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BRITISH CAVE RESEARCH ASSOCIATION

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A PRELIMINARY HYDROLOGICAL STUDY IN OGOF FFYNNON DDU, BRECONSHIRE

P.M. O'Reilly & L.G. Bray

Summary

Comprehensive water sampling in Ogof Ffynnon Ddu is a difficult problem because of the size of the system; in 1972 a reconnaissance survey was carried out under extremes of discharge and the specific conductance of the samples was measured and converted to total hardness. The resulting water hardness profiles shed some light on several hydrological problems within the system.

1. INTRODUCTION

A study of the literature reveals that a great deal of work has been carried out in the field of limestone solution studies. The South Wales region, however, has received only a little attention; apart from the work of Williams (1963) on the solutional load of the Neath and Mellte, that of Ede (1972) on Gower and part of the North Crop, and more recently that of Bray (1969, 1971, 1972) on the chemistry of cave waters, there have been no detailed studies on individual cave systems. The work of Thomas (1954a, 1954b, 1963, 1970) has largely been concerned with the examination of surface phenomena such as dolines and other superficial karst features.

The discovery in recent years of many miles of cave passages in the Craig-y-Nos area has stimulated much research, but the solutional processes existing in these caves are still largely unknown. One of the authors (Bray) has pioneered a series of investigations on the chemistry of the waters in the caves of the area, and it was his work that provided the background for this study. It is apparent from the results of his early work that the processes involved in the solution of limestone in the North Crop are far more complex than previously thought. In short, Bray believes that the three factors (not all of which are necessarily involved in a given cave system) are: (i) carbon dioxide via the 'traditional route', which in fact may be of relatively little importance, (ii) free sulphuric acid, especially in waters running from peat-covered Millstone Grit, and (iii) easily oxidised organic matter, especially materials such as humic acids etc. It seems that the simplified picture of limestone solution so often quoted may be a long way from reality in this region.

With a view to carrying out a long-term hydrological study in Ogof Ffynnon Ddu a series of sampling runs were carried out in the summer of 1972. One author (O'Reilly) had on previous occasions taken water samples for analysis from the cave, and without exception the large volumes needed for accurate titration made sampling an arduous procedure. The sites sampled were usually decided logistically rather than scientifically and consequently the results were inadequate to provide a complete picture of the solution processes at work in the cave. The particular problems associated with sampling are the distances to be covered underground and the potentially vast number of sites of interest, involving the transport of large numbers of water samples to the surface for treatment in the laboratory.

2. SAMPLING SCHEDULES

It was decided to carry out the preliminary study by collecting as many samples as possible from all parts of the cave under extremes of discharge, and to use these as a guide to develop a full-scale sampling routine. Thus two sampling programmes were run:

2.1 Conductivity Sampling

Small (66 ml) samples were collected and their specific conductance was measured. The small size sample meant that a party of two or three moving quickly through the cave could easily carry some 60-100 samples without the normally attendant problem of overloading. It is possible to convert readings of specific conductance to total hardness values with a fair degree of reliability (Bray 1971) and it was felt that knowing even the approximate total hardness at different parts of the cave an overall picture of the solution processes at work in the cave could be obtained, and from this the more important sites could be chosen for detailed study. The sites that were samples are listed in Table 1.

2.2 Detailed Sampling

On the basis of the results from the conductivity sampling and on Bray's earlier work a small number of sites were chosen for more detailed study. This paper deals only with the conductivity sampling; analysis of the other samples is considered elsewhere (Bray and O'Reilly (1974)).

The field work took place during late July and early August 1972; samples were taken under base flow conditions at the end of a drought period, and under high runoff conditions, a week later. The drought period was at the end of July – there had been no rain for some three weeks and only occasional light showers for similar period before that. The resurgence discharge was low, probably less than 0.01 cumecs. The flood terminated the drought – during the first weekend of August in a period of intense rainfall some 40 mm of rain fell in 24 hours and the resurgence discharge rose to approximately 0.1 cumecs.

Under these conditions it proved impossible to sample upstream of the Confluence in Ogof Ffynnon Ddu II, and the time involved in collecting samples prevented an excursion to Ogof Ffynnon Ddu III. Nonetheless those samples collected provide a basis for the crude comparison of the two extreme discharge conditions. An indication of the location of the sites sampled is given in Figure 1 and the full national grid references are shown in Table 1.

Table 1. Lists of sites sampled, conductance measured, and computed total hardness values.

	SITE	NGR (Prefix SN)	Base Flow Specific Conductance (μmho.Cm^{-1})	Base Flow Total Hardness (ppm)	High Run-Off Specific Conductance (μmho.cm-1)	High Run-Off Total Hardness (ppm)
Mainstream	Smith's Armoury	87521628	154	69	–	–
	Cloister Cascade	87281618	154	69	–	–
	At	87041599	170	77	–	–
	Maypole Bridge	87021604	170	77	–	–
	Maypole Inlet	86421561	154	69	–	–
	Maypole Inlet	86411561	154	69	–	–
	Oxbow Sump	86181548	170	77	–	–
	Below Sump	86151544	154	69	–	–
	Pothole	86041541	162	73	–	–
	Before Marble Showers	85901531	169	77	–	–
	After Marble Showers	85911529	154	69	–	–
	Before Waterfall	85891525	169	77	–	–
	After Waterfall	85891524	177	81	–	–
	Before Confluence	85621519	–		115	49
	Flood Bypass Sump	85521516	216	101	128	56
	Bedding Plane Sump	85481514	231	108	–	–
	Dip Sump	85241527	239	62	134	59
	The Sump OFD I	85121531	231	108	–	–
	Step	84951528	231	108	–	–
	At	84891524	239	62	–	–
	Near Pluto's Bath	84891523	246	116	131	57
	At Gothic Pool	84781518	231	108	140	62
Tributaries to Main Stream	Inlet in Smith's Arm	85711623	224	105	105	–
	Cloister Cascade	87281617	224	105	–	–
	The Wee	87121618	246	116	–	–
	Waterfall Chamber	87041598	231	108	–	–
	Swamp Creek	86551567	208	97	–	–
	Maypole Inlet	86411561	224	105	–	–
	Lugubrious Inlet	86291551	246	116	–	–
	Drips into Pothole	86121543	231	108	–	–
	Marble Showers	85921530	216	101	–	–
	Waterfall Inlet	85891525	200	93	–	–
	Inlet at	85881519	216	101	–	–
	Inlet at	85881519	292	139	–	–
	Inlet at	85731522	216	101	–	–
	Inlet at	85721521	193	89	–	–
	Piccadilly Stream	85521522	308	97	339	163
	Divers Pitch Inlet	85401516	262	124	277	132
	Connection Passage	85241529	315	151	–	–
	Waterfall OFD I	85201534	339	163	370	179
	Rocky Holes Inlet	84971535			324	155
	Drips near Plutos	84921525	277	132	–	–
Cwmdwr Stream	Jama first entry	85591553	577	(285)	331	159
	Jama second entry	85601547	539	(276)	346	166
	At Boulder Choke	85651544	539	(276)		–
	After Boulder Choke	85651541	–		354	165
	Before Smith Choke	85651535	516	(254)	–	–
	After Smithy Choke	85651534	524	(258)	–	–
	Before Confluence	85621520	401	(195)	339	163
Cwmdwr Stream tributaries	Cwmdwr Entrance	85731560	231	108	224	105
	Dim Dwr Trickle	85631560	285	135	–	–
	Inlet at	85701542	231	108	–	–
	Drips at	85651629	177	81	–	–

	SITE	NGR (Prefix SN)	Base Flow Specific Conductance (μmho.Cm^{-1})	Base Flow Total Hardness (ppm)	High Run-Off Specific Conductance (μmho.cm-1)	High Run-Off Total Hardness (ppm)
Miscellaneous	Dugout Trickle	84951536	–	–	362	175
	Pi Chamber Drips	85051536	–	–	246	116
	Shale Crawl Drips	85061526	–	–	300	143
	Drips on Fault at	85321529	185	85	–	–
	Collapse Chamber Inlet	85371517	185	85	–	–
	Stream At	85481518	262	124	–	–
	Trickle from Roof	85541523	262	124	293	140
	Joint Inlet	85411528	308	97	324	155
	Heol Eira	85411528	185	85	231	108
	Drips at	85541537	254	120	–	–
	Pool in Oxbow	86151547	316	151	–	–
	Salubrious Passage	86461575	231	108	–	–
	Salubrious Passage	86501589	224	105	–	–
	Drips	86511594	246	116	–	–
	Cairn Cha. Inlet	86471606	262	124	–	–
	Aven near Crevasse	86791600	262	124	–	–
	Aven before Shambles	86871602	246	116	–	–
	Aven before Traverse	86881602	254	120	–	–
	Aven on Traverse	86951606	231	108	–	–
Surface	Sink Pwll Byfre	87441660	57	20	36	9
	Resurgence	84721508	254	120	142	63
	Limekiln pool	85451534	131	113	–	–
	Grit Doline	85951524	–	–	–	–
	Cwmdwr Quarry Pool	85701558	140	62	–	–

Note: figures in parentheses ( ) are believed to be invalid estimates of total hardness (see text, Section 3).

3. TREATMENT OF SAMPLES

Samples were collected in 66 ml polystyrene bottles with screw caps. They were taken to the laboratory at Penwyllt where they were immersed in a thermostat bath at 25°C until thermal equilibrium had been reached. The conductance was measured using a direct reading WPA CM25 conductivity meter in association with a dip-type conductivity cell having platinum electrodes (Walden Precision Apparatus Ltd., Shire Hill, Saffron Walden, Essex). Most cave chemistry results are expressed in terms of hardness values (ppm) and so as to relate the results of this work to that of others an attempt is made here to convert the specific conductance to total hardness using a graph of specific conductance against total hardness applicable to these particular results with the best fit line calculated by a least square analysis, (Bray 1969), (see figure 2). In using this sort of correlation there is a risk in that the ions governing the conductivity of cave water include calcium, magnesium, sodium, potassium, chloride, bicarbonate and sulphate: only the calcium and magnesium ions register in the total hardness estimations; experience has shown that in the Penwyllt area most of the cave and surface waters conform to a general pattern in that their electrolyte balance is much the same, but to assume that all waters conform is incorrect and could lead to erroneous deductions. In particular the high conductivities observed in the Cwmdwr stream in the cave pose a problem – measurement by titration of the total hardness of this water shows that the points do not fall on the best fit line in figure 2. For example one sample of that stream, with a conductance of 524 μmho.cm^{-1} has a true total hardness of 167 ppm. which includes more than 30 ppm sulphate. The calculated value was 258 μmho.cm^{-1}. The correlation in figure 2 is thus considered not to be entirely valid for the Cwmdwr Stream and consequently the total hardness scale on the vertical axis of figure 3 applies only to those waters whose electrolyte balance is normal.

4. RESULTS

The results obtained are summarised in Table 1. Values of specific conductance have been converted to total hardness using the correlation shown in figure 2. No accurate monitoring of the discharge was made as the study was at this stage purely a preliminary one. Approximate discharge figures have already been mentioned.

5. DISCUSSION

One is well aware of the dangers of making too many predictions from one or two sets of data, but it will require many years of study before a comprehensive survey of all the hydrological sites in Ogof Ffynnon Ddu can be carried out, but any conclusions, however tentative, are valuable at this stage.

5.1 Conductivity Profiles and Flow Regimes

The results of the survey are displayed as in figures 3 and 4, which show in schematic form the variation in conductivity (and hence, total solute load) throughout the cave under the conditions in which the sampling took place. It is usual to classify cave waters according to their origin and this has been done in most karst areas, the distinction being drawn between percolation water (diffuse flow) with high solute content and swallet water (conduit flow) with lower values. In Ogof Ffynnon Ddu there is only one swallet under normal conditions (Pwll Byfre) although during flood, minor points of engulfment do occur at many locations above the system. All the cave streams apart from the Main Stream must therefore represent some form of percolation water.

The relationship between runoff and rainfall in the Ogof Ffynnon Ddu catchment is of interest. In summer evaporation and transpiration are at a maximum and the amount of soil moisture is low, resulting in base flow conditions in the cave. Under these conditions the total percolation contribution to discharge is c. 40% (the Cwmdwr Stream alone accounting for c. 25%). This situation also occurs during long cold winter periods when the surface is frozen. During early autumn, precipitation replenishes the soil moisture but, unless the rainfall is intense, heavy flooding is relatively rare. These are 'average' conditions, and in this case percolation accounts for c. 50-60% of the total discharge (the Cwmdwr Stream c. 20%). During late autumn, winter and spring the runoff remains 'average' since field capacity has been reached, and it responds rapidly to increases in rainfall, so flooding is common. In this type of flood the percolation increment may be as much as 70-80%. Flooding also occurs after periods of base flow especially following intense rainfall. In this type of 'flash' flood the more rapid response of the swallet water results in a low proportion of percolation water in the discharge (probably only c. 15-20%).

The sampling conditions in this study were such that the amount of tributary (percolation) addition to the Main Stream was relatively small, one set of samples corresponding to base flow and the other to a flash flood.

The results obtained provide an approximate idea of the relationship between solute load and discharge. It can be seen at once from figure 3 that, at least under base flow conditions, the solute load of the water of the Main Stream rises very rapidly from the sink to the point where it is first seen in the cave (Smith's Armoury) – a distance of approximately 300 m – while over the next 5 km of open passage it remains relatively constant, except that the addition of high concentration water from the Cwmdwr Stream is responsible for a noticeable rise in solute load at the Confluence. This rise is smaller under flood conditions because the increase in volume of the Cwmdwr Stream is much less than that of the Main Stream. It appears that, in general, there is little variation in solute load over long distances of streamway. This is certainly true for base flow and probably also for high run-off although it was not possible to confirm this for the streamway in Ogof Ffynnon Ddu II and III during flood. In drought the solute load remains fairly constant at c. 70 ppm throughout Ogof Ffynnon Ddu III and II – the flood figure for this

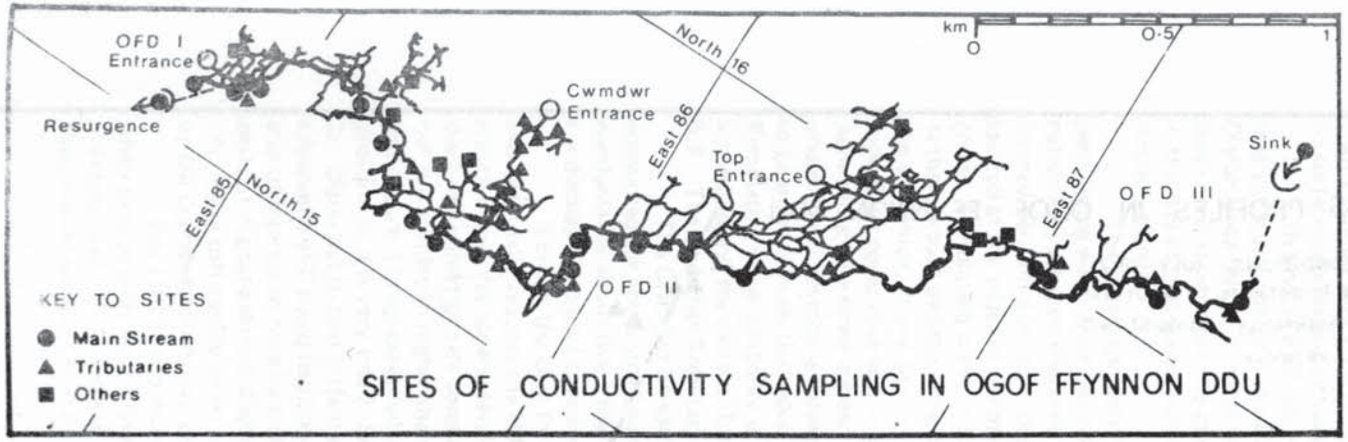

Figure 1.

The location of the sites at which samples were collected for conductivity measurements.

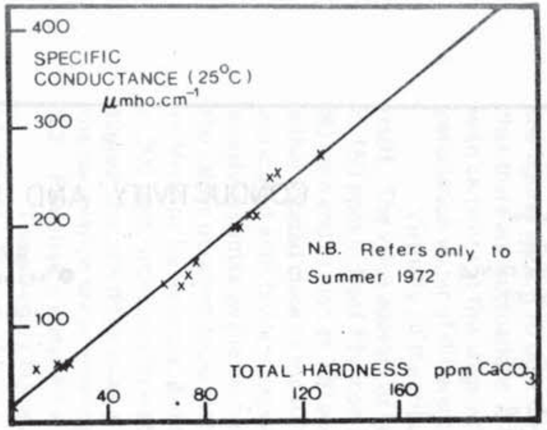

Figure 2. Relation between specific conductance and total hardness (Summer 1972). This graph is not of general application because it includes factors related to the equipment used, particular conditions etc.

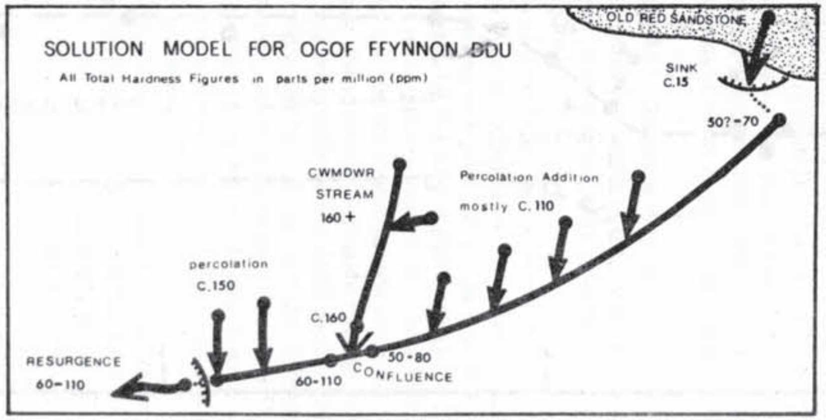

Figure 4. Schematic representation of a tentative 'solution Model' for Ogof Ffynnon Ddu based on this work.

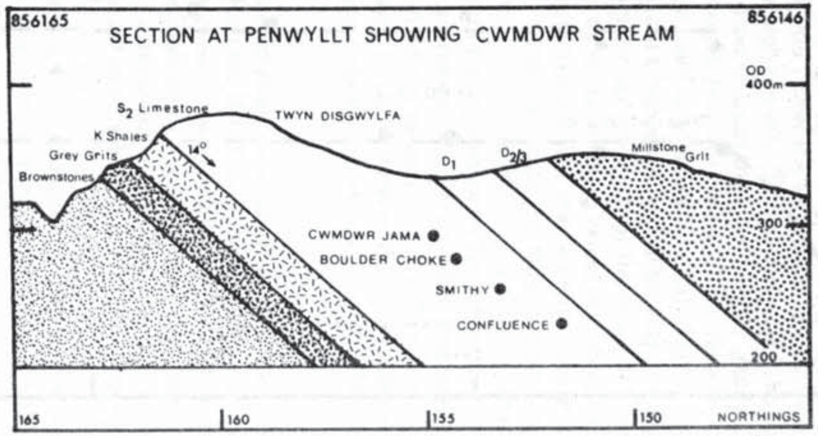

Figure 5. Section through Penwyllt (north-south) showing location of the Cwmdwr Stream and the possible source of its water. (Note: The vertical scale is exaggerated). (Geological information from Weaver (1972)).

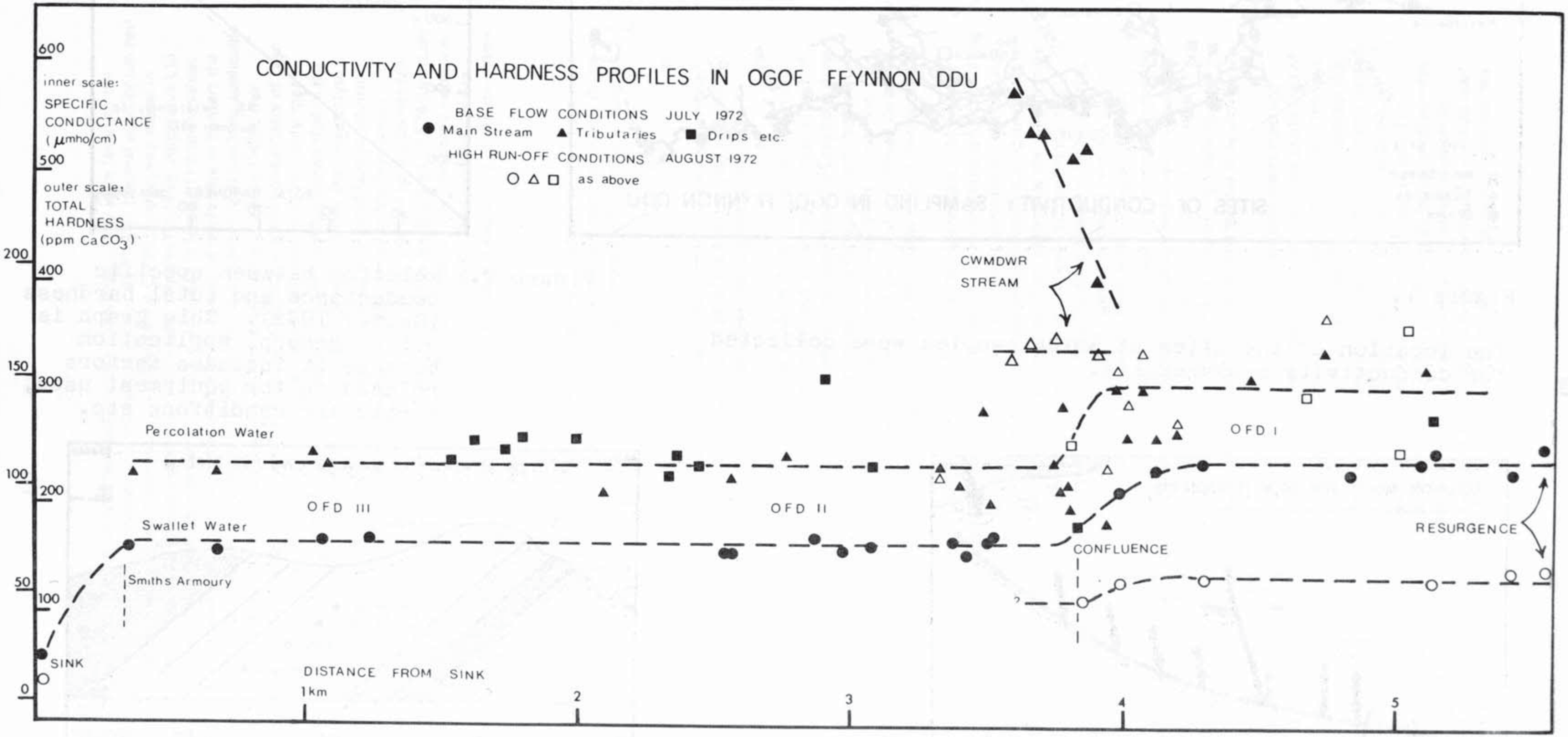

Figure 3. Specific conductance and total hardness profiles showing the largely uniform nature of these quantities throughout the system. (The broken lines are generalised guides only).

part of the cave is probably c. 50 ppm; in Ogof Ffynnon Ddu I after the addition of the Cwmdwr water, the figures are c. 110 ppm for drought and c. 60 ppm for high run off. Close examination shows, however, that there are fluctuations in these values as the stream passes through the cave, but it is impossible to state with certainty at this stage whether they are due to the stream dissolving its bed or to the addition of percolation water of different total hardness to the stream itself or to a combination of both.

Virtually all the tributaries to the Main Stream have a higher total hardness than the Main Stream itself. The value appears to be in the region of c. 110 ppm throughout most of the cave but increases to c. 150 ppm in Ogof Ffynnon Ddu I. There is a good deal of scatter in these values with samples as low as 80 ppm and as high as 160 ppm being recorded. Those percolation inlets that are low in value are usually either located close to the surface, are derived from small discrete sinks on the Millstone Grit edge, or are associated with faults along which the water can move more freely and in this way their flow regimes more closely resemble swallet water than percolation water. With the notable exception of the Cwmdwr Stream the values obtained show that there is little real difference between percolation water and swallet water. In Mendips for example, percolation water displays total hardness values up to c. 240 ppm, and in Gower c 300 ppm, while swallet water is usually very much lower. In Ogof Ffynnon Ddu the results of this work suggest that the differences are far less marked, and tend to indicate a relatively integrated flow pattern for the percolation water entering the cave.

5.2 Percolation Water Flow Regimes

The generally higher values associated with the percolation water above Ogof Ffynnon Ddu I are of interest. Topographically, the area above Ogof Ffynnon Ddu II and III is largely open moorland with rough pasture; there are numerous dolines and surface depressions which Williams (1963) has conclusively shown to be of solutional origin, and which occur for the most part on drift-covered dip-slopes. The amount of drift cover is extensive and the distribution of limestone pavements is very restricted. The area above Ogof Ffynnon Ddu I, on the other hand, consists of enclosed pasture with many trees; there are virtually no surface depressions or pavements and the drift cover is thinner.

Thomas (1970) has carried out an extensive study of surface solution in the area and has found that structural controls of solution rates are very strong. The proximity of the region to the Swansea Valley Disturbance results in numerous sub-horizontal and sub-vertical minor fracture planes within the rocks; these are distinct from the more easily recognised joints or bedding planes. He found that local variations in the rate of post-glacial surface solution have been determined largely by the incidence and form of these fracture planes.

The topographical differences between the two regions above the cave now become more relevant; percolating water from the open moor appears to enter the cave through what is probably a well-integrated network to solution channels linked to the numerous surface depressions. Most of these depressions have formed beneath a cover of drift derived from the Old Red Sandstone, although there are some hollows located at the edges of pavements where more concentrated solution has taken place at the junction of grikes. Percolating water in such a system would expend much of its solutional capability close to the surface as there would be little time or opportunity for an increase in carbon dioxide content through contact with the soil which, in any case, in this region is probably low in organic content and hence carbon dioxide. The superficial cover thus acts largely as an inhibitor of surface solution preventing the formation of dissected pavements; the cover appears to channel the water underground. The amount of surface lowering of the underlying limestone is consequently quite small. In the Ogof Ffynnon Ddu I area the flow pattern appears to be more diffuse, the lack of solution hollows indicating the less integrated nature of the flow. Percolating water probably utilises a network of micro-channels formed along the fracture planes in the limestone and the more diffuse nature of this type of flow would result in generally higher hardness values.

5.3 The Cwmdwr Tributary Stream

The Cwmdwr Stream is the largest tributary of the Main Stream and under base flow conditions accounted for about one quarter of the total discharge – (about one tenth in the flood) it has an electrical conductance about twice that of all other water in the cave. It displays a tardy response to rainfall, but the conductance dropped considerably under high run-off (figure 3).

It enters the cave through a boulder choke, flows as a misfit along the floors of several passages and eventually reaches the Main Stream at the Confluence having flowed for some distance along a vadose trench below the general level of the Smithy passages. Referring to figure 3 it can be seen that under low discharge conditions its conductivity has dropped considerably by the time it has reached the Confluence but it is still much higher than that of the Main Stream. It is the only stream in the whole system to display this apparent progressive fall in solute load and the reasons are not obvious since the volume of tributary addition to it is very small. Smith (1969) reported a similar phenomenon in Branch Passage in Pollnagollum, Co. Clare, but in that instance the passage was floored with a moonmilk-type calcite deposit that was apparently still being laid down – no such deposit is forming in the bed of the Cwmdwr Stream. It is also of interest to note here that those streams that do have a moonmilk-type deposit on the floor in other parts of the cave do not display a progressively falling hardness – even the trickle over Heol Eira, a long impressive soft calcite bank, has a low value. Until more accurate monitoring of the flows and solute loads of the Cwmdwr tributaries is carried out, this feature cannot be explained.

Ede (1972) also noted the general lack of high content percolation water in the North Crop, and when dealing with Ogof Ffynnon Ddu he suggested a very rapid through-flow time for water to the Top Entrance area. He found that most of the drips were still aggressive though generally lower in calcium than similar samples taken by V.H. Williams (1963) in Ogof Ffynnon Ddu I. He also commented that the discharge from Ffynnon Ddu was relatively high throughout the summer and discounting any major long-term percolation addition, he suggested the underlying Old Red Sandstone as a possible alternative source of water. The results of the present work make this suggestion seem very unlikely. Apart from the geological structure being unfavourable, no water with the required low hardness (about 20 ppm for water from the Old Red Sandstone) has been found within the cave. It has been suggested that the water of the Cwmdwr Stream might derive from the Old Red Sandstone core of the Craig-y-Rhiwarth anticline to the north of the cave. Apart from the high solute loading of the stream being inconsistent with this origin figure 5 shows that it is more likely to represent the drainage of Twyn Disgwylfa, the hill now being actively quarried.

The relatively high conductance and solute load indicate a diffuse origin for the water, which is consistent with the comments already made about the percolation pattern in the Ogof Ffynnon Ddu I area. The high total hardness values arise partly from the unusually high sulphate content of the water (c. 30 ppm). This has been found to be over three times that of most of the other water in the cave. High sulphate concentrations are usually due to the presence of calcium sulphate (gypsum) and there are considerable quantities of selenite crystals in the parts of the system located near the Millstone Grit/Limestone contact and although none are known they may well occur in the undiscovered part of the Cwmdwr Stream.

5.4 An Indication of Further Extensions

The major region of interest to cavers in Ogof Ffynnon Ddu is the unknown cave between the sink at Pwll Byfre and Smith's Armoury. The survey shows the cave 'passing by' the sink and water runs largely south-eastwards to reach the point where it is first seen in the cave. Weaver (1972) showed a fault running near Pwll Byfre and it may be that this aids the passage of the water. In the resurgence end of the cave, however, water following faults appears to have a low hardness, which does not explain the observed rise from c. 20 ppm at the sink to c. 70 ppm in the cave. Bray (1972) explained the phenomenon chemically in terms of oxidation of organic material. Experimental oxidation of organic material is a tedious process best carried out at 100°C with acidified potassium permanganate or by boiling with potassium dichromate and concentrated sulphuric acid in the presence of a catalyst – for it to proceed so well at about 10°C in a cave suggests the possibility of some form of biological activity. It is also possible, however, that there has been the addition of a small amount of high content percolation water before the stream appears in the cave. For example it would only require a stream similar in hardness and proportion to the Cwmdwr Stream to bring about the observed rise. There is a large limestone region to the north east of the end of the cave in which no cave discoveries have been made yet. There are a number of depressions and a greater thickness of limestone here than over much of the rest of the cave. The presence of such a stream is a real possibility and until a major programme of percolation water tracing, discharge and hardness measurement and other chemical analysis has been carried out, it will not be possible to discount entirely the possibility of further major extensions to the system.

6. CONCLUSIONS

1. A preliminary investigation of stream solute loads in Ogof Ffynnon Ddu has been carried out by collecting samples of the water and measuring its specific conductance, with a view to obtaining an overall picture of the present day solution processes and isolating potentially interesting hydrological sites in the cave.
2. The indirect measurement of total hardness via specific conductance has proved to be a convenient technique for complex cave systems, as the small size sample needed enables a greater number of sites to be visited and an overall picture of the magnitude of the solutional load and of changes in that load to be built up quickly.
3. The results indicate that the total hardness of the Main Stream (c. 50-110 ppm) is lower than might be expected in view of the fact that all the internal input to it is of percolation origin.
4. The results suggest that there is generally little marked distinction between percolation water and swallet water; almost all the tributaries respond fairly rapidly to rainfall and have relatively low hardness values (c. 110-150 ppm); these values are lower than that for similar water in, for example, the Mendips or Gower.
5. There appears to be a difference between the pattern of percolation from the open moorland (integrated) and that from the more cultivated area nearer the Tawe (more diffuse).
6. The drainage of Twyn Disgwylfa is also diffuse but the water of the Cwmdwr Stream has a higher proportion of sulphate of unknown origin than has been found elsewhere in the region.
7. There appears to be no direct or indirect addition of percolation water from the Old Red Sandstone as has been suggested by Ede (1972).
8. This preliminary investigation has been successful in pinpointing several sites worthy of further investigation, in particular that unknown region between the sink at Pwll Byfre and the point where the water is first seen inside the cave, and also the Cwmdwr Stream. Future work will concentrate on these areas and will largely be concerned with detailed monitoring of sites in an attempt to establish a more definite relationship between solute load, discharge and rainfall, and between percolation and swallet water.

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PRELIMINARY OXIDATION STUDIES ON SOME WATERS FROM THE OGOF FFYNNON DDU SYSTEM, BRECONSHIRE.

By L.G. Bray and P.M. O'Reilly

Summary

Analytical results from water samples from the Ogof Ffynnon Ddu system are presented and the changes taking place in the levels of hardness and organic matter content along the streamway are considered.

INTRODUCTION

Attention has been drawn to the importance of water-borne organic matter in the processes of cave enlargement, but the early work relied mainly on water samples from surface sites (Bray 1972). The present study extends the work by examining the results from samples collected from specially chosen sites within the Ogof Ffynnon Ddu system.

EXPERIMENTAL

(a) Fieldwork

For this work advantage was taken of the information from an extensive conductimetric study of the Ogof Ffynnon Ddu cave waters (O'Reilly and Bray, 1974). Sampling was limited to sites of major importance, allowing larger volumes of water to be collected at each site and a wider range of tests to be performed than would normally have been the case. It was planned originally to collect samples from a selection of sites of cave chemistry interest: the results of the conductimetric study showed so clearly the importance of The Confluence area of the cave that samples were collected from this area in preference to apparently similar sites elsewhere in the cave. This is the first time in South Wales that detailed chemical work has been possible on samples collected from sites chosen wholly for their chemical interest. These sites are listed in Table 1 which also shows other sites of chemical interest: the positions of the Ogof Ffynnon Ddu sites are shown in Figure 1.

The details of the samples that were collected are shown in Table 2. Some use was made of transparent PVC bottles but these proved to be too fragile for routine use underground.

The samples from within the cave were collected during a period of exceptionally dry weather when many of the tributary streams were dry. Those from sites 4, 5, 6 and 7 were collected on a different sampling trip from samples from sites 2 and 3, and some results should not be used in direct comparison; for example, values for organic matter content were obtained from different batches of determinations and are not wholly consistent. Results from site 10, the Ffynnon Ddu resurgence, were fairly constant throughout the period and it is felt that they can be used with results from sites 2 and 3 as well as those from sites 4, 5, 6 and 7. A programme of continuous monitoring of water conductivity at the resurgence showed that this was remarkably stable during the period of these tests.

(b) Techniques

Most of the experimental techniques have been described (Bray 1969, 1971, 1972; Stenner 1969) and only a new method is described here.

An additional oxidation test was used for this work in an attempt to assess the organic matter content of the waters. Previous work had relied on incubation of the water with acidified potassium permanganate for 4 hours at 27°C to provide an arbitrary measure of organic matter content (Bray 1972). It was felt that a test was needed giving a greater depth of oxidation of organic matter without using the dichromate value test (which requires the use of concentrated sulphuric acid together with a toxic catalyst and thus was unacceptable on social grounds). The 30-minute 100°C permanganate value test suggested by Wilson (1959) was used as a starting point but modifications were needed before consistent results could be obtained, even within a given batch of samples.

In the modified method, 50ml of sample was pipetted into a 100ml glass bottle, 10ml 2N sulphuric acid was added followed by exactly 10ml of 0.0125N potassium permanganate solution. The bottle was capped and the contents mixed; it was placed on one side until the other bottles of the batch of samples were ready. The caps of the bottles were loosened and the bottles were placed in boiling water in a water bath, where they were agitated at intervals during a period of 1 hour. At the end of this period the bottles were cooled quickly to room temperature. The excess potassium permanganate in each bottle was treated with about 0.2g potassium iodide (excess) and the liberated iodine was titrated with 0.0125N sodium thiosulphate from a burette using starch as indicator.

It was necessary to perform all determinations in duplicate and to perform "blank" tests using distilled water instead of a sample. The extension of the incubation period to 1 hour and the mechanical stirring of the boiling water gave consistent results between pairs of estimations within a given batch, although one author (LGB) feels that not too much significance should be placed upon direct comparison of results from different batches of estimations. There is some evidence that the distilled water used throughout this test (for solution preparation and for "blanks") should be freshly distilled and should be stored in glass bottles rather than in polythene containers.

SITE NUMBER AND NAME	GRID REFERENCE	SITE DESCRIPTION	REASON FOR CHOICE OF SITE
OGOF FFYNNON DDU SYSTEM			
1 Byfre Fechan Stream	8770 1690	Flows from slopes of Fan Gihyrich	Provides water flowing from Old Red Sandstone
2 Pwll Byfre	8744 1660	Main sink for OFD system	To investigate changes in water flowing from sink into streamway of cave
3 Smith's Armoury	8752 1628	First appearance in cave of water from sink	
4 Main Stream, below Maypole Inlet	8641 1561		With (5) to investigate changes in water flowing along open streamway
5 Main Stream, above Confluence	8562 1519	Above confluence with Cwmdwr stream	To investigate mixing of two streams of dissimilar water
6 Main Stream, below Confluence	8552 1516	Below confluence with Cwmdwr stream	
7 Cwmdwr stream, above Confluence	8562 1520	Above confluence with Main Stream	
8 Cwmdwr stream	8565 1535	Above Smithy Boulder Choke	To investigate changes in water flowing through boulder Choke
9 Cwmdwr stream	8565 1534	Below Smithy Boulder Choke	
10 Ffynnon Ddu	8472 1508	Resurgence for OFD system	
OTHER SITES			
11 Heron Rising	8432 1565	Resurgence, E. of R. Tawe	Known sources of water with low dissolved oxygen content
12 Fish Tank Rising	8405 1540	Resurgence, W. of R. Tawe	

TABLE 1. DESCRIPTION OF SAMPLING SITES

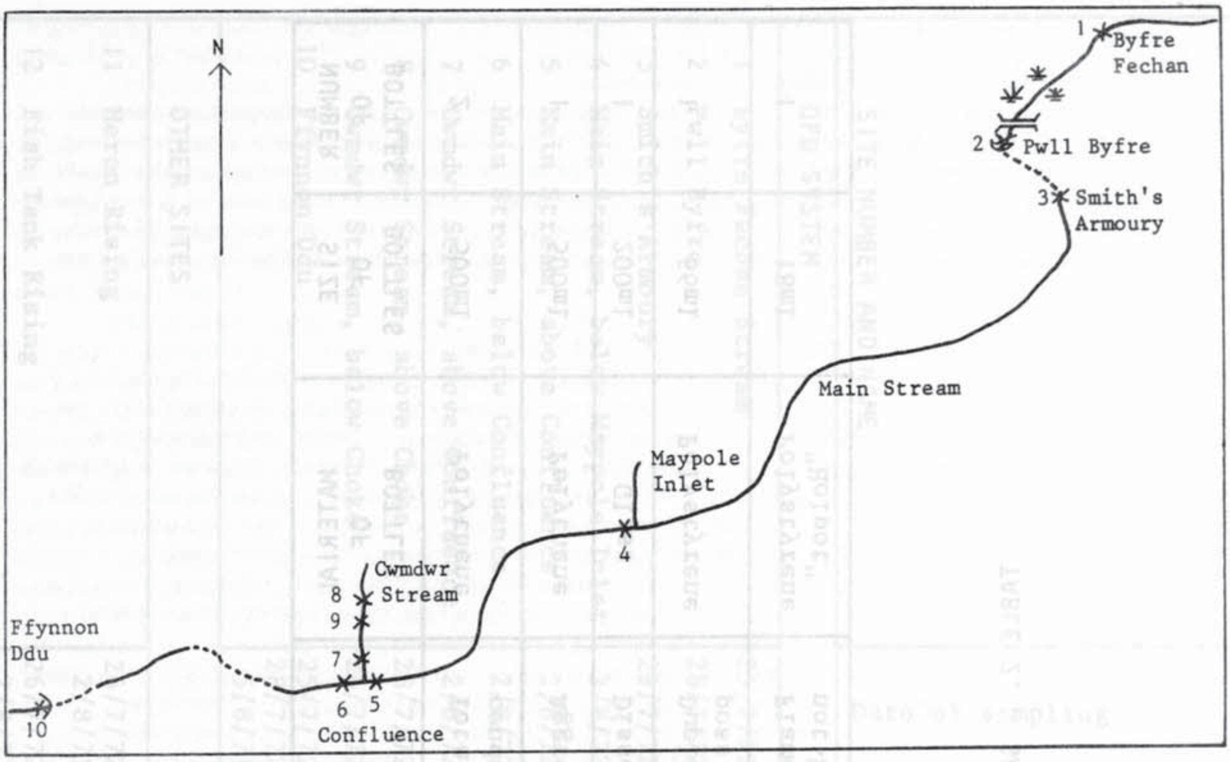

FIGURE 1

SKETCH MAP OF SAMPLING SITES IN OGOF FFYNNON DDU SYSTEM

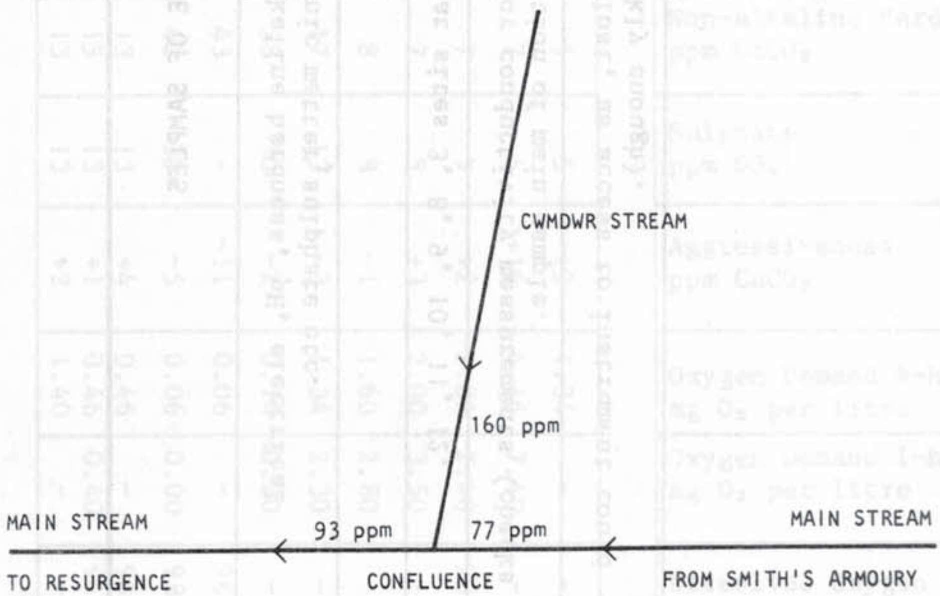

DIAGRAM OF WATER FLOW AT THE CONFLUENCE

FIGURE 2

NUMBER OF BOTTLES	SIZE OF BOTTLES	MATERIAL OF BOTTLES	PURPOSE OF SAMPLES
2	500ml	Polythene	Total hardness, alkaline hardness, pH, electrical conductivity, organic matter, sulphate etc.
1	500ml	Polythene	Aggressiveness.
1	200ml	Glass	Dissolved oxygen, at sites 3, 8, 9, 10, 11, 12.
1	66ml	Polystyrene	Duplicate sample for conductivity measurements (checks possible contamination of main sample.
1	18ml	Polystyrene "Holpot"	Flame photometry (lost, as access to instrument could not be gained quickly enough).

TABLE 2. SAMPLE DETAILS

	SITE NUMBER AND NAME	Date of sampling	Total Hardness ppm $CaCO_3$	Alkaline Hardness ppm $CaCO_3$	Non-alkaline Hardness ppm $CaCO_3$	Sulphate ppm SO_4^{2-}	Aggressiveness ppm $CaCO_3$	Oxygen Demand 4-hr 27°C mg O_2 per litre	Oxygen Demand 1-hr 100°C mg O_2 per litre	Dissolved Oxygen (%)	Specific Conductivity µmho per cm. (25°C)	pH
	OFD SYSTEM											
1	Byfre Fechan Stream	25/7/72	23	18	5	5	+9	1.34	-	-	60	7.3
2	Pwll Byfre	28/7/72	22	15	7	5	+16	4.16	7.40	-	60	7.1
3	Smith's Armoury	29/7/72	73	66	7	5	+2	2.04	2.40	93	151	7.9
4	Main Stream, below Maypole Inlet	2/8/72	69	62	7	5	+3	2.00	3.50	-	140	7.6
5	Main Stream, above Confluence	2/8/72	77	69	8	8	-1	1.60	2.80	-	162	7.6
6	Main Stream, below Confluence	2/8/72	93	76	17	13	-3	1.34	2.30	-	200	7.7
7	Cwmdwr Stream, above Confluence	2/8/72	160	122	38	30	-2	0.14	0.20	-	447	8.0
8	Cwmdwr Stream, above Choke	28/7/72	169	126	43	-	-11	0.06	-	96	508	7.7
9	Cwmdwr Stream, below Choke	28/7/72	167	125	42	30+	-5	0.06	0.00	98	524	8.0
10	Ffynnon Ddu	25/7/72	108	95	13	13	+4	0.46	-	96	246	7.9
		28/7/72	112	97	15	13	+1	0.46	0.40	94	254	8.0
		5/8/71	76	63	13	13	+2	1.40	-	-	169	7.6
	OTHER SITES											
11	Heron Rising	26/7/72	97	89	8	10	+17	0.10	-	70	208	7.8
		2/8/71	95	88	7	8	+16	0.05	-	66	203	7.5
12	Fish Tank Rising	26/7/72	131	120	11	10	+6	0.06	-	74	277	7.9
		2/8/71	126	115	11	8	-1	0.00	-	71	250	7.8

TABLE 3 COLLECTED RESULTS

Under the conditions of the experiment

Oxygen demand = (Titre "blank" − titre "sample") x 2
(in mg oxygen per litre).

Attention has been drawn to the doubt of what is being measured by permanganate oxidation tests (Holden, 1970). It was considered by Wilson (1959) that the permanganate value (oxygen demand) of a moorland water arose mainly from the humic acid content of that water. In the absence of an easily-applied method for direct estimation of organic matter the present authors use the 4-hour 27°C and 1-hour 100°C permanganate values (oxygen demands) as convenient but arbitrary ways of expressing the relative amounts of easily-oxidised organic matter in the cave waters of the Penwyllt area. The former values are quoted to allow comparison with earlier work.

RESULTS

The experimental results are presented in Table 3, and it may be useful to re-state the meaning of certain terms. Hardness values and aggressiveness values are quoted in ppm $CaCO_3$ (i.e. in mg $CaCO_3$ per litre). The term "total hardness" implies the total of calcium hardness and magnesium hardness (total Ca^{2+} and Mg^{2+} ion concentrations) calculated as ppm $CaCO_3$ equivalent. "Alkaline hardness" is a measure of the hydrogen carbonate ion concentration (HCO_3) expressed in terms of ppm $CaCO_3$ equivalent. The difference (total hardness − alkaline hardness) is known as "non-alkaline hardness" and is a rough-and-ready measure of soluble calcium and magnesium compounds other than the hydrogen carbonates, expressed in terms of ppm $CaCO_3$ equivalent: in the Penwyllt area these are mainly sulphates. A positive value for aggressiveness indicates a water with limestone-attacking power and a negative value indicates a water tending to deposit calcium carbonate if in contact with limestone.

Oxygen demand (permanganate value) is given as mg oxygen absorbed per litre. Dissolved oxygen values are quoted as percentage saturation at the temperature of the water concerned at collection.

The total hardness values obtained by titration were used together with the measurements of electrical conductivity at 25°C to establish the total hardness/electrical conductivity correlation used in the conductivity study of the cave (O'Reilly and Bray, 1974). The temperature used for the conductivity measurements (25°C) may seem unorthodox in caving terms but it is the temperature regarded as standard for such measurements. Eventually it is hoped to link the results obtained from cave waters with published data for ionic mobilities: these are available for the 25°C temperature.

Some results for 1971 are included as they are used in the discussion.

DISCUSSION OF RESULTS

A set of analytical data for an individual water is of little value in isolation. It is only when comparisons can be made between results from different waters that tentative conclusions can be advanced: this requires the availability for reference purposes of many sets of data for waters from different sites and for waters from a given site under different conditions.

One of the authors (LGB) has put forward as a basis for discussion an approach to the chemical processes of cave enlargement (Bray 1972). This established a direct relationship between the aggressiveness of surface waters and the oxidizable organic matter content of those waters. It suggested that additional limestone-attacking power could be generated within a cave by oxidation of the water-borne organic matter (mainly "humic acids") to give simpler substances which might themselves be capable of limestone attack. The implication of the suggested route for limestone attack was that of the various factors i.e.

(i) carbonic acid attack by the "traditional route",
(ii) attack by free sulphuric acid contained in peaty water,
(iii) attack via oxidation of organic matter,

that involving organic matter might well be the controlling factor for the Ogof Ffynnon Ddu system.

Such a suggestion needed support from evidence obtained from within the cave system. In outline, if the organic matter route for limestone attack were of major importance, it would be expected that a moorland water with relatively low hardness but high organic matter content when it sank into a cave would gain hardness but lose organic matter on its way through the streamway of the cave. It is interesting to compare the predictions of this hypothesis with the experimental results obtained.

THE OGOF FFYNNON DDU SYSTEM

The results from the Ogof Ffynnon Ddu system cover the flow of most of the water from the Byfre Fechan stream to the north of the cave, into the Pwll Byfre sink, out into the cave at Smith's Armoury, through the Main Stream passage via The Confluence to the resurgence at Ffynnon Ddu.

It is interesting to note that the water leaving the Old Red Sandstone slopes of Fan Gihyrich as the Byfre Fechan stream is less aggressive and has a lower organic matter content than the water actually entering the Pwll Byfre sink. The Byfre Fechan stream flows between areas of peat bog but seems to take little water from the peat bogs and it is only within a few hundred metres of the Pwll Byfre sink that the organic matter content and aggressiveness of the water rise. It seems that most of the organic matter entering the cave at the Pwll Byfre sink drains into the Byfre Fechan stream near the abandoned mineral tramway bridge. Chemical tests suggest that, under flood conditions, the drainage pattern of the area changes as there is a great change in the electrolyte balance of the water entering the sink (Bray 1972).

The relatively high aggressiveness of the water at Pwll Byfre (+16 ppm) cannot be ascribed to the presence of free sulphuric acid as the near-neutrality of the water (pH 7.1) and the low sulphate content

(5 ppm SO_4^{2-}) rule out this possibility. It must be ascribed to the organic matter carried by the water, presumably as "humic acids".

Once the water has entered the Pwll Byfre sink it is not seen again until it emerges into the cave at Smith's Armoury. By this time significant changes have taken place: the hardness has increased from 22 ppm to 73 ppm and the level of the organic matter has dropped from 7.40 to 2.40 mg oxygen absorbed per litre (using the 1-hour 100°C test). In outline this pattern is repeated all along the streamway to the resurgence, a steady increase in hardness being accompanied by a steady drop in organic matter. This observation is consistent with the hypothesis that additional aggressiveness is generated within the streamway by oxidation of organic matter and that this "latent aggressiveness" is spent almost immediately by limestone attack with consequent increase of hardness.

The conductivity study showed that The Confluence area of the cave was hydrologically one of the most important areas of the cave (O'Reilly and Bray, 1974). Chemically, the differences between the water in the Cwmdwr stream and that in the Main Stream are very great. The Cwmdwr stream water is the hardest flowing water so far encountered in caves in the Swansea Valley, with a high sulphate content (over 30 ppm) suggesting contact with a rock containing more than the usual proportion of calcium sulphate, if not with gypsum itself. There is the possibility that this high sulphate content might be caused by pollution from the Twyn Disgwylfa quarry but, for this to be the case, there would need to be massive and regularly repeated spillage of a material such as sulphuric acid; this is to be investigated further. The level of organic matter in the water is very low indeed (1-hour 100°C oxygen demand less than 0.2 mg per litre). It would appear that this water must be diffuse origin percolation water.

It is an interesting feature of the Cwmdwr stream that the hardness of the water decreases as it proceeds downstream. The very high hardness value of the water above the Smithy Boulder Choke (169 ppm) is accompanied by a substantial negative aggressiveness (−11 ppm). At The Confluence the Cwmdwr stream water hardness has dropped to 160 ppm and it has less tendency to deposit calcium carbonate (aggressiveness −2 ppm).

The situation at The Confluence may be represented as shown in Figure 2, where total hardness values are given. Using the values shown the relative flow of water in the two streams meeting can be calculated:

$$\frac{\text{Flow in Cwmdwr stream}}{\text{Flow in Main Stream above Confluence}} = \frac{1}{4.19}$$

i.e. the contribution of the Cwmdwr stream to the total flow of water leaving The Confluence is about one-fifth (19.3%).

It had been hoped to use the results from the Cwmdwr stream to investigate possible changes taking place when water carrying organic matter flowed through a boulder choke. As the organic matter content of the water in the Cwmdwr stream was so low this part of the study failed.

QUANTITATIVE EXAMINATION OF RESULTS

It has been shown above that the pattern of increasing hardness accompanied by decreasing organic matter content for water flowing from sink to resurgence is qualitatively that to be expected from the "organic matter" route for limestone attack. It is interesting to examine the results in greater detail. For this purpose the alkaline hardness value is used; it approximates to the calcium and magnesium hydrogen carbonate levels in the water (into which materials it is reasonable to consider that organic matter might eventually be converted by oxidation and limestone attack within the streamway) and the value is free from sulphate content complications. In the instance to be quoted the 1-hour 100°C oxygen demand values are used. It is convenient to consider various sections of the streamway as separate water-courses and the section from Pwll Byfre to Smith's Armoury is considered in detail. For this section the alkaline hardness of the water increases from 15 ppm to 66 ppm while the oxygen demand decreases from 7.40 to 2.40 mg oxygen per litre, i.e. the changes are an increase of 51 ppm in alkaline hardness for a loss of 5.0 mg per litre in oxygen demand. This may be expressed in the form of an equation:

$$\frac{\Delta \text{ alkaline hardness (increase)}}{\Delta \text{ oxygen demand (decrease)}} = \frac{66 - 15}{7.4 - 2.4} = \frac{51}{5.00} = 10.2$$

It is possible to consider several other sections of the streamway for which compatible oxygen demand values are available. In the sections including the Ffynnon Ddu resurgence as one site there is the problem that the values for alkaline hardness and for oxygen demand are affected by the very hard but organically very "clean" water entering the Main Stream from the Cwmdwr stream at The Confluence. Fortunately the approximate relative flow of water in the two streams is known and a "corrected" value for the alkaline hardness (i.e. that value which would be found but for the contribution from the Cwmdwr stream) can be obtained. In a similar manner it is possible to obtain "corrected" values for the oxygen demand. The "corrected" alkaline hardness is 91 ppm $CaCO_3$ equivalent and the "corrected" 1-hour 100°C oxygen demand value is 0.45 mg oxygen per litre.

It is possible to relate the changes in alkaline hardness to a different arbitrary measure of organic matter content, the 4-hr 27°C oxygen demand. In this case the "corrected" oxygen demand for the Ffynnon Ddu resurgence is 0.54 mg oxygen per litre.

Table 4 summarises the results for various sections of streamway as separate watercourses and for the streamway as a whole. Uncorrected values are appropriate for the section "Main Stream Below

TABLE 4

RELATIONSHIP OF CHANGES IN ALKALINE HARDNESS WITH CHANGES IN OXYGEN DEMAND

SECTION OF STREAMWAY	INCREASE IN ALKALINE HARDNESS $\Delta CaCO_3$	DECREASE IN 1-Hr 100°C OXYGEN DEMAND $\Delta OxDe(1Hr)$	RATIO $\frac{\Delta CaCO_3}{\Delta OxDe(1Hr)}$	DECREASE IN 4-Hr 27°C OXYGEN DEMAND $\Delta OxDe(4Hr)$	RATIO $\frac{\Delta CaCO_3}{\Delta OxDe(4Hr)}$
Pwll Byfre to Smith's Armoury	51	5.00	10.2	2.12	24.1
Pwll Byfre to Ffynnon Ddu(*)	76	6.95	10.9	3.62	21.0
Smith's Armoury to Ffynnon Ddu(*)	25	1.95	12.8	1.50	16.7
Main Stream, Below Maypole Inlet to Main Stream, Above Confluence	7	0.70	10.0	0.40	17.5
Main Stream, Below Maypole Inlet to Ffynnon Ddu(*)	29	3.05	9.5	1.46	19.9
Main Stream, above Confluence to Ffynnon Ddu(*)	22	2.35	9.4	1.06	20.8
Main Stream, below Confluence to Ffynnon Ddu	21	1.90	11.1	0.88	23.9

Notes: Hardness values in ppm $CaCO_3$
Oxygen Demand values in mg O_2 per litre
(*) Corrected values used, see text

Confluence to Ffynnon Ddu" as the analytical results for the water leaving The Confluence include the effects of the water from the Cwmdwr stream.

Examination of the ratios obtained using the 1-hour 100°C values shows the ratios to be nearly constant with a mean of 10.6. Apart from one ratio (that for the section "Smith's Armoury to Ffynnon Ddu") the ratios show only a small scatter about the mean. Statistical examination shows that, for a 99% confidence in the ratio, it should lie between 9.0 and 12.3. With so few results statistical analysis must be used with caution, but the experiment is regarded as satisfactory especially when the experimental difficulties are considered.

The 4-hour 27°C oxygen demand estimation oxidises the organic matter less than the 1-hour 100°C test and the oxygen demand values for the lower temperatures would be expected to be lower in general, with the ratios obtained being higher than those calculated from the 1-hour 100°C values. This is found; the mean under the less forcing conditions being 20.6. The scatter about the mean is greater and the 99% confidence limits are relatively wide, from 16.6 to 24.6. This is to be expected; as the 4-hour 27°C oxygen demand values are small differences between them must be small and the effects of errors greater.

These results show that, using two methods of assessing organic matter content of cave waters, the ratio $\frac{\text{change in alkaline hardness}}{\text{change in organic matter content}}$ is a constant. If the organic matter oxidation hypothesis is accepted this is an important result. It shows that the oxidation of a given amount of organic matter produces the same amount of limestone-attacking power and increase in alkaline hardness, wherever in the streamway it is oxidised. In turn, this suggests that the same basic processes of organic matter oxidation and limestone attack operate all along the streamway: if oxidation proceeded in distinct stages in separate sections of the streamway it is unlikely that the ratios would be so constant. That any "latent" aggressiveness generated by the oxidation of organic matter in the streamway is used up in limestone attack almost immediately is shown by the non-aggressiveness of the waters in the streamway. Clearly, these results are important and further work is planned to investigate the changes in greater detail.

The near-constancy of these ratios does NOT show that the SPEED of conversion of organic matter into limestone attacking material is the same throughout the streamway, either in terms of time or in terms of distance travelled along the streamway. There would seem to be very real difficulties in making estimations of this sort other than under drought conditions but, if the experimental problems could be overcome, it is possible that a very great advance could be made in the prediction of the nature of the watercourses in "unknown" sections of streamway.

It must be admitted that, from this work, no additional information has been gained on how the processes might operate. The considerable changes taking place between the Pwll Byfre sink and the first appearance of the water at Smith's Armoury, the short period of time involved and the relatively low temperature suggest the intervention of some form of biological agency. It has proved quite impossible to reproduce in the laboratory the hardness increases taking place in the cave. Attempts were made to trickle water from Pwll Byfre down a column containing limestone through which carbon dioxide-free oxygen was passed. In no case was the increase in hardness found to exceed the "initial" aggressiveness of the water, i.e. no "latent" aggressiveness was generated under these conditions.

Under low water conditions the Ogof Ffynnon Ddu system is remarkably efficient in removing easily oxidised organic matter from the water flowing through the streamway (e.g. 95% of the 1-hour 100°C oxygen demand value of the water entering the Pwll Byfre sink is lost by the time the water has reached the Ffynnon Ddu resurgence). If the small amount of easily oxidised organic matter left in the water at Ffynnon Ddu were to be oxidised and converted into additional alkaline hardness, the hypothetical maximum alkaline hardness would be

$97 + (0.46 \times 20.6) = 106$ ppm using the 4-hour 27°C value

and $97 + (0.40 \times 10.6) = 101$ ppm using the 1-hour 100°C

oxygen demand value, suggesting a mean of 103 ppm $CaCO_3$ equivalent. Under partial flood conditions (5/8/71) the alkaline hardness of the water leaving the Ffynnon Ddu resurgence was 63 ppm and the 4-hour 27°C oxygen demand was 1.40 mg oxygen per litre. If the organic matter were to be converted into a hardness increase the maximum hardness would be

$63 + (1.40 \times 20.6) = 92$ ppm

a value in fair, if not good, agreement with the value found for drought conditions. It will be interesting to see whether there is any sort of constancy to this hypothetical maximum hardness under changing weather conditions.

THE CRAIG-Y-NOS RESURGENCES

The following discussion is largely conjectural and must be recognised as such: it is given as an example of the arguments possible when experimental values from given sites are considered in conjunction with hypothetical ideas developed from work at other sites.

The two risings are within the grounds of Craig-y-Nos Castle (the Adelina Patti Hospital). One of them, to the west of the River Tawe, feeds what was once a large outdoor fish-tank and became known as "Fish Tank Rising". The other, to the east of the River Tawe, is almost on the axis of the eastward continuation of the Swansea Valley Disturbance. It rises beneath Craig-y-Rhiwarth and has been dammed to provide a large artificial lake; it is known as "Heron Rising".

These resurgences attracted attention as providing waters containing only about 70% to 80% of the appropriate saturation concentration of dissolved oxygen. By contrast the waters from the Dan-yr-Ogof resurgence and from the Ogof Ffynnon Ddu resurgence contained almost the saturation concentration of dissolved oxygen. The two minor resurgences provide waters containing very little easily oxidised organic matter. This suggests that such organic matter as might once have been present in the waters has been oxidised at the expense of the oxygen dissolved in the waters flowing in fully-flooded fissures, with consequent lowering of the dissolved oxygen contents of the waters.

The total hardness of the two waters was somewhat different with that from Fish Tank Rising being slightly harder (131 ppm compared to 97 ppm) and the sulphate contents of the waters were the same at 10 ppm SO_4^{2-}, However, the important difference is that, whereas Fish Tank Rising provides water of limited aggressiveness (-1 ppm, 1971; +6 ppm, 1972) that from Heron Rising is markedly aggressive (+16 ppm, 1971; +17 ppm, 1972). Conjectural application of the organic matter oxidation hypothesis suggests an explanation for this difference. It suggests that water reaching Fish Tank Rising percolates through limestone during at least the final stage of its travel so that any "latent" aggressiveness generated during the underground oxidation of organic matter within the water has been lost by reaction with the limestone, so that the water emerges substantially non-aggressive. The water reaching Heron Rising must have percolated through limestone for part of its journey, during which it gains hardness and loses organic matter. Then, at a stage when some organic matter remains, the water encounters a rock against which the substances causing limestone aggressiveness have little effect. The oxidation process continues and the water leaves Heron Rising markedly aggressive.

Heron Rising is situated almost on the axis of the anticline of the eastward continuation of the Swansea Valley Disturbance and study of the geological map shows Lower Limestone Shales to be exposed at the core of the anticline (Cantrill, 1898) and this has been confirmed more recently (Taylor, 1973 private communication).

GENERAL CONCLUSIONS

The principal results of this study show that:

(i) there is a steady loss of easily oxidisable organic matter from Main Stream water as it flows along the streamway from sink to resurgence,

(ii) there is a steady gain in hardness of the water in the Main Stream as it flows along the streamway from sink to resurgence,

(iii) the increase in alkaline hardness obtained for the loss of a given amount of oxidisable organic matter is almost constant for separate sections of the streamway and for the streamway as a whole,

(iv) the basic processes of oxidation of water-borne organic matter seem to be the same throughout the streamway.

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CAVES OF THE STRYDPOORT MOUNTAINS, NORTHEASTERN TRANSVAAL, SOUTH AFRICA.

by Margaret E. Marker

In the Transvaal the Proterozoic (younger Precambrian) Dolomite Series is important as a karst formation. In this paper the general distribution of caves in the Strydpoort Mountains which straddle the northern part of the arcuate dolomite outcrop is considered and three of the larger cave systems are discussed in detail.

The Dolomite Series of the Transvaal System consists of four conformable stages: the Transition Shales, the Main Dolomite, the Banded Ironstone and the Upper Dolomite (Table 1). The karstic Main Dolomite consists of well-bedded, grey-blue magnesian limestone

Table 1: The Geological Succession of the Transvaal System

Pretoria Series		
Dolomite Series	Upper Dolomite	± 400 m
	Banded Ironstone	250 m
	Main Dolomite	2000 m
	Transition Shales	40 m
Black Reef Series		

with intercalated bands of chert. Ferruginous shales with interbedded asbestos compose the overlying resistant Banded Ironstone. The emplacement of the Bushveld Igneous complex to the south of the Strydpoort Mountains caused tilting, folding and faulting with the instrusion of igneous dykes. The east to west folds are arranged en echelon, are overfolded to the north and are associated with a series of anticlinoria and synclinoria.

The rugged Strydpoort Mountains consist of high altitude plateaux cut across dolomite and preserved in part by their position between resistant outcrops of quartzite to the north and ironstone to the south (fig. 1). Deep water gaps incised by allogenic rivers rising on the Pietersburg Plain to the north compartmentalise the outcrop. Between these major drainage lines, lesser deeply incised valleys drain southwards towards the Olifants River (fig. 1).

Fifteen caves of varying size have been recorded in this area (Table 2). Some are only short vadose tunnels at the sites of former springs; others are extensive cave systems such as Wolkberg or Beatrice I. Valley-side entrances are usual, shaft entrances being confined to regions of minimal dissection. In this respect the caves fit Partridge's (1968) karst model for cave formation in dolomite under conditions of cyclic water-table lowering. He suggested that caves develop by solution close to the water table surface, along lines of structural weakness. During this phreatic phase the cave is enlarged by solution and upward piping but also becomes partially choked with residual earths. With rejuvenation the cave enters a vadose zone and a second cave begins to form near the new water table level. A vertical opening into the first cave results from the combined effects of surface lowering and upward piping and talus material enters from the hillside later to be cemented into breccia. Collapse may enlarge the first cave or cause a cavity above it. Ultimately the breccia fill is exposed on the surface; the second cave enters the vadose zone in turn and a third cave begins to form at the new water table level. Although clearly oversimplified, this model has been applied successfully to complex cave systems on the mature highveld surface and in more dissected terrain at Makapan. In many respects it is also applicable to the caves of the Strydpoort Mountains since, in essentials, it proposes that caves can exist simultaneously at different levels and at different stages of development, and also that caves are phreatic in origin, are modified by vadose action and finally become dry.

Almost every cave in the Strydpoort Mountains shows signs of a phreatic origin. In some cases modification by vadose flow is apparent, in others the present cave level rests on top of collapse debris which conceals the former phreatic level. Most caves are dry and partially choked with cave earth, collapse debris and calcium carbonate deposits. The entrances are usually adit-type since in mountainous terrain cave entrances occur in valley sides as slope incision is faster than surface lowering.

Solution in the dolomitic limestones of the Transvaal has been concentrated vertically through major fissures or has acted more or less horizontally along bedding planes and joints. Such horizontal levels appear to be related to former piezometric surfaces. Bretz (1942) has shown that horizontal cave levels may be the underground equivalents of surface erosion levels since phreatic and paraphreatic solution is closely associated with ground water movements near the piezometric surface. This has been demonstrated for various parts of Europe (Sweeting 1950; Stelcl 1964; Bögli 1966) and for the Transvaal (Marker and Moon 1969). Nevertheless this view has not received universal acceptance and local anomalies within a limited region often appear to refute the concept (Waltham 1970; Moon 1972). In the northeastern Transvaal, however, there is statistical evidence that four distinct groups of cave levels exist and it seems likely that their altitudinal groupings were controlled by water table levels related to specific surface planation levels (fig. 2). The following detailed discussion considers one cave representative of Groups I and II, Wolkberg, and two caves in Group III, Beatrice I and Hoogenoeg.

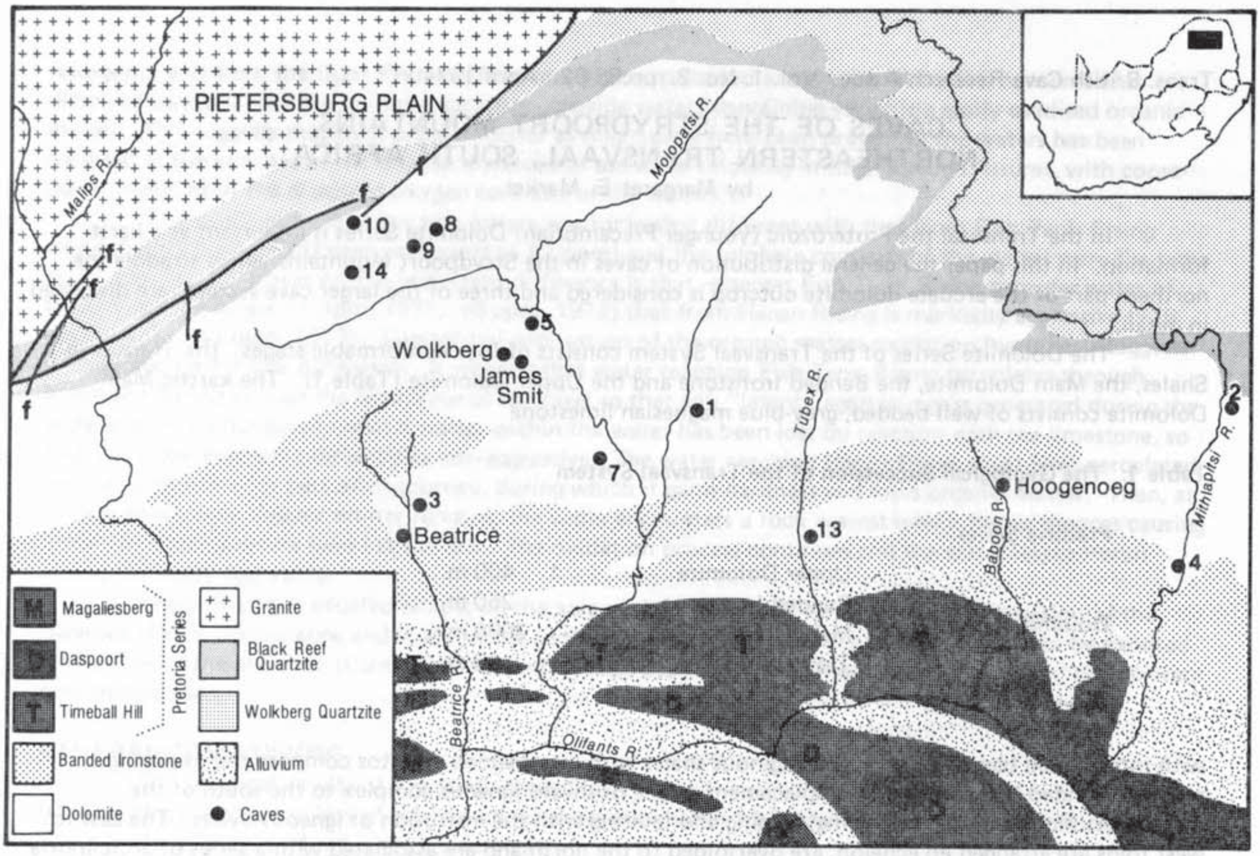


Fig. 1 The Strydpoort Mountains, northeastern Transvaal (2 = Mithlapitsi, other cave numbers refer to Table 2)

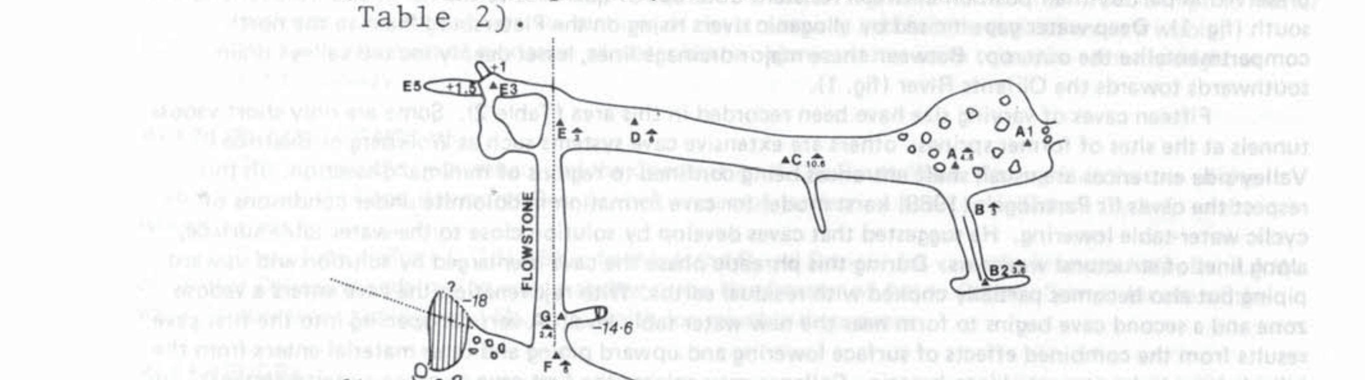


Fig. 4 Beatrice Cave: Plan and Section.

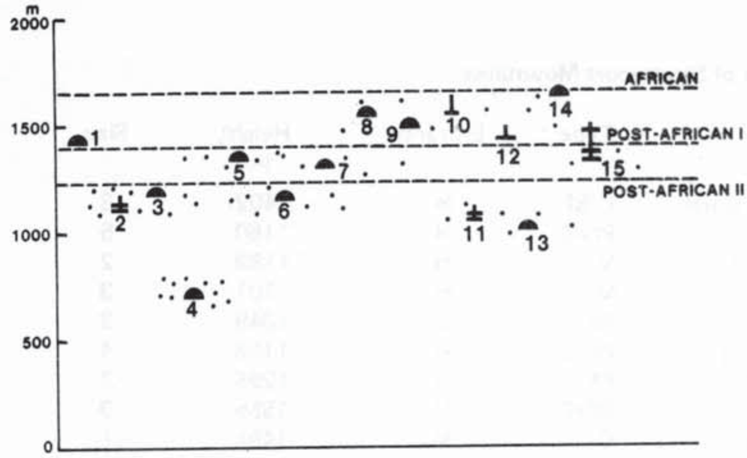


Fig. 2 Altitudinal grouping of caves (numbering refers to Table 2: Horizontal dotted lines represent the main surface erosion bevels).

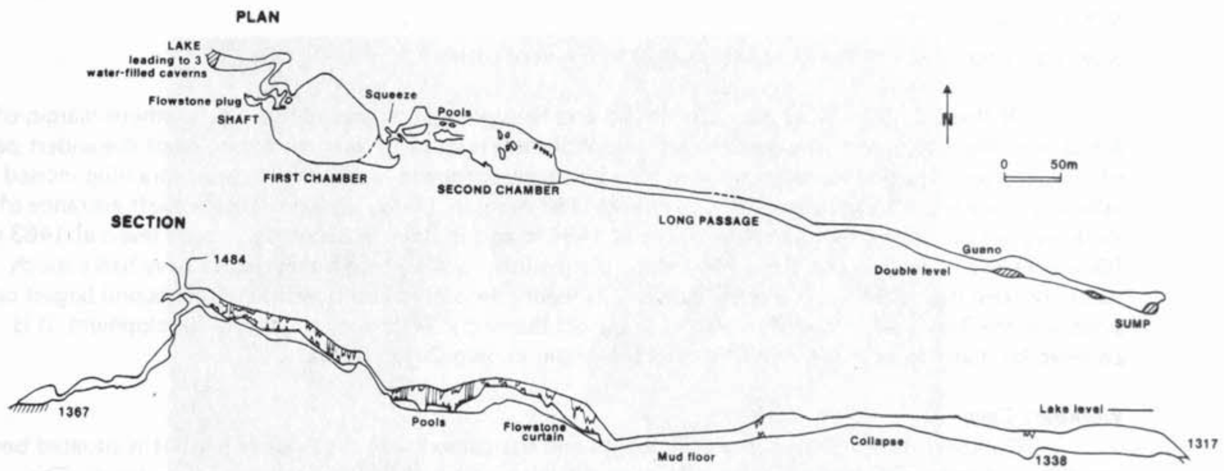


Fig. 3 Wolkberg Cave: Plan and Section (Long Passage surveyed S.A.S.A. 1966, First and Second Chambers surveyed S.A.S.A. 1969).

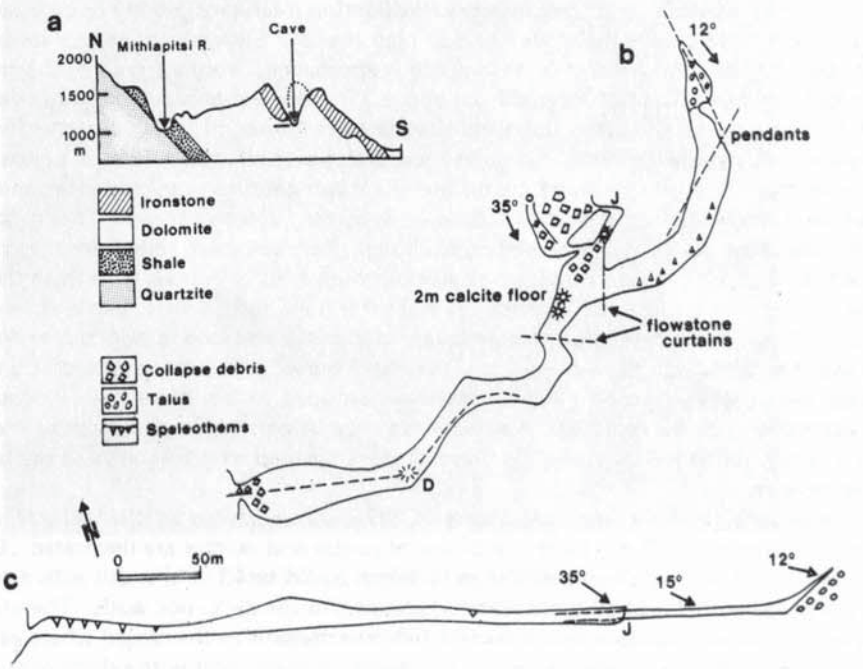


Fig. 5 Hoogenoeg Cave: (a) Position in relation to geology, (b) Plan, (c) Section.

Table 2: Caves of Strydpoort Mountains

	Name	Type	Entrance	Height (m)	Size	Levels (m)
1.	Ashmole Dales	C/BP	H	1402	3	1400
2.	Beatrice I	Ph/C	H	1160	5	1130, 1115, 1110
3.	Beatrice II	V	H	1189	2	1189
4.	Cork	V	H	701	3	701
5.	Helen	Ph	V	1349	3	1346
6.	Hoogenoeg	Ph/V	H	1158	4	1158
7	Island Blue	Ph	H	1295	?	
8.	Mimosa	BP/C	V	1555	3	1545
9.	Mimosa Dam	C	V	1494	?	
10	Nel	F	V	1646	4	1570
11	Paswene	BP/C	H	1097	5	1082, 1067
12	James Smit	Shaft	V	1463	4	1439
13	Tubex	V	H	1006	1	
14.	Van Eeden	F/V	H	1646	3	1640
15.	Wolkberg	Ph/C	V	1486	6	1463, 1367, 1326

C = collapse; BP = Bedding plane; Ph = Phreatic; V = Vadose; F = Fault; H = Horizontal entrance; V = Vertical entrance.

Size is on a nominal scale from 1 = very small to 6 = very large.

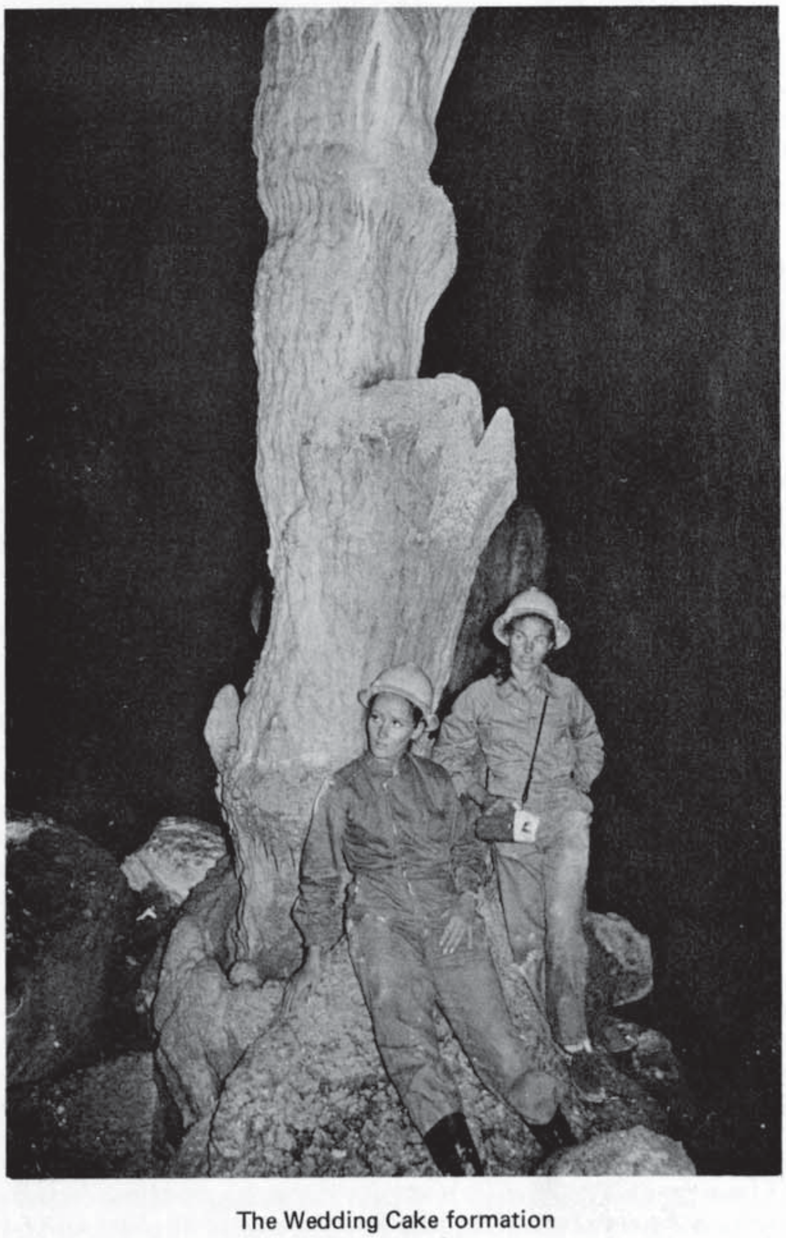
Of these three sizeable caves, Beatrice I and Hoogenoeg are located near the southern margin of the Strydpoort Mountain dolomite outcrop whereas Wolkberg is situated near the midpoint of the widest part of the outcrop. Beatrice I and Hoogenoeg have adit-type entrances reached from south-draining incised valleys and are low altitude caves at 1130 m and 1158 m respectively. By contrast the shaft entrance of Wolkberg lies on a dissected plateau remnant at 1484 m and in its extensive cave system, levels at 1463 m (Group 1) 1367 and 1326 m (Group II) can be distinguished. Wolkberg is believed to have had a much longer history than either of the other caves. It is highly decorated and is probably the second largest cave system in the Transvaal. Purchased by the Transvaal Provincial Authority for future development, it is believed by many to be more beautiful than the better known Cango Caves.

Wolkberg Cave

Wolkberg is over 860 m in overall length and has a maximum depth of 155 m. It is situated beneath the dissected remnants of the African surface in the headwaters of the Molopatsi drainage basin. The entrance on the eastern side of a small summit at 1484 m is a 26m shaft, opening from a sinkhole 30 m in diameter. Some 366 m west and 23 m lower is a similar shaft opening into the adjacent James Smit cave. Although as yet there is no proven connection between these caves, it seems unlikely that one small hill should contain two independent cave systems; further exploration may therefore extend Wolkberg to include the James Smith system.

The main portion of the Wolkberg System consists of two large caverns and a passage extending 600 m southeast to a water sump; in the opposite direction a series of pitches leads down to a lake 110 m below the surface. The cave is therefore linear in plan (fig. 3). Each section will be described in turn. The First Chamber, 107 m in length and 60 m in width is approached from the foot of the shaft over loose collapse debris and talus that has entered from above. The slope continues for 30 m below the shaft till a level platform is reached; the lower slope and the platform consist of firmly cemented breakdown coated in calcite supporting large speleothems. Some of these stalagmite pillars are 12 m in height and 3 m in diameter. The whole chamber is white, the floor, ceiling and walls being entirely covered in secondary flowstone growth which is now inactive. The floor is covered in 50 mm of white powder; many formations have fallen and some show cracks and recementing as though there had been some settling of the breakdown cone since their first formation. However, as guano is known to have been worked in the 1930s (S.A.S.A. 1969) the damage may be recent. Towards the walls the floor again slopes steeply down. Along the north wall remains of cave pools preserve alternate layers of mud fill and calcite that may represent seasonal flooding with the formation of calcite rafts. These have buried pillars to a depth of 1.5 m. Cemented into the topmost calcite layer are duiker bones tentatively ascribed to the Stone Age. This suggests that the active phase ended with the entry of the bones since they lie on the surface. Most of the large calcite formations exhibit evidence of re-solution and many are covered with aragonite of the subaqueous and crystalline varieties.

The Second Chamber, discovered only in 1965, is approached by the Squeeze, a twisting pitch with an overall descent of 28 m; there is a choice of routes and neither are decorated. Unlike the First Chamber, in the vast Second Chamber, 137 m in length by 24 to 43 m in width with a ceiling 18 m to 22 m in height, large speleothems of all types stand in contrast to the dark rock walls. The uneven floor is coated in calcite which conceals collapse debris, except near the margins of the cavern where earth floors can be seen. The humidity is high; speleothems are active and perched pools with calcite rafts can be found under



The Wedding Cake formation
in Wolkberg Cave,
Strydpoort Mountains,
Transvaal.

boulders. Along the southern wall there is evidence of alternate earth fill and calcite layers similar to those described from the First Chamber but these have been active in the recent past. Again many of the formations show signs of re-solution. The southeastern end of the Second Chamber, beyond a cemented collapse cone, is even more irregular and there is evidence of recent roof fall where chert bands are intercalated with dolomite. Collapse becomes more frequent beyond the flowstone curtain that marks the limit of the Second Chamber and the entrance to the Long Passage, a linear tunnel cave with few speleothems. Some 152 m from the end it has developed as a double phreatic tube with perched calcite floors overlying breccia. The passage terminates under the sloping ceiling in a mud-floored sump, 0.6 m in depth. In this passage there are three large, probably interconnected, pools of water at a depth of 155 m below the surface.

The decoration in the Second Chamber, that is in the lower parts of the cave system, exhibits some interesting features. Many of the pillars are massive, pointing to a long period of formation after the initial collapse. Contemporaneous with their formation flowstone cemented the collapse. Re-solution interrupted this long period of calcium carbonate deposition and many of the larger formations are now covered by a secondary growth of fine crystals which may be aragonite. Close to the southern wall are small grottos with intricate crystal and helictite formations growing on top of earlier deposits. In one massive pillar crystal growth has taken place upwards and outwards in a fan form so that each layer grows out from the main pillar akin to the scales of a palm trunk. This pillar appears to be essentially similar to those in the Gouffre de Padirac, France. There growth is attributed to capillary movement of fine water droplets under humid conditions (Gèze 1965). In this chamber there is also evidence of speleothem decay. Ceiling drip associated with bat guano has eroded splash cups in many places. The calcite has turned to white mud and moon milk, probably of bacterial origin (Picknett 1969), has been reported (S.A.S.A. 1969). This occurs despite the limited patches of guano. The dry white powder so common on the floor of the First Chamber is likely to be similar dessicated, rotted calcite.

The part of the cave system that lies west of the entrance is in marked contrast to the rest of the cave. A first short passage leading from the foot of the entrance shaft is blocked by flowstone; this may represent a former connection with James Smit cave. On the north wall beyond this passage, a series of pitches lead down through collapse-filled fissures and undecorated mud-coated passages to a lake 113 m below the ground surface. Tha lake occupies the western end of a large chamber some 45 m long by 12 m wide having a maximum height of 15 m. Only a few straw stalactites and mud stalagmites are found on the lakeside mud banks. A window in the west wall leads into a second chamber also containing deep water and access beyond this is via narrow lofty fissures into two small grottos 9 m above the lake. It is likely that the cave continues further both above lake level, as indicated by the strong draught and also through submerged passages but this section has not yet been explored (S.A.S.A. 1969).

The cave survey in January 1969 revealed a difference in water level of 42.7 m with the lake lying 113 m below the shaft entrance, and the sump, approximately 850 m distant, 155.5 m below the surface. When the cave plan is related to surface topography, the sump is seen to lie closer to the main Molopatsi valley at a height of 1326 m whereas the lake underlies a dry tributary system some 122 m higher. Thus the difference in level may reflect a local gradient. Water analyses from both show that they are not identical. Perched calcite ledges indicate that lake levels were at some time 90 m higher than at present; these high lake level phases may possibly have been contemporaneous with re-solution in the First Chamber. However, even in the past ten years the lake level has fallen at least 4.3 m as a result of drought conditions with no recharge periods.

To summarise, the Wolkberg system has two distinct parts, the main cave system and the lake section approach which may represent a recent underground piracy such as described by Warwick (1960). The main cave system is dominated by horizontal levels believed to have formed during period of stillstand and these transgress the regional dip of 20° to 50°S. There is little evidence that this cave was ever affected by vadose flow despite its linear plan, for the level plateaux which are features of both chambers are believed to represent mud-infilled lake floors sealed by calcite. Vadose flow would have dissected such deposits.

Beatrice I cave was first surveyed in April 1973 although it has been known for some time. It covers an area approximately 150 m by 120 m and has a maximum length of 300 m (fig 4). It is therefore fairly extensive for a dolomite cave. Like Wolkberg it contains permanent water and in this respect it is a typical of Transvaal caves which usually lie well above the regional water table as a result of recent dissection.

In plan the system shows distinct structural control, passages being aligned almost east to west and north to south. One major alignment followed by passage E-F is, however, on a vertical bedding plane, thus it is not correct to speak of joint control in such contorted strata. In section, phreatic levels at ±1135 m and between 1125 and 1130 m can be distinguished. The present irregular floor results from extensive collapse. In the entrance passage between A and E phreatic anastomoses and keyhole passages are visible at the lowest floor level, whereas the centre of the passage is occupied by a rubble mound derived from collapse of the shaly Banded Ironstone roof. This, the first section of the cave, has developed by phreatic solution, in anticlinal dolomite beneath an insoluble Banded Ironstone arch. Extensive large-dimension collapse has created the main chamber beyond F. From the phreatic passage floor at F the maximum height of this chamber is now of the order of 30 to 35 m. It is postulated that this chamber is located at the intersection of two or more structural weakness lines which facilitated the solution of a large cavity now buried beneath collapse material. The high percentage of chert in the collapse material may indicate its lesser cohesion which permitted collapse on a large scale. Surveying was complicated by the size of the blocks.

On the far side of the collapse cone, descent into other phreatic passages is possible. Le Cordeur and Justin's lakes occupy extensions of these passages and the cave system may continue for some distance beneath present water level.

The four water bodies in the cave are apparently only poorly connected since their free water surfaces lie at different altitudes (Table 3). It is possible that the smaller water bodies may be perched, like the pools in Wolkberg Second Chamber, but the larger ones are more likely to represent a regional water gradient. When this is plotted, it is seen to slope in the direction of the major Olifants River to the south. Such differences in water level have been established for Wolkberg where the gradient is in the direction of maximum incision and for Sterkfontein, 50 km west of Johannesburg, where the gradient is in the direction of the Blaubank spring (Wilkinson 1973). It seems likely that the piezometric surface in the Transvaal dolomite usually has a considerable gradient.

Table 3: Altitudes of water levels in Beatrice I, April 1973

Gerrard's Hat	1136.4 m
Collapse Fissure	1132.0 m
Justin's Lake	1126.0 m
Le Cordeur lake	1122.0 m

Speleothem deposits are limited. The roof in the phreatic passage between E and F is decorated. One stalagmite mound now suspended from the roof has Banded Ironstone fragments embedded in its base indicating that it developed resting on a former collapse floor, which thus predated the flowstone phase. There is also some evidence here of two phases of calcium carbonate deposition interrupted by a period of re-solution, indicative of a former high water level. In this respect the sequence of deposition is similar to that of the Second Chamber at Wolkberg but simpler.

The second series of flowstone deposits are located on the shores of Le Cordeur lake. Rimstone pool and fluted flowstone coat one wall and active stalactites and stalagmites of up to 20 cm diameter occur at the far end of the chamber. The relative scarcity of calcium carbonate deposits is, however, a characteristic of most low level caves in the northeastern Transvaal.

Hoogenoeg Cave

Hoogenoeg at 1158 m is a horizontal passage cave near the head of Baboon Kloof some 20 km east of Beatrice I. It is located beneath a spur between two valleys; the summit is capped by a massive dolomite cliff but a few hundred metres to the north this is replaced by a col. The arched cave entrance is approached from a talus slope on the western side and lies in the massive dolomite, part of a synclinal outcrop 400 m south of the Banded Ironstone contact (fig. 5). The dip of the beds ranges from 35° to 12° through the cave

The cave is linear and consists of horizontal passages widening out in places to form caverns. Although in part structurally controlled, most of the fissures transect the passages at an angle and the plan of the cave indicates a fluvial origin. The cave terminates 146 m from the entrance in a series of boulder collapse cones. This collapse has been directed by fissure weaknesses and at J has filled a former cavern. When the cave plan is related to the external topography it is apparent that the southern passage walls must be overlain by only a thin layer of dolomite. Hill talus material has entered on this side to form a 30° talus slope. The blocked extremities of the cave appear to underlie the col which may therefore have been created by cave collapse. Massive beds of dolomite are here replaced by thin shaly dolomite interbedded with chert, highly susceptible to collapse.

Numerous rock pendants and anastomosing passages indicate a phreatic origin, perhaps beneath the Post African surface at 1220 m. The horizontal passages which transgress the steep area dip support this argument. The initial period of cave formation would thus antedate the deep valley incision and concomitant reduction of the spur.

Scalloping along the walls and the development of foibes near the junction of passages are evidence of the later vadose phase which may have been associated with a spring emerging at the present entrance after valley incision had begun. At the present, damp mud and water-cut channels in the floor fill show that on occasions water still flows through the cave to sink at D. In July 1969 surface water emerged only 3 km downstream and 61 m lower than the cave floor.

Large speleothems are common: near the entrance badly damaged stalactites are aligned along an east to west fissure; flowstone screens of large proportions occur where other fissures concentrated percolating water. Calcite floors were formed contemporaneously with these speleothems and are overlain by more recent waterfall travertines. In some cases the earlier calcite sheets are undermined and broken by recent water scour. Only at the far end of the cave above the debris cone are active straw stalactites and helictites found.

For the most part passage floors are composed of stoneless red earth, in some cases underlain and in others overlain by flowstone thus suggesting two periods of earth deposition. In places recent cave roof spalling has littered boulders along the passage but large scale collapse is confined to the far end of the cave. Hoogenoeg is thus a small cave which has suffered truncation and collapse as a result of vigorous Quaternary incision.

CONCLUSIONS

Most caves of the Strydpoort Mountain dolomite outcrop are phreatic in origin and their levels can be associated with specific peizometric surfaces in turn related to periods of stillstand. Local anomalies occur but over the whole area it is true to say that cave systems can be correlated with erosion surfaces or periods of stillstand. Vadose modification of phreatic systems is uncommon except in the case of certain low altitude linear caves such as Hoogenoeg. Collapse is frequent and appears to have resulted from changes in the hydrological balance occasioned by rejuvenation.

The older caves contain many beautiful formations but the younger low-altitude caves have few. The rate of speleothem formation is now slow. It seems likely that this is related to the general diminution in the efficacy of karst solution in the Recent Period. Sequences of speleothem formation interrupted by periods of re-solution associated with high underground water levels are preserved in the caves. These are believed to record Quaternary climatic fluctuations from dry to wet and therefore it can be deduced that the major period of karst solution that formed the caves in which the sequences are preserved, must be pre-Quaternary. Since the Pliocene Period in South Africa is conceded to have been dry, the major karst period is probably Miocene in age. Thus the caves of the Strydpoort Mountains are very old and now inactive.

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QUANTITY AND RATE OF LIMESTONE SOLUTION ON THE EASTERN MENDIP HILLS, SOMERSET.

by D.P. Drew

ABSTRACT

Data on $CaCO_3$ concentrations and on discharge were collected for a three year period for the sinking streams and resurgences of a small area of karst on the eastern Mendips, Somerset. The information was used to compute solution rates within the area.

Rates of erosion for 1966 were found to be 49.9, 100.9, and 84.1 m^2/year/km^2 in the three catchments studied when computed using the Groom and Williams formula. The use of different formulae yielded different results as did variation in the time intervals on which the mean data used in the computations was based.

Many attempts have been made to calculate the amount and rate of removal of limestone from karstic areas. The methods used and quality of the data available have varied widely.

During a three year period (1964-1967) an intensive study was made of the hydrological and solution characteristics of three small karst basins on the north flank of the Beacon Hill pericline, eastern Mendip (Drew, 1967, 1968), and sufficient data concerning discharge and dissolved limestone contents were available to permit basin erosion rates to be computed.

Details of the three drainage basins (St. Dunstan's Well, Ashwick Lower and Ashwick Higher) are given in Table 1.

Table 1

Basin	Area Km^2	% Limestone	Base flow Discharge in million litres/week	Max. Discharge 1966 in million litres/week
St. Dunstan's Well	5.78	46	36–45	264
Ashwick Lower	2.64	53	21–27	111
Ashwick Higher	2.58	46	21–27	

The risings are fed, in part, by a series of small streams which sink at the junction of the Lower Limestone Shales and the Black Rock Limestone, though the majority of the outflow at the risings is of percolation origin. The three catchments are physiographically similar, consisting largely of a limestone plateau part wooded, part grassland, with a cover of freely drained Brown Earth, 76–120 cm thick, on the limestones and Surface Water Gleys and poorly drained acid Brown Earth, 45–76 cm deep, on the Old Red Sandstone core of Beacon Hill. Precipitation in the year for which the limestone erosion figures were compiled, amounted to 1420 mm in the St. Dunstan's catchment and 1350 mm in the Ashwick catchments. Mean annual temperature in the area is approximately 10°C. For location and geological maps of the area see Drew (1968).

Definition of the individual catchment areas was carried out by an intensive programme of water tracing and reasonably sharp subterranean divides were established, though these did not coincide with surface watersheds (Drew 1968).

Of the methods commonly used to evaluate the rate of corrosion of limestones, the formula proposed by Groom and Williams (1965) appears to be best suited to the data available on eastern Mendip; the equation is:

$$X = \frac{M}{D\ A\ 10^6} \qquad (1)$$

where

X = rate of limestone solution in m^3/year/Km^2

M = mass of limestone (or calcium carbonate) removed in one year in grams
M = mean calcium carbonate [or limestone] content of the water x total annual basin discharge)

D = density of the limestone

A = catchment are in Km^2

This formula enables the total quantity of limestone removed (M) to be calculated whilst also taking into account the density of the particular limestone (the thickness of strata removed will depend in part on its density, and the size of the catchment.

More commonly used is the formula developed by Corbel (1959):

$$X = \frac{4\,ETn}{100} \qquad (2)$$

where:

X = value of limestone removal in m^3/year/Km^2

E = water surplus in decimetres

T = mean calcium carbonate concentration in the waters in mg/litre

$\frac{1}{n}$ = proportion of limestone in the basin as a fraction of the total area of the basin.

The density of the limestone is assumed to be 2.5 kg/m^3. There are several disadvantages inherent in the use of this formula:

(i) The value of (E), normally obtained by subtracting water loss (by evapotranspiration) from precipitation, will not necessarily correspond to the amount of discharge.

(ii) No account is taken of variations in densities between limestones.

(iii) The assumption that all the limestone dissolved in the waters originates from the limestone-surfaced area of the basisn, i.e. ($\frac{1}{n}$) is not always correct.

Williams (1963, 1964, 1965, 1968) modified Corbel's formula slightly to calculate erosion rates in Co. Clare and Galway, Eire. When discharge records were not available for a catchment he suggested that the following formula should be applied:

$$X = \frac{ETn}{10D} \qquad (3)$$

where:

D = density of the limestone (kg/m^3)

T = mean calcium carbonate (or limestone) content of the water in mg/litre.

For areas where discharge records were available he substituted the equation:

$$X = \frac{QTn}{10^9\ AD} \qquad (4)$$

where:

X = rate of limestone solution in m^3/year/Km^2

Q = annual discharge in litres

T = mean total hardness of the water in mg/litre

$\frac{1}{n}$ = proportion of the total basin area occupied by limestones

D = density of the limestones (Kg/m^3)

A = area of basin in Km^2

The same criticisms apply to these formulae as to that of Corbel except that account is taken of the variation in density of the limestones and in (4) discharge figures are used instead of estimated run-off.

In view of the disadvantages mentioned above of the Corbel formula, that of Groom and Williams was preferred. The use of the ($\frac{1}{n}$) component (fraction of the basin composed of limestone) was not considered to be relevant in the present study as all the sinking streams of the area have an appreciable concentration of calcium carbonate present (50-110 ppm) before they cross the sandstone-limestone shale boundary. This may be derived from calcareous matter in the sandstone or from the liming of fields for agricultural purposes. Thus, to obtain a true estimate of limestone solution from the limestone outcrop itself, the quantity of solution accomplished by the surface streams must be subtracted from total limestone removal over the basins, measured at the resurgences.

Discharge and calcium carbonate records for the sinking streams at the sandstone/shale boundary, of a comparable accuracy to those available for the risings, were not available; therefore no attempt was made to differentiate between the two forms of solution, and rates of solution given are for calcium carbonate over the whole area of the catchments.

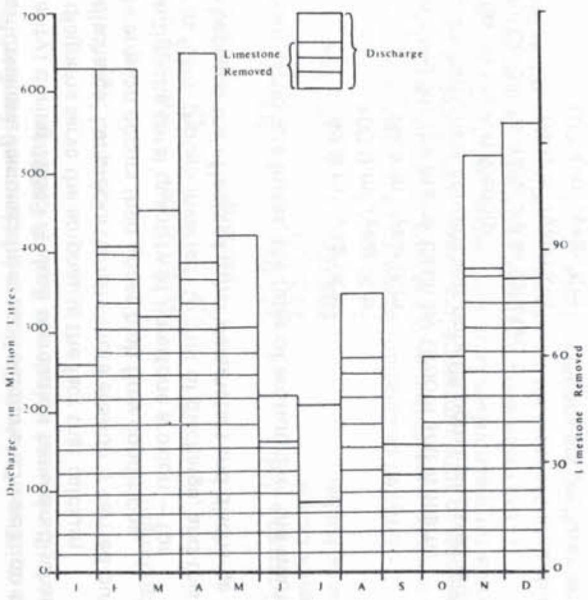
As accurate, continuous discharge records were available for the three catchments, and the mean specific gravity of the limestones established (2.6), the only major variable outstanding was the mean calcium carbonate content of the water (T). In the evaluation of total calcium carbonate loss from any area during a specific period it is assumed that the accuracy of the result will be greater as the time period is divided into smaller and smaller segments with respect to mean calcium carbonate and discharge values. Corbel appears to have based much of his work on the results of analysis of only a few water samples (for calcium carbonate) per year. Williams (1964) calculated mean hardness on the basis of the joint mean value of summer and winter average concentrations, sampling at irregular intervals throughout the year. Groom and Williams (1965) recognised three main flow levels in the Mellte Basin, South Wales. For the year during which detailed sampling was undertaken, flow was high for 38 days, normal for 175 days and low for 153 days. Mean calcium carbonate values were established for each of these flow states and the quantities of limestone removed during each period totalled to give the year's limestone loss.

For the year 1966 for which the solution rate estimate was made for eastern Mendip, seven day periods were the shortest practicable unit for which viable mean calcium carbonate figures were available at the risings. At least two and up to six analyses of calcium carbonate content were available from each rising for every week of 1966, and thus acceptable mean weekly values could be calculated. Accurate weekly discharge figures for the risings were also available, so weekly loss from each rising could be computed and summated to give annual loss in each case, thus permitting substitution in the Groom and Williams formula to find the rate of erosion.

Total quantities of calcium carbonate removed from the three catchments during 1966 (= the sum of mean weekly $CaCO_3$ values x weekly discharge) were found to be:

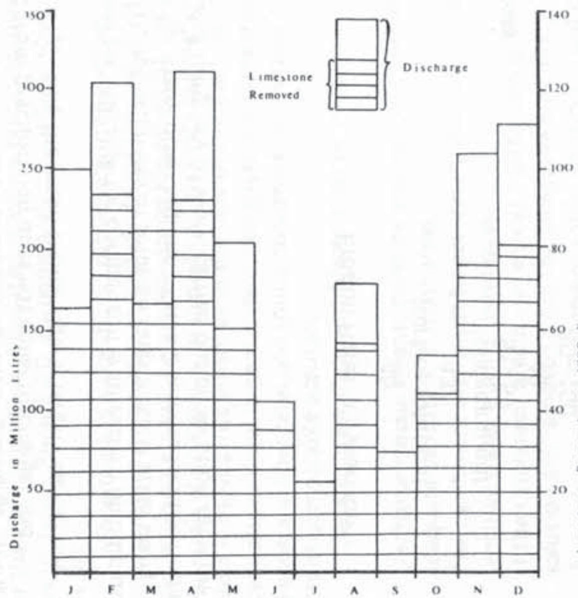
St. Dunstan's Well	778,522 kg
Ashwick Lower	719,100 kg
Ashwick Higher	586,600 kg

Fig. 1



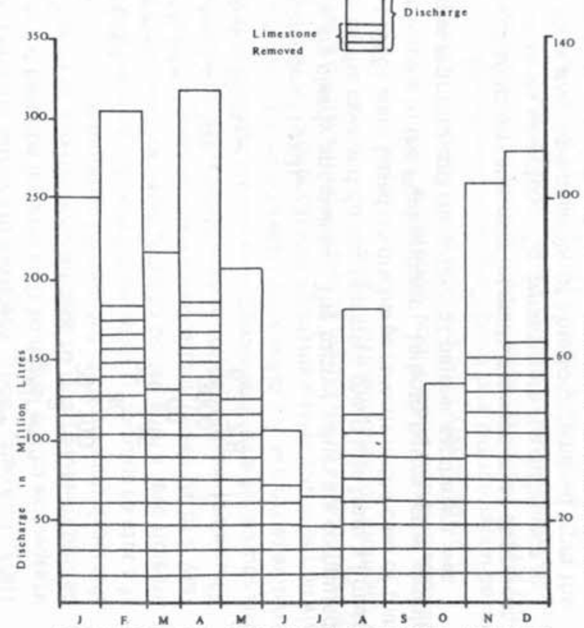
DISCHARGE AND LIMESTONE SOLUTION, ST. DUNSTAN'S WELL CATCHMENT 1966

Fig. 2



DISCHARGE AND LIMESTONE SOLUTION, ASHWICK LOWER CATCHMENT 1966

Fig. 3



DISCHARGE AND LIMESTONE SOLUTION, ASHWICK HIGHER CATCHMENT 1966

Figures 1, 2 and 3 illustrate the quantity of limestone removed from each catchment in relation to discharge (monthly intervals are used for greater clarity) during 1966. A close correlation between discharge and the total quantity of erosion is apparent. The diagrams serve the emphasise the fact that calcium carbonate concentration increases with decreasing discharge, i.e. proportionally more erosion is carried out under low flow conditions but, overall, less absolute erosion occurs than under high flow conditions. Discharge is not necessarily the only parameter affecting the total quantity of limestone erosion – for example, the temperature curve for 1966 is similar in form, though inverted, to that of discharge, and this may affect solution rate. However, differentiation between the effects of other parameters and discharge on solution rate, is not possible.

On the basis of these figures for total calcium carbonate losses, the rates of erosion over the whole catchment areas during 1966 was:

St. Dunstan's Well	49.9 m^3/year/Km^2
Ashwick Lower	100.9 m^3/year/Km^2
Ashwick Higher	84.1 m^3/year/Km^2

These values are considerably higher than that established for the Mellte Basin by Groom and Williams (15.77 m^3/year/Km^2), but in their work mean calcium carbonate content was only 65 ppm compared with 203 ppm, 320 ppm and 278 ppm for the three risings on eastern Mendip.

Values derived for eastern Mendip using the Corbel formula are as follows:

St. Dunstan's Well	64.0 m^3/year/Km^2
Ashwick Lower	102.4 m^3/year/Km^2
Ashwick Higher	88.1 m^3/year/Km^2

The comparatively high degree of agreement between the sets of figures obtained using the two formulae is largely fortuitous as in the Corbel equation the effects of underestimation of discharge (in the Ashwick catchments evapotranspiration subtracted from precipitation does not equal discharge) and overestimation of mean calcium carbonate content (T), using the mean annual figure, largely cancel one another out.

No values for rates of solution in other areas are available for comparison with eastern Mendip using the Groom and Williams formula (Mellte Basin apart), but estimates of solution rates in karst areas using Corbel's formula or other methods have been made for many other regions. Table 2 summarises the findings of some such workers. Janda (1971) provided a useful summary of work carried out on solution rates on non-calcareous rocks.

Table 2: Workers, Rates of Erosion and Areas

Worker(s)	Area(s)	Erosion Rates m^3/year/Km^2
Sweeting, 1964, 1965, 1966	N.W. Yorkshire	40 (surface solution)
	N.W. Yorkshire	43 (underground)
Williams, 1964	Co. Clare and Galway	51–57
Corbel, 1959	Sligo, Mendips	40
Pigott, 1965	Derbyshire	50–100
Pitty, 1968	Derbyshire	75–83
Versey, 1959	Jamaica	72
Corbel, 1959	Alaska	770
Binggeli, 1961	Southern Alps	250–300
Smith, 1969	Canadian Arctic	2
Gams, 1965a	Slovenian karst	20–100
Gams, 1965b	Postojna, Yugoslavia	80
Pulina, 1966	Western Caucasus	75–145
Aubert, 1967	Swiss and French Jura	100
Smith et al, 1968	Pollnagollum Cave, Co. Clare	3000
Corbel et al, 1965	Punkva, Jedovnicky, Moravia	6.2–7.8

Other rates for Arctic environments are given by Hellden (1973).

The values for Pollnagollum and Moravia are clearly anomalous. The former values are computed for limestone loss from the actively eroding floor of the cave and do not represent mean loss from a limestone basin. The low values computed by Corbel et al (1965) were based on discharge records in the case of the Jedovnicky Basin and indirectly computed water surplus in the Punkva Basin. In both basins water samples for calcium carbonate analysis were taken 2-3 times monthly and the extent of neither catchment was accurately defined.

It is doubtful whether valid comparisons of solution rates may be made between areas at present as the accuracy of the data used in each calculation varies so widely. To demonstrate the difference in results obtained using data of varying degrees of accuracy, total quantity of limestone removed from the east Mendip catchments was calculated using increasingly generalized mean calcium carbonate values. The results are shown in Table 3.

Table 3: Total Calcium Carbonate loss (annual) for East Mendip catchments using various mean Calcium Carbonate Values and Runoff Estimates

Catchment	Annual loss in kilograms			
	A Weekly mean Ca + discharge	B Monthly mean Ca + discharge	C Annual mean Ca + discharge	D Annual Ca + Water Surplus
St. Dunstan's Well	778,522	812,500	966,800	968,300
Ashwick Lower	719,100	719,000	781,900	674,400
Ashwick Higher	586,600	602,000	675,800	573,500

Limited calculations involving short interval sampling (30 minutes to one hour) over periods of up to one week, suggest that even the losses given in Table 3A are a considerable overestimation. Thus the differences in total limestone loss values (and therefore solution rates) is considerable; increasing the time intervals for mean values causes increasing overestimation of solution rate in this case.

If the mean annual calcium carbonate concentrations are used in conjunction with the water surplus data available for the area (precipitation minus potential evapotranspiration) the limestone loss figures resulting are shown in Table 3D.

The value obtained for St. Dunstan's Well is similar to that in Table 3C as water surplus appears to be equal to discharge in this catchment. However, the figure is well in excess of that obtained using discharge data and weekly mean calcium carbonate content. The figures for the two Ashwick risings are lower than in Table 3C as calculated effective precipitation is less than metered discharge. The Ashwick values in Tables 3A and 3D are comparable but this is solely due to the discharge underestimation in Table 3D.

Thus there is a significant difference in the values calculated for a particular area as the time interval on which mean calcium and discharge measurements are based is altered. The author considers that weekly intervals are not fully adequate as the effect of flash floods may be blurred in this time. One to two day intervals are necessary to provide an accurate estimation of solution rate using this technique. This problem is most acute when, as in the case of the East Mendip springs, both discharge and solute concentrations show large standard deviations from the means (i.e. the spring regime is flashy). Springs with constant flow rates and solute concentrations would only require a longer sampling interval to yield results of comparable accuracy.

Several other major problems must be overcome in order to provide a valid estimate of solution rate.

(i) Discharge measurements must be accurate and continuous. Indirect calculation of run-off is not an adequate substitute in most areas.

(ii) The catchment area must be accurately delimited — this will involve the use of highly refined and sensitive water tracing techniques.

(iii) If the catchment area is not entirely composed of limestone, account must be taken of limestone in solution not removed from the limestone outcrop.

(iv) Accurate assessment of the quantity of calcium and magnesium carbonate concentration in the water is difficult. E.D.T.A. titrations are normally only accurate to within 2-3 ppm and the presence of various trace elements in the water can falsify the results obtained from titrations (Terjesen et al, 1961; Picknett, 1964); therefore the values obtained could be inaccurate by 1 to 5 per cent irrespective of the length of time interval adopted for the evaluation of mean hardness values. It may be that measurements of specific conductivity to measure all dissolved matter is more relevant in this work than titration for specific carbonates.

(v) If a rate of solution is to be established for an area, and especially if the value is used to compute total erosion over a long period of time, mean solution rates should be obtained for a lengthy period of time (say 5 to 20 years), and account must be taken of likely changes in any of the parameters over time. The values established for eastern Mendip are relevant only to 1966.

All the sources of error mentioned above could operate to produce a cumulative error in any one case. An alternative technique for calculating rates of limestone solution has been developed by Hanna (1966) involving the direct measurement of limestone loss. A micro-erosion meter is used to measure the rate of lowering of blocks of limestone at specific points within a catchment. This method has several advantages over the more conventional techniques.

Limestone Solution under Flood Conditions

Comparatively little previous work has been undertaken on the relative quantities of limestone removed under normal and flood flow conditions though Douglas (1964) summarised some findings. During several storms on eastern Mendip detailed calcium carbonate analyses were made to calculate total limestone solution due to the individual flood pulses.

Figure 4 shows a storm hydrograph at St. Dunstan's Well and the volume of water emitted during the storm over a four day period. Calcium carbonate loss was calculated for 12 hour intervals during these four days, 2 to 8 samples of water being analysed every 12 hours and the mean values adopted. Figure 4

Fig. 4

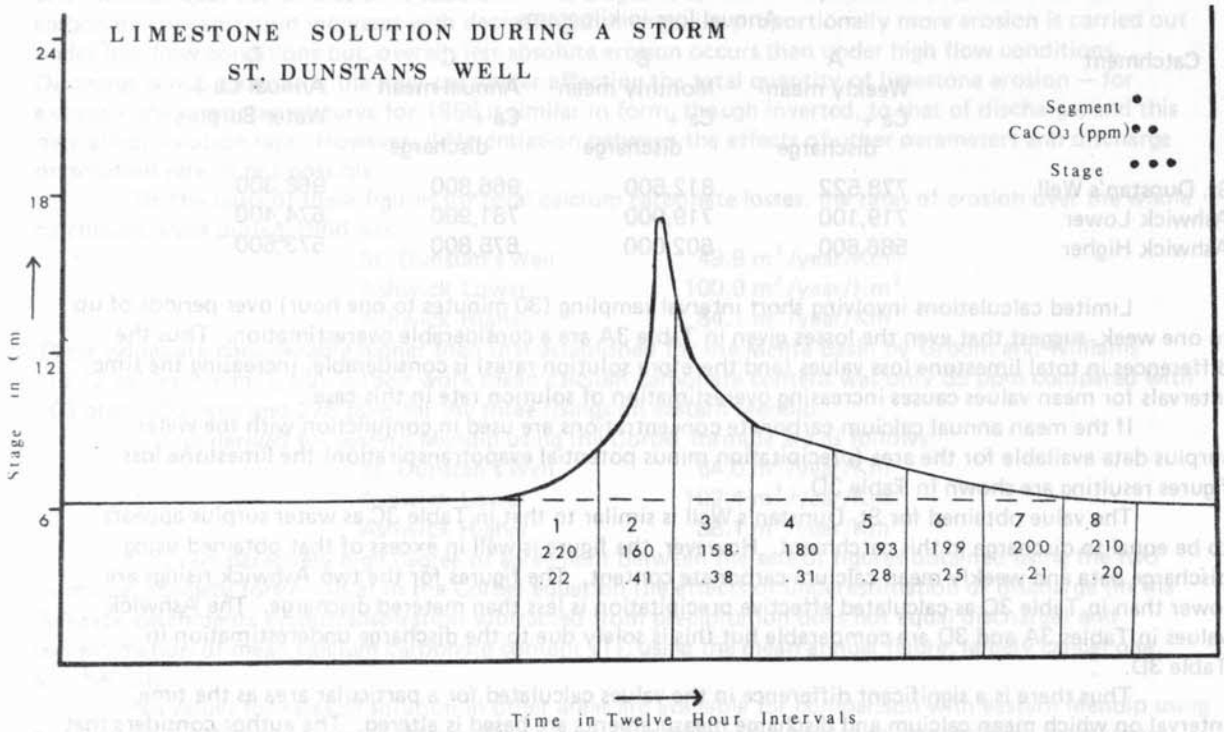
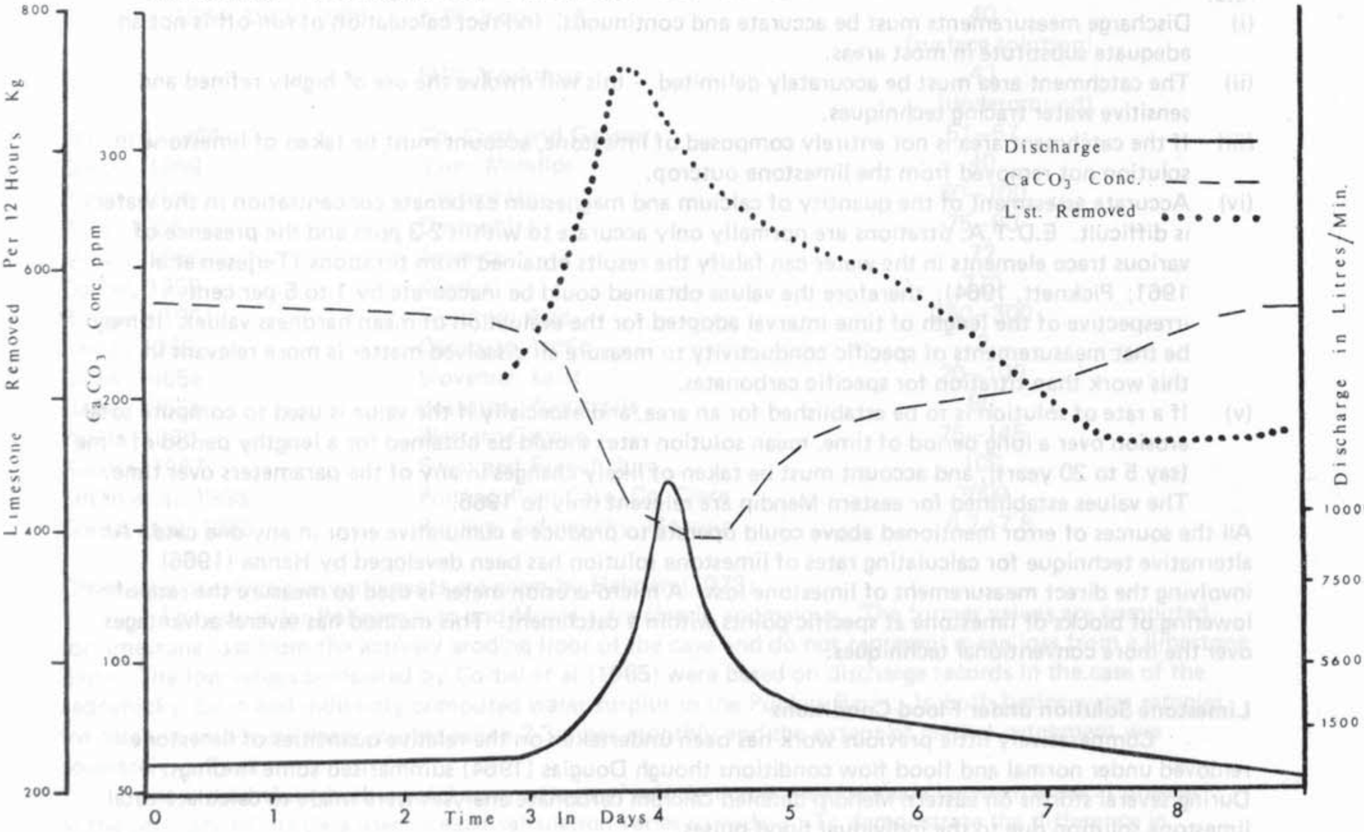


Fig. 5

STORM VARIATIONS IN DISCHARGE, LIMESTONE REMOVAL AND CALCIUM CARBONATE CONTENT AT ST. DUNSTAN'S WELL



also shows mean calcium carbonate content of the water and discharge for each of the eight intervals. Amount of limestone removed during each successive 12 hour period was:

1.	565 kg	5.	599 kg
2.	761 kg	6.	560 kg
3.	663 kg	7.	514 kg
4.	626 kg	8.	470 kg

– a total weight of 4758 kg removed during the storm. This compares with a value of 4211 kg removed during the following 4 days when discharge and calcium carbonate concentration had returned to their normal base flow levels. Thus, normal flow solution was 88.5 per cent of storm solution over 4 day periods. Other normal/storm solution relationships computed for St. Dunstan's Well were 96 per cent, 81 per cent and 81.2 per cent indicating that slightly more solution in absolute terms is accomplished under flood conditions, though concentration falls.

Figure 5 shows discharge, calcium carbonate values and total limestone removed plotted graphically for the storm analysed above. The positive correlation between discharge and total limestone solution, and the negative correlation between calcium carbonate concentration and total limestone solution, are both apparent.

The comparatively small increase in erosional loss during the storm conditions does not agree with the findings of Douglas (1964) for the Green River, Kentucky, or those of Wolman and Miller (1960) who suggest that the removal of material is far greater under high discharge conditions. Two explanations are offered for this discrepancy:

(i) The sharp negative response of calcium carbonate concentrations to increased discharge may be a local phenomenon.

(ii) The rates of limestone loss computed are solely for solutional load and take no account of the suspended bed loads of the streams. During flood conditions the risings on eastern Mendip become markedly turbid indicating a very large increase in non-solutional load, which may significantly increase gross erosional loss during storm conditions.

CONCLUSIONS

The maximum removal of limestone from the area (as against calcium carbonate concentration in the water) is coincident with maximum precipitation and therefore maximum discharge. Corbel (1959) suggested that the aggressiveness of water towards limestone increases with decreasing temperatures, but some confusion appears to have arisen between calcium carbonate concentration in the water and the total amount of limestone removed – an increase in one does not necessarily correspond to an increase in the other. Groom and Williams (1965) showed that in the Mellte Basin, calcium carbonate concentrations are higher during the summer months than during the winter and concluded that aggressivity was therefore at a maximum during the summer (maximum temperature) thus refuting Corbel's hypothesis. However, the summer is also the period of minimum discharge, and until discharge and calcium carbonate concentrations are related, the total amount of limestone removed during any one period is not apparent. On eastern Mendip calcium carbonate values are at a maximum during the summer months, but the greater amount of erosion is carried out during the winter. There is no indication that temperature is responsible for this change; discharge would appear to be all important, although it is not possible to state this with any certainty as a comparison would need to be made of removal rates at similar discharges in summer and winter.

The relationship between temperature, solution rates and discharge can only accurately be gauged by comparison of results of observations and analyses from areas of contrasting climate.

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THE CAVES OF THE BEINN AN DUBHAICH AREA, ISLE OF SKYE

by Peter F. Ryder

The following article is the result of several visits to the Isle of Skye by members of the Moldywarps Speleological Group, made with the intent of making a thorough examination of the outcrop of the Cambrian Durness Limestone in the Beinn an Dubhaich area, where several small caves (Smith, 1968; Webb 1967; Whitehead 1965) were known to exist. Following an initial visit in September 1968, expeditions to the area were made in April and September 1971, and May and August 1973, resulting in several new caves being discovered and surveyed, and all known caves surveyed or resurveyed.

Following their reading of Ryder's article (1971) in 'Descent' magazine, describing part of the 1971 M.S.G. work, members of the University College of London Speleological Society visited the area in July 1972 and turned their attention to the north flank of Beinn an Dubhaich, an area not previously visited by M.S.G. parties, finding a variety of new caves including Uamh an Ard Achadh, the longest cave so far discovered on the Isle of Skye (Fig. 1). Members of the Grampian Speleological Group visited the area three times during 1973, finding more new caves on the north side of Beinn an Dubhaich.

So far each group concerned has published the results of its labours, in varying degrees of detail, individually, with some inevitable confusion over cave names etc. This article attempts to draw together all known work so far and describe, in outline, the known systems.

I am very grateful to Alan Jeffreys of G.S.G. and John Sanders of U.C.L.S.S. for their willing co-operation and supply of material along with permission to use their surveys.

The Area – a brief summary of geology and topography.

For a detailed account of the complex geology of the Beinn an Dubhaich area, the reader is referred to the Geological Survey maps, sheet 71 (Glenelg) and to the excellent map by C.E. Tilley (1951). The basic pattern of the area is that of a curving outcrop of the Durness Limestone of Cambrian age, running from the head of Loch Slapin eastwards and then northwards towards Broadford. Beinn an Dubhaich (reaching a height of just over 775 ft.) rises almost from the shore of Loch Slapin, and is a Tertiary granite intrusion (its actual form still somewhat problematical) splitting the limestone outcrop, which encircles it, forming the lower part of both north and south sides of the hill. The majority of the caves in the area are associated with small streams which gather on the granite area, and sink on flowing onto the limestone.

North east of Beinn an Dubhaich the limestone forms a curving ridge, swinging north to flank the western side of Loch Lonachan, and then rising to Ben Suardal (927 ft.). In this area, however, no impervious strata overlie or lie adjacent to, and at higher levels than, the limestone. Consequently, no streams flow onto the limestone, and there are few caves, although other karstic phenomena (e.g. limestone pavements) are well developed.

The limestone of the Beinn an Dubhaich area has been intruded by a profusion of igneous dykes, which obviously influence the development of many of the caves. The relationships between cave passage development and igneous bodies provide a field open to study which is apparently virtually untouched.

The caves of the area fall naturally into two main groups, the first being those on the south side of the hill, where the limestone forms the lower part of the north side of the Allt nan Leac valley, the south side of the valley being mostly formed by overlying Jurassic strata. Several streams flowing off Beinn an Dubhaich sink at the granite/limestone contact, and resurge at valley floor level, 30-100 ft. below.

The second group of caves are situated in Coille Gaireallach, on the north side of the hill, a geologically complicated area of patches and bands of limestone (supporting oak woodland) intermingled with granite (expressing itself in ill-drained areas of heathland, with few trees). These different vegetation types do serve to make the granite/limestone distinction very obvious, whilst in summer the deep bracken and profuse herbage of the woodland areas serve to make the cave entrances almost impossible to find. Several small streams sink and resurge up to half a dozen times in their courses down this hillside.

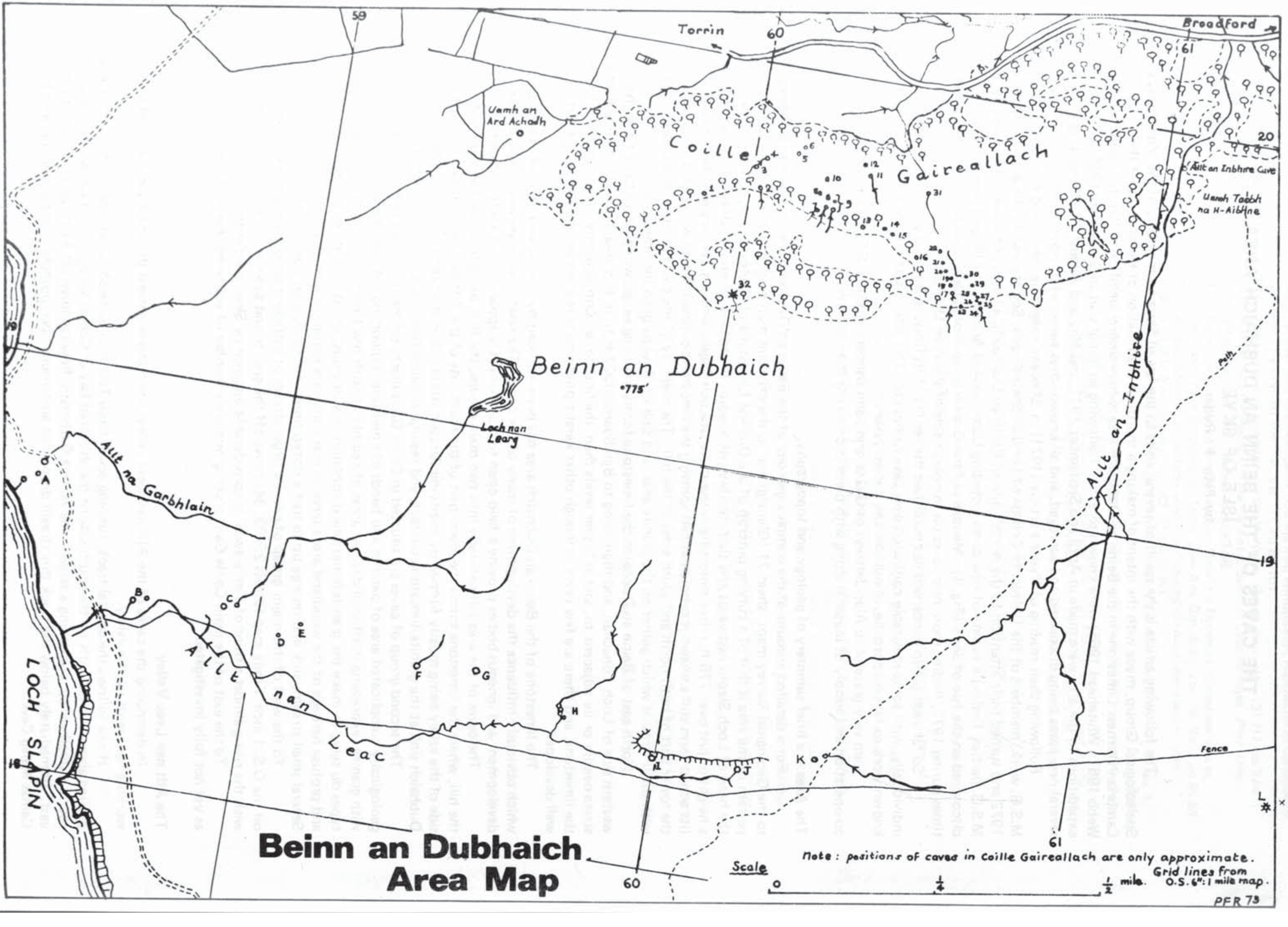
To the west of this major group of caves a larger stream of sufficient proportions to merit depiction on the O.S. 1 inch:1 mile map (sheets 25, 33, 34) flows off the granite and sinks at Uamh an Ard Achadh, with the rising almost a third of a mile away (a considerable distance by Skye standards).

To the east of the main Coille Gaireallach group are a number of scattered smaller caves, in an area as yet not fully investigated.

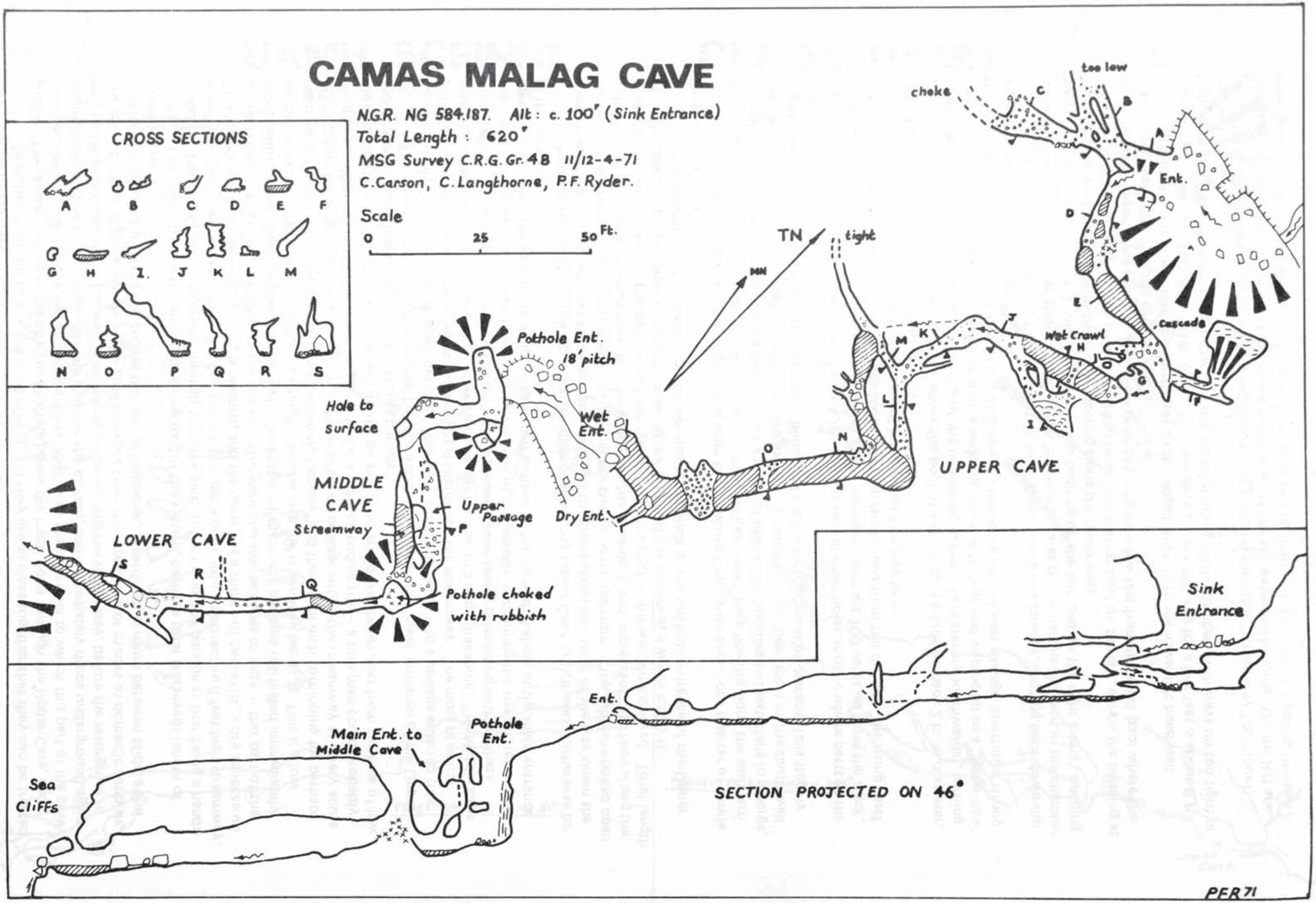
The Allt nan Leac Valley

In describing the caves of the Allt nan Leac valley, the systems nearest the coast are described first, working eastwards up the valley.

If one follows the coastal track, running south from Torrin to Suisnish, limestone is first encountered passing above the sea cliffs on the south side of the sheltered bay of Camas Malag. The track winds inland round a small valley, containing a stream, the Allt na Garbhlain, flowing down off Beinn an Dubhaich, to the east. Immediately below the track this stream drops into an obvious open pothole – the upper entrance to Camas Malag Cave.



Beinn an Dubhaich
Area Map


CAMAS MALAG CAVE
N.G.R. NG 584.187. Alt: c. 100' (Sink Entrance)
Total Length: 620'
MSG Survey C.R.G. Gr. 4B 11/12-4-71
C.Carson, C.Langthorne, P.F. Ryder.
Scale
0 25 50 Ft.
CROSS SECTIONS
A B C D E F
G H I J K L M
N O P Q R S
TN
MN
tight
choke
too low
Ent.
Cascade
Wet Crawl
UPPER CAVE
Pothole Ent. 18' pitch
Wet Ent.
Dry Ent.
Hole to surface
MIDDLE CAVE
Upper Passage
Streamway
LOWER CAVE
Pothole choked with rubbish
Sink Entrance
Ent.
Pothole Ent.
Main Ent. to Middle Cave
Sea Cliffs
SECTION PROJECTED ON 46°
PFR 71

(A) Camas Malag Cave (Fig. 2)

In reality there are two separate caves here, but they are so close together that they can be treated as one. The stream sinking in the obvious sinkhole below the track flows through the Upper Cave, and resurges over an igneous dyke, which has obviously controlled the base level to which this part of the cave could develop. The stream flows over the dyke on the surface, and immediately drops underground again into the Middle Cave, which has several entrances dropping into the streamway, before the resurgence in the sea cliff. One of these entrances has unfortunately been the repository of masses of domestic rubbish, and this obnoxious tip effectively chokes the cave at this point, providing a division between Middle and Lower Caves.

The Upper Cave is the most interesting part of the system, having a total (surveyed) length of c.400 ft. The stream can be followed through from the sink to the rising, the passage at first being a hands-and-kness crawl, developing, after a flat-out section through a pool, into an attractive 8 feet high streamway. This lowers again just before the rising is reached, and the caver has a choice of two exits, a dry squeeze up over a boulder, or a crawl out through the stream. There are two side passages of note in this part of the cave, besides a few small ox-bows (see survey). The longer of these side passages is situated immediately inside the upper (sink) entrance, and runs straight ahead where the streamway bends 1. This is a low bedding, and forks into two, the right fork becoming too low, and the left branch continuing for perhaps 40 ft. before becoming too low and choked. The second side passage enters the streamway at a very acute bend about 90 ft. from the lower entrance, and this is a tight ascending rift – a thin man could probably proceed further than the 15 ft. or so shown on the survey. This could well be an inlet from the area of low and choked bedding planes seen in the first side passage.

The stream, after flowing on the surface for about 30 ft. from the lower entrance of the Upper Cave, suddenly falls 20 ft. into an open pothole. Nearby a small hole drops into a passage entering this pothole about 10 ft. down, and a second hole drops straight into the streamway. The most practical entrance to this section of the system is a few yards nearer the sea, in a large shakehole. The Middle Cave is basically one large passage, divided in places into upper and lower levels, connecting with all these entrances and the base of the open pot. The lower level of the passage, containing the stream, terminates downsteam in the rubbish tip, which chokes an open pothole in the same shakehole as the main entrance to this section.

Assorted rubbish from this tip is scattered throughout the Lower Cave, which would otherwise be a very pleasant walking-sized stream passage, entered from the rising about one third of the way down the sea cliffe – and reached by an easy scramble. The roomy passage ends upstream in the rubbish-choked open pothole – an exit could be made here, but it would be rather hazardous and unpleasant. Halfway along the length of this section a small passage enters from the north, in the roof – this was not explored. Total length of the Middle and Lower Caves is c.220 ft., making the length of the system as a whole c.620 ft.

Recent dumping of domestic rubbish has also taken place in the sinkhole entrance of the Upper Cave – this is most unfortunate.

Following the coastal track southwards from Camas Malag Cave, after about one quarter of a mile one comes to a bridge over a much larger stream, the Allt nan Leac itself, here flowing along the southern edge of the limestone outcrop. Above the track are a series of impressive cascades and waterfalls in a gorge, the north side of which, and parts of the south, are formed by Durness Limestone (most of the south wall of the ravine is of the overlying Jurassic strata). Below the track a further series of cascades falls steeply into the sea.

Scrambling up the gorge from the track, one passes several small holes, mostly where parts of the stream pass underground for a few yeards, and rise again. However, perhaps 100 yards up from the track, there is a tributary on the north, which rises about 50 ft. up the hillside from the stream. The rising itself is a small pool, but just above this there is a small but obvious entrance to –

(B) Uamh Sgeinne (Cave of Knives) (Fig. 3)

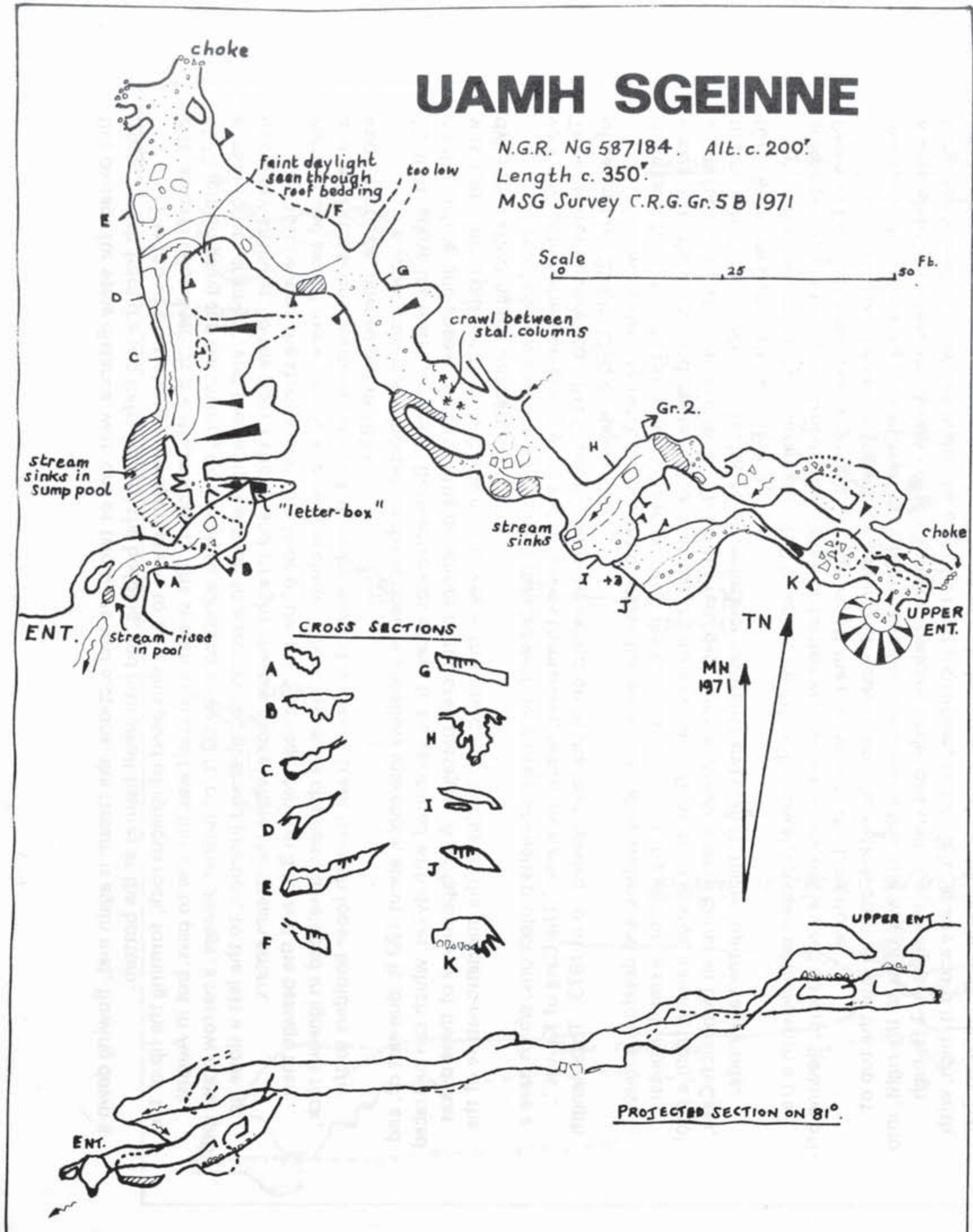
The entrance to this cave, directly above the pool of the rising, is a tube perhaps 2 ft. in diameter, sloping quite steeply upwards (against the dip of the limestone, which is here steeply southwards), turning right and then left into a chamber developed on a bedding, about 4 ft. high and sloping up to a "letter-box" at its top end. In the floor of the chamber is a narrow rift dropping into a lower passage, emitting a strong draught and a sound of a stream.

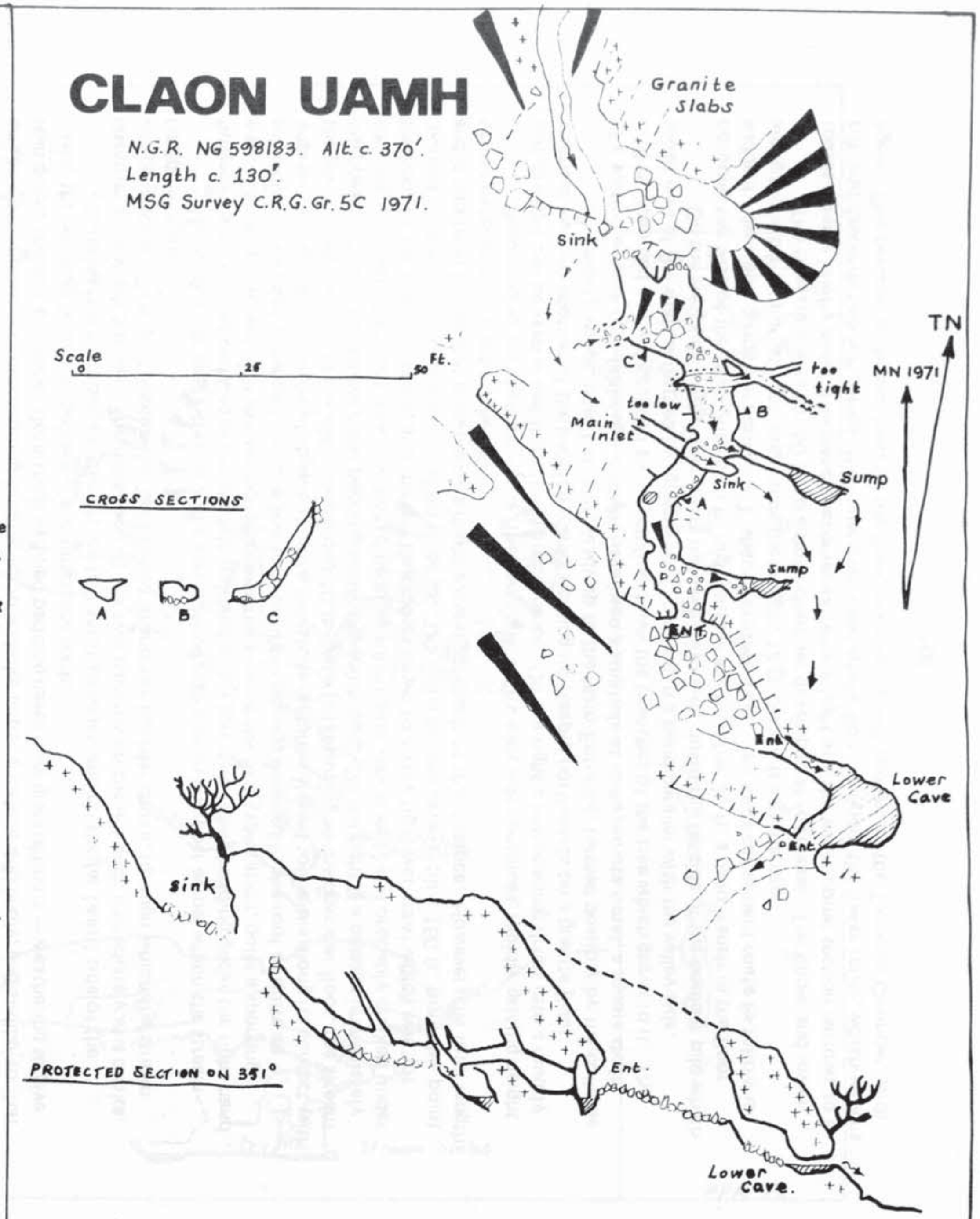
The "letter-box" about 3 ft. wide and 1 ft. high, drops into a low passage, running back down-dip under the floor of the chamber above – with which it communicates by the narrow rift seen in the chamber floor. This passage drops to a 'T'-junction, with a low bedding on the left, and on the right a small opening into a large sloping bedding, with the stream flowing along the lower edge.

Entering the bedding, the stream is seen to drop into a sump pool on the left, which the bedding at the 'T'-junction also curves round to join. This pool can only be a few feet from the small pool where the stream rises, just in front of the cave entrance.

Upstream, the streamway continues over a very jagged floor, with the lower left hand wall apparently of igneous rock. After 30 ft. or so, the streamway turns right, and for a few feet is about 6 ft. high. Straight ahead at this point is a low bedding, opening into a small chamber, with ways on too tight or choked.

The stream itself rises from a tiny hole under one wall, but the main "streamway" continues, doubling back on itself, apparently following a higher level of the same slanting bedding. On the left are some good formations, several columns about 2 feet high joining floor and roof. After crawling through


UAMH SGEINNE
N.G.R. NG 587184. Alt. c. 200'.
Length c. 350'.
MSG Survey C.R.G. Gr. 5 B 1971
Scale 0 25 50 Ft.
choke
faint daylight seen through roof bedding
too low
crawl between stal. columns
Gr. 2.
stream sinks in sump pool
"letter-box"
stream sinks
choke
UPPER ENT.
ENT.
stream rises in pool
TN
MN 1971
CROSS SECTIONS
A B C D E F G H I J K
UPPER ENT
ENT.
PROJECTED SECTION ON 81°.


CLAON UAMH
N.G.R. NG 598183. Alt. c. 370'.
Length c. 130'.
MSG Survey C.R.G. Gr. 5C 1971.
Scale 0 25 50 Ft.
Granite Slabs
Sink
too tight
too low
Main Inlet
Sink
Sump
Sump
ENT.
Ent.
Lower Cave
Ent
TN
MN 1971
CROSS SECTIONS
A B C
sink
Ent.
Lower Cave.
PROJECTED SECTION ON 351°

this passage for some distance, with one or two quite low sections, the stream is again met, flowing down a jagged trench from the top (left) edge of the bedding, and into small fissures at the bottom.

The top of the bedding here again seems to be a thin band of igneous rock, forming the lip of the 3 ft. waterfall down which the stream enters. The stream inlet itself was too low to pass, but in August 1973 some digging and hammering here allowed access to some 60 ft. of further passage, a narrow crawl into a small square chamber, and then a tight section to a second chamber and junction, to the left a slope up into a dry chamber, to the right a choke, and straight ahead a choke where the stream enters.

Just beyond the stream inlet, the floor of the main passage steps up 3 ft. and the passage then narrows and ascend more steeply as a narrow chute. This rises into a chamber, developed in igneous rock, and rather loose and shattered, about 4 ft. high. Beyond is a short crawl through loose boulders to the upper entrance, opened out in 1973.

The upper entrance is located on the surface in a shallow shakehole, about 120 ft. due east of, and 35-40 ft. above the lower entrance. Both entrances appear to be associated with dykes, which can be traced on the surface, and appear to control the directions of the cave passages. A surface survey of these dykes was made, but it did not tie in with the cave survey – this could well be due to the magnetic nature of the dyke rock affecting the compass.

Throughout the cave the limestone is studded with very sharp siliceous projections, which have a very destructive effect on caving gear, and on cavers themselves, hence the name "The Cave of Knives". The cave was surveyed to CRG Grade 5C, with the exception of the inlet opened up in 1973. Total length of passage is c.350 ft. (270 ft. surveyed).

Following the Allt nan Leac upstream, above the gorge, the valley widens, and develops a much more level floor, for the better part of a mile. Near the commencement of this section, a small tributary enters from the north, and can be followed across the marshy valley floor to its source, a rising from a pool at the foot of a wall of igneous rock. This is the resurgence of the stream seen in Beinn an Dubhaich Cave, the main entrance of which lies c.100 ft. away further eastwards and c.35 ft. higher up the valley side.

(C) Beinn an Dubhaich Cave (Fig. 4)

This system has two entrances, c.100 ft. apart, the 'Main Entrance', an open pothole with a tree growing in it, and the more obvious Sink Entrance further east, where a reasonable sized stream, flowing off Beinn an Dubhaich passes underground, on flowing off the granite onto the Limestone.

At this sink, the cave is entered by a squeeze through a boulder ruckle, opening into the top of another inclined bedding, down which the stream cascades. Descending this, the way on is to the right, into a small chamber, where the stream sinks in a choked bedding under one wall. On the right, a 1 ft. high crawl emerges after a few feet under the wall of a roomy chamber, about 15 ft. square and 6 ft. high, with on the right another inclined bedding running up to a choke under a surface shakehole, and similar to that seen below the sink entrance. Both these inclined bedding caves have granite floors – weathering to give rise to the red mud found in the cave – and limestone roofs.

Entering this chamber, on the left are two small passages, and on the far (west) side of the chamber a third low passage. The right hand of the two passages on the left ends immediately in a choke. with a descent which until September 1971 ended in another boulder choke, through which the stream could be heard.

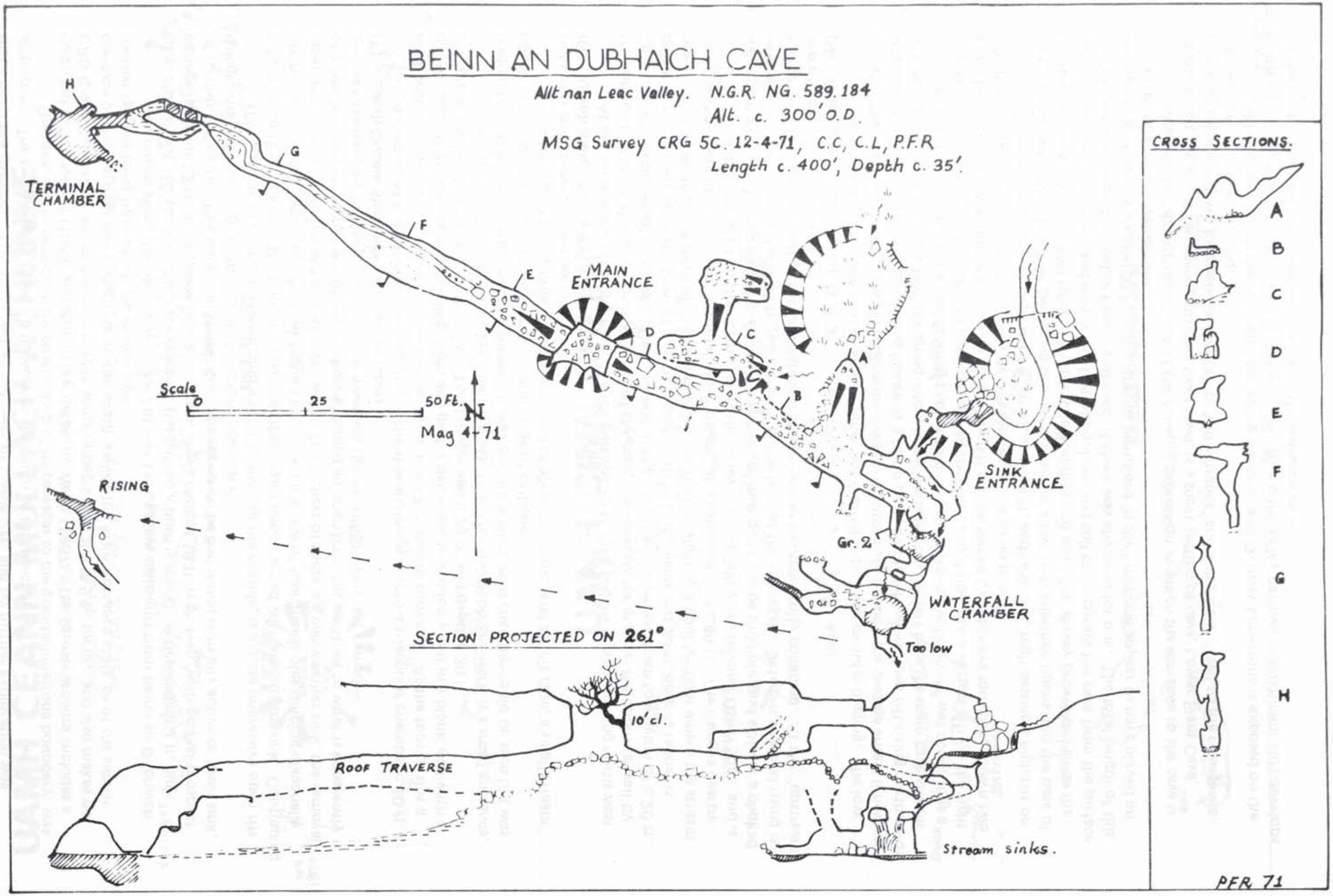
This choke was easily cleared and a way opened into a small chamber across which the stream flowed, from a choked bedding under the left wall and into a low descending bedding under the right hand wall. This was followed – in the wet conditions at the time of the first exploration, quite a sporting procedure – through a low section for a few feet, until the passage emerged in the roof of quite an impressive chamber with walls of steeply dipping limestone metamorphosed to marble along its contact with the granite. At the foot of the easily descended 10 ft. waterfall dropping to the chamber floor, the stream disappears into an impenetrably low bedding under the south wall. On the right is a passage immediately splitting into two. The right fork is a choked bedding running up very steeply and probably choked under the floor of the chamber above, and the left fork closes down to a very tight wet crawl which was not 'pushed' – it may well be choked after 10 ft. or so. The rising for the cave is still c.150 ft. from this point and it had been hoped that passable cave might extend for much of this distance. However, the total length of this extension only approaches 50 ft.

Returning to the chamber above, the low crawl on its west side continues, rapidly gaining height and daylight can be seen ahead from the Main Entrance. On the right a low opening drops into a muddy chamber and yet another of the bedding planes slanting up steeply northwards on a granite floor.

The main passage, now 7 ft. high, leads up to the Main Entrance, formed possibly by the collapse of a section of cave roof (although it might have been a sinkhole at some remote time), a square shaft c.10 ft. deep and easily descended by scrambling down the branches of the tree which grows in it. The south wall of the shaft is formed by igneous rock, running in a band parallel with the valley side.

On the west side of the open shaft the cave continues, down the far side of the boulder pile which occupies the base of the shaft, into an 8 ft. high passage again. After 30 ft. a deep trench in the floor suddenly develops, giving the passage a 'T'-shaped cross-section. The most convenient route to follow is along the wider section at roof level, since the trench, 12 ft. below, is very narrow.

The traverse is easy for 50 ft. to a small chamber developed at roof level. The upper and lower routes diverge briefly here. The trench becomes extremely tight and the wider upper section narrows to a rift, and descends two 6 ft. drops, the lower over a stalagmite flow, to rejoin the lower route, which widens again. This passage, with deep mud on the floor, then swings left and enters the Terminal Chamber, with


BEINN AN DUBHAICH CAVE
Allt nan Leac Valley. N.G.R. NG. 589.184
Alt. c. 300' O.D.
MSG Survey CRG 5C. 12-4-71, C.C, C.L, P.F.R
Length c. 400', Depth c. 35'.
TERMINAL CHAMBER
MAIN ENTRANCE
SINK ENTRANCE
WATERFALL CHAMBER
RISING
Too low
Gr. 2
Scale 0 25 50 Ft.
Mag 4-71
N
SECTION PROJECTED ON 261°
ROOF TRAVERSE
10' cl.
Stream sinks.
CROSS SECTIONS.
A
B
C
D
E
F
G
H
PFR 71

2 ft. of static water, the roof height dropping from 20 ft. where the two routes converge, to 8 ft. On the left of the chamber a small triangle of airspace continues above water level, the water deepening to 4 ft. on that side of the chamber. This airspace does not seem of usable size, and no further exploration was attempted. The rising pool is about 75 ft. away to the south of this point.

The cave, and in particular the relationship of its passages to the granite/limestone boundary, was described by Whitehead (1965) and also, in less detail, by Webb (1967). The former account includes a CRG Grade 2-3 survey, which does not tally in some respects with the M.S.G. survey, and also makes no mention of the apparent dyke which forms the south wall of the Main Entrance shaft, or of the similar parallel igneous band from which the stream rises.

Continuing along the north side of the Allt nan Leac valley, eastwards from Beinn an Dubhaich cave, after about 150 yards a small cave entrance (D) behind a bush is found. A descending 3 ft. high passage leads for 25 ft. to a squeeze over a mudbank into a choked 10 ft. high aven, with no real prospect of further extension. This oddment of cave does not appear to be connected with any active or fossil sink, being some distance south of the granite/limestone boundary.

100 yards or so further eastward, and a little further up the hillside, is a quite impressive open rift c.15 ft. deep (E), choked at the bottom (a possible dig), again unconnected with any stream sink. Continuing up the valley, at the same level, the next feature of interest is a row of four shakeholes running diagonally down the valley side from north east to south west. The highest of these is a wet weather sink, the removal of a few boulders in the bottom of the sinkhole exposing an open hole, the entrance to what is apparently the cave explored by Northern Pennine Club members (Smith 1968). This was named –

(F) Uamh Craobh Sheileach (Willowtree Cave)

A descent of 6 ft. through the boulders in the shakehole opens into a triangular chamber c.10 ft. long, with at its end a tight squeeze onto another drop of c.12 ft. (easily climbed). At the foot of this a narrow passage of walking height swings right and gently descends, to suddenly end in a blank wall with a tiny gravel choked bedding cave at its floor. Total length was c.70 ft. and depth c.30 ft.

In the lowest of the line of shakes running down from Uamh Craobh Sheileach is a small entrance, leading to a 20 ft. drop amidst boulder ruckle. A way on into a more solid chamber could be seen but was not forced, since the whole ruckle seemed on the verge of collapse.

A further quarter of a mile up the valley, and at about the same level as this cave, a small stream sinks into an impressive open pot –

(G) Uamh Sluic (Pit Cave)

At the surface this takes the form of a rift perhaps 70 ft. long and 15 ft. side running north west to south east. The overhanging north east wall of the hole is formed by the granite, the opposite wall by limestone metamorphosed to marble. The west end of the rift is easily climbed down to a depth of c.20 ft. below which the pot takes the form of a vertical shaft c.10 ft. in diameter and 20 ft. deep (a ladder is required). The walls are of vertically bedded marble, and drop straight to a boulder floor where the stream sinks, without any indication of horizontal development, at a total depth of c.40 ft. The rising is nearby.

The last of the sinks on the north side of the vallev is about 200 yards beyond Uamh Sluic, and is shown on the 1:25000 map (NG51). A small stream drops into quite a large sinkhole, and sinks in a choked inclined rift. The rising is about 60 ft. lower down, at the foot of the valleyside. Between sink and rising is a large depression, where part of the underground stream course has apparently collapsed. At the "upstream" end of this is the entrance to –

(H) Claon Uamh (Slant Cave) (Fig. 3)

The entrance to this was choked when found, but cleared with a few minutes digging. The low entrance itself appears to be formed in an igneous dyke, and immediately inside the passage enters limestone and enlarges. To the right is a descending fissure to a sump pool, to the left an inclined rift rising northwards to a horizontal crawl for a few feet, dropping into a larger passage. On the left here the main cave stream enters via a 3 ft. waterfall from a low bedding plane and promptly sinks in the floor. In wet conditions a second, smaller, stream flows from the main passage beyond this and drops into a narrow rift on the right a few feet beyond the choked main stream sink. This rift can be forced by sideways squeezing, down two 3 ft. drops, to a wider section where the water disappears into a sump pool.

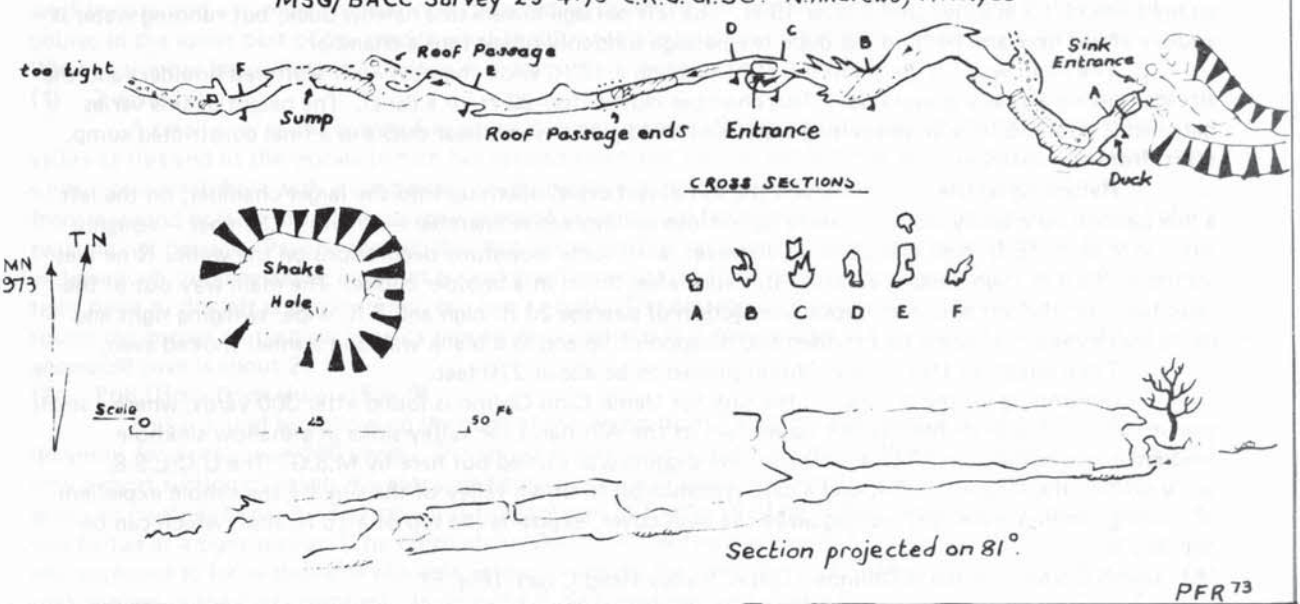
The main passage continues for 15 ft. or so, about 4 ft. wide and 3 ft. high passing a high rift on right, which forks, both branches becoming too narrow within a few feet, and then opens into the base of the final inclined rift choked 20 ft. up with unstable boulders and soil. The survey proves this to be the same rift as seen in the sink, and only a few feet of boulders and soil can separate the cave from the surface – a 'top entrance' could probably be easily opened, if there was any need for one. The total length of this interesting little cave is about 130 ft. – the igneous intrusions in the limestone appear to have played an important role in its development.

Between the "downstream" end of the collapse depression in which the entrance to the cave is situated, and the actual resurgence at valley floor level, is a short section of cave, Lower Slant Cave, involving a squeeze down between boulders at its 'top entrance' and a short wet crawl to the resurgence. This section is some 25 ft. long.

Above Claon Uamh the Allt nan Leac valley narrows, and Durness Limestone is exposed on the south side of the main stream as well as on the north. Where the valley narrows, a prominent cliff develops on the north, and on a ledge half way up this is the entrance to –

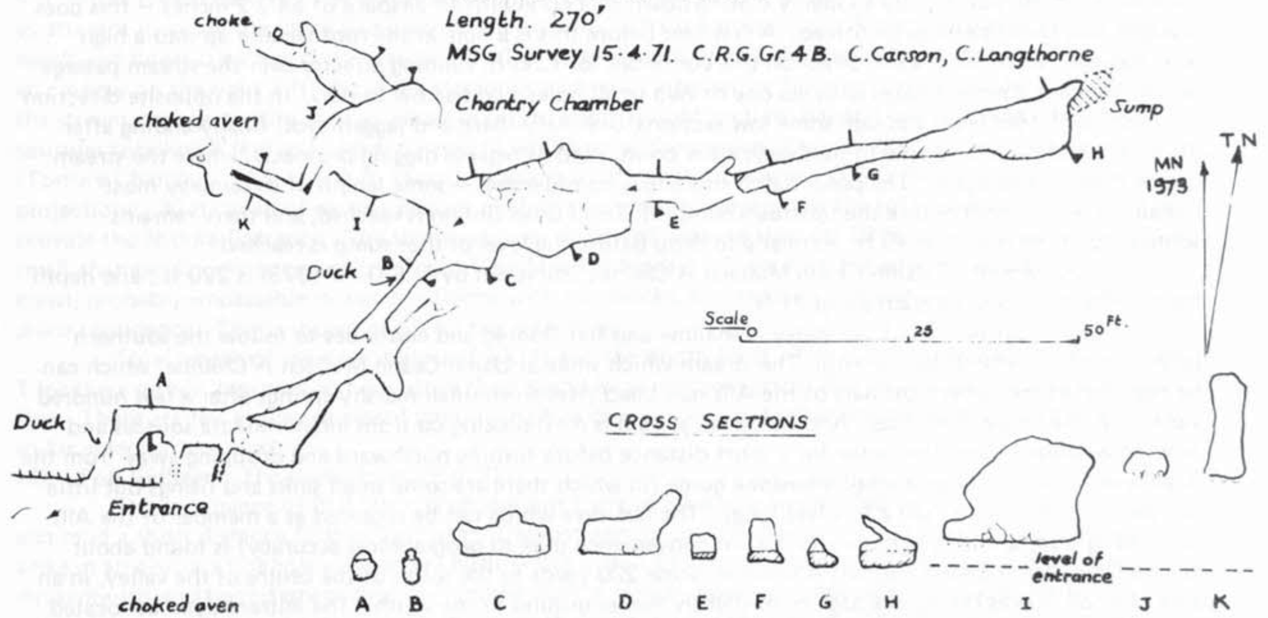
UAMH CEANN MULLACH A'CHLINNE

N.G.R. NG 604.183. Alt: c. 515'
Length: 220' Depth: 21
MSG/BACC Survey 23.4.73 C.R.G. Gr.5C. N.Andrews, P.F.Ryder



UAMH CINN GHLINN

N.G.R. NG 601.182. Alt: c. 450'
Length. 270'
MSG Survey 15.4.71. C.R.G. Gr.4B. C.Carson, C.Langthorne



(J) Uamh Cinn Ghlinn (Valley Head Cave) (Fig. 5)

The entrance to this was dug out by an M.S.G. party at Easter 1971. A small hole at the foot of the cliff beside the actual rising, drops into a small "chamber" mostly occupied by 3 ft. of water and a large boulder. A duck alongside the boulder leads into a low arched passage running parallel with the cliff 'up-valley', with about a foot of airspace above deep clear greenish water. This forks – the left branch has very little airspace, and the right branch is a crawl over some boulders, with chinks of daylight entering from the cliff face. The two branches rejoin, and a junction is reached. To the right the passage end immediately and straight ahead is a boulder choke after 15 ft. The left passage lowers to a narrow duck, but running water is audible ahead here and beyond the duck the passage suddenly opens into a chamber.

The main way on here is to the right through a 15 ft. wide chamber with scattered boulders and the stream flowing across a gravel floor. This chamber closes after 30 ft. to a canal. The height of this varies between 2 ft. and 6 ft. with deepening water and ending after some near ducks in a final constricted sump, 60 ft. from the chamber.

Returning to the point at which the initial wet crawl opens up into the larger chamber, on the left a low passage up a sandy slope suddenly opens into an impressive chamber – Chantry Chamber – roughly circular in plan, 15 ft. high and 20 ft. in diameter, with some flowstone decorations on the walls. Nine feet up the wall a 4 ft. high passage enters – this ends after 20 ft. in a boulder choke. The main way out of the chamber is on the left and is an impressive section of passage 20 ft. high and 6 ft. wide, swinging right and rising quite steeply to come to a sudden and disappointing end in a blank wall and a small choked aven.

Total length of Uamh Cinn Ghlinn proved to be about 270 feet.

Continuing up the dry valley, the sink for Uamh Cinn Ghlinn is found after 300 yards, where a small stream meandering from the shallow upper part of the Allt nan Leac valley sinks in a shallow sinkhole amongst some bushes. In 1971 a little abortive digging was carried out here by M.S.G. The U.C.L.S.S. party visiting the area in 1972 found a cave entrance 50 ft. down valley of the sink by the simple expedient of hearing running water and pulling away the peat cover, exposing the top of a 15 ft. shaft which can be climbed to –

(K) Uamh Ceann Mullach A'Chlinne (Upper Valley Head Cave) (Fig. 5)

The entrance shaft, apparently associated, as so often, with an igneous dyke, drops into a small stream passage here 4 ft. high and 2 ft. wide. Upstream the passage widens and lowers, to an easy crawl, ending in a narrow and unpleasant duck and 6 ft. climb up to a second entrance, dug out by U.C.L.S.S., in a not-at-all-obvious place in the side of the sink depression.

Downstream from the main entrance shaft, the streamway continues for c.70 ft., generally being of narrow 'stooping' size, before suddenly closing down to a pool with an airspace of only 2 inches – this does draught, and could perhaps be forced. A few feet before this is a hole in the roof leading up into a high level passage. In an 'upstream' direction this continues for c.30 ft. running directly over the stream passage below, which it communicates with via one or two small holes, too narrow to pass. In the opposite direction the high level route leads through some low sections, over very sharp and jagged rock, finally ending after 40 ft. in a section too narrow to pass and rather constricted as regards digging prospects, where the stream can be heard ahead again. The potential of this site is considerable – some length of streamway must remain to be explored before the upstream sump of Uamh Cinn Ghlinn is reached, and there remains something in the region of 40 ft. vertically to drop before the level of that sump is reached.

Total length of Uamh Ceann Mullach A'Chlinne (surveyed by M.S.G. in 1973) is 220 ft., and depth from entrance to downstream sump 21 ft.

The upper Allt nan Leac valley is shallow and flat floored and continues to follow the southern boundary of the limestone outcrop. The stream which sinks at Uamh Ceann Mullach A'Chlinne, which can be regarded as the uppermost part of the Allt nan Leac, rises from small marshy springs after a few hundred yards, but the valley continues. Another small stream is met, picking up from indeterminate sources and flowing westward along the valley for a short distance before turning northward and dropping away from the 'high level' valley through a small limestone gorge (in which there are some small sinks and risings but little prospect of caves more than a few feet long). The last cave which can be regarded as a member of the Allt nan Leac group (and this as more a matter of convenience than of geographical accuracy) is found about ¾ mile from Uamh Ceann Mullach A'Chlinne, some 200 yards to the south of the centre of the valley, in an area of small shakes taking drainage from slightly higher ground to the south. The entrance can be located by a solitary tree which grows beside it. This cave is –

(L) Poll an Neach Di-Chuimhnichte (Pit of the Forgotten One)

In this case the length of name threatens to exceed that of cave. In the shakehole in which the solitary tree grows are two small entrances, the larger with some loose boulders which unite in a vertical fluted shaft dropping about 20 ft. into a small chamber, with no horizontal development. A rope is useful for the descent. The naming of this small pot demands some explanation – the entrance was located by Alan Riles of M.S.G. on a surface walk and he also noticed what he described as "gnashing" noises issuing from the hole. This prompted some degree of trepidation when the hole was returned to – the easiest approach is by walking from Kilchrist over the limestone ridge and Loch Lonachan – three days later. Noises were again heard, and Alan, descending, found an almost fully grown sheep at the bottom (occupying most of the small chamber). This, despite its enforced sojourn for an unknown period in the hole, seemed unhurt and was rescued, with great effort, after tying it up in a boilersuit and dragging it up the shaft, which in places seemed rather narrower than the sheep. Hence the name.

The Coille Gaireallach Area

The order in which the known caves in the Coille Gaireallach woods are described is as follows – the majority of the caves are situated towards the south side of the main woodland area, where this joins an area of treeless hillside developed on the granite. These caves are described working from west to east, and where a group of caves follow a stream course downhill (northward) through the woods, in an order proceeding downhill from the nearest cave at the granite limestone boundary. Both M.S.G. and G.S.G. have carried out rough surveys of the whole area. The G.S.G. account allots a letter to each stream course, from west to east, and a number to each cave, proceeding downhill, on that course. But sections of the stream course in the lower part of the woods are difficult to relate to sinks on the granite/limestone boundary. Where a site has been allotted a code in this account, however, this is included.

(1) Twisted Cave

A small sink at the granite/limestone contact, a short distance to the east of the most prominent valley at this end of the woods (which has various sinks and risings, but nothing penetrable). The stream sinks into a small hole with an impassably tight passage leading off, through which can be seen daylight from a second hole. From this one may proceed downstream by crawling round a large boulder into a tight twisting rift passage. Passing the boulder, one drops six feet to floor level and proceeds along a rift only wide enough to be passable, and that by awkward crawling, at floor level. After about 15 ft. of low crawl a tight bend to the left is encountered, too low to pass. The passage does appear to sump a few feet round the corner, but a clear view cannot be obtained and this may not be the case. The total length of accessible cave is about 25 ft.

(2) Poll Iffrin (Hell Hole) (Fig. 6)

This is found by following the edge of the wood from Twisted Cave, eastwards and somewhat downhill for a little over 200 yards. The actual stream sink is impenetrable (although a slit beside it drops into a short section of cave), the entrance being a few yards away westwards, in a 12 ft. deep pit at the granite/limestone contact. The cave was first entered at Easter 1973 by G.S.G. members, whose exploration was halted at a tight section (The Chip) about 200 ft. in. A few days later, a M.S.G. part "found" the cave and explored as far as the same obstacle, initially naming the cave Uamh an T-Shelf (Shelf Cave, from the rock shelves in the first chamber). In July the G.S.G. returned and after a little work, managed to pass the constriction, finding the middle entrance, and then continuing downstream to find the stream passage accessible for the whole of its subterranean course, to the rising.

The cave entrance takes the form of an open pit, easily climbed down, from which a muddy slope drops into a low chamber. To the right the stream enters from an impassably low bedding and drops about 4 ft. into a trench between shelving areas of chamber floor (these only persist for a few feet, so it is pointless to attempt to evade the inevitable crawl in the stream). The streamway, a little too narrow to permit easy hands-and-knees crawling, continues for 40 ft. or so to a sharp bend right and a low squeeze in the stream, an ox-bow on the right 3 ft. above the stream providing an alternative, but even tighter, route. Beyond this the stream passage continues as an easier crawl, to another tight section, beyond which a series of small cascades totalling 5 feet in all leads to a slight widening of the passage, decorated by some formations (Torture Chamber). Another 3 ft. cascade leads to a narrow section where G.S.G. hammered away chert projections. 30 ft. or so of narrow passage lead to a hole out to daylight in the roof, which was widened to provide the Middle Entrance. The streamway continues, of walking size, for 20 ft. to a 3 ft. waterfall into a small chamber largely occupied by a pool (The Meeting House). From here the streamway lowers to a wet crawl, probably impassable in wet conditions with two ducks, and remains low and wet to the bedding plane resurgence. This is shown as (3) on the area map.

Total length of the cave is around 400 ft and the depth 45 ft. The G.S.G. only claim C.R.G. Grade 1 for their survey, reproduced here, since they found large compass errors due to an area of strong magnetic flux. There are few extensive closed circuits in Skye cave surveys and other anomalies may exist which has so far escaped detection.

(4) Poll Eidheann (Ivybush Hole) (Fig. 7)

The resurgence of Poll Iffrin is on the east bank of a surface stream, fed by small risings out of grass and mud a short distance further upstream. Downstream of this resurgence, after a few yards the water sinks in an obvious sinkhole with an ivy bush – this is Poll Eidheann, explored in 1973 by G.S.G. members. An awkward and tight descent through boulder ruckle, which, however, appears quite stable, leads into a small chamber with two routes on, the lower, to the right, taking the stream. The left passage forms a dry ox-bow, rejoining the stream after 20 ft, and a wet crawl leads to a second small chamber where the stream sinks in a low passage to the right. Straight ahead is a dry passage ending too tight after 7 ft., although running water is audible beyond the constriction, which might be passable with digging. Total length of the cave is around 75 ft.

Continuing downhill from, and to the east of, Poll Eidheann, an area of granite surrounded by limestone, obvious as a large boggy clearing in the woods, is found. At the lower edge of this clearing and near its north west corner, is a small cave (5), in an obvious shakehole. 15 ft. of small and narrow passage connect its two entrances. 30 yards or so further to the north east is the entrance to –

(6) Uamh Sgoilte (Slit Cave) (Fig. 7)

The entrance to this is an obvious slit 12 ft. long and 2 ft. wide (thus giving the name, which was arrived at independently by both G.S.G. and M.S.G.) At the west end of the rift a small stream enters from a small passage just below the surface – this can be followed for 15 ft. to a choke where faint daylight is visible. The stream drops about 12 ft. into the rift (easily scrambled down) and flows into a downstream

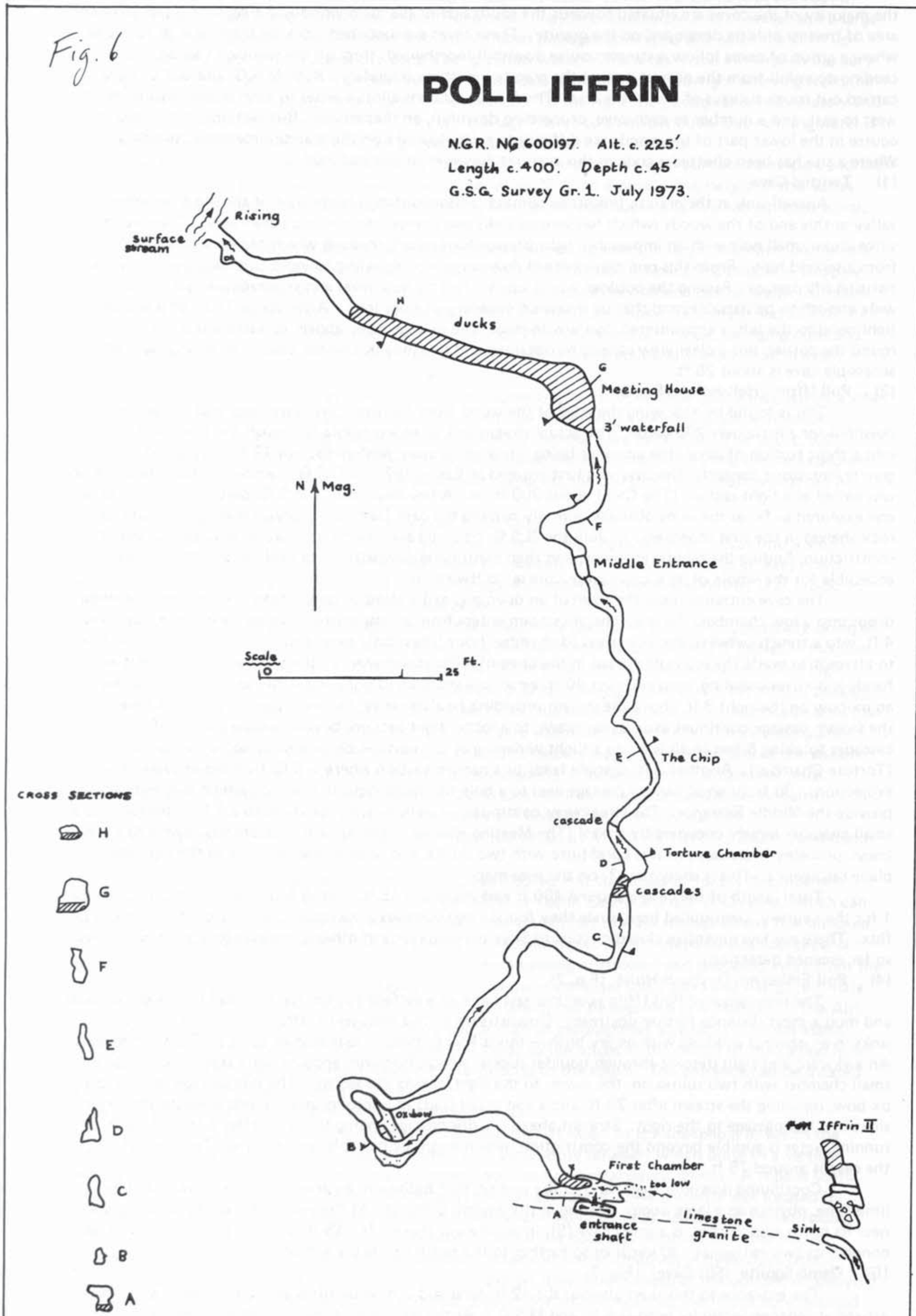


Fig. 6
POLL IFFRIN
N.G.R. NG 600197. Alt. c. 225'
Length c. 400'. Depth c. 45'
G.S.G. Survey Gr. 1. July 1973.
Rising
surface stream
H
ducks
G
Meeting House
3' waterfall
N Mag.
F
Middle Entrance
Scale
0
25
Ft.
The Chip
E
cascade
Torture Chamber
D
cascades
C
oxbow
B
First Chamber
too low
A
entrance shaft
limestone
granite
Sink
Poll Iffrin II
CROSS SECTIONS
H
G
F
E
D
C
B
A

POLL EIDHEANN

N.G.R. NG 600198
Alt: c. 175'
Length. 75'
G.S.G. Survey Gr. 1
May 1973.

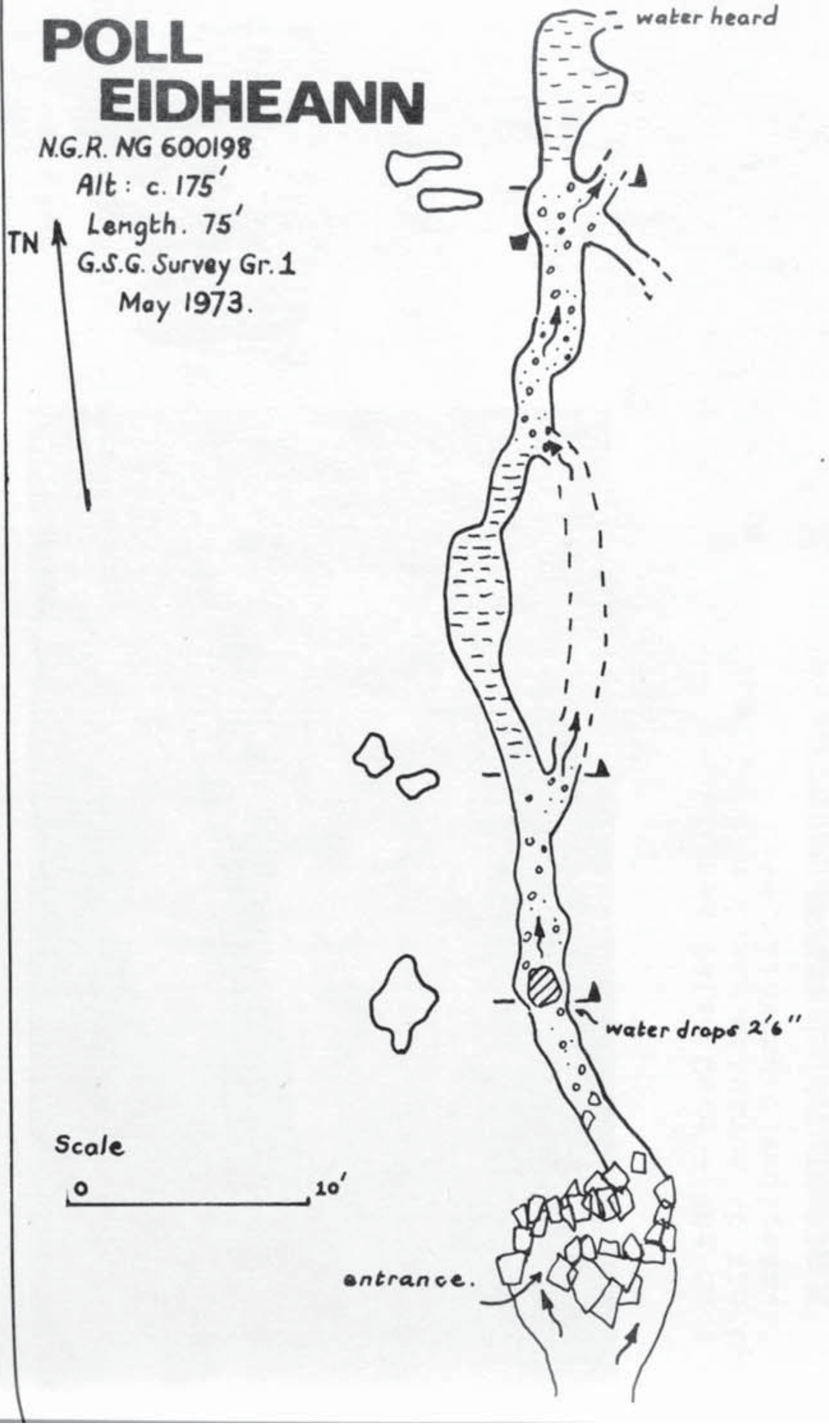
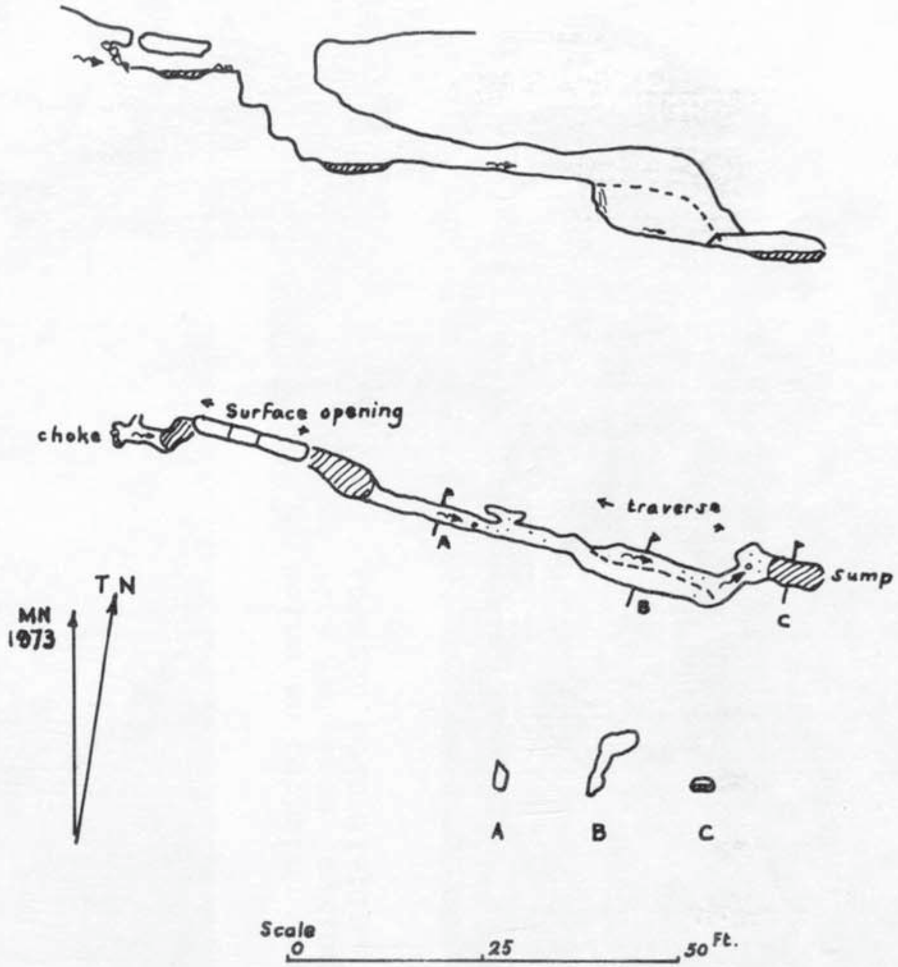


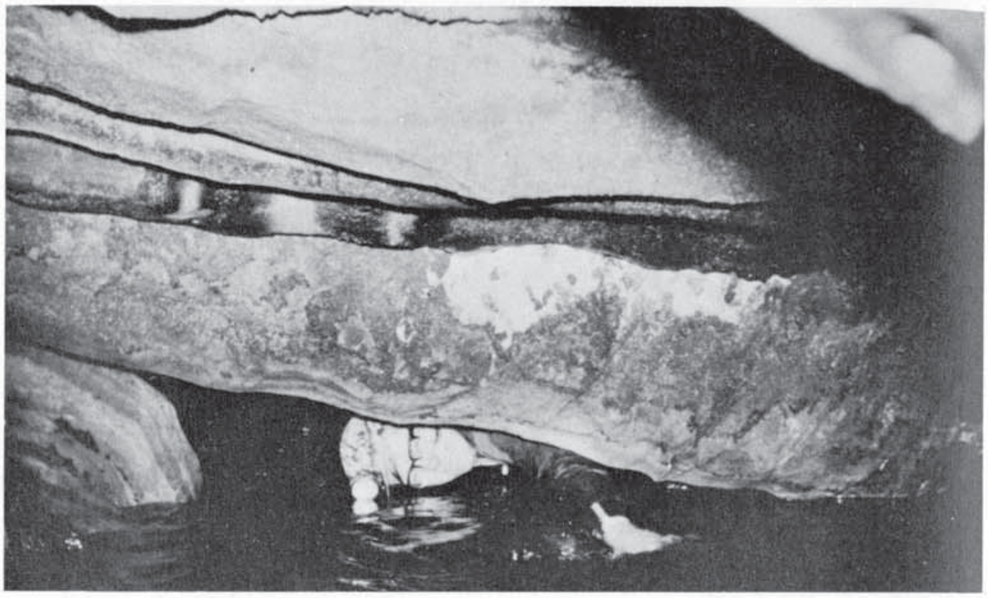
Fig. 7.

UAMH SGOILTE

N.G.R. NG 601198 Alt. c. 125'.
Length 85'. Depth 25'.
MSG Survey C.R.G. Gr. 2. May 1973



CAVES OF SKYE



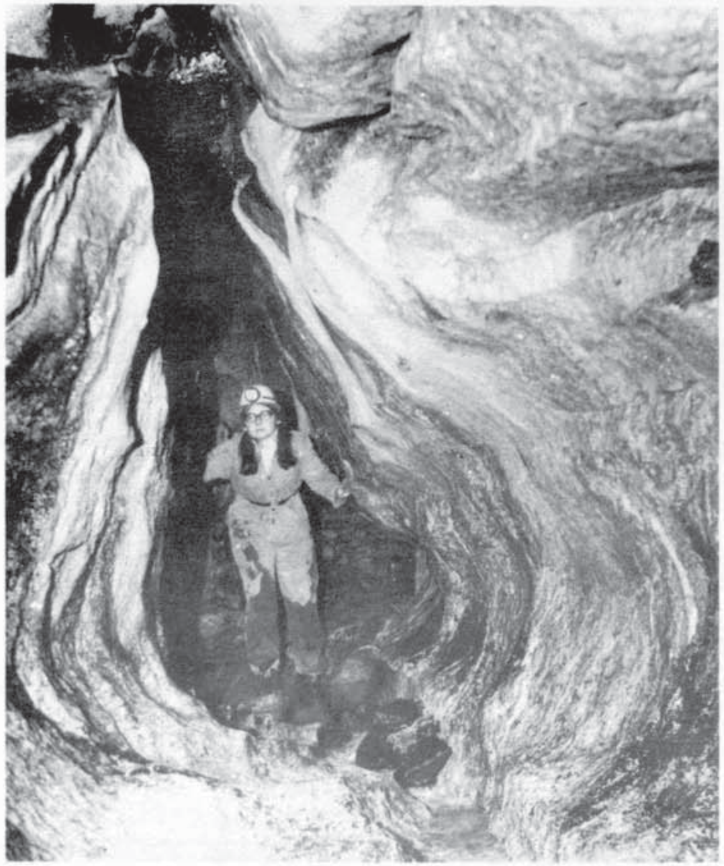
1. Camas Malag Cave - the duck near the lower entrance to the Upper Cave, looking downstream.

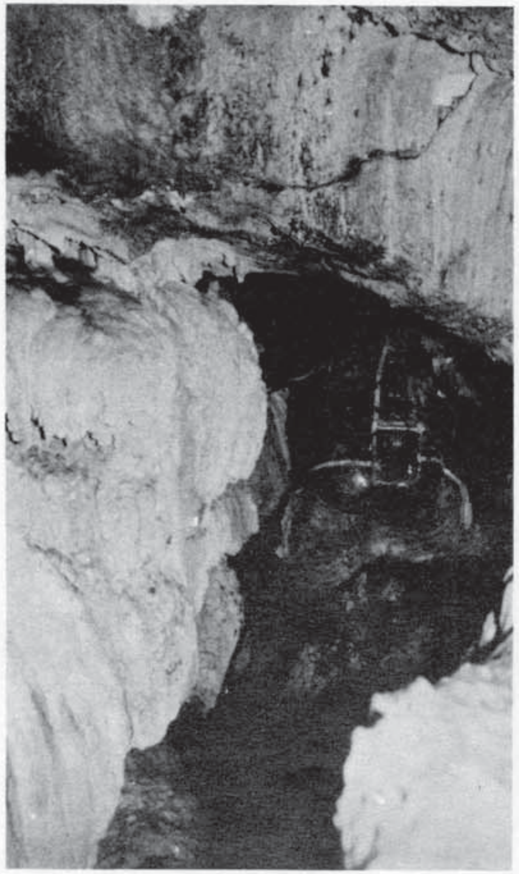
2. Camas Malag Cave

- the Upper Entrance sinkhole.

3. Beinn an Dubhaich Cave - the Sink Entrance looking west towards Loch Slapin.

5. Uamh an Ard Achadh -
looking upstream.





4. Beinn an Dubhaich Cave -
roof traverse.

6. Uamh an Ard Achadh -
looking downstream.

CAVES OF SKYE

7. Claon Uamh - the entrance.

8. Claon Uamh - the slanting rift

9. Claon Uamh - the main passage looking upstream.

passage passable by hands-and-knees crawling. After 25 ft. the floor drops 6 ft. into a narrow trench, and an easy traverse is necessitated, dropping to rejoin the stream at a double bend to the left, beyond which the passage shuts down to a low crawl and sumps within a few feet.

Total length of the cave, including the short upstream passage is about 85 ft. The cave stream probably feeds an impenetrable rising further down the hillside.

Returning to the major granite/limestone boundary on which Poll Iffrin is situated, and continuing eastward, several small impenetrable sinks are passed, before a group of open sinks is reached, around Uamh an T-Sill. The first sink reached (7) has a reasonable sized entrance which immediately shuts down to a tight crawl, becoming too constricted after c.15 ft. However, by walking due north for about 80 ft. down the hillside into the woods, an obvious depression is found where the stream rises and sinks again. This is –

(8) Uamh Coile (Cave of the Woods) (Fig. 8)

The upstream passage from the entrance depression can be entered and followed, at first as a hands- and -knees crawl, but lowering, for c.30 ft. to where it turns sharp left and becomes too low – although a little digging in the floor would allow further progress. This point is little more than 30 ft. from the constriction in the sink (7), but this is of more formidable nature, and a through-trip would necessitate considerable work.

The downstream passage from the entrance depression is Uamh Coile proper. This was first explored, and surveyed, by U.C.L.S.S. in 1972. After an initial scramble through boulders a steeply descending 3 ft. high passage leads to a tight S-bend, cleared of stones and debris on the first exploration and into a more roomy chamber, where the stream sinks in the floor. Beyond is a low crawl, also needing digging when first explored, running sharp left and rejoining the stream. The stream passage then becomes a high and narrow rift, with some sharp bends, and in places constrictions at stream level forcing a traverse in the roof. This, after a short crawl, suddenly drops, via a 10 ft. waterfall, into a roomy chamber 10 ft. wide, 20 ft. long and 15 ft. high. This suddenly closed to a low crawl – some digging here by G.S.G. enabled a little further progress to a right hand bend, and then 10 ft. of crawl to a left hand bend, the passage beyond being too low, and showing signs of recent sumping. Total length of the cave is about 250 ft.

Returning to the initial sink for Uamh Coile, (7), a few feet further east is an obvious stream sink, the Main Entrance of –

(9) Uamh an T-Sill (Cave of the Seed) (Fig. 8)

There is an apparent confusion of names in the case of this cave – apparently the Gaelic can equally well be translated as Cave of the Seed, or Cave of the Fairies – local enquiry suggested that the former was correct, the name being derived from a time when local farmers used to store grain in the cave to conceal it when the landowner came to take his due. G.S.G. members found human remains (Skull Chamber) and consequently renamed the hole 'Skeleton Cave'.

Two sinks near the granite/limestone contact feed into the cave, the Main Entrance, and, a few yards further east, and nearer the actual geological boundary, the South Entrance.

The Main Entrance is a large depression, with on its north side the opening dropping into the cave proper and on the east a smaller opening. This drops into a small passage, to the left communicating with the main cave a few feet inside the Main Entrance, and to the right, beyond a small sink in the floor, an upstream passage. This is at first an easy crawl, to a right hand bend, and then to a very acute and tight left hand bend, before emerging in the smaller depression of the South Entrance.

From the Main Entrance a short section of roomy boulder strewn passage drops steeply to the base of an impressive open pot, 15 ft. square and 20 ft. deep. Two passages lead on from this. On the north side a narrow tube drops very steeply to open into a small chamber with a striking sump pool occupying all the floor – this appears to be of considerable depth, but was plumbed to a mere 10 ft. By stepping across the pool, access can be gained to a small winding passage which rises to a constriction which allows a view into the small chamber where the human remains were found – Skull Chamber.

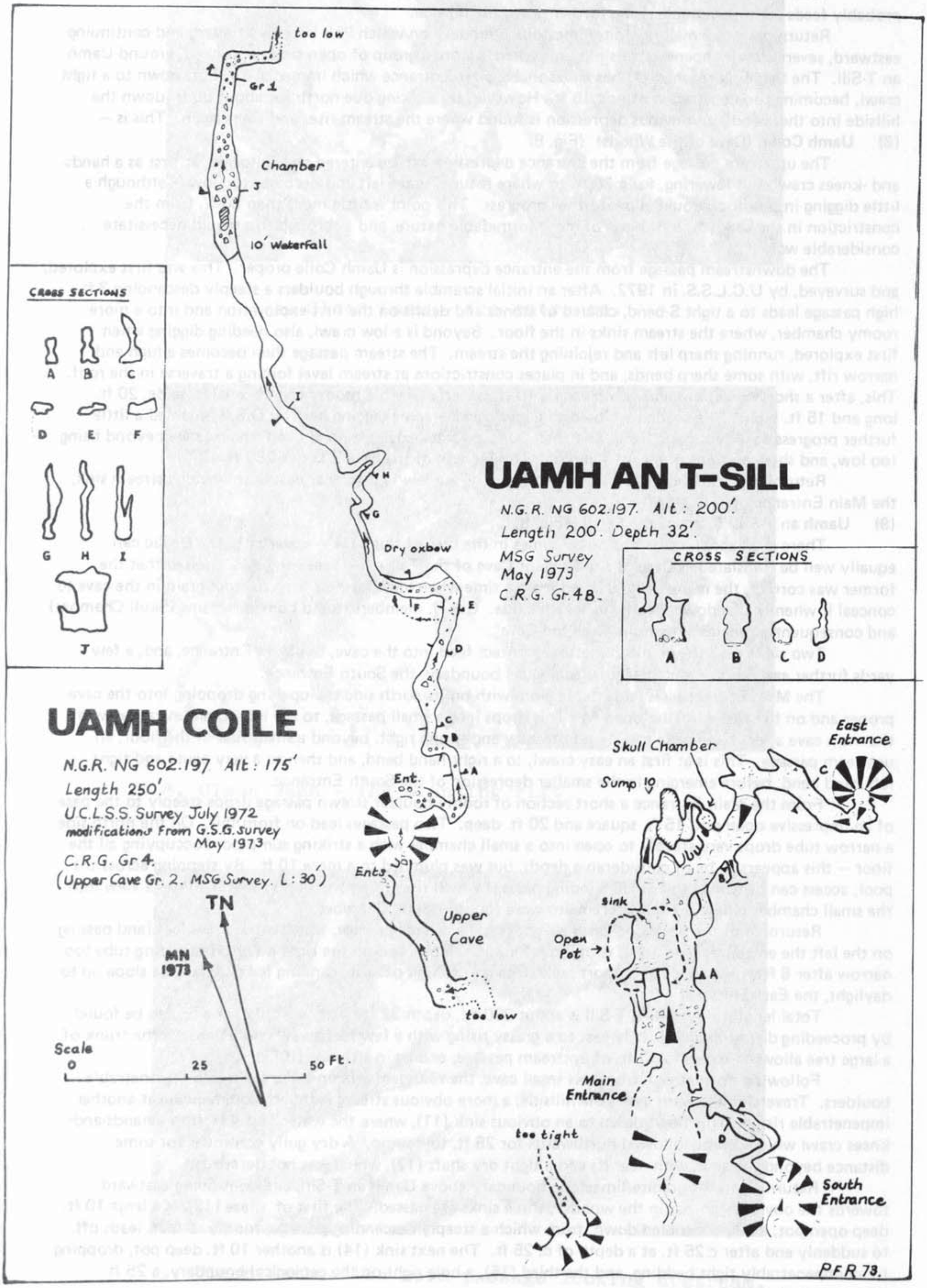
Returning to the open pot, on the right (east) is a large passage, which after a few feet (and passing on the left the entrance, via a 10 ft. drop, into Skull Chamber, and on the right a tight descending tube too narrow after 6 ft. rises steeply to a short crawl into a 4 ft. high passage, running for c.30 ft. to a slope up to daylight, the East Entrance.

Total length of Uamh an T-Sill is about 200 ft., depth 32 ft. The most likely rising can be found by proceeding downhill and slightly east to a grassy rising with a few feet away a hole beneath the trunk of a large tree allowing access to 10 ft. of upstream passage, ending in a sump. (10).

Following downstream from this small cave, the resurgent stream sinks again into impenetrable boulders. Traversing eastward along the hillside, a more obvious stream is found, commencing at another impenetrable rising. This flows down to an obvious sink (11), where the water falls 4 ft. into a hands-and-knees crawl which can be followed northwards for 28 ft. to a sump. A dry gully continues for some distance beyond the sink, with near its end a tight dry shaft (12), which was not descended.

Returning to the granite/limestone boundary above Uamh an T-Sill, and continuing eastward towards the obvious "corner in the woods", three sinks are passed. The first of these (13), is a large 10 ft. deep open pot, easily scrambled down, from which a steeply descending passage, roomy at first, leads off, to suddenly end after c.25 ft. at a depth of c. 25 ft. The next sink (14) is another 10 ft. deep pot, dropping to an impenetrably tight bedding, and the third (15), a hole right on the geological boundary, a 25 ft. deep hole with no passages.

From the "corner of the woods" one can traverse along the hillside into the woodland, for a short distance, until a gully is found. In this a small stream sinks at –


UAMH AN T-SILL
N.G.R. NG 602.197. Alt: 200'
Length 200'. Depth 32'.
MSG Survey
May 1973
C.R.G. Gr.4B.
CROSS SECTIONS
A B C D
too low
Gr.1
Chamber
10' Waterfall
Dry oxbow
CROSS SECTIONS
A B C D E F G H I J
UAMH COILE
N.G.R. NG 602.197 Alt: 175'
Length 250'.
U.C.L.S.S. Survey July 1972
modifications from G.S.G. survey
May 1973
C.R.G. Gr.4.
(Upper Cave Gr. 2. MSG Survey. L: 30')
TN
MN
1973
Scale
0 25 50 Ft.
East Entrance
Skull Chamber
Sump
Ent.
Ents.
Upper Cave
Sink
Open Pot
too low
Main Entrance
too tight
South Entrance
PFR 73.

(16) Uamh Slaodach (Awkward Cave)

This merely consists of c.20 ft. of low, awkward and tight passage, ending too low.

Continuing eastward through the wood, two much larger gullies, or small valleys are found, descending the hillside from the edge of the granite, at the top of the woods, and uniting to form one stream course. The caves in these gullies are numbered from the head of the gully downhill, taking the western gully first, which continues downhill of its confluence with the eastern.

Caves in the Western Gully

At the head of the gully the small stream sinks, below a 15 ft. waterfall, in its bed, and resurges a short distance downhill, through boulders. It then flows on the surface for some distance before sinking in its bed again, a few feet from an open entrance (17) giving access to the streamway. A narrow walking-sized passage continues for c.40 ft. to a hole in the roof, where exit can be made. Following the stream for a further 20 ft. through a hands-and-knees crawl, leads to the resurgence (18).

The stream, below (18), flows on the surface for a few feet before sinking into impenetrable fissures. A few yards further down the gully is an obvious open mossy hole 6 ft. deep, only a few feet from the side of a small surface stream – this is the water from the caves in the eastern gully, at the foot of that gully (the two gullies joining here) rising from an impenetrable resurgence, to then pursue a predominantly surface course for some distance, in the same small valley as several cave entrances connecting with the stream from the western gully, which remains predominantly subterranean.

The open hole beside the stream (19), gives access to the subterranean west gully stream again. Upstream is too tight, but downstream, although low at first, develops into a stooping size passage for c.80 ft. before opening to daylight again at (20).

The western stream then pursues a semi-surface course for a few yards, before sinking again. A few yards further downhill is a horziontal slit-like entrance on the west side of the gully (21). A bedding crawl of c.10 ft. leads to a 3 ft. drop into a cross-rift, to the right choked, to the left dropping to a static sump, apparently of some depth.

Continuing down the gully, the small eastern stream, which has remained on the surface from its rising near (19), then sinks in a choked sink. A few yards away to the north west is an obvious shaft, the entrance to –

(22) Uamh an T-Shelf (Shelf Cave) (Fig. 9).

The entrance shaft is c.15 ft. deep and easily climbed down, opening at the base into a roomy chamber, with three passages leading off. That on the right is an inlet (the eastern stream?), a streamway initially 5 ft. high, and rising round two corners to a boulder choke where daylight can be seen. The passage straight ahead is a tubular crawl above a rock shelf, dropping after a few feet into a wider bedding passage, also reached by the left passage from the entrance chamber. This bedding, passing two low inlets on the left, descends gently to a wide pool, which appears to sump completely.

Total length of this attractive little cave is c.80 ft. and depth c.20 ft.

Returning uphill to the granite/limestone boundary, and then eastwards again, one comes to the first of –

Caves in the Eastern Gully

The first open hole seen is a short distance to the west of the actual gully head (23), and is a narrow descending rift, entry to which would require some digging. At the head of the gully itself, a small stream sinks at (24), into a very tight jagged rift, possibly too tight to be accessible. Following the shallow gully downhill, the next open hole is (25). A debris slope drops into a low chamber, where the stream enters from a choke. Downstream is a 6 ft. drop, and then the passage narrows, ending too tight where daylight from (26) is visible. Length of this section of cave is c.35 ft.

At (26) is an obvious shake hole with the impenetrably tight upstream passage connecting with (25), and on the opposite side a low entrance (dug out in 1973 by M.S.G.) connecting with a downstream passage, of stooping size, continuing for c.50 ft. to a tight hole back to the surface (27).

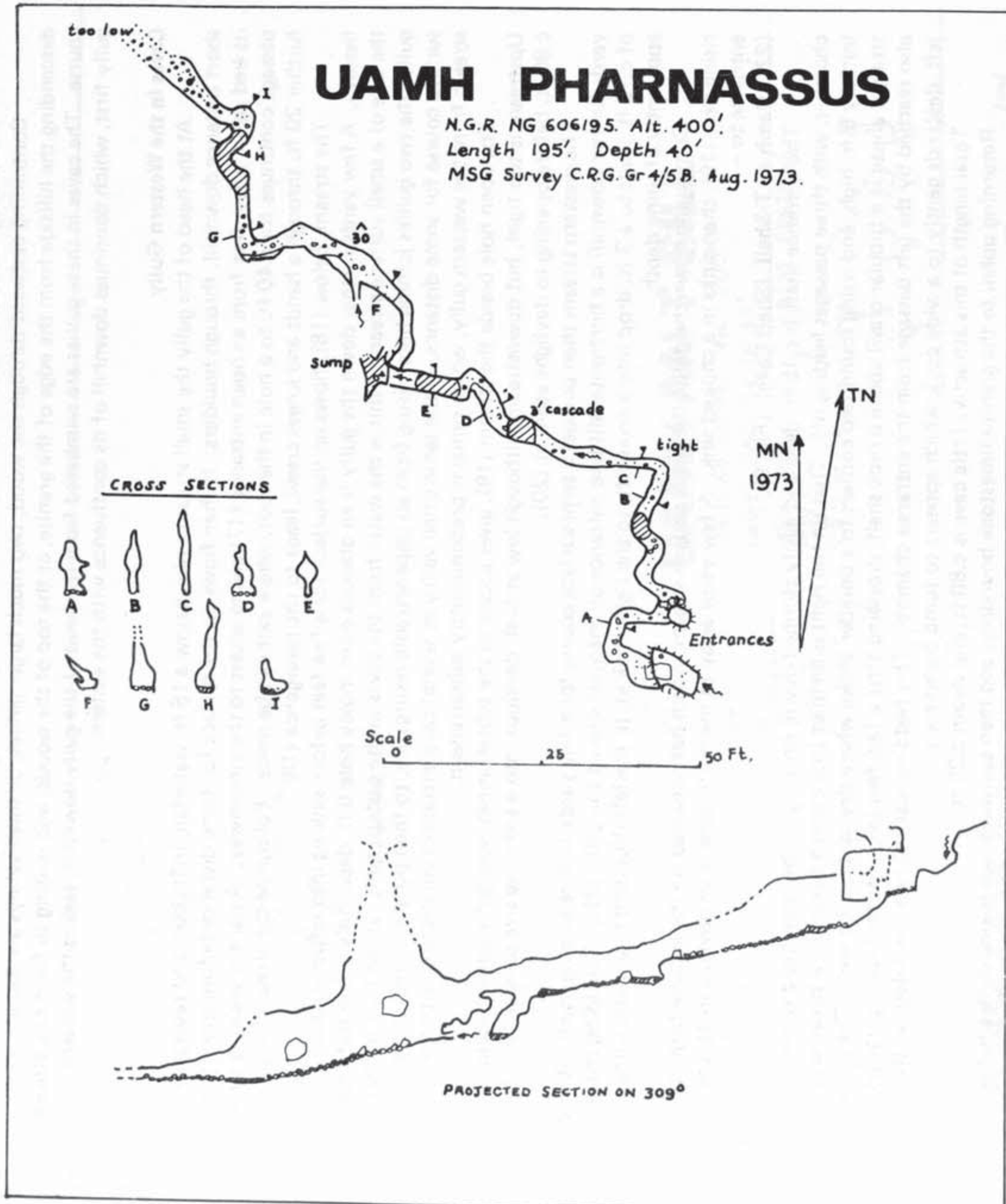
A few yards further downhill one comes to –

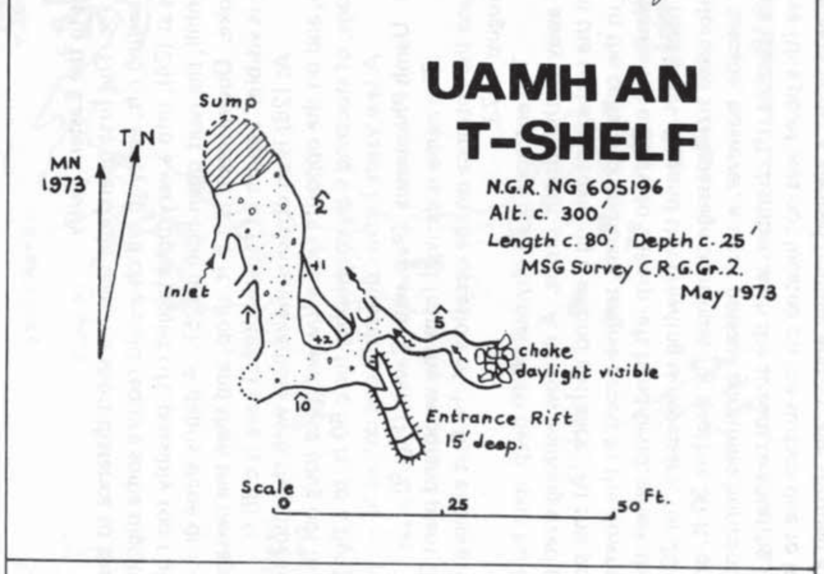
(28) Uamh Pharnassus (Parnassus Cave) (Fig. 9)

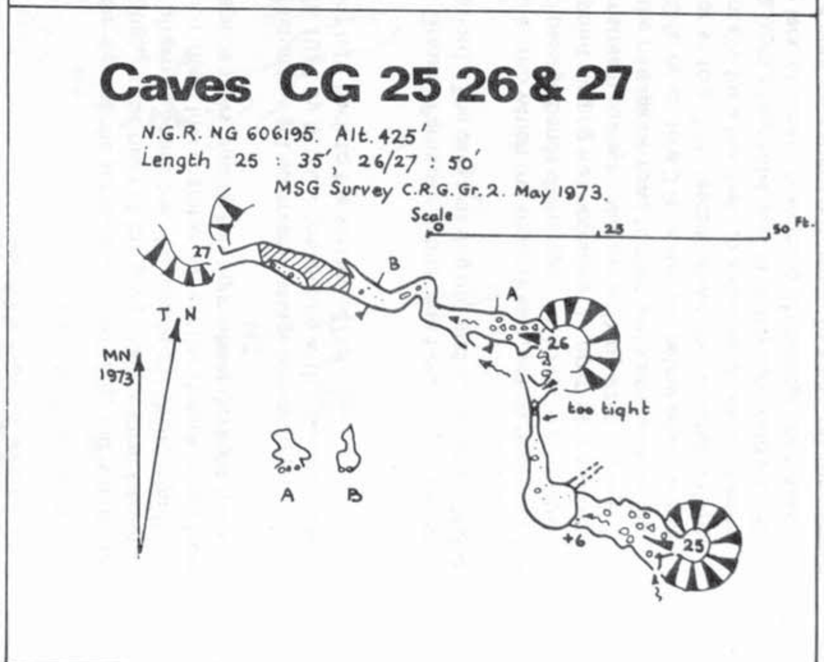
(The name is derived from the woodland plant Grass of Parnassus, which was flowering in profusion around the entrance on the occasion of the first exploration). The cave was dug out and surveyed by M.S.G. in August 1973.

The entrance is an obvious 10 ft. deep open hole, into which the small stream, which resurges a few feet away further uphill, drops. A narrow walking-sized passage bends sharp right for 15 ft. to a collapse from the surface, providing a second entrance. At this point digging was necessary, to open up a narrow slot in the collapsed boulders, to give access to the downstream passage. Narrow walking-sized passage continues for c.30 ft. to a sharp left hand bend, where the passage narrows further and some hammering was necessary. Beyond this crawling is necessary, for 20 ft. or so, to a 3 ft. waterfall, below which a more comfortable sized passage continues for another 30 ft. or so to a 7 ft. cascade down into a sump. Above this cascade, however, a small passage continues horizontally for a few feet, to a narrow descent, opening into a sizeable rift chamber, with the stream re-entering from a tiny tube, and faint daylight visible c. 30 ft. above (this point was not located on the surface due to lack of time). A winding rift passage continues with a squeeze under a wedged boulder and a crawl through a pool, to a sharp left bend. Beyond this the passage lowers to a choked bedding, where digging might allow a little further progress, although no enlargement is visible.

Fig. 9.


UAMH PHARNASSUS
N.G.R. NG 606195. Alt. 400'.
Length 195'. Depth 40'
MSG Survey C.R.G. Gr 4/5B. Aug. 1973.
too low
I
H
G
30
F
sump
E
D
3' cascade
tight
C
B
A
Entrances
MN
1973
TN
CROSS SECTIONS
A
B
C
D
E
F
G
H
I
Scale
0
25
50 Ft.
PROJECTED SECTION ON 309°


UAMH AN T-SHELF
N.G.R. NG 605196
Alt. c. 300'
Length c. 80'. Depth c. 25'
MSG Survey C.R.G.Gr.2.
May 1973
Sump
T N
MN
1973
Inlet
2
+1
+2
5
10
choke
daylight visible
Entrance Rift
15' deep.
Scale
0
25
50 Ft.


Caves CG 25 26 & 27
N.G.R. NG 606195. Alt. 425'
Length 25 : 35', 26/27 : 50'
MSG Survey C.R.G. Gr. 2. May 1973.
Scale
0
25
50 Ft.
27
B
A
26
T N
MN
1973
too tight
A
B
+6
25

Total length of the cave is c.195 ft. and depth c.40 ft.

Continuing downhill from Uamh Pharnassus, after some distance another open hole is found, at (29). A narrow rift drops c.20 ft. to a passage to the right, ending in a 'T'-junction with an impassable rift. Total passage length is c.30 ft.

A little further downhill again one comes to another opening, (30), the last in which the eastern gully stream is seen underground – at a depth of 6 ft. the stream is met, but the passages it flows from and into are impassably small.

A few yards away is the small rising near (19), and, as described above, the eastern stream then remains on the surface for some distance, possibly finally joining the western stream underground in Uamh an T-Shelf.

Walking on down valley from Uamh an T-Shelf, the combined streams resurge again from a low sumped rising, and then, after briefly sinking and rising again through impenetrable holes, flow on the surface for some distance before sinking into an obvious cave entrance (31). A roomy hands-and-knees crawl continues for 25 ft. to a sump. A few yards away the stream resurges, from an impenetrable rising, and flows on the surface to the foot of the woods.

A thorough investigation of the Coille Gaireallach woods cannot be claimed, and there doubtless remain further caves to be found in this area. All the caves so far described have been in the main area of woodland. Further up the north side of Beinn an Dubhaich is a smaller area of limestone, also supporting woodland (the highest woodland on the hillside). Near the highest point of this are several large shakeholes, including –

(32) Poll Ceann A'Choille (Wood Top Pot).

This is an obvious stream sink, in a steep sided bouldery shakehole about 20 ft. deep. In the base of the shakehole a scramble down through boulders and debris leads to a very steeply descending tube, for c.20 ft. to a sump pool. Total depth, from the surface, is c.40 ft.

Uamh an Ard Achadh (High Pasture Cave) (Fig. 10)

This sytem is quite different, in many ways, from the other caves in the area. The longest cave so far found on Skye, it shows at least two stages of passage development, and has the appearance of being of greater age than most of the systems around Beinn an Dubhaich. The long, and generally roomy stream passage, is much less steeply graded in longitudinal section than most local caves, and is reminiscent of a typical "Yorkshire" cave.

The entrance was dug out, and the cave explored, and surveyed, by U.C.L.S.S. in 1972 who named the cave from the rubbish tip at the entrance, and the mount of debris from this scattered down the streamway, Tin Can Alley. The name "High Pasture Cave" (suggested by a local farmer, as descriptive of the cave's position) has since been adopted, although the original name has been kept for the first section of the stream passage.

The sizeable stream sink which feeds the cave is in an obvious small valley, running north eastwards. The stream sinks beside a 10 ft. deep hole, choked with domestic rubbish. The cave entrance is c.70 ft. away to the north east, in a hole surrounded by a low stone wall, against the north side of the dry valley which continues from the sink.

As easy descent through a ruckle of boulders and empty spirits bottles leads into the streamway. Upstream is an impassably low bedding, but downstream, at first a hands-and-knees crawl, rapidly enlarges to a stooping size passage showing attractive cross sections, and some pleasant formations. A small aven, and impassably narrow inlet, is passed on the right and the stream passage continues, generally 4-5 ft. high, and of similar width, until a junction is reached, c.130 ft. from the entrance. On the right a slope leads up into a dry passage, with many calcited bones scattered across the floor. This is at first of comfortable walking height, but lowers to a bedding and chokes c.50 ft. from the stream passage.

Turning left at the junction, the downstream passage continues, c.10 ft. high, the upper part (which is really a continuation of the dry side passage) diverging briefly from the lower to form a short high-level ox-bow, for 30 ft. to another junction.

Straight ahead at this junction, the high-level section of the passage leaves the streamway again and continues for 60 ft. at first being of walking size, then, after a scramble over some boulder, lowering to 4 ft. high, with a 2 ft. deep static pool. The final section widens to 12 ft. forming a chamber and the passage ends in a calcited choke.

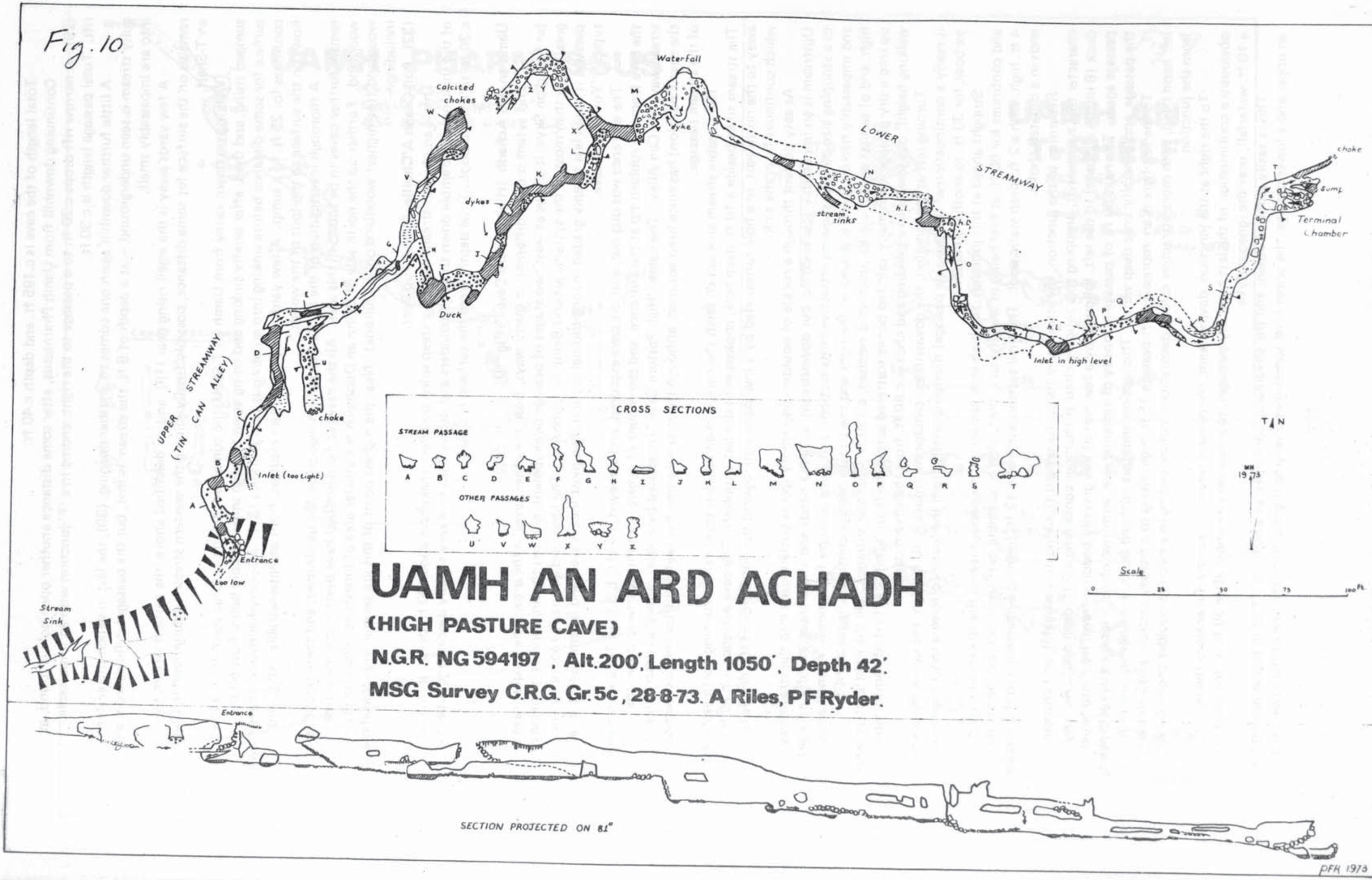
Returning to the junction, the streamway turns sharp right (looking downstream), and changes character to a narrow rift, dropping to a roughly circular chamber containing a 2 ft. deep pool. An easy duck (8 inches airspace) to the left, followed by a few feet of low gravelly bedding crawl, lead into larger passage again. The next 50 ft. of passage is mostly of stooping size, with two obvious igneous dykes crossing the passage, and generally knee deep water. This section ends in a lefthand bend, and another junction.

To the left here is an impressive rift passage 15 ft. high, rising to a muddy section, and another left hand bend, with more attractive calcite decorations, before ending in a calcited boulder choke 60 ft. from the junction.

To the right at the junction, downstream, the passage retains its roomy dimensions (being obviously a continuation of the left hand dry passage), to a bouldery chamber after 30 ft. at the head of a 10 ft. waterfall, over the igneous dyke.

This is easily climbed down, and the streamway continues, as a high rift. This in places divides into an upper and a lower passage, the upper level sometimes diverging slightly from the line of the lower, and

Fig. 10



UAMH AN ARD ACHADH

(HIGH PASTURE CAVE)

N.G.R. NG 594197 , Alt. 200', Length 1050', Depth 42'.

MSG Survey C.R.G. Gr. 5c , 28-8-73. A Riles, PF Ryder.

meandering where the lower does not. The passage widens to a 12 ft. wide and 10 ft. high chamber, some 90 ft. downstream of the waterfall, and the stream sinks in a low choked passage under the right wall. This chamber ends where the passage divides into upper and lower levels again, for 30 ft. or so, reuniting where the stream reappears from under the right wall. After a short section of 20 ft. high rift, the upper and lower levels diverge again, the upper level here taking the form of a bedding plane, with on the right a small inlet from an impassably small tube, the inlet stream cascading down into the lower level of the passage. Beyond this point the upper level begins to descend, in relation to the lower (with which it communicates frequently) and the passages in general lose height, so that 50 ft. beyond the inlet both levels are hands-and-knees crawls, and both within a vertical range of 6 ft. The two routes rejoin, to allow walking again (although here there is still an "upper level" in a way, in the form of a very small roof tube which in places is separate from the main passage.

The passage suddenly ends in the Terminal Chamber, 18 ft. long, 12 ft. wide and 10 ft. high, its far wall a solid boulder slope. The stream drops away into a low passage under the left wall, part flowing straight into a small sump, the remainder into a narrow rift, accessible for 15 ft. as a rather aquatic crawl, to end impassably narrow and boulder choked.

The final choke can probably be correlated with an extensive collapsed area apparent on the surface, and there seems little hope of further extension. The cave stream was fluorescein tested by M.S.G. in May 1973 to a rising about ¼ mile away from the sink, found by walking down the obvious dry valley, past the collapsed area (where there are more rubbish tips) to where a stream issues from impassably low bedding planes on the south side of the valley. Sinks in the west part of the Coille Gaireallach woods may also feed this rising. Flow through time was about 8 hours, in moderately wet weather conditions – there had been recent rain, but the streams were hardly in spate.

Total length of the cave is about 1,050 ft. and depth from entrance to sump 42 ft. (from M.S.G. Grade 5 survey).

The development of the cave poses some interesting problems, and three separate stages of passage development are tentatively suggested. Development does seem to have been predominantly vadose, since there is little in the way of what is normally classified as evidence for phreatic activity.

(i) Possibly Pre-Glacial. A streamway existed, now represented by the dry side passages in the section of the cave above the 10 ft waterfall, fed by the surface stream sinking at a point lower down the present dry valley than the now active sink. The furthest "upstream" point of this old system now accessible is the choke in the first side passage on the right, going downstream – this side passage retains a considerable amount of fill which might conceivably be of Glacial origin. The next two side passages, on the left, now separated by calcited chokes, are obviously the same passage, the terminal chokes being shown by the survey to be only 10-15 ft. apart. Further downstream, the high level passages are relics of this old streamway, gradually descending to merge with the present active passage just before the Terminal Chamber.

(ii) Possibly Pre-Glacial, or Inter-Glacial. The present entrance series developed, the sink either being in the present position, or perhaps where the entrance is now.

Either during this stage or the next, the lower levels of the Lower Streamway (i.e. below the 10 ft. waterfall) developed, possibly during a period when the stream was re-activated, e.g. by melting ice, following a period of quiescence.

(iii) Possibly Post-Glacial. (There is little evidence for separating postulated stages (ii) and (iii) beyond the fact that the entrance series does appear to show more development than the streamway between the second and third dry side passages above the waterfall). The stream abandoned the section of its former route now represented by the second and third dry side passages, developing a new route, i.e. the lower section containing the duck. The former route was blocked by a major collapse, represented by the calcited chokes.

One interesting, and confusing, piece of evidence can be seen at the point where the second dry side passage joins the streamway – a section of channel developed in the floor of this passage which appears to suggest a former stream joining the present streamway at this point, i.e. flowing southwards along the second dry side passage, in the opposite direction to the postulated direction of the stream which formed this passage. However, this feature may be of comparatively recent origin, formed at a period when an inlet from the area of the calcited chokes was active (as may still flow in wet conditions).

A more detailed inspection of this impressive cave may yield further evidence as to its developmental history – at the moment the above theories are put forward merely as suggestions.

Small Caves East of the Coille Gaireallach Area

The Coille Gaireallach area can be taken as being bounded to the east by a major stream, the Allt an Inbhire, which drains the east side of Beinn an Dubhaich, and has its source in the same upland valley as the Allt nan Leac. The woodland area does, however, continue for some distance east of this stream. A brief inspection of the Allt an Inbhire (which flows from granite to limestone, and vica-versa, several times), revealed two small caves. Walking up the stream from the Broadford-Torrin road, and passing a tributary on the left which flows through an impressive limestone gorge, the first cave found is –

Allt an Inbhire Cave

This is an obvious rising on the left bank, fed by sinks in the stream bed (amongst granite cobbles) perhaps 200 yards upstream. The water level at the rising was lowered by digging, to allow easier entry into a low arched passage. After 20 ft. of narrow wet crawl this turned sharp right through a near-duck, and 15 ft. of further low wet passage to where an impassably small fissure connected back with the streambank.

The stream passage went through an acute double bend to the left here, and this was probably too tight to pass, the passage beyond being very narrow, with low airspace — another 10 ft. or so could be seen. Total length of accessible passage is 35 ft.

Continuing upstream, passing various small impenetrable sinks and risings, a narrow entrance is found a few feet from the stream, also on the left bank. This is —

Uamh Taobh na H-Aibhne (Streamside Cave)

A tight section of rift leads to a left turn into a more roomy slanting rift, ending too low. Length is around 30 ft.

The remaining two small caves are beyond the area shown on the map accompanying this article. The arrangement of streams east of the Allt an Inbhire observed by the writer does not seem to tally with that shown on the O.S. map — hence there is some difficulty in locating the caves.

A normally dry stream bed runs down to the road a short distance east of the Allt an Inbhire. This can be followed upstream from the road almost half a mile, to where the stream sinks in pools in its bed. Several hundred yards downstream of this sink, beside a large static pool, a small hole was found beneath the roots of a tree (in the left bank, looking upstream) a little digging opened out —

Uamh A'Phuill (Pool Cave)

The small entrance drops into a passage which drops steeply down beneath the surface stream bed, down a muddy slope, into a chamber perhaps 5 ft. wide and 10 ft. long, the floor of which is occupied by a pool 2-3 ft. deep, with no apparent exits, and much mud. This peculiar little cave does not, then, appear to be connected with any active system, and is c.20 ft. long and 15 ft. deep.

Returning to the road, and walking further eastward, i.e. towards Broadford, a very obvious massive igneous dyke is seen, descending the grassy hillside, beyond the wooded area, as a prominent ridge, round the foot of which the road curves. Striking up the hillside a hundred yards or so to the west of this dyke, a small choked rising is found (in a small patch of woodland). If one walks up the open hillside beyond, for perhaps two hundred yards, towards the ruined house at Kilchrist, a collapse depression is found, where the stream rises and sinks again. This is —

Kilchrist Cave

At the upstream end of the depression is an obvious (except in summer, when the bracken is high) cave entrance, perhaps 8 ft. wide and 3 ft. high. This openes into a stooping height passage, bedecked with ferns, which after 20 ft. closes down to a short crawl to a total choke. Total length is c.30 ft. The stream is fed by a small sink which can only be a few feet beyond the choke, which in turn is fed by a small stream rising from marshy ground.

At the downstream end of the entrance collapse depression a little digging was attempted, but the passage seems thoroughly choked.

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Sheffield S10 3AY

Gazeteer of Caves in the Beinn an Dubhaich Region.

Cave Name	*Alt. Names* (Trans. of Gaelic bracketed)	*Grid Ref.*	*Alt.*	*G.S.G. Ref. No.*
(a) Allt nan Leac Valley				
(A) Camas Malag Cave		NG 584187	c.100 ft.	
(B) Uamh Sgeinne	(Cave of Knives)	NG 587184	c.200 ft.	
(C) Beinn an Dubhaich Cave	Allt nan Leac Cave	NG 589184	c.300 ft.	
(D)		NG 590184	c.300 ft.	
(E)		NG 590184	c.325 ft.	
(F) Uamh Craobh Sheileach	(Willowtree Cave)	NG 594184	c.425 ft.	
(G) Uamh Sluic	(Pit Cave) Allt nan Leac Pothole	NG 595184	C.425 ft.	
(H) Claon Uamh	(Slant Cave)	NG 598183	c.370 ft.	
(I) Uamh Aosda	(Ancient Cave)	NG 600183	c.450 ft.	
(J) Uamh Cinn Ghlinn	(Valley Head Cave)	NG 601182	c.450 ft.	
(K) Uamh Ceann Mullach A'Chlinne	(Upper Valley Head Cave)	NG 604183	c.515 ft.	
(L) Poll Neach Di-Chuimhnichte	(Pit of the Forgotten One)	NG 616184	c.625 ft.	
(b) Coille Gaireallach Area				
CG 1 Twisted Cave		NG 599196	c.325 ft.	
CG2/3 Poll Iffrin	(Hell Hole)	NG 600197	c.225 ft.	D 1/2
CG 4 Poll Eidheann	(Ivybush Hole)	NG 600198	c.175 ft.	D 2
CG 5		NG 601198	c.125 ft.	
CG 6 Uamh Sgoilte	(Slit Cave)	NG 601198	c.125 ft.	X 1
CG 7		NG 602197	c.225 ft.	G 1
CG 8 Uamh Coile	(Cave of the Woods) Chert Rift Cave	NG 602197	c.175 ft.	G 2/3
CG 9 Uamh an T-Sill	(Cave of the Seed) (Cave of the Fairies) Skeleton Cave	NG 602197	c.200 ft.	X 2
CG 10		NG 602198	c.150 ft.	X 3
CG 11		NG 603198	c.150 ft.	
CG 12		NG 603198	c.150 ft.	
CG 13		NG 603196	c.215 ft.	I 1
CG 14		NG 603196	c.215 ft.	
CG 15		NG 603196	c.215 ft.	J 1
CG 16 Uamh Slaodach	(Awkward Cave)	NG 604196	c.300 ft.	
CG 17/18		NG 605195	c.375 ft.	K 3
CG 19/20		NG 605195	c.350 ft.	K 4
CG 21		NG 605195	c.325 ft.	K 5
CG 22 Uamh an T-Shelf	(Shelf Cave)	NG 605196	c.300 ft.	K 6
CG 23		NG 606194	c.475 ft.	
CG 24		NG 606194	c.475 ft.	
CG 25		NG 606195	c.450 ft.	
CG 26/27		NG 606195	c.425 ft.	
CG 28 Uamh Parnassus	(Parnassus Cave)	NG 606195	c.400 ft.	
CG 29		NG 605195	c.375 ft.	
CG 30		NG 605195	c.350 ft.	
CG 31		NG 604198	c.150 ft.	K 8
CG 32 Poll Ceann A'Choille	(Wood Top Pot)	NG 600194	c.500 ft.	
Uamh an Ard Achadh	(High Pasture Cave) Tin Can Alley	NG 594197	c.200 ft.	A 1
Area East of Coille Gaireallach				
Allt an Inbhire Cave		NG 610199	c.150 ft.	
Uamh Taobh na H-Aibhne	(Streamside Cave)	NG 610198	c.175 ft.	
Uamh a'Phuill	(Pool Cave)	NG 613200	c.150 ft.	
Kilchrist Cave		NG 614202	c.175 ft.	

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NOTE ON THE EXPLORATION OF THE AVENC DE LA PUNTA, MAJORCA

by J. A. Encinas

This note gives information about the archaeological exploration of the **Avenc de La Punta** (Pollensa, Balearic Islands), where an incineration room and a sanctuary sacred to bull-worshippers dated from the 4th-3rd century B.C. were found.

The most important objects preserved in this cave are some wooden idols. They represent the bull, possibly a god-symbol of the pre-Roman culture in the Balearic Islands.

As a consequence of the intense speleological explorations that have taken place, these past seven years in the Balearic Islands, an inventory has been made of the majority of caves considered of archaeological interest. These caves contain deposits of the most varied cultural phases.

In a chasm of the "La Punta" mountain range, speleologists found a sanctuary, or funeral chamber for incineration rites, dating from 370 B.C. with wooden bull-like idols.

Study of the materials has been directed by the archaeologist Damiáú Cerdà, who will shortly be publishing his findings. A careful investigation was carried out of the environmental conditions of the cavern from the time of the deposits to the present, in order that the circumstances favouring preservation of the wooden idols in a cave environment might be determined.

Co-ordination of the archaeological work and other speleological studies has permitted an analysis in depth of the original conditions and the subsequent evolution of the deposit.

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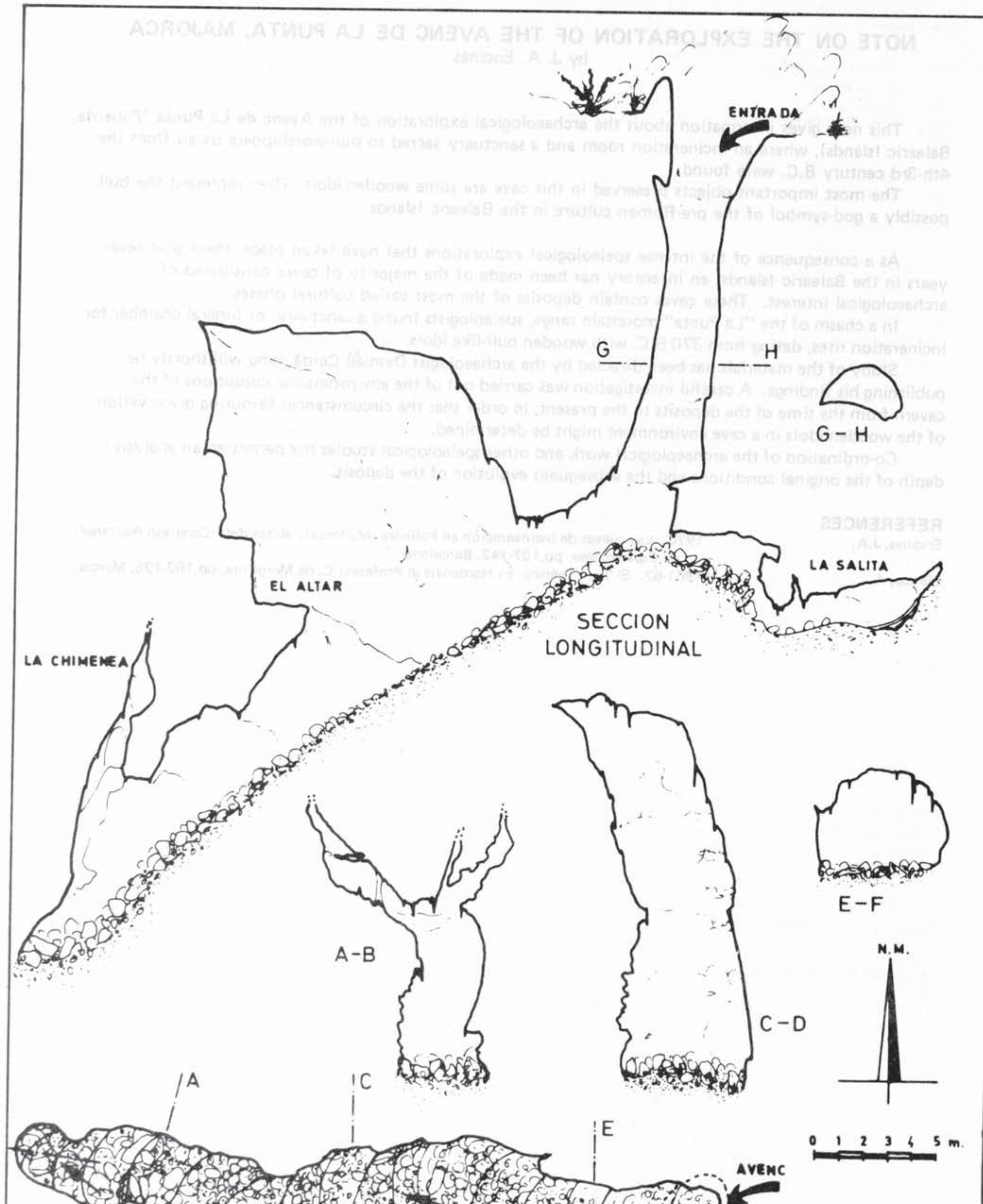
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AVENC DE LA PUNTA
POLLENSA.(BALEARES) ..00.02-VI.(P-11) .– 30-9-1973
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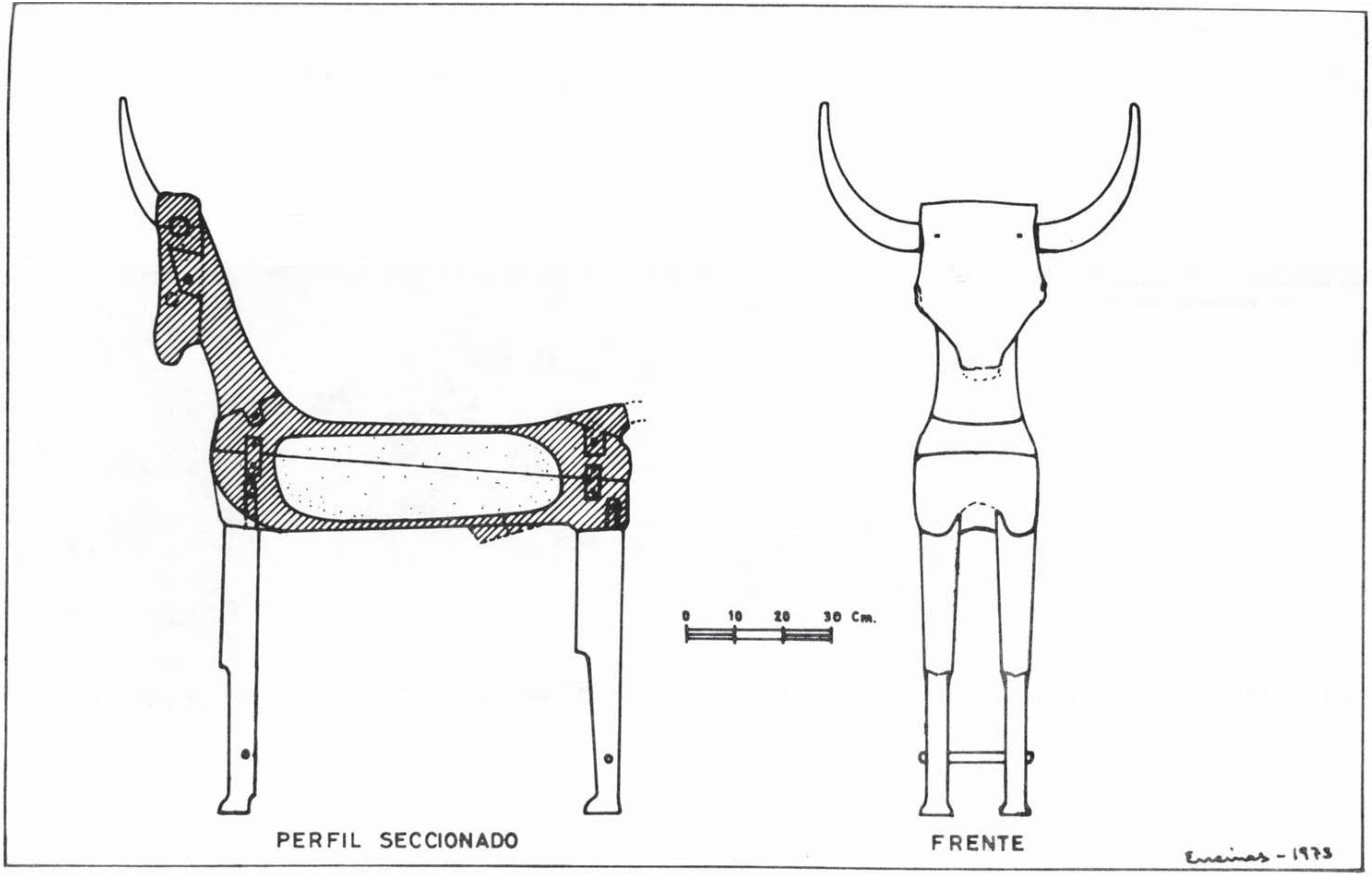
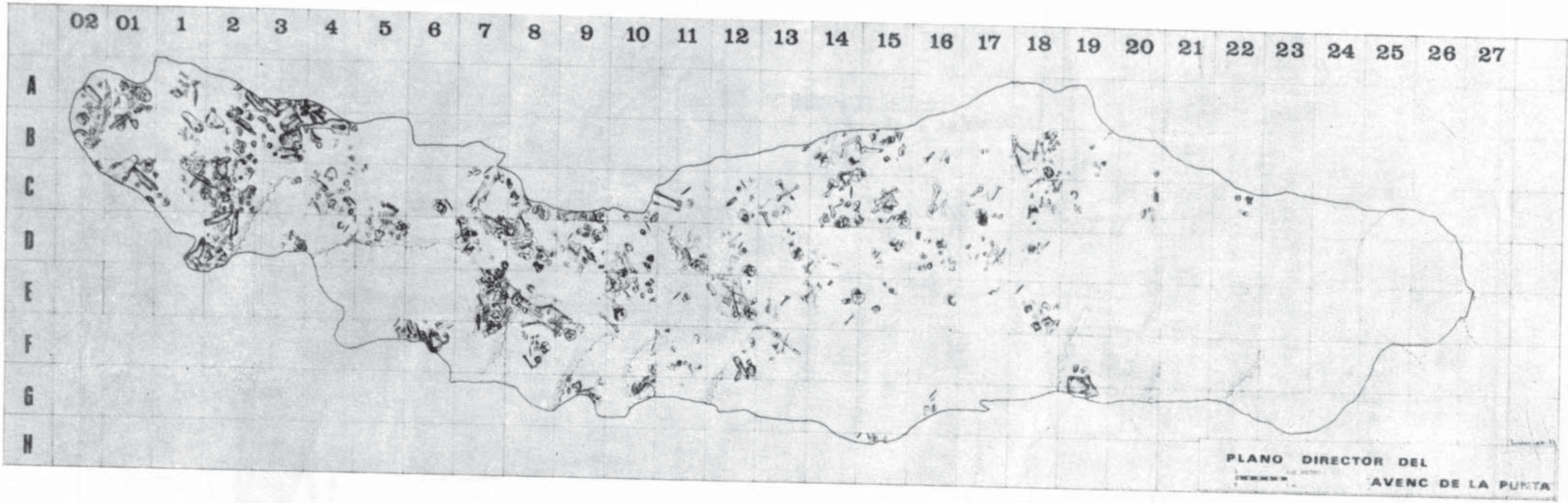
Z = 130 m.
TOPOGRAFIA: J.A.ENCINAS S. Y A. COMPANY
Encinas - 73



INTENTO DE RECONSTRUCCION DEL TORO Nº 1
"AVENC DE LA PUNTA" (POLLENSA)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PLANO DIRECTOR DEL
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