemmings, P.F. (1972) Regional hydrogeological assessment; No. 475.
Nattrass, A.J. (1970) Water measurements and site survey; No. 203.
Ockenden, A.C. (1972) Geophysical surveying; No. 425.
Ring, G.N. (1971) Water measurements, structural surveys; No. 325.
Stroud, M.J. (1973) Borehole surveys, historical survey; No. 577.

These reports are available for inspection at The City University.

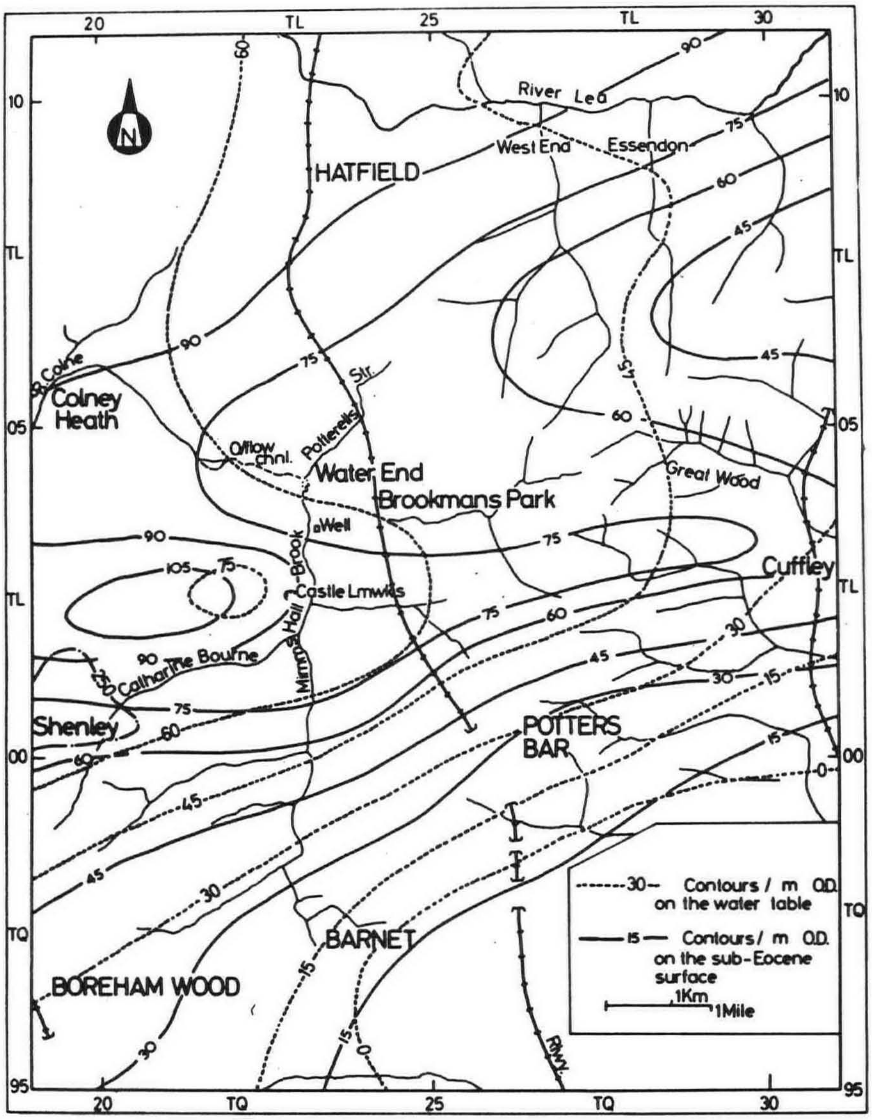

Fig.1. Hydrological and structural features around the Water End swallow hole complex.

SITE SURVEY

Existing large-scale Ordnance Survey maps of the Water End complex do not show sufficient topographical details for the purposes of the present geological survey; the complex, therefore, was resurveyed at a 1:500 scale using tacheometry and levelling (Fig. 2). The complex comprises two types of swallow hole:

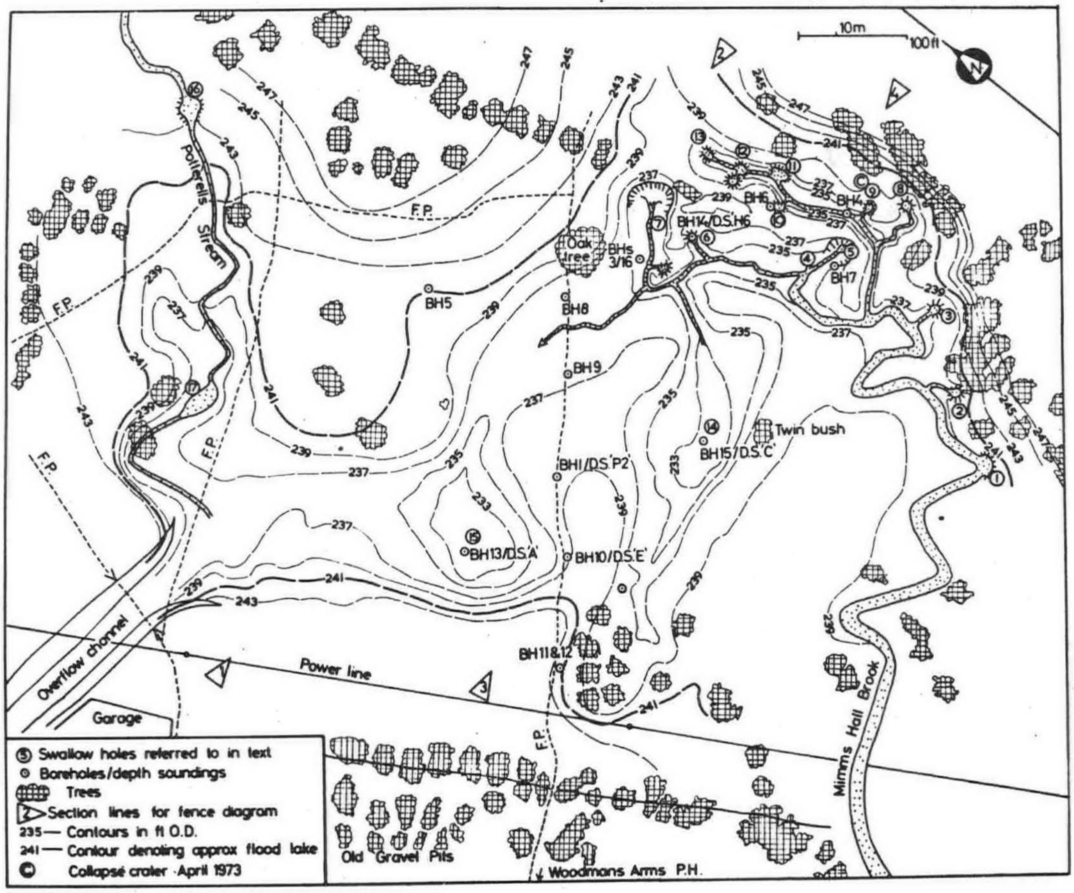

Fig. 2. Survey of the Water End swallow hole complex, January, 1970.

(1) Funnel-shaped holes (Nos 1 - 13, 16 and 17), in which the water drains directly into fissures in the Chalk, the surface of which can occasionally be seen at their base, beneath steep banks of alluvium. These holes are often choked with vegetation and domestic refuse; otherwise there is a free entry for stream water.

(2) Soakaway basins (Nos. 14 and 15) in which water percolates slowly into alluvium which floors shallow basins.

It is not generally appreciated by visitors to the swallow hole complex that the only part to which the public has free access is the footpath which crosses the complex behind the "Woodmans Arms" public house (TL229043). In recent years the immediate area of the complex has been devoted to the rearing of game birds and the owners have adopted the policy of allowing vegetation to grow to afford a good cover for the birds.

The vegetation varies considerably across the site and three clearly contrasted zones can be related to changes of soil and soil moisture:

(1) Along the river channels, around the swallow holes and in the floor of the flood-lake, there is a profuse summer growth of *Persicaria* , which dies off in the autumn when flooding is frequent.

(2) Fringing the flood area are nettles and dock, also profuse in summer growth.

(3) The higher ground around the lake is covered by various types of coarse grass and dense thickets of hawthorn.

The general area of the swallow hole complex is bounded by low banks whose geology is somewhat obscure. There is no doubt, however, that the south-eastern margins of the complex are formed from mounds of industrial refuse, dumped there in the 1950s. On the western side sand and or gravel was once dug in shallow workings behind the Woodmans Arms" but the age of this material is uncertain. To the north, around Marchmoor, a large patch of till has been mapped by the Geological Survey (1 inch : 1 mile sheet 239, Hertford).

Weekly observations on the occupation sequence for the swallow holes were kept from August 1969 to January 1970 and also over shorter periods at numerous other times. The processional occupancy sequence appeared to take the following form: Hole No. 1 was occupied first and often took the whole of the Mimms Hall Brook flow after times of only light rainfall.

With increased run-off, Holes 4 and 5 next came into operation. Hole 5 was the most effective of all the Water End holes at the time of the survey, taking possibly 80% of all infiltration when Holes 1, 4 and 5 were in operation and perhaps 30% of the total infiltration when all the holes were operative. Next, the water made its way along the channel to Hole No. 7, a composite depression often containing more than one open fissure, one of which was usually the second most effective swallet. Following this, the water began to build up in the channel and when the water level had risen by about 50 cm, Holes 3, 6 and 14 began to function. A rise of another 30 cm resulted in the functioning of Holes 9, 10 and 11, 2 and 15, with Hole 8 the last of all to be occupied. Finally, the lake forms over Holes 14 and 15, and at this stage 12 and 13 come into operation. In January 1970, all the holes were choked with stream debris except 1, 4 and 11. In the Potterells Stream, Hole 16 usually took the whole of the discharge, Hole 17 coming into operation in wet weather.

The recessional sequence of occupancy was broadly the reverse of the processional sequence, though the persistance of surface bodies of water related strongly to the degree to which any individual hole was temporarily choked with floating debris. The loci of the swallets are by no means static and important changes in the occupation sequence have been noted since the observations recorded above were made. Fig. 2 simply records the swallow-hole loci at one particular time (January 1970). Migration of fissure axes in inclined sub-cylindrical swallets has been observed in a number of cases, while a collapse took place in April 1973 at C on Fig. 2. This was about 1.5 m deep and 2 m in diameter and had no apparent connection with the existing pattern of drainage channels.

When compared with some of the old records, the swallow holes which have been active in the last ten years or so appear to be of modest size. Evans (1944) recorded, for instance, that in 1928 Mr. R. Butler descended into a newly-formed swallow hole to a depth of "30-40 ft". (9-12 m).

BOREHOLE INFORMATION

To try to determine the geological structure of the site, 16 hand auger holes were made down to a maximum depth of 4.6 m. Boreholes were concentrated along the public footpath, at points where the path crosses the centres of zones of notably high and notably low electrical resistivity, and otherwise at points of hydrogeological interest. The holes were 5 or 10 cm in diameter; there was no difficulty of penetration in clay, sand or chalk, but many holes were stopped by gravel. From an analysis of the results of the auger holes and the restivity survey together, it was concluded that a number of holes were stopped only just short of the Chalk surface, either in the Eocene Bull Head Bed, or in Holocene gravel immediately above this. Samples were taken at 30 cm intervals or when there was an obvious change of material. Notes on the groundwater conditions were also made.

The information forthcoming from these boreholes has been used as a basis for the fence diagram (Fig. 3), which also incorporates the indirect evidence of the resistivity soundings.

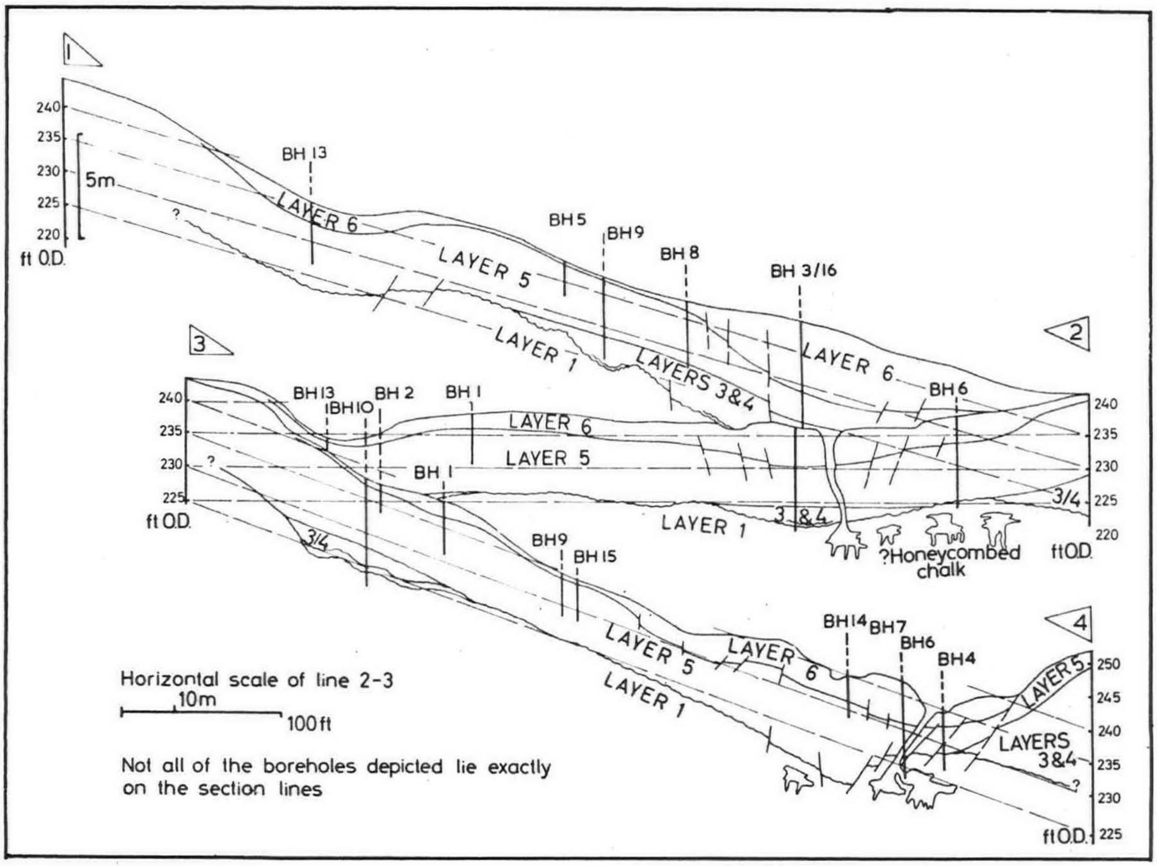

Fig.3. Fence diagram to show the subsurface structure of the Water End swallow hole complex.

The boreholes reveal that the swallow hole complex comprises a six-layer structure, as follows:

6.	Dark grey or black soft organic silts and clays up to 2.25 m	Holocene, possibly Pleistocene
5.	Light brown firm silty clay, sometimes gravelly in part up to 2.45 m	
4.	Greenish-brown firm clay up to 1.05 m	Sparnacian or Subrosion residue
3.	Greenish-brown and reddish-brown homogeneous sand up to 0.45 m	
2.	Firm brown silty clay, with occasional chalk fragments up to 0.27 m	
1.	White soft chalk, with flints + 0.47 m base not reached	Cretaceous

The dark-coloured organic clays of Layer 6 appear to be restricted to the area bordering the Mimms Hall entrance channel and the ground adjacent to the two lines of active fissure-type swallets in the eastern part of the complex. Their highly plastic state and organic content suggest that they are flood lake deposits of the last few decades or at most centuries. A maximum thickness of this layer was found in BH16; only very thin developments of the organic clay are present in the flood lake area of the western side of the complex, which suggests that the thickness variation may be related to solution subsidence of certain parts of the lake floor rather than to the original profile of the flood lake area.

The interface between the soft organic clays and the firm brown clays of Layer 5 is not sharply defined and it is presumed therefore that there is no hiatus between the two. The lithological difference is possibly related to some geographical change in the Mimms Hall Brook Valley, possibly some vegetational change in the area in comparatively recent historical times. Layer 5 sediments are also very gravelly in parts and large spreads of gravelly clay are undoubtedly present (1) between the active holes of the two feeder streams (2) to the north of the Potterells Stream and (3) along the western margin of the complex. The gravelly-clay is probably the earliest post-Glacial material. It floors the Mimms Hall Brook Valley for a distance of several kilometres above the complex (the outcrop mapped by the Geological Survey, (Sherlock and Pocock 1924), as "Valley Gravel"). However, several patches of "Glacial Gravel" were mapped by the Geological Survey to the north and east of the complex and the possibility that some pockets of fluvioglacial materials may lie unrecognised within the bounds of the complex should not be disregarded.

In some boreholes the gravel deposits lie directly on the Chalk, but in others, BH3, 10 and 16, greenish-brown stone-free clays and greenish-brown sands were revealed, the latter being identical with sands of accepted Reading Beds type which are preserved above the Bull Head Bed in the walls of the Castle Limeworks Chalk Pit (TL 230028), 1.5 km away. As the main outcrop of the Reading Beds is generally thought to occupy the gently sloping ground above the swallow hole complex on its eastern side, one might expect that the supposed Reading Beds materials would also be found in borehole BH4, immediately above the Chalk, the top of which occurs at 227 ft, O.D., a depth of 7.35 ft (2.22m) below ground surface. Their absence in this hole indicates therefore that pipe-forms which preserve conical or cylindrical masses of Reading Beds as at Castle Limeworks Chalk Pit (Kirkaldy 1950, Thorez et al, 1971) also underlie the complex.

The firm brown silty clay of Layer 2 calls for little comment. The equivalent material in the Castle Limeworks is the matrix of the Bull Head Bed or the solution residues marginal to pipes, materials which have also been observed in the West Hertfordshire Main Drainage sewer trenches close to the complex (1972). The Chalk of Layer 1 appears to be in no way different from that revealed in the numerous artificial sections in the general vicinity of the complex, indeed from that occasionally visible in the funnels of the larger swallets.

A number of samples taken from boreholes 3 and 13 were submitted to Dr. M. C. Boulter of the North East London Polytechnic for palynological analysis. He reports that only those taken from the uppermost 80 cm zone of Layer 6 proved to be fossiliferous, the flora being unquestionably post-Glacial and little different from the modern flora of the area. All samples from Layer 5 were barren. Prospects for demonstrating that the swallow holes have a long post-Glacial history and preserve a detailed record of climatic and geographical change in the alluvial fill appear to be remote; indeed, the opposite appears to be indicated by present evidence.

THE RESISTIVITY SURVEY

For further interpretation of the subsurface hyrogeology of the swallow hole complex, a resistivity survey was conducted over the central parts of the complex, using a BISON 2350 Resistivity Meter. A Wenner electrode configuration employing a 6 m-electrode spacing between stations was adopted as being the most practicable for traversing the often densely overgrown areas between the lines of swallets. The traverses were supplemented by eight depth soundings, made at selected points of hydrogeological interest.

The results of the depth soundings were plotted on log/log graph paper and compared with a series of standard graphs (Mooney and Wetzell 1956) so enabling a rough model of the subsurface structure below these points to be obtained. These models were further enhanced by computer-based programming. In five cases an attempt was made to compare the co-axial results of augering with depth soundings, but the comparisons proved not to be wholly satisfactory. In BH1/D.S. 'P_2', (Fig. 2), the depth soundings revealed discontinuities at 2.1 m, 3.3 m and 8.5 m. The borehole was stopped by gravel at 2.1 m, and it is conjectured that the Chalk surface corresponds to the 3.3 m discontinuity.

In the case of BH10/D.S. 'E', the Chalk revealed at 3.9 m in the borehole was not marked by a corresponding discontinuity in the depth sounding, the shallowest of these changes being at 4.5 m, below which there are two other changes.

In the cases of BH13/D.S. 'A' and BH15/D.S. 'C', the boreholes became blocked by gravelly material at a depth of 60 cm above a major change in the resistivity sounding, which, bearing in mind the fore-going, might reasonably be deduced to be the Chalk surface. It is interesting that the change from clay to gravel was not itself obvious in the depth sounding.

In the case of BH14/D.S. 'H_6' there is no correlation between depth at which the borehole became blocked (1.8 m) and the change of resistivity. The main change occurs at a depth of 5.4 m below ground surface, this being interpreted as the position of the Chalk surface.

The resistivity traverse survey using the Wenner configuration took the form of ten NE-SW lines of readings at 6 m-intervals, the lines being 18 m apart. The point results were subjected to a computer-based surface trend analysis based on theory derived from Forsyth (1957). The analysis reveals five parallel zones of relatively high or relatively low resistivity, the trends of which are almost exactly NW-SE.

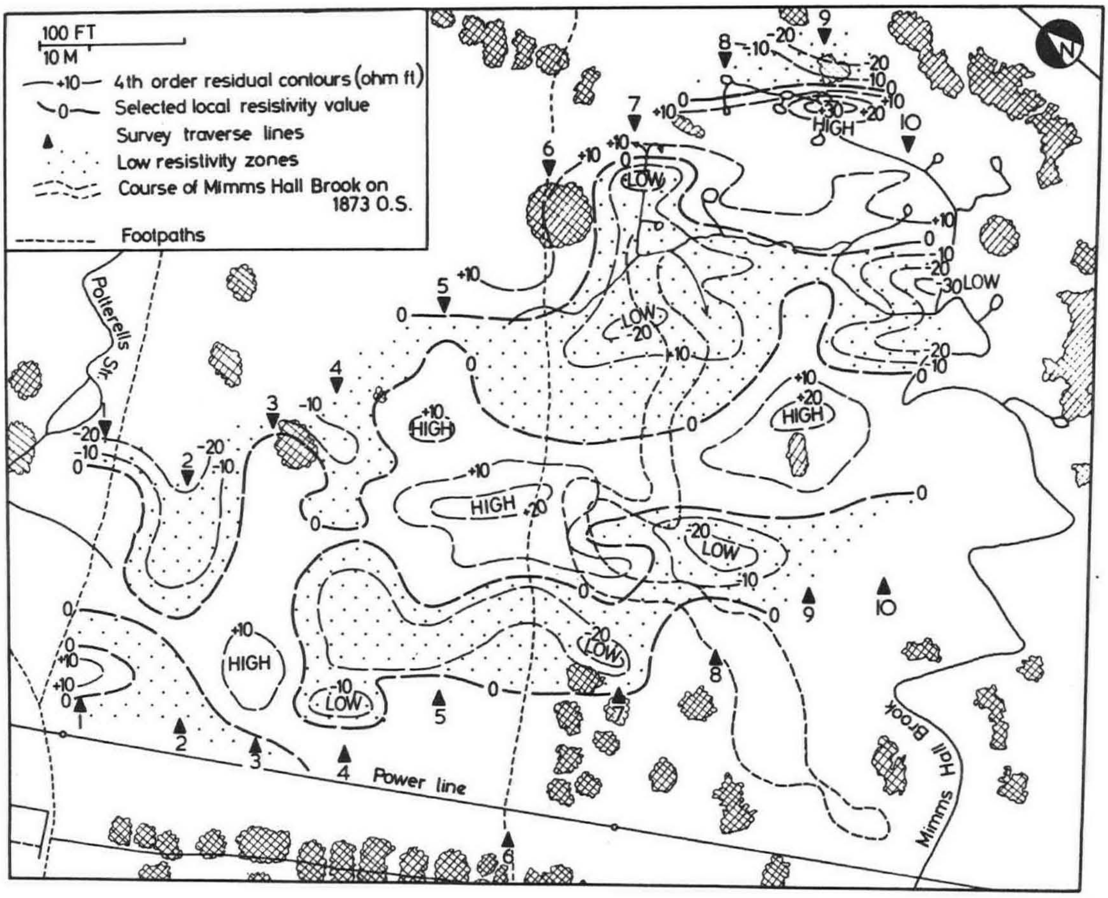

Fig. 4. Map to show the results of the resistivity traverse survey.

Unfortunately, there was very little correlation between data forthcoming from the borehole programme and the resistivity trend analysis. The comparatively low resistivity zones are affected by regular flooding, whereas zones of high resistivity are rarely flooded. The lowest resistivity values, however, do not directly correspond with the most frequently flooded areas; it seems probable therefore that the pattern of resistivity variation reflects some structural or hydrological factor deep within the Chalk itself, and is not directly pertinent to the swallow holes themselves.

It is interesting to note, however, that the lines of swallow holes and the zones of high and low apparent resistivity are co-linear. It is, of course, quite possible that both are features controlled in large measure by chance subrosional developments during the formation of the swallow hole complex. Possibly both features are in some way related to pre-Pleistocene cross-fractures in the Chalk; surveys of vertical and sub-vertical joints in the few recent local exposures of Chalk in pits at Castle Limeworks, Bedwellpark Farm (TL 283091) and Ox Wood (TL 269091) all show a strong development of a joint set having a similar NW-SE trend (Fig. 5).

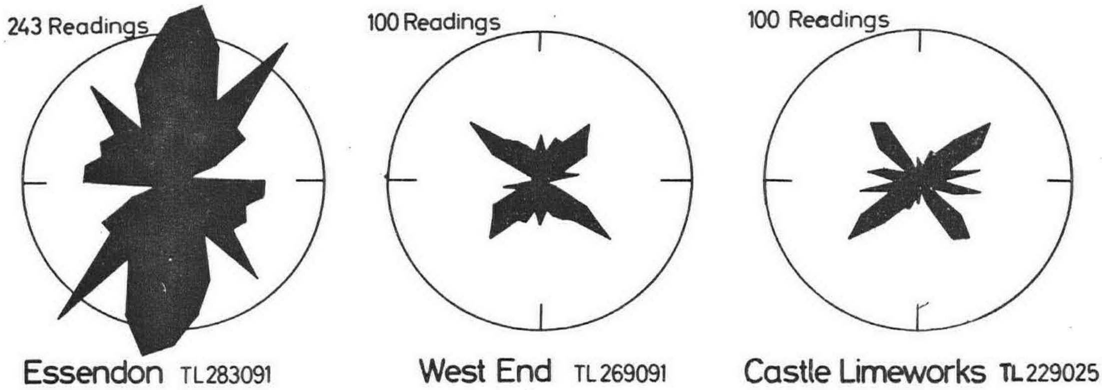

Fig.5. Rose diagrams to show the trends of joints in the Chalk exposed at Essendon, West End and Castle Limeworks.

THE WATER END COMPLEX IN A REGIONAL HYDROGEOLOGICAL SETTING

The general structure of the Chalk on the northern side of the London Basin is fairly well known and requires little further elaboration here (Water Resources Board 1972). The general form of its upper surface in the south Hertfordshire area is indicated on Fig. 1. The average dip of the northern limb of the Basin is about $\frac{1}{3}^{o}$ - a gradient of about 8 m per km to the southeast, though there are a number of subsidiary folds superimposed on the main structure. There are no known faults in the northern limb; certainly none is even hinted at from the behaviour of well-flows when considered in a regional sense.

An east-west strike fault has been postulated by numerous authorities along the Upper Lea valley between Hertford and Hatfield to account for the emergence of the Chadwell and other springs. However, in the case of the Wimbledon Fault, a strike feature, on the southern limb of the London Basin, there is a significant lowering of permeability near to the fault, and faulting of any kind in Chalk is now generally thought to have produced plastic crushed-chalk gouges of relatively low permeability and which act as barriers to groundwater flow (Higginbottom 1966).

The water table falls from Water End in two directions, roughly at right angles to each other (Fig. 1). The steepest hydraulic gradient is towards the southeast and it exceeds 1:100 in this direction; but this does not so much indicate the direction in which the water might be expected to flow as the presence of a relative barrier of low permeability. What causes the barrier is not certain but it is roughly co-extensive with the southern limb of the Shenley-Broxbourne anticline, the isopiestic contours being especially close-spaced in the area between Boreham Wood and Potters Bar.

The dye tests of Morris and Fowler (1937) show that groundwater travels north-eastwards from Water End along the trough of the Colney Heath - Hoddesden Syncline. The recorded flow-through times average 5500 m/day, indicating the presence of open fissure systems, the joints being extensively widened by solution effects - this despite the fact that the structure is synclinal and the hydraulic gradient low. Despite a general reduction of the spring flows into the Upper Lea Valley, no long term fall of the isopiestic surface has been detected in this area. The general level of the surface in the area surrounding Water End lies at about 12 m below ground surface, as shown by the remarkably constant level (even after flood conditions at Water End) in the North Mimms Well about 500 m south of Water End. No trace of the dye introduced into the Water End swallow holes in the 1927-35 experiments was observed in this well but when a group of swallets in the Catharine Bourne was treated, the dye was seen. This indicates that a steeply conical water mound must underlie the Water End Complex, suggesting in turn that the Chalk is honeycombed by a complex fissure system which allows free percolation down to the regional isopiestic surface.

GEOMORPHOLOGICAL EVOLUTION OF THE COMPLEX

There seems to be general agreement that the path for the development of the complex was first set during the mid-Tertiary tectonic episode which folded the local Cretaceous and Eocene sediments and produced open-jointed axial fissure systems in the Chalk along the axis of the Colney Heath-Hoddesden syncline. The erosional history of this structure is undoubtedly complex and presumably extends back far into the late Tertiary; certainly, the pre-Pleistocene development of the south Hertfordshire landscape is not easy to reconstruct and there are hints that the whole area was inundated by seas of the Pliocene North Sea Basin, perhaps more than once. It is not until the Pleistocene that we can begin to trace with some certainty the erosive events which led to swallow hole development. Before discussing the latter, however, it is important to remember that the Water End complex is far from unique, either in type or scale. Smaller systems of swallets are frequent in that area of Hertfordshire where slopes in the London Clay stand well above the Chalk-Tertiary junction; there is an equally impressive complex in the Great Wood at Cuffley (TL 288047).

Wooldridge and Kirkaldy (1937) postulated that the Radlett-Mimms depression, of which the Mimms Hall Brook occupies the eastern half, was formed by a loop of an old course of the Thames, which became diverted by way of north Middlesex, Hampstead, Barnet and Ware by one of the earlier glaciations. Later glaciation modified the drainage out of the loop by blocking the pre-Glacial Valley of the Brook with a plug of boulder clay, where it formed a tributary of the Lea near Hatfield, thus causing it to flow northwestward into the Colne Valley.

In post-Glacial times, a wide tongue of valley gravel was deposited in the floor of the Brook (see Section 3), this material possibly representing a redistribution of fluvio-glacial deposits of slightly earlier age. Solution effects associated with the swallow hole complex cannot be proved to be older than this spread. Kirkaldy (1950) explained the vertical sand-filled pipes of the Castle Limeworks Chalk Pit in terms of their being older examples of the same type of swallow holes as are found at Water End, having been formed at a time when the valley floor was at a higher level. The authors, however, would prefer to regard the Castle Limeworks pipes as genetically distinct phenomena, which were formed by subrosion of the Chalk beneath a continuous Reading Beds cover (see also Thorez et al, 1971 and Walsh et al, 1973); they prefer to regard the Castle Limeworks pipes as belonging to at least two phases of development, the first of which could theoretically be as early as the Eocene.

It is difficult to decide whether the Water End complex is losing or gaining in void space at the present time, and whether the surface of the complex is gaining or losing in mean height. Two mutually opposing geomorphological processes are operative in these respects. On the one hand there is a loss of rock material from the complex through solution of the Chalk down to an unknown depth below the surface. In this way the total volume of sediments in the complex is reduced and, through at least local, if not widespread solution subsidence, the surface of the complex is lowered. On the other hand there is a gain of sediment in three ways (1) that liberated as an insoluble residue from the Chalk, (2) that being washed down into the holes (both subsurface gains) and (3) a general build up of mud on the floor of the flood lake at times of flood. For most of the year, (i.e. on all those occasions except when the flood lake is formed) the "base level" for the system is the lip of the overflow channel. Clearly, when the latter is in operation, sediments introduced into the system can also be lost from it through the overflow channel.

Cratering of the complex by cavity roof collapse has been observed on a limited scale by the authors in recent years and is believed to have been repeatedly observed for many years before this survey began. But, from general considerations, the authors believe that, volumetrically, this effect is more than compensated for by the sediment trapped by plant growth on the floor of the flood lake. Seasonal layering in the alluvium is not easy to discern but the thickness of those layers may be of the order of one centimetre per year in some parts of the complex. It would clearly be desirable to effect some long-term observation of this property by implanting rigid reference posts or by precise levelling. No relics of infilled past subsidence craters have been observed by the authors around any part of the existing stream course or funnel-type swallets; cratering processes then, while spectacular, may have assumed a greater than deserved importance in geomorphological considerations. Regarding the subsurface conditions, it is not possible at present to make any estimate as to whether the Chalk of the area of the water mound below the complex is getting progressively more or less honeycombed, nor, indeed, whether there is some self-regulating conflict of solution, collapse and infilling which ensures a relatively static evolutionary model. Nor is it obvious how this condition can be determined without an extensive drilling programme.

Efforts have been made to determine how the complex has evolved during historical times. Following reports by some local inhabitants that the swallow hole area was once the site of gravel diggings, the authors have especially tried to find evidence for or against the hypothesis that the holes are not so much natural features as artificial excavations which, through lack of foresight on the part of the gravel excavators, have accidentally diverted the Mimms Hall Brook from its natural channel. Maps of the area have been traced back to 1676 (B.L. Catalogue K.15) while the Ordnance Survey published a 1 inch to the mile scale map in 1822, and 6 inch maps in 1877, 1919 and later.

Maps of 1676 and 1749 show that the Mimms Hall Brook and the Potterells Stream joined directly; though no swallets are marked, it is probable that the maps are of too small scale for them to have been considered. The O.S. map of 1822 shows the Mimms Hall Brook channel to follow a much more westerly course across the complex than it does today. Similarly, the 1877 6 inch map shows stream courses which bear little relation to the present drainage, and what was shown as the main drainage channel then is now only a vague marshy depression. The principal change in channel flow, following which the development of open fissures seem to have been constrained to the eastern half of the complex, seems to have taken place between the times when the field surveys were made for the 1877 and 1919 maps. None of the maps shows any record of artificial excavations near to the active swallow holes of the present time. Records of flooding have been traced back to the beginning of the present century and there are indications that there has been an increase in the frequency of flooding since the construction of the A1 Barnet by-pass in the late 1920s.

The last important change in the geography, and possibly the sedimentology of the complex evidently took place about 40 years ago. Local inhabitants speak of Water End in pre-World War II years as being ... "a favourite picnic spot ... in grassy meadows ... the holes being considered dangerous and were fenced off." This is hardly true of the present appearance of the site.

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CAVE SCIENCE

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THE DESIGN OF SCALING POLES

by J. S. Davis

Amendment to the article in BCRA Transactions Vol.7 No.4 pp.200-204. Dec.1980

Following the appearance of the above article on the design of scaling poles, I received comments from John Fraser and Ivan Young concerning the basic equations which I had used for calculating the failure load of a scaling pole by bending or buckling.

It is clear that the reaction of the wall was neglected in the original article resulting in the need for a reappraisal of the whole problem. The case of failure was previously considered as in fig.1, but should have included the reaction of the pole as shown in Fig.2.

Fig. 1.

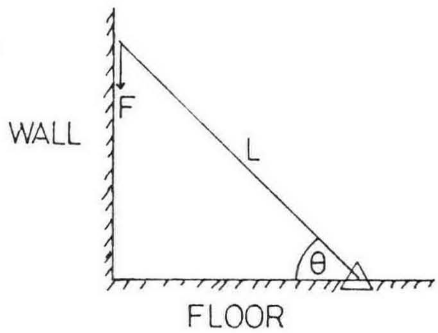
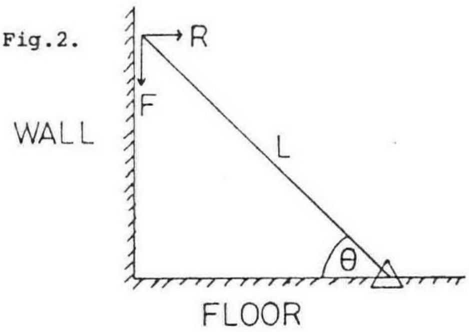


Fig.2.



△ denotes rigid joint

It should also be noted that the method of holding the bottom of the pole was not precisely stated, although implied as rigidly fixed. It is important that the method of holding the ends of the pole should be stated as it seriously affects the pole strength.

There are four different ways in which the ends of the pole may be held, resulting in different formulae for calculating the load required to cause failure.

The buckling loads of struts are calculated using the Euler Buckling formulae as previously stated and depend on the pole end conditions as follows:

case (a) one end constrained in direction and location, other end free (case used in previous paper)
Euler buckling load = $\frac{\pi^2.E.I}{4L^2}$ see Figure 3

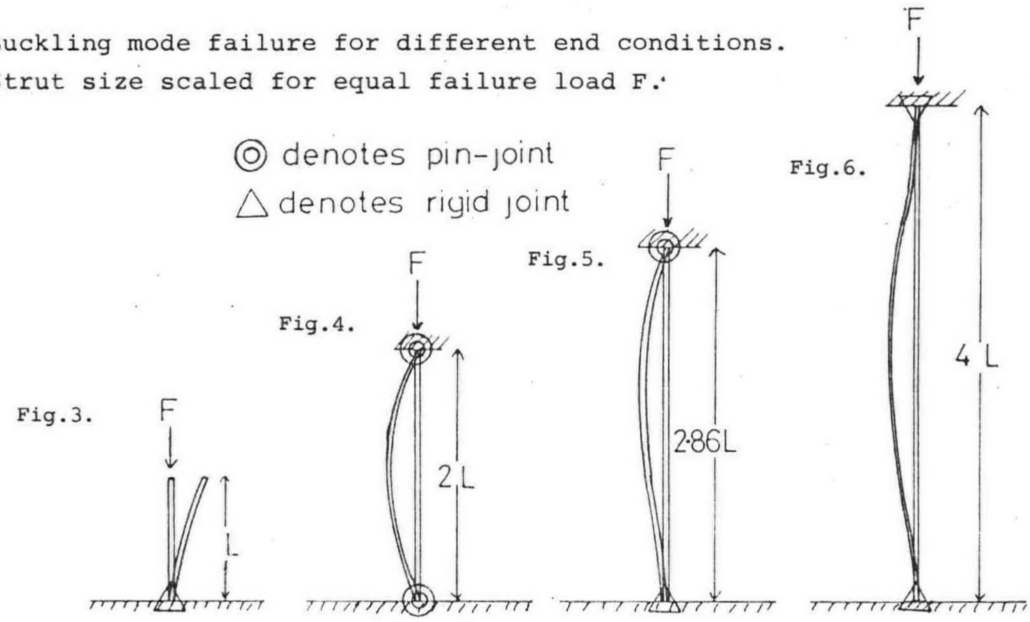
case (b) both ends constrained in location, but not in direction, i.e. pin-jointed or pivoted
Euler buckling load = $\frac{\pi^2.E.I}{L^2}$ see Figure 4

case (c) both ends constrained in location, but only one constrained in direction
Euler buckling load = $\frac{2\pi^2 E.I.}{L^2}$ see Figure 5

N.B. The factor 2 is a close approximation and not exact.

case (d) both ends constrained in location and direction
Euler buckling load = $\frac{4\pi^2.E.I}{L^2}$ see Figure 6

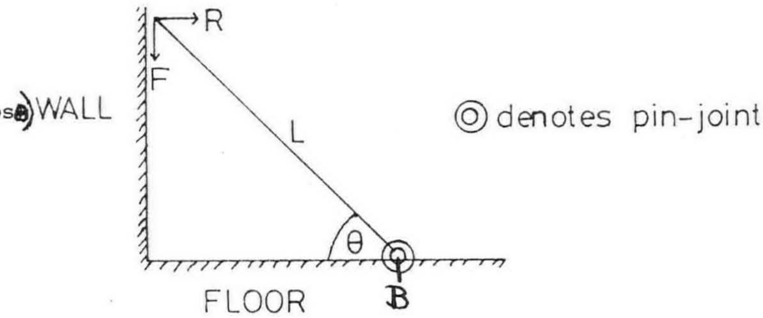
Figs.3-6. Buckling mode failure for different end conditions.
Strut size scaled for equal failure load F.



Ivan Young suggested that case (a) was the worst case, but only really applicable if someone was bolting straight up a wall (see fig.3), which was highly unlikely and needlessly pessimistic. He suggested that case (b) was most likely to be normal and in the event of someone wedging the bottom of the pole between boulders, then case (c) was more likely because any sensible caver would rest the pole on the wall or in a convenient groove.

The consequences of his remarks with which I agree are that case (b) should be taken as the most likely mode in which a scaling pole would normally be used, thus increasing the strength by a factor of 4 over case (a). The buckling force for case (b) can be derived by resolving the forces in fig.7. The weight of the pole is ignored in the calculation.

Fig.7.
(Buckling force along the pole $= F\sin\theta + R\cos\theta$)



However, in this case, there is no bending force applied to the pole because the loads are applied at the ends of the pole so that by taking moments about B:

$$FL\cos\theta - RL\sin\theta = 0$$

$$\therefore \quad R = \frac{F\cos\theta}{\sin\theta}$$

substituting for R gives:

$$\text{Buckling force} = F\sin\theta + \frac{F\cos\theta.\cos\theta}{\sin\theta}$$

$$= \frac{F\sin^2\theta + F\cos^2\theta}{\sin\theta}$$

$$= \frac{F}{\sin\theta}$$

Therefore the Buckling force $= \frac{F}{\sin\theta}$ as pointed out by Fraser and Young, not $F\sin\theta$ as previously stated by myself.

It should be noted that if any other case is taken where either end is rigidly held or if a load is applied other than at the ends of the pole, then there will be a bending moment.

Therefore, the strength of the pole depends on the angle of inclination and decreases with θ, and does not increase with θ as previously stated.

The buckling loads have been calculated for case (b) and are shown in Table 1, but it should be noted that these are calculated for a pole when vertical, i.e. when $\sin\theta = 1$.

The formulae used for calculating the buckling loads is:

$$\text{Euler buckling load} = F_{max} = \frac{\pi^2.E.I}{L^2}$$

where π = 3.142

E = Young's modulus for HT 30 aluminium alloy
= 4500 tons/sq.in.

I = second moment of the area of a tubular section
$= \dfrac{\pi(d_2^4 - d_1^4)}{64}$

d_2 = outside diameter

d_1 = inside diameter

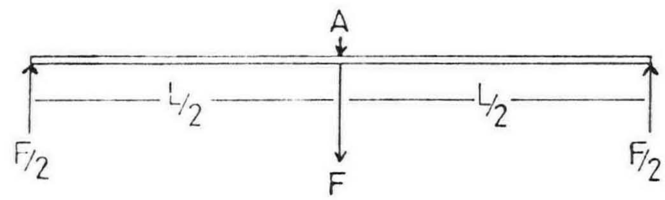
L = length of the pole

$$\therefore F_{max} = \frac{\pi^3.E\ (d_2^4 - d_1^4)}{64L^2}$$

BENDING LOADS

The bending loads required to cause failure can be calculated using the worst case where the load is applied in the middle of a horizontal pole as in fig.8.

Fig. 8.



The stress at A $= \sigma_{max} = \dfrac{My}{I}$

where σ_{max} = Tensile strength of the material (0.2% proof stress)
= 16.5 tons/sq.in. for HT30 aluminium alloy

M = maximum bending moment = $F_{max}/2.L/2$

F_{max} = maximum load

y = distance at which maximum stress occurs from the neutral axis of the section which for a tubular section is equal to the outer radius, i.e. $d_2/2$

L, d_1 d_2 & I are defined as before

$$\therefore \sigma_{max} = \frac{My}{I} = \frac{\left[\dfrac{F_{max}}{2} \cdot \dfrac{L}{2} \cdot \dfrac{d_2}{2}\right]}{\left[\dfrac{\pi.\ (d_2^4 - d_1^4)}{64}\right]}$$

by rearrangement,

$$F_{max} = \frac{\sigma_{max} . \pi . (d_2^4 - d_1^4)}{8.L.d_2}$$

The calculated bending loads for pole failure are shown in Table I and represent the worst values and may be increased as the pole becomes more vertical.

Table I

Values of F_{max} for Buckling and Bending Loads for a Scaling pole with both ends constrained in location, but not in direction.

Tube Size: Outside Diameter d_2 (ins)		1.906	2.500	2.813	3.000	3.250
Inside Diameter d_1 (ins)		1.554	2.244	2.487	2.744	2.994
Tube Gauge		7	10	8	10	10
$(d_2^4 - d_1^4)$ $(ins)^4$		7.37	13.71	24.36	24.31	31.21
		F_{max} Buckling Loads (lbs) (Vertical Case)				
Pole Length (ft)	30	277.7	516.6	918.0	916.1	1176.1
	25	399.9	744.0	1321.9	1319.2	1693.6
	20	624.9	1162.4	2065.4	2061.2	2646.2
	15	1110.9	2066.6	3671.8	3664.3	4704.4
		F_{max} Bending Loads (lbs) (Horizontal Case)				
Pole Length	30	155.9	221.1	349.1	326.7	387.2
	25	187.1	265.3	419.0	392.0	464.6
	20	233.8	331.6	523.7	490.0	580.7
	15	311.8	442.2	698.3	653.4	774.3
Mass/unit length of pole (lbs/ft)		1.13	1.12	1.56	1.35	1.47

N.B. Masses of poles do not take account of overlap.

Values of E and σ_{max} for HT30 Aluminium Alloy are: E = 4500 tons/sq.in.
σ_{max} = 16.5 tons/sq.in.
(0.2% proof stress).

Examination of Table I shows that for a 16 stone caver (100 kg) using a 25ft. 3.00 inch diameter scaling pole, there is a safety factor of at least 5 for failure by buckling when vertical and a factor of 1.7 for failure by bending of the same pole when horizontal. Consequently, it is not advisable to use such a pole in a horizontal position, but it is quite safe to use it when vertical or steeply inclined.

Further comments from John Fraser concerning lifelining are of a more practical nature and will be incorporated in a future article.

I must express my thanks to both John Fraser and Ivan Young for their alert reading and courtesy of allowing me to correct myself.

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A STUDY OF THE CONCEPTUAL CRITERIA HELD BY CAVERS FOR THE PERCEPTION OF DANGER

A. Champion

"Men explore the deepest darkness ... clinging to ropes in the pits ... they dig to the sources of rivers ... but where is wisdom to be found?" Job Chapter 28

Abstract

The potential of repertory grid technique is illustrated by a study of the ways in which three experienced cavers perceive various hazards. Analysis of the results reveals that hazards are discriminated between in terms of "poor planning - poor moving" along with an independent assessment of the extent of inherent danger involved in an activity. A discussion of the results draws several implications for safety and goes on to offer ideas for further research.

INTRODUCTION

This investigation uses a well established psychological technique in a first attempt to understand the ways that cavers identify and discriminate between caving hazards. The perception and control of danger forms an intrinsic part of sporting caving; indeed Cohen (1964) suggested that the recognition of the possible adverse consequences of an activity was essential for stimulating a safe performance. It is a common experience for cavers to express differences of opinion about caving hazards. One person tackles every hazard with the careful application of all available safety precautions whilst another person thinks nothing of ignoring even the basic safety rules of the Caving Code (National Caving Association, 1976). The study of how cavers perceive danger is an essential step in the path towards improving the safety standards of the sport.

There are many valid methods of investigating these psychological processes but in this study reliance is placed upon Personal Construct Theory (Kelly, 1955). The essence of the Theory is that "Man looks at his world through transparent patterns or templates which he creates and then attempts to fit over the realities of which the world is composed ... Let us give the name Constructs to these patterns which are tried on for size. They are ways of construing the world." The theory asserts that each person has his own unique way of discriminating between things in the world and as life goes on a person is constantly trying to develop an increasingly accurate mental model in order to predict events.

A common biasing effect of psychological studies occurs if the participants have the opportunity to give answers which they assume will be pleasing to the investigator. Personal Construct Theory overcomes this problem by a technique known as the Repertory Grid. The method allows participants to generate their own questionnaire which is then completed independently by each person. The results are next fed into a specially developed computer programme from which tables and diagrams are produced to provide a picture of the person's mental model.

REPERTORY GRID TECHNIQUE

The Cavers

The three male cavers participating in the study had all been caving for at least five years, occasionally together and most often in the Yorkshire Dales. Each person had a different background of caving experiences and they had each taken up a different specialist pursuit in the sport. Caver "A" was introduced to caving within the traditions of a big club and in recent years he had been a member of several overseas expeditions. Caver "B" had picked up caving techniques from a variety of acquaintances and he counted cave diving as his specialist pursuit. Caver "C" was active in a University caving club although he had recently taken to climbing underground avens in search of new passages.

Elicitation of caving hazards

A meeting was held between the investigator and the three cavers in a quiet room of the Craven Heifer Inn at Ingleton on 16 July 1977. Caver "C" had

TABLE 1 List of Caving Hazards Selected by Three Cavers

CAVERS				
"A"	"B"	"C"	ALL	
x	x			Insecure belay for ladder, rope or lifeline
x				Tether, ladder, krab or rope mechanically unsound
		x		Knots tied incorrectly
				Non-use of lifeline on pitch or traverse or climb
		x		Failure to observe the prevailing weather conditions before descent
	x	x	(1)	Failure to take spare lighting on a long trip
x	x	x	2	Insufficient care taken when climbing dislodged rocks
x				Tourists throwing rocks down an open shaft
	x	x	(3)	Dislodging miners "deads" in a mine
	x	x	(4)	Digging in an unstable choke, without shoring
x	x	x	5	Bad air in airbell between sumps
x	x			Getting caught underwater when diving a sump
x				Line through sumps becoming loose when diving
				Being swept away in high water conditions
		x		Negotiating a strenuous and tight squeeze
	x			Effect of a minor fall on inadequately clothed party, leading to exposure
x	x			Being inadequately clothed for trip into cave via a swim
x	x	x	6	Inexperience of party, especially leader
	x			Getting stuck by panicking in a tight squeeze
		x		Getting lost or off route due to not reading survey or guide beforehand
x	x	x	7	Rope abrasion on SRT rope
		x		Failure to use a natural back-up belay to a bolt
	x			Failure of ascender or descender device
		x		The presence of loose rock on a climb or traverse
				Change in water level whilst underground
	x	x		Taking novices or any party on a trip too hard for them
x				Cramp whilst swimming underground
x	x	x	8	Loose rocks in boulder choke
				Off route in a sump and becoming stuck
	x	x		Slippery rock at the top of pitches
x	x			Two off-set pitches rigged with one ladder which is not rebelayed for the second drop
x				Too many people down the hole causing confusion
x	x	x	9	Poorly supervised novices

TABLE 2 List of Derived Constructs

1+ controllable	- uncontrollable	-1
2+ lack of thought	- bad luck	-2
3+ due to my party	- due to another party	-3
4+ technical factor	- physical factor	-4
5+ poor planning	- poor moving	-5
6+ likely to kill	- unlikely to kill	-6

TABLE 3 Layout of the questionnaire

	controllable				uncontrollable
	1	2	3	4	5
1. failure to take spare lighting on a long trip					
2. insufficient care taken when climbing dislodged rocks					
3. dislodging miners "deads" in a mine					
4. digging in an unstable choke, without shoring					
5. bad air in airbell between sumps					
6. inexperience of party, especially leader					
7. rope abrasion on SRT rope					
8. loose rocks in boulder choke					
9. poorly supervised novices					

come prepared with a written list of 29 caving hazards. Cavers "A" and "B" then suggested a further five hazards which were included in the list shown in Table 1.

The next stage was to reduce the list of caving hazards to a manageable size for consideration in the limited time available for the study. Cavers "A", "B" and "C" each in turn selected the most meaningful hazards by placing a tick in the appropriate space of Table 1. The cavers were found to have only six hazards in common, therefore agreement was reached regarding the inclusion of a further three hazards to form the list of consensus dangers marked 1-9 in Table 1.

Derivation of constructs

The nine consensus dangers were to form the basis for deriving the cavers' personal constructs but first a careful explanation of the technique had to be given. The jargon word "construct" was replaced in this description by reference to the simpler term "classification scale". Examples were given of caves having entrances which ranged between extremely tight to huge and the amount of daylight just inside which may vary from broad daylight to pitch blackness. A group of three of the consensus hazards was then selected and introduced to the three cavers by the question: "In what important way are two of these hazards similar but different from the third?" One of the cavers responded by suggesting that two of the hazards were "controllable" whilst the third hazard was "uncontrollable". This process of discrimination was repeated with differing sets of hazards until the list of six constructs shown in Table 2 was derived.

Rating the constructs

The nine consensus caving hazards and the six derived constructs were easily arranged into the form of a questionnaire. Each of the constructs had a separate sheet such as the example in Table 3. The constructs were divided into a five point scale as a compromise between the sophisticated seven division scale and the rather crude option of binary markings. All the cavers quickly appreciated that the task of completing the questionnaire merely required each hazard to be rated in turn on the constructs by placing ticks according to one's personal assessment. For instance the "failure to take spare lights on a long caving trip" may be perceived as an entirely "controllable" hazard in which case the sheet would be marked in the number "1" position. Each caver worked alone for a few minutes putting numbers to the questionnaire so that three repertory grids aligned by hazard and constructs were produced.

Processing the data

The questionnaire responses yielded a total (9 hazards x 6 constructs x 3 cavers) of 162 "bits" of information. They were transcribed into matrix format as given in Table 4. Preliminary checks on the data established that no spaces had been accidentally left blank.

TABLE 4 The Completed Grids

Caving hazards	Caver "A" Constructs						Caver "B" Constructs						Caver "C" Constructs					
	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
1	1	1	1	2	1	5	1	1	1	1	1	5	1	1	1	1	1	5
2	2	2	1	2	4	1	2	2	1	4	5	2	2	2	2	5	5	2
3	2	3	1	2	4	1	1	1	1	5	1	1	1	3	1	5	5	1
4	1	2	1	2	2	2	1	1	1	4	2	1	1	2	1	4	2	3
5	2	2	4	4	2	1	4	4	4	4	4	2	4	5	4	5	3	2
6	1	1	1	2	1	4	2	1	1	2	1	4	2	3	1	3	3	2
7	2	2	2	2	2	1	4	2	1	1	3	1	1	1	1	1	2	2
8	3	4	5	3	5	2	4	4	3	4	4	3	4	4	2	5	5	2
9	1	1	1	2	1	4	2	1	2	2	1	5	2	1	1	3	1	5

The statistically significant relationships between factors in the completed grids were identified using Spearmans Rank-order Correlation as described by Beals et al (1968). This analysis was facilitated with a computer programme (Slater, 1972) known as the Oxford adaption of the Grid Analysis Package or "Ingrid 72" for short. The programme was run on the I.C.L. 1904S computer at the University of Aston in Birmingham. "Ingrid 72" applied principal component analysis to the three individual grids. An iterative process using a least squares criterion determined the best fit for a selected number of axes through points in space. Information regarding the principal independent axes was available in a table of the computer printout referring to vectors, loadings and residuals. In this way any significant features about the perception of danger, formerly hidden in the matrix of empirical data, were revealed in a geometrical model.

Each of the tables in the computer printout was searched for significant relationships using the appropriate rules of a statistical dragnet of proven design (Slater, 1972; Smith et al, 1976). The cavers' grids were subjected to the Bartlett Test which identified only two significant axes or underlying trends. Another table of results known as the Analysis of Component Space established that these two underlying trends accounted for over 75% of the variability whilst a third underlying trend accounted for a further 10% of the variability. It was therefore considered that the cavers' perception of dangers could be presented accurately in the form of two dimensional maps.

Naming the underlying trends

The names of underlying trends in the cavers' mental models were found by reference to a table in the computer printout. The table of Vectors, Loadings and Residuals was inspected to locate the three constructs and hazards having the highest loading value for each cavers three significant components. The relevant information is presented in simplified form in Table 5.

TABLE 5 Naming the Underlying Trends

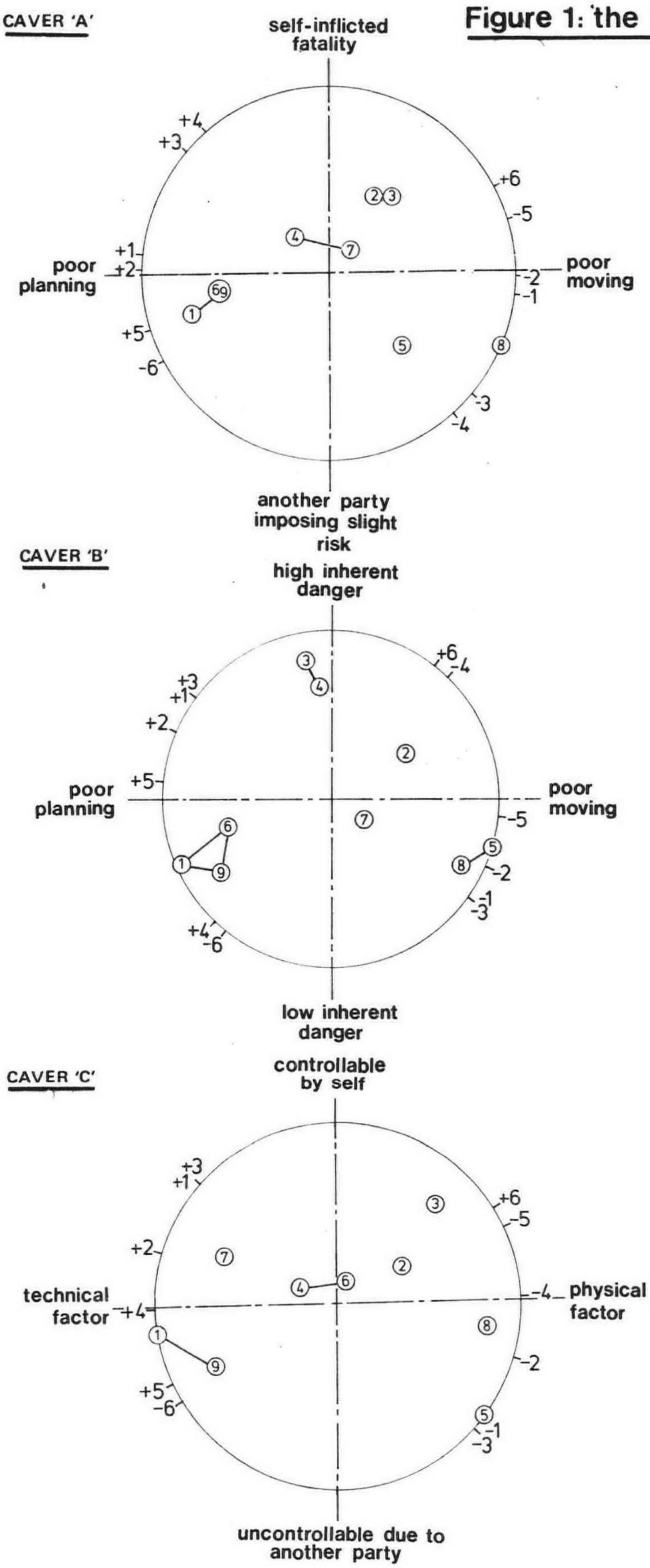
	Caver "A"			Caver "B"			Caver "C"		
FIRST COMPONENT	"poor planning"			"poor planning"			"physical factor"		
hazards	1	6	9	5	1	8	1	8	5
constructs	+5	-6	+3	+5	+2	+1	-4	-5	-2
SECOND COMPONENT	"self-inflicted fatality"			"low inherant danger"			"uncontrollable due to another party"		
hazards	3	2	4	3	4	9	5	3	
constructs	+3	+6	+4	-6	-4	-1	-1	-3	-5
THIRD COMPONENT	"serious hidden danger"			"undefined"			"serious danger in a risk-taking situation"		
hazards	5	7	8	7	8	9	7	2	9
constructs	+5	+6		-4	-6	-3	+6	+4	-2

The underlying trend is in each case named according to the "thing" which the highest loadings have in common. Caver "A" has a first component, for example, derived from hazards 1, 6, 9 and constructs +5, -6, +3, which are best described by the term "poor planning". Only the third underlying trend of caver "B" defies description under a single label and this was marked "undefined".

Displaying the mental models

The procedure for producing a diagram of the cavers mental models involved further use of the table of Vectors, Loadings and Residuals. The first step for caver "A" was to identify the highest and lowest loadings of hazards on the principal component. A horizontal axis was then drawn across the centre of the sheet and calibrated according to the range of loadings. The second component was shown as a vertical axis intersecting the first component in the centre of the sheet and at a value of zero. The position of each hazard was next plotted by using the loadings of each element on these first two components as if they were map references. Those hazards found to be closely related, using a criterion of 0.68 or half the unit of expected distance in the computer printout, were shown with linkages. After all the hazards were plotted as shown in Fig. 1, a circle was drawn which passed through the furthest points from the intersection of the axes. The next step merely repeated this procedure in order to locate the constructs. These were projected onto the circle so as to avoid any confusion between hazards and constructs. Representations of the mental models used by cavers "A", "B" and "C" are shown in Fig. 1. The two components in each case are named as the underlying trends and construct poles are shown in the correct orientation through the mental models.

Figure 1: the mental models



RESULTS

A cursory inspection of the cavers' mental models shown in the figures, reveals some remarkable similarities along with a few notable differences. The horizontal component of the mental models of cavers "A" and "B" indicates a primary concern with "poor planning - poor moving" as a basis for the perception of all caving hazards. The "poor planning" pole of the component is in close proximity to hazards 1, 6 and 9 (failure to take spare lighting on a long trip; inexperience of party, especially leader; poorly supervised novices) whilst the "poor moving" pole features hazards 5 and 8 (bad air in airbell between sumps; loose rocks in boulder choke). The same overall picture is apparent for caver "C" although the "poor planning - poor moving" dimension is termed "technical factor - physical factor".

The next most important underlying trend runs vertically through the mental model. Caver "A" thinks of hazards in terms of the potential for a "self-inflicted fatality" which may perhaps be interpreted as a concern about being in a situation where he unwittingly causes his own death. The dimension "high - low inherent danger" used by caver "B" is again consistent with the theme of assessing danger in terms of probable severity of injury. Caver "C" differs from cavers "A" and "B" by making no special mention of whether or not the danger is excessive. It is interesting that caver "C" perceives dangers not so much in terms of worst consequences but rather the extent to which he can or cannot exert any control.

The rules for analysis of the results, provided by Slater (1972) and Smith and Steward, (1976), specify that the most influential hazards are situated at the periphery of the mental models. The figures show that all three cavers agree about the importance of hazards 1, 5 and 8 (failure to take spare lighting on a long trip; bad air in airbell between sumps; loose rocks in boulder choke). It is notable that exposure to hazards 5 and 8 is generally perceived as being entirely "bad luck".

With varying degrees of emphasis, each caver perceives those hazards involving loose rocks (2, 3, 4 and 8) as being most likely to kill. An inverse correlation between constructs 5 and 6 (poor planning - poor moving; likely to kill - unlikely to kill) is apparent for cavers "A" and "C" which suggests that the extent of the hazard depends on the manner of contact with the loose rocks. The slightly different perception of caver "B" indicates that in certain situations the degree of hazard from loose rocks is influenced by another unknown factor which acts independently from the cavers contact with the rocks.

The dispersion of hazards 4, 6 and 7 (digging in an unstable choke without shoring; inexperience of party, especially leader; rope abrasion on SRT rope) tends to be at the core of the mental models. Not every caver has exactly the same configuration of hazards but the overall patterns indicate that there is considerable uncertainty about the nature of these hazards.

The mental models cannot be assumed to be totally representative of both past and future exposure because work by Blake et al (1951) has shown that abnormal perceptions may be induced by starvation, drugs and lack of sleep. The perception of danger is influenced by many other factors which cannot be so easily quantified. A discussion of some of these factors and the limitations of mental models is presented elsewhere (Champion, 1976). The results identify the prominent features of mental models used for the perception of caving hazards by three healthy, male cavers, each having a unique background of caving experiences and each describing their views in a comfortable, indoor situation. Appropriate caution must be exercised in seeking to generalise from these findings.

DISCUSSION OF RESULTS

The names given to underlying trends have a close similarity with the major themes of other research. Cavers "A" and "B" have a first dimension of "poor planning - poor moving" whilst caver "C" has a dimension with roughly equivalent meaning but termed "technical factor - physical factor". These conceptual criteria are similar to the "skill of coping with dangerous environment" described by Ross (1974) and the "scope for personal control" identified by Champion (1977). The second component of the mental models has slight differences of emphasis between the three cavers but a dominant theme is the range of hazards between high and low levels of inherant danger. This dimension seems to be similar in nature to the concept of "dreadfulness" of a hazard as described by Ross (1974) and the "injury potential" underlying trend found by Champion (1977).

Further support for these two main dimensions comes from a recent study using the repertory grid technique in a variety of activities including the concensus of a group of experienced cavers. In this study, Pérusse (1980), found two principal dimensions - "scope for human intervention" and "dangerousness" - both of which had a number of sub-factors.

A parallel may also be drawn with the transactional stress response model (McGrath, 1974) which involves the perceived demands of a hazard being weighed against the perceived resources of the person. Themes of this balancing process correspond with an assessment of the inherent danger and the scope for personal control.

Some of the constructs found in this study are directly comparable with those constructs found by Green and Brown (1976), Lowrance (1976) and Champion (1977) as follows:

1+ controllable/preventable/many alternatives available/preventable
-2 bad luck/ - /dread hazard/very difficult to identify danger
3+ due to my party/blame assignable/ - /operators fault
6+ likely to kill/high risk of death/ - /very likely to kill

The fact that the Bartlett Test found more than 10% of the factors unexplained, after the extraction of two components, suggests that the cavers have several more constructs than the six derived. It is reasonable to expect that the missing constructs used for the perception of danger will be similar in nature to those described by other researchers. The criterion of "meaningfulness" derived at an early stage of the method and subsequently ignored may, for example, be found to consist of the following constructs:

"very often encountered in my caving - never encountered in my caving"
"very likely to cause an accident - very unlikely to cause an accident"
"danger is immediately present - danger is dependent on other things".

SAFETY IMPLICATIONS

It is possible for the results to be interpreted in many different ways but some of the most important safety implications should be made clear by studying firstly those hazards completely overlooked in Table 1 and then working through to those hazards given special prominence in the mental models.

Hazards omitted by all three cavers

Quite obviously there are many hundreds of caving hazards not included in Table 1 but of the 34 hazards only four were not considered to be sufficiently "meaningful" for further study.

Caver "C" suggested that the reason for their having overlooked the hazard "non-use of a lifeline on pitch or traverse or climb" was because of the common practice of only bothering with this precaution when tackling pitches of more than 25 feet. Clearly the sad case of a competent caver once falling a few feet from the Roof Tunnel pitch in Kingsdale Master Cave, leaving him paralysed for life, has faded from the memory of these cavers. In the opinion of caver "C" a lifeline should be used on short pitches if the caver is feeling tired or is troubled by the volume of falling water.

The three experienced cavers seem to have very little regard for other hazards which may cause falling despite the fact (Forder, 1981) that falls underground are the most common form of accident and they account for almost a third of all fatalities. It is conceivable that the majority of these falls happen to inexperienced cavers although there are few facts available to support this assertion.

The hazards of "being swept away in high water conditions" and a "change in water level whilst underground" were not included by any of the cavers even though very serious accidents have occasionally taken place in caves such as Ogof-Ffynnon-Ddu and Mossdale Caverns.

All three cavers overlooked the hazard "off-route in a sump and becoming stuck" but caver "B" has since offered the following explanation: "the hazard is not too relevant to standard caving (for "stuck" substitute the word "dead"!) and as a diver I would <u>not</u> rate it as the worst diving hazard anyway. It's a bit in the same class as abseiling off the end of a rope"!

Hazards included by only one caver

There is some evidence that the background experiences of cavers tend to influence their selection of "meaningful" hazards. The experience of caver "A" on the club meets of a large pothole club are presumably behind his being the only caver to note the hazard of "too many people down the hole causing confusion". Similarly, the climbing interests of caver "C" may contribute towards his being the only one of the three cavers to note the hazards of "knots tied incorrectly" and "presence of loose rock on a climb or traverse".

Hazards omitted despite being part of a cavers specialist activity

Table 1 shows that certain hazards are recognised by two cavers but ignored by the caver who could most reasonably be expected to encounter the hazard as part of his specialist interest. For example, the hazard "failure to take spare lighting on a long trip" was selected by cavers "B" and "C" but not by caver "A". This state of affairs could be explained by caver "A" never having experienced light failure during his expedition trips or that he has always managed to overcome the problem of light failure in one way or another. It could on the other hand be indicative of a "blind spot" in the cavers perception of this potentially serious hazard.

Another hazard omitted by caver "A" is that of the "failure to use a natural back-up belay to a bolt" but soon after the grid completion exercise caver "A" happened to witness the failure of a bolt belay which resulted in his friend falling 20 feet and sustaining a broken leg injury. This accident led caver "A" to the view that if ever taking part in another study he would now include the "non-use of a lifeline on a pitch ..." as a serious hazard.

The same kind of inconsistency is notable for caver "B" - the cave diver - in his omission of "line through sumps becoming loose whilst diving" and for caver "C" - the aven climber - in his omission of "insecure belay for ladder, rope or lifeline". It therefore seems advisable periodically to warn cavers about the need for certain safety precautions.

Hazards included by all three cavers

It seems reasonable to suggest that the hazards selected by all three cavers as being the most meaningful are the ones which deserve the most attention by other experienced cavers. A weakness in this line of argument has however been noticed in the case of the hazard "bad air in airbell between sumps". Caver "B" is of the opinion that this hazard would not normally have been recognised had it not been for the publicity given, only a few months before the study, to the deaths of three cavers in the Langstroth Cave/Pot connection sumps. It follows that the awareness of cavers to a particular danger may be only a temporary phenomenon immediately after a very serious accident. Another reason for caution in considering the status of the nine selected hazards is that the low priority given to cave diving is in marked contrast with the high fatality rate. Analysis of the accident statistics (Forder, 1981) revealed that only 1.9% of all accidents, occurring between 1935-1980 in Yorkshire and the Mendips, were concerned with sump diving but the 11 resulting fatalities take second place, after "falls", as being the most common form of caving fatality.

Hazards featuring in the mental models

There are many interesting associations between the underlying trends, constructs and hazards although discretion must be exercised rather than reading too much into the results. One may, however, reasonably predict that the high correlation between "planning" hazards 1, 6 and 9 is evidence of the same position in the mental model being occupied by similar hazards such as "failure to observe prevailing weather conditions before descending". Several other planning hazards were not elicited, for instance "failure to inform a responsible person before descending" but presumably these would be accommodated in the mental models at the cluster of the hazards 1, 6 and 9. There would indeed have been good reason for alarm if any of the three experienced cavers had thought of these planning hazards as basically a matter of "bad luck"!

Those hazards resulting from poor planning (1, 6 and 9) are consistently clustered towards the "unlikely to kill" position whilst those involving loose rocks (2, 3, 4 and 8) are, with varying degrees of emphasis, perceived as being "likely to kill". This observation was subsequently explained by caver "A" in the following suggestion: "Do we tend to be overly aware of nasty, violent dangers such as boulders rather than something 'softer' such as floods or hypothermia, where the body is not broken?" Whatever the subjective reasons for the cavers concern about rockfalls, there is justification for this concern from work by Forder (1981) which found that although rockfalls only account for about 5% of accidents they have a surprisingly high fatality rate.

It would be interesting to discern which, if any, of the cavers are more inclined to rig SRT pitches as a free-hang rather than place reliance on rope protectors. Precious little information is, however, revealed from comparison of the mental models in Fig. 1. The central position of the hazard "rope abrasion on SRT rope" is indicative of the cavers giving it fairly low importance although the linkage made by caver "A" between this hazard and "digging in an unstable choke, without shoring" could be interpreted as a preference for ladder and lifeline techniques!

CONCLUSIONS

1. Experienced cavers perceive hazards primarily in terms of the scope for advanced planning and the nature of movement once engaged in an activity. A secondary independent assessment is made regarding the extent of inherent danger involved in an activity. This secondary criterion may be further modified by considerations of whether or not the danger is controllable by oneself.

2. The mental models held by the cavers participating in this study have a similar overall structure but with differences of emphasis for certain hazards.

3. The cavers' responses suggest the existance of other as yet undefined constructs used for the perception of caving hazards.

4. Even these experienced cavers tend to underestimate hazards which involve laddering shafts, exploring stream caves and diving sumps.

5. There are indications that cavers are most aware of a particular hazard for a period soon after an accident but in time familiarity with the hazard breeds fresh contempt for the relevant safety precautions.

6. A person's caving club and/or his specialist interests appear to bias the perception of dangers in a way which is only partially understood.

7. Experienced cavers perceive hazards arising from poor planning as being unlikely to kill whereas poor movement in regard to loose boulders is considered to be likely to kill.

FURTHER RESEARCH

Several tables of results in the computer printout were ignored for the sake of concentrating on the presentation of mental models. Further systematic searches for associations between cavers, constructs and hazards may go some way towards answering several interesting questions about the perception of danger.

The extent of correlation between various constructs is certainly worthy of examination by using the appropriate table of the computer printout to produce a factor analysis diagram. One might reasonably expect there to be a positive correlation between "lack of thought - bad luck" and "due to my party - due to another party". Similarly any future work could easily check whether there is, as this study finds, an inverse correlation between "poor planning - poor moving" and "likely to kill - unlikely to kill".

Several of the constructs derived in the study appear to be more concerned with allocating blame than they are with the prevention of an accident. "Poor planning - poor moving" is, for example, less useful for accident prevention than is the underived construct of "takes a specialist caver to control the danger - any caver can control the danger". It is notable that the cavers do not appear to discriminate between hazards which are likely to put only one person at risk and hazards which put every person in the cave at risk. Any future study could supply these constructs and others of interest such as "cavers could easily get an accident victim out of cave - cave rescue team would be needed in the event of an accident".

One weakness of the repertory grid technique is that the cavers may think of it as a game having very little relevance to their thoughts whilst actually caving. A way of overcoming this problem was suggested by caver "C" in that constructs such as "the hazard is aggravated by tiredness/floodwater/bad communications - the hazard is not aggravated by tiredness, etc." may be supplied to cavers in any future study.

The repertory grid technique has great potential for testing a number of other hypotheses. It seems reasonable to suggest that the most valuable general insights into the perception of caving hazards will come from studying a large number of similar groups of cavers in order to compare the consensus mental models. Expedition cavers may be found to take certain hazards for granted whilst qualified instructors of novices may be found to exaggerate the risk of certain hazards.

The movement of hazards in the mental model from an important outer position towards the core of the structure provides an indication of whether the saying: "familiarity breeds contempt" has any validity amongst cavers. Repertory grid technique clearly enables an investigator to measure the extent to which cavers are influenced by a hazard immediately after it has led to a serious caving accident.

The grid could reveal some interesting views about caving equipment and techniques. Small bolts have an immediate safety benefit as belay points for SRT enthusiasts but the corrosion of metal components in the cave environment creates a risk of sudden failure for another caving party at some time in the future. It seems fairly certain that cavers will have differences of opinion about the value of these small bolts.

The technique clearly has many fascinating applications but one of the most valuable could be as a means of measuring the effectiveness of various methods of improving the accuracy of cavers' perception of danger. Films, posters, training sessions and specific caving experiences are all worthy of consideration. What often passes for safety training could in fact turn out to be no more than the temporary shuffling of hazards along constructs or the acceptance of hazards into core positions of the mental models. Grids obtained before a first aid training session could be compared with grids taken afterwards in order to check the idea (Glendon, 1978; Devine, 1981) that this training promotes the safety consciousness of cavers. There is even a strong possibility that participation in the repertory grid technique may itself encourage the development of a more accurate evaluation of caving hazards!

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A REVIEW OF WORLD TROGLOPEDETINI (INSECTA, COLLEMBOLA, PARONELLIDAE) INCLUDING AN IDENTIFICATION TABLE AND DESCRIPTIONS OF NEW SPECIES.

Jane M. Wilson

ABSTRACT

The taxonomy of the tribe Troglopedetini is reviewed and a table to identify the 25 species is given. *Troglopedetes churchillatus* Wilson and *Troglopedetes nepalensis* sp. nov. from the caves of Nepal are described with a brief discussion of their cave dwelling habits. *Troglopedetes madagascarensis* sp. nov. is also described.

RESUMÉ

La taxonomie de la tribu Troglopedetini est revue et un tableau aux 25 espèces est présenté. *Troglopedetes churchillatus* Wilson et *Troglopedetes nepalensis* sp. nov. des grottes de Népal sont décrits avec une brève discussion de leurs coutumes habitudes de vie dans les grottes. *Troglopedetes madagascarensis* sp. nov. est décrit aussi.

INTRODUCTION

During a caving expedition to the Himalaya, studies were made of the biology and micro-climate of the Pokhara Valley caves and others (Turner 1977 a and b; Wilson 1977 a and b; Durrant et al. 1979). Among the many interesting animals collected (table 1 and Appendix) were two undescribed paronelloid Collembola (springtails) which are common in the Pokhara caves. One is a troglobite, the other a troglophile; both belong to the genus *Troglopedetes* within the tribe Troglopedetini. In order to classify these new species effectively and describe them with respect to closely related Collembola, it was necessary to review the literature on the Troglopedetini. Some confusion seems to have developed in the taxonomy of this tribe so it is hoped that this review will clarify several problems.

The taxonomy of the Troglopedetini is muddled. Some difficulties are due to the fact that the tribe appears to be diphyletic (Massoud 1978 pers. com.). The contrasting presence or absence of a sub-divided Antenna IV and the one or two rows of dental spines all within this one tribe encourages me to support Massoud's view. The confusion is made worse by taxonomists' use of different characters to define their species which makes comparisons very difficult. Most Troglopedetini have been described from less than 10 specimens, several from only one individual. In most cases no representatives of these species have been discovered since. Fjellberg (1976), in his interesting paper discussing the occurrence of different forms within the same collembolan species, underlined the dangers of describing a species from a few individuals. If these few individuals are later found to be from the edge of the geographic range of that species, they may not be morphologically characteristic of that species.

TRIBE TROGLOPEDETINI BÖRNER 1913

The Troglopedetini are Entomobryoid Collembola. This means that they have a well developed furca (so they can spring well), abdominal segment IV is at least twice as large as any other body segment and the Post Antennal Organ is absent. The eyes tend to be reduced (i.e. fewer than the maximum of eight on each side) or absent and many species live in caves.

Representatives of the tribe have scales on their bodies. The dens has one or two rows of spines on its posterior face and the mucro tends to be much longer than that of their brothers in the tribe Paronelli. Various taxonomists have placed the Troglopedetini in families: Entomobryidae, Cyphoderidae and the Paronellidae and the tribe certainly provides a link between the three families.

Five genera have been described within the tribe (*Troglopedetes**, *Cyphoderopsis*, *Trogolaphysa**, *Troglopedetina** and *Trogonella)*, of which only the three asterisked are here recognised as valid.

Genus *Troglopedetes* Joseph

Troglopedetes Joseph, 1872: 180, Type-species: *Troglopedetes albus* Joseph 1872: 180, by monotypy (Gurtal, S. Austria).

Troglopedetes Absolon 1907: 335, Type-species: *Troglopedetes pallidus* Absolon, 1907: 335 (= *T. albus* Joseph, 1872) by original designation. Junior homonym, independently proposed, of *Troglopedetes* Joseph, 1872, syn. nov.

Cyphoderopsis Carpenter, 1917: 566 Type-species: *Cyphoderopsis kempi* Carpenter, 1917: 288. Synonomy with *Troglopedetes* Absolon by Bonet, 1931: 362.

Bonet (1931) synonymised *Troglopedetes* and *Cyphoderopsis* because there is no obvious way of separating the two taxa. But despite the overlap between the two genera, several new species have been described in *Cyphoderopsis* since 1931. The taxonomists involved have not commented on their use of the junior synonym.

It is likely that the scale-like appendage that characterises *Cyphoderopsis kempi* (the type-species) was an aberration of the single specimen seen by Carpenter and, since it is now so deteriorated that it is now hardly recognisable as a Collembolan, the presence of the appendage cannot be confirmed. I currently follow Bonet in his placement of *Cyphoderopsis* as a junior synonym of *Troglopedetes*.

There may, however, be a case for reserving *Cyphoderopsis* for old world Troglopedetini with two rows of dental spines and undivided Antenna IV i.e. *kempi*, *gracilis* and *lamottei*. Further study and more specimens are required.

DIAGNOSIS

Troglopedetes are with one or two rows of simple dental spines,
with or without sub-divided Antenna IV,
with or without ommatidia (ocelli).

DISTRIBUTION

Most representatives have been collected from Europe and Asia but two species have been described from Africa. They are often found in caves and over half of the known species are troglobites. If found on the surface, they are most frequently found in leaf litter of under stones. The genus currently contains 19 species.

Catalogue of species of *Troglopedetes*

1 . *T. albus* Joseph

Troglopedetes albus Joseph 1872: 180, Type material not located, presumed lost; AUSTRIA.
Troglopedetes pallidus Absolon, 1907: 335, YUGOSLAVIA. Synonymy suggested by Paclt (1946:83)
Troglopedetes pallidus distinctus Absolon & Ksenemann, 1942: 6, YUGOSLAVIA. Joseph's description reads"Ich reihe hieran eine neue augenlose Podure *Troglopedetes albus* sp. nov. mit einem Springschwanz von fast der Lange des Korpers aus den Grotten von Cumpole, Podec und Gurk in Unerkrain ..." i.e. a blind Collembolan with a furca almost as long as the body.

According to Hörn and Kahle (1936) Joseph's specimens have been dispersed: "Joseph, Gustav (1828-ca.1891) Sammlg. 1907 via W. Hoefig, 1920 via Standinger and Bang Haas (Dresden-Blasewitz) vereinzelt" and it seems most unlikely that his types will be recovered.

Paclt (1946: 83) suggested that *Troglopedetes albus* was a *nomen nudum* but Ellis and Bellinger (1973: 57) correctly indicate that the name is available under the criteria of the International Code of Zoological Nomenclature. Paclt says that it is highly probable that *Troglopedetes albus* Joseph is identical with *Troglopedetes pallidus* Absolon. The geographical distribution of the two species and the scant description of *T. albus* do not negate this view. No other *Troglopedetes* species are known from this part of Europe. However, it is difficult to understand why Absolon should have used the name coined by Joseph without referring to him, unless it was a great coincidence.

According to Bogojevic (1968) this species has been collected again recently from Yugoslavia.

TABLE 1 : SPECIES LISTS FOR SOME HIMALAYAN CAVES

	MAHENDRA GUPHA N. Pokhara: height 1100m. c. 200m of passage	ODERIBUWAHN GUPHA N. Pokhara: height 1100m c. 80m of passage	WINDOW CAVE N. Pokhara: height 1100m c. 20m of passage
COLLEMBOLA	Hypogastrura carpetana Onychiurus yodai (Lobella kraepelina) Sinella sp. Troglopedetes church* T. nepalensis* Isotomeilla minor Cryptopagus thermophilus Folsomides exiguus	Lepidocyrtus sp. Troglopedetes church* T. nepalensis*	Troglopedetes churchillatus
THYSANURA	Nicoletia		
EARWIGS	Forcipula sp.	Forcipula sp. Nala nepalensis	
BOOK LICE	Liposcelis sp.	Liposcelis sp.	
BUGS	+		
MOTHS	+	Tinea antricola	+
BEETLES	Cryptobium humerale Philodactylae larvae	Cryptobium humerale Cercyon sp.	Leiodid
ANTS etc.	Brachyponera spp. Lophomyrmex sp. Pachycondyla luteipes	Pheidole sp.A	Pheidole sp.B
FLIES (bat-flies listed below)	Conicera kempi Drosophila sp. Leptocera rufilabris		
MITES	Hypoaspis spp.B,C&D Uropodids	Hypoaspis sp.B Machrocheles sp. Uropodids Schweiba sp. ?Linopodes sp. Oribatids	Machrocheles glaber gr.
SPIDERS etc.	Sparassids Linyphiids Salticiids Pholcids	Linyphiid Theridiids Pholcids	Sparassids Lynyphiids Pseudoscorpiones
MILLIPEDES	Trachyiulus sp.	Trachyiulus wilsonae* Polydesmida sp.	
WOODLICE	+	+	
CRABS	(Potamon atkinsoniamum)		
SNAILS	Macrochlamys sp.	Macrochlamys sp.	
WORMS	Dichogaster sp.	Dichogaster sp.	Dichogaster sp.
BATS each with their bat-flies in [ ]	Rhinolophus macrotis Hipposideros bicolor [Raymondia molossa] Hipposideros armiger [Stylidia ornata] [Brachytarsina sp.] Megaderma lyra [Raymondia molossa]	+	+
PLANTS	Various Phycomycetes 'Wall Fungus'	Phycomycetes, Fungi Imperfecti & inwashed flowering plants	Phycomycetes

KEY	
Probable Troglobites	ringed
Guanophiles	underlined
Accidentals	(in brackets)

TABLE 1 continued·

KAARR JUNGLE CAVE N. Pokhara: height 1100m. c. 20m of passage	HARPAN RIVER CAVE S. Pokhara: height 1000m. 1500m of passage	CHOBHAR GORGE CAVES Katmandu: height 1200m 200m + passage	DOON VIEW CAVE N. India height 1000m c. 100m of passage
Hypogastrura carp.			
Onychiurus yodai			
	Sinella		Hypogastrurids
Troglopedetes church*	T.nepalensis*		Pseudosinella sp.
T. nepalensis*			
	Forcipula trispinosa		
		Wegneria cerodelta	W.cerodelta
	(Philonthus rivularis)		
	Neoblemus championi		
	Gyrinids		Histerids
	Dytiscids		
			Brachonid
		Conicera kempi	Conicera kempi
		(Phebotomus longiductus)	
Hypoaspis sp.			Hypoaspis sp.A
			(Haemaphysalis montgomeryi)
Uropodids			
Linyphiid			
Salticids	Harvestmen		
Pseudoscorpiones			
		Podoglyphiulus nepalensis*	
		Strongylosomida sp.	Strongylosomida sp.
		(Potamon sp.)	
Chorodes; hairworm			
			Rhinolophus lepidus
Hipposideros armiger	Hipposideros armiger	Hipposideros cineraceus [Raymondia molossa]	Hipposideros armiger
	Rousettus leschenaulti		
		Megaderma lyra [Raymondia molossa]	
Phycomycetes	Phycomycetes, Fungi Imperfecti & "Lichen"	Phycomycetes	Phycomycetes

KEY:
others are Troglophiles
++ group present in cave
most accidentals are omitted
* signifies new species

2. *T. kempi* (Carpenter)

Cyphoderopsis kempi Carpenter 1917: 566. Holotype, N.E. India (B.M.(N.H.)) (examined)
Troglopedetes kempi (Carpenter) Bonet 1931: 362.
I have examined the only existing specimen of *T. kempi* (at the British Museum). It is in such a poor state of preservation that it is hardly recognisable as a Collembolan. Carpenter gave adequate drawings.

3. *T. gracilis* (Carpenter)

Cyphoderopsis gracilis Carpenter, 1924: 288. N.E. India
Troglopedetes gracilis (Carpenter) Bonet, 1931: 362.

4. *T. absoloni* Bonet

Troglopedetes absoloni Bonet, 1931: 363. SPAIN

5. *T. cavernicola* Delamare

Troglopedetes cavernicola Delamare, 1944: 30. PORTUGAL
Troglopedetes wichmanni Delamare, 1950b: 295. *Nomen nudum* listed from "Grottes de l'Ile de Crete" without description. This animal has never been described but I suspect that this species is identical with *Troglopedetes cretensis* Ellis, 1976: 306. *Troglopedetes cretensis* is so similar to *T. cavernicola* Delamare from Portugal, that I suspect that Delamare decided not to describe *T. wichmanni* as a separate species. The chaetotaxy and other characters of *T. cavernicola* and *T. cretensis* are similar enough to suggest that these are not separate species, but in view of the lack of opportunity to examine specimens, I consider it most satisfactory to leave *T. cretensis* as valid for the present.
Troglopedetes wichmanni Delamare, 1950 is *nomen nudum*.

6. *T. machadoi* Delamare

Troglopedetes machadoi Delamare, 1946: 101. PORTUGAL

7. *T. lamottei* (Delamare)

Cypherodopsis lamottei Delamare, 1950a: 44. W.AFRICA. I follow Bonet (1931) who synonymized *Cypherodopsis* with *Troglopedetes*.

8. *T. ruffoi* Delamare

Troglopedetes ruffoi Delamare 1951: 44. ITALY
Figure 3 shows the chaetotaxy of the specimen held at Museum National d'Histoire Naturelle, Brunoy (Paris). *Troglopedetes ruffoi* has long wing-like basal teeth (on the claw) which are longer than the empodial appendage. The long body setae and enormously long antennae are characteristic adaptations to cave life. This is almost certainly a troglobitic (tbt) species and unlikely ever to be found in the epigean domain (epig).

9. *T. orientalis* Cassagnau & Delamare

Troglopedetes orientalis Cassagnau & Delamare 1955: 385. LEBANON

10. *T. vandeli* Cassagnau & Delamare

Troglopedetes vandeli Cassagnau & Delamare 1955: 387. LEBANON

11. *T. canis* Christiansen

Troglopedetes canis Christiansen 1957: 86. LEBANON

12. *T. lindbergi* Stach. Comb. Nov.

Troglopedetina lindbergi Stach, 1960: 546. AFGHANISTAN. Delamare stipulated that *Troglopedetina* is a genus of Troglopedetini with sub-divided Antenna IV. *T. lindbergi* has no such subdivision and belongs within *Troglopedetes*. *T. lindbergi* has no ommatidia but does have pigment where the eyes once were.

13. *T. ceylonica* (Yosii) Comb. Nov.

Cypherodopsis ceylonica Yosii 1966a: 386. CEYLON, N.E.INDIA. Following Bonet (1931) this species belongs within *Troglopedetes*. Yosii (1966b) further described his species with material from Sikkim and Assam (India).

14. *T. sexocellata* (Yosii) Comb. Nov.

Cyphoderopsis 6-ocellata Yosii 1966a: 387. TAIWAN, INDIA. Yosii is again using an abandoned genus without justifying this decision.

15. *T. decemoculata* (Prabhoo). Comb. Nov.

Cyphoderopsis decemoculata Prabhoo 1971: 37. S. INDIA. Prabhoo does not justify his use of the abandoned genus.

16. *T. cretensis* Ellis

Troglopedetes cretensis Ellis, 1976: 306. CRETE
This species is very close to *T. cavernicola* Delamare 1944 but Ellis justifies its designation as a separate species. *T. cretensis* may be identical with the undescribed *T. wichmanni* of Delamare 1950b: 295.

17. *T. churchillatus* Wilson

Troglopedetes churchillatus Wilson *in* Durrant, Smart, Turner & Wilson, 1979: 47. Lectotype Adult NEPAL (BM(NH)), here designated (examined). See page 220 and Figs. 1-4 for the description of this species.

18. *T. nepalensis* sp. nov.

see page 221 and Figs. 3 & 5 for the description of this species.

19. *T. madagascarensis* sp. nov.

See page 222 and Figs.6-8 for a preliminary description of this species.

Genus *Trogolaphysa* Mills

Trogolaphysa Mills, 1938, Type-species *Trogolaphysa maya* Mills, 1938, by monotypy.

DIAGNOSIS

Trogolaphysa are with two rows of simple dental spines,
without a sub-division of Antenna IV,
with or without ommatidia.

A new world genus found both in caves and on the surface. Salmon (1964: 134) proposed that *Trogolaphysa* is a junior synonym of *Troglopedetes* but I consider the genus sufficiently distinct and therefore valid.

1. *T. maya* Mills

Trogolaphysa maya Mills, 1938: 184. MEXICO

2. *T. millsi* Arlé

Trogolaphysa millsi Arlé, 1946: 28. Two syntypes BRAZIL. This species was described from just two individuals from Rio de Janero and these are clearly immature. *T. millsi* is quite different from the type-species and its affinities are unclear. Delamare (1950b: 293) placed it in *Troglopedetina* but without justifying this. It has not been collected since and descriptions based upon immature specimens can be misleading. It seems convenient to leave *T. millsi* with the other American species in *Trogolaphysa*, for the present.

3. *T. delamarei* (Massoud & Gruia) Comb. Nov.

Troglopedetes delamarei Massoud & Gruia, 1973: 339. CUBA. The undivided antenna IV and two rows of dental spines and external teeth basally on the empodium of the claw make this species closer to the type-species of *Trogolaphysa* than to the old world *Troglopedetes*.

Genus *Troglopedetina* Delamare

Troglopedetina Delamare 1945: 41. Type-species *Troglopedetina jeanneli* Delamare 1945, by monotypy.

DIAGNOSIS

Troglopedetina are with one row of simple dental spines,
with a sub-divided Antenna IV,
with at least 1+1 ommatidia,
and with numerous elongated scales which are greatly swollen at their apices.

Ommatidia are unreliable taxonomically and can be so variable that Poinsot (1971) considered that eye number should not be used to separate species. Absence or number of eyes gives little phylogenetic information, but only shows adaption to living in caves or sub-soil habitats.

The sub-division of Antenna IV and the presence of a single row of dental spines do not separate *Troglopedetina* from other members of the tribe although there is a good case for reserving the genus *Troglopedetina* for all the Troglopedetini with sub-divided Antenna IV and one row of spines on the dens: these are mainly the African species. All known *Troglopedetina* species have eyes and are surface dwelling (epigean).

Three described species are recognised and in addition Delamare (1950b: 293) gave names for six 'new' but undescribed *Troglopedetina* from Kenya and the Ivory Coast. He described these species as having one to three ommatidia on each side of the head. These six species must all be regarded as *nomina nuda* but emphasise that *Troglopedetina* is an African genus.

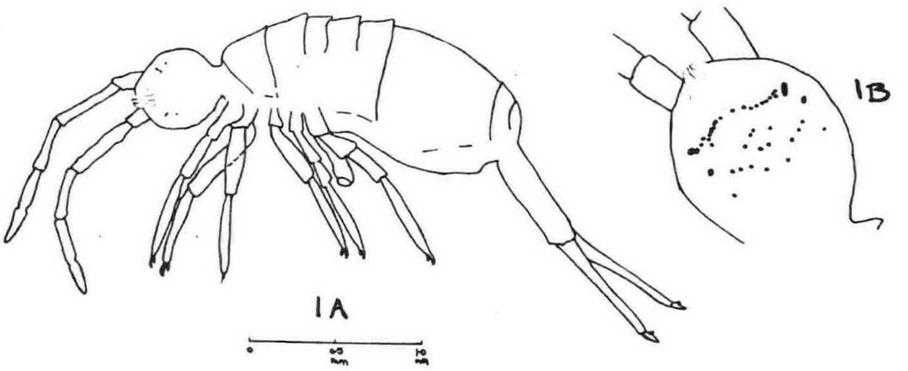
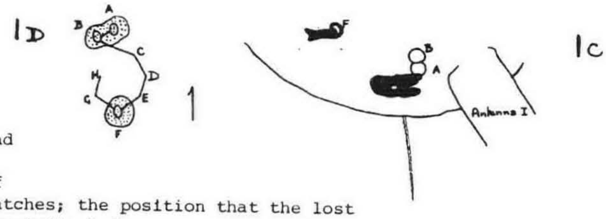


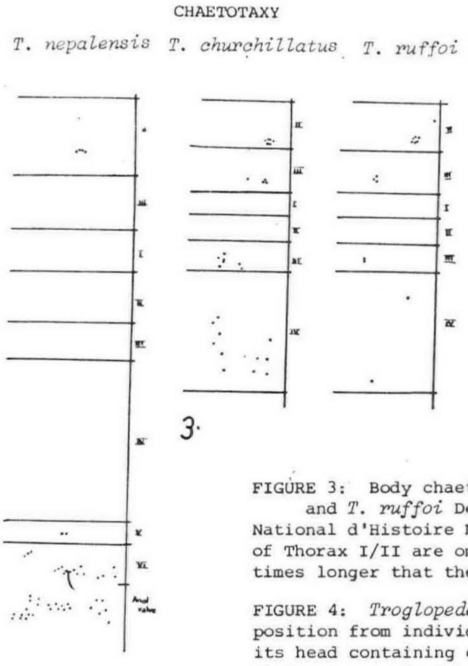
FIGURE 1: *Troglopedetes churchillatus* Wilson



1A Habitus of the Lectotype; 1B Head chaetotaxy and eye-spot pigment of the same individual;
1C The right side of the head behind the first antennal segment showing how the eye-spot pigment may not surround the lenses. The bases of the head setae are shown; 1D Diagram of the right ocellar patch (after Guthrie 1906) showing the position of A, B and F ocelli with their associated pigment patches; the position that the lost C, D, E, G and H ocelli would have occupied is also indicated.

FIGURE 2: *Troglopedetes churchillatus* Wilson

2A Shows the mid-claw and 2B the hind claw on the feet of the lectotype.
2C Is two drawings of the same claw; the apparent differences in shape were achieved by moving the claw on the microscope slide; 2D, E and F Are mucrones on the springing organ (furca) of *T.churchillatus*; 2D shows the mucrones of the same individual; 2E Illustrates the mucro and the finely ciliated spines on the dens; 2F Shows the mucrones and dentes. Note that the dens in thickly covered with scales and setae. One row of dental spines is present on each dens.



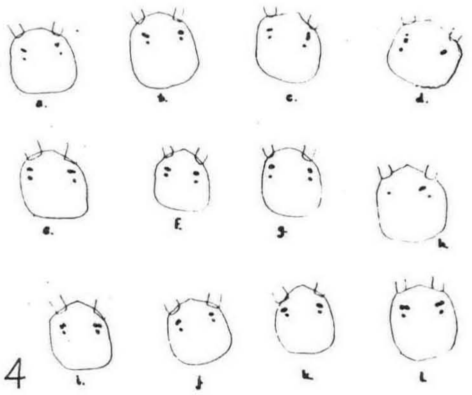


FIGURE 3: Body chaetotaxy of *Troglopedetes nepalensis* sp. nov., *T. churchillatus* Wilson and *T. ruffoi* Delamare. *T. ruffoi* is drawn from the specimen at the Museum National d'Histoire Naturelle, Brunoy. The 2-3 rows of setae at the anterior edge of Thorax I/II are omitted in each case. In *T. ruffoi* these setae are about three times longer that the empodium.

FIGURE 4: *Troglopedetes churchillatus* Wilson. The eye-spot pigment varies in position from individual to individual. 4h has only eye-spot on the left side of its head containing only one lens thus it has just 1+3 lenses. In contrast 4d shows an animal with 3+1 pigment patches containing the normal number of 3+3 lenses.

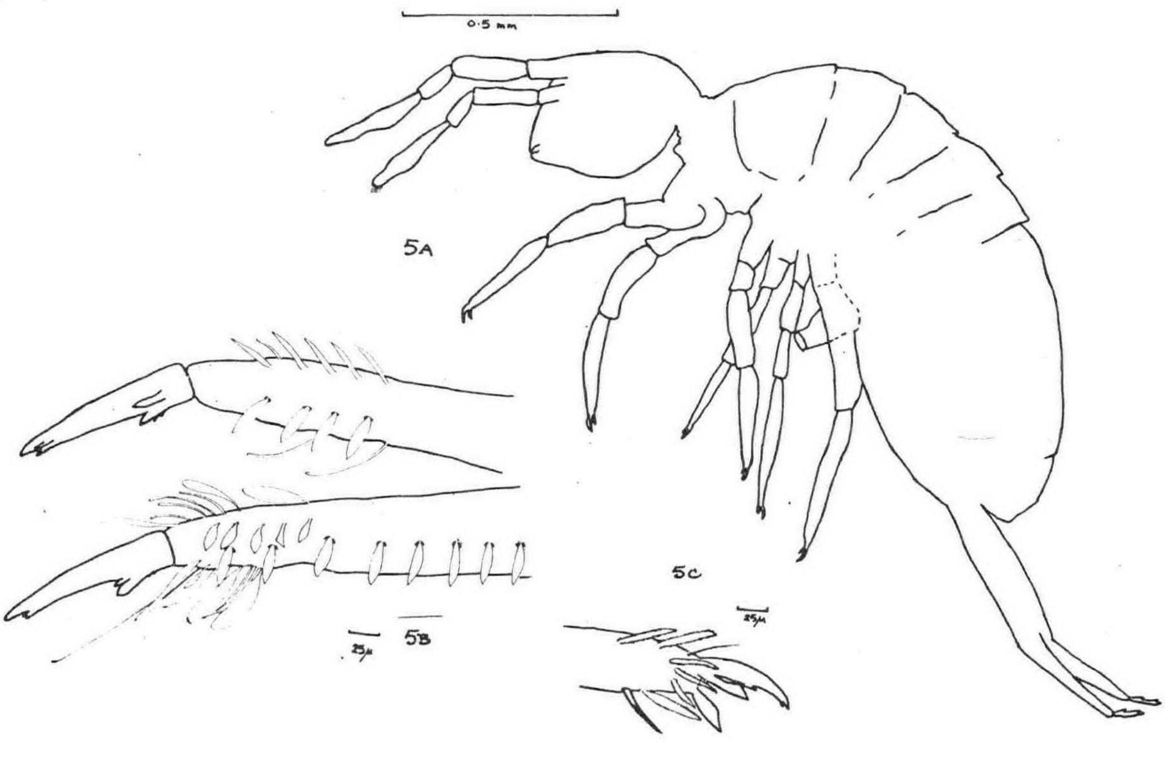


FIGURE 5: *Troglopedetes nepalensis* sp. nov. 5A habitus ; B: mucro and part of the dens; note again the abundance of scales and setae and the single row of dental spines. (Some anterior spines and setae are omitted). 5C shows a typical claw with the pointed tenent hair.

The elongated scales seem to be the only character peculiar to *Troglopedetina*. In the absence of the time and material necessary to investigate the relationships between *Troglopedetina* and *Troglopedetes*, it seems reasonable to recognise *Troglopedetina* as a genus containing:-

1. *T. jeanneli* Delamare
   Troglopedetina jeanneli Delamare, 1945: 41. KENYA
2. *T. tridentata* Salmon
   Troglopedetina tridentata Salmon 1954: 161. UGANDA.
3. *T. schalleri* Hüther
   Troglopedetina schalleri Hüther 1962: 219. SUDAN.

TAXA REJECTED FROM THE TROGLOPEDETINI

Trogonella Delamare, 1951b Type-species *Trogonella pauliani* Delamare, 1951b by monotypy.

This monotypic genus was described from just three individuals, which are all apparently immature *Paronella* sp. (Z. Massoud 1978, pers. com.). The genus is therefore a junior synonym of *Paronella*.

Cyphoderus lavaticus (Stach) *comb. nov.*
Cyphoderopsis lavaticus Stach 1960: 545 *C. lavaticus* has an empodial appendage that is characteristic of *Cyphoderus* (Z. Massoud 1978, pers. com.), and its mucro is unlike any other member of the Troglopedetini and so it has been rejected from this tribe.

SPECIES OF UNCERTAIN POSITION

Troglopedetes nayakensis Stach 1960: 543 is also unlike other troglopedetines. It does not possess the dental spines that are characteristic of the Troglopedetini and the rather scanty description that Stach gives, makes it difficult to know where its affinities lie.

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In summary, I restate that *Cypherodopsis* is a junior synonym of *Troglopedetes*. The genus *Trogonella* is rejected from the Troglopedetini, leaving the tribe with three genera: *Troglopedetes* (with 19 old world species), *Troglopedetina* (with three African species) and *Trogolaphysa* (with three American species).

IDENTIFICATION TABLE FOR SPECIES OF TROGLOPEDETINI

Table 2 has been constructed to facilitate quick and easy identification of the world Troglopedetini. The information it contains is abstracted from published descriptions, supplemented with a few observations on specimens at the British Museum (Natural History) in London and Muséum National d'Histoire Naturelle at Brunoy. Attempts have been made to standardise descriptions but in many cases this was not possible without reference to specimens. Table 2 does show how inadequate many descriptions are - a point that is hidden in dichotomous keys. The table has the advantage over a key in that it can be used to identify mutilated specimens and it should also continue to be useful even after many more species have joined the ranks of the Troglopedetini.

Some of the antenna:head ratios quoted are those I have measured from small-scale published illustrations and so may only be very approximate. These figures are underlined to on Table 2 column 3 to distinguish them from measurements taken from specimens.

The numbers of mucronal teeth quoted in Table 2 should be regarded with caution as ribs, lamellae, serrations and undulations may be interpreted in different ways (P.N. Lawrence 1981, pers. com.). Goto and Ögel (1961) pointed out that there can be substantial intra-specific variation in the mucro and that some "mutants" may even have an abnormal number of mucronal teeth. Ideally this present study should have been based more upon types, but time did not permit a search for the type specimens that are still available. So this is offered as a guide and a basis for further study, rather than a definitive work.

Any species which has only been collected from caves is designated a troglobite (tbt) here. Further collections may well show some of these to be troglophiles (tphl).

TABLE 2

IDENTIFICATION TABLE FOR THE TROGLOPEDETINI OF THE WORLD

Group	Species	Range	Troglobite, troglophile or epigean	Antenna:head length (or d: antenna: head diagonal)	Ratio of Antennal segments: I:II:III:IV	Antenna IV sub-divided	Eyes	Empodial teeth internal	Empodial teeth external	Empodial appendage	Tenent hair clubbed?	Teeth on mucro	Serrations before mucronal teeth	Scales present on dens?	Rows of dental spines	Length in mm.	No. examples described	Reference
EUROPEAN TROGLOPEDETES	*Troglopedetes albus* syn. nov.	Austria Yugoslv	tbt.	2.3:1	1:1.6:1.5:2.6	-	-	2	-	simple	-	4	-	+	1	1.4	3	Joseph 1872 (Absolon 1907)
	T. albus distinctus	Yugoslv	tbt.	?	1:1.7:1.6:3	+	-	2	-	simple	-	5	-	+	1	1.6	1	Absolon and Ksenemann 1942
	T. absoloni	Spain	tbt.	?	?	-	-	3	-	simple	+	5	-	+	1	1.5	1	Bonet 1931
	T. cavernicola	Portug'l	tbt.	1.3:1	1:1.8:1.3:3.3	+	-	3	-	simple	+	5	-	+	1	1.2	6	Delamare 1944
	T. machadoi	Portug'l	tbt.	?	1:2.3:1.8:3.2	-	-	3	-	intern. notch	+	6-7	4	+	1	1	7	Delamare 1946
	T. ruffoi	S.Italy	tbt.	4:1	1:1.8:2:2.5	+	-	4	-	simple	-	4	-	-	1	2	1	Delamare 1951a
	T. orientalis	Lebanon	tphl?	4:1	?	+	-	3	-	simple	-	7-8	+	-	1	2	34	Cassagnau and
	T. vandeli	Lebanon	tbt.	1.6:1	1:2:1.7:3.4	+	-	3	-	simple	-	2-6	4?	-	1	1.5	7	Delamare 1955
	T. canis	Lebanon	tbt.	1.1:1[d]	?	+	-	3	-	?3 ext. serratn	+	6	4	+	1	?	?5	Christiansen 1957
	T. cretensis	Crete	epig.	2:1[d]	1:1.9:1.4:2.9	+	-	3	-	simple	+	5-6	-	+	1	1	8	Ellis 1976
ORIENTAL TROGLOPEDETES	*T. kempi*[@]	Assam	tphl.	1.5:1	1:1.6:1.2:2.8	-	-	4	-	simple	-?	3	2	+	2	1.5	1	Carpenter 1917
	T. gracilis[@]	Assam	tbt.	2:1[d]	1:2:2:3.3	-	-	-?	-	simple	-	3	-	+	2	1.5	15	Carpenter 1924
	T. lindbergi[1]	Afghan	tbt.	c.1:1	?	-	-	3	-	simple	+	4	-	+	1?	1.6	1	Stach 1960
	T. ceylonica[@]	N.India Ceylon	epig.	1.8:1	1:2:1.5:3.5	-	-	3	-	simple	-	3	3	+	1	1.4	1	Yosii 1966a and b
	T. sexocellata[@]	Taiwan Bombay	epig.	3:1	1:1.7:1.1:2.7	-	3+3	2-3 3-4	- 2	simple	-	4-5 5-6	-	+	1	1.5	10 29	Yosii 1966a *sensu* Prabhoo 1971
	T. decemoculata[@]	S.India	epig.	1.5:1	1:1.5:1.3:2.6	-	5+5	3	1	simple	-	5	1	+	1	0.7	28	Prabhoo'71(& '76)
	T. churchillatus	Nepal	tbt.	2.3:1	1:1.8:1.6:2.7	+	3+3	3	-	simple	-	4	-	+	1	2.6	26	Wilson 1979 (in Durrant et al)
	T. nepalensis	Nepal	tphl.	1.7:1	1:2.1:1.1:3.1	-	+	3	-	simple	1	5	2	+	1	1.6	21	sp. nov.
AFRICAN SPP.	*Troglopedetes lamottei*[@]	Guinea	epig.	?	?	-	-	4	1	simple	+	3	-	+	1	1.5	1	Delamare 1950a
	Troglopedetina jeanneli	Kenya	epig.	1.1:1	1:2.2:1.2:3	+	1+1	4	-	simple	+	4	-	+	1	1.5	9	Delamare 1945 and 1950b:293
	Troglopedetina tridentata	Uganda	epig.	1.3:1	1:1.8:1.3:3.2	+	1+1	3	2	extern. notch	-?	4-6	-	+	1	1	?	Salmon 1954
	Troglopedetina schalleri	Sudan	epig.	?	1:1.6:1.3:2.7	+	1+1	3	-	notched	+	4-5	-	+	1	0.8	7	Hüther 1962
	Troglopedetes madagascarensis	Madagsc.	tbt.	4:1	1:2:1.7:2.7	-	1+1	3	-	notched	+	c.5	-	+	2	2.5	44	sp. nov.
NEW WORLD	*Trogolaphysa maya*	Mexico	tphl.	4.5:1	1:1.4:1.3:2.9	-	-	4	2	extern. serratn	-	4	-	-	2	1.7	2	Mills 1938
	Trogolaphysa millsi	Brazil	epig.	1.5:1	1:1.3:1:1.7	-	2+2	3	-	simple	-	4	-	+	2	0.6	2	Arlé 1946
	Trogolaphysa delamarei[2]	Cuba	tbt.	3.7:1[d]	1:1.7:1.6:2.7	-	-	4	2	simple	-	4	-	+	2	2.9	5	Massoud and Gruia 1973

SPECIES WHICH DO NOT BELONG IN THE TROGLOPEDETINI

Species	Range	Troglobite, troglophile or epigean	Antenna:head length	Ratio of Antennal segments	Antenna IV sub-divided	Eyes	Empodial teeth internal	Empodial teeth external	Empodial appendage	Tenent hair clubbed?	Teeth on mucro	Serrations before mucronal teeth	Scales present on dens?	Rows of dental spines	Length in mm.	No. examples described	Reference
Trogonella pauliani	Africa	epig.	1.5:1	1:2:2.1:4.7	-	6+6	2	2	intern. notch	+	4-5	-	?	2	?	3	Delamare 1951b
Cyphoderus lavaticus[@]	Afghan	tbt.	?	1:2:1.6:3	+	-	2-4	-	extern. notch	-	6	-	+	-	2.2	1	Stach 1960
'Troglopedetes' nayakensis[2]	Afghan	tbt.	1.4:1	?	-	-	3	-	simple	?	4-5	-	+	-	0.8	2	Stach 1960

NOTES: @ indicates that the species was formerly placed within the genus *Cyphoderopsis*,

1 that the species was in the genus *Troglopedetina*, and,

2 that the species was formerly in the genus *Troglopedetes*.

SPECIES DESCRIPTIONS

Troglopedetes churchillatus Wilson in Durrant et al. 1979: 47. (Figs. 1-4).

This interesting Collembolan was named in memory of Sir Winston Churchill.

DESCRIPTION

A lightly pigmented or white collembolan of maximum length 2.6mm. Usually 3+3 eyes. Habitus as in figure 1A; an active, fast-moving species that was never found in aggregations.

Antenna to head length 2.3:1; antenna to head breadth 2.8:1 and antenna to body length (i.e. head and body) 1:1.9. Ratio of antennal segments 1-1V as 1:1.8:1.6:2.7 (head length 20.7; breadth 17.2) i.e. 14%:26%:23%:37%. Antenna 1V divided into two almost equal sub-segments in the ratio 1.1:1.

The number of ommatidia visible and the position and distribution of eye-spot pigment are variable (see page 4). One individual apparently had 1+3 lenses (figure 4H).

Legs without scales; tibiotarsal hairs not clubbed. Tenent hairs pointed. Empodium tri-dentate, with an additional minute tooth externally. Lanceolate empodial appendage (with small external tooth), bulging basally (figures 2A, B and C).

Manubrium:dens:mucro ratio 15:16:1 (i.e. 46%:51%:3%). Four teeth on the mucro (figures 2D, E and F). No teeth-like serrations after the basal tooth of the mucro. A single row of dental spines which are covered with minute setae. These are only visible under high magnification so can easily be missed. Usually about 38 spines on each dens; the number varies between 22 and 40 and is even inconsistent between the dens of the same individual. Dens has setae and many scales. Body chaetotaxy as shown in figure 3.

Troglopedetes churchillatus Wilson is close to *Troglopedetes sexocellata* (Yosii, 1966a) *comb. nov.* but differs in the following:

T. sexocellata has no sub-divided antenna 1V.
T. churchillatus has a stouter mucro than *T. sexocellata*, and its mucronal teeth are more pronounced.
Both species have long wing-like basal teeth on the empodium but *T. churchillatus* has an additional notch, i.e. three basal teeth internally.
The maximum length of *T. sexocellata* is quoted as 1.5mm. (Prabhoo 1971), compared to *T. churchillatus* at 2.6mm.
T. churchillatus appears to be restricted to caves, while *T. sexocellata* is an epigean species. Differences in the ratios of appendages are apparent; see Table 3 below.

Table 3: RATIOS OF APPENDAGES IN SOME ORIENTAL *TROGLOPEDETES*

	Troglopedetes churchillatus	*T. sexocellata* (Yosii 1966)	*T. kempi* (Carpenter 1917)	*Troglopedetes nepalensis*	*T. ceylonica* (Yosii 1966)
Antennae I:II:III:IV	1:1.8:1.6:2.7 (14%:26%:23%:37%)	1:1.9:1.1:2.7 (19%:35%:22%:24%)	1:1.4:1.2:4 (15%:24%:18%:42%)	1:2.1:1.1:3.1 (17%:29%:16%:42%)	1:2:1.5:3.5 (13%:25%:19%:43%)
Antenna: head	2.3:1	3:1	about 1.5:1	1.7:1	1.7:1
Furca Man:dens:mu	46%:51%:3	52%:38%:10%	-	51%:37%:13%	54%:36%:10%

MATERIAL EXAMINED

Lectotype, INDIA: Pokhara, Mahendra Gupha (here designated); J.M.Wilson,Sept-Oct. 1976 16 paralectotypes collected from Mahendra Gupha and Oderibuwahn Gupha (caves) by the author; 5 from Kaarr Jungle Cave by Christopher Smart and 4 from Window Cave by Gillian Durrant during September and October 1976. (Wilson, 1977a and b; Durrant et al. 1979).

The caves are at an altitude of about 1100m. in the Pleistocene limestone of the north Pokhara Valley of Nepal. Appreciable quantities of guano have built up in the caves thanks to the insectivorous bats that roost there, but the Collembola were most often found away from the guano deposits, on calcite-covered rock.

The types are at the British Museum (Natural History), London; Brit. Mus. 1977-177

ADAPTATION TO THE CAVE ENVIRONMENT

The fact that *T.churchillatus* was not found in the numerous leaf litter and under-stone habitats searched implies that it is a troglobite (tbt). The Pokhara Valley caves have developed in soft Pleistocene limestone which is overlaid by conglomerate. As the limestone (and thus the caves) is very young, the fauna has had little time to adapt to cave life; there are no older cavernous deposits nearby, so cave-adapted species could not have immigrated from elsewhere. Barr (1967) stated that most cave-adapted species were isolated in caves during the Pleistocene or before and so it seems feasible that *Troglopedetes churchillatus* could have evolved from its surface ancestors some time during the last two million years.

REDUCTION IN EYE NUMBER

Guthrie (1906) made some interesting points on the number and arrangements of collembolan ommatidia (ocelli). He suggested that throughout the order, lenses A to H could be identified and that particular ocelli disappear in a characteristic sequence when there is reduction in eye number. In most *Troglopedetes churchillatus* collected only three lenses were visible on each side of the head, and these correspond to lenses A, B and F of Guthrie. *Lepidocyrtus sexocellata* Guthrie, with 3+3 ocelli, has undergone similar reduction of eyes, a "considerable portion of the eyespot between the first two (ocelli A and B) and the last (F) destitute of ocelli. This intermediate space, having lost the ocelli, has also lost its pigment, and there remain a cephalic and caudal spot containing,respectively, two and one ocelli" (Guthrie 1906).

Figure 1D has been adapted from Guthrie's diagram of the ocelli of *Lepidocyrtus sexocellata* and shows the position of ocelli A, B and F with their associated pigment patches, and the positions that the lost ocelli C, D, E, G and H would be expected to occupy. Figure 4 shows that the arrangement of pigment patches is variable, 4D showing an animal with 3+3 lenses in 3+3 pigment patches. Figure 1C shows how pigment may not surround the lens.

Troglopedetes nepalensis sp.nov. (Figures 3 and 5)

DESCRIPTION

Blind and white with a maximum length of 1.6mm.; pigment is wanting and there is no ocellar pigment; habitus as in figure 5A; an active little springtail and quite difficult to catch.

Antenna to head length in the ratio 1.7:1; antenna to body length 1:2.4. Antennal segments I-IV as 1:2.1:1.1:3.1 (i.e. 17%:29%:16%:42%). Antenna IV not sub-divided. Scales numerous on the head.

Claws as in figure 5C; two strong wing-like basal teeth and a weak sub-apical tooth; lanceolate empodial appendage; 2-3 basal teeth-like serrations before the 5 mucronal teeth; a single row of spines on each dens; dens densely covered with setae; manubrium:dens:mucro as 51%:37%:13%. The chaetotaxy is shown in figure 3.

Troglopedetes nepalensis is close to both *Troglopedetes kempi* (Carpenter, 1917) and *Troglopedetes ceylonica* (Yosii, 1966) but differs from them in several characters. Like *T. ceylonica*, the claw of *T. nepalesis* bears two strong internal wing-like basal teeth and both species have a third weak internal tooth. In *T. nepalensis* this is sub-apical, but in *T. ceylonica* it is stronger and more proximal. In contrast, *T. kempi* has two weak internal teeth in addition to a small basal pair.

T. nepalensis has 5 mucronal teeth compared to the 3 of *T. kempi* and *T. ceylonica*. *T. nepalensis* and *T. ceylonica* have one row of dental spines which contrasts with the two rows of *T. kempi*. *T. ceylonica* is described as achaetotic by Yosii, figure 3 shows that *T. nepalensis* has a group of four setae on thoracic segment II

The dental scale-like appendage reported in the one specimen of *T. kempi* studied by Carpenter, is wanting in *T. nepalensis* and *T. ceylonica*. Ratios of appendages of the three species are in Table 3.

As *Troglopedetes nepalensis* is able to live and reproduce both in caves and on the surface, it should be regarded as a troglophile (tphl). It is tempting to suggest that *T. nepalensis* is no longer found above ground in the Pokhara Valley due to habitat changes brought about by intensive agricultural practices in the area.

MATERIAL EXAMINED

Holotype: INDIA, Pokhara, Mahendra Gupha; J.M.Wilson, Sept.-Oct. 1976.

20 paratypes collected by the author during September and October 1976 from Mahendra Gupha and Oderibuwahn Gupha (caves) at about 1100 m. above sea level in the north of the Pokhara Valley; from the Harpan River Cave (Waltham et al. 1971) at about 1000 m. in the south of the Pokhara Valley near the airport; and from leaf litter under rhododendrons between Naudanda and Suiket at an altitude of about 1300 m. about 16 km. north-west of Pokhara in Nepal. Types are at the British Museum Brit. Mus. 1977-117.

Additional specimens were collected by the author during December 1981 from Gupteswary Cave at Kusma (Waltham et al. 1971:63). The cave is in conglomerate at about 1000 m. and about a 30 km. walk to the west of Pokhara in Nepal. It is quite well known in the area as a Hindu shrine; it must be visited bare-foot. The 27 specimens from Kusma are also lodged at the British Museum; collection number Brit. Mus. 1982-150.

Troglopedetes madagascarensis sp. nov. (figs. 6-8).

A long series of this new species was collected during the course of the 1981 Southampton University Expedition to Madagascar by the author and Mary Wilson.

DESCRIPTION

A white active collembolan that is common in the Dark Zone of the Grotte d'Andrafiabé (cave) in Northern Madagascar.

It is about 2.5mm. long and its habitus is as in figure 6. It is achaetotic and is probably a troglobite.

Most specimens have 1+1 eyes but as there is not usually any pigment associated with the lenses, they are quite difficult to see.

Antennae are a little shorter than the combined length of head and body; ratio of antennal segments I-IV as 1:2:1.7:2.7 (head breadth 1.2; head length 1.8) i.e. 13.6%:27.3%: 23.6%:36.4%. Antenna IV is not sub-divided.

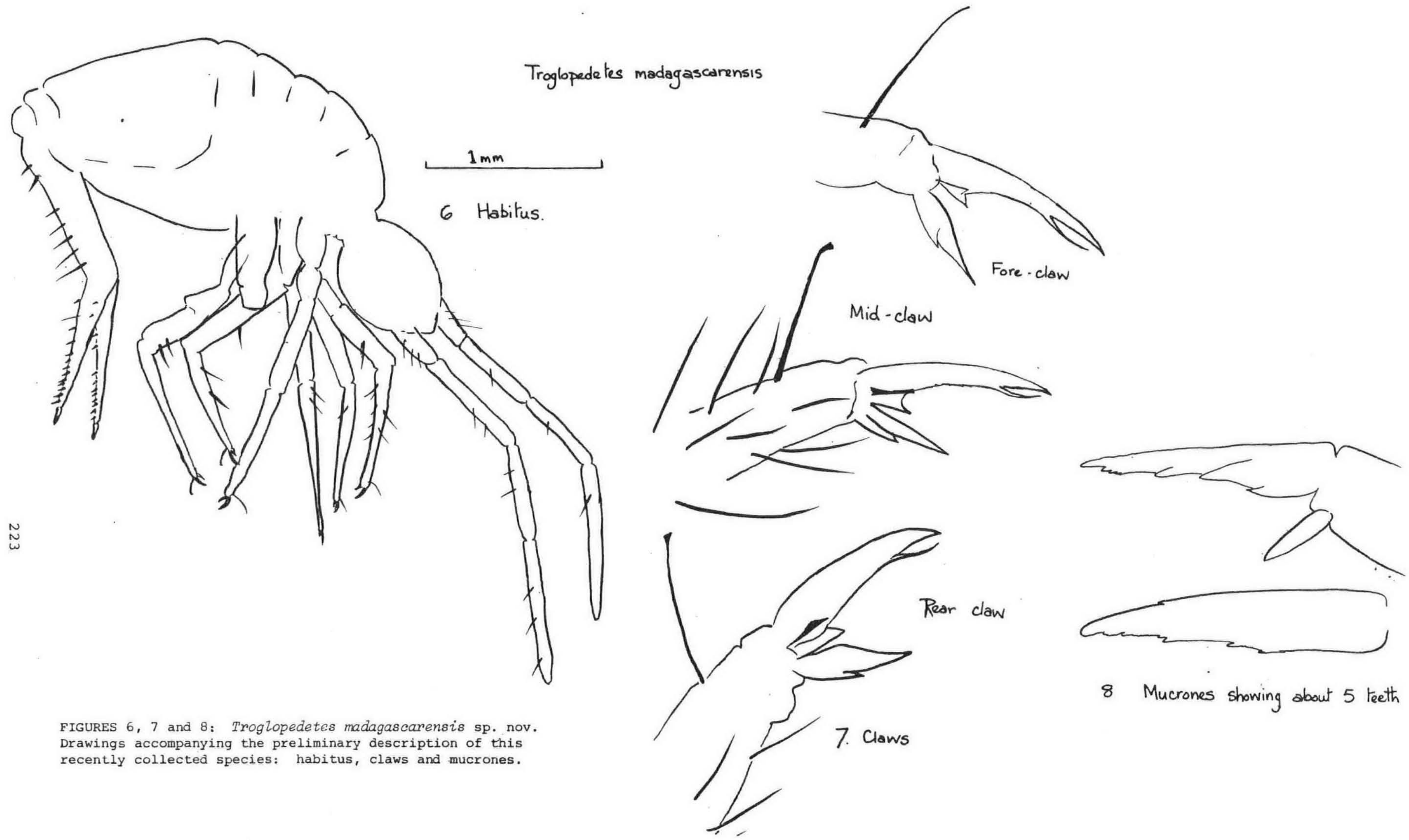
The claw has two wing-like basal teeth on the empodium and a long distinctive additional tooth apically. The empodial appendage has a large external notch which is an unusual feature among the Troglopedetini. The tenent hair can be either pointed or clubbed; in most specimens both forms were present. Tibiotarsal hairs are pointed.

The mucrone is elongate and bears about 5 tiny teeth; the numerous serrations on the mucrone make it difficult to determine the exact number of teeth present; the thick dental spines on the posterior face of the furca are arranged in two rows; under high magnification it can be seen that each is covered with minute setae. Manubrium:dens:mucro are in the ratio 12.2:13.3:1 i.e. 45.9%:50%:3.8%.

This brief description will be elaborated at a later date.

MATERIAL EXAMINED

Holotype and 42 Paratypes are at the British Museum (Natural History) Brit. Mus. 1982-160. Representative specimens have also been presented to the Malagasy National



FIGURES 6, 7 and 8: *Troglopedetes madagascarensis* sp. nov. Drawings accompanying the preliminary description of this recently collected species: habitus, claws and mucrones.

Collection at the Jardin Zoologique et botanique de Tsimbazaza in Tananarive, Madagascar.

All specimens were found on or near bat guano or carcases in the Dark Zone of the Grotte d'Andrafiabé. This is an 11 km. long cave system in the extreme north of Madagascar; it is in the middle Jurassic limestone that lies about 40 km. north of Ambilobé and 60 km. south of Diégo-Suarez. A description of the cave is given by Boase, Wilson and Wilson (1982) and a full description of the ecology of the cave will be published later.

APPENDIX

HIMALAYAN FAUNA COLLECTED BY THE SPELEOLOGICAL EXPEDITION 1976

Among the specimens collected during this six month expedition were many of interest. For example, a long-legged new centipede has been described by Dobroruka (1979). A complete list of the hypogean fauna collected by us from the Indian and Nepali caves is in the expedition report (available from the author) and Table 1 summarises this. The new millepedes listed are described in two papers by Mauriès (1982). The blood-feeding sandfly was of sufficient interest to feature in a paper by Lewis (1981) and the cave-dwelling moths are mentioned by Robinson (1980:100,110).

ACKNOWLEDGEMENTS

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Our 135-page Himalayan Expedition report is available from the author at £1.50 plus postage (presently 50p inland).

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