PROCEEDINGS

8th BIENNIAL CONFERENCE

AUSTRALIAN SPELEOLOGICAL FEDERATION

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PROCEEDINGS OF THE EIGHTH BIENNIAL CONFERENCE OF THE AUSTRALIAN SPELEOLOGICAL FEDERATION

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A. Goede of
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R. Cockerill of
the Southern Caving Society.

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Party in Exit Cave
Nick Cummings (T.C.C.)

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EDITORIAL

It is with great pleasure and a sigh of relief that the editors present to you the Proceedings of the Eighth Biennial Conference held in Hobart in December 1970. Unlike the proceedings of the Seventh Conference, they are not a transcript as it was felt that more effective use could be made of the available space by contributors writing their papers specifically for publication.

We are grateful to all those who contributed to the conference programme and it was a pleasant surprise to find such a large number of really interesting and worthwhile papers presented on a considerable variety of topics. It is also gratifying to record the ready co-operation of many authors in the preparation of their texts for publication. The increasing maturity of Australian speleological activities appears to be reflected in the greater interest taken in scientific, conservation and technical aspects of caves.

We acknowledge the help of a number of individuals in preparing the proceedings for publication. Therese Goede and Jackie Dermody did much re-typing of hand-written and revised articles. We are much indebted to Steve Street who provided the tape recording equipment for the conference activities. Steve Street, Noel White and Therese Goede were also instrumental in helping with the difficult and tedious task of deciphering the discussions that followed most papers and with their conversion to intelligible English. A good deal of editing had to be done but the editors trust that this has not changed the original meaning of any of the questions and answers.

We wish to thank our printers — Advance Publicity and particularly their manager, Mr Chris Wren, and his staff for their assistance in producing a quality publication. We are particularly grateful to the Tasmanian Government for its financial assistance towards the cost of publication. Following an approach made to the Deputy Premier and Chief Secretary of Tasmania, the Hon. K.O. Lyons, a grant of two hundred dollars was made to the Tasmanian Caverneering Club for this purpose. Without this contribution these proceedings would very likely not have seen the light of day. We are also grateful to the Deputy Premier for performing the Official Opening of the Eighth A.S.F. Convention.

It may be of interest here to record some of the problems encountered in producing the proceedings. Much work could be saved in future if *all* contributors submitted a double-spaced, type-written copy of their paper at the time of the conference together with diagrams and photographs suitable for reproduction. Diagrams should be drawn clearly in black ink on white paper with typed or stencilled lettering and photographs should be original prints with a high degree of contrast and definition. Because of poor quality some photographs submitted for the proceedings had to be rejected.

Considerable problems arose because discussions after papers had to be translated from tape. This proved unsatisfactory despite the high quality of the equipment due to varying voice quality and distance from microphone together with frequent interruptions and howls of laughter drowning out witty answers. As most questioners did not identify themselves names are not indicated. At future conferences discussions should be taken down in shorthand.

Finally the Australian Speleological Federation should give some thought to the future production of the conference proceedings. In the introduction of the transcript of proceedings of the Adelaide Conference the then president of A.S.F.—Major R. Webb—stated that:

"It is proposed that in future the host Society appoint a secretary to produce the transcript, hire a professional if necessary, and charge the fees to the Conference. This should ensure that we will not be so dependent upon the goodwill of the energetic few".

Unfortunately this proposal has the effect—for financial reasons if no other—of lumbering the "energetic few" of the host society (-ies)—who are already doing their share in running the host society (-ies)—not only with organizing a conference and all it entails but also with the tedious job of producing the conference proceedings afterwards. Only in a centre with a large number of clubs, e.g. Sydney, is this difficulty likely to be avoided.

Another problem in producing the proceedings is finance. More by good luck than management and aided by economies made possible by the unexpectedly large attendance was the five dollars per head charged as the actual conference fee available in toto for publication costs to which the generosity of the Tasmanian Government added another two hundred dollars providing a seven hundred dollar fund. This was only marginally sufficient to produce professionally 350 copies of a publication of the standard which you have before you. Future conference committees should also bear in mind the large number of copies—approximately one hundred—that have to be provided gratis to libraries and overseas exchange. Hopefully the one hundred and fifty copies available for sale will create the beginnings of a fund for future proceedings.

However, we suggest that A.S.F. give some consideration not only to the financial problems involved but also to the appointment of a permanent editor of future proceedings provided such a person can be found. Only when these problems are solved can we expect to achieve the regular publication of proceedings of a standard befitting the Australian Speleological Federation.

February 1972

The Editors:
Albert Goede
Robert Cockerill

TASMANIAN KARST AREAS

by

Albert Goede

Introduction

The two most significant groups of rocks in Tasmania in which cave development has occurred are unfossiliferous dolomites presumed to be of Precambrian age (>500 million years) and the Gordon Limestone of Ordovician age (approximately 450 million years). The latter is by far the most important cave forming rock and accounts for some 90% of all known caves in Tasmania. Both Gordon Limestone and Precambrian dolomites outcrop only in the western half of the state in areas of high to very high rainfall and frequently in rugged terrain covered by dense wet forest vegetation. Further details of Tasmanian karst areas are given in Hughes (1957) and Goede (1967).

Small outcrops of Permian limestones (approximately 250 million years) occur in the eastern half of the state but do not usually contain caves with one exception – near Gray in the northeast where a few small caves are found. Finally we find that on the Bass Strait islands occur scattered outcrops of Pleistocene dune limestone (aeolianite) – a rock quite familiar to cavers from South and Western Australia where it may contain extensive cave systems. In our state only two small caves have been found in it – one each on Flinders and Cape Barren Islands. The caves are of interest chiefly because of their fauna while Ranga Cave on Flinders Island did also contain a bone deposit of considerable interest – excavated a few years ago by Dr Jeanette Hope of the Australian National University.

Precambrian dolomites

They are scattered throughout the western half of the island (Fig. 1) and for lack of evidence to the contrary are all assumed to belong to a single stratigraphic horizon. This may not be true since the structure and stratigraphy of our Precambrian rocks are very complex. The only extensive cave systems found so far in the dolomite are at Hastings. Some small caves have been found at Tim Shea near the Florentine Valley, Trowutta and Montagu. In the last few years members of the Southern Caving Society have investigated a dolomite area at Mt Ronald Cross but have been hampered by inaccessibility, bad weather and in the case of one promising swallet an excess of running water.

Mount Anne – Weld River area. An extensive area with a marked contrast between the southern portion of the outcrop which stands up as a steep-sided ridge and the northern portion – an area of subdued relief in the headwaters of the Weld River. The last area was first visited by cavers – members of the Monash Bushwalking Club – in 1969 and they reported only a few small caves. Its most interesting feature so far is a geomorphological one as some of the dolomite stands up in the form of sheer-sided "castles" or "towers" – a characteristic commonly found in the tropics but unusual in temperate climates. Although this area has far less caving potential than the Mount Anne ridge it should be investigated if only because of its interest to the geomorphologist.

At Mount Anne the dolomite outcrops on a ridge north-east of the summit for a distance of at least three miles at an altitude of between 2500 and 3200 feet. The ridge – partly overgrown with dense alpine scrub – has some very large collapse dolines and numerous smaller shafts while knife edges and pinnacles of dolomite are common (Plate 1). The few sinkholes so far investigated by the Tasmanian Caverneering Club have all proved to be blocked by talus at the bottom and this is not surprising as at this altitude a lot of frost shattering must have occurred during the cold periods of the Pleistocene. Even so there may be some shafts that will connect with horizontal cave systems at depth. From the point of view of cave development the Mount Anne ridge has a few things in its favour as the local relief of the dolomite is up to 2000 feet and also the beds are dipping very steeply so that even if numerous impure layers are present selective solution of favourable beds can produce very deep caves. The valley that separates the north-east ridge from the mountain mass to the south is at least partly excavated in dolomite but has also been heavily glaciated and the half a mile long lake it contains (Lake Timk) is probably due to glacial overdeepening rather than solution. Its shores have recently been explored and the water flowing out of the lake was found to drain underground into two swallets whose resurgence is unknown. A little further downstream another large enclosed depression marks the site of a former lake now completely drained.

Another peculiar feature of the dolomite is the coexistence of surface and underground drainage in the same area compared to areas of Gordon Limestone where – provided there is enough relief – all the water will go underground almost as soon as it reaches the limestone.

Gordon Limestone

This limestone of Ordovician age is the most important from a caving point of view and major caving areas such as Mole Creek, Junee-Florentine and Ida Bay are developed in this rock. Excluding the far south of the state the Gordon Limestone is strongly folded but at Ida Bay and Precipitous Bluff it is gently dipping with dips of less than 10° except where drag dip has occurred near major faults. Two areas will be discussed in detail.

Mole Creek. This area is representative of one where the limestone is strongly folded. Its geology has been mapped in detail and its geomorphology has been studied by Jennings (1967). The extent of the limestone is approximately five

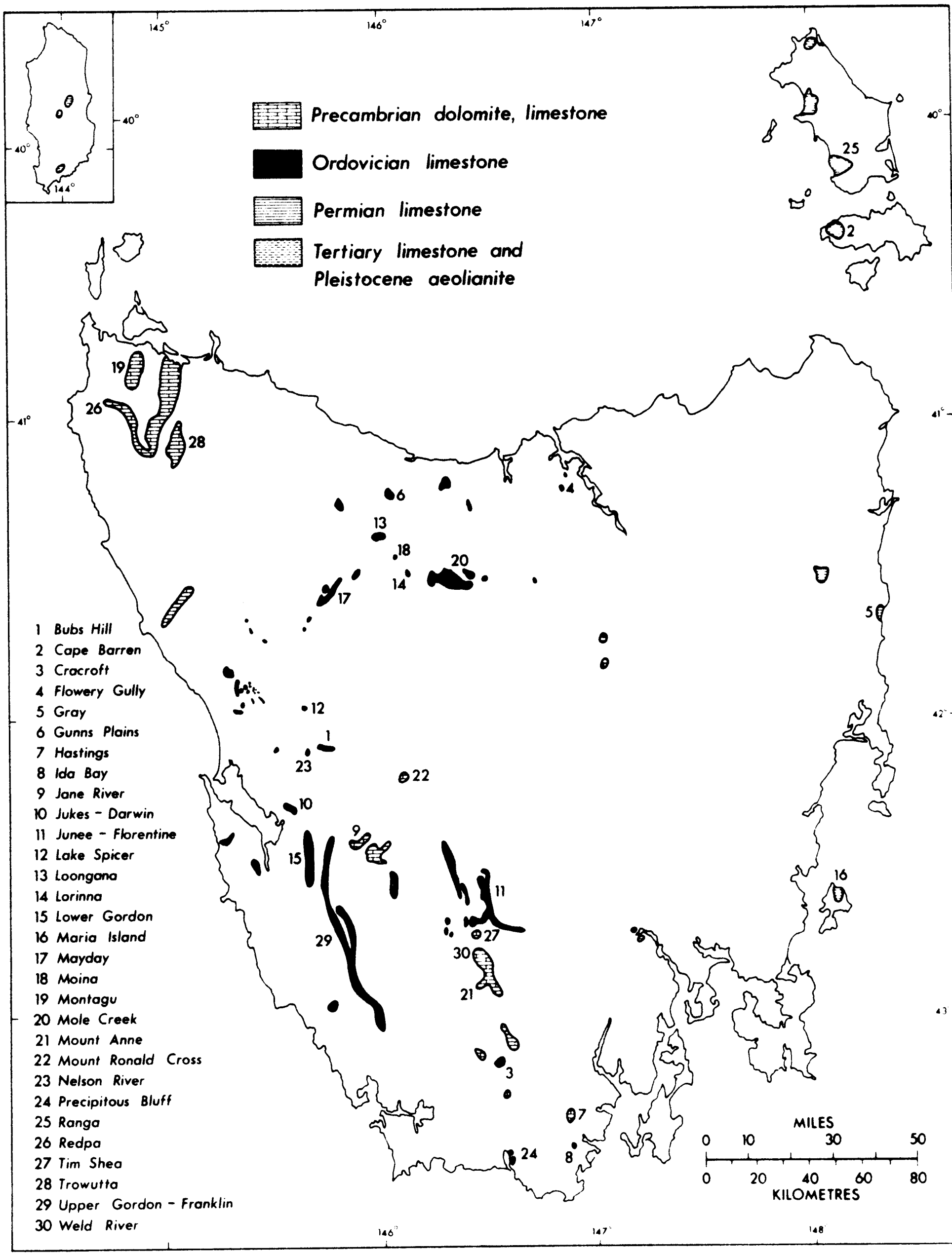

Figure 1 — Map showing distribution of karst areas in Tasmania

Plate 1 — View of portion of dolomite ridge north-east of Mt Anne looking east from vantage point above entrance to Kellers Cellar

by fifteen miles with this rock occupying a broad east-west trending synclinal trough. The limestone area is partially bisected by an anticlinal ridge of the underlying Moina Sandstone plunging towards the east. In comparison with most other Tasmanian karst areas the rainfall is relatively low from about 40 inches in the east to 60 in the west. Cave development is extensive and well over one hundred caves are known.

There is relatively little bare limestone at Mole Creek most of it being soil covered. The bare limestone features especially rillenkarren that are so characteristic of many areas in New South Wales – resulting from the direct impact of rain on the limestone – are poorly developed at Mole Creek. It is much more common here to get rundkarren – rounded solution grooves formed under a cover of soil or humus.

The underground drainage particularly around the headwaters of the Mole Creek is complex and water tracing has been carried out by J.N. Jennings and the Tasmanian caving clubs working under his guidance (Jennings and James, 1967; Jennings and Sweeting, 1959). The resulting pattern is very interesting and shows that at least some of the headwaters of the Mole Creek make a double crossing of the surface divide between the Mole Creek and the Lobster Rivulet.

Common features of many caves at Mole Creek are remnants of sand and gravel fills which were probably deposited during cold periods of the Pleistocene. As a result of considerable frost weathering and the supply of glacial outwash from the icecap located on the Central Plateau heavy bedloads were supplied to the headwaters of streams going underground at the foot of the Western Tiers. Cave deposits in Marakoopa Cave have been described in detail by Burns (1960).

Ida Bay. The area contrasts with Mole Creek in that the limestone is almost flat-lying while outcropping on the lower slopes of two prominent hills – Marble Hill and Lunes Sugarloaf. At the latter it is overlain at an elevation of approximately 400 feet by a sill of Jurassic dolerite. The only known cave in this hill is Loons Cave which has almost a mile of passages. A fault runs between Lunes Sugarloaf and Marble Hill and at Marble Hill the limestone outcrops at elevations of up to 950 feet where it is overlain by Permian tillites, mudstones and sandstones. Deep shafts are concentrated at or close to this contact and can sometimes be linked with horizontal cave systems at depth. Examples are Mini Martin and Midnight Hole which connect with Exit Cave and Mystery Creek Cave (Entrance Cave) respectively.

A spectacular breach of a major surface divide occurs at Marble Hill where Mystery Creek – once a tributary of the Lune River – has been captured by underground drainage (Goede, 1969). It now flows through the divide by way of Mystery Creek Cave and Exit Cave to join the D'Entrecasteaux River. In addition an anabranch of this river also goes underground and joins Mystery Creek in Exit Cave giving rise to a flooding problem in that section of the cave downstream from the junction.

Several features of Exit Cave are of interest to speleologists. There are at least two higher horizontal levels indicating early stages in the development of the system while another outstanding characteristic is the occurrence of numerous cylindrical or elliptical shafts (e.g. Devils Stovepipe) leading up towards the surface. Overseas such shafts are often referred to as avens or domepits. Gypsum is abundant in certain portions of the cave (Edies Treasure, Lost Squeeze) and appears to be associated with a thin bed of now deeply weathered shale. This bed may originally have been a pyritic shale and oxidation of pyrite may be the source of the gypsum. Gypsum crystals up to three feet long have been found and to our knowledge are unique in Australia. There is evidence that growth of gypsum crystals has locally caused considerable weathering of the limestone by flaking.

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DISCUSSION

Q *These vertical shafts – is there any particular reason why they are near the contact?*

A The contact obviously wasn't always where it is now. You would expect to find shafts further from the present contact which at one time or another carried water. The water would go underground as soon as it reached the sandstone-limestone contact and there are obviously shafts further out marking former positions of the sandstone cap but they are more difficult to locate and many have been filled in by rockfalls and debris, so that the most likely and easiest place to look is along the contact where most of the holes have been found.

Q *I noticed another cave in your earlier paper, Loons Cave in another hill. Has much work been done on that as far as a link with Exit is concerned?*

A No, it is in a different hill, Lunes Sugarloaf, which is the next hill to the east and the limestone only extends up about 400 ft and is then overlain by dolerite.

C *I noticed it was an efflux.*

A Yes.

Q *Any idea of source? What about extensions to the right hand side going into Exit? There are quite a lot of passages.*

A It's a long way from Exit. Loons Cave carries little water except after heavy rain and it's just local drainage coming off the dolerite and when you get far into the cave there are a lot of dolerite boulders which have come down through shafts in the limestone. The cave itself has about a mile of passages of fairly small dimensions. It has obviously never been a major underground drainage system.

Q *What is the cause of the difference in altitude of the limestone?*

A There is a fault between Marble Hill and Lunes Sugarloaf which downthrows limestone on the eastern side by about 500 ft.

Q *Has any work been done in this area? Has the faulting influenced any cave development?*

A There are no caves close to the fault. The geological mapping of this area is deplorable. There is one geological map available from the Mines Department and I suspect that the geologist who mapped it sat in a hut rather than go out into the field. There are very large areas shown as Permian which are in fact Gordon Limestone which is much more extensive than indicated by this map. The same applies to the Junee area which has also been very poorly mapped which is one of the reasons why some of the caves so long escaped detection.

C *Try and get the National Parks over there before the mining companies discover it is limestone and try to quarry it.*

A Which area are you most interested in protecting? Ida Bay is a problem because it is already covered, and has been for some time by leases from the Commonwealth Carbide Company. This company is in considerable financial difficulty at the moment. The Commonwealth Government has threatened to withdraw the tariff protection which it now enjoys unless it becomes a much more efficient operation, and I very much doubt whether it will be able to do so. Therefore quarrying at Ida Bay may cease in the near future. If it does I think it will be our chance to get some protection for this area. The Junee area is less of a problem because it is under control of the Australian Newsprint Mills and most of the swallets are in fact within the boundaries of the Mt Field National Park. There is no threat of damage to the caves at present.

SOME GEOCHEMICAL ASPECTS OF LIMESTONE SOLUTION

by

Noel White

Introduction

The last two decades have seen great advances in our knowledge of the origin and development of caves, due largely to the increasing application of quantitative scientific methods to their study. The purpose of this paper is to introduce a few of these more important recent advances to a wider audience of Australian speleologists. My approach will be to first review the basic information essential to any understanding of limestone solution, then to use this information in discussing four aspects of the geochemistry of limestone solution.

Basic Geochemistry of Limestone Solution

For the purposes of this discussion we will restrict ourselves to solution caves formed in limestone. For simplicity limestone will be considered to be pure calcium carbonate ($CaCO_3$), and all calcium carbonate will be considered to be in the form of calcite.

The components which are generally of most importance in limestone solution are calcium carbonate, water, and carbon dioxide (CO_2).

(a) The system $CaCO_3$-H_2O

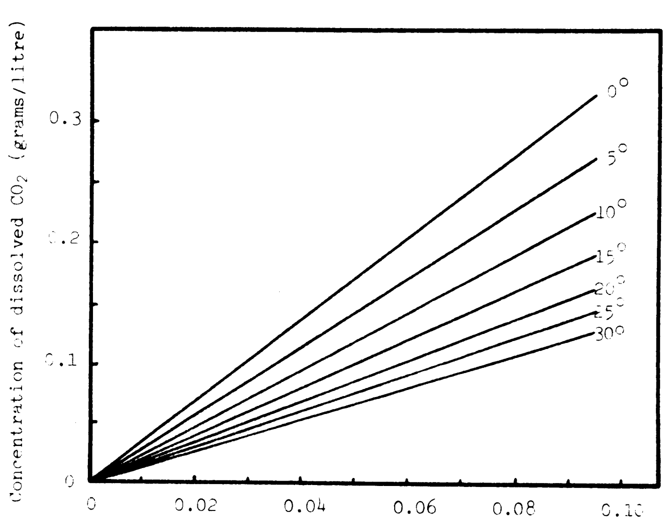
To what extent is pure water capable of dissolving limestone? Although pure water does not occur in nature, the question is of interest as it indicates how important other components are in dissolving limestone to form caves. Bogli (1960) quotes the following figures:

10 parts per million $CaCO_3$ at 8.7°C
13.1 " " " $CaCO_3$ at 16°C
14.3 " " " $CaCO_3$ at 25°C

From thermodynamic data Garrels and Christ (1965) calculate a value of 12.6 p.p.m. at 25°C. Thus pure water is capable of dissolving a small though significant amount of limestone, and the amount increases with increasing temperature.

(b) The system H_2O-CO_2

Carbon dioxide occurs in the atmosphere to the extent of about 0.03%, or 3 x 10^{-4} atmospheres pressure. Thus natural waters always contain some carbon dioxide dissolved as an impurity. Much higher concentrations can occur in air contained in soil. There is a straight line relationship between the pressure of carbon dioxide in the gas phase, and the concentration dissolved in the water when equilibrium has been reached. As is always the case for gases, the solubility decreases with increase in temperature (see Figure 1).



Partial Pressure of CO_2 (atm.)

Figure 1 – Relationship between concentration of CO_2 dissolved in water and CO_2 pressure in the gas phase for temperatures between 0° and 30°C. (Modified after Holland et al. 1964)

(c) The system $CaCO_3$-H_2O-CO_2

For this system we must consider two possible situations, one where it remains open to its atmosphere after the addition of the limestone, and another where it is closed.

When calcium carbonate is placed in water containing dissolved carbon dioxide, it dissolves to a much greater extent than it would have had it been placed in pure water. This is because the water and carbon dioxide react with the carbonate ions in the calcium carbonate, converting them to bicarbonate ions.

$$CO_3^{2-} + CO_2 + H_2O \rightleftharpoons 2HCO_3^-$$

This causes more limestone to dissolve until the concentration of calcium and carbonate ions required by its solubility product is reached. As well as allowing more limestone to dissolve, this also allows more carbon dioxide to dissolve. If the system is closed to its atmosphere before the limestone is added, however, no more carbon dioxide is available to take part in further reaction. If we consider the situation at 25°C and for the normal atmospheric partial pressure of carbon dioxide, then according to Garrels and Christ (1965) only 14.1 p.p.m. of calcium carbonate will dissolve, which is very little more than dissolved in pure water (12.6 p.p.m.). If, however, the system is left open to its atmosphere with a fixed partial pressure of carbon dioxide, more carbon dioxide is available to dissolve and react with the calcium carbonate. The result is that much more calcium carbonate dissolves. For the same temperature and carbon dioxide pressure as above, 39.8 p.p.m. of calcium carbonate will be dissolved at equilibrium, or approximately three times that which would have dissolved in pure water (Garrels and Christ, 1965). For any given partial pressure of carbon dioxide the lower the temperature the higher the solubility of calcium carbonate (see Figure 2), and for any given temperature the higher the partial pressure of carbon dioxide the higher the solubility of calcium carbonate (see Figure 3).

Figure 3 clearly illustrates the two situations discussed above. If limestone is placed in water in equilibrium with and open to an atmosphere containing a constant partial pressure of carbon dioxide, the concentration of calcium carbonate in solution will increase until an equilibrium concentration is reached. The path the changing composition will follow at 10°C is shown by the dotted line in Figure 3, where carbon dioxide pressures of 0.1 and 0.01 atmospheres (10^{-1} and 10^{-2} atm.) are shown as examples. If the limestone is placed in water which is in equilibrium with, but no longer open to, an atmosphere with a given partial pressure of carbon dioxide, then in this case the path the changing composition will follow is shown by the dashed line in Figure 3. Clearly the amount of calcium carbonate finally dissolved in this case is much less than for the open system.

Both these situations are important in cave formation. The closed system occurs when water flows into completely filled cave passages, and the open system occurs whenever water is simultaneously in contact with both limestone and a carbon dioxide containing atmosphere, whether this be normal air, or the interstitial atmosphere contained in soil.

The Mixing Effect

This phenomenon, also known as mixing corrosion or "mischungskorrosion", was first pointed out by Bogli in 1963. The basic concept is extremely simple, and it is amazing that it had not been appreciated before.

As noted above, for a given temperature the amount of calcium carbonate which will dissolve in water depends on the pressure of carbon dioxide. This is usually shown by means of a graph of calcium carbonate concentration versus carbon dioxide pressure. The three types of graph used are shown in Figure 4 (a - c). The first of these is probably the most common (Figure 4a). The two ordinates are both plotted on logarithmic scales, and the resulting graph is a straight line. The second (Figure 4b) is identical to that shown in Figure 3, where the vertical scale is linear, and the horizontal scale is logarithmic. This produces a curve which is concave upwards. The third type of plot, shown in Figure 4c, is not commonly used. In this case both ordinates are linear, and the resulting curve is concave downwards. It is this graph which is of importance in understanding the mixing effect. The same graph is shown in greater detail in Figure 5.

In Figure 5 all waters with compositions which plot in the field below the curve are undersaturated with calcite at their particular carbon dioxide pressure, and will be aggressive towards limestone. Similarly, all waters with compositions which plot in the field above the curve are supersaturated with calcite, and will tend to deposit it. If we take two points A and B on the curve, then these represent two waters, both saturated with calcite at a particular carbon dioxide pressure. If we mix solution A with solution B, then all the possible compositions which can be formed by mixing the two solutions in any proportions, are represented by the straight line joining A and B on the graph. Note that this line always lies in the undersaturated field. Thus even though solutions A and B are both saturated with calcite, mixtures of them are not, and hence are capable of dissolving more calcite. This is what is known as the "mixing effect".

The precise amount of undersaturation produced by mixing two given solutions is difficult to determine, however Thrailkill (1968) shows that the greatest total undersaturation (undersaturation per unit volume times total volume) will occur when the volume of solution A is much greater than that of solution B (probably about 30 times greater). There are several circumstances which would tend to counteract the mixing effect. These are discussed by Thrailkill (1968), who examines the magnitude of the mixing effect, and shows that, given favourable conditions, the mixing effect is clearly capable of playing a major role in cave formation.

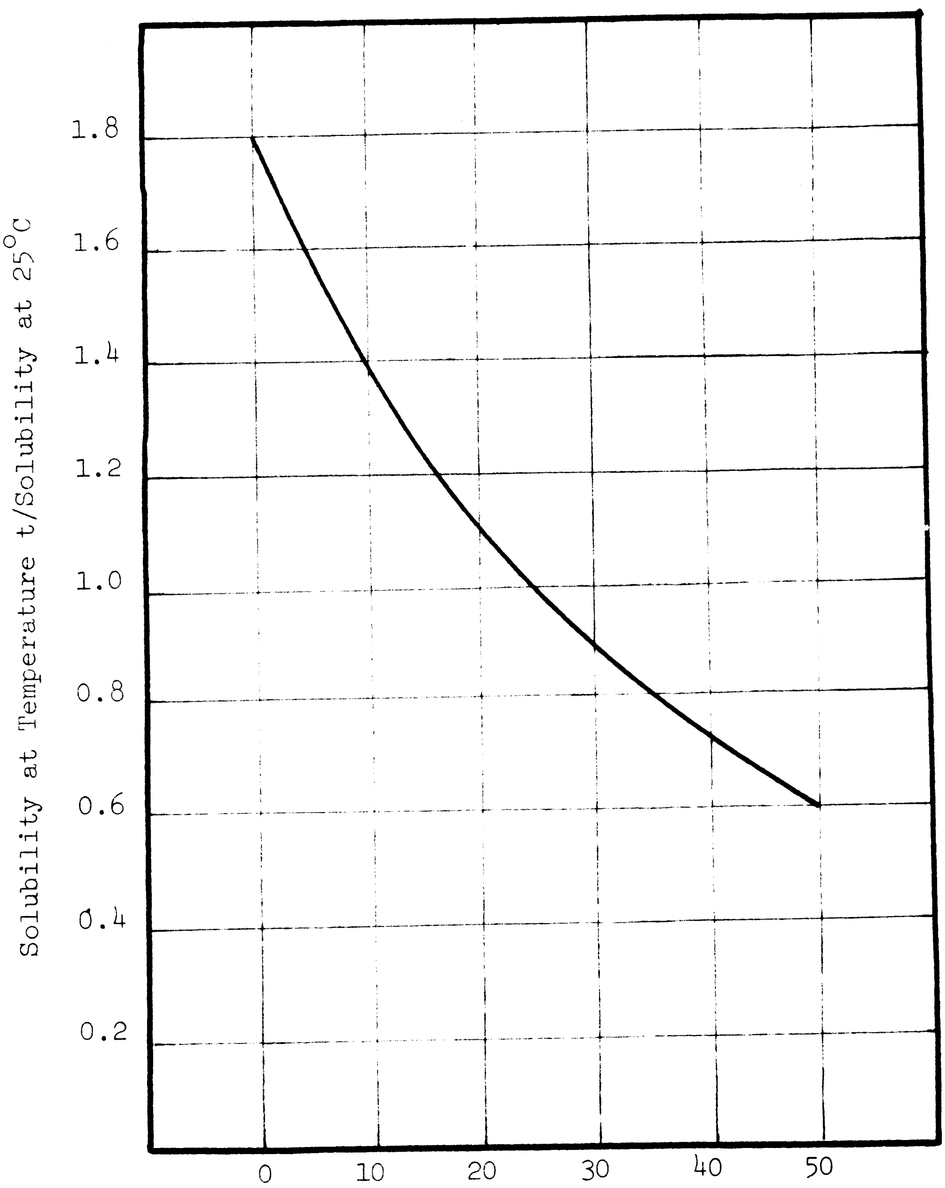
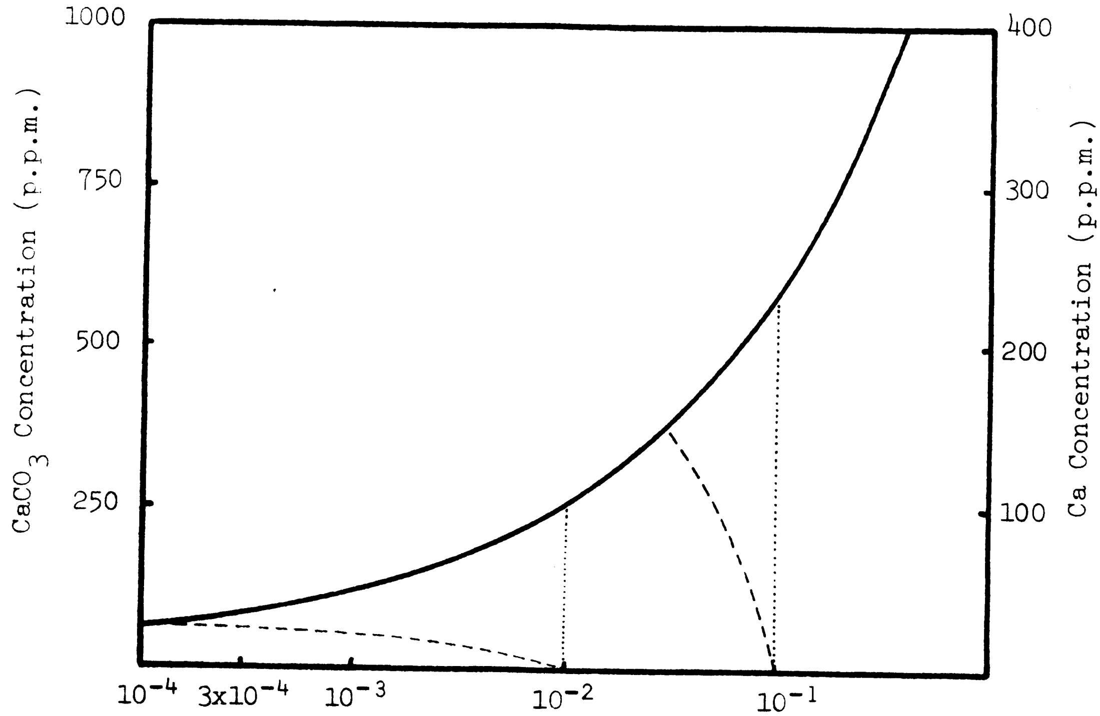


Figure 2 — Effect of temperature on solubility of calcite in water in the presence of atmospheric CO_2. (Hem, 1959)



Partial Pressure of CO_2 (atm.)

Figure 3 – Changes in composition of carbonated water during equilibration with calcite at 10°C in the presence (dotted lines) and absence (dashed lines) of a vapour phase. See text.

(Modified after Holland et al, 1964)

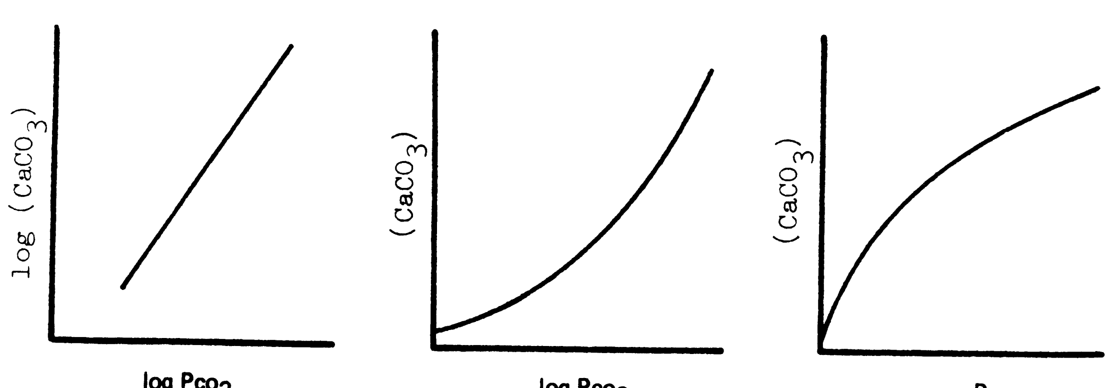


Figure 4 – Standard forms of calcite saturation diagrams. (a) log – log (b) semi-log (c) linear See text.

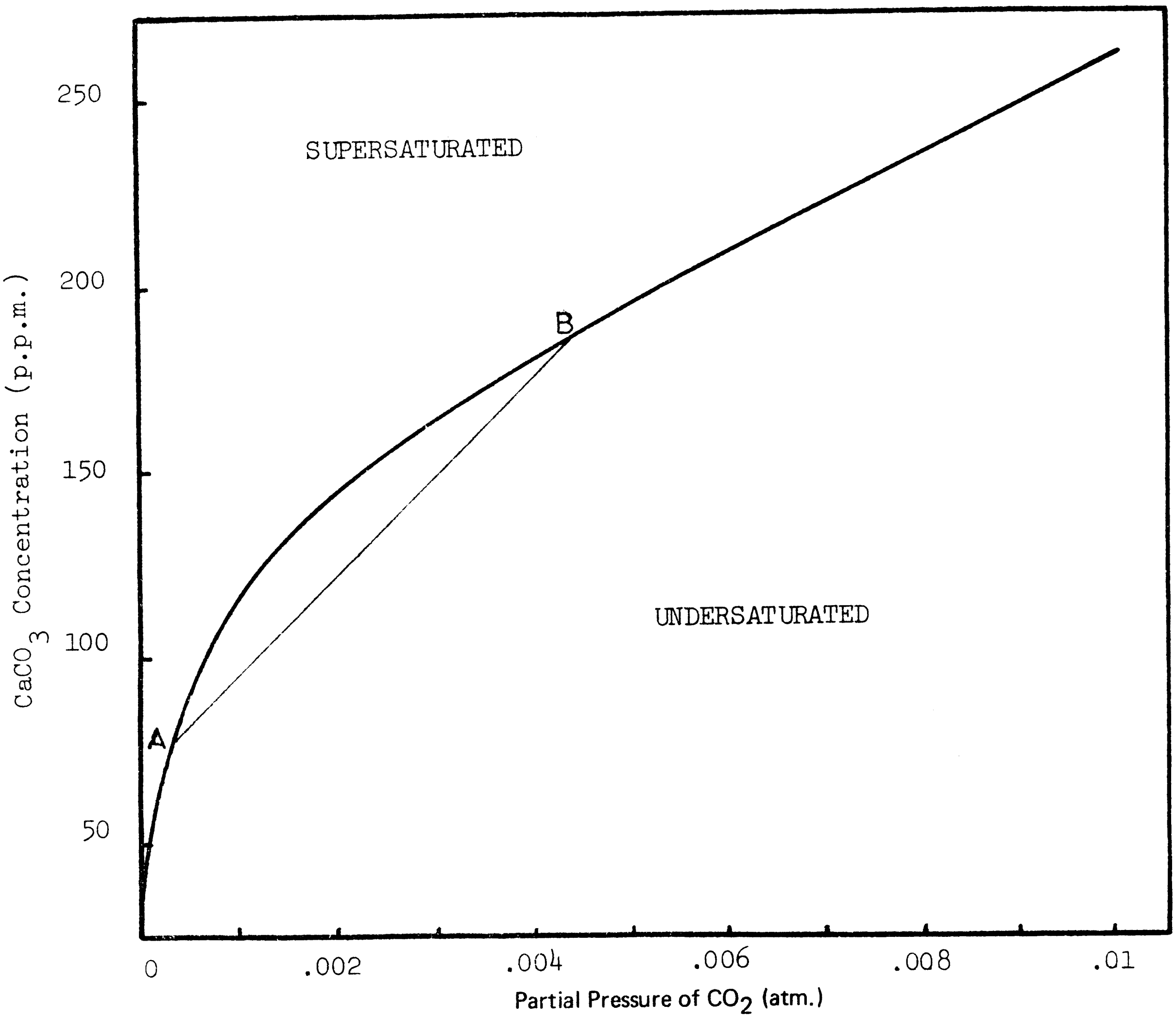


Figure 5 – Solubility of calcite in water at 10°C in the presence of carbon dioxide. See text for explanation.

The mixing effect is probably most important when vadose seepage water mixes with shallow phreatic water. The resulting solution probably explains the common occurrence of horizontal cave systems, apparently formed when completely filled with water, where horizontal geological control is absent (Bogli, 1964).

The Temperature Effect

In (c) above it was noted that for a given partial pressure of carbon dioxide, the lower the temperature the higher the solubility of calcium carbonate (see Figure 2). Hence if water saturated with calcite is cooled, it can then dissolve more calcite, provided that it is still in contact with its atmosphere.

During summer, water infiltrating into limestone may be several degrees warmer than the ground-water body. As it passes through the rock it approaches the rock temperature, and gains additional aggressive power as it cools. Thrailkill (1968) shows that the aggressive power of water, in contact with normal atmospheric carbon dioxide pressure, is appreciably increased by cooling as little as 1C°. It would appear, therefore, that cooling is a likely mechanism for cave excavation, assuming the system is open to a carbon dioxide pressure at least equal to that of the normal atmosphere.

As for the mixing effect, there are several circumstances which may tend to counteract any undersaturation caused by cooling. The kinetics of limestone solution are more favourable then deposition, however, so that even if the net result is no temperature change, or even warming, the temperature effect may still be an effective process in the excavation of caves.

Flow

The chemical process of limestone solution is profoundly influenced by physical conditions. Apart from pressure and temperature, whose influence is obvious, the rate of flow of water in a cave has been considered important by a number of workers. In general, the higher the flow rate the greater the agitation, and agitation favours solution of a solute. This is simply illustrated by the fact that sugar dissolves more rapidly in a cup of tea if it is agitated by stirring.

Kaye (1957) published results of a series of simple experiments which demonstrated clearly that solvent motion is an important factor in limestone solution. When relating his results to cave development he concluded:

> "By comparing the similarity of the plexus of tabular openings of a typical limestone aquifer with an integrated system of tubes filled with water, it can be seen that the velocity of ground-water movement below the water table varies considerably, both from one conduit to another, and within conduits, depending on the role played by the different conduits in draining the system. Because solution rate is affected by relative movement of solvent and limestone, fast-flowing conduits enlarge preferentially over slow-flowing feeder conduits. In consequence a system of openings that were initially all of the same width develops into one of various widths. This certainly must be considered a factor in the solution of large limestone caverns". (Kaye, 1957, p.45)

Another aspect of the influence of flow on cave development was investigated by Weyl (1958). He started with a porous limestone and calculated how far water would penetrate before becoming 90% saturated with calcite. He considered water flowing by laminar flow under gravity down a vertical capillary of given radius. For a radius of 0.02 mm he showed that there is virtually no penetration, while a capillary of 0.25 mm radius permits a penetration of over 1 metre. When the size of the capillary increases to about 1 mm radius turbulence sets in, but by this time penetration is about 500 metres. He also calculated that a fracture will be equivalent to a capillary with radius 0.82 times the width of the fracture, a result which is no doubt more relevant when we are concerned with non-porous limestones.

This particular interest of Weyl's figures is that they show that water can be aggressive after penetrating very considerable distances underground. This is in marked contrast to the conclusion of Bogli (1964), but is to some extent supported by analyses by Back and Hanshaw (1970).

Humic Acids

Many authors have commented on the possible role of humic acids in limestone solution, but in the absence of experimental work have been unable to evaluate their role. Humic acids are extremely complex organic chamicals which are refractory residues in the decay of vegetable matter.

Murray and Love (1929) considered the effects of various low molecular weight acids which occur in plants or are formed by their decay, and they carried out a series of rather naive experiments involving fermentation of leaves. They concluded that "Bacterial action, through formation of organic acids, must be much more effective in making limestones porous than atmospheric carbon dioxide". (Murray and Love, 1929, p.1475). They also comment in their abstract:

> "Experimental evidence shows that, under favorable conditions, these acids may be the most effective solvents of limestone that exist in nature". (Murray and Love, 1929, p.1467)

Although I know of no other work which has been pbulished as yet, further work is presently being done on the geological role of humic acids. This is being done by Mr W. Baker of the Tasmanian Mines Department, Hobart, who at my request ran limestone and dolomite in his apparatus with 0.1% humic acid solution at 25°C. For comparison he also ran them under the same conditions with water saturated with carbon dioxide (closed system). For both limestone and dolomite the 0.1% humic acid solution was approximately three times as effective a solvent as the saturated solution of carbon dioxide, and the limestone dissolved to about twice the extent of dolomite (W. Baker, 1970, pers. comm.).

In another experiment (Baker, 1971, pers. comm.) the solubility of calcite in 0.1% humic acid solution was compared with its solubility under identical conditions in water through which air was bubbled, i.e. an open system with atmospheric partial pressure of carbon dioxide. In this case the humic acid solution was approximately nine times more effective a solvent than the water (10.250 grams calcite compared to 1.175 grams).

A 0.1% humic acid solution is much stronger than would normally be encountered in nature, however humic acids are such potent chemicals that even at much lower concentrations they clearly have a significant role to play. Visitors to western Tasmania will have noticed the characteristic "cold tea" colour of creek water there. This is caused by dissolved humic acids. In this same area the limestone is recessive and usually covered by buttongrass swamps. This is probably due in part to strong solution of the limestone by waters carrying much dissolved humic acid.

The four aspects of the geochemistry of limestone solution considered above are four which I consider important, and generally inadequately known to Australian speleologists. The mixing and temperature effects are especially important as they allow water to gain extra aggressive ability where it will do the most good in forming caves – deep below the surface. The mixing effect also allows a plausible explanation of an otherwise inexplicable phenomenon, the common occurrence of horizontal caves of shallow phreatic origin. Flow phenomena are easily overlooked, but are probably of great importance, particularly in the very early stages of cave development. Very little is known of the influence of humic acids, however it seems probable that in some areas, such as western Tasmania, their influence may be strong.

Much attention has been given to the study of the carbonate minerals, so that a wealth of data is available in the geological and chemical literature. Despite this we seem only now to be getting a reasonable understanding of the geochemical processes operative in forming caves. A proper appreciation of the complexities of the interactions of these processes, however, still seems far off.

Acknowledgments

Permission from W. Baker to publish results of his work on humic acids is gratefully acknowledged. Thanks are due to A. Goede and E. Hamilton-Smith for helpful criticism of the manuscript.

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DISCUSSION

Q *With respect to the work that has been done on the distance that water can travel through a conduit before it becomes saturated – you mentioned that beyond a diameter of perhaps one millimeter the water becomes turbulent therefore the theoretical data starts to break down. Does this turbulence therefore increase the solubility per unit distance and shorten the distance that the water will travel before it becomes saturated?*

A With the change in flow from laminar to turbulent or D'Arcy flow it would increase the turbulence and hence shorten the distance – presumably.

Q *Does this phenomenon of mixture corrosion require water to be under hydraulic head or can it have a free air surface?*

A It will occur in either case. The presence of an air surface would increase the undersaturation. Consider the situation. You have your two bodies of water mixing under air. Having mixed they are capable of dissolving more limestone, but by virtue of the air being present some of its carbon dioxide content will be able to dissolve and hence increase the aggressiveness of the water. So you get solution of the limestone aided by the presence of extra carbon dioxide.

Q *Let's say you have got two saturated solutions, one carrying say 120 p.p.m. and another carrying say 30 p.p.m. How many extra parts per million can the mixed solution take up? I am trying to get this as a kind of measure of the quantitative effectiveness of mixing corrosion.*

A You're pulling figures out of the air and it is very difficult to calculate and certainly not the thing to figure out in my head. Thrailkill actually calculated the effect of mixing corrosion in terms of his "standard undersaturation". At any rate it would probably be easier to glance through his paper later on. Nevertheless in terms of his "standard undersaturation" it is very much greater than the temperature effect. It is very significant.

Q *Noel, you were talking about the formation of the initial cavity and I heard a paper in which it was claimed that cave enlargement was caused mainly during flood pulses, or are you just talking about the initial capillary stage?*

A I'm not only concerned with the initial capillary stage but with cave enlargement as well. The role of flood flow is dealt with by Thrailkill but I chose not to discuss this as one of the aspects presented.

Q *Do you know if anyone has done any sequential measurements of pH as you pass down say a swallet? Presumably the pH ought to become steadily less acid. Starting perhaps with humic acid in the water are any measurements being done on this?*

A You are concerned with the role of humic acids in this?

Q *Well, carbon dioxide would be affecting it too.*

A Consider just humic acids.

C *They would be moving from, well pH 3.5 is the lowest I have found with humic acids and that is an English figure.*

A That would be an average figure.

Q *Do you think it gets as low as that here?*

A What I recall from Bill Baker's solutions, he has gone to great pains to remove stray cations and anions so that it was only humic acid and I think that it had a pH of that order.

Q *How do you determine saturation? Do you use a conductivity meter?*

A In Baker's experiments with humic acids there is no attempt to determine the saturation. The runs were done for a given time. Actually when you get saturation calcium humates precipitate, so actually what you are concerned with is not what the saturation value is but how much it is capable of dissolving in a certain time.

Q *It seems to me that you'd get some idea of the activity of the water by taking a series of pH readings as it goes down. Has it been done?*

A I question that you would learn a great deal from this because you are dealing with very dilute solutions of humic acids perhaps between .01 and .001%, so that probably the pH differences are going to be less than your natural variation anyway, so that it would be difficult to find any particular trend. Also of course under normal conditions you have water from different sources coming in.

C *I did a bit of playing around with pH measurements but we found they weren't accurate. But it will give you some indication of how long the water has been underground and which is going to where, and it might give some additional information which is easier to obtain than by using fluorescein. I have some figures if anyone is interested.*

A I'm inclined to think that you are dealing with such a complex system that the interactions are way beyond our understanding as yet. You are trying to single out one effect from the net result of many things interacting.

C *pH has been found not to be particularly useful because it is strongly affected by changes of temperature as well. There is no set pH at which a solution becomes saturated. What is rather useful is to use a pH meter and then add finely ground limestone to the mixture and measure the pH again and get the difference between a reading where the solution is saturated and a reading where the solution is undersaturated.*

LAVA CAVES IN NORTH QUEENSLAND
EINASLEIGH–MT SURPRISE AREA

by
Alistair Watt

Introduction

During the winter of 1970, I was fortunate in having the opportunity of visiting a caving area which has fascinated me from my first reading of its descriptions in the A.S.F. Handbook (Matthews, P. Ed., 1968): "Undara North; a lava tunnel extending for 16 miles" and "Undara West; a lava tunnel extending for 24 miles". These two impressive sounding caves in the Einasleigh-Mount Surprise area of North Queensland however, are perhaps the least known on the Australian mainland.

Unfortunately, these tunnels are not complete in that they cannot be fully explored throughout their length due to numerous collapses but the largest intact section known at the moment is nearly half a mile in length. No doubt further exploration could produce perhaps the longest lava caves in the world.

The Einasleigh–Mount Surprise Area

The Undara lava tunnels are probably unique in that what might be called a "Grade 4" survey of them is marked on a 1:250,000 scale map, the Einasleigh sheet of the geological series (E/55-9 1962) – a rare scale for a cave survey! The tunnels were actually first located from this map by speleos.

The Einasleigh–Mount Surprise area is geologically part of the largest volcanic "province" in Queensland – the McBride Shield. This huge basaltic plateau occupies about 2,000 square miles in an area 180 miles W.N.W. of Townsville. The plateau consists of Cainozoic olivine basalt, the most recent flow probably being extruded within the last 1,000 years (White, 1962). The general landform is perhaps only impressive for its monotony, with the flat wooded lava plains broken only by mini craters and protruding granite "tors" such as Barkers Knob.

Some 110 craters are associated within the "province", with the two lava tunnels running from a central point, Undara Crater, towards the northern and western boundaries of the area. The tunnels actually originate very near to the main Hann Highway, although this end has never been explored for "enterable" caves.

Formation of Lava Tunnels

The mode of formation of lava tunnels has already been well elucidated by C.D. Ollier (1963) in *Helictite* but a brief summary of the generally accepted theory should be useful as a guide.

Consider a lava flow moving down from its point of extrusion. The surface exposed to the air will naturally cool and solidify first with still molten layers underneath. If the solid surface is then breached further downstream, the lava can flow out leaving the tunnel cavity. This principle is easily envisaged at Einasleigh, with the thin lava roofs and slightly dipping caves following the surface contour.

The Lava Caves in the Barkers Knob Area

Although the lava tunnels are known to stretch over a total distance of over 30 miles, only a very small part of this (in the neighbourhood of Barkers Knob) has been explored and caves entered.

The main cave known, Barkers Cave, is located some 20 miles south-east of the township of Mount Surprise, and is well known to the locals, at least by hearsay. In an article in "Down Under" Henry Shannon (1969) suggests that Barkers Cave is *not* part of the main Undara West Tunnel. He bases this comment on the position of the tunnel relative to Barkers Knob as indicated on the geological map. However, from a study of other available maps it seems possible that a cartographic error occurs on the geological map and that Barkers Cave *is* part of the Undara Tunnel. It certainly follows the same direction as the line of collapses of the Undara Tunnel.

Barkers Cave is situated in a small collapse crater approximately one quarter of a mile from a small granite "tor" – Barkers Knob. This "tor" incidentally affords an impressive view of the non-spectacular landscape, but only the nearby caves can be seen from its summit.

The entrance slopes down over the boulder collapse onto the floor of a huge tunnel 40 feet high and 40 feet wide with a somewhat flattened oval shape (Plate 1). This cave entrance is undoubtedly the most impressive ever seen by the author. A vast passage can be seen extending into the darkness for hundreds of feet, with the walls stained with green, red, black and white bandings. A survey of the cave and adjacent surface features is presented (Figure 1) together with a number of selected cross-sections (Figure 2). The lava roof is only 2′6″ thick at the entrance, so a collapse over a cave this size is not really surprising! From the entrance the cave continues slightly winding for approximately 2,400 feet to

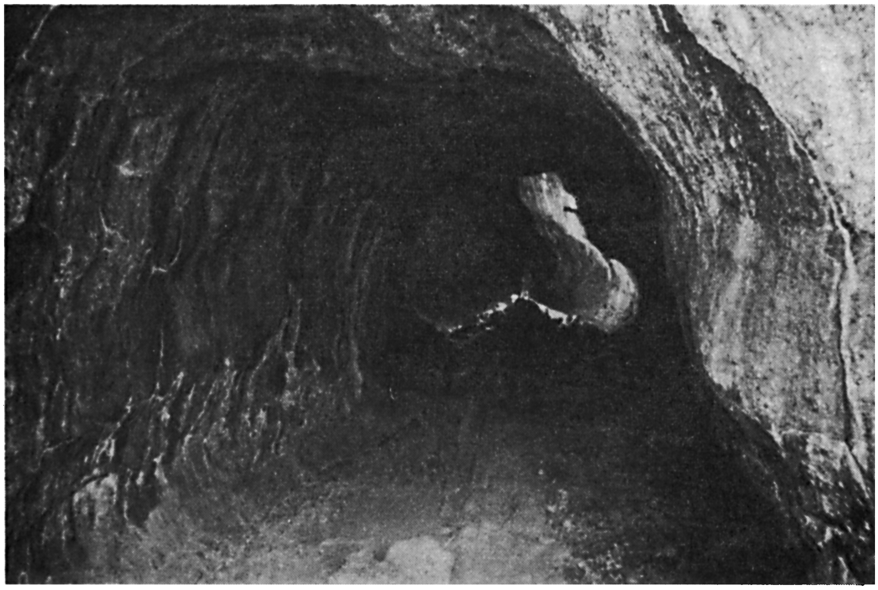

Plate 1. Barkers Cave. The Entrance

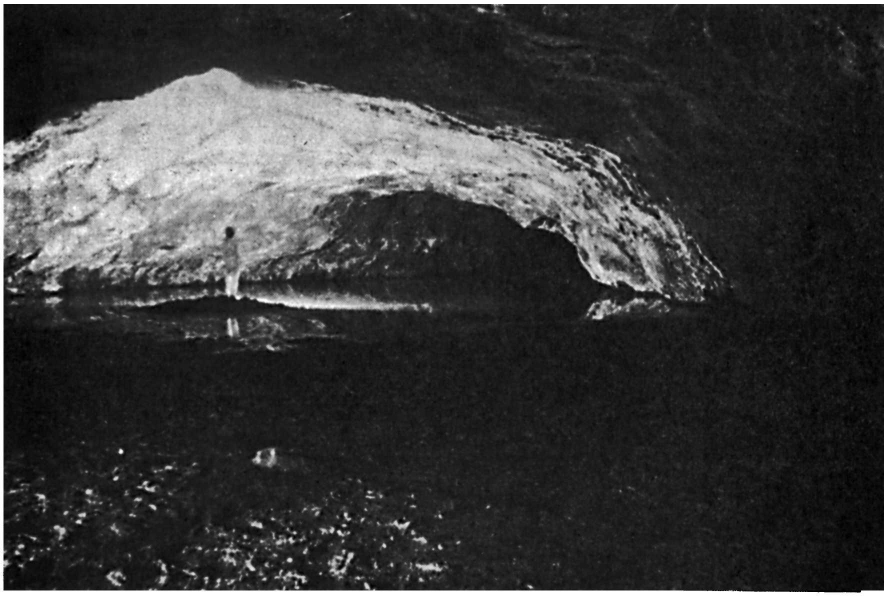

Plate 2. Barkers Cave. Terminal Lake

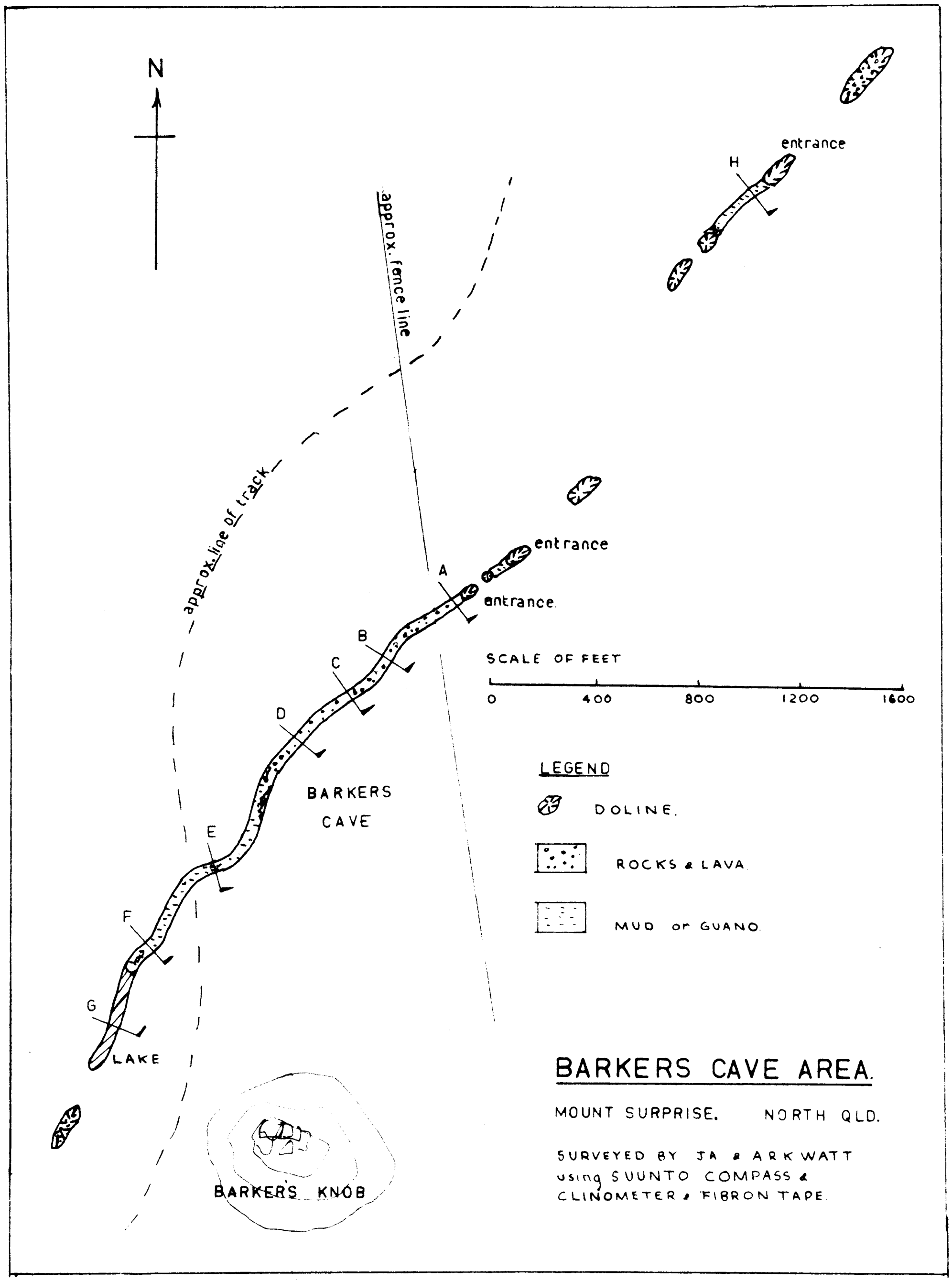

Figure 1 — A survey of Barkers Cave and adjacent surface features

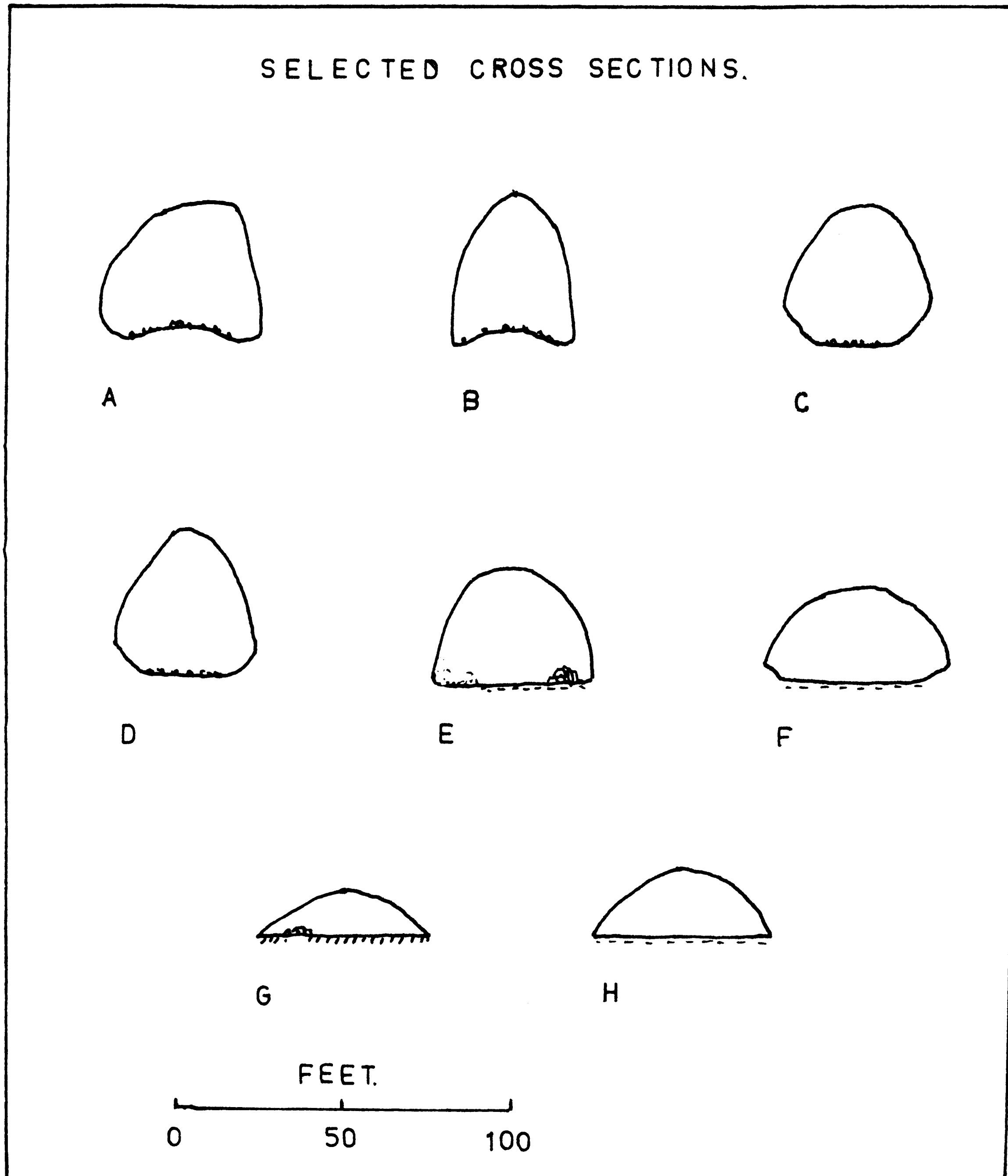

Figure 2 — Selected cross-sections of Barkers Cave. Positions are indicated in Figure 1.

an evil smelling lake seemingly consisting of bat urine (Plate 2). The lake extends for another 250 feet until the roof dips sharply down to meet the water. There are no side passages along the whole length. From the entrance to a point some 1,100 feet in the floor is composed of a solid lava surface. Here a small 5 foot drop occurs and henceforth the floor is mud covered suggesting that the cave fills up further in "the wet". A raised central lava bench (see survey sections) extends some way into the cave. Throughout its length the cave is virtually intact with only two minor collapses where the lava layering is revealed. Near the entrance the walls and floor are covered with a cave-coral like formation which gradually disappears along the cave. Barkers Cave must certainly be the finest example of the simple lava tunnel configuration yet known in Australia, very much dwarfing its Victorian counterparts.

A colony of approximately 2,000 bats inhabited the cave during our visit.

In view of the limited time available we were able to explore only for about two miles along the Main Tunnel on a S.W.—N.E. line from Barkers Knob, but other smaller caves, including one 300 feet long, were found. Other larger caves (up to 1,000 feet long) have been reported by Peter Dwyer (pers. comm.) of Queensland University to exist further towards One Hundred Mile Swamp. "Road Cave", a cave indicated by the manager of Whitewater to be near Iron Pot Creek approximately four miles away, could not be located.

Undoubtedly many more caves remain to be discovered in the Undara West Tunnel area and the Undara North Tunnel has probably never been visited by speleologists.

Access to the Area

Although tracks are shown on the Einasleigh maps, they are extremely rough and on the actual lava stony rises a high ground clearance vehicle is essential. It would only be possible to approach the area in the dry season due to the "black soil" patches and the numerous creek crossings.

The Undara West Tunnel is probably best approached from Whitewater Station on the main (bitumen) Mount Surprise to Mount Garnet road although it is actually on Rosella Plains property. The manager here is a very helpful character and willing to give further details. He, in fact, offered to send out his plane to look for us if we were not back at the station within a specified time. The track from here is ten miles to a vague 'T'-junction with the road towards Barkers Knob faintly visible back to the right. Barkers Knob is approximately 9 miles further along and is easily recognised standing up about 200 feet high towards the left. The cave is on the opposite side of the fence to the Knob. The main tunnel line runs along at varying distances south of the track from the 'T'-junction. If it is only intended to visit Barkers Cave rather than the tunnel area, the best approach would probably be from Mount Surprise. Most other tracks shown on the geological map are now non-existent.

It is hoped that this paper will stimulate some interest in this fascinating area with extremely good possibilities of finding "new caves". A detailed description of location has been given for this purpose. An area of some 130,000 acres including the Undara Tunnels has been proposed as a National Park (Bourke, 1970), however there seems little point in taking the land if no one visits it.

Acknowledgments

Grateful thanks are due to Henry Shannon and Peter Dwyer of U.Q.S.S. for information. They are the only two speleos known to me who have visited the area. I must also thank my wife for assistance with the survey.

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DISCUSSION

Q *Regarding the formation at the entrance, the cave at Bunyah Mountains has good calcite formation, but it is restricted to the entrance chamber where it is in contact with the outside air. Did you find any formation on the inside of the cave?*

A It is just near the entrance of the cave. You get calcite formations in lava caves, there are some in Holy Jump as well. There are some very nice calcite flowers and flowstone in the lava caves there.

C I think there is one point that could be brought out, which I noticed, that is that the lava crust which you see as part of the cave floor is very rapidly buried by sediments. Sediments increase gradually as you go into the cave and in effect that is what the series of sections are showing. Another thing we have found rather interesting is that many of these channels in the mud of the cave were in fact pits formed by water dropping from cracks in the roof. It made quite an interesting pattern, to a greater extent than I have seen in any of the limestone caves.

C We don't really know where the cave is to the nearest 3 or 4 miles, whether the long cave, Barkers Cave, which is half a mile long, is part of those main tunnels. I rather think that the map is wrong, the main tunnel is misplaced and Barkers Cave is part of that tunnel.

Q *This tunnel was located purely by means of aerial photographs?*

A You can't follow it very clearly on the ground. You can only stand at one known entrance and look across and see the next one and walk across and follow the same line all the way through. We did for a mile and a half, something like that.

Q *What is the actual rock when you are inside it? Is it relatively fresh basalt or is it altered in any way?*

A I would say near the entrance it is covered in calcite, further in the basalt skin is exposed. As the molten lava drains out it leaves a skin round the edges.

Q *What I found at Bunyah Mountains was that there was quite extensive secondary alteration of the basalt and it was probably about 50% zeolite type minerals and a residual clayey material. I just wondered if you had found anything like this?*

A No, it is very fresh basalt.

Q *You haven't been to the Mt Hamilton lava caves, have you?*

A I've not been to Mt Hamilton but I have been to a few in Victoria.

Q *They are very complex, in fact is is more a sort of maze. Cliff Ollier has done a survey of it, it was very complex. There must be some other way for forming lava caves apart from the laminar flow theory.*

A Well there is as I said the steam theory. There is evidence for steam cavities in Hamilton Cave, I believe.

C I wonder if there is a feature present that I have noticed in Byaduk Caves. If you look into the dolines there as well as the main cavity going through which generally connects up such as the Church Cave and so on, you always find a number of other tubes going off in different directions, some only going a few feet, some only about 6 feet across and you notice this tremendous criss-cross. You have got small tunnels going here, there and everywhere and at some later stage big ones just cut through this. We are puzzled by this criss-cross.

A Well, for some reason the Victorian lava caves are much more complex than the ones in Queensland as you will see from the survey when it is published. It is just a simple straight tunnel, no side passages at all. This already seems to be covered by Ollier in his article in *Helictite*, but he seems pretty confident that the surface tension effect does bring the lava to a cylinder.

C There is no incompatability between a reticulate floor plan and this surface tension type effect. If you look at river channels which are pretty much the same thing there is great variation in the types that you can have – a reticulate type pattern similar to the braided stream which is like Mt Hamilton or a simple one more like a conventional single channel stream.

Q *As you are going into the cave the sections across it were they towards the supposed source? The shape seems to be going the wrong way.*

A Looking back towards the source the cave was gradually getting smaller.

C Yes, the profile would seem to me to be more consistent with going away from the source.

A No, this is what usually happens in lava caves.

C The profile produced has got nothing to do with the directions of the source at all. It is just that the end of the cave has been cluttered up with sediment. A full section of the lava cave is exposed where you have lava crust floor.

A The cave roof definitely does dip, I am pretty confident of that.

Q *Are you saying that this sediment has been carried in the present entrance?*

A Yes.

Q *The present entrance is downflow?*

A Yes, it is down.

Q *Has there been post Tertiary tilting in the area?*

A No.

C According to the survey, there is a very large collapse not much past where the end of the cave is.

Q *That is a probable source for the sedimentation?*

A No, the entrance is the source of sedimentation.

Q *Are these dolines collapse dolines or could they have been vents?*

A They are collapse dolines.

Q *I noticed you mentioned that there are considerable numbers of bats in these caves. I wonder if there is any evidence of the types of minerals that have been noted in a couple of Victorian caves resulting from inter-action of guano and basalt.*

A It is a possibility finding the minerals. I don't know of any information but it may be possible to find them there. You've got the thick mud and guano.

Q *On your map you showed a series of black marks to indicate I think you said the tunnel. What do they actually represent?*

A That is part of the 4 inch geological map – that is how they show the tunnels.

Q *Does the black represent the dolines?*

A They have just put blobs where the dolines are. They don't show the size of the dolines.

Q *Can you get any indication of the possible length of cave by the distance between the blobs?*

A I would say no.

Q *If I remember rightly you were saying that things go smaller as you went along the line so that you wouldn't have to get these very large tunnels. Did you say this?*

A That is what could happen, yes.

C *And that is towards the source.*

A That is towards the exit.

C *But you started well away from the source.*

A Yes, this is just a thought, but the cave did seem to be getting smaller downflow but the tunnel actually doesn't continue past that point.

C This business of getting smaller as you move downstream is explicable quite easily as far as I am concerned. As the flow gets further away from the source it cools more rapidly.

C I have no argument with that but I thought he was referring to upstream getting smaller which would have been strange.

C You have got to remember you are looking at a small section of the middle of a flow which goes miles in one direction and miles in the other.

AN INVESTIGATION OF A "WATER TABLE" IN THE BUNGONIA LIMESTONE

by

Warwick Counsell *

Introduction

Referring to Figure 1 it can be seen that the limestone plateau south of the Bungonia Creek Canyon consists of one very large eastern outcrop and several narrow belts separated by shale bands. The strike is fairly constant at 10° with the dip averaging about 45°. The limestone is enclosed by folded slates in the east, and quartzite and other metamorphics in the west. In the south, the limestone becomes lenticular and eventually disappears.

The watershed of the eastern outcrop can be sufficiently well defined to indicate that all rain falling on it is directed to one of four major depressions, having a total area of about 200 acres. Four major caves reach a static water level which has been described as the water table. This level shows little change during rain or drought.

Resurgences in the area are very small, many no more than a trickle, except for one, the "Efflux", which flows at a significant, though still small, 0.05–0.1 cusecs. Unfortunately this would appear to drain one of the smaller lenses to the west being separated from the major outcrop by a thick shale band.

In an endeavour to find out what happens to the 29 inches of rain which falls on the limestone each year and drains into the caves, the University of New South Wales Speleological Society with the help of members from the Sydney Speleological Society and the University of Sydney Speleological Society has been collecting information which will eventually indicate how to approach the problem most effectively.

By far the most publicised of our activities in the area has been the introduction, at Easter, of 9.75 kg (about 22 lbs) of the dye, Rhodamine B into the Grill cave (B44) and the monitoring of the red colour through the phreas.

Despite the fact that the stream at the injection point has a discharge of only 0.003 cusecs (about 1 gallon per minute), in less than two days the dye had migrated to the second sump of the Grill cave, a distance of approximately 400 feet. (This cave has two branches, each reaching water.) One week later, the dye was detected in the Drum cave (B13), approximately 700 feet further on.

After nine months of careful observation no sign of the dye has been found in either of the other two major caves – B31 (Argyle Pot) and B4/5 extension (Fossil/Hogans) or at any of the resurgences in the area.

Technique

Existing surveys of the caves at Bungonia are of little use for our purpose, and so we have found it necessary to level through the caves (using hydrostatic or manometric methods) in order to measure very accurately their depth. At the same time due to lack of low level aerial photographs of the area we have had to run compass and tape traverses around the major dolines to determine their catchments.

Fortunately, near to the cave area, there is a farmer who reads a rain gauge every morning and has been able to supply rainfall figures for the whole year (and every year since 1928). Early in the coming year we should be able to install an automatic pluviograph on site and thus enable the exact time of rain to be registered.

Rhodamine B was chosen as most suitable because it can be detected at lower concentrations than can fluorescein or other similar dyes. It is also more stable under alkaline conditions, and is not so readily absorbed into clay (a very important factor for long term work). Furthermore, it is essentially a coloured dye and can therefore be estimated using a colourimeter or similar instrument.

All the dye was dissolved in methylated spirits and transported to the injection point in plastic jerry cans. Monitoring was carried out by the two classical methods, observation and activated charcoal. The latter was placed in all the cave sumps and at all resurgences in the area.

Observations and sampling were limited only by access to the caves. We would have been very fortunate if we had been able to sample every hour for 2000 hours but as it turned out we were lucky to get a sample every two weeks. Whilst none of the caves are particularly severe there is foul air in the deep ones and sometimes samples were taken when the CO_2 concentration was above 3.5%.

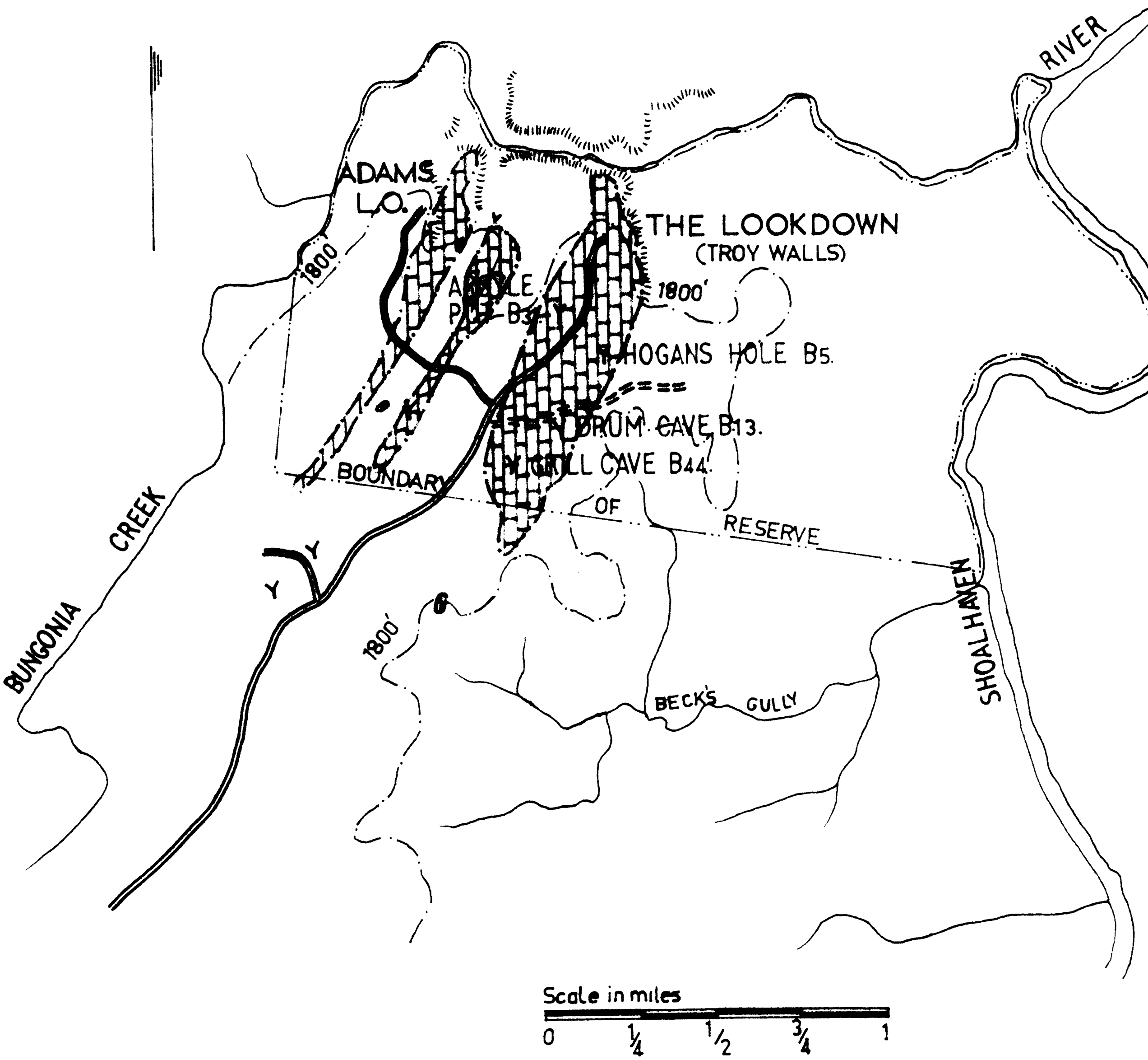
Sampling has continued up to the present but all those which are not discussed were either negative or too dilute to allow estimation of their dye content with a spectrophotometer.

Results

The catchment of the Grill cave is 2,200,000 sq. ft. or about 51 acres, while that of the Drum cave is 720,000 sq. ft. or about 16.5 acres. Therefore, one inch of rain represents 180,000 cu.ft. (for the Grill) and 60,000 cu.ft. (for the Drum) of water over the catchment. Estimating how much of this water is available for flow or percolation through the limestone, to the aquifer, is beyond the scope of this paper and so I am presenting the figures only for reference, not for inference.

* University of New South Wales Speleological Society

Figure 1



LEGEND
CAVES - - - - - - - Y
ROADS - - - - - - -
CREEKS - - - - - -
CONTOUR - - - -
CLIFFS - - - - - -
RESERVE BOUNDARY - - - -

BUNGONIA CAVES N.S.W.

UNIVERSITY of N.S.W.
SPELEOLOGICAL SOCIETY

INFORMATION TAKEN FROM MAPS BY FLINTER & N.S.W. DEPT. OF LANDS. DECEMBER 1970

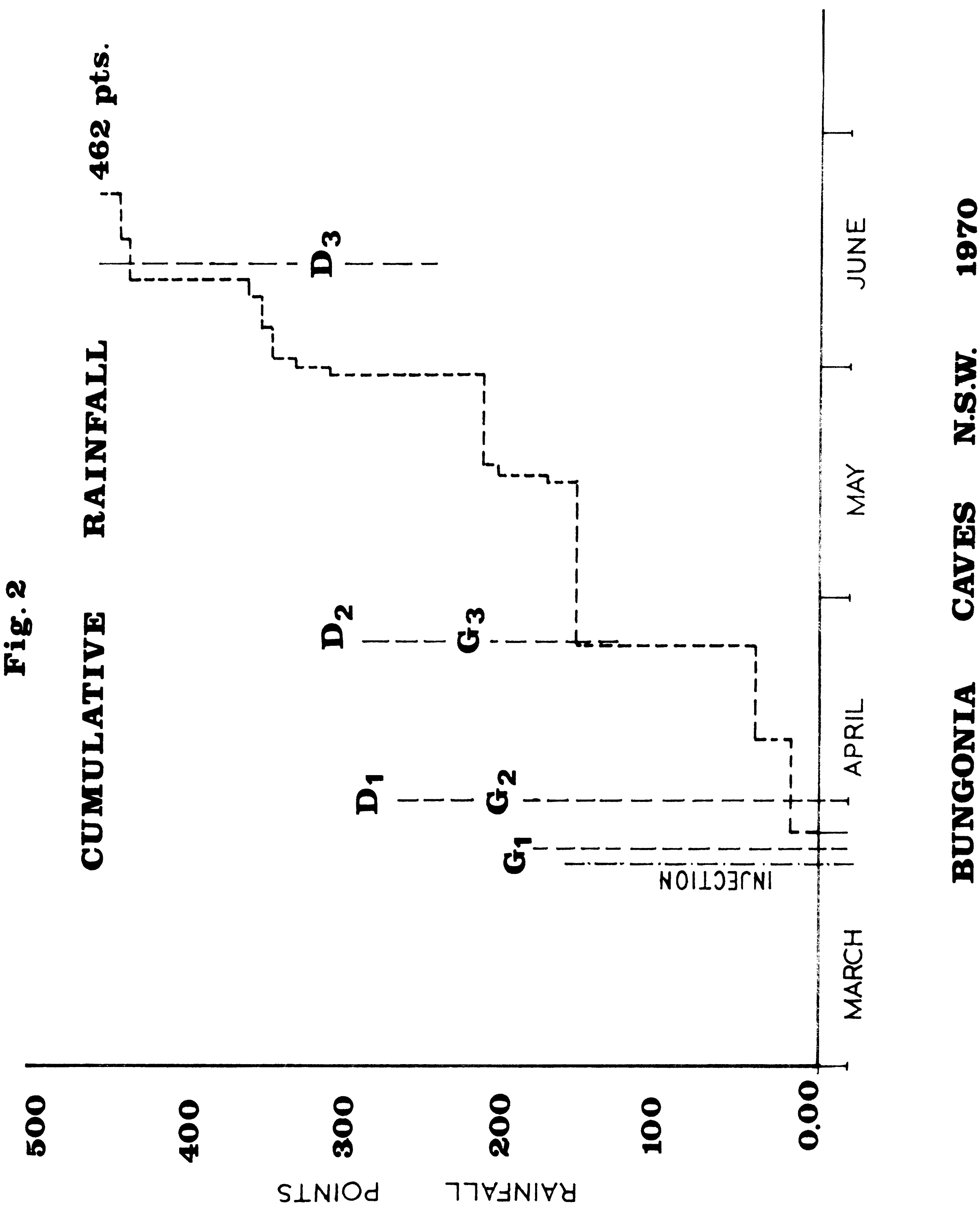


Fig. 2
CUMULATIVE RAINFALL
BUNGONIA CAVES N.S.W. 1970

TABLE I

Sample Date	Grill	Drum	Rainfall	Comment
23/3/70	6.1 kg/cu.ft.	–	–	Initial injection
28/3/70	G_1 24.5 gm/cu.ft.	–	Zero	40 hours
4/4/70	G_2 220 gm/cu.ft.	D_1 2.8 gm/cu.ft	17 pts	
25/4/70	G_3 2.8 gm/cu.ft.	D_2 37 gm/cu.ft.	136 pts	
20/6/70	–	D_3 7 gm/cu.ft.	292 pts	

Table I lists the sampling dates and the absolute concentrations of the useful samples as taken from *both* caves. It also includes the rainfall between sample dates.

TABLE II

Date of Sample	Grill	Drum
28/3/70	G_1 400 cu.ft.	–
4/4/70	G_2 44,000 cu.ft.	D_1 –
25/4/70	G_3 3,500,000 cu.ft.	D_2 264,000 cu.ft.
20/6/70	–	D_3 1,400,000 cu.ft.

Table II states the volume of water which would need to have been added to the original injection of 9.75 kg. to produce the observed concentration of each of the samples.

Discussion of Results

Of prime significance in Table II is the effectiveness of the 136 points of rain which fell between the 4/4/70 and 25/4/70 in flushing most of the dye from the Grill cave into the Drum cave. This indicates very effectively that the Grill is actually "upstream" of the Drum. Also of significance is the fact that despite considerable further rain there is no evidence of flushing of the dye from the Drum further "downstream".

TABLE III

	Date of Sample	Sample	Expected *
GRILL 3(a)	28/3/70	G_1 400 cu.ft.	400 cu.ft.
	4/4/70	G_2 44,000 cu.ft.	31,000 cu.ft.
	25/4/70	G_3 3,500,000 cu.ft.	250,000 cu.ft.
DRUM 3(b)	**Date of Sample**	**Sample**	**Expected ***
	25/4/70	D_2 264,000 cu.ft.	380,000 cu.ft.
	20/6/70	D_3 1,400,000 cu.ft.	1,100,000 cu.ft.

Table III compares the actual recorded dilution with the expected dilution, the latter calculated from catchment areas and recorded rainfall. It will be noted that for dilution in the Grill it is necessary to include only the Grill "injection", but for the Drum, being "downstream" from the Grill it is necessary to include both the Drum and the Grill. The figure for dilution of G_1 is calculated by considering the discharge of the stream at the point of injection as 0.003 cusecs for 40 hours.

* **For reference only.** There are insufficient results to observe the effect any unit amount of rain has on the dilution.

No consideration is being made of the dye losses due to absorption and dissociation which are taking place continually.

The dye moved through the phreas at more than 200 feet per day and with an influx of water to flush it along probably at a considerably faster rate. Yet it failed to appear in B4/5 extension (the sump of which is only about 400 feet away from the Drum) or B31 (1200 feet away), nor did red water resurge at the major efflux in the area (3,000 feet away).

Conclusion

Any preliminary study such as this cannot provide sufficient data for a prediction of relationships between, say, rainfall, catchment and phreatic movement. It can, however, expose a few facts which offer directives to further investigation.

Dye has been used with limited success under conditions of extremely low discharge to show that there is significant flow within the phreas. Despite this evidence of flow, dye does not migrate to the lakes in all caves, nor does it appear at any known resurgences.

There is a definite flushing effect due to large influxes of rain water yet this effect is not uniform, for example, it is not evident in the sump of the Drum cave.

Until accurate levelling proves that there is a common water level in the caves at Bungonia, there is little to indicate that they are all freely connected, or that a water table (perched or otherwise) is present.

Acknowledgments

The writer is grateful for assistance given by Ian Wood, Ron Allum, Andrew Pavey, David Barnes and other members of U.N.S.W.S.S.; Joe Jennings, Julia James and various other people from S.U.S.S., S.S.S. and C.S.S.

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DISCUSSION

C *I think your dilution factors are doubtful. Seventeen points wouldn't have provided very significant rain. I don't think you have proved your water flow from Grill towards Drum Cave. You have not disproved water tables being common to all the other caves because the others could flow towards the Drum too.*

A That is right, if the Drum dye lasted for so long it had obviously not been diluted. Now the catchment of the Grill and Drum Caves is a total of about 2,900,000 sq. feet while the total catchment of the four major depressions is in the order of 9,000,000 sq. feet. If you are interested in the technique that I use for estimation of why there would be even dilution throughout the whole lot I will discuss it later. The expected dilution if they were flowing towards the Drum would be many times greater than what we did get.

Q *O.K. The connection is downstream from where you put the dye in the sump then where is the connection between the other two caves?*

A If it is true that means that none of the caves there are level. Now if they are not level and this is not a water table there is no flow. The water that was in the Drum just doesn't move even after the 20/6/70 that is, three months later, the dye that was in the Drum was still at quite a high concentration so obviously there is no downstream. If something represents a watertable there then it is the Drum level, that is the only thing it can be. The other caves can't be upstream because if they were upstream there would be more water than there is. If they are downstream then either the water in the Drum would move faster because it would continue into this hypothesized further link or otherwise the dye from here would have to move into them.

Q *My suggestion is, the Drum is the furthest downstream of all the caves you have seen, the Drum water could well be a backwater . . .*

A It is almost certainly a backwater.

Q *. . .but that any connection between the caves occurs downstream of the Drum Cave. Now the next question is: Have you seen the dye since . . . ?*

A No, it has not appeared anywhere.

C *. . . because I have for many years had a hypothesis that the water would not appear in the Bungonia efflux.*

A Of course it won't appear in the Bungonia efflux. This is something Joe Jennings has mentioned. It is quite clear that the efflux does not drain this since it runs at approximately 30 times the flow of the little stream in the Grill. If the water can travel 700 or 800 feet in a week then surely it is going to get there in at least a month since it is only another 500 feet further, but there is no sign of this. We have monitored every efflux in the area, but this study is not to investigate which efflux. It is to investigate exactly what the watertable is like and it proves that there is just not a watertable.

Q *Did you expect otherwise?*

A The thing is that one has got perched water. Whether it is a perched watertable or just puddles is something that is important to what we are trying to do. We intend to put level recorders at each sump and we are negotiating with the Water Board to install a pluviograph to continuously monitor the exact time of the rainfall. Then by the momentary rising of the sump, if it rises, we will know when it is reaching the actual aquaflow and this is important.

SEARCH AND RESCUE IN TASMANIA

by

D.F. Turner

Extensive areas of rugged country in Tasmania present many difficulties which from time to time have received a good deal of attention. To minimize such problems the Hobart Walking Club has produced an excellent pamphlet called "Safety in the Bush" which is issued free by the Health Education Council of the Health Services Department in Hobart and I strongly recommend it to you if you are planning to visit some of the remoter parts of the state.

The mountain areas of western Tasmania containing most of our caves are prone to sudden, extreme changes of weather and the danger of death from exposure is an ever present hazard. The victim of exhaustion and exposure can pass with startling suddenness from a state of consciousness to unconsciousness and death particularly underground where darkness, cold and very wet conditions are often combined (commonly called the "Tasmanian effect" by local cavers). We should always take every possible precaution to reduce the risk of a search and rescue call-out. However, humans being what they are a search and rescue organization is essential.

In Tasmania the police are charged with the responsibility for land search and rescue operations and it is their duty to organize search parties. The Commissioner of Police has appointed Superintendent Tom Howard for this task and he has a small specialist body of men to effect small scale searches. In the event of a large scale search he can call upon a core of experienced members from various out-door clubs be it caving, walking, climbing, skiing, etc. In such cases the police provide mainly liaison and assistance.

Procedure

On notification from the police the civil co-ordinator moves to police headquarters where a search and rescue room is available containing telephones, maps etc. This is manned by both police and civil personnel and acts as a centre of information for parties leaving for the search area by keeping in constant touch with police already in the search area. Decisions are made here concerning the optimum size of the search party, the number of back up personnel and the kind and amount of logistical support required.

The police on the recommendation of the co-ordinator can ask for army support which usually takes the form of mobile communication units – landrovers equipped with walkie talkie sets – and supplies of field rations. Because of changeable weather conditions in Tasmania speed is essential but movement of searchers into the search area must be strictly controlled as too many well meaning but incompetent volunteers can cause loss of time.

Operational requirements

The needs for efficient operations can be seen as:

(1) The establishment of effective communications between police headquarters and the search area.

(2) Quick organization of a reconnaisance team to get into the search area to assess requirements of equipment and personnel.

(3) Back up teams for relief and widening of the search.

(4) Stretcher and track-cutting parties to assist doctor or first aid people to carry out the rescued if needed. Rainforest and button-grass plains in remote mountain areas can pose quite a problem.

(5) Areas remote from a road may require the establishment of road head and forward base camps and logistical support such as tents, food, cooking equipment and medical aids.

(6) Most equipment such as ropes, ladders, climbing gear, lights, etc. is usually supplied by the clubs. Special gear, wireless communications and aircraft can be supplied on request by police, army or civil defence.

(7) Control of the mass media. This is a job for a public relations officer or journalist who issues regular statements on behalf of the police or search and rescue co-ordinator. These must be accurate as much harm can be done by ill-informed reporting. Co-operation with the press and clear, concise statements of facts are the best way to avoid being misquoted.

Outdoor clubs can reduce the need for search and rescue by better instruction and training of their members. Make it a habit to notify your club secretary, president, family or friends where you are going, with whom you are going and when you expect to return. Remember the life you save could be your own! The keyword is PREVENTION. Remember that most search and rescue work can be avoided by training, careful planning and the application of common sense. Before going bush a little thought should be given to the simple rules laid down in "Safety in the Bush".

Why the police?

They have the organization and the ability to call on government resources as well as being in a position to obtain the release of essential search and rescue people from government –, semi government –, and in some cases civil employers. All search and rescue members called out by the police are covered by workers compensation in this State and at present a system of reimbursement for loss of pay incurred by search and rescue teams is being investigated. If successful it is hoped that this will further improve the efficiency of our search and rescue efforts.

Conclusion

There will always be people who get lost or injured in the bush or in a cave but remember that a team effort of search and rescue carried out quickly and efficiently utilizing the best resources of man and woman power can frequently bring things to a successful end. Sometimes search and rescue can be a frustrating and dangerous operation and more often than not it is not a member of your club who is involved. Accidents do happen so be prepared and always have your equipment ready for immediate action.

IMPORTANCE OF COMMUNICATIONS IN A CAVE RESCUE

by

Peter Robertson

Because of the large number of people generally involved in a cave rescue it is most important that everyone knows exactly what their job is and to whom they are responsible. Without this knowledge confusion will most certainly result.

But this is not all that is needed. A reliable and accurate means of passing information and requests is also required — hence communications.

The means of passing messages falls into several categories:

A
The most common and simplest is by **word of mouth** between two people. If however, three or more people become involved in passing the message then each may shorten or lengthen it depending on the person and it may even lose some of its original information.

This will cause all sorts of complications during an emergency through loss of time and wasted effort.

Therefore all messages should be written down concisely and then passed on for delivery. It is also a good idea to have the reply returned on the same piece of paper as confirmation.

B
The second method is by **visual signals.** However this method can be too easily misinterpreted and should be avoided in a rescue unless all else fails!

C
Written Message — this method should be the most accurate as no distortion of the message content can occur between the two parties concerned as it passes through many hands, but it is slow and liable to loss or damage and is therefore not completely satisfactory for cave rescue work particularly if the cave is long or wet.

D
Telephone — this allows fast, accurate and reliable passing of messages with no interference, and is most certainly the best system but it requires the physical effort of laying a cable from the outside control centre to some convenient point close to the scene of activity underground. It can also require vast lengths of cable.

E
Radio telephone — or two way radio as it is commonly known, is certainly the most flexible system of giving point to point communication and if set up and operated with strict control can match the telephone system.

Its main limitation is that it is unpredictable in its ability to reach the inside of a cave and therefore should not be relied upon as the primary cave to outside communication path.

It is however the only efficient way of despatching and controlling search parties and supplies outside the cave and its use and operation will be considered here.

Considerations when choosing a radio telephone system are:

(i) terrain — flat or hilly
(ii) area of coverage — square miles
(iii) access — roads or walking
(iv) siting of the base station.

Terrain versus frequency:

Flat country: HF (high frequency) and VHF (very high frequency) will work well but VHF can suffer if the communications path is between two vehicles and the country is slightly undulating. But a good VHF base site will overcome this problem.

HF suffers particularly in limestone areas because of absorption in the ground and because of the low power of the transmitter and inefficient aerial systems used. VHF is good on all these points.

Hilly country: VHF works very well as signals will bounce off hills and be reflected into valleys but like all radio systems dead spots will be found. Moving a few feet or yards will quite often restore communications.

It should be noted that the Country Fire Authority of Victoria and E.F.S. of South Australia have changed to VHF.

Area of coverage will vary from state to state but it will generally be found that a blanket coverage can be obtained for a radius of three miles using VHF regardless of the terrain and up to 15 miles with selected sites. I might add this is back to a base station. Car to car will need to be almost line of sight.

Access to an area will determine the type of equipment used. If vehicles can reach within easy distance of a cave entrance then the use of mobile radios is recommended. These can then take the role of a secondary base or relay station.

Portable sets are very effective for short distance communications, i.e. across paddocks, but can not be relied upon for longer distances.

Siting of the VHF Base Station radio. This is the most important link in a radio system as all control comes through it. It is very important to position it where the maximum coverage can be obtained. The aerial should be as high as possible so the top of a hill is the best position.

Operation of a radio telephone system

The P.M.G. issue the licence for operation and allocate the base call sign and frequency, e.g. V.S.A. has the call 3DM base.

This must be used by the base on each call and each mobile must call back to the base giving the mobile call sign and the base call sign.

Both C.E.G.S.A. and V.S.A. have chosen the phonetic alphabet as call signs for their mobiles with no overlap so that if mobiles are moved in from one area to another no confusion can result only the base call sign will change for the visiting mobile.

Therefore a mobile calling base will call Alpha calling 3DM base. The base would then answer 3DM receiving Alpha.

If both parties receive loud and clear then messages can be passed. Messages are completed when the base answers 3DM out.

Other mobiles can then call base.

Persons using radios should speak clearly and into the microphone and say *over* when their message is complete.

In a recent search and rescue exercise at Buchan the radio system consisting of a 10 watt base radio installed at our hut using a 50 foot mast with a ground plane aerial and five 10 watt mobile sets and two 27MHZ portables was used extensively to control personnel.

The base under the control of the S. and R. leader despatched four cars to selected caving areas. These vehicles were parked at positions where good reception could be obtained back to base. These then became local control stations. Each party was told that four blasts of the horn meant that they must return to their control car. They then commenced their search pattern.

In an area where a control vehicle could not get good reception a relay vehicle was available to bridge the gap but was not required and was then used as a messenger vehicle for supplies etc.

In an area where a vehicle could not gain access, two portable units were used; one left at the control vehicle and one with the party.

As it turned out this area was the one that the rescue took place in. The party reported back to the control vehicle the situation and the equipment required. The control passed this to the base who then recalled the remaining vehicles and directed them to the rescue area. The messenger vehicle brought the requested supplies. A telephone was then run into the cave and back to the portable radio thus completing the final link.

In conclusion from personal experience, VHF seems to be the best system.

Equipment is small and can easily be transferred from one vehicle to another. Aerials are more efficient and small in size and can be gutter mounted.

High power for the transmitters and a good base site all go to make a simple easy to operate and reliable radio telephone network for search and rescue.

DISCUSSION

C *In the practice rescue that CQSS had on Limestone Ridge they had three parties with mobile radios from the police but they had also borrowed some from the Railway Department used on the coal trains. We were able to borrow five at once. They had three inside the cave which overcame any problems there.*

A Their radios worked O.K.?

C *They had no trouble at all.*

A I have only tried one portable 10 watt unit in a cave and it worked very well. In fact over a distance of a quarter mile but that was only one instance.

Q *What frequency were you using in that instance on your communications inside the cave? The citizen band 27 MHZ works well along a straight passage but it won't go through more than about 10 feet of limestone.*

A I don't know what it is, I would suspect it is VHF.

I The trouble is the higher the frequency, the less penetration. For cave communications you need the low frequency around 500 KHZ.

Q *Were your portable transceivers the same frequency as the base units in your vehicles?*

A No, they were 27 MHZ units.

Q *Can you get the pair for the one frequency?*

A Yes, but they cost about $430.

C The cost of these units is a bit less than the 27MHZ we are using. The other point is that it is often an advantage not to have them all on the same frequency. You get so much coming through that one base station can't handle the whole thing, and you have got walkie-talkies going plus your main unit. If you can separate them it is probably a good thing in many ways.

Q *What are the prices of the units that you are using?*

A I too work for a very good company.

C *When you apply for these radios on the same frequency you stipulate on the application form the frequency you want explaining that your area is a country area and you are not going to use your radio in a metropolitan area.*

A If people are considering this, it would be a good idea to standardise because each group can move into another area and we are all on the same channel. In places like the Nullarbor it all comes in handy. Strictly speaking it's illegal but this is beside the point.

Q *Do you use these radios on a normal weekend's caving?*

A Yes.

Q *Is it also a consideration that the higher the frequency the less wattage you need for a given coverage?*

A If it is line of sight the power does not matter. We try and work on line of sight as much as possible, but you are right.

A REVIEW
SOME RECENT ADVANCES IN CAVING EQUIPMENT AND TECHNIQUES

by

Andrew J. Pavey*

Synopsis

A review of new equipment and techniques, which covers karabiners; tape; anchor devices–pitons and jam nuts; abseiling–brake bars and variations; prussiking–knots and mechanical devices, their use, with particular emphasis on Jumar techniques; belaying–glove belay and mechanical devices, Sticht brake, brake bar, Jumar.

Introduction

The aim of this review is to acquaint Australian cavers with some of the advances, in both equipment and manufacture and use, made by climbers in recent years. These techniques and equipment usually percolate through to the Australian caver extremely slowly–due partly to isolation and partly to conservatism.

A Karabiners

The most important development in karabiner manufacture has been the production of light alloy karabiners which are as strong (and in some cases much stronger than) steel karabiners, whilst being much lighter. They are manufactured by several reputable companies – Cassin, Stubai, Chouinard. Strengths are approximately 2000 Kg – e.g. Cassin have two models, red gate – 1800 Kg, blue gate – 2200 Kg. They are available with screw gates, but these do not seem popular.

British Mountaineering Council tests in 1963-4 revealed the following Karabiners with a minimum strength of over 3000 lbs with *gate closed:*

1. ASMU 'D' (8,800 lbs), Simmond 10mm Oval (3780 lbs), Cassin 1800 Kg 'D' (3770 lbs), ALLOY 'D' (NA), 1300 Kg 'D', Hiatt 'D' (5750 lbs), Marwa Kidney (3065 lbs) Stubai 'D'.
2. ONLY the ASMU 'D' exceeded 2000 lbs sideways.
3. ONLY ASMU 'D' (2840 lbs), Marwa Kidney (2780 lbs), Hiatt 'D' (2600 lbs) approached requirement of 3000 lbs with gate open (Blackshaw 1965).

Many of these brands showed variations over several karabiners. Some of the karabiners tested broke with loads as small as 300 lbs.

B Tape

Tape is available in two basic constructions – stiff (i.e. solid) and tubular (i.e. hollow tube, usually flattened).

Type	Size	Material	Strength	Use
Solid	½"	Nylon	1000 lbs	Tie-offs on pitons
	1"	Nylon	2000 lbs	Abseil slings, etriers etc.
	2"	Terylene	4000 lbs	Waistlines (Fig. 1)
Tubular	½"	Nylon	1750 lbs	Crackers, tie-offs etc.
	1"	Nylon	4000 lbs	Anchor slings, etc.

The most useful to cavers are the 2" terylene (seatbelt webbing) which is used for waistlines. 1" nylon for abseil slings, prussik loops, etc. The tubular tapes are generally softer and stronger. All tapes abrade fairly easily so care is essential. 'Tiger's Web' which is coloured pink has a safety weave such that when it has lost 35% of its strength white flecks show through the pink.

Tapes should always be joined by the 'tape knot' (Fig. 2). This knot should be tightened under load before use.

* University of New South Wales Speleological Society.

Fig. 1
Waist harness—constructed from 2" webbing waistband and 1" webbing thigh loop (Swami Seat). Karabiner links two together. Webbing tied with tape knot.

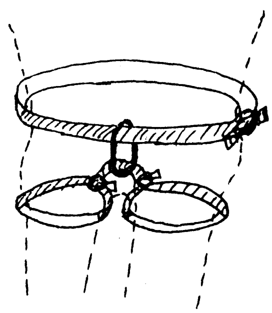
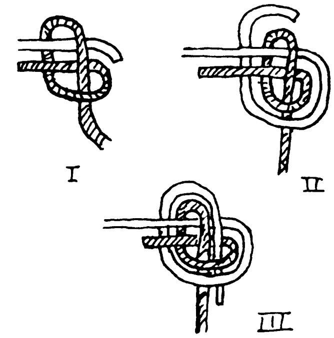


Fig. 2
Tape Knot, tighten before use.



C Anchor devices

1. Jam Nuts

The latest concept is that of the 'jam'. This usually takes the form of a metal block which is inserted in a crack which narrows in the direction of the expected loading. Thus the block is easily inserted in the wide section of the crack (and removed) but under loading it jams in the crack.

The strength of this arrangement is very high, during testing it is usual for the sling through the jam to break first.

These jams are available in a large variety of sizes, shapes, etc. The most common is the cracker which consists of a piece of hexagonal duralium rod, with tapered ends and with holes for a sling through the short axis. The larger sizes have lightening holes to reduce their weight. The slings can be tape (stiff or tubular), rope or wire rope. A certain stiffness in the sling can be a great aid in placing jams in difficult cracks, for this purpose the wire slings are best, followed by stiff tape. A large selection can be carried varying in size from ½" x ¼" up to 4" x 2". The size is limited only by the imagination of the manufacturer and the ability of the caver to carry it. The larger the number the better the chance that you will have one that fits the crack that you are standing next to. For illustration of use, see Figure 3.

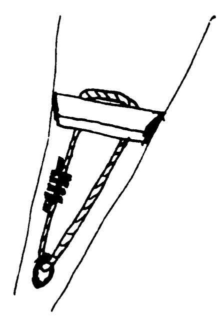
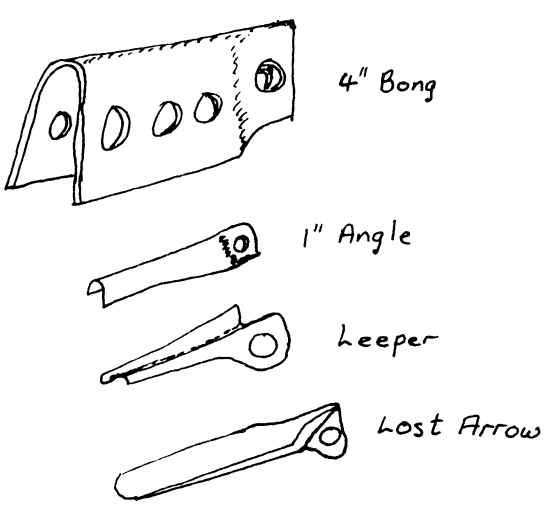


Fig. 3
Artificial chockstone placed in narrowing crack.

2. Pitons

Fig. 4 — Modern Chromolly Pitons



Recent development (mainly by the Americans, Yvon Chouinard and Ed Leeper) in piton design and materials have produced incredibly strong modern pitons. These are made of (aircraft quality) chromium molybdenum steels, which combined with high quality control have produced pitons which may be re-used perhaps 50 times (unlike the older soft steel types which may be re-used often only once or twice). Despite exhaustive searches, it would appear that nobody has reported a Leeper piton broken in service in the years since they were introduced.

Piton shapes have also changed slightly. Angles and their larger stablemate 'Bongs' are essentially 'U' section. Leepers have a 'Z' section (Fig. 4). The four bearing surfaces of these give enhanced grip in difficult situations. Angles should always be placed with the 'U' upside down (in horizontal cracks), never sideways—due to the springiness you will have difficulty in removing them.

Chromolly pitons are produced by Chouinard ('Lost Arrow', 'Bugaboo', 'Bongs', 'Angles'), Leeper, Dolt, Stubai and Hiatt.

Hitens pitons are of nickel-chromolly steel.

Prices vary with size and manufacturer—generally in the range $A2—$3.

3. Bolts

These are an essentially Australian contribution, especially the keyhole bracket (Thrutch, Sept/Oct 1967). See Figure 5.

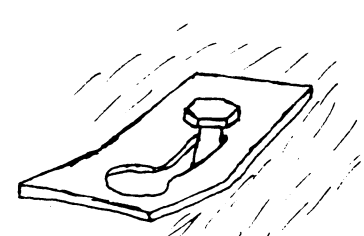


Fig. 5
Keyhole bracket on bolt.

The 'Bolt' is simply a high tensile bolt hammered into a hole in the rock slightly smaller than itself. If part of the thread is filed off the lower end, placement is easier. It is also useful to use a small piece of plastic pipe to blow the rock dust out of the hole after you finish with the rock drill. The strength depends on the quality of placement and on the rock strength. Ideal loading is transverse.

D Abseiling

The traditional method of 'Classic' and 'Over the Shoulder' have been superseded by the use of brake bars. These cause far less damage to the rope and provide more control of descent rate. The brake bar derives its frictional braking effect from bending (not twisting) the rope.

The brake-bar itself is an aluminium bar which is slid on to the karabiner so that the rope can be quickly inserted and once in place cannot be removed under tension (see Fig. 6). Either ½" or 1" angle pitons or two karabiners clipped across one another can also be used (see Fig. 7 and 8).

Gloves (leather) are recommended. Fast abseiling is possible but should be avoided, the heating effect on karabiners etc. is quite high and could easily cause thermal damage to the rope. The brake-bars should not be used on non-monofilament ropes – especially Manilla.

Should a caver lose control during an abseil it is possible to stop the fall by pulling down on the abseil rope from the bottom (see Fig. 9).

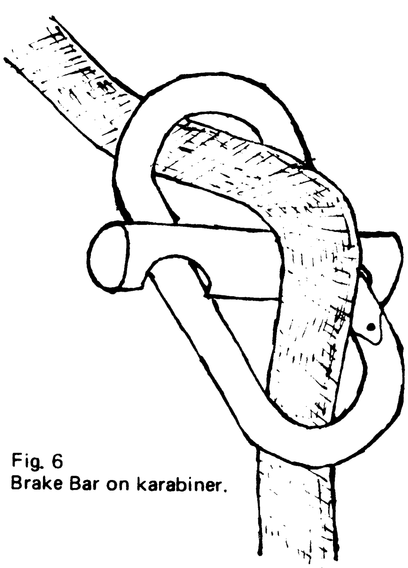


Fig. 6
Brake Bar on karabiner.

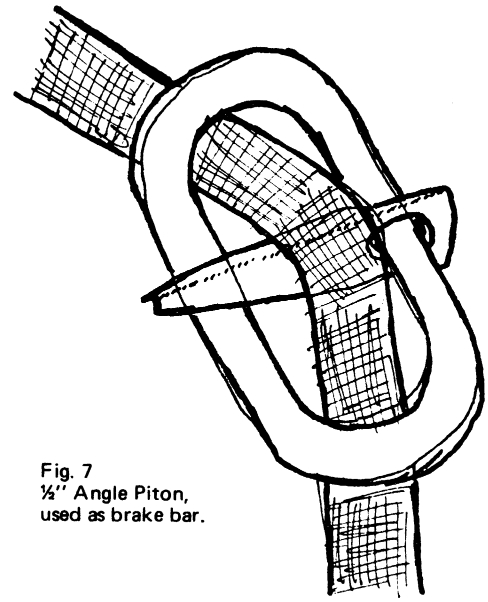


Fig. 7
½" Angle Piton,
used as brake bar.

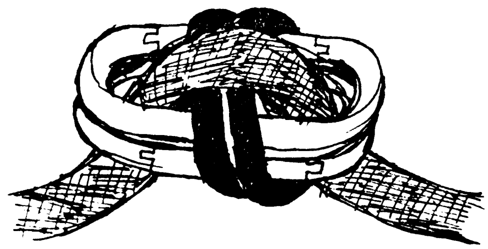


Fig. 8
Crossed Karabiners.
Note reversal of gates
of the karabiners.

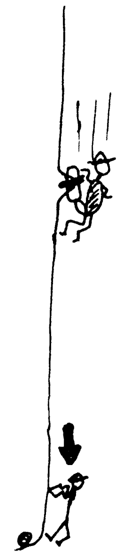


Fig. 9
Stopping an uncontrolled abseil
by applying downward force to
rope from below.

E Ascending

The traditional method of safely ascending a rope was to use three prussik knots. These have now been augmented by other knots such as the Pemberthy knot and by mechanical devices. The main reason for this seems to be ease of use. The prussik knot is often slow and difficult to loosen.

1. Knots

(i) Prussik knot

Attributed to a Prussian (Dr Prussik). See Figure 10. It is safest in the 6 strand form (as shown) but can be used with only four turns. It is often difficult to loosen after is has been heavily loaded.

(ii) Bachmann knot

This uses a karabiner as a handle (see Fig. 11), very easy to loosen hence better than a standard prussik knot.

(iii) Pemberthy knot

This is a relatively recent addition by Larry Pemberthy of Mountain Safety Research(USA), loosens easily, has excellent grip. Its main disadvantage is that it must be tied in a length of rope—the ends of which are joined to make a sling.

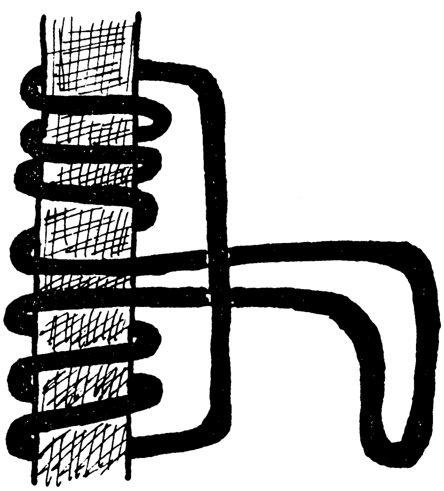


Fig. 10
Prussik Knot — 6 loop version.

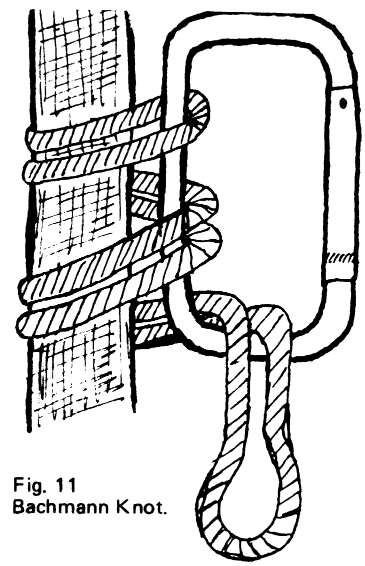


Fig. 11
Bachmann Knot.

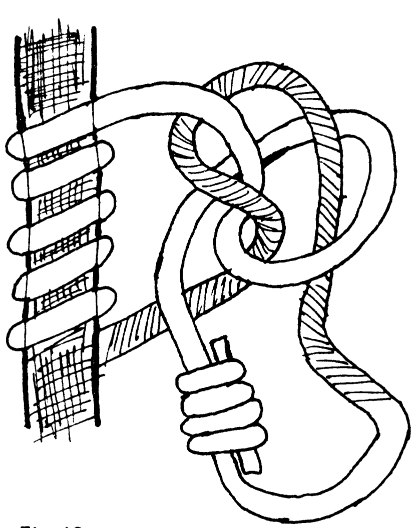


Fig. 12
Pemberthy Knot.

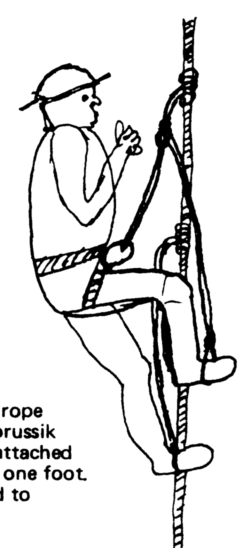


Fig. 13
Method of attachment to rope using 3 slings but only 2 prussik devices. Top ascender is attached to both waist harness and one foot. Other ascender is attached to remaining foot.

2. Mechanical devices

(i) Hieblers (Austrian)
These are the simplest and least safe, also the lightest and cheapest (see Fig. 14). Grip is essentially by bending the rope whilst under load. There are no 'teeth' or 'ridges' to enhance grip. Later models have a 'safety lock' which is a most insecure piece of wire (hopefully) designed to stop the main rope from slipping out.

(ii) Jumars (Swiss)
The most complicated, expensive but useful of the mechanical prussikers. Their leading advantage is the ease with which they can be removed to continue past knots etc. on the main rope. Also, due to the handle, they protect the knuckles whilst prussiking against the face. Grip is partly by bending of the rope, but mainly by an eccentric cam covered with 'teeth'. These are (nominally) softer than the rope and should not damage it. The safety clamp is spring loaded and easily manipulated with the fingers. They are tested to a load of 660 pounds (?? NSS News Feb 1969). See Figure 15. (Cost $21 a pair, includes airfreight from Scotland.)

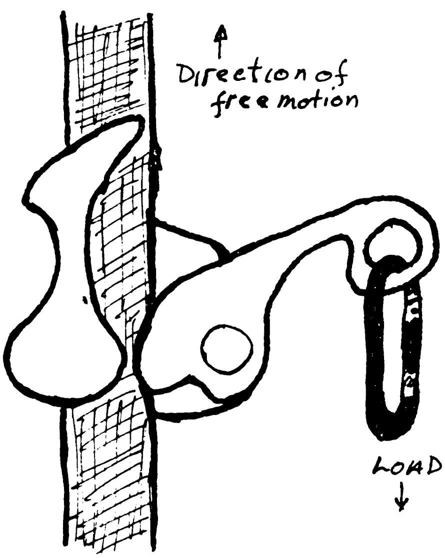


Fig. 14
Hiebler prussiker.
When weight is applied to the karabiner the eccentric cam is forced to clamp the rope.

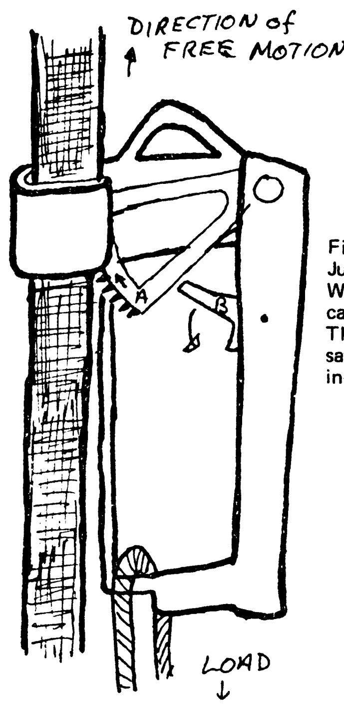


Fig. 15
Jumar ascender.
When loaded the toothed eccentric cam (A) engages and clamps on the rope. The rope cannot be removed until safety catch (B) is pulled down, as indicated.

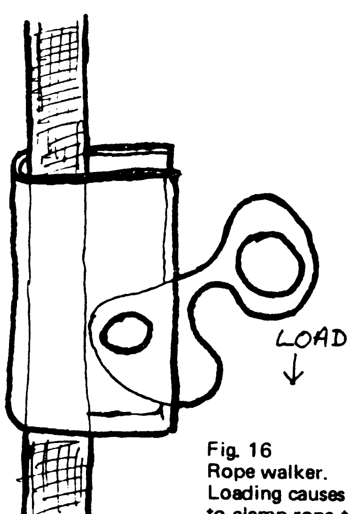
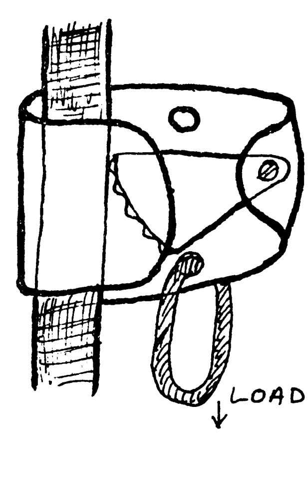


Fig. 16
Rope walker.
Loading causes eccentric cam to clamp rope to inside of 'U'-shaped housing.

Fig. 17
Clogger ascender.
Eccentric cam clamps rope inside 'C'-shaped housing under load. The rope cannot be removed whilst karabiner is clipped in.



(iii) 'Rope walkers' (USA)
The more popular of the American attempts to 'build a better prussiker'. These were originally designed for cave conditions, in contrast to (i), (ii), (iv) which were designed for mountaineering. They consist of a 'U' section aluminium plate, with an eccentric cam with 'one or two' ridges. The cams must be removed to insert the rope—the most major disadvantage. They are tested to 1000 pounds. (Cost $US14.50 a pair, add freight.)

(iv) Cloggers (British)
These are very similar to the 'rope walker' (see (iii) above), however the use of 'C' section aluminium plate enables the rope to be inserted without removing the eccentric cam. They cannot be removed from the rope when a karabiner is in place. (Cost $A8.50 each.)

(v) Mechanical ascending device (USA)
This is a 'one-off' device at present and is mentioned here for comparison. The MAD is powered by a 2HP, 2-cycle gasoline motor. It has an integral centrifugal clutch and gearbox, and a home-built transmission driving a Vee groove pully. For control there is a twist trip throttle and an instant stop button. There is also a built in Jumar cam to stop any descent. Technical figures are: 2 mpg; 150 lbs load @ 37 ft/min.; weight 23 lbs. (Cost approximately $US120.)

3. Comments on techniques of use

We thus have many methods of attachment to a rope such that force in one direction results in gripping, whilst force in the opposite direction produces sliding motion. Hence using two slings with the appropriate knot or device at the top we can ascend a rope (see Fig. 13).

Jumars are very popular with mountaineers and are the most useful of the mechanical devices.

Although speeds as high as 80 ft a minute have been claimed for the prussik knot, the mechanical devices can be used to attain much higher speeds. Using Jumars in the 'ropewalking' position (see Fig. 20), we have attained speeds of 150 ft/min. It should be noted that these high speeds cannot be continued for any distance due to physical fatigue. If used correctly, however, there can be considerable saving in energy by prussiking as opposed to ladder climbing.

The method we (UNSWSS) have developed is a combination of 'rope-walking' and the 'Yosemite' methods (Appendix 1).

One Jumar is attached directly to the foot (Fig. 18), as closely and tightly as is comfortable, the other is held in both hands and has two slings — one to the waist harness, the other to the remaining foot (see Fig. 19).

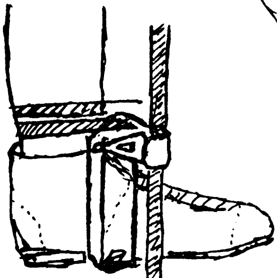


Fig. 18
Detail of attachment of Jumar to foot.

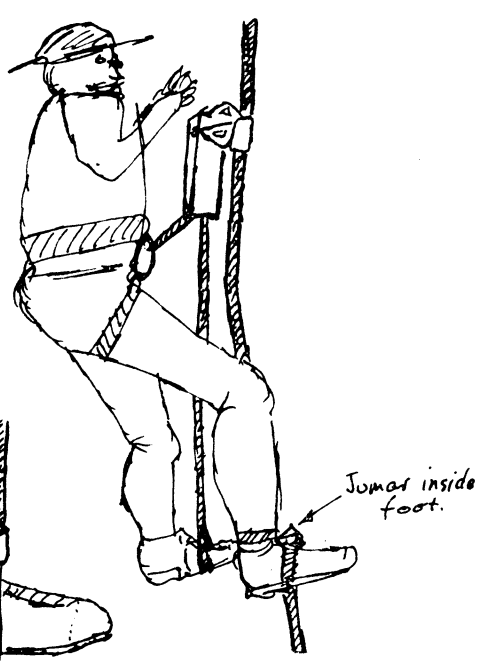


Fig. 19
UNSWSS method of prussiking using Jumers. One Jumar on foot (right), other foot in sling from upper Jumar.

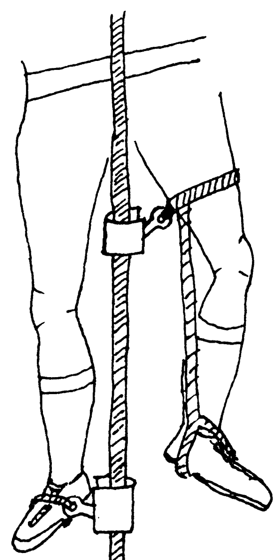
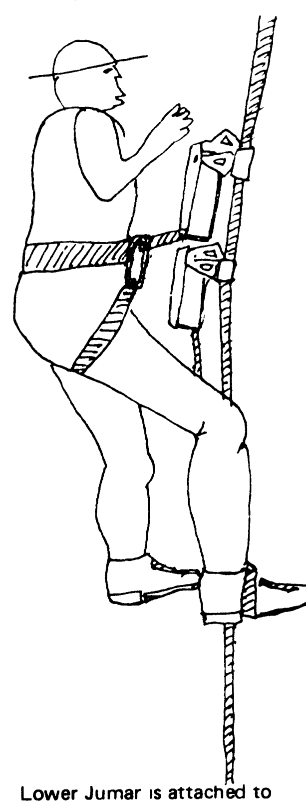


Fig. 20
'Rope Walker' set-up.



Lower Jumar is attached to lower foot. Upper Jumar to waist harness only.

The sequence of movement is to grip the upper Jumar and move the lower foot up, then stand up whilst pushing upper Jumar up till the waistline pulls tight, then move lower foot again. A good rhythm can be maintained and resting on the waistline is very comfortable, should it be necessary.

4. Rope

For prussiking on long face walls it is necessary to have a rope with zero twist and stretch. We use a Terylene multiple plait rope (i.e. a 'kernmantle' construction) 1½" circumference, breaking strain 38 cwt. The stretch of the rope is 4' in 300' (i.e. 1½%).

5. Comparison of abseil/prussik *vs* ladders

Abseiling/prussiking in caves is only for the experienced. It involves costly specialist equipment and to be effective all members of the group should own their own equipment. The abseil/prussik method is of considerable advantage – both in bulk and weight – over the ladder technique and becomes more so as the lengths of individual pitches become greater and caves become harder of access – especially in mountainous regions.

If we neglect common factors such as waist harness and two karabiners plus rope (for belaying on the ladder or prussiking) the weight of equipment necessary for each technique is:

(i) Prussiking – brake bars and karabiners for abseil,
Jumars and slings for prussiking,
weight: 3 pounds (regardless of length of pitch)

(ii) Laddering – ladders and traces, weight: 12 pounds per 100 ft.

It is obvious that where weight is a factor the abseil/prussik method must be preferable.

On a cost basis:

(i) Abseil/prussik – terylene rope: $27/100'
Jumars: $21 a pair
tape: $3
5 karabiners: $11.50

(ii) Ladder – (Bonwick) ladders are $75 a hundred feet (at cost)
Manilla rope: $3/100'.

Hence the longer the pitch the cheaper it is to use the abseil/prussik technique.

F Belaying

The latest belay techniques have taken away the emphasis on taking the strain on the belayer's body and have transferred it to the belay anchor. It is therefore necessary when using these techniques to be confident of the security of the anchors.

(i) Glove belay.
The belay rope is passed through a karabiner attached to the anchor and then back parallel to itself. The two strands of rope are gripped by gloved hands. Frictional braking is achieved by the rope rubbing against itself and also in the small radius around the karabiner. The closer the hands are to the karabiner and the tighter the grip the greater the braking effect. The heat is spread along the rope and does not cause local heating problems in synthetic ropes (see Fig. 22).

(ii) Sticht brake.
The sticht brake (a German innovation) is merely an aluminium plate with a slot of the size appropriate to the rope in use (approximately 3 diam. long and 1 diam. wide). The loop of rope is pushed through the slot and clipped into the anchor karabiner. The brake plate normally has a light cord to stop it sliding down the main rope. Braking is obtained simply by separating the two (parallel) parts of the belay rope, friction is developed on the plate and karabiner (Fig. 23).

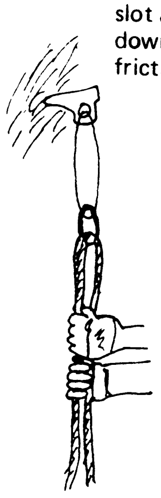
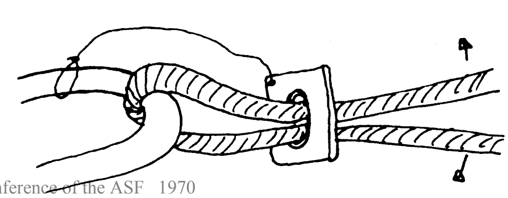


Fig. 22
Glove Belay.
Rope is gripped in both gloved hands–close to karabiner.

Fig. 23
Sticht Brake.
Braking effect increases as ends of main rope moved apart.



Both (i) and (ii) are essentially dynamic methods which can also be effectively used for second belaying as well. They are easier to use for leader belaying however.

(iii) Brake Bar.
A brake bar can be used for belaying. The brake bar and karabiner are attached to the anchor and rope is easily paid out or stopped. This method is best used for belaying down a pitch – taking in is inconvenient (see Fig. 24).

(iv) Jumar.
A Jumar can be used for belaying up a pitch. A weight must be attached to the 'top' of the Jumar so that the rope slides through the Jumar when taking in (see Fig. 25). The Jumar will naturally grip as soon as any downward force is exerted on the rope.

Fig. 24
Brake bar used as belay

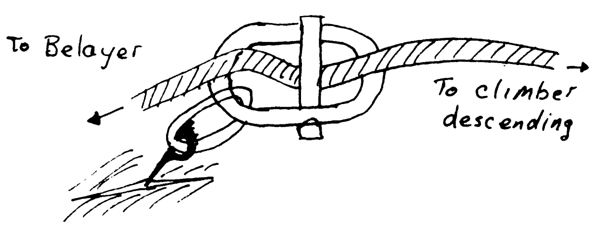
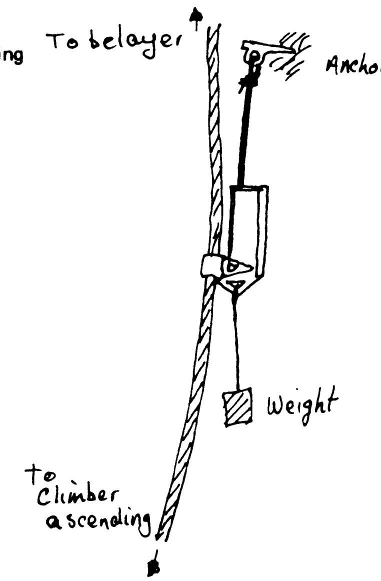


Fig. 25
Jumar used for belaying



APPENDICES

1. Ropewalking technique

One of the ropewalkers (see (iii)) is attached closely to one foot, the other is strapped (elastically) to the other knee with a sling to the foot. The knee attachment is only to keep the ropewalker in place – the foot takes all the weight. A third sling is placed between the waistharness and a prussik knot on the rope (for safety reasons). See Figure 20.

The technique is to 'walk up' the rope using the arms to maintain balance. It is only recommended for about 40 ft. before resting. The technique seems to be very tiring on the arms.

2. Yosemite method

One Jumar is connected directly to the waistharness, the other is a long sling to one (or both) foot.

The technique is – stand up on a foot sling, sliding waist Jumar up, sit back on waistharness and move other Jumar up, then stand up etc. See Figure 21.

Notes

1. Tests by the Americans (NSS News, Feb 1969) suggests that the ropewalkers are best for caving, they are cheap, virtually failsafe, carry higher test loads and cause less damage to rope.

   However, they are not nearly so useful for general purpose outdoor sports. Jumars have extensive use in hauling, rescues, belaying etc. They are easier and quicker to use and have several attachment points.

2. Americans use 3/8" (diam.) polypropylene hard-solid braided rope (Sampson 2 in 1?).

3. Load-unload cycle tests show that for the ropewalkers (at least) most of the weight when prussiking is taken up by the outer sheath of the rope. The cam reduced the strength of the rope by 50% and eventually broke the outer sheath of the rope. This is attributed to unequal support by the housing and the cam ridges on each side of the rope.

4. Never wear a pack whilst prussiking – it is extremely tiring.

5. 'Cable laid' refers to rope constructed of several strands (usually 3) twisted around each other). 'Kernmantle' construction is a central core surrounded by a braided sheath (to protect the core from abrasion).

6. Jumars can be used for hauling equipment (or bodies etc.) in the following manner. One Jumar hangs upside down held in position by a weight, the rope passes through this Jumar and thence through a karabiner above. A second Jumar with a foot sling is used to pull the rope through the karabiner. The leg muscles do all the work. The first Jumar holds the load between movements of the second Jumar (Fig. 26).

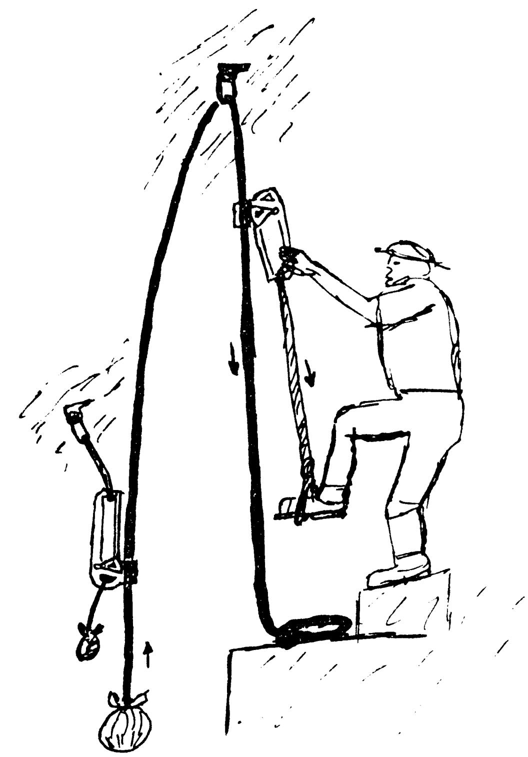


Fig. 26
Use of Jumars for equipment hauling. Leg muscles do the work. The lower Jumar supports the load whilst upper Jumar is moved up.

3. Availability of equipment

All the techniques referred to in this review require items of modern specialist (rockclimbing) equipment. Duty on many of these items was recently relaxed, so that lower prices at Australian retailers have generally resulted.

Equipment may be obtained from:

Infinity Equipment P.O. Box 137, Toowong, Qld, 4066	– Extensive stocks of tape, crackers, pitons, karabiners, cloggers, ropes, etc. Good mail order service.
Paddy Pallin Pty Ltd 69 Liverpool St, Sydney, NSW, 2000	– Small selection of karabiners, tape, crackers, rope, etc.
Mountain Equipment Pty Ltd 167 Pacific Highway, North Sydney, NSW, 2060	– small selection of karabiners, tape, crackers, rope, etc.
Graham Tiso 44 Rodney St, Edinburgh 7, UK.	– Jumars, tape, karabiners, rope, Hieblers, etc. Excellent, fast air mail order service.
Gibbs Product Co. 854 Padley St, Salt Lake City, Utah 84108, USA.	– rope walkers

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DISCUSSION

Q *I noticed you tend to use pigskin gloves exclusively in belaying. Do you find there is any danger of the natural oils in the gloves reducing friction? The oil makes it sort of slippery on the surface especially when they are wet.*

A We haven't experienced any troubles with this at all. Gloves are highly recommended especially for belaying.

Q *Are they leather or pigskin?*

A These are leather.

C *I have used pigskin gloves for rockclimbing and in practice it is safe. We have dropped a 150 lb odd weight over a cliff and stopped it within feet using the dynamic belay so there are no worries.*

A I usually wear gloves when I go caving mainly to keep my hands clean to take pictures. I have found it extremely useful. Even if you get mud on the gloves you can still very effectively use them on belays so there is no problem.

C *One more thing about these dynamic belays, we have had a bit of practice with B.R.C. in Brisbane, belaying lengths of rail and nearly everyone made the mistake of stopping the piece of rail too sharply which in actual use would probably break their patient's back.*

A I agree with this entirely. If you are going to use the dynamic system of belaying and make it dynamic you have to let the rope run through for a while. This makes it much easier on the person.

C *Alloy karabiners – there are three or four brands on the market that won't open under load. This would be convenient but could also be inconvenient and very dangerous too. The Simmond especially and the Cassin you have illustrated would be very difficult to open. Pitons– I have a report from National Engineering and one of the things pointed out is that chromium-molybdenum pitons in hard rock such as limestone can't be used anywhere near the number of times that you have mentioned – perhaps four or five times.*

C If you hammer a bolt into a hole and keep on hammering you will notice that the head starts to rock back and forth when you get it in too far. It seems a lot of people keep on pounding it, setting up a nice little stressed area near the head of the bolt exactly where the stress is going to come onto it if anything happens. Brake bars emphasize twist in a rope. They push it down the rope till you get to the bottom end and if it is a big drop you have yards of rope twisted around itself and this can be quite inconvenient. I have used brake bars extensively now for four or five years and this is a major disadvantage.

Q *What type of rope were you using them on?*

A Both kernmantle and nylon.

C The karabiner brake bar is a bit doubtful. There is a danger of the karabiner sliding up into the opposite gate unless you are using screwed ones which I noticed you weren't in the photograph.

C In Queensland we use four karabiners and oppose the gates on both pairs.

C I would like to emphasize that this type of thing is for experienced people. This goes for virtually all the techniques that have been described – you have to practice them first.

Q *I noticed that you were using kernmantle perlon for prussicking. Have you any views on this? Most people tend to think it is not wise.*

A I wasn't using kernmantle perlon for prussicking. The rope we were using for prussicking is terylene of kernmantle construction.

C *It is this kernmantle construction that is worrying me. I am concerned about the outer sheath removing itself.*

A I agree. This is brought out in the written paper. I decided not to cover several of these minor points in the talk since the details are in the published version. The Americans did tests on their rope walkers which showed that the outer sheath breaks leaving the inner sheath virtually untouched, but all the stress is on the outer sheath when you are using one of these devices.

C *I have been using pigskin gloves extensively on an Outward Bound course and taking numerous falls over three or four weeks. After a while the gloves glaze which can be most embarrassing.*

A I would expect the glaze to be removed if you were using them for caving.

C Terylene ropes can produce a fair amount of friction on the hands and whilst there are techniques of using brake bars it is very easy to pick up the end of the rope and produce a large increase in friction which can be very painful if you are not wearing gloves.

Q *Is there much likelihood of banging your knees continuously against the walls when prussicking with these clamps on a straight wall without any overhang?*

A It depends on the technique. If you are multiple limbed you can get away with it quite easily. We noticed this at the top of Big Hole. The Jumars are especially handy as opposed to the cams because of the handle construction, you can just move the Jumar up without smashing your knuckles. When you are using them on your legs you have to develop a different technique (demonstrated). This in effect produced a greater gain in height per movement when near the rock because I was only pulling the bottom leg up till it was straight and then leaving it, whereas when on the upper section you lift your foot higher to get your knee around the wall and therefore you gain over a foot on each movement which speeds things up tremendously.

C *I have been using the Black's figure of eight, it is a beauty for twisting the rope though it is about the only one I know that you can lock very easily which does prove rather useful, especially if you have somebody in trouble on a ladder. Has any work been done on figure of eights, whether they are good or bad?*

A I don't think anyone has actually done tests on them. My personal view is that I don't like them because they put the rope through too much of a bend.

C With brake bar abseiling if something does happen to someone while they are abseiling, there are two techniques you can use to get around this problem. If you have a Jumar, a cam or something else on the rope above you to which you are attached when you get hit and become unconscious your natural reaction is to let go and if this device is attached to your waistline it will stop you immediately. Alternatively if there is someone standing at the bottom and they haul heavily down on the rope while someone is using a brake bar or figure of eight this will effectively slow them down. The Americans have averted several major accidents and turned them into minor ones by using this technique.

Q *Do you think there is a danger of excessive stress by three way load to the karabiner from the abseiling sling waist loop connection?*

A No, three way load never develops because of the tape. When you arrange it you have to set it for your own shape. My things are set to fit me. When you put the karabiner in the two inch tape the one inch tape will sit in the bottom of the karabiner. There is no problem with three way loading. If you try to put it on someone else with a bigger waist say, the slings may be a bit too short and then you have a possibility of three way loading.

Q *It is not excessive three way loading, is it?*

A It shouldn't be. It is only your body weight.

C *The point about using a terylene rope as opposed to kernmantle is that terylene stretches very much less than nylon and therefore the problems of the rope abrading on the rock in the time that you come up are reduced.*

A I had 120 feet of kernmantle Mammutt climbing rope about 11 mm (standard climbing perlon ropes stretch about 25% under loading) and I was prussicking about 70 feet. It was running over a sandstone edge and very little attempt had been made to pad the edge. By the time I reached the top there was a horrible hole in the sheath and it had started to cut into the core – this worried me. We avoid this here by using protectors around them. They are lengths of water hose which are hung on the rock at the point where you expect wear. After the last person has abseiled you insert the rope in it for prussicking up. You usually don't get any wear when abseiling as long as you move smoothly. The rope is simply put into this piece of hose where it will rub over the rock. This ensures that you don't rub the rope on the rock while you are prussicking because virtually all prussicking techniques will involve a constant rhythmic loading on the rope. Terylene rope stretches about 1½% which is pretty good compared to 25% for kernmantle and about 40% for nylon. So you get very little bounce.

Q *I notice your protector is split directly along its length. Would it not be better to put a helical split in it?*

A I wouldn't be sure about this.

Q *Do you use plain bolts rather than expansion bolts?*

A We rarely use expansion bolts.

Q *Do you find it quite safe for ladders?*

A Yes. The only person I saw who did any tests on this was Bryden Allen from the Sydney Rock Climbing Club, who privately circulated a short paper on it in which he maintained that a standard high tensile bolt driven into a hole was better than an expansion bolt.

Q *Have you found that the driving fatigues the bolt?*

A They have found that this doesn't essentially weaken the bolt driven straight in. The other point is that Terriers, Rawl plugs etc. are highly expensive whereas you can get the standard high tensile bolt for 5 cents at the local hardware store, which makes it incredibly cheap. There has been a big controversy in Sydney climbing circles over placing bolts. They consider that they deface the rock as they are a permanent feature which is why they recommend crackers.

PHOTOGRAPHY IN WET CAVES

by

Bob Woolhouse

(Assistant: Frank Brown)

My own experience of cave photography has been restricted to Great Britain, France and Tasmania, where humidity always approaches 100%. Under these conditions the effects of breathing, wearing damp clothing, or worst of all smoking, are to produce a fog which can significantly affect visibility under certain lighting conditions. This can be very noticeable to a wet caving party in a show cave. Where they use their own headlights fog is a serious problem, but when they reach the illuminated section the fog apparently disappears. Similarly, a flash mounted on the normal accessories shoe is likely to give serious fogging (Fig. 1).

In this diagram the formation 16 feet from the camera is correctly illuminated. The light intensity in the space S immediately in front of the camera lens and six inches from the flash will be approximately a thousand (32^2) times brighter than this. If there is nothing in S this will of course not affect the resulting photograph. Even if we are smoking, the proportion of S occupied by water droplets is very small, but when these droplets receive a thousand times the correct exposure they give the effect of a uniform bluish haze over the whole picture. Contrast is reduced and colours are washed out.

There are various ways of arranging the lighting to reduce this effect. One method is to move the flash further back, compensating by increasing the aperture. This is recommended by photographic professionals with no caving experience as it gives even overall lighting with no 'hot spots' (Fig. 2). The fog is illuminated only slightly more than the subject, and unless very thick it will have little effect on the final result. However, this result will vary from unsatisfactory to completely confusing. The centre of interest may be correctly exposed, but will be masked by overexposed foreground, and in a passage 'foreground' can be everywhere except in the centre.

Any method of lighting other than the two described should give acceptable results. A real cave does have a 'hot spot' – the viewer's headlight – so why not put one in the picture. Generally it is best to avoid two 'hot spots'. Psychologically this gives two centres of interest which only a first rate artist may be able to combine into an outstanding picture. A comparison of results produced by a single light source with those from multiple light sources seems to suggest that cave photographers are not first rate artists.

Essentially there are two types of photographers.

The first is the portfolio type who is attempting to get a single slide which will carry off all the prizes at competitions. He needs plenty of money for gadgets and several helpers to act as porters and models. Normal caving parties avoid portfolio types and the rest of these notes do not apply to this class of photography.

The second type is the documentary type who is attempting to record caving as an activity. This can only be attempted by a photographer who is not a nuisance to a caving party. Cavers like being photographed, particularly in exhibitionist postures on overhangs. However, most people are not prepared to wait very long in this sort of position. If the photographer has to call for extra light to be shone on the model so that he can use his range finder he is likely to lose the model in one way or another. Also an exploring party has plenty to carry without helping with photographic gear. This means an active caving photographer must have the strength of mind to scrap everything but the bare essentials of a simple camera and lighting set up. He may be pleasantly surprised to find that simplifications forced on him by necessity improve the quality of his results.

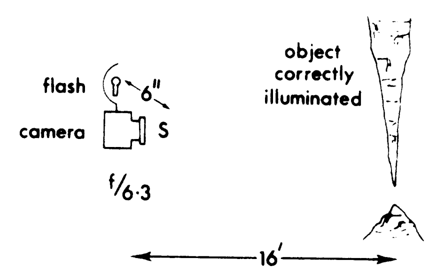


fig. 1 Flash mounted on camera
Light intensity at S is 1000x that at object

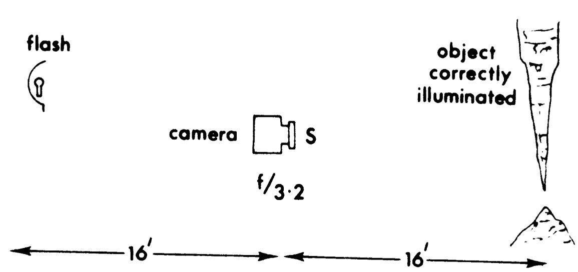


fig. 2 Flash well behind camera
Light intensity at S is 4x that at object

Complete inventory of materials required for documentary work

1. Camera in ever ready case worn under overalls.
   2 plastic bags to waterproof camera in emergency.
   I waterproof ammunition tin ONLY if the cave is very wet and tough, e.g. Herberts Pot, Mole Creek.
   OR
   1 diver's camera instead of all the above.
2. Enthusiastic assistant with experience of cave photography equipped with a capacitator flash firer and a 2 oz. tobacco tin of P.F.1B flash bulbs.
3. 1 caving party with some idea of how you intend operating.

Notes:

(a) The photographer normally provides film and bulbs and owns the copyright on any results, but these results are the product of a joint effort and all members of the party are entitled to copies at cost.

(b) If the photographer wishes to retain the co-operation of his models he must not only be able to focus instantaneously by guesswork, but also be prepared to point and fire without worrying unduly that nothing can be seen through the viewfinder. A moderately wide angle (35-40 mm) reduces the chance of decapitating the subject and gives more depth of focus. A high speed film will allow the use of smaller apertures to compensate for focusing errors.

The system in action

The assistant must be able to judge distances since he is responsible for the accuracy of the exposure. As a general rule he will be between the camera and the centre of interest, which will appear as though lit by his headlight. It is better to avoid calculations during a series of action shots. For example, to get a climbing sequence along the river passage of Kubla Khan, the order of progression would be actor, assistant, photographer. Assuming a flash factor of 100, the camera is set at bulb f/8, 12 feet, giving a depth of field between six and sixty feet (35 mm lens). The assistant keeps about 12 feet behind the actor while the photographer is free to pick the most suitable position without needing to re-adjust any camera setting. When the photographer is in a good position he shouts 'photograph' and blows a single whistle blast if necessary. The assistant feels for the switch on his helmet mounted flash and calls 'ready to fire'. The photographer calls 'shutter open', while the actor continues to move. Immediately the flash has fired the photographer calls 'shutter closed' and blows two whistle blasts. The whistle signals are used in noisy passages to prevent a light being pointed at the camera while the shutter is open. The whole party must know exactly how the process operates. The shutter may be open for as long as a second, and inevitable camera movement during this period will cause any light pointed at the camera to give a pattern of zigzag streaks over a considerable part of the slide. The assistant changes the bulb before moving on, so that the whole process hardly causes a check to the movement of the party. An experienced assistant can cling to the wall with one hand while shorting the flash contact onto the reflector, but nevertheless we find that the convenience of a switch is worth having.

Anyone considering trying this system will have noticed that the difficulties are ones of personnel rather than of equipment. Any assistant worth having must be a competent photographer in his own right and as such will want to bring his own camera. It may help to persuade him to co-operate when he realizes that he will be the silhouette in all the impressive action shots. The party should decide that although any member may carry a camera for static (portfolio) photos, only one camera will be used for action sequences.

Proceedings 8th National Conference
Australian Speleological Federation

SOME CAVES AND KARST OF CENTRAL EUROPE
(summary only)

by

John R. Dunkley

In 1969 the author travelled extensively through Europe, Africa and Asia, visiting caves in South Africa, Rhodesia, Kenya, Lebanon, Germany, Switzerland, Austria, Czechoslovakia, Hungary and Yugoslavia, and attending the 5th International Congress of Speleology in Stuttgart as Australian delegate.

An illustrated travelogue was given of the post-Congress field trips and further excursions. Visits were made first to such Swabian caves as Laichingen, Barenhole and Falkensteinhole and to the sinking of the Danube between Immendingen and Tuttlingen and its rising at Blaubeuren on the other side of the continental divide. The Swabian Alps were on the margins of the Wurm glaciation. Its caves are small and not very common; they appear of more interest to archaeologists, and the area generally to geologists, than to the speleologist.

In Switzerland several days were spent in the Jura, a geologically complex area containing many karst basins and lakes. Some karst aquifers have been tapped for hydro-electricity and water supply. There are some very deep pots in this area but the main interest is speleo-hydrology which occupies a whole department at the University of Neuchatel.

A feature of the alpine karst is the impressive and characteristic severely karren grooved limestone pavements, glaciated in the Pleistocene and often with caves blocked with glacial erratics. Examples were inspected at Tours d'Ai above Leysin, on the upper Muotathal Valley, and on the Dachstein and Tennengebirge in Austria. The 70-mile long Holloch at Muotathal was entered briefly and the phenomenon of *mischungskorrosion* was explained by the leader Dr A. Bogli. At Werfen the author was guest of the owners at Friz Oedl Haus, enabling a detailed inspection of the ice section of Eisriesenwelt. In Vienna he attended a meeting of the local speleo *Verband*, who organized a one day car trip to nearby caves and related features.

In Czechoslovakia an itinerary was prepared by the Director of Tourist Caves who met the author at Bratislava and conducted a brief trip around the city, an indication of the immensely good relations between speleologists and government authorities throughout this part of Europe. Visits were made to several Slovakian caves and to the Karst Museum at Liptovsky Mikulas.

In Yugoslavia the author stayed with Dr Ivan Gams one night and at the Karst Research Centre at Postojna three nights. On a conducted car tour, visits were made to a cross-section of typical karst features near Planina and Cerknica poljes, an area incorporating karst windows, ponors, potholes, blind valleys, arches and innumerable dolines. The best known cave in this area is of course Postojna Cave with its initial mile-long electric railway but by far the most impressive cave the author has ever seen turned out to be less well known Skocjanska Jama, which contains a roaring river and one huge chamber 900 feet long, 200 feet wide and 300 feet high.

Throughout the trip the author was overwhelmed with hospitality and impressed with the good relations between speleos and cave owners. He was impressed more by the sheer size and grandeur of the great European caves than by their beauty. Only those in Czechoslovakia, especially Demanova, approached Jenolan in beauty.

CAVES AND KARST IN SWITZERLAND

by

Willi Grimm*

The Swiss Society of Speleology is the equivalent organisation of ASF in Australia. It was founded by the Geneva group in 1939, at this time the only caving organization. Until this foundation, not much interest was dedicated towards caving, although, some single caves like the 'Holloch', 'Schnurenloch', Beatushohle' and others had been explored earlier.

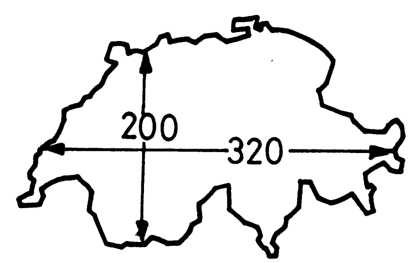
The Swiss Society of Speleology is made up of 15 different groups, 9 from the French part of Switzerland, 6 from the German and 1 from the Italian part, which gives a total of approximately 500 members. The majority of the active cavers (38%) are aged between 20 and 30; 14% are below 20; 29% are between 30 and 40 and the remaining 19% are above 40.

The Swiss Society of Speleology has available a total of 2000 metres of wire-ladders, 23 telephone sets, 13 rubber dinghies, 11 diving suits, 8 aqualungs, 7 climbing poles, 2 winches plus all the usual caving gear.

Swiss caving activities differ a bit from the Australian ones; not very much in purpose and aim, but mainly in techniques and gear and also the distances we have to travel to reach caves. For instance, a caver living in Bern, the capital of Switzerland, would travel 60 miles to Beatenberg, the most potential caving area. Of course, there are caves much closer, but you can also go further. Unfortunately, if you travel more than 150 miles in either direction, it means you are going caving in another country. Switzerland is 118 times smaller than Australia, just about half the size of Tasmania, and it measures only 320 miles across.

The majority of cavers wear an overall with a zipper and prefer carbide light. The footwear is either rubber boots or climbing boots. The first mentioned does not exactly fit in the ASF safety code but, in Switzerland, a lot of large caves contain rivers; there is not much mud, but only clean, eroded rock surfaces. The only passage-way is often the river. For expeditions lasting 10 to 30 hours, it is essential to keep your feet dry. Therefore even hip-high fishing type boots are used. Boots mounted with triqounis are seldom used.

Switzerland compared with Australia



The size of Switzerland in kilometres

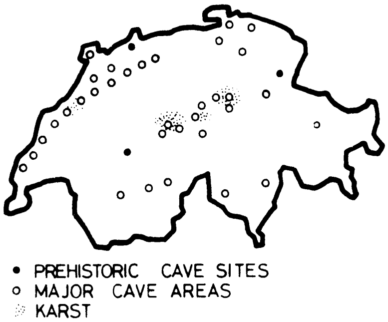
The ropes used are mostly nylon and other synthetic fibres. Even kernmantel ropes are common. The conventional natural fibre ropes disappear steadily. Their only usage is for gear lowerings etc.

Also knots do differ from the ones used in Australia. Belaying is done over one shoulder. The method practiced here, in which the rope is around your waist is hardly known.

Caves can be found all over Switzerland. The Jura stretches from Geneva along the border towards Basel, and the limestone Voralps stretch from Leysin across the country to the Bodensee. They are very abundant in caves and extremely suitable for karstification.

* Schweizerische Gesellschaft fur Hohlenforschung
Victorian Speleological Association

CAVES & KARST IN SWITZERLAND



About 50 to 60 years ago was the time of important prehistoric excavations in the northern, central and eastern part of Switzerland. The "Schnurenloch", situated high on the western slopes of the Simmen Valley (Simmental) was obviously a dwelling for the extinct cave bear. Over a digging period of 10 years this cave yielded 16,000 bones and artifacts; 95% of all the bones found belong to the cave bear. The cave is 32 metres long and its width varies between 3 and 4 metres. The deposits, with a depth of 4 to 8 metres, showed a unique profile and they discontinued excavation to preserve the remaining 7 metres as heritage. A wooden barrier was built but has been removed on different occasions to allow scientists to carry out further studies.

On the northern side of Lake Thun (Thunersee) and Lake Brienz (Brienzersee) is a large karst area, covering 60 square miles. The karst is in altitudes between 1300 and 2200 metres above sea level. Throughout this area Cretaceous limestone is covered by Eocene sandstone. Glaciers removed the sandstone in some parts and exposed the limestone. The glaciers even shifted layers of the bedded limestone away and today a well developed layer-terraced karst field is present. This section of uncovered karst spreads out over 15 square miles.

Since 1966 two groups of the Swiss Society of Speleology, Bern and Interlaken, have been systematically exploring the field. A paper was produced dealing with the basic questions and problems in exploring the karst and it was distributed to every caver involved. The surface was surveyed first and then was divided into rectangles 100 metres long and 50 metres wide. The first rectangle to be explored contained two erratics (Karrentische) with well defined pedestals, 3 canyons, 1 horizontal cave and 41 shafts. The cave seemed to be at a very young stage with elliptical passages, the total length of them being 200 metres. The shafts all ended on two levels, either at 6 or 15 metre depths. The bottoms are filled with frost shattered rocks.

On these levels the water disappears through inch high fissures along the bedding planes. One of the many questions was: where does the water go to? Three tracing tests gave a fantastic result. Forty kgs of sulforhodamine was dissolved in a deep shaft on the Schrattenfluh. After 40 hours spent travelling 20.8 km (beeline) the red water could be seen in the lake of Thun (Thunersee), near Interlaken. At a depth of 10-15 metres is an efflux merging into the lake which has about the same outflow as the nearby "Beatushohle". At the same time a fissure resurgence, the "Gelber Brunnen" (yellow fountain) showed the same red colouring. With this tracing one of the largest cave and karst waters in Switzerland was proved and a long awaited explanation to a puzzle had started to be answered.

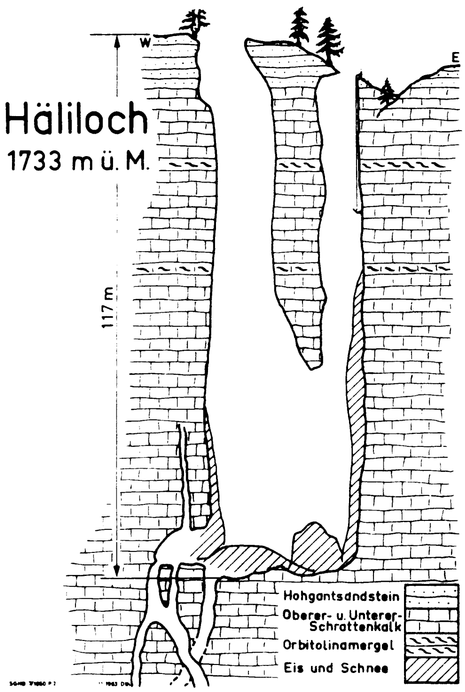
In 1928 an enormous amount of chaff and sawdust was thrown into the "Haliloch", a 117 metre deep shaft in the same area. After 7 to 9 days the chaff and sawdust was detected in the "Beatushohle". In 1946 a similar tracing was made but this time with fluorescein. It proved the previous tracing was right, but it appeared soon after 30 to 48 hours. The third tracing was in a shaft near to a large faultline which crosses the karst. It was thought to penetrate to great depth but because the shaft was acting as a sink, its bottom was blocked with rocks, soil and other material. However, the water could be traced with fluorescein. It proved this area also belongs to the Seefeld-Hohgant karst area.

The three longest caves in Switzerland are:

1.	Holloch	103,705 metres	(64.436 miles)
2.	Grotte de Milandre	8,074 metres	(5.444 miles)
3.	Neuenburgerhohle	4,720 metres	(2.832 miles)

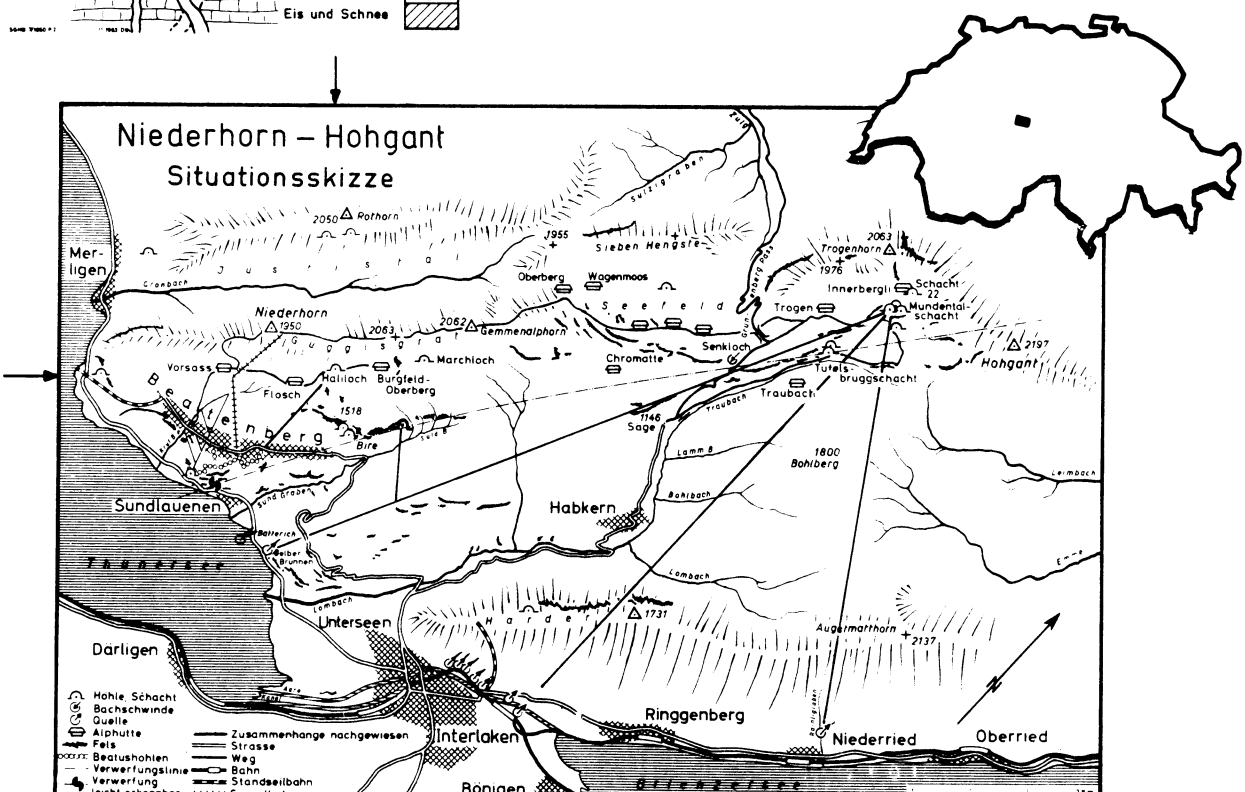
The three deepest caves are:

1.	Holloch – 107 metres + 633 metres =	740 metres	(2428 feet)
2.	Gouffre du Chevrier	510 metres	(1673 feet)
3.	Gouffre du Petit-Pre	426 metres	(1397 feet)



The Seefeld-Hohgant karst area

the arrows indicate the situation of the "Haliloch".



Translation of the signs as shown on the map above and in tne same order:

cave, shaft	connections proved
sink	road 2nd class
resurgence	road 3rd class
hut	railway
rockface	rail driven by cable
Beatuscave	chair lift
faultline	
fault clearly visible	

BRIEF REVIEW OF MT ETNA CONSERVATION CAMPAIGN 1969–1970

by

Andrew W. Graham

This relatively informal paper is purposely brief, firstly as R.K. Headland in his paper to the Seventh Biennial Conference covered the period to December, 1968 and secondly, the history of conservation efforts at Mt Etna and Limestone Ridge is contained in the University of Queensland Speleological Society's publication "Mt Etna Caves". I shall also be covering recent developments not recorded elsewhere.

Early 1969 saw a redirecting of effort after news of the initial refusal of Central Queensland Cement to relinquish part of their leases for the formation of a National Park. A "Workshop on Mt Etna" produced a number of possible guidelines, attitudes and actions. P.H. Caffyn in March made the initial complaint about a breach of the "66 foot limit" at Winding Stairway Cave. This produced a test case to see if the Government and Company were serious about the conditions imposed on mining, and served as the basis for subsequent publicity.

In April the Australian Conservation Foundation replied to a letter outlining the (then) present state of affairs, and noted that a report on alternative supplies of limestone would be of great assistance. The setting up of a non-student body, the Queensland Cave Conservation Council resulted in letters exerting further pressure on Government and Company.

Apparently the Company was still under some pressure, for at an interview in August, U.Q.S.S. learnt of a possible compromise solution in which the Company was to retain a (non-cavernous as far as was known) connection between the remnant east and west leases after the proposed National Park was excised. U.Q.S.S. then made a formal approach along these lines but received no reply.

Summary of major correspondence

15 November 1969 Inspection of some damage to caves by U.Q.S.S. Secretary and a Livingstone Shire Councillor. Press coverage.

6 December 1969 Area of Recreation Reserve R272 almost doubled to 204 acres (this addition did not include any cavernous limestone as far as is known).

8 December 1969 U.Q.S.S. received copy of letter from Mines Minister to Premier.
- protracted negotiations not yet concluded.
- pointed out no objections raised when Mining Lease applied for.
- technical opinion at time of granting leases was caves of no tourist value.
- bat protection not considered at all at that time.
- therefore no conditions imposed on leases.
- after possible damage to bats pointed out, Mt Morgan and Central Queensland Cement agreed to certain restrictions on mining. Agreement is voluntary but Central Queensland Cement re-asserted that it intends to comply.
- *undertaking* to leave a barrier of not less than 66 feet between workings and the main entrances of the habitat caves and to direct the workings so as to keep clear of any cave structure if such is known.
- unfortunately an accidental breakback of rock had occurred in one case reducing the distance to 55′ 4″ Company is directing operations clear of caves.
- no blasting occurred within zone, no damage to cave or bats, work stopped in area.
- Company is not prepared to agree to a proposal to surrender part of its leases until alternative supplies of limestone are located of sufficient quantity and quality that can be delivered to the works at no extra cost.
- with this end in view, the Department of Mines is carrying out a programme of drilling at no cost to the Company, and when the results of this drilling are known and an evaluation of ore reserves made, the Company will be in a position to decide on the above proposal.

24 December 1969 A reply to letter of 8th December, sent to Department of Mines pointing out that
- leases were all granted before U.Q.S.S. first visited Mt Etna in 1962.
- Government geologist had reported favourably on caves 18-2-26.
- bats should have been considered.

	– U.Q.S.S. geologist disputed accidental nature of breakback, and claimed drill marks were inside the 66 feet limit. – Department had photographs of damage to a cave.
29 January 1970	Department of Forestry advised U.Q.S.S. similarly to reply from Department of Mines regarding Mt Etna but informed U.Q.S.S. that negotiations between Mt Morgan and the Departments was proceeding regarding a National Park on part of R272 (over the road from Mt Etna). Doubt existed if the whole of the cave area was covered by the proposal.
20 February 1970	U.Q.S.S. second report on damage in caves to Department of Mines, Premier and Company. Claimed natural degradation rate accelerated by action of quarry.
12 March 1970	Department of Mines reply to U.Q.S.S. of 24 December 1969: – if promises breached inadvertently there can be no legal redress. – the Company's decision must be awaited. Any attempt to rush the investigation at this stage would be detrimental.
16 April 1970	U.Q.S.S. sent to Department of Mines and Forestry, a traverse of Johannsen's Cave and sketch of cave locations for Limestone Ridge.
23 April 1970	U.Q.S.S. wrote to Department of Mines and Cement Company showing location of most westerly cave on Mt Etna.
June 1970	Determination of accurate locations of caves on Limestone Ridge commenced by traverse.
1 July 1970	Joint signatories U.Q.S.S., Central Queensland Speleological Society, Superintendent Olsen's Caves, Manager Cammoo Caves, Rockhampton Field Naturalists Club wrote to Premier and Ministers for Mines, Labour and Tourism. They stressed concern at slow progress in negotiations and underlined need for recreation caves as opposed to Tourist Caves.
2 July 1970	U.Q.S.S. notified of major new cave on Limestone Ridge, Elysium.
14 August 1970	U.Q.S.S. map of Limestone Ridge sent to Chief Government Geologist; Department of Mines, Forestry; Central Queensland Cement, Mt Morgan. Shows location of 28 caves accurately.
7 August 1970	Forestry revealed that the area offered for surrender by Mt Morgan did not cover the cave system completely.
17 August 1970	U.Q.S.S. verbally confirmed that negotiations were taking place only for ML 306 (the most northern lease) on Limestone Ridge.
15 September 1970	Forestry Department was informed of further efforts (confidential) towards establishing a National Park in the area. Proposals are to await outcome of present negotiations.
22 October 1970	U.Q.S.S. asked Department of Mines for latest information on negotiations, and also of drilling results.
11 November 1970	Central Queensland Cement gave notice to Central Queensland Speleological Society of restrictions of entry onto leases where mining operations were being carried out. Also – "the nature and effect of the operations are such as to render the immediate area unsafe to unauthorized entrants".
22 December 1970	U.Q.S.S. sent a plan of Limestone Ridge showing extent of Elysium to all parties concerned.

Policy problems

Lack of communication and delay in replies from the Company and the Mines Department hamper efforts. In addition the Company has developed an attitude of –"you should not be on leases (i.e. in caves) therefore you cannot see damage" – and complaints are therefore not well received.

Lack of guidelines. It appears that, as the western quarry has now been commenced, the eastern quarry is not to proceed any further west. This, apart from relatively minor bulldozing in the overlying Mt Etna Trig member sediments, leaves the amended Government proposed area for a National Park intact. There is no indication as to how long it will remain so.

The fate of Limestone Ridge, apart from Johannsen's Cave, is completely unpredictable. A survey shows the extent of the presently known cavernous area and there is no doubt that the remainder is just as cavernous. How the undertaking of the company applies to many of the Ridge caves is difficult to gauge – what defines a major cave?

There are those who favour pressing only for total preservation, while previously some favoured preservation of Mt Etna at the expense of Limestone Ridge and now some vice versa. The Australian Conservation Foundation has another policy, and Forestry (National Parks) will accept any cavernous area of the Reserves for preservation.

What the final result will be, I cannot even begin to predict now, but to mis-quote, and as shown by the Winding Stairway Cave incident at Mt Etna, "the price of preservation is eternal vigilance".

CONSERVATION PRESSURES AT BUCHAN

by

Nicholas White*

The question of conservation has been with us for a very long time now. In fact speleologists have been aware for a long time of the necessity to retain caves as they were originally found. Conservation and pollution problems have hit the popular media in a big way and it is extremely hard to give a balanced talk when dealing with such emotional problems. Indeed the more one talks the more there seems to be a backlash against conservation issues.

In Victoria with regard to Buchan and the surrounding limestone area very little effective conservation activity has taken place despite a good deal of talk. The V.S.A. in particular is just beginning to have an awareness of the problems facing it. These problems have not as yet resulted in much total destruction of caves. I will at this stage try to outline some of the problems and indicate where steps are being taken or should be taken to remedy the situation.

The basic problems are no different from any others that are being experienced around Australia and in other parts of the world. The major predators of caves at Buchan are human. The area around Buchan is quite fertile grazing land. The farmer, in pursuing his activities, has played havoc with the landscape. Clearing and cultivation have resulted in a lot of soil movement which has undoubtedly closed and silted up many entrances. This has been helped by the hilly terrain. The other problems farmers have had to contend with are stock losses down caves and burrowing by rabbits in the vicinity of cave entrances. From talking to local farmers it is apparent that quite a few holes have been closed up. In some cases this has been achieved by the use of explosives. Closing up of entrances is particularly easy as many of the entrances are small and none of them would present the same problems as are experienced at Naracoorte. There have been no recent examples of any of the major cave systems being blocked up by such means but there have been instances where farmers have threatened such action.

The other use farmers have put caves to has been for the disposal of rubbish. Household rubbish, old fencing wire and animal carcasses litter the entrances of many caves. No concerted action or cleaning up of such caves has been initiated although littering within caves is kept to a minimum by its removal by members of V.S.A.

The next question is one of cavers. Buchan is some distance from Melbourne but access to the area is extremely easy and more and more people are visiting the area all the time, both as tourists and to do some caving. Accessible caves are spread over quite a radius and protective legislation covers only a few caves in the Buchan Reserve. There are three other areas set aside as reserves: the 18 acre reserve in the Potholes area at Murrindal, the Pyramids area but excluding Dalley's Sinkhole, and the complex of Murrindal and Lillipilli caves.

Control of these areas is very loose except for the Buchan Reserve and falls under the Lands Department.

Caving is pursued by quite a number of groups and individuals within the Buchan area. The major concern is over non-affiliated groups over which V.S.A. has no ethical or moral control. The V.S.A. has provision for affiliation of groups. This has resulted in the University groups of Melbourne, Monash and Royal Melbourne Institute of Technology being members as well as some of the Walking Clubs and one scout group. With regard to these groups we have very close co-operation and they respect our mutual concern for leaving caves as they are found. We are able to help them in a number of aspects such as training of beginners, provision of equipment and giving them the use of our facilities and access to records when we see fit. V.S.A. has adopted a list of caves which are to be used for instructional purposes. These caves have been chosen to provide representative types, sizes and technical problems for the beginner. To some extent these caves have already been extensively vandalized. This sort of procedure has eased the problems of damage to decoration and kept rank beginners and prospective members out of our more dangerous or technically difficult caves.

Despite steps such as these of loose affiliation with V.S.A. we have been singularly unsuccessful with a lot of small groups who appear at Buchan on an irregular basis and often cause us a great deal of concern in the way they go about their caving. Examples of groups entering our deeper potholes with inadequate or unsound equipment are relatively common. Some of them are quite capable of using V.S.A.'s name to gain access to caves. It is very difficult for V.S.A. to retain a responsible image in the locals' eyes when it is so easy to associate acts of vandalism or trespass with us.

I hope I have covered this question of trying to cope with unaffiliated cavers (for want of a better term) but I fear that V.S.A. is meeting with no more success than some other societies.

At times "gem" hunters have proved a nuisance, in one instance at East Buchan a group was found by the owner of the property carrying a sugar bag full of formation. This type of desecration has certainly gone on and will continue to occur. V.S.A. has begun to overcome some of the problems of the more dangerous or valuable caves by means of

* Victorian Speleological Association

cave gates. As yet only Scrubby Creek has been done but Honeycomb and Dalley's Sinkhole are also on the list. This measure is regrettable and also questionable as to its efficacy, as gates have been broken in other places.

I might at this point pass on to caving in Buchan Caves Reserve. All caving has been banned in the Reserve as a result of irresponsible behaviour not directly attributable to V.S.A. or its members. V.S.A. approached the Lands Department who control the Reserve personally with a very carefully stated case for our continued access to the area. The response was extremely negative to say the least and, I might quote at this stage from their reply: "... the caves in this Reserve have been surveyed and mapped by qualified persons over the years and repetitive work of this nature is not likely to be of value to the Committee". They provide only one let-out and that is that they do not wish to hinder "genuine scientific research in the caves". This avenue has not yet been pursued but will be in the near future.

This sort of attitude seems to permeate the Public Services and in this case they are purely interested in tourism. At present while it is regrettable that we cannot enter the caves it is giving them a necessary rest from undue pressure of irresponsible groups and thus provides some positive measure of protection.

The next question to discuss is mining and quarrying. With regard to mining leases there are quite a few scattered over the limestone areas. These are nearly all in the name of Rio de Janeiro Mines or G. Milton. These, I feel, do not present a threat to any of our caves. There is no active mining going on although there have been pockets of galena-silver which have been worked with limited success. The likelihood of a significant mineral find in the area is limited. When it comes to extractive industries the threat of destruction of caves becomes very much more real. I do not propose to go into detail at the moment mainly because I have not really researched the question. At present there is only one quarry working and that is Rocky Camp. This has been in operation for some years. They have broken into about two small caverns but the hill on which the quarry is situated is otherwise barren of accessible caves. There is another licence applied for by L. & K. McRaes to which V.S.A. has made a formal objection. The area covered by this application covers two extremely significant caves, Cloggs Cave and Mabel Cave. As yet apart from discussions with the applicants we have not been successful in our objection to including the areas containing these caves in the lease.

The most recent significant development in terms of extractive industries is the action of Gippsland Minerals in buying up the old Sutton property and part of Mr Hodges' property presumably with the intent of quarrying activities. They have not as yet made formal application for a licence and nor has V.S.A. enquired about their intent. There are quite a few caves threatened in the area. These include Scrubby Creek, S.S.S. Cave, Stormwater, The Canyons and related caves. Something will have to be done in the near future with regard to saving some or all of this area as it contains particularly, one of the major cave systems.

To round off the picture at Buchan, V.S.A. is being faced with problems which are familiar to most of you. Success in achieving conservation needs a much more active programme by the club such as more vigorous objection to extractive industries' licences and perhaps bring the whole area under the control of a body such as the National Parks Authority. V.S.A. should be at the spearhead of this activity. The only thing of a real constructive nature is the start which has been made by the club on a booklet describing the area in detail and stating the case for conservation of the caves in it. To some extent this has prompted me to write this paper to provide a background of the problems which will have to be faced if there are to be any caves left for future generations.

DISCUSSION

Q *Pardon my ignorance but when someone buys a farm do they have to get a lease in order to mine?*

A In Victoria, for an extractive industries' licence, there is a licence and a lease. Lease refers to Crown Land, licence to private land. The owner of private land has no quarrying rights. If someone wants to peg private land he can come to an arrangement whereby he pays compensation for damage to the land.

SOME ECONOMIC PRINCIPLES IN CONSERVATION ISSUES

by
John R. Dunkley

There is a large and growing literature on economic aspects of conservation which the author did not have the opportunity to peruse. Consequently, and because of time limitations here, this paper covers only a few rather general economic principles which are perceived as having particular applicability to a conservation framework. The concepts would be equally applicable to any conservation problem, emphasizing that caves are but one of many environmental issues with which we should be concerned.

Introduction

In this paper I do not propose to examine the economics of particular cases of cave conservation. What I want to do is to point out briefly the approach which economists make to conservation issues in general, to indicate some of the pitfalls in thinking to be avoided and to make easier an understanding of more technical papers on particular issues.

In our society the decisions as to which goods and services will be produced, how much and who will get them rests basically in a market system where values of widely differing commodities are reduced to the common denominator of money. Money price controls the commodities which are produced and they are allocated to the highest bidder. The economist says that the problem is solved by the interaction of supply and demand.

This paper will discuss these problems of theory:

1. whether a particular resource will be conserved or not;
2. how much of it will be conserved;
3. who will benefit by the setting aside of it—i.e. how to allocate the benefits of conservation.

Conservation is treated as a commodity — a good or service for which there may or may not be a market. In our case, though, fundamental problems arise:

1. there is trouble in reducing conservation values to a common denominator of money;
2. the price paid is really a 'social price' in the sense that it is a price paid jointly by society and not individually by consumers.

The "cost" of conservation

First, let us examine the "price" of alternative resource uses, since this is a term often bandied around in conservation arguments. There are three ways of looking at price as a cost paid for obtaining the benefit of a commodity: the financial cost, the economic cost and the social cost.

The financial cost is a very unreliable criterion of resource allocation. The reason is not merely that it is not easy to put a money value on alternatives. It is in fact quite easy in principle to obtain comparative figures using the present value approach which will be discussed later.

The economic or real cost of one alternative is simply any other one that we have to go without if we choose the first. The real cost of incorporating Colong Caves Reserve within the Kanangra-Boyd National Park is simply the limestone that we thereby have to forgo, together with such secondary and now non-existent effects of the purchasing power that miners would have earned. In this respect however, it is important to remember that in a full employment economy like ours this latter factor is not as significant as the politicians, particularly those representing rural electorates, would have us believe. For if Fred Smith does not work for APCM Ltd, he can work for GMH or anyone else and hopefully earn the same income, making the same contribution to Gross National Product without mining limestone.

The social cost is the hardest one to pin down. It includes all sort of intangible, non-monetary and subjective aspects like aesthetic appreciation, protection of rare species for pure scientific value, and possible redistributional effects caused by having to move people around. There is no market in which a price can form and evaluation is therefore rather subjective. There are, though, quantitative methods which while not entirely satisfactory do yield results more objective than the rather emotional outbursts we have heard in the past about the "public interest".

(a) there is the opportunity cost approach, the same as economic cost which says merely that the value of the intangible benefit is equal to the *monetary* value of the alternative economic use;

(b) in a few cases there is the possibility of direct construction of a market demand curve as in recreational projects.

For example, a very rough calculation shows that the holding of this speleological convention in Hobart brought at least $10,000 of mainland money down. The field trips to Mole Creek will yield local businesses at least $500 — a substantial amount for a country village. Yet I calculate that at the moment, Tassie caves have approximately 1% of the visitor usage of those in N.S.W., where we have 10 times as many cavers in far fewer caves. If caving here approaches

N.S.W. in popularity – which Heaven forbid – then in 10 or 20 years cavers will be supporting the Mole Creek economy. What price more dairy farming, timber cutting or dam building?

(c) there is a more general possibility which I call the individual marginal utility approach. This is a method of measuring the satisfaction which individual consumers gain from consumption of varying quantities of a commodity. The economist's approach to this concept is rather abstract. Consider the maximum sum of money which various individuals would pay rather than forgo a particular commodity altogether. For given quantities, different people are prepared to pay different amounts, but they are alike in that each will pay more for the first few units consumed than for subsequent units. On a hot day you may be prepared to pay as much as one dollar for a bottle of beer rather than go without, and if the price of beer is only fifty cents you will drink merrily until the value you place on the next bottle is less than fifty cents. Unless of course you are irrational which would not be unlikely. These individual monetary units can be summed to obtain an estimate of the social demand curve, i.e. of the quantities which people together would want to consume. In principle these methods give some measure of the demand for commodities and provide a decision framework in which will be determined whether or not a resource will be conserved.

How much conservation?

Let us now consider *how much* of the commodity will be supplied, i.e. how much land of a particular type will be conserved. Land is subject to the general law of supply, that the higher the going price paid by consumers (in our case, conservationists or recreationists, picnickers etc.) the more is supplied, whether by private owners or by the Crown. There are two main interferences with the operation of a free market here:

1. The fact that land is limited in quantity (in one sense there is an absolute limit but in another supply is variable because of the differing uses to which land may be put). This means that a higher price does not necessarily have the effect of calling forth more land but simply re-allocates the existing supply among those consumers most willing to pay. In practice, supply of land is quite inelastic and therefore the price paid for its use contains an element of economic rent (see below).

2. Crown land may not necessarily be called forth by higher prices. The fact that Crown land is owned jointly by society members means that there is no one person ready to release it when a high enough price is paid. On the other hand, more land can be released than the price would warrant if the government considers this in the interests of society at large. This has assumed the importance of an election promise in New South Wales.

Conservation as investment

Conservation as a commodity is a special case of a resource in that it comprises elements of both land and capital. To the economist, setting up a national park is equivalent to investment in new capital as well as allocation of existing land (investment being defined as addition to capital stock). A properly protected natural resource of any kind is part of the country's capital stock held as such in order to provide the means of producing goods and services both now and in the future. Now a wise business manager is constantly assessing his company's need for new capital to enable the firm to grow. Similarly a country should be constantly assessing its needs for new ways of ensuring its future prosperity. But to do this requires that some resources which would otherwise have been consumed are instead kept for the future.

The question is, *how much* to put away for the future. How much to invest? this is the same as asking how much of our present stock of goods and services should be *saved* for the future.

If we conserve too much, we cut our present living standards for a doubtful future; if we conserve too little, we depreciate our capital stock of resources on which the future prosperity of the country is based. It is too easy for polar viewpoints to emerge here. It is easy for the miner to say: let us mine that area, for in doing so we provide raw materials for industry, create employment, and put purchasing power in the hands of the consumers, and perhaps provide export income with which to purchase other consumption or capital goods, either of which contribute to our rising standard of living. It is easy for the conservationist to say, let us protect that park area, for it will provide recreational outlets for a growing population, aesthetic attractions for the aesthete, and ecological protection of flora and fauna.

Normally, open market forces will determine how resources will be re-allocated. The major problem is that the kind of goods which conservationists want preserved are those where private property rights do not exist. To prevent exessively rapid and uneconomic depletion, conservationists propose to control the rate by establishing government authorities. Too often, their emotive arguments for such action fail to appreciate that there may be cogent economic support as well.

How does the economist approach the issue?

Now a business man will only invest in capital if it can show him a rate of return at least equal to the going rate of interest, otherwise he may as well live on his money equivalent capital. Therefore, the expected rate of return obtained by conserving an area must exceed the rate of interest as well as exceeding the rate of return on alternative land uses, e.g. mining. Furthermore, investment in *newly* conserved land must be at least sufficient to balance the depreciation of existing similar resources.

From an economic viewpoint, much of the price of land of any kind is a pure economic rent — rent being here defined as that part of the price of a commodity which does not affect the amount of that commodity supplied. Willingness to pay at least the rental price to get some of the land is an objective way of:

1. asserting that the use made of the good will yield greater value than other uses;
2. getting that good assigned for future use;

Strictly speaking, potentially conserved land resources have an element of quasi-rent, meaning that it involves an implicit cost payment that has no effect on the amount conserved now, but does affect the amount in existence in the future. The same principles apply.

It is, of course, virtually impossible to pre-determine rental and interest components of land price. The best way to reduce comparisons to a common denominator is to consider the expected present value of alternative resource uses. In the case of Colong, for example, this means considering the present value equivalent of all future returns from recreation etc., and comparing this with all future returns from mining. Present value tables show, for various rates of interest, the amount you would have to receive now which, if invested at the going rate of interest, would yield the returns expected alternately from mining and recreation uses. The significant point is that a low but rising annual return over a long period of time (e.g. from recreation or just from caving) soon exceeds in value a high but declining annual return over a shorter time, e.g. from mining.

Having decided whether to conserve a natural resource and if so how much, there is still the question of how to allocate the benefits among members of society. Consider a national park. Even when it has been declared there are still problems of allocating portions to competing interest groups. One of the ways of achieving this is in zoning and I dealt with the principles of this in a paper at the Mirboo North Conference. In economic terms zoning (different areas for different uses) has the function of differentiating the product just as the motor car market is differentiated into the sports car market, the four wheel drive vehicle market, the station sedan market etc. In a differentiated market it is possible for different buyers to be charged different prices according to the real or imagined differences in the product. The prices may or may not be paid in money terms — they may be opportunity costs, in particular a cost expressed by the substitution of time for money, e.g. wilderness area.

The important point here is that users of certain zones of a park may be able to virtually exclude others from that zone merely by being willing to pay a higher price for use of that zone. Thus cavers will place a higher value on their right to use the Yarrangobilly special area of Kosciusko National Park than will bushwalkers, who will themselves be prepared to pay a higher price than the average tourist. This is merely the market exercising its function of re-allocation. Each individual has his own demand curve for the use of Yarrangobilly caves, but for any given quantity cavers will pay a higher price than most people. Therefore it may be that cavers may form a specialised market sufficient to keep the 'price' of Yarrangobilly well above what would be the social price, and therefore make more likely the preservation of the area. Another way of looking at this is to say that if all comers are charged the same rate to enter the park, then cavers will call forth a greater usage than any other individual or group.

The prevailing social framework

There are several important facets of our whole way of life in Australia which ultimately impinge on the microcosm of caving. The most significant is that current economic growth theory is founded on assumptions of ever-increasing material wealth helped by rapid population increase and resource development. To attack this assumption is heresy. Politicians and the public alike seem convinced that our future prosperity requires rapid population growth and professional economists simply have not come to grips with the possibility of economic growth with static population. Now economists calculate that every 1% increase in output of the goods and services on which our current living standards depend requires a 4-5% increase in capital production. This means that material resource development commands abnormally high returns, making conservation that much more difficult. At the same time, the over-emphasis on capital goods limits current living standards without necessarily leading to saving of sufficient recreational reserves and national parks to ensure our future prosperity in the areas that will matter most. Just remember that tourism and recreation are the world's fastest growing industries.

So the single greatest pressure on conservable resources is brought about ultimately by population increases and the resulting overemphasis on acquisition of material capital. We urgently require a new economic theory of zero population growth. As well, the economists need to contrive a method of quantifying non-economic measures of our living standards (such as aesthetic and humanitarian aspects) so that Gross National Product becomes a true measure of the performance of the whole economy, and, as the first President of the Australian Speleological Federation, Professor Brian O'Brien, remarked to S.U.S.S. last year, what we need is a concept of Gross National Loss. This would quantify the long term loss of resources, or negative production brought about by wanton pollution and wasteful practices, in the same way that Gross National Product measures material production of goods and services.

Conclusion

In summary, this paper has pointed out some theoretical principles by which:

(a) money values may sometimes be placed on non-monetary commodities;
(b) decisions may be made as to whether a given resource should be consumed now or conserved for the future;
(c) economic analysis can be applied to certain essentially non-economic phenomena;
(d) a decision framework may be made for the allocation of public property among competing non-economic ends.

It has also been pointed out that the placing of a special price on the use of a public commodity is not necessarily just revenue-hunting but is a rational method of restricting resource usage to those most willing to pay. Finally, it has been suggested that fitting conservation into the general framework of resource allocation is prejudiced by inadequacies in current economic theory and social thinking. The solution lies at the very least in the devising of a truly representative measure of our living standards, and in a serious examination of the effects of rapid population growth on the non-quantifiable aspects of our standard of living, those aspects which concern a conservationist most.

If there are any practical lessons arising from this, they are these:

1. Do not complain too loudly about having to pay to enter national parks. The price is not a revenue device but a method of allocating available park among those most willing to pay.
2. There is something to be said for the practice some societies have of charging trip fees. They serve the function not merely of raising revenue for the club, but also of ensuring that the only cavers who visit certain areas are those who place a value on the resource at least as great as the price paid (if rational).
3. You may have a greater *economic* effect on your caving areas than either you, the local community, or potential miners realise.

In concluding, I would like to reinforce my frequent exhortations that caves are but one of the many environmental issues, that the same principles apply in general, and that every other conservation issue that you support affects prevailing social and economic thought and makes it that much less likely that another cave will be mined away.

A QUANTITATIVE APPROACH TO CAVE CONSERVATION

by
Jim Seabrook

If we are to consider conservation as an attempt to minimise damage to a particular resource so as to preserve the resource for posterity then a way of recording the damage that is occurring to the resource becomes necessary. I will attempt to discuss four different methods of recording the amount of damage that has occurred in caves.

The first and most graphic method is a pictorial description of the cave. This would involve a series of pictures taken of various parts of the cave. Each picture would have to have a map reference and bearing and elevation figures supplied so that a similar picture may be taken at a later date for comparison. It would also be desirable to have the picture taken in colour and produced on a ten by eight format. The desire for colour can be explained by the tendency for a black and white photo to give a false impression of the cave. This method is purely qualitative and would be ideal for public relation purposes but has cost as the major objection to its extensive use.

The second system involves a verbal description of the cave taking note of several areas in which damage can be seen. These areas are:

(1) Markings on the walls;
(2) Amount of floor that has been turned into tracks;
(3) Damage to delicate formations;
(4) Damage to massive formations;
(5) Amount of rubbish left in the cave.

The description can also include any other damage of note in the cave. This system is probably the most versatile as it requires the least amount of effort to give a reasonable idea of the state of the cave. Unfortunately the system is still highly qualitative and very subjective.

A higher degree of objectivity can be obtained by using a grading similar to that used by rockclimbers.

DG0 — A cave that has not been entered, i.e. unexplored.

DG1 — This is a cave that has been entered by only a few people. It has virtually no markings on the walls. A track through only the obvious passages. Delicate formation that obstructs the track is the only formation that has been damaged and, of course, there would be no rubbish left in the cave.

DG2 — The cave is fully explored (excluding any undiscovered areas) with the damage associated with such exploration having occurred. Tracks are still well kept to and not much damage has occurred to formation off the tracks. Some of the flowstone is becoming soiled and any delicate formation placed so that some care would be required to avoid damaging it has been broken. Arrows are beginning to appear on the walls along with some other very occasional markings. An occasional flashbulb or carbide dump may be seen but would be unlikely.

DG3 — This would be a recently discovered but popular cave or a long known but much less popular cave. Arrows become frequent and initials become more common. Tracks are wide and more diffuse. A large percentage of the accessible delicate formation has been broken. Flowstone has become soiled while tracks crossing flowstone have become stained by people who have not taken the precaution of removing their boots and overalls before crossing it. You can expect to find some rubbish somewhere in the cave.

DG4 — This is a badly damaged cave with writing on the walls becoming common. All of the floor has been walked over, the delicate formations have been extensively damaged and a large percentage of the massive formations have been stained. Some of the massive formation has been broken. Rubbish has become common and one could expect to find flashbulbs, paper, carbide and similar litter in the cave.

DG5 — This is an extensively damaged cave with large amounts of writing on the wall. The floor has become extensively trampled. All the delicate formations have been broken and most of the massive formation has been damaged. There is evidence of extensive deliberate vandalism. Large amounts of rubbish are to be found in the cave.

DG6 — This cave has been removed by mining.

This system is more objective than the second method and also introduces a quantitative element into the description. A single cave could have several ratings for different parts. This method could also be coupled with the second method as a shorthand way of describing a particular part of the cave.

Unfortunately this method is not as quantitative as is desired: there are only five effective groups, and there is no definite mathematical relationship between any of them.

A way to overcome these problems is to obtain an index for each of the indicated areas (i.e. walls, formation etc.) and to combine them with appropriate weighting factors so as to average or coefficient.

(1) By taking a series of ten inch squares at random at shoulder height as one moves through the cave one can obtain an approximation of the area of marking on the wall. For each square, take the total length of marking and multiply by its width to obtain a percentage. These percentages are then averaged out over the number of squares used.

(2) The amount of track space can be estimated as a percentage of the floor area.

(3) The number of delicate formations broken can be obtained as a percentage of the total number of delicate formations (delicate formations to include helictites, small stalactites, small stalagmitesand crystal formations).

(4) Massive formation can be taken as the area stained or broken as a percentage of the total area (massive formation to include flowstone, columns and non-fragile stalactites, stalagmites and also large shawls).

(5) Damage to the previous four categories occurs geometrically where as the amount of rubbish that accumulates in a cave appears to follow a more linear progression. If we therefore take a logarithmic function of the number of pieces of rubbish left in a particular area the figure should conform to the other four indices.

If these indices are taken from a number of areas in the cave spaced at intervals of say 20 minutes travelling time throughout the cave, then by combining the indices from a particular area in this form:

$$D_{dl} = \frac{aA + bB + cC + dD + e \log fR}{n}$$

where A = index from wall markings
B = index from track space
C = index from delicate formation
D = index from massive formation
R = number of items of rubbish

a, b, c, d, e, f, are weighting factors for their appropriate index and n = the number of indices used in that particular region.

It is necessary to introduce weighting factors for each of the indices so that the absence of any of them should not affect the result, e.g. there may be no formation in the particular region, or the floor may not give a definite track area. The weighting factors can be obtained by taking the average of a large number of values for a particular index from many caves, the average for each index is then adjusted by the weighting factor so that the weighted average for one index is equal to the average of the unweighted averages of the other indices.

To obtain the final coefficient for the cave it only remains to average the various coefficients for the various regions:

$$C_d = \frac{\sum_{1}^{m} C_{dl}}{m}$$

where m = the number of regions
C_d = coefficient of destruction.

This method is truly quantitative and may be used in statistical analysis. As an example of one of its applications C_d could be plotted against: entrance size, distance from campsite, length of time known, distance from road, distance from nearest large city.

If there is some doubt as to a particular cave's rate of damage a series of readings at regular time intervals could be taken to see just how much damage is occurring. Similarly a standard could be set whereby if a cave approaches it those concerned with the conservation of the particular cave should start thinking of taking positive steps towards further protection, e.g. a gate, asking the local landholder to restrict access, or getting the government to take legislative steps towards protection.

In many cases the above four systems can be used for only part of a cave as well as for individual caves or possibly for a whole area.

FOSSIL RESEARCH AT VICTORIA CAVE NARACOORTE, SOUTH AUSTRALIA

by

R.T. Wells

(Presented by A.W. Lake)

The fossil chamber in the Victoria Cave at Naracoorte was discovered in August 1969 and appears to be one of the richest deposits of Pleistocene marsupial bones yet discovered in Australia. Most of the fossils recovered so far are already known, yet the deposit is still of great scientific importance. To understand why, it is necessary to have some insight into the discipline of vertebrate palaeontology and some knowledge of previous work in this field in Australia.

Vertebrate palaeontology, like every scientific specialization is a search for the answers to certain fundamental questions. These are:

1. *What* are fossils?
2. *When* did a particular fossil live?
3. *How* and *where* did it live?

and 4. *What* is its place in evolution?

Most of the early workers in this field were concerned only with the first question, with morphological systematics or the study and description of fossils. They did not recognise the need for accurate stratigraphic localization, that is, they did not concern themselves with the second question, *when* did the fossils live? One of the major tasks facing vertebrate palaeontologists today is to relocate the classic localities in order that the material collected previously can be allocated to a definite stratigraphic horizon.

A recent example is the work of Allan Barthelomai of the Queensland Museum. He has re-examined the De Vis collection taken from the Darling Downs in the 1890's and has been able to show that this collection actually represents two distinct faunas.

The Wellington Caves in New South Wales have been the source of much of the early marsupial fossil material described by the famous British anatomist, Sir Richard Owen, and although this material forms the basis of our current knowledge of the Pleistocene vertebrate faunas, there has been no serious attempt to elucidate the stratigraphy within these caves.

The work involved in determining the time relationships within a cave deposit is very slow and painstaking and therefore it is not surprising that unprotected deposits have been rapidly exploited.

At Naracoorte we were fortunate that the discovery of the undisturbed fossil deposit was made in a new section of an established tourist cave and is therefore effectively protected from unwitting explorers and over-zealous collectors. This unique situation has enabled us to plan our approach to the excavation in a systematic manner which we hope will allow us to do more than just name the fossils. It should give us some insight into the past ecology of southern Australia.

The deposit is some 250' x 60' x 8' deep — so large that it is unlikely that it will ever be fully exploited. In fact at this stage we are planning to leave half the chamber in its original condition. Our approach so far has been to map and grid the surface of the deposit and excavation has commenced at several grid locations. At one end of the cave a test pit is being dug down to basement rock to give us some insight into the general stratigraphy of the deposit. Core samples have also been taken to further help in this interpretation.

Several techniques are being used to remove the bones. Large and fragile specimens are isolated on a column of earth and encased in a plaster jacket. These are then removed to a surface laboratory for further treatment. Other specimens are treated on site with either shellac or an acrylic. Each specimen is given a number which indicates its position in reference to the grid and its depth in the sediment. Carbon samples, wherever they occur are collected in aluminium foil and suitably catalogued. These will later be used for radio isotope dating of the deposit. All the overburden is run through a sieve to remove the remains of the small animals. Sediment samples are treated with oxidizing acids and examined for their fossil spore content. Because of the high humidity within the cave, all the fossil material is removed to a surface laboratory which has been kindly provided by the South Australian Government Tourist Bureau.

Rather than just give a check list of the animals we have identified, I feel it would be more informative to discuss them in terms of the currently accepted classification of marsupials as proposed by Dr David Ride in 1964. Ride groups the super-families of marsupials into 4 distinct orders, three of which occur in Australia.

Order I The Marsupicarnivora or Marsupial Carnivores

This order is represented in Australia by the super-family *Dasyuroidea* and includes such animals as the Tasmanian Wolf, Tasmanian Devil, native cats and pouched mice. The following members of this group have been identified in the cave deposit:

1. *Thylacinus* (the canine teeth) of the Tasmanian Wolf.
2. *Dasyurus*, the native cat (teeth and skull portion).

and 3. *Antechinus* and *Sininthopsis* (the small pouched mice).

Order II The Paucituberculata

These are South American only.

Order III The Peramelina, represented by the bandicoots, an omnivorous group. The cave deposit has yielded both long nosed bandicoot (*Peramales*, two species) and the short nosed bandicoot (*Isoodon*, one species).

Order IV The Diprotodonta

This is the largest of the Australian orders and includes the family Phalangeridae, possums, cuscus and marsupial lions; Wynyardiidae, an Oligocene fossil from Tasmania; the Vombatidae, the wombats; Diprotodontidae, the large quadrupedal diprotodonts and finally the largest family, Macropodidae, the kangaroos.

Amongst the possums (Phalangeridae) we have identified Pigmy Possums, Gliding Possums and Ring Tailed Possums, but so far there is a surprising absence of the ubiquitous Brush Tail. Also included in this group is the Cave Lion with its unusual tooth structure about which there has been much controversy. The skulls of six of these animals have been discovered so far. Wombat skulls have been found and identified as belonging to the genus *Vombatus*, a smooth nosed wombat.

At present it is thought that there are at least five evolutionary lines within the Diprotodontidae, the largest, and possibly best known, being represented by *Diprotodon australis* from Lake Callabonna in the north east of South Australia. The diprotodontids at Naracoorte are slightly smaller animals (about the size of an ox) represented by the genus *Zygomaturus*. A skull, several jaws, teeth and skeletal elements have been uncovered.

The family Macropodidae is particularly well represented in the Naracoorte deposit. This family can be divided into two groups, the Macropodinae, a line represented by present day kangaroos and the Sthenurinae, an extinct group of short tailed kangaroos. Amongst the Macropodinae we have a large suite of fossils ranging from the small Bettongs or rat kangaroos to the giant grey kangaroos (which appear to be larger than present day greys). Many species of the extinct short-tailed kangaroos (Sthenurines), including both the browsing and grazing forms as well as the giant of all kangaroos, *Procoptodon*, are present in the deposit. Pes and jaw elements of the giant wallaby, *Protemnodon*, have also been identified.

As well as this vast range of living and extinct marsupials, the deposit also contains the remains of lizards, birds and rodents. This particular faunal assemblage, and the fact that it seems at present to lack any members of the genus *Rattus* would indicate that the deposit is considerably older than others previously discovered in the South East of South Australia.

Several theories have been advanced for the origin of the deposit, including such speculation as: it was a den of *Thylacoleo*, or that animals were washed in or that it was a natural animal trap. However, at this stage we have insufficient evidence to support any one hypothesis to the exclusion of others.

Undoubtedly this deposit is scientifically important but of equal importance is the example this project provides. How can we co-operate with Government Departments to conserve for future generations some of the excitement of these discoveries?

The South Australian Government Tourist Bureau is to be highly commended for its enthusiastic support and financial backing of this project. Their interest has led to the establishment of an underground museum of prehistory where the general public can view the discovery and the subsequent excavations at first hand and they have also established, in their new ticket office complex on the Caves Reserve, a large laboratory and museum for the preparation and display of these remarkable fossils.

Furthermore the enthusiastic support of the members of C.E.G.S.A. should not escape comment. It has involved many thousands of hours of painstaking work over the last 18 months, yet the project can still be considered to be in its infancy.

This is only one of the many projects being conducted by C.E.G.S.A. in the Naracoorte Caves Reserve.

DISCUSSION

Q *Did they find a* Thylacoleo *in New England?*

A *Thylacoleos* have been found in many places. As I mentioned they found some in the Wellington Caves.

Q *The one found in New England had three young trapped under it presumably due to a cave collapse in alluvium. Surely it would have stomach contents which would resolve the problem whether it was carnivorous or not.*

A I haven't heard anything about this. If you have any information, please send it to Bob Willis or to C.E.G.S.A. There is a lot of argument to be settled.

THE BAT POPULATION OF THE NARACOORTE CAVES AREA

by

Elery Hamilton-Smith *

Introduction

The Bent-winged bat, *Miniopterus schreibersii* (Kuhl 1819), probably has the most wide-ranging natural geographical distribution of any mammal (Brosset 1966). It occurs throughout Southern Europe, the Middle East, Africa, Southern and Eastern Asia, the Malay-Indonesian archipelago, New Guinea and Australia. This is the only bat recorded from the caves of the Naracoorte area.

The bats of the sub-family Miniopterinae, which contains only the genus *Miniopterus*, are all remarkably similar, and their proper classification into species remains confused. A great number of sub-specific names have been erected for the forms which are generally considered to comprise *M. schreibersii*. Many of these have been based on differences in colouration and it is now generally recognized that colour differences in bats are an inadequate basis for taxonomic differentiation, as these are subject to wide ranges of individual, seasonal or regional differences. Two such sub-species have been recognised in Australia, with *M. s. orianae* inhabiting the Kimberleys and Arnhem Land regions and *M. s. blepotis* occurring along the Eastern and South-Eastern coastlines. There is a geographical separation between these two major populations and there are minor but apparently consistent differences (J.E. Hill, pers. commun.).

This paper summarises some results of studies on the "Naracoorte" population of *M. schreibersii*. Although this population is not able to be separated from others in South Eastern Australia on morphological grounds, it has a clear distinctiveness on biological grounds.

M. schreibersii and the territorial concept

Australian studies, ably summarised by Dwyer (1968), indicate that in South-eastern Australia it is possible to distinguish a number of relatively discrete populations of *M. schreibersii*. Each such population is based upon a specific maternity site which is used annually for the birth and early development of young. Furthermore, each such population generally only moves about in the course of each year within a specific territorial range. These territorial ranges may overlap with each other, but even when this occurs, transfer of any individual bat from one population to another appears to be the exception rather than the rule.

It is extremely difficult to compare these results with those from studies in other countries. Many of the studies on *M. schreibersii* have been extremely limited, either in the number of individuals or in the geographical area studied, Kuramoto et al (1969) in Japan, as an example, have only studied the movements and behaviour of this species in several caves of the Akiyoshi-dai plateau. It is clear from their report that these caves are used throughout the year by males, but females are rarely found in summer, having presumably moved to the maternity site which remains unknown at this stage (Kuramoto, pers. commun.). Most European studies have been based upon hibernating sites and little attention has been given to maternity sites or to differences between young and mature individuals. However, a careful examination of results from Hungary (Topal 1956, 1962), Czechoslovakia (Gaisler & Hanak 1969) and Spain (Balcells 1964) strongly suggests similar patterns to those of Australia.

Territory and movements of the "Naracoorte" population

What I have chosen to call the "Naracoorte" population of *M. schreibersii* is based upon the maternity site at the Naracoorte Bat Cave (S3 in Matthews 1968). The use of this cave as a maternity site has been described by Dwyer and Hamilton-Smith (1965) and will be further discussed below. Since 1961, bats from the population have been captured, marked by numbered aluminium or monel metal bands being clipped to the forearm, and released (Simpson & Hamilton-Smith, 1965). An analysis of recaptures then enables deductions to be made about the movements and geographical territory of the population concerned.

Some results of these studies on the Naracoorte population have already been reported by Hamilton-Smith (1965) and Dwyer (1968). Dwyer demonstrated the integrity of the Naracoorte population, reporting only five exchanges of membership with other populations but did not fully resolve the status of the populations found at Portland and Byaduk. Eighteen movements were recorded between the Portland-Byaduk and Warrnambool districts, with ten movements between the Portland-Byaduk and Naracoorte districts.

* Hon. Associate in Zoology, South Australian Museum.

TABLE 1. RECAPTURES WITHIN THE APPARENT NARACOORTE POPULATION TERRITORY (CAVE NUMBERS FROM MATTHEWS 1968)

Area	Site	S6	S5	S9-10	S11-12	S33	S68	S69	NON-CAVE	S42	S101	S113	NOONAN'S	S52	S54	ROBE	BENARA	S109	SNAKE
NARACOORTE AREA	BAT CAVE (S6)	149																	
	BIG CAVE (S5)	15	-																
	TOMATO-STICK CAVE (S9-10)	44	-	2															
	CATHEDRAL CAVE (S11-12)	1	-	-	-														
	FOX CAVE (S33)	4	-	-	-	-													
	"CAVE PARK" CAVE (S68)	-	-	-	-	-	-												
	HODGES CAVE (S69)	11	-	3	1	4	-	-											
	VARIOUS NON-CAVE SITES	8	-	-	-	-	-	-	-										
LOWER SOUTH-EAST AREA	QUARRY CAVE (S42)	1	-	-	-	-	-	-	-	-									
	MT. BURR CAVE (S101)	38	-	4	-	-	-	9	-	-	1								
	GLENCOE WEST CAVE (S113)	13	-	-	-	-	1	-	1	-	11	13							
	NOONAN'S CAVE	5	-	-	-	-	-	-	-	-	2	1	2						
	FIVE CORNERS CAVE (S52)	3	-	1	-	-	-	-	-	-	1	2	-	-					
	DROP DROP CAVE (S54)	18	-	-	-	-	-	2	-	-	3	14	3	4	7				
	MARINE CAVE, ROBE	25	-	1	-	-	-	1	-	-	-	-	-	-	2	1			
	UN-NAMED CAVE, BENARA	-	-	-	-	-	-	-	-	-	-	3	-	-	5	-	-		
	UN-NAMED CAVE, WANDILO (S109)	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
	SNAKE HILL (VICT.)	18	-	1	1	-	-	1	-	-	1	-	1	5	39	-	-	2	61
	PORTLAND	11	-	-	-	1	-	1	-	-	-	2	2	-	4	-	-	-	2
	BYADUK	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

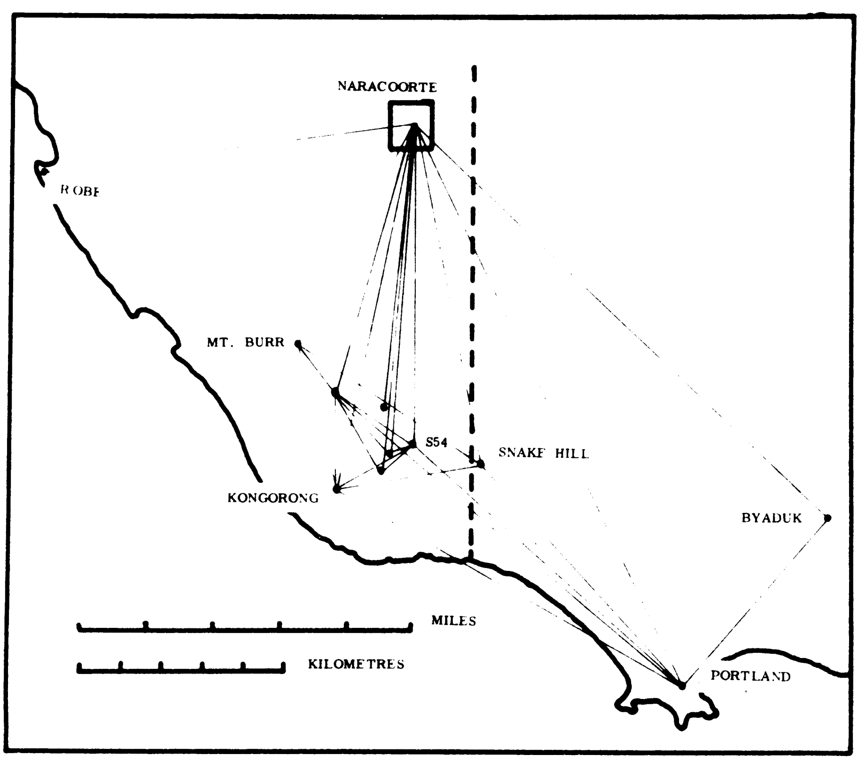


FIG. 1 PATTERN OF RECORDED MOVEMENTS WITHIN THE TERRITORY OF THE NARACOORTE POPULATION

A further analysis is presented here. The data upon which Dwyer (op.cit.) is based was obtained from an inspection of records held by the banding office at the C.S.I.R.O. Division of Wildlife Research. That given here is based upon my own records and so although the earlier parts of my data will have been available to Dwyer, there may well be further data available at the Banding Office which have not yet been made available to me. (This suggestion is supported by four reports from Dwyer and from Purchase (1969) shown in table 2 which do not appear in my own records.) Table 1 and Figure 1 show all recaptures recorded within the South-East of South Australia (including Snake Hill, which is in fact marginally inside Victoria but geographically can well be considered as part of South Australia's lower South-East) together with all movements between this region and the Portland-Byaduk area. Table 2 and Figure 2 show all movements (which are known to me) between the Naracoorte population and other populations. Cave names and numbers cited have been taken from Matthews (1968) and Sexton (1965). A complete list of

Band Number	Sex	Banded	Re-captured
20/05638	M?	North Sydney, N.S.W. 23.vi.63	S113, Glencoe W., S.A., 30.viii.65, 30.i.66 (F?)
20/08723	F	Cheltmore, N.S.W. 31.iii.63	Snake Hill, Vict. 27.v.67 (Purchase, 1969)
20/15324	F	S5, Naracoorte, S.A. 13.vi.64	Fig Tree Cave, Wombeyan, N.S.W., 13.vi.66
20/15620	F	Spring Creek Cave, Buchan, V., 18.vii.64	S52, Mt. Gambier, S.A. 23.vii.66
20/16760	F	S3, Naracoorte, S.A., 18.ix.65	Maroondah Aqueduct, Healesville, V., 5.vii.66 (Seebeck & Hamilton-Smith 1967)
20/27401	M	Grasmere Cave, Allansford, V., 3.iv.66	S3, Naracoorte, 4.ii.67
	M	S69, Joanna, S.A., 6.xi.61	Panmure Cave, Panmure, V., 21.iii.65 (Dwyer 1968)
	F	S3, Naracoorte, S.A., 13.vii.64	Wombeyan, N.S.W., 23.ix.64 (Dwyer 1968)
	F	S3, Naracoorte, S.A., 13.viii.64	Wombeyan, N.S.W., 13.vii.66 (Dwyer 1968)

TABLE 2 : Movements between the Naracoorte population and other populations.

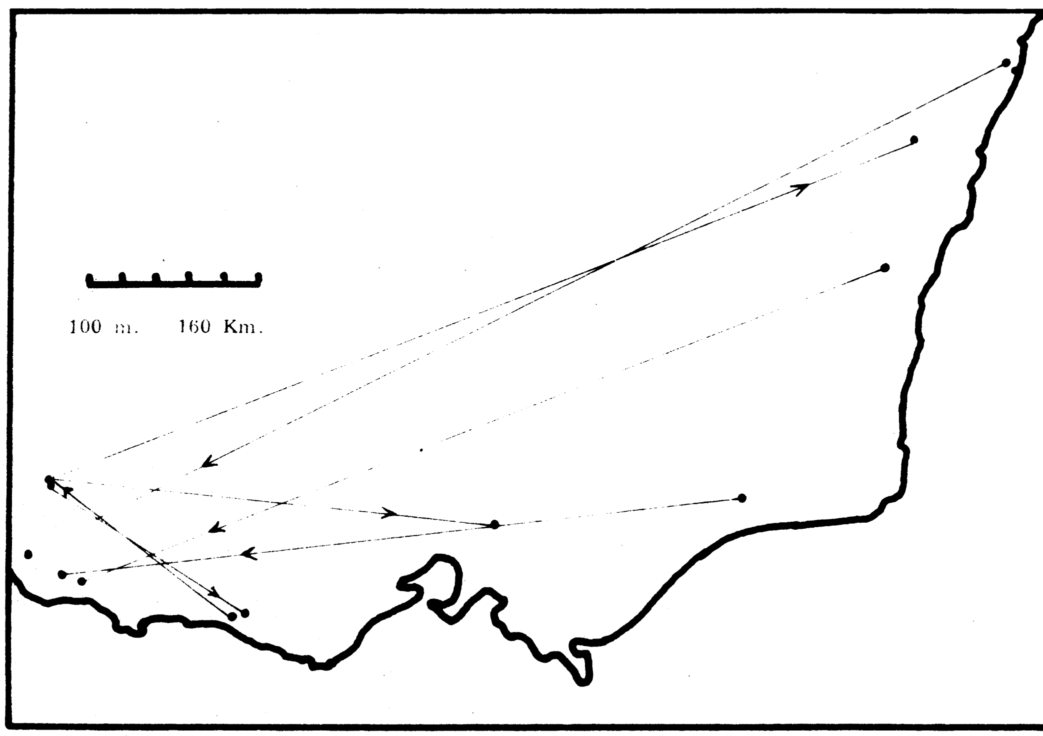


FIG. 2. MAP SHOWING MOVEMENTS BETWEEN THE NARACOORTE POPULATION AND OTHER POPULATIONS.

sites known to have been used by bats within this area is also given in Appendix 1.

To summarise these tables, 622 bats banded in the South-East of South Australia have been re-captured. 236 of these were re-captured at the site of banding, 355 elsewhere within the South-East of South Australia, 26 in the Portland-Byaduk district, and 5 in other areas.

Thus, this analysis gives strong support to Dwyer's conclusions, and does not significantly add to it nor further clarify the status of the Portland-Byaduk district. I have not attempted to assign any significance to relationships between various sites, as it could be clearly demonstrated, at least in this case, that such apparent relationships are due to factors arising out of patterns in search intensity and timing, rather than to real bio-geographical factors.

The Annual Cycle and Cave Use

As with most temperate-zone bats, *M. schreibersii* exhibits an annual reproductive and movement cycle. This has been described for the North-eastern New South Wales population by Dwyer (1965), while Dwyer and Hamilton-Smith (1965) have discussed some differences in the Naracoorte population. Our data showed that the Naracoorte population differed from others in South-Eastern Australia in that parturition occurred from mid-October to late November as contrasted to the early December to mid-January period of other populations. In addition, the maternity cave population at Naracoorte contained approximately 50% of male bats, while in other populations no more than 10% of males were found in such sites and these were all yearlings.

More recent data confirm these observations, but it is now possible to add some details on the general year-round patterns of use in the Naracoorte Bat Cave and other caves in the area. The greater part of the population departs from the Bat Cave during February and early March. The small number which remain consist of both male and female adults in approximately equal proportions throughout autumn, but the number of females decreases until nearly all bats in this cave during early spring are adult males which roost in a solitary way. Large numbers of animals commence to return to the cave during September, and form clusters, largely of pregnant females, which roost separately from the few solitary males. Thus, on 1-2 September 1962, collecting 160 bats which were roosting alone or in very small groups yielded only 12 females, while 80 collected from a cluster of several hundred included only 3 males. By late September and early October, the population has usually returned to its equal division between males and females, and solitary roosting is virtually replaced by roosting in large clusters, although segregation between various groups is preserved. However, the basis of this segregation is not completely clear – some groups are comprised almost entirely of a single sex while others are mixed, and at least some such groupings appear to retain their integrity over at least several weeks.

Population increase continues throughout October, and parturition commences towards the end of October, but is generally completed by the end of November. The young bats are placed in domed areas of the roof, which unfortunately from a research viewpoint, are too high to be accessible. The most recently born are placed in the central areas of each dome, so that the eldest of each year's new population are found around the outer edges of the nursery cluster. By the second week of January, the oldest move away from this clustering and commence to re-group in another part of the cave. These older juveniles are weaned and flying actively, but because of the inaccessibility of the nursery groupings, it is impossible to establish the exact sequence and timing of these developmental stages. The juveniles commence their flying within the cave, but rapidly progress to flying in and out of the cave entrance following the evening exit flight of the adults as a preliminary to the progressive establishment of the adult feeding flight pattern. By early February, all juveniles have moved into the new grouping, and their distributive flights from the maternity cave to other parts of the population territory then begin.

It is also of interest to report further data on the climate of this cave, as that contained in Dwyer & Hamilton-Smith (1965) was somewhat incomplete. The Cave is entered through a collapse into a large tunnel which runs in a roughly South-Easterly direction to an extremely large domed room in which the bulk of the bat population is generally found. The temperature in the tunnel ranges from 13.0°C to 15.0°C between winter and summer. In the big room, winter temperatures may drop as low as 16°C while in summer temperatures near the floor range from 19°C to 25°C. The air temperature in the small roof domes where the juvenile bats roost has been recorded at 30°C, while placing the sensing unit amongst the clustered bats registered 33°C. This demonstrates in a more spectacular way than similar caves in warmer areas the "incubator" effect of these maternity sites.

A number of caves in the immediate vicinity (e.g., Big Cave, Tomato-Stick Cave, Cathedral Cave) are generally devoid of bats between September and March. During the March to September period, these have populations of varying size, but up to several thousand, consisting of roughly equal numbers of males and females. Juveniles are rarely seen in these caves, Hodges Cave (S69) seems to have no regular patterns of use by bats; groups of up to 1,000 have been seen in this cave at various times of the year and have had varying sex-age compositions: for most of the year, bats are absent. By contrast, caves in the Lower South-East (e.g., Drop-Drop, Mt Burr Cave, Snake Hill, etc.) have large populations (up to perhaps 10,000 but generally less) during autumn, winter and spring which again are generally equally divided between males and females but often contain juveniles. A small population remains in these caves throughout summer.

The Portland-Byaduk area, as pointed out by Dwyer (1968), appears to be within the territory of both the Naracoorte and Warrnambool populations. The Portland Bat Ridges caves certainly have a year-round occupancy by bats, with movement to and from Byaduk and other caves in the Portland area. On my own visits to the Bat Ridges (generally in summer), I have found the population to consist largely of adult males; the lowest percentage of males I have recorded at this site is 75%. However, this may not be the case at other times of the year. Dwyer (op cit) has suggested that a further maternity site may exist in the Portland area, but this has not been located, and unless there are a larger number of female bats in this region at other times of the year than can be accounted for from Naracoorte and Warrnambool, there seems to be little evidence to substantiate this suggestion at present. By contrast with Dwyer's experience in N.S.W., this is the only cave frequented by the Naracoorte population from which I have consistently found such an inbalance in the population.

Some Notes on Associated Organisms

Parasites on the Naracoorte population of *M. schreibersii* include the widespread tick, *Ixodes simplex simplex* Newmann; several mites, including *Ichoronyssus aristippe* Domrow, *Spinolaelaps miniopteri* Zumpt & Patterson, and *Spinturnix* sp. nov.; and two Nycteribiids, *Nycteribia parilis vicaria* Maa and *Penicillidia* sp. nov. The most interesting of these are the two undescribed new species listed here, both of which are currently in the process of study and description, and both of which appear to be virtually confined to bats of the Naracoorte population.

The Naracoorte Bat Cave houses an interesting population of invertebrates, the numbers of which reach staggering figures in mid-summer and decline almost to extinction in winter. The widespread guano mite, *Cilliba coprophila* Womersley, which was first described from this cave, may reach densities of 1,000 individuals per square inch of surface area. Harris (1970 and in prep.) has been studying a similar community of guanophiles in the Carrai cave of N.S.W. and although the general features of these communities appear similar, there are clearly a number of differences in detail. Interestingly, the Naracoorte cave appears to have a much greater diversity of species at the macroscopic level and although the microscopic life has not been examined, the remarkable temperature fluctuations of the Carrai guano reported by Harris do not appear in the same way at Naracoorte, where guano temperature generally seems close to that of the cave atmosphere. Unfortunately, no studies have been yet made of the micro-fauna (and flora) of the Naracoorte community.

A listing of the recorded species from this cave is presented in Table 3 for comparison with other similar caves (e.g. Hamilton-Smith 1969). It will be noted that the Diplopoda (millepedes), Opiliones (harvestmen) and parasitic Hymenoptera (wasps) which occur in many similar caves of the Eastern states are absent.

CRUSTACEA	
Isopoda	"Slaters" – various species, all undetermined, found on drier patches of guano, cave walls, etc.
ARACHNIDA	
Araneida	Various spiders, all undetermined, live amongst guano and on cave walls
Acarina	*Cilliba coprophila* Womersley (Fam. Cillibidae)
	Asternolaelaps australis Womersley & Domrow (Fam. Ichthyostomatogasteridae)
	Tyroglyphus dewae Womersley (Fam. Acaridae)
	These three species are all from guano in the cave.
Pseudoscorpiones	*Protochelifer naracoortensis* (Fam. Cheliferidae) Endemic to this cave and found in guano throughout the year.
INSECTA	
Collembola	Undetermined species found in drier parts of the guano
Dictyoptera	*Gislenia australica* (Brunn.) (Fam. Blattellidae) is common throughout the cave in summer
Orthoptera	*Novotettix naracoortensis* Richards (Fam. Rhaphidophoridae) has only rarely been collected, and then always near the entrance.
Pscoptera	*Lepinotus reticulatus* Enderlein (Fam. Trogiidae) has been collected from a dead bat near the entrance.
	Psyllipsocus ramburi Selys-Longchamp (Fam. Psyllipsocidae) lives on drier parts of the guano
Diptera	Families of which representatives occur in association with the guano include Chironomidae, Psychodidae, Sciaridae, Phoridae, Sphaeroceridae, Anthomyiidae, Muscidae
Lepidoptera	*Monopis* sp. (Fam. Tineidae) occurs on the guano and may reach densities up to 50 per sq.ft.
Coleoptera	*Speotarus lucifugus* Moore (Fam. Carabidae) roves over the guano in summer
	A small Histerid, undetermined, may reach densities of 150 per sq. ft.
	Quedius sp. (Fam. Staphylinidae) occurs throughout fresh areas of guano
	Nargomorphus minusculus Blackburn (Fam. Anisotomidae) is found occasionally.
	Ptinus exulans Erichson (Fam. Ptinidae) is common, and occurs in both fresh and dry areas of guano.
	Corticaria sp. (Fam. Lathridiidae) is found throughout the fresh guano, but only in small numbers.
	A small beetle belonging to the Fam. Jacobsoniidae and probably to a new genus occurs in fresh guano with a density of up to 10 per sq. in.

TABLE 3: Summary of invertebrate fauna found in Bat Cave, Naracoorte.

The Biological Status of the "Naracoorte" Population

This presentation has highlighted a number of ways in which this population differs from others in South-Eastern Australia. These are summarised in Table 4. It will be clear from this data that the Naracoorte population is biologically distinct, although some aspects remain unclear. The timing of spermatogenesis and mating is not known precisely enough to indicate whether mating between individuals from different populations would be likely, nor is it known to what extent an individual moving from one population to another might acquire some of the behavioural and biological characteristics of the "adopted" population.

Naracoorte population	Other populations
Parturition occurs mid-October to late November	Parturition occurs December to mid-January (except Warrnambool – mid-November to end December)
Adult males present in maternity cave during summer	Adult males absent from maternity cave during summer
Other caves generally house roughly equal proportions of males and females	Other caves generally house groups with dominance of one sex (except Warrnambool)
Parasites include *Spinturnix* sp. nov. and *Penicillidia* sp. nov.	Parasites include *Spinturnix psi* and *Penicillidia oceanica*

TABLE 4: Summary of differences between the Naracoorte population and other South-Eastern Australian populations.

One can note here the usefulness of detailed observations on any individual which is known to have moved from one population to another. This, unfortunately, is rarely possible, and could only be established by checking the details of each bat recaptured at the actual time of re-capture. To cite an annoying example: Bat no. 20/05638 was recorded as a male when banded in North Sydney; it was re-captured at S113, Glencoe West but its sex not noted; it was again recaptured at the same site, and on this occasion, its sex was recorded as female. Obviously, one observer was in error. *If* the bat concerned is actually a female, then the fact that it was obviously not breeding in the summer of 1966 *might* be significant. Similarly, examination of the parasitic fauna on any such bat would be extremely useful.

It will be seen from table 4 that the Warrnambool population, which overlaps with that of Naracoorte in the Portland-Byaduk district, shows some similarity, although it is certainly more akin to the general pattern of Eastern Australian populations than to that of Naracoorte. It might be noted here that the Warrnambool population is also characterised by extreme localization within a few caves over a comparatively small geographical range, even though other caves exist within reasonably close proximity.

There is general acceptance of the view that Australian bats are of Asiatic origin and entered this continent by a series of migrations from New Guinea (Simpson 1961). The South-Eastern *M. schreibersii* of Australia provide a good example of a "stepped cline" in biological variation and this is generally accepted as evidence of former isolation of particular populations. It seems reasonable to suggest from the available evidence that the *M. schreibersii* of South-Eastern Australia have resulted from at least three successive but separated migrations which entered Australia at different times and which enjoyed long periods of geographical isolation. That population now based at Naracoorte might represent the first entry to Australia, the Warrnambool population the second entry, and others N.S.W. and Victorian populations a third entry (or series of entries). The isolation of these populations permitted the gradual differentiation of characteristics which is now evident.

Even if mating between individuals from different populations does occur, today it is clear that this is likely to be rare and gene flow between populations would be restricted, thus tending to preserve the integrity of each population.

Further Research Questions

Two kinds of further research are worthy of discussion. On the broad scale, it will clearly be useful to seek definition of the various populations occurring in *M. schreibersii* throughout its range. Studies paralleling those of Dwyer and myself will not only clarify the taxonomic questions raised in this genus, but could probably contribute a great deal to our knowledge of historical zoogeography. As a minor example, it would be of considerable interest to define the population characteristics of *M. s. orianae* in Northern Australia and to compare these with those of Timor, New Guinea and other Australian populations.

However, it is probably more immediately useful to list some outstanding and relatively simple research tasks in relation to the Naracoorte population.

1. Further analysis of available data, including
   (a) extension of the analysis presented in this paper to include all records held by the banding office
   (b) full analysis of sex-age data in relation to all caves in South-Eastern South Australia
   (c) full analysis of all data relating to the Portland-Byaduk district, including sex-age ratios of samples.
2. Continuing banding studies with particular attention to the biology of individuals which are detected as having moved from one population to another.
3. Further field work throughout South-Eastern South Australia to examine the timing of cave use throughout the area and the measurement of sex-age composition throughout the year.
4. Studies to clearly define the nature and timing of the reproductive cycle in this and other populations.
5. Replication of the studies by Harris on ecology of the guanophile community.

Acknowledgments

Although this is only a brief review, the work programme involved has been greatly assisted by the co-operation of many people and organizations. The Australian Bat-Banding scheme has provided bands and office support for the programme; the M.A. Ingram Trust has assisted with equipment; the South Australian Museum and the Speleological Research Council have facilitated studies of the associated invertebrates; the South Australian Tourist Bureau and its staff have not only permitted access to caves under their control but have assisted in numerous practical ways; other banders, notably Peter Dwyer and the late John Edge, have freely exchanged information; many speleologists, particularly Miss Beth Sowden, Mr and Mrs F. Aslin, Messrs Warren Kennedy, Ken Heyne and Andrew Spate have given essential practical assistance in the field; various specialists, particularly Dr T.C. Maa and Mr R. Domrow, have determined specimens and discussed their findings; Graeme Wilson has assisted with the presentation of diagrams.

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APPENDIX

Caves from which *M. schreibersii* has been recorded in South-eastern South Australia and South-western Victoria.

S3	Bat Cave, Naracoorte
S5	Big Cave, Naracoorte
S7-8	Blackberry Cave, Naracoorte
S9-10	Tomato-Stick Cave, Naracoorte
S11-12	Cathedral Cave, Naracoorte
S15	Sleeping Cave, Glenelg River
S19	Monbulla Cave, Penola
S30	Robertson Cave, Joanna
S33	Fox Cave, Joanna
S42	Quarry Cave, Mt Burr
S52	Five Corners Cave, Mt Gambier
S54	Drop Drop Cave, Mt Gambier
S59	Lost Cave, Naracoorte
S61	Graveyard Cave
S62	Un-named Cave
S63	Rendlesham Cave, Rendlesham
S68	Cave Park Cave, Naracoorte
S69	Hodges Cave, Joanna
S72	Standing Cave
S90	Gran Gran Cave, Mt Burr
S101	Mt Burr Cave, Mt Burr
S109	Un-named Cave, Wandilo
S110	Un-named Cave
S113	Glencoe West Cave, Glencoe West

Noonan's Cave, Kongorong
Marine Cave, Robe
Un-named Cave, Benara

Amphitheatre Cave, Glenelg River
Snake Hill Caves, Myora
Cave Hill, Heywood
Fern Cave, Portland
Bat Ridges, Portland
Cape Bridgewater Caves, Portland
Byaduk Caves, Byaduk

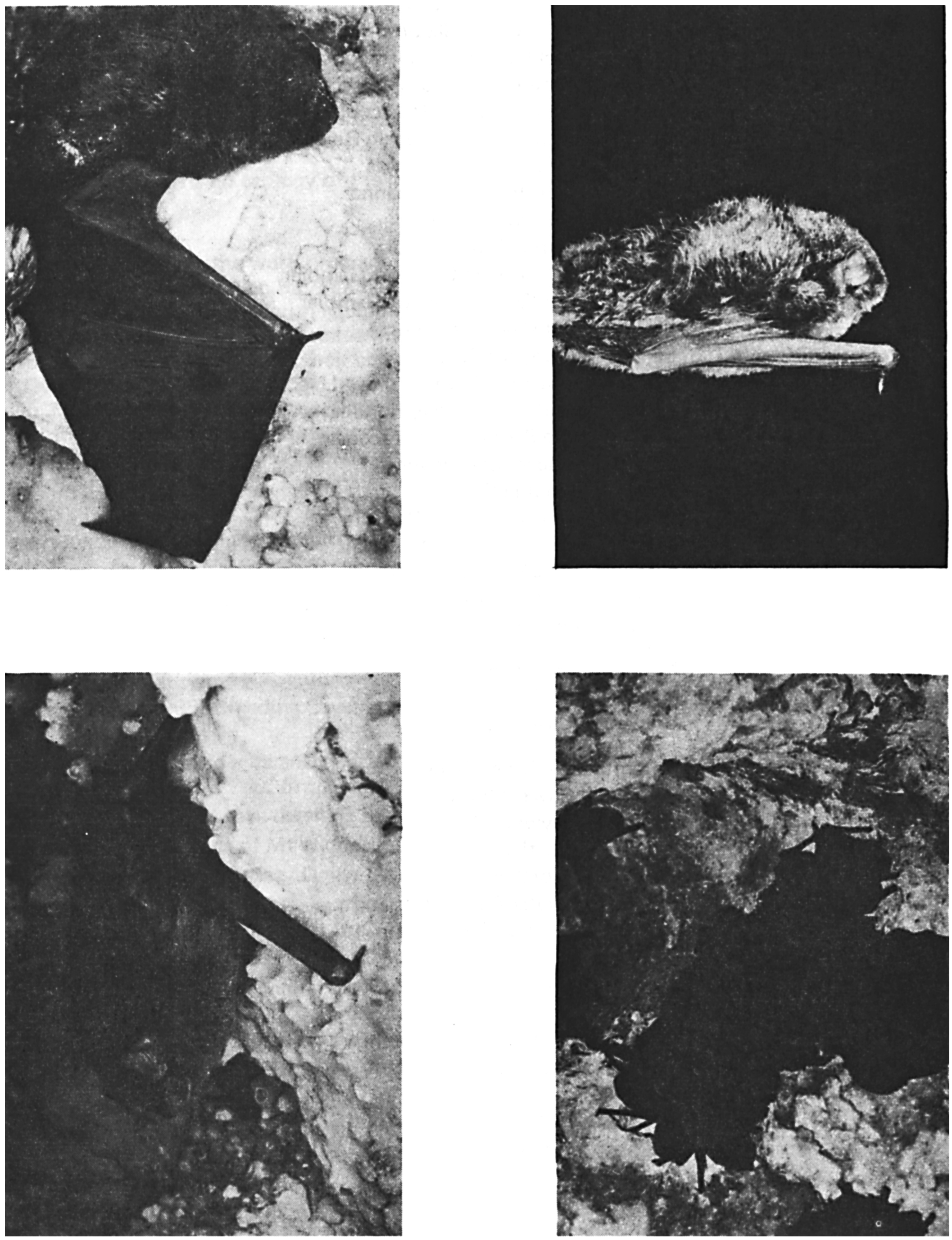

Plate 1: The Bent-winged Bat *(Miniopterus schreibersii)* from Naracoorte, South Australia. The second photograph shows the folding of the wing which accounts for the common name ("long-fingered bat" in German) and which is a distinctive feature in recognition of the genus.

DISCUSSION

Q *Is that the only albino bat that has been seen in Australia?*

A It is the only one that has been seen in Australia. We have seen one other that had white on the bottom half, that's if bats have a bottom half. The only other albino *Miniopteris* recorded is one that has been seen by Russ Mumford in Kenya about three months after this one was seen in Australia. It is the only other white *Miniopteris* known. White bats are in fact very rare and probably the reason for this would be that an albino bat would be an even more obvious target for an owl than the normal coloured one, and so the selection out of albinos would be pretty effective.

C *Quite often you see bats with little patches of white only a ¼ inch in diameter.*

A Yes.

Q *I am wondering if the caveless country between Rockhampton and Riverton might be one factor involved in segregation of bat populations?*

A What we don't really know at the moment, although Peter Dwyer is gradually getting it sorted out, is what happens with *Miniopteris* in Queensland, how many populations are there, what are their patterns, and Peter is still trying to sort this out. There's a maternity cave at Riverton. There are two maternity sites at Rockhampton and the status of each of these in respect to the other is not clear, but by the time we get to Rockhampton we are moving into tropical patterns rather than temperate and this bat in tropical areas in other parts of the world does not have this dependence on a single enormous colony but tends to have a number of smaller colonies. I know Peter has located maternity sites further north in the Mt Surprise area and at Chillagoe, but again we still do not know the full significance or status of these. But once we do, this will probably give a lot more evidence as to what might have happened with the southern ones.

Q *There seems to be yet another factor in making for relatively few incursions across this say tropical barrier. Is it combined with the geographical limitation of possible maternity sites?*

A That is right, and in fact of course it is only being able to spread south of Queensland because it has found sites in which it can get domes and conserve hot air. Without some sort of incubator sites this bat cannot spread out of the tropics.

Q *At Naracoorte especially in the summer, all the bats there, juveniles, females, plus the ones involved in giving birth and feeding and what have you, are in huge clusters in the hottest parts of the cave at the hottest time of the year. In the winters, springs and autumns at Naracoorte and Buchan they tend to be individuals lower down the walls in colder and harsher environment. Care to comment?*

A Peter Dwyer has done work on this. It is one of the obvious things that in summer one gets this incredible clustering in terribly hot caves. In winter, if the same cave is used the roost moves from the domes down on to the exposed points and you get bats resting in what appear to be the colder parts of the cave. Now at the same time those bats are in fact entering a period of torpidity and it is in their interests to remain fairly cool as there is very little food available for them outside. As long as they remain fairly cool they will remain in deep torpidity and not use up energy. Peter's proposal is that this movement to the cooler areas enables them to remain in torpidity, conserve energy, until such time as food is available and they can move into the warmer conditions and again become active.

NOTES ON AUSTRALIAN CAVE HARVESTMEN

(Abridged version. A fuller account is to be published elsewhere)

by

Glenn S. Hunt*

Whilst some components of the arthropod fauna of Australian caves are comparatively well known, members of the order Opiliones (harvestmen) have been little studied. Harvestmen, however, are important predators in many caves, as are their arachnid relatives, the spiders and pseudoscorpions. In Australia there is growing interest in ecological relationships within cave communities (Harris, 1970; Richards, 1971) and it seems desirable to expand the fragmentary notes hitherto published on Australian cave harvestmen.

Harvestmen have a nearly world-wide distribution but most of the 3,500 or so species are found in moist forested areas from the tropical to temperate zones. The layman often confuses harvestmen with spiders and in some museums it is not unusual to find specimens in bottles ostensibly containing only spiders. Harvestmen have the following characteristics, which, taken together, readily distinguish them from other arachnid orders. The cephalothorax is broadly joined to the abdomen and this immediately separates them from the spiders which have a narrow "waist", the pedicel. The chelicerae are pincers, not fangs. The second legs are usually the longest and are the main tactile organs. They generally tap the ground ahead when the animal is moving. Harvestmen usually have two eyes on a median eye-mound. A pair of stink glands opens onto the body above the legs and a defensive secretion is released when the animal is seriously disturbed.

General comments on the Australian cave harvestmen fauna

The order Opiliones is divided into three suborders, each of which is represented in Australia. The only Australian species of the primitive mite-like Cyphophthalmi is found in leaf litter (Forster, 1955). Cavernicoles have been recorded in Europe and South Africa (Vandel, 1965).

The suborder Palpatores is represented in Australia by the family Phalangiidae (sub-family Megalopsalinae) and the Acropsopilionidae. Species in the latter group are usually found in leaf litter and have not been recorded in caves. The Megalopsalinae occur in Australia and New Zealand, usually in lower vegetation strata and under logs. They are extremely long-legged and are sometimes confused with the familiar daddy-long-legs spider. As in other Phalangiidae, there are no troglobitic species in the Megalopsalinae, though they may occupy an important position in the cave food web (Richards, 1960; 1963; 1971). Large numbers may be found in the twilight zone of the cave and constitute part of the parietal fauna. It is probably best to regard the cave as an extension of the normal sheltered surface habitat.

Members of the suborder Laniatores have robust, heavily sclerotized bodies. They are readily distinguished from the Palpatores by their strong raptorial pedipalps, nearly always heavily armed with spines and a strong claw. Most species are found under or in rotting logs, under loose-fitting rocks, or in leaf litter and moss in forested areas. Several cavernicoles have been described from temperate latitudes.

Three families occur in Australia, the Phalangodidae, Assamiidae and Triaenonychidae. Most phalangodids and assamiids occur in northern Australia, none occur in Tasmania (or New Zealand). They do not have any cave adapted representatives in Australia, though many phalangodids in Europe and North America are true troglobites often possessing extreme cave adaptations including complete eye and pigment loss and marked leg elongation (Vandel, 1965; Goodnight and Goodnight, 1960; 1967). The few specimens collected in Australian caves can probably be classified as "accidentals".

Australian Laniatores possessing some degree of "cave adaptation" belong to the Triaenonychidae, sub-family Triaenonychinae, which also includes all the cave adapted New Zealand species. The Triaenonychidae have an essentially southern distribution: southern Africa, Madagascar, Australia (where they have a typically Bassian distribution), New Caledonia, New Zealand and southern South America. Four described species occur in North America, two of which have been recorded in caves. Cavernicolous Triaenonychidae are listed in Table 1 with an indication of the cave adaptations they possess. Two closely related families contain cavernicolous representatives. The Erebomastridae contains some interesting cave species (Briggs, 1969) while the Travuniidae of Europe and Japan contains many species with striking cavernicolous modifications.

Cavernicolous adaptations in Australian harvestmen

In general, cavernicolous harvestmen exhibit, to varying degrees, three modifications which are regarded as cave adaptations: long and thin legs, depigmentation and eye regression.

* School of Zoology, University of New South Wales.

Table 1: Cavernicolous Harvestmen of the family Triaenonychidae

Country	Species	L	T	C	D	R	S	Source
South Africa	*Speleomontia cavernicola* Lawrence	X			X	X		Lawrence (1931)
	Larifuga sp.							Lawrence (1964)
Madagascar	*Ivohibea cavernicola* Lawrence						X	Lawrence (1959)
	Tanalaius milloti Lawrence						X	"
	Millomontia brevispina Lawrence	X			X?			"
	Decarynella gracillipes Fage	X	X	X	X			Fage (1945) Lawrence (1959)
Australia	*Holonuncia cavernicola* Forster	X			X			Forster (1955)
	Holonuncia sp. *ex* Colong Cave	X			X	X		Hunt (in prep.)
	Holonuncia spp. *ex* NSW caves	X			X			"
	new genus, new species *ex* Victoria	X		X	X			"
	Monoxyomma cavaticum Hickman	X	X	X	X			Hickman (1958)
	Monoxyomma sp. *ex* Mole Creek	X	X	X	X			Hunt (in prep.)
	Calliuncus sp. *ex* Western Australia	X			X			"
New Zealand	*Hendea myersi cavernicola* Forster	X	X		X			Forster (1954)
	H. spina Forster	X	X		X			Forster (1965)
	H. takaka Forster	X			X			"
	H. maini Forster	X	X		X			"
	H. aurora Forster	X			X			"
	H. coatesi Forster	X	X		X			"
	H. townsendi Forster	X	X		X			"
	Nuncia (Nuncia) marchanti Forster	X	X		X			"
	N. (N.) kershawi Forster	X	X		X			"
	N. (N.) townsendi Forster	X	X		X			"
United States	*Sclerobunus cavicolens* (Banks)	X		X?	X			Goodnight and Goodnight (1943)
	Zuma acuta Goodnight and Goodnight				X		X	Briggs (1967)

L, T, C, D and R = possible cavernicolous adaptations   S = found also on surface

L = long and thin legs
T = increase in tarsal segmentation
C = modification of tarsal claws
D = depigmentation
R = eye regression

The Australian cave species listed in Table 1 have relatively longer legs than surface species, except *Monoxyomma rotundum* Forster from northern Queensland. The two Tasmanian species of *Monoxyomma* show greatest lengthening. Because of their sensory role, it migl t be expected that the second pair of legs in cave harvestmen are more greatly elongated relative to the other legs. No significant difference has been detected in Australian species, however.

Forster (1965) recognised a tendency for increased tarsal segmentation correlated with increased leg length in New Zealand cave species. The Tasmanian *Monoxyomma* spp. are the only Australian species in which this is evident.

Another modification which seems to occur in some cave forms affects the tarsal claw. In *M. cavaticum*, *Monoxyomma* sp. from Mole Creek, and the species in the Buchan area, the claws are greatly elongated. In *Monoxyomma* spp.

there may be some tendency for shortening of the lateral prongs on the claws of legs 3 and 4, as is the case for *Decarynella gracillipes* Fage of Madagascar (Lawrence, 1959) and *Sclerobunus cavicolens* (Banks) of the United States (Goodnight and Goodnight, 1943).

Partial depigmentation has affected the majority of Australian cave species, as is the case for the New Zealand fauna (Forster, 1965). Most are straw-yellow or orange in colour whilst closely related surface species are orange-brown, reddish-brown or dark-brown.

Complete loss of eyes has been recorded in only one triaenonychid, the South African *Speleomontia cavernicola* Lawrence. *Holonuncia* sp. from Colong Caves, New South Wales* has much smaller eyes than other cave or surface species in the genus and is the only Australian harvestman to have undergone eye regression. The retina and lens are still present, however. The eyemound is also relatively low in the Colong species, paralleling a similar trend amongst cave harvestmen in other countries.

As the biology of Australian species has not been studied and the fauna outside caves not adequately sampled, no attempt is made in this paper to assign species to the categories of troglobite or troglophile. Many European species, thought to be restricted to caves, have subsequently been found on the surface (Juberthie, 1964).

Composition and distribution of the Australian Cave Harvestman fauna

Only three described triaenonychid genera in Australia contain cave adapted species: *Holonuncia* Forster, *Monoxyomma* Pocock and *Calliuncus* Roewer. A new genus will probably be erected for the Victorian cave species.

New South Wales. Although Forster (1955) placed specimens from Jenolan and Yarrangobilly Caves in the same species, *Holonuncia cavernicola*, it is now clear they are distinct (Hunt, in prep.). Hamilton-Smith (1967) records *H. cavernicola* from Basin Cave, Wombeyan, and from Wyanbene Cave near Braidwood. Again, it seems that these forms belong to different species. Until a study of the New South Wales cave harvestmen is complete, the name *H. cavernicola* should only be applied to the Jenolan Caves populations. *Holonuncia* spp. have also been collected at the Isaacs Creek (where the population may be in danger), Tuglow, Colong, Cleifden, Bungonia and Wee Jasper Caves. The genus has numerous surface representatives, including an undescribed species from bush-land in Sydney's suburbs.

Victoria. The species collected from caves in the Buchan area apparently belong(s) to a new genus which is very closely related to *Holonuncia* and has affinities with the Tasmanian species placed in *Monoxyomma*. Further male specimens are required before the status of different populations in the Buchan area can be assessed.

Tasmania. One species, *Monoxyomma cavaticum* Hickman occurs in the Hastings and Ida Bay caves in the south but a closely related species has recently been collected from the Mole Creek Caves in northern Tasmania. One surface species, *M. silvaticum* Hickman, has been described from north-east Tasmania (Hickman, 1958), and has recently been collected in a mine adit at Lottah and a small granite cave near Scottsdale. These three species will have to be removed from *Monoxyomma* and placed in a new genus (Hunt, in prep.).

Monoxyomma cavaticum is apparently common in Mystery Creek and Exit Caves, Ida Bay, where it is found associated with the glow-worm *Arachnocampa (Arachnocampa) tasmaniensis* Ferguson (Goede, 1967). *Hendea myersi cavernicola* Forster preys on New Zealand glow-worms (Richards, 1960) and this may also be true for *M. cavaticum*.

Western Australia. The only species to show cavernicolous modifications is *Calliuncus* sp. from Labyrinth Cave, Margaret River area, in the South-West (Table 1).

Large numbers of the megalopsaline *Spinicrus minimus* Kauri occur just inside entrances of various caves in the Margaret River—Augusta area and the triaenonychid *Nunciella aspera* (Pocock) has been taken under rocks in the entrance doline of Strongs Cave (Hunt, 1971). The former is probably the species to which Hamilton-Smith (1967) refers. Neither is confined to caves.

An interesting new species wrongly determined as *Spinicrus* sp., has been collected from several caves and dolines on the Nullarbor Plain (Richards, 1971). Numerous individuals were taken on the surface at night in the vicinity of Lynch Cave (J.W.J. Lowry, pers. comm.).

Spiracle structure indicates the Nullarbor species is more closely related to species in the south-west of Western Australia than to those in eastern States. The structure is so radically different that the Western Australian species will have to be placed in a new genus. Spiracle structure has been regarded as a useful family character (Silhavy, 1970) but in the Megalopsalinae appears to be of value at the generic level.

Contrary to Richards (1971), the Nullarbor harvestman does not fill a gap in an east-west distribution of the genus *Spinicrus* Forster, but links this component of the Nullarbor fauna with species to the west.

* Maps showing locations of cave areas are given by Matthews (1968).

Conclusions

It is evident that there are gaping lacunae in our knowledge of Australian cave harvestmen; even the basic systematics remain to be worked out. Taxonomic confusion has resulted in mistaken generalizations about the zoogeography of Australian species. A taxonomic study of the Australian cave triaenonychids is in preparation but more material, especially series containing both sexes and samples of the surrounding surface fauna, is required before the amount of intraspecific variation, interspecific affinities and cavernicolous adaptations can be assessed. Any observant speleologist, equipped with a bottle containing 70% ethyl alcohol (or methylated spirits), a pencil and note book, can make a useful contribution in this regard. Care should be taken not to "over-collect", however, as many populations may be quite small and extremely vulnerable to the predations of over-zealous collectors.

A study on the biology of Australian cave harvestmen is also overdue, especially with regard to the degree of physiological adaptation to the cave environment.

Addendum

Since writing, a new cavernicolous species has been collected by T. Goede in King Georve V Cave at Hastings, Tasmania. The species is closely related to *Lomanella exigua* Hickman but the appendages are much elongated and the body depigmented. *L. exigua* has been collected from surface habitats about 15 miles to the north, but to date *L. raniceps* Pocock is the only *Lomanella* species to be taken from surface habitats at Hastings.

Acknowledgments

I am grateful to those people who have collected specimens from different caves, especially Albert and Therese Goede who have collected large series of Tasmanian surface and cave harvestmen, and Jackie Lowry who has collected interesting material in Western Australia, including the Nullarbor Plain. I would like to thank Michael Gray, Arachnologist at the Australian Museum, and Elery Hamilton-Smith, Honorary Associate of the South Australian Museum, for allowing me to examine material in their care; and also Dr R.R. Forster, Director of the Otago Museum, New Zealand, and Prof. V.V. Hickman, Emeritus Professor of Zoology, University of Tasmania, for allowing me to examine material in their possession. I am also grateful to Dr Aola M. Richards, University of New South Wales, for her advice and assistance.

Erratum

According to Juberthie (1964) the South African triaenonychid *Speleomontia cavernicola* is eyeless but Lawrence's (1931) description indicates this species has well developed eyes. Juberthie has been followed in this paper but presumably in error.

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SOUTHERN CAVE-BEETLE FAUNA IN PERSPECTIVE

by

Barry P. Moore

Troglobitic beetles have excited the interests of entomologists and others ever since the first completely blind species were described from Europe over a century ago. In the intervening years northern cave systems have been extensively explored and more and more such species have been discovered in both the Old and New Worlds, so that by now a fairly clear picture of their biology, distribution and evolution has emerged. But not surprisingly, perhaps, comparable work on southern cave faunas has lagged far behind. The first concerted survey here was started in New Zealand some 15 years ago and a rich troglobitic fauna soon came to light, with several species of trechine Carabidae, in particular, attaining levels of morphological development fully comparable with those of the most adapted European forms.

Similar discoveries were hardly to be expected from the dry caves of mainland Australia but those of Tasmania appeared altogether more promising, both on grounds of present wet condition and of past climatic history, and they had, in fact, already produced our only troglobitic beetle in *Idacarabus troglodytes* Lea (Carabidae: Zolinae).

Recent explorations by both local and visitng cavers have fully justified these expectations and we now have quite an impressive list of troglobites from the island state. These additions culminated in the discovery at Ida Bay, some two years ago, of the first completely blind species (a trechine carabid) to be detected in our region—a veritable milestone in southern biospeleology. It therefore seems opportune and most appropriate to attempt to draw a new perspective of our cave-beetle fauna at this Congress in Hobart.

Studies on northern faunas soon established a number of general principles concerning the evolution of cave faunas. Most notable was the fact that troglobites (obligate cavernicoles) attain their greatest diversity in caves of the temperate regions and their present distributions reflect, rather closely, the maximal extensions of glaciation during the Pleistocene period. In effect, the favoured region dovetails with our conception of the Pleistocene periglacial zone, where caves apparently offered a refuge for stenothermic animals from the climatic vicissitudes of those unstable times. The known distribution of troglobitic carabids of the genus *Pseudanophthalmus* (Fig. 1) illustrates this principle particularly well, although many other examples could be cited from either side of the Atlantic ocean.

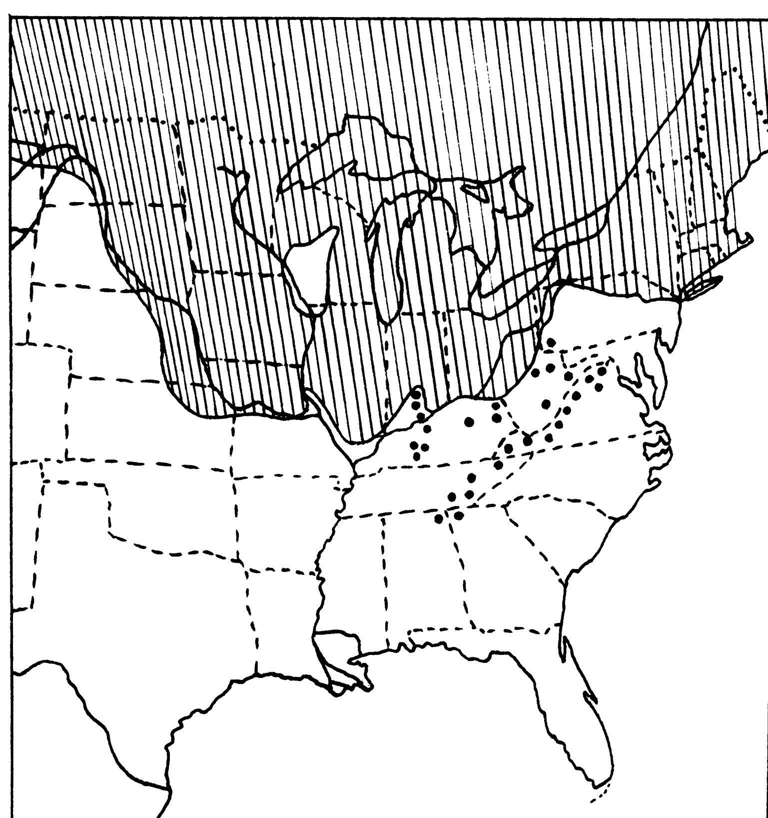


Figure 1:

The approximate distribution of troglobitic carabid beetles of the genus *Pseudanophthalmus* in N. America. The hatched area indicates the limits of glaciation in the Pleistocene. (After Jeannel, 1943, with additions).

The pressures of climatic change were, of course, much less testing in the tropics and it is not surprising, therefore, that cave faunas at those latitudes include very few troglobites. Troglophiles (facultative cavernicoles), on the other hand, are abundant in tropical caves, where they exploit to the full the greatly augmented food supply.

For the most part, troglobitic beetles appear to have been derived from groups that were, in a sense, preadapted to life underground and in continual darkness; these were mainly inhabitants of the deep litter layer of cool, temperate, deciduous forests and many still occur in such habitats today. These beetles included primary detritus feeders belonging to the Anisotomidae and secondary predators of the Carabidae and these two families remain dominant in the northern cave faunas at the present time.

Troglobites have become so specialized that they are all but prisoners of their environment and are able to migrate only by means of subterranean fissures that may link, intermittently, their normally isolated retreats. Local variation is thus a striking feature of many troglobitic groups.

Troglophiles are more mobile and less restricted in their habits; they may persist for many generations underground if food supplies permit, but they are equally capable of subsisting upon surface sources and they not infrequently move from one habitat to the other. Guanophiles and other dung-feeders form a case in point: they are more or less polyphagous and their cave populations wax and wane with those of the bats and other mammals that provide their food.

Now, with our greatly increased knowledge of southern cave faunas (except, unfortunately, in S. America) we are much better able to assess the overall compositions and distributions in the light of the northern researches. The general parallelism in development is then, I believe, quite striking, although certain qualitative differences between the two hemispheres continue to exist. Thus, the Australasian troglobitic beetles so far known are all Carabidae and the great majority belong to the subfamily Trechinae, but their distribution patterns are closely concordant with our ideas of the extents of the southern Pleistocene periglacial zones. In New Zealand troglobitic beetles occur widely but they appear to reach their richest development in South Island (May, 1963); in Australia they are known only from Tasmania (*Idacarabus*, 2 species; *Goedetrechus*, 2 species; *Tasmanotrechus*, 1 species).

The extent of Pleistocene glaciation in Australia is not entirely settled but it certainly included upland Tasmania (Jennings and Banks, 1958) and a small area of the mainland centred about the Snowy Mountains. Thus the greater part of lowland Tasmania would have passed through at least one periglacial phase, and the distribution of our troglobitic beetles there is entirely accountable. On the same bases one might expect a similar occurrence in the higher mainland cave systems (Cooleman and Yarrangobilly) but to date no troglobite or indeed, any convincing troglophile has been discovered in this region. Possibly there may yet be such a species awaiting discovery, or perhaps the region was too circumscribed to retain a well developed cave fauna through the vicissitudes of post-Pleistocene Australia (Moore, 1964). In any event, the anomaly is a small one in the general context of troglobitic evolution here.

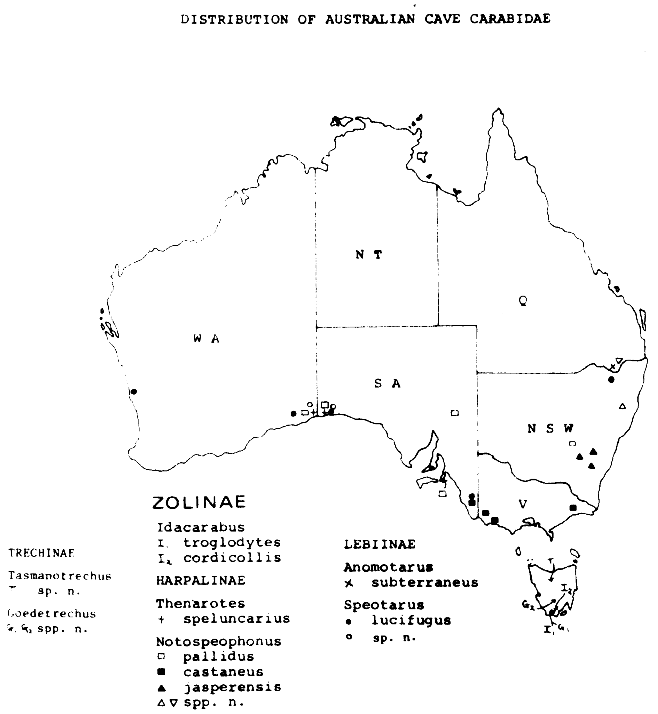
In composition also, our troglobitic beetle fauna shows some minor divergences from the northern pattern but these result from differences in early surface faunas rather than from differential evolution in the cave environment. Thus in our two *Idacarabus* species (*troglodytes* Lea and *cordicollis* Moore) we have the only known troglobitic Zolinae (Merizodinae) but this subfamily is entirely confined to the southern hemisphere. Then again, the lack of troglobitic Anisotomidae in southern caves, in marked contrast with the northern faunas, does no more than reflect the extreme paucity of this family in surface habitats in our area. Their role as detritus feeders in both types of habitat in Australasia must presumably be played by some other group of arthropods, possibly the Acari.

The rather numerous troglophiles of mainland Australia give the appearance of a somewhat attenuated tropical-type cave fauna and this is exactly what might be expected on grounds of palaeoclimate and present-day food supplies. The salient carabid genera are *Notospeophonus* (Harpalinae), with about five closely related species and *Speotarus* (Lebiinae) with two. Their known distributions are outlined in Figure 2. These beetles have fully developed eyes and wings and, although hardly ever found outside the cave environment, they apparently do migrate across the intervening open spaces. A specimen of *Speotarus* sp.n. taken by Mr G.W. Anderson at light a few years ago, on the Eyre Peninsula, S.A., and well away from any known cave system, gives the clue we needed. This same species, incidentally, is known from several of the Nullarbor caves.

Both *Notospeophonus* and *Speotarus* have numerous close relatives in the surface faunas, in *Lecanomerus* and *Anomatarus*, respectively, and isolated species of each of these predominantly surface genera are also known from caves. Therefore, although Harpalinae and Lebiinae are certainly atypical as cave dwellers overseas (they are known from caves elsewhere only from New Zealand and Africa, respectively), they are entirely in keeping with the surface fauna here.

Of the other families of beetles represented in our caves (15 are listed by Hamilton-Smith, 1967), none is specially noteworthy from the biospeleological viewpoint but a few are of interest on other grounds. The latter include the enigmatic family, Jacobsoniidae, represented by a new genus and species from bat guano in southern caves (Hamilton-Smith, 1967) and, in the Staphylinidae, the rat parasite *Myotyphlus jansoni* (Matth.) now also known to be free-living

Figure 2: Distribution of Australian Cave Carabidae



(Hamilton-Smith and Adams, 1966), and the Japanese *Philonthus parcus* Shp., established as a guanophile in several caves of New South Wales (Moore, 1968).

To sum up, then, we may say that the general characteristics of the Australasian cave beetle faunas are in keeping with the concept of a Pleistocene derivation for troglobites, and that such anomalies, in comparison with northern faunas, as still exist may be accounted for on the bases of differing ground faunas and divergences of palaeoclimate in Recent times.

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DISCUSSION

Q *For some reason at Yarrangobilly there aren't any of these troglobitic beetles. Is it possible that due to its altitude the area was glaciated?*

A There is a possibility. It is by no means at the top of the mountains and no two authorities agree exactly how far the glaciers came down. It could well be that it was a shade too close to the edge of the glaciers to be an effective harbour. The caves at the moment look very suitable for the sort of life we are looking for but obviously they haven't been in the past for some reason or other.

Q *In which case they'd be searched for at Cooleman?*

A We have been in Cooleman quite a lot but the Cooleman Caves are not terribly extensive and when you go in them you get the impression that it wouldn't have taken much of a dry period outside to dry them out. They don't look a firm enough refuge for really adapted cave fauna. We have a few troglophiles there but that is all.

THE DISTRIBUTION AND POSSIBLE ORIGINS OF TASMANIAN CAVE CRICKETS

by

Aola M. Richards*

(An abridged version of a paper given to the Biology Section, Australian Speleological Federation Conference, Hobart, December, 1970 Read by Albert Goede)

Cave crickets have been recorded from 14 of the limestone areas in Tasmania, and are widely distributed throughout the island. They also occur in granite caves, mine adits and on the surface. So far nine species are known belonging to three genera. *Micropathus* Richards extends throughout the western and southern parts of Tasmania, and a single specimen is known from a granite cave near Scottsdale in the north-east. It appears to be the dominant genus on the island. *Parvotettix* Richards occurs in the northern, central and eastern regions. The two genera overlap in caves at Mole Creek in the north and the Florentine Valley in the centre. They converge at Mt Cygnet in the south-east where they occur in different mine adits, and at Hobart where *Micropathus* occurs on Mt Arthur at an altitude of 1040 metres, while *Parvotettix* occurs almost at sea level (Richards, 1970). *Cavernotettix* Richards is a Mainland Australian genus (Richards, 1966), extending from the Southern Highlands of New South Wales to the Furneaux Islands in Bass Strait (Richards, 1967). It is associated with *Parvotettix* in caves on Flinders Island and Cape Barren Island, but has not been recorded from the Tasmanian mainland.

The distribution of the four species of *Micropathus* suggests that in the past they were influenced by Pleistocene glaciation. They may have been forced out of much of the central-west by the extensive glaciation in this area, and, due to geographic isolation caused by unfavourable conditions, speciation eventually occurred. *M. tasmaniensis* Richards became established in the south-east, *M. cavernicola* Richards in the coastal central-west and *M. fuscus* Richards in the north-west (Richards, 1964, 1968). The close relationship between the species suggests that speciation has been comparatively recent. The present day distribution of the species indicates that they have re-colonised the central-west after the retreat of the ice and the return of a milder climate. *Micropathus montanus* (Richards, 1971) is paler than the other species in the genus, and the fact that is has a limited range and occurs at a relatively high altitude in the centre of the glacial region suggests that it may have been established there for a considerable period of time.

While Pleistocene glaciation may have influenced the distribution of *Micropathus*, there is no evidence that it had any effect on the distribution of the four species of *Parvotettix*. Apart from the Florentine Valley/Junee area and Mt Rex, this genus is established in coastal and lowland regions (Richards, 1968, 1970, 1971).

Cave crickets are wingless insects, extremely sensitive to temperature changes and requiring a very high relative humidity, so they are unlikely to be carried passively across Bass Strait by strong winds. *Cavernotettix* probably reached the Furneaux Islands via the land bridge which extended from Wilson's Promontory to Flinders Island during the Pleistocene and until as recently as about 10,000 to 15,000 years ago (Jennings, 1971). *Micropathus* and *Parvotettix* may also have used this land bridge to reach Tasmania. As neither of these genera show close affinities with south-eastern Mainland Australian genera, they probably either migrated to Tasmania before the Pleistocene or they have evolved independently in Tasmania. The Furneaux Islands were also connected to north-eastern Tasmania during the Pleistocene and up till about 8,500 to 10,000 years ago (Jennings, 1971), thus permitting *Parvotettix* to migrate there from Tasmania. As the last land bridge between northern Tasmania and Flinders Island was about 1,500 years later than that between Wilson's Promontory and Flinders Island, this could explain why *Parvotettix* is not known from Victoria or southern New South Wales, and it supports a Tasmanian origin for this genus. It is strange that migration between Tasmania and the Furneaux Islands should have been in one direction only, and that *Cavernotettix* has been unable to cross Banks Strait and establish itself in north-eastern Tasmania.

Acknowledgments

I should like to thank Albert and Therese Goede, Tasmanian Caverneering Club, Hobart; Bob Cockerill and Kevin Kiernan, Southern Caving Society, Hobart; and John Whinray, Flinders Island, for their invaluable assistance in collecting specimens throughout Tasmania and the Furneaux Group.

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DISCUSSION

(answers by Albert Goede)

Q *Are the different genera readily identifiable by naked eye?*

A *Micropathus* and *Parvotettix* are very distinct from each other. *Paravotettix* is much smaller, it has very pronounced spines on its legs and with experience you discover it has a different way of sitting on the rock surface. It positions its hind legs so that the upper and lower part actually touch whereas *Micropathus* has its hind legs more extended. Normally *Parvotettix* is overlooked but when you have had some practice in collecting you do in fact very readily distinguish the two genera. *Parvotettix* occurs as individuals sometimes mixed up with a large population of *Micropathus* and unless you are looking for it you are likely to miss it completely.

Q *May I ask whether there are linkages apparent between* Micropathus *and the New Zealand fauna?*

A I have no idea. I think at one stage, this is quite some time ago, Aola said that there were fairly close links between *Micropathus* and some New Zealand genera but just how close this link is I wouldn't be able to say.

C *I have friends doing some biological collecting in the Kent Islands. They may be able to collect from caves there.*

A I think the places to look for them in the Kent Islands would be mutton bird burrows as there are no known caves there.

C *There is a large cave on one of them.*

A A sea cave or a limestone cave?

C *It is quite a large dry cave in granite.*

A It would be a possible habitat.

Q *What is the association of cave crickets with caves in their multiplication? How much do they rely on caves?*

A They appear to spend the whole of their life cycle within the cave. During the night at least a portion of the population appears to move out. Elery would be able to tell you more about this, but the whole life cycle is apparently completed in the cave except that the population is dependent on an outside food supply and therefore has to move out during the night.

C At the tourist end of Newdegate at Hastings, if a party enters during daytime or early evening, and comes out late at night, going in you won't see a cricket anywhere, coming out you see literally hundreds of them, hanging off the gate, the walls and the rocks.
The first collection of a new species of *Micropathus* was made completely by accident. When returning from the top of Mt Ronald Cross late at night, we were walking down the road back to the cars and one of the lads had his headlight on and saw what he thought was a spider on the road. This turned out to be a new species of *Micropathus*. At a lower altitude we collected *M. tasmaniensis* in some fissures at Davis Creek. I suspect that in this area *tasmaniensis* does not rely on caves at all because of the ecological conditions present. A later collection of the same new species was from the twilight zone in Virgo Cave at an altitude of 3100 feet.

Q *Is it known what these things live on? I was thinking of* Micropathus *in particular.*

A Their habits have been described in detail for two Tasmanian species. Dr Richards came over here and made a close study of these. They appear to be omnivorous and apparently can even be cannibals.

C *They definitely can be cannibals. If you collect half a dozen and put them in the same tube you end up with one or two very fat ones.*

C *Having seen hordes of them in some of the old mine adits on Mt Jukes and Mt Darwin they must be just about self perpetuating unless they live on bauera.*

C *If I can make one other comment on this business of their biological relation to the cave, I sometimes suspect they are a bit like the glow-worm. Everyone sees thousands of glow-worms in caves and about the only ones collected are from caves. If you search carefully you find them all over the place in fern gullies, but you really have to look for them. Now I suspect the same is even more true for cave crickets. They live in places like fern gullies. They are even harder to see than the glow-worm because they not only don't glow but they are negatively phototropic and if you wander around with a light looking for them, if they can, they will get away from you. As far as I know there has been done very little collecting of the kind which would reveal them in the bush. It would need to be very specialized collecting or something like the lucky chance just described. I suspect they may be there.*

A I think the very fact that they live in mine adits in non-limestone areas gives a certain indication that they must occur on the surface.

DISTRIBUTION OF TASMANIAN CAVE FAUNA

by

Albert Goede

Introduction

Only a few years ago the cave fauna of Tasmania was little known but especially during the last five years considerable collecting has been carried out by the writer and his wife while Bob Cockerill and Aleks Terauds of the Southern Caving Society have also made valuable contributions. As well a limited amount of collecting has been done by interstate visitors Dr Barry Moore, Dr Aola Richards, Elery Hamilton-Smith and Mrs Mary Mendum.

The writer does not pretend to be a professional zoologist and his collecting has been that of an amateur acquiring knowledge and understanding as he went along. He is very grateful to those zoologists who have offered encouragement by their identification and description of material.

A Geographical Approach

Being a geographer the writer's main interest is in determining the distribution patterns of cave species and the relationships of the Tasmanian cave fauna to that of mainland Australia and the other southern continents but this paper deals only with the first aspect. Cave animals are usually classified on an ecological basis using both distribution and physical characteristics. The first such classification was proposed by Schiner in 1852 (Richards, 1962) while the most recent modification is one suggested by Hamilton-Smith (1971). The author feels that there is an advantage in using a classification based only on known distribution characteristics. Tasmania being an island with a considerable number of isolated limestone areas provides an ideal situation to which such a classification can be applied. Tasmanian cave species can be grouped into six classes on this basis:

(1) Accidental visitors. They are generally regarded as of no interest to a student of cave fauna as they are surface species occasionally washed underground by floods or trapped in shafts and fissures. However, on occasion they prove to be of considerable interest in Tasmania where much of the surface fauna is poorly known. A good example is a beetle collected from Mystery Ck. Cave (Ida Bay) a few years ago which was found to belong to a sub-family (Adeliinae) not previously recorded from Tasmania.

(2) Regular visitors with state-wide distribution. Although regularly found in caves they also occur on the surface and range throughout the state wherever climatic conditions are suitable. An example is the Tasmanian Cave Spider *(Hickmania troglodytes)* first described from a cave at Mole Creek but now known to occur in caves throughout the state as well as in dark damp places on the surface. It belongs to a very small group of relict spiders (family: Hypochilidae) which are now found in four widely separated parts of the world: North America, China, Chile as well as Tasmania (Hickman, 1963).

Another well known example is the Tasmanian glow worm *Arachnocampa tasmaniensis*. The glow worms are luminous larvae of a primitive fly belonging to the family Mycetophilidae and large populations are found in some caves especially Exit Cave at Ida Bay. Not restricted to caves they are found in wet forest and mine adits throughout Tasmania.

(3) Regular visitors with regional distribution. Individual species are found only in a portion of the island but each species is found in more than one limestone area indicating that they are not confined to caves even though they may not have been collected on the surface. Two genera of cave crickets in Tasmania (family: Rhaphidophoridae) are good examples (figs. 1 and 2). The genus *Micropathus* has four species recorded from caves—three with a distinct and non-overlapping distribution in Western Tasmania while the fourth may be a relict occurring only at Mt Ronald Cross as far as known. The common occurrence of *Micropathus* spp. in mine adits supports the view that they are not confined to caves but due to their nocturnal habits are rarely collected on the surface. The second genus *Parvotettix* has three species recorded from caves.

Although neither genus contains species exclusively cave inhabiting, collecting from caves and mines is the easiest way to establish the approximate distribution pattern of each species. Cave collecting normally does not help to determine the exact location and nature of the boundary between two closely related species unless by chance such a boundary happens to pass through a limestone area – a situation existing at Loongana where two species of *Micropathus* are involved.

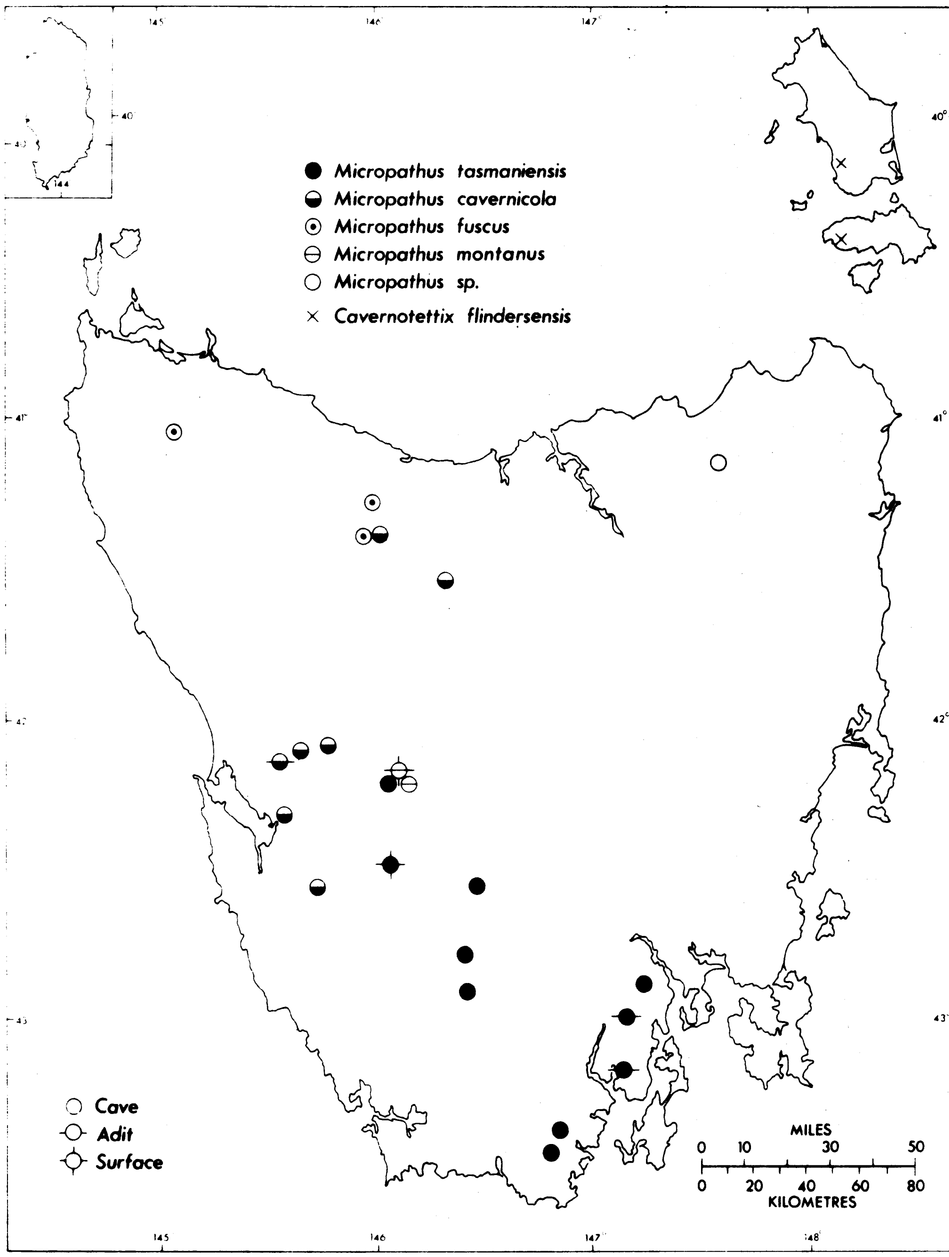

Figure 1: Distribution of the rhaphidophorid genera *Micropathus* and *Cavernotettix* in Tasmania.

The distribution map (fig. 1) indicates that *M. fuscus* is found in areas to the north while *M. cavernicola* occurs to the south. The limestone area at Loongana extends E.W. for a distance of 3 miles along both sides of the River Leven (fig. 3) and cave crickets have been collected from three caves. Contrary to expectation *M. cavernicola* was found in two caves on the northern side of the river while *M. fuscus* was found in one cave on the southern side. Rivers do not provide perfect barriers to the migration of cave crickets which are quite capable of moving over the surface of pools of standing water while logs may also provide crossing points. Nevertheless a large fast flowing river such as the Leven must present at least a partial and temporary barrier to a species extending its territory. In such a situation man made structures such as bridges would provide easy crossing points and it is particularly interesting to find that both Mostyn Hardy and Swallownest Caves are located close to the only two bridges in the area while Leven Cave is some distance away from either one.

This leads to the hypothesis that *M. cavernicola* is expanding its territory northwards at the expense of *M. fuscus* and has managed to establish itself north of the river where man made crossing points were available. If true the small population of *M. fuscus* in Leven Cave represents a relic of a once more extensive distribution and is likely to be replaced soon by *M. cavernicola*. Continued observation of the fauna of Leven Cave may provide further support for the hypothesis.

(4) Distinct but closely related species in separate limestone areas. When this situation occurs where two limestone areas are close together and yet separated by non-carbonate rocks there is a strong suggestion that the common ancestor to the two cave species is no longer present on the surface – at least not in the same area. The classical Tasmanian

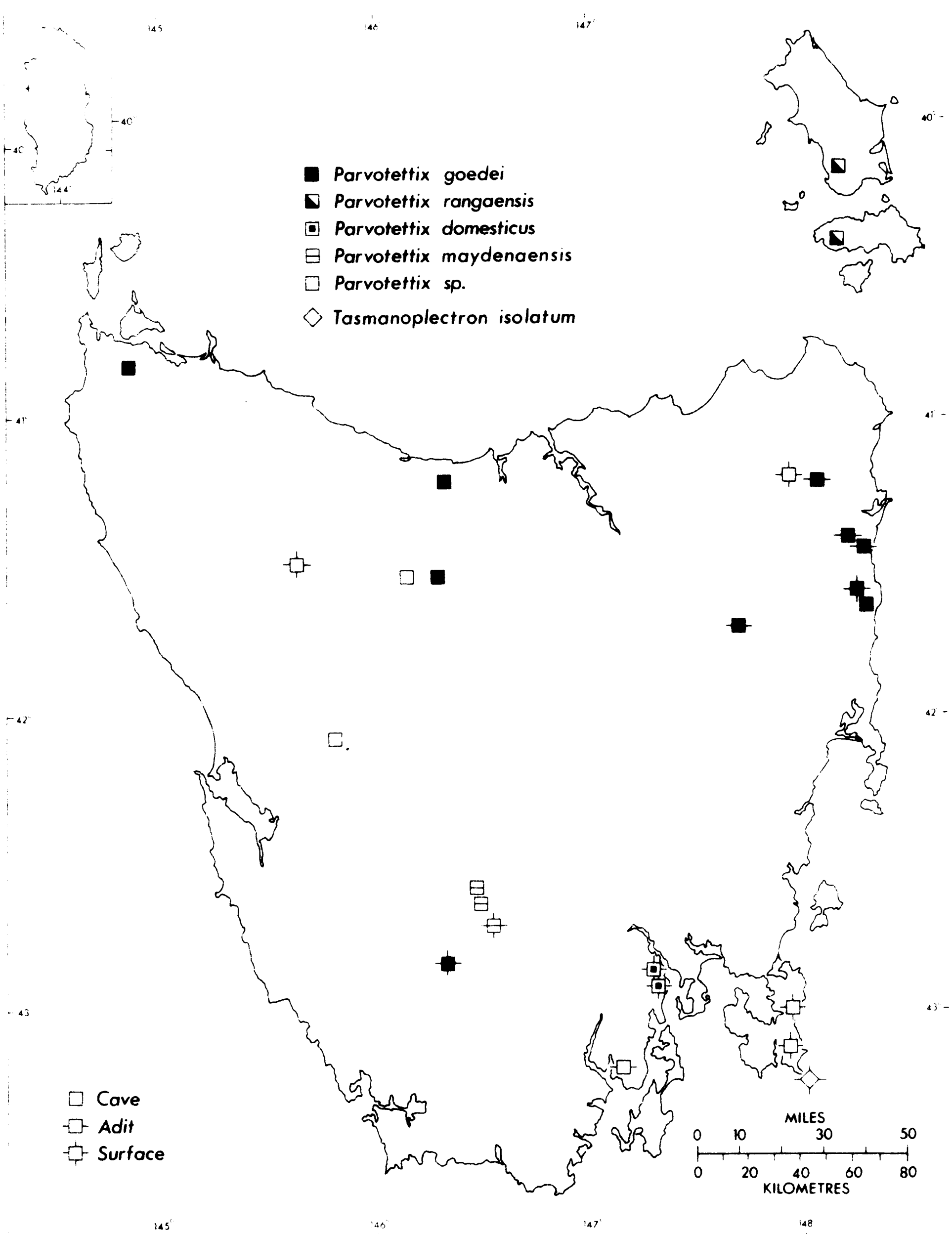

Figure 2: Distribution of the rhaphidophorid genera *Parvotettix* and *Tasmanoplectron*.

example is found at Ida Bay and Hastings which although only a few miles apart have caves developed in two different rock types not in contact with each other—cave development at Ida Bay has taken place in Ordovician limestone while at Hastings it has occurred in Precambrian dolomite.

Two distinct species of cave beetles both belonging to the genus *Idacarabus* (subfamily: Zolinae) are found in the two areas. *Idacarabus troglodytes* is known from six caves at Ida Bay while *Idacarabus cordicollis* has been recorded from three caves at Hastings. So far this is the only Tasmanian example for two limestone areas in close proximity to each other. It contrasts with the example of the harvestman *Monoxyomma cavaticum* which although known only from caves has been recorded from both the Hastings and Ida Bay areas.

(5) Species occurring in only one limestone area without close relatives in other areas. Two interesting examples have been recorded. From a stream cave at Mole Creek phreatoicids either belonging to or close to the genus *Crenoicus* have been collected. The genus is known only from Victoria and N.S.W. and its occurrence has not been recorded elsewhere in Tasmania. A new species of millipede belonging to a new genus in the family Dalodesmidae has been collected from several caves at Ida Bay where it is not uncommon but collecting in the Hastings caves has so far failed to turn up either this or a related species. If this distribution pattern holds true it provides strong evidence that the animal is a true cave dweller.

(6) Species occurring in only one cave or system of related caves within a limestone area. This category is difficult to demonstrate and requires detailed collecting in all known caves within an area. A possible example may be the occurrence of an eyeless form of the shrimp *Anaspides* in the Wolf Hole at Hastings. It may well be confined to this system only as collecting at Newdegate Cave in the same area has revealed only specimens with well developed eyes.

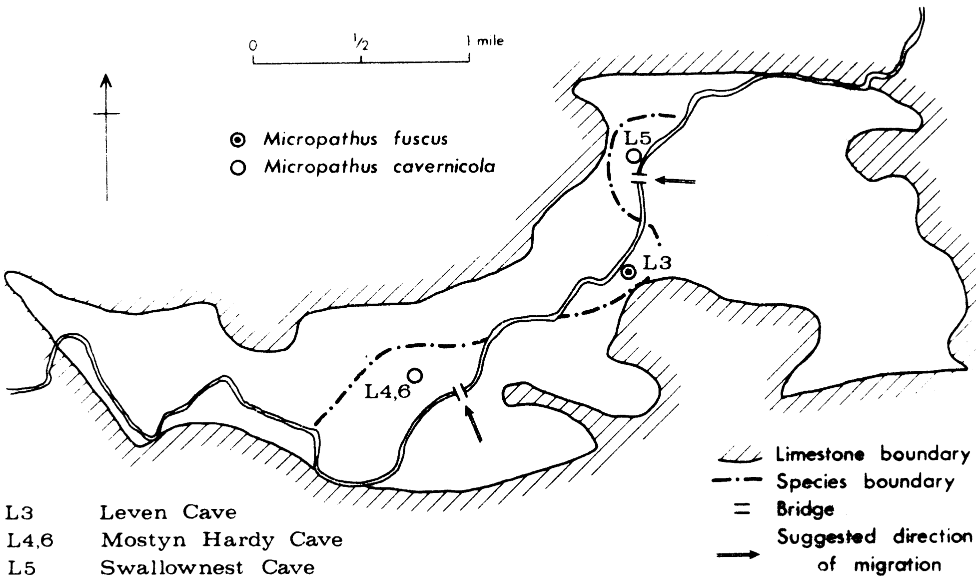

Figure 3: Occurrence of species of *Micropathus* in the Loongana area.

Distribution patterns versus morphological characteristics

Providing that distribution patterns are well known they are more reliable indicators of whether or not a particular animal is a true cave dweller than physical adaptations such as loss of eyes, long legs, sensory hairs and loss of pigment. Similar characteristics are shown by organisms in a number of other habitats such as leaf litter, soil and groundwater (Vandel, 1965) and such animals could easily be mistaken for true cave dwellers when found after having been accidentally washed underground by a flood.

The Ida Bay millipede although blind is not necessarily adapated specifically to the cave environment since all members of the family Dalodesmidae including surface species lack eyes. A number of species in the family are deep soil dwellers and the Ida Bay species was probably derived from a soil dwelling ancestor. Similarly the cave phreatoicid known from Mole Creek cannot be regarded as cave adapted because it is eyeless since many surface species belonging to this group also lack eyes.

In the last few years three new—apparently cave adapted—species of pseudoscorpions belonging to the genus *Pseudotyrannochthonius* have been collected from caves in three areas—Mole Creek, Hastings and the Florentine Valley, two of which have been described by Dartnall (1970). The Mole Creek species *(P. typhlus)* is completely eyeless but the Hastings species *(P. tasmanicus)* while lacking eyes was found to have a small pair of eye lenses present in the three specimens collected underground. However, a fourth specimen was found on the surface in a rotten log and this proved to be the only specimen without eye lenses making it apparently more cave adapted than the three specimens collected underground.

An entirely geographical classification of cave fauna avoids the thorny question of whether or not a particular species shows morphological adaptation to a cave environment and has the added advantage that it is much more easily grasped by the amateur speleologist who can make an important contribution by collecting both underground and on the surface in limestone areas.

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DISCUSSION

Q *You were saying that you used the fact that a species occurs at Ida Bay and not at Hastings as the criterion for a true cave dweller. Couldn't it be that the meteorological conditions within the cave or within the entrance of the caves at Hastings are different to Ida Bay and are unsuitable for this particular species or are there many other controls which would have to be considered before one can use this means to make that decision?*

A Loons Cave unlike the others at Ida Bay has, superficially at least, conditions much more like those at Hastings, and this is the one which has the largest population of millipedes. The limestone here is overlain by dolerite and the cave contains a lot of clay and appears to be very similar to the Hastings caves.

Q *It may be confounding the issue a bit but what happens if you shift a few of them from Ida Bay to Hastings . . .*

C Tut, tut (chorused interjection).

Q *. . . and determine whether or not they do fit in with the environment?*

A I think this would be criminal. By doing so you would destroy possible evidence.

C *A further difference between Ida Bay and Hastings is that the latter is in dolomite and Ida Bay is in Gordon limestone.*

A I am aware of that but I am doubtful that it would be very important in determining the distribution of the species.

Proceedings 8th National Conference
Australian Speleological Federation

SOME ASPECTS OF THE AUSTRALIAN CAVERNICOLOUS FAUNA

by

Elery Hamilton-Smith*

Introduction

The South Australian Museum has given particular recognition to the significance of research on cave-dwelling fauna. Although some speleologists will already be familiar with the programme on which I am engaged for the Museum, others will no doubt be interested to know the details of it. Firstly, specimens collected from caves are curated as a separate collection with its own register. This ensures their ready accessibility and makes an overview of the cave fauna much easier than would be the case if the specimens were incorporated into the massive general collections. Secondly, as specimens come to hand, every effort is made to identify these or to pass them on to specialist taxonomists for study, identification and, if necessary, description of new species. When new species are described from the collection, then the holotypes are transferred to the relevant section of the general collection for the safe-keeping accorded to holotypes as part of normal Museum practice. Thirdly, two indices have been established in which all available data, both on this collection and on any other available information on Australian cave fauna, is recorded. One index is arranged according to the identity of species and the other according to the locality from which species have been recorded. It is thus easy to find all available data on any specific category of fauna or on the total fauna of any specific cave or cave area. Fourthly, a comprehensive library of material on biospeleology has been established and indices to relevant literature are maintained.

This programme is readily available for the assistance of speleological societies or individual speleologists throughout Australia (subject only to my own time limitations). Specimens forwarded will be identified or passed on for identification wherever possible and the results notified. Although we will be glad if such specimens can be retained, they will always be returned if this is requested. However, I would emphasise the importance of placing specimens either in a State museum or in the National collections held by C.S.I.R.O. Material in private collections is inaccessible and subject to considerable risk of loss.

I would also like to comment briefly on the difficulty in providing rapid identification of specimens. Many families of Australian invertebrate animals have not been studied at any depth and are very imperfectly known. In many cases, such a family is not currently being studied by anyone and so no specialist can be found to provide an accurate determination. Even if a family is currently being studied, it is often necessary to carry out an immense amount of further research before a particular specimen can be accurately identified or described as new. This can be, and often is, intensely frustrating to the collector. At the same time, there has been an immense increase in basic zoological research in Australia during recent years; the cavernicolous fauna has attracted particular attention and it is probably true to say that the cave-dwelling fauna is now better-known than that of many other comparable limited habitats. The South Australian Museum programme alone has resulted in a number of taxonomic papers describing new species of cave-dwellers. A number of papers have also been published summarising the cave fauna of specific areas or dealing with special aspects of biospeleology.

The present paper describes some conspicuous characteristics of the Australian mainland cave fauna and discusses the implications of these for thinking about the origin and history of this fauna. Let me stress at this point that Australian biospeleology is still at a very early stage of development and further that the history of a cave fauna can only be fully understood within a framework of geological and climatic history which in Australia is far from clear. So only extremely tentative hypotheses can be advanced, but I believe it is useful to try and do so as even a tentative hypothesis provides some sort of framework within which we can test the significance of our knowledge and seek further data.

Ecological classification and history

Most speleologists will be familiar with the traditional Schiner-Racovitza ecological classification of cave fauna into the three categories of Trogloxenes, Troglophiles and Troglobites. The way in which this classification has been used has often been far from satisfactory. Some categories of fauna e.g., parasites, do not fit readily into these three divisions and their placement therein confuses rather than clarifies their ecological status. I have proposed elsewhere (1971) a revised scheme of classification which attempts to resolve some of the problems in use of the Schiner-Racovitza system and although there is neither time nor need to fully outline this here, one aspect of it is important to the argument of this paper. The troglobitic category is traditionally reserved for those species which show some clear morphological modification in keeping with their cave-dwelling habit. The troglophiles thus include both species which also live on the surface and those which are confined to the caves but have not developed morphological modi-

* **Hon. Associate in Zoology, South Australian Museum**

fications. Attention has been drawn to this problem by others, e.g., Barr (1963, 1968), and I have proposed that the troglophiles can more usefully be divided into two categories, which I have labelled first and second level troglophiles. I believe this distinction is not only useful from an ecological viewpoint, but that it makes possible a clearer relationship between ecological classification and the history of a fauna.

First-level troglophiles are those species which are able to live their total life cycle within the cave but which may also be found outside of caves. **Second-level troglophiles** are those which are apparently confined to caves, but which do not show the morphological modifications which distinguish the troglobites. They are species which have been isolated in caves by the extinction of their surface-dwelling ancestral populations. It is likely that this extinction has occurred too recently to permit the development of troglobitic modifications. Barr (1963, 1968) suggests that they are potential progenitors of troglobitic species and that, given favourable conditions over sufficient time, they may well evolve into troglobites.

Troglobites are species which have become obligate cavernicoles, are thus confined to the cave environment, and show clear morphological modification accordingly. It is not clear what minimum period of isolation within caves is necessary to permit the evolution of troglobitism, but the most generous estimates generally correspond with that of Barr (1968) when he says "Many troglobites apparently colonized caves during the Pleistocene, some of them at least as late as the Sangamon (Riss-Wurm) interglacial, about 300,000 years ago". Others adopt a more conservative approach, e.g., Vandel (1964, tr.1965), who makes statements such as "Terrestial cavernicoles are for the most part descendents of a tropical fauna which populated Europe and North America during the first part of the Tertiary". Various kinds of climatic or other change may cause the extinction of surface-dwelling populations and consequent isolation of species, and Vandel (op.cit.) refers to troglobites as being relicts of thermophilic, glacial, hydrophilic or marine populations.

If climatic change proceeded in the same direction and at a constant rate of change, we could expect to find a complete range of stages in cave colonization in any cave fauna. However, it is well known that climatic change has not only been subject to changes in direction, but that some changes have been relatively sudden. We find that any particular cave fauna may comprise various elements which can be related to particular stages in cave colonization and similarly to specific climatic or other changes. In many cases, of course, we lack the detailed knowledge to establish clear historical patterns in the development of a cave fauna, but evidence is accumulating that the origin of troglobites seems to be related to sudden and dramatic changes, rather than gradual ones. Barr (pers. comm.) has referred to the idea of "catastrophe" as being fundamental to the isolation of cave-dwelling populations.

Another important and related aspect of historical biospeleology is the speciation which occurs in isolated populations. If a widely distributed population is suddenly to be extinguished from all but a few isolated sites, which may be caves, then each such isolated population is likely to evolve in a distinctive way, developing its own peculiar characteristics and ultimately forming a number of distinct species. However, in addition to this mechanism, it must be emphasized that most widespread species show considerable variation from point to point within their distributional range. Although it may not be possible to separate neighbouring forms from each other, forms chosen from widely separated parts of the geographical range may be very different from each other. So, if such a species suffers general extinction, leaving a few isolated and widely separated relict populations, these may well be immediately readily separable from one another.

Previous discussion on the origin of Australian cavernicoles

Moore (1964) pointed out that the Australian cave beetles known at that time were troglophilic and derived from weakly hygrophilous groups. He suggested that earlier cave inhabitants may have suffered secondary extinction, probably as a result of hot dry inter-glacial or post-glacial periods, leaving the cave environment vacant for fresh invasion during the post-glacial.

I suggested (1967b, 1969), without elaboration, that structural factors leading to flooding and later dehydration of cave systems may have also played a significant part in the secondary extinction of earlier cave faunas. When discussing the fauna of the Nullarbor caves, I proposed that the presence of the troglobitic cockroach *Trogloblattella nullarborensis* indicated the isolation of this species since the Tertiary, and hence gave support to the suggestions of Jennings that cave genesis may have been initiated at the close of the Tertiary and that climatic conditions on the Nullarbor have not undergone major change. This line of reasoning was rejected by Richards and Lane (1969) but followed by Main (1969) when describing *Troglodiplura lowryi*. I also divided the remaining species into three categories: second-level troglophiles, first-level troglophiles which although still living in surface habitats do not appear to do so on the Nullarbor, and first-level troglophiles which are still prevalent on the Nullarbor Plain surface. It was suggested that this indicated past climates had probably been slightly wetter than the present.

The other significant discussion has centred about the specific issue of the North-West Cape fauna (Mees 1962, Richards, 1963) but has largely been concerned with the distinctive characteristics of that fauna.

Three major characteristics of Australian cave fauna

1. The Paucity of Troglobites

Australia's first troglobite was the fish *Milyeringa veritas* described from North-West Cape by Whitley (1945). From the same locality, Holthuis (1960) described the two shrimps *Stygiocaris lancifera* and *S. stylifera* and Mees (1962) described an eel, *Anommatophasma candidum.* Despite further investigation, summarised by Richards (1963), no further species have been collected from this area. Williams (1964) has since described two further shrimps, *Parisia unguis* and *P. gracilis*, from the Katherine Caves. These six species, as is typical of tropical troglobites, are all aquatic marine relict species.

Four troglobites so far have been recorded from the Nullarbor caves. These are the cockroach *Trogloblattella nullarborensis* described by Mackerras (1967), the remarkable trapdoor spider *Troglodiplura lowryi* described from dead material by Main (1969) and not yet seen as a living specimen, and two currently undescribed spiders, both of which are briefly discussed by Lowry (1970).

Some other species which are currently being studied may prove to be truly troglobitic, but it would be premature to comment on their ecological status at this point. However, several are apparently relicts of considerable antiquity, e.g., a Phreatoicid from Wee Jasper, N.S.W. and two species of Millepede from Buchan, Victoria, and these will be taken into account in the discussion below.

It is also necessary to comment at this stage on the Pseudoscorpions. Beier (1967) refers to several of these as "true cave-dwelling species" and others, including myself (1967b) have referred to them as troglobitic. In view of the lack of significant morphological modification (absence of eyes is not unusual in this order, even being the normal condition in many genera, and cannot be construed as a result of cavernicolous habit) and the association of most mainland cave-dwelling species with bat guano, it seems preferable at this point to adopt the conservative approach and treat these as troglophiles.

Thus, at this stage, we can only with certainty list 10 troglobites for mainland Australia. This contrasts markedly with many other countries, and although up-to-date figures are not readily available for comparison, various published figures suffice to demonstrate the relative paucity of our own fauna in this regard. Barr (1960) noted approximately 250 species from U.S.A.; Nicholas (1962) listed 170 from Central America; Ueno (1964) refers to at least 150 species; Strinati (1969) lists approximately 60 from Switzerland; and in all of these countries (with the possible exception of Switzerland) new troglobites are being discovered and described at frequent intervals.

2. The Abundance of Second-level Troglophiles

Although some species which have as yet only been collected from caves prove to also live in other habitats, it is striking to note the number of second-level troglophiles so far recorded from our caves, some of which enjoy an extremely wide distribution. It has already been mentioned that Barr (1963, 1968) has referred to the occurrence of such species in the U.S.A. but it would appear that they are relatively few in number compared with the proportion occurring in the Australian fauna. My own knowledge of the Japanese cave fauna indicates that in that country, second-level troglophiles are relatively unusual while troglobites are extremely diversified and numerous.

I sometimes reflect that Australian biospeleology may be in a position analogous with mammalogy. It has been said that the classification of the placental mammals into 16 orders with the lumping of all marsupials into one order is not so much a reflection of the validity of the classification, but a comment on the fact that mammal classification was based on European experience by zoologists who were placental mammals. If mammalogy had been established first in Australia (and by zoologists who were themselves marsupials) we might well have a very different pattern. Perhaps if biospeleology had fifty years of development in Australia before any serious study was made of cave fauna elsewhere, we would find considerable significance attached to the second-level troglophile rather than to the troglobite. Perhaps the incredible fauna of Japanese caves would be seen as impoverished! More seriously, I suspect that studies of our cave fauna may tell us a great deal more about the process of cave colonization than might be learnt from other countries.

Rather than merely cataloguing the second-level troglophiles, it will probably be of more value to example their occurrence in a couple of well-known groups. Twelve pesudoscorpions have so far been recorded from caves on the Australian mainland. None of these have been recorded from any other habitat. Their distribution is tabulated in Table 1, and it will be seen that 9 species have each only been taken from a single cave. In several cases, caves in close proximity to each other have yielded quite different species. A particularly interesting pattern is demonstrated by

Protochelifer cavernarum, of which the nominate sub-species occurs across the whole of Southern Australia, while the sub-species *P. c. aitkeni* is confined to Abrakurrie Cave.

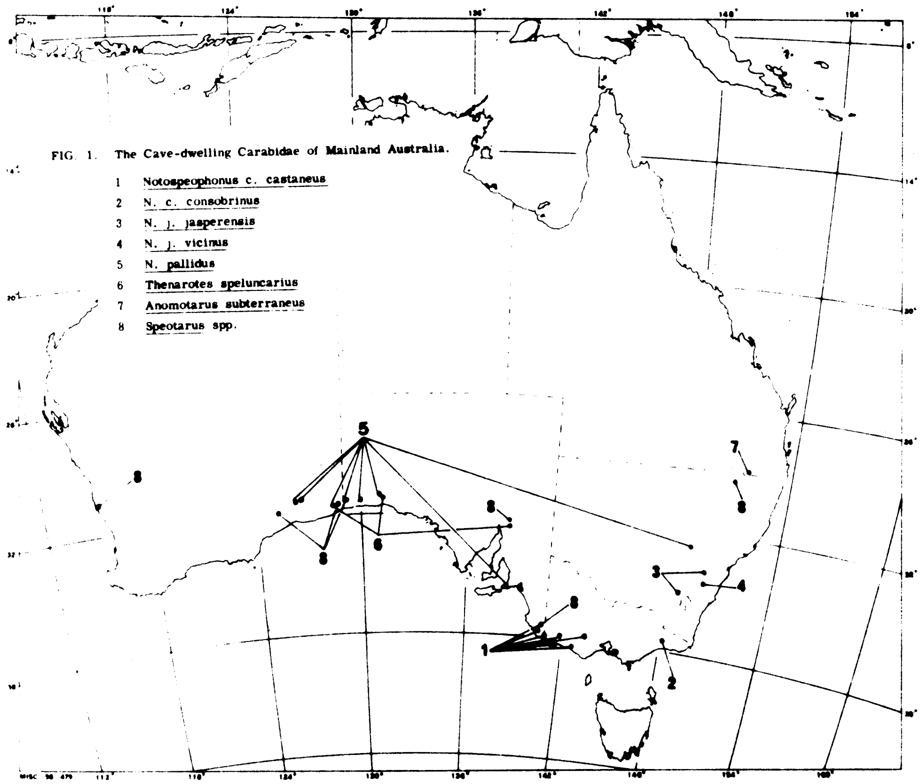
Family CHTHONIIDAE	
Austrochthonius cavicola Beier	Cathedral Cave, Naracoorte, S.A.
Sathrochthonius teuna Chamberlain	Southern Limestone, Jenolan, N.S.W. Basin Cave, Wombeyan, N.S.W. Punchbowl Cave, Wee Jasper, N.S.W. (?)
Pseudotyrannochthonius jonesi Chamberlain	Cave, 'probably in the Blue Mountains'
P. hamiltonsmithi Beier	Mt Widderin Cave, Skipton, Victoria
P. gigas Beier	Byaduk Caves, Victoria (2 caves)
Morikawa cavicola Beier	Grill Cave, Bungonia, N.S.W.
Family CHERNETIDAE	
Sundochernes guanophilus Beier	Fig Tree Cave, Wombeyan, N.S.W.
Troglochernes imitans Beier	Dingo Cave, Nullarbor, W.A.
Family CHELIFERIDAE	
Protochelifer naracoortensis Beier	Bat Cave, Naracoorte, S.A.
Protochelifer cavernarum cavernarum Beier	Murder Cave, Cliefden, N.S.W. Belfrey Cave, Timor, N.S.W. (also caves unspecified, Cliefden and Timor) Ashford Cave, N.S.W. Clogg's Cave, E. Buchan, Victoria Murrawijinee n.3 Cave, Nullarbor, S.A. Lynch Cave, Nullarbor, W.A. Mullamullang Cave, Nullarbor, W.A. Super Cave, Nambung River, W.A. Gooseberry Cave, Jurien Bay, W.A.
Protochelifer cavernarum aitkeni Beier	Abrakurrie Cave, Nullarbor, W.A.
Family CHEIRIDIIDAE	
Cryptocheiridium australicum Beier	Murra-el-elevyn Cave, Nullarbor, W.A.

Table 1: Cave-dwelling Pseudoscorpions of the Australian mainland.

Another useful example is the Carabid beetles, which include 9 second-level troglophiles along with a number of first-level species. The distribution of the second-level troglophiles is mapped in Fig. 1 and demonstrates some intriguing patterns of relict distribution and speciation. The five described species and sub-species of *Notospeophonus* provide an interesting problem in the relative chronology of their development and the mechanism responsible for speciation in this instance. The genus *Speotarus*, with species described from Naracoorte, South Australia and Ashford, N.S.W., but in which the overall pattern of speciation remains unclear, at least to me, (but see Moore, this volume) has a remarkably wide scatter of apparently isolated populations, typical of a relict species.

3. Australian cavernicoles may belong to different sections of major taxa from similar species in other countries

Moore (1964) first drew attention to this characteristic in relation to the cave Carabidae. Of our second-level troglophiles in this family, 6 belong to the Harpalinae and 3 to the Lebiinae, both of which rarely occur in caves elsewhere. On the other hand, the sub-family Trechinae which is generally dominant in cave faunas is only represented in Australian mainland caves by *Trechimorphus diemenensis*, a first-level troglophile from Bungonia, Jenolan and Buchan. I pointed out in earlier papers (1966, 1967b) that a somewhat similar pattern could be demonstrated in the mites. It is now possible to cite two further examples of particular interest.



Of the twelve pseudoscorpions listed above, 6 belong to the Chthoniidae which are commonly cavernicolous in other countries; 2 to the Chernetidae and 3 to the Cheliferidae, both of which are only very rarely recorded from caves elsewhere, and 1 to the Cheiridiidae, of which I can trace no previous record from a cave. In this instance, it must be noted that the family Neobisiidae, which contains some 60% of the cavernicolous pseudoscorpions of the world, is confined to the Northern hemisphere and is hence not available to colonise Australian caves.

The other more striking example is afforded by the beetle family Cryptophagidae. One species has been named from an Australian cave (in Tasmania) but I have currently in preparation descriptions of a further two forms. In addition, I have specimens which probably belong to three further distinct forms (but am lacking male specimens of these, so am unable to be certain of their identity). All of these belong to the genus *Atomaria* of the sub-family Atomariinae. All Cryptophagids taken from caves elsewhere belong to the genus *Cryptophagus*, sub-family Cryptophaginae. Both these genera are widely distributed throughout the world, and so both appear to be equally available as potential colonists of the cave habitat in Australia and elsewhere.

Discussion

In spite of considerable research, the general geochronology and climatic history of the Australian Quaternary and Recent remains unclear (Brown et al 1968). This is even more so in the Northern parts of the continent (Jennings 1969). Jennings (e.g. 1967, 1968a) has continually emphasised our lack of knowledge about these aspects when discussing the genesis and development of Australian caves, and the lack of this data is equally a problem in reaching some understanding of the history of cave fauna.

The present evidence indicates that a relatively hot and wet Tertiary was followed by a cooler Quaternary, in which there was negligible glaciation and in which wet and dry periods alternated, although the timing, sequential and geographical relationships or actual climate of these periods remains unclear. This in turn has been succeeded by a more arid Recent. It is also generally accepted that considerable uplifting of the Eastern Highlands occurred during the Quaternary, but this was probably initiated during the Tertiary and continued over an extended period (see discussion by Jennings 1968a).

Examination of the cave fauna itself enables one to make some assumptions about the relative age of particular components. On this basis, I believe it is possible to distinguish five major groups and it is then possible to propose tentative hypotheses about some aspects of their origin.

The marine relicts of Northern Australia are possibly the most ancient, as all are widely separated from their nearest relatives. Both the fish have been placed in distinctive genera, the affinities of which are far from clear (Mees 1962), while the shrimps, although closely related to other living species, have their near relatives in Madagascar (Holthuis 1960, Williams 1964). However, it must be pointed out that their origin as cavernicoles is not necessarily related to the time of their colonization of brackish or fresh (*Parisia* spp.) water from the ocean. All belong to families which have been adapted to freshwater for a very long period and Vandel (1964, tr. 1965) cites the example of Atyid shrimps from Oligocene freshwater deposits, although he is in error in stating that all Atyids are fresh-water species (Holthuis 1963).

The zoological evidence suggests that the **cockroach and spiders of the Nullarbor** can be attributed to the late Tertiary. I still believe that this gives support to the suggestion that cave genesis on the Nullarbor was initiated at this time, although I realise that more direct evidence would be essential for confirmation of this suggestion.

At this stage, I would like to spend a little time on the question of our paucity of other troglobites. It must be emphasized that many of our caves are of relatively recent origin and would not have been available for colonization at a sufficiently early point in time. The caves of the aeolian limestones are mainly of Pleistocene or even Recent genesis (Jennings 1968b) and it is extremely doubtful if they are sufficiently ancient to have developed a troglobitic population. The caves in the Miocene limestones of South-eastern South Australia may well have been initiated, but faced considerable fluctuations in sea-level during the Pleistocene (Blackburn et al 1965) and so again, would not have been available. In the Eastern Highlands a large proportion of the caves occur in relatively small areas of "Karst Barre" limestone, that is, with morphological and hydrological development being dependent upon erosional levels in the surrounding and relatively impermeable rocks (Jennings 1967, Sweeting 1960). In these areas, cave genesis can be related to Pleistocene water levels (Sweeting 1960) or to various stages in the erosion of surrounding rocks (Jennings 1964) and in at least some cases, to the orogenetic movements of the Eastern Highlands (Jennings 1967). Thus, some of these caves are of relatively recent origin, while others have been subject to extremely wet conditions and to vadose development followed by dehydration as the erosion of the surrounding landscape has lowered the water levels (Jennings 1964).

Some of these caves contain a fauna which includes **species of considerable antiquity**, whose status remains unclear. These include the Phreatoicid of Wee Jasper and the Millepedes of Buchan referred to above. At Wee Jasper, Jennings (1964) has shown that the stream responsible for the development of the Punchbowl-Signature system now flows through the Dogleg Cave within which the Phreatoicid occurs. This species has probably followed the down-cutting of the stream, even though this has involved migration between what are now separate caves. The millepedes at Buchan both occur in caves which have obviously maintained a continuing relationship to the stream responsible for their development over an extremely long period. The available evidence suggests that these species may have colonised the caves concerned since at least the early Pleistocene.

The fourth group are the **Second-level Troglophiles.** These are not uncommonly found in caves which have only been available for colonization during the mid-recent, and so it seems reasonable to date their period of colonization as during the late Pleistocene and early Recent. Assuming the validity of the "catastrophe" concept referred to earlier, this would suggest some drastic change in climatic or other conditions during the mid-Recent which led to the extinction of the surface-dwelling ancestral populations.

It not only seems likely that this change was one of increasing aridity, but it is interesting to note similar indications from other fields of research. Crocker (1949), in discussing the history of Australian vegetation, suggests an onset of aridity during the mid-Recent and that this was "sudden and drastic". Wakefield (in press) as a result of studying fossil mammals from the Pyramids Cave at Murrindal, Victoria, proposes that the earlier mammal fauna of wet sclerophyll forest "collapsed dramatically" and was replaced by the modern dry forest fauna.

Summarising the above discussion, I am suggesting that the paucity of troglobites is due primarily to the fact that Australia has few caves which were (1) available for colonization during the Tertiary or early Pleistocene and (2) have enjoyed relatively stable conditions since that time. However, many of these caves became available during the later Pleistocene, and were colonised by various species, some of which have been isolated as second-level troglophiles, probably by aridity during the mid-Recent. There has not been space in this paper to deal with other than a few cave areas, but evidence to support this proposal is available in respect of many other Southern cave areas.

Finally, there are the **first-level Troglophiles**, which in fact are actively colonizing the cave environment at this point in time. We can see some interesting examples where change in environment is occurring and isolation of cave populations may in fact be in progress. I have already referred to the Nullarbor species which appear to have vanished from the surface in that area, even though widespread elsewhere. A second instance is the beetle *Mystropomus subcostatus*, normally a dweller in the leaf-litter of dense rain-forest (Britton 1970), which is abundant in the Mt Etna Caves of Queensland, but is rare and probably vanishing from surface environments in that area. I have also described elsewhere (1968) a different kind of "catastrophic" change which has occurred in the Mt Widderin Cave of Victoria. In this case, the desertion of a cave by what was apparently a nursery colony of the bent-winged bat has drastically changed the environmental conditions of the cave, but a few of the former guanophile species have survived within the cave.

Only one aspect of our cave fauna remains for comment in this discussion and that is the extent to which Australian cavernicoles are derived from different sections of major taxa from those of other countries. I would suggest that we cannot fully elucidate this problem without a much more detailed understanding of the biology of the taxa concerned, but that this characteristic of our fauna is probably related in some way to its relatively recent origin compared with the troglobitic forms from elsewhere.

Acknowledgments

An overall review paper of this kind obviously owes its existence to the work and co-operation of an immense number of people. The list of references below gives some indication of this, but in addition, many of these authors and others have assisted by personal discussion of the issues dealt with here. Many cavers have contributed either by collecting specimens or by assisting the author on his own fieldwork. The fact that a paper of this kind is possible at all is an indication of the level and quality of co-operation throughout Australian speleology.

Two organizations must, however, be specifically named. The South Australian Museum (Director, Dr W.G. Inglis) has assisted immensely through the provision of facilities and support for the study of Australian cave faunas. The Speleological Research Council Inc. (Sydney) has provided financial assistance.

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DISCUSSION

Q *You mentioned the pseudoscorpions in Australia as being both on the surface and underground. Have the underground ones no modifications?*

A These twelve species are only known in the caves and I don't believe any of them are significantly modified for cave conditions.

C *I don't think you can validate your point about caves not being available for colonization. In some areas there are caves which started early and have continued ever since. This would include Mt Etna which I think is a residual probably dating from some time in the Miocene and standing up in a sea which I think was developed in the Pliocene. Another point indicated by this karst barre feature is that many of the areas have been wiped out at various periods e.g. Cooleman. It is quite recognizably not a cave system at all. We are rather lucky to have so many of our limestone areas bearing caves right now. Let's say there is some small act on the part of providence considering the paucity of limestone. The position is that the caves are periodically wiped out as each knick point creeps up the river. These knick points are steadily moving up river. They have been doing so continuously but each time it involves the obliteration of the cave area between the time that one knick point arrives to give you rejuvenation and the time of eventual destruction. Few of them have remained continuous. Colong for example is entirely a late system. Jenolan shows more evidence of continuity as a river system. This suggests that it is not universally applicable, but I think it is applicable to sufficient of the cave areas to make your point valid. The mid-Recent break is marked by the very widespread occurrence of river terraces and marine benches right around the coast in which the previous river channel system has changed from one that is reasonably well fit to the valley to the present one where most streams are strongly underfit. I think this means that a very drastic change did occur and the evidence for that is very good.*

C I suspect several places where we might in fact look for troglobitic fauna in the mainland. Where in fact we generally haven't looked, are the high level caves which may by chance have a very, very long period of stability as relatively dry. There has been a quite interesting paper from Switzerland recently where one such cave yielded something like nine troglobites to everybody's utter astonishment. It is a tin pot little cave which has been sitting high up on the mountain apparently for an extremely long time and I sometimes wonder about some of the high level caves in our eastern cave areas. It might be worth devoting a lot more attention to these from the biological point of view.