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Foreword

If the reaction of many of those who attended the Eleventh Biennial Conference of the Australian Speleological Federation, (Cavconact) is any guide, the conference was a marked success. The editors hope that the proceedings of the conference will be as happily received by the caving fraternity. We apologise, especially to authors, for the long delay between conference and publication. Whilst this was at least partly the result of slothfulness on the part of the editors, we would like to point out that we did not receive the last papers until June. The comments made by Albert Goede and Andrew Graham as editors of the proceedings of the Eighth and Tenth Conferences respectively still apply. Many of the papers arrived so untidily handwritten or typed that editorial reading was impossible, references were missing or inaccurate and, perhaps most aggravating of all, well over half of the figures had to be redrawn. Inconsistencies still remain but we hope that those that are left do not detract too badly from the whole publication.

Editors of future proceedings would be well advised firstly, not to do so and secondly, to lay down firm guidelines and deadlines and to stick to them. Standards for presentation, citation, and so on should be circulated before the conference, perhaps by recommending one of the widely circulated style manuals. Consideration should be carefully given to the prospect of rejecting papers which do not come up to scratch as regards quality of content, style and presentation. As those of you who read this volume in its entirety will realise the standard of the papers varies, in our opinion, from excellent to extremely poor; this is, of course, a rather unsatisfactory situation for an official ASF publication; improvement will only come through harsh editorial policy.

In our opinion, serious consideration should be given by ASF to abandoning the production of conference proceedings. Bibliographical difficulties, non-appearance, variety of standards, and the sheer hard work of coercing cavers to provide the goods at both ends of the production process, among other problems, perhaps negate the value of such publications.

The views expressed in this volume are those of the respective authors and are not necessarily those of the Australian Speleological Federation or of its member societies.

We would like to take this opportunity to extend our thanks, on behalf of the Australian Speleological Federation, to Judith Wright McKinney for opening the conference. Her entertaining and thought provoking speech provided a fine background for the conservation-oriented papers which followed and which, to a large extent, set the pace for the marked success of the conference.

Finally, we would like to thank all those who made the conference a success and those who contributed to the proceedings. Production of this publication was assisted by Adrian Davey, who also designed the cover. Special thanks are also due to the ANU Central Printing staff; Bruce George, Ian Cottrell and, especially, Cynthia MacDonald who expertly interpreted and executed the editorial policy in the typesetting process.

John Brush
Marjorie Coggan
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EVALUATION OF CAVES AND KARST

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Abstract

The development of the Australian National Estate legislation is outlined. The dependence of this legislation upon a concept of "place" rather than upon an ecosystem approach is criticised. Practical issues to be considered in making recommendations for registration of caves or other karst features as part of the National Estate are then outlined. These include:

significance vis-as-vis representation

the problems in assessment of significance, particularly in respect to essentially subjective aspects

the benefits and potential dis-benefits of registration

the definition and delimitation of a place for purposes of registration;

Introduction

In 1973, the Australian Government appointed a Committee of Inquiry to examine and report upon the "National Estate"and the ways in which its preservation might be fostered. The Committee presented its report in 1974[1] and by the date of its tabling in Parliament, an Interim Committee had already been established to continue the work of the Inquiry and to lay the foundation for further action[2].

In 1975, legislation establishing a permanent Australian Heritage Commission and empowering this Commission to act upon matters relative to the National Estate was passed[3]. This act is now being amended[4], and the Commission was apppointed in 1976, holding its first meeting on 26th July, 1976.[5]

The concept of a register of the National Estate has become increasingly significant during this process. The original Report, in listing recommended functions of a National Estate Commission, included:

> *"To organize and commission any studies, research work and investigations it considers necessary . . . . To prepare formal registers of National Estate property based on these studies."*[6]

The report of the Interim Committee suggested a considerable simplification and their total list of functions reads:

"* *to advise the Ministers on all matters related to the National Estate*

* *to prepare and maintain national registers of the National Estate*

* *to arrange for or commission such research as the Commission thinks necessary for the identification, classification, protection, enhancement, preservation, or management of the National Estate."*[7]

You will note that the register now appears above the research clause.

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The 1975 act spelt out the functions of the Commission in seven sub-sections, of which one dealt with registration.[8] These functions are now being amended only by deleting the Commission's functions in relation to recommendations upon expenditure or grants by the Australian Government.[9] However, a recent statement by the Chairman says:

> *"The Commission has two general roles. The first is to provide general policy advice on all issues affecting the National Estate – research, professional training, information and publicity, environmental education, and so forth. The second is to establish a Register of the National Estate. The National Estate, for those to whom the term is new or unclear, includes all sites of significance to Australia, whether prehistoric, historic or natural, related to Aboriginal or white culture or to cultural history or natural history".*[10]

He then continues to point out the urgency and importance of the register, and it is now clearly seen as the Commission's primary task, at least for the time being.

One might interpret all of this process as a gradual castration of the visionary principles expressed in the first report, or alternatively, as a matter of woolly idealism being replaced by sound administrative common sense. I am not arguing for either viewpoint, but merely making the point that the register has now become a central element in the Australian Government's program for the National Estate, and that the first report, probably the best-known of the documents to which I have referred, does not reflect the present situation.

At the commencement of 1976, the Australian Speleological Federation received a grant (paid via the Australian Conservation Foundation) from the Interim Committee on the National Estate to carry out a study of the criteria and principles to use in deciding which caves and other karst features should be placed upon the register of the National Estate.

The Federation's approach to this study has been described in its newsletter[11], and has been pursued largely by mail at this stage in order to try and involve members throughout Australia. Questionnaires have been circulated, completed and returned. Discussion papers, of various degrees of intelligibility, have been circulated, discussed and comments returned to the study committee. All this process will continue into 1977, and will be fully reported upon at the conclusion of the study.

This paper has been prepared to outline a number of issues arising from the study, and hopefully to generate further discussion and feedback.

The Concept of Place

A perusal of the various official documents dealing with the National Estate makes it clear that one basic assumption underlying virtually all thinking is that the National Estate consists of a series of discrete "places". Admittedly, the legislation defines a "place" as "a site, area, or region.....", but other than in some sections of the first report (particularly 'the captions to plates') there is little evidence of understanding natural ecosystems and their complex inter-relationships.

Of course, this is no new problem. We are all familiar with legislation which prevents one from killing or capturing an individual native animal yet remains utterly silent about wholesale destruction of the environment which is vital to the survival of that same animal species. Regrettably, we now have, in the National Estate legislation, laws which can recognise the significance of a cave, but which could all too easily ignore the dependence of that cave upon a large watershed area and the stability of water table levels.

Perhaps it is too difficult to write legislation so that it does effectively come to grips with ecosystem concepts – or perhaps our legislators could not or did not wish to face the implications of an ecosystem approach.

Whatever the cause of the situation, it seems to me that the position of bodies such as the Federation is clear. We do have to understand the implications of an ecosystem approach, and we do have to frame our own recommendations in the light of that approach.

The practicality of doing this is another question. For instance, it is clear to any who have seen Easter Cave, Western Australia, that the integrity of that uniquely beautiful and fragile cave is very much dependent upon the stability of local groundwater levels and the chemical composition of that groundwater. However, none of us could confidently predict the long-term impact (or lack of it) of any activities on the ground surface within the surrounding country – we just do not know enough – yet it is quite possible forestry activities many miles away might ultimately lead to destruction of that cave.

Nevada's Devil's Hole is only one of the many examples of caves which have been disastrously affected by other activities at a considerable distance, even though Devil's Hole itself is a National Monument and hence a protected "place".[12] It should serve as a warning to us.

Before proceeding to further discuss the issue of how we might best define and delimit a "place" for purposes of our own recommendations, there are some other matters which also bear upon this problem.

Outstanding or Representative?

The approach to defining the National Estate seems to assume that it should consist of particularly "significant" places. Thus, the legislation states:

> *"For purposes of this Act, the national estate consists of those places, being components of the natural environment of Australia or the cultural environment of Australia, that have aesthetic, historic, scientific or social significance or other special value for future generations as well as for the present community".*[13]

However, the first report certainly implied that some attention should be given to recognising the range of environmental features which exist and the need to ensure preservation of a sample of all elements.[14] Current practice in land conservation planning virtually throughout the world certainly emphasises the need to ensure preservation of representative sample of all land systems, and not just those which happen to seem "significant" at some particular point in time. Although analysis of questionnaires returned by our own members is not complete, a preliminary count indicates that Australian speleologists have a strong preference for the representative approach.

This starts a whole new game. So far, our study has concentrated upon the notion of "significance" and we have made a great deal of progress in this direction. However, if we are to consider representation instead of or in addition to, significance, then we need a taxonomy (systematic classification) of caves and karst features, establishing the various classes, genera and species of caves from which a sample might be drawn.

Grimes[15] has suggested on taxonomy, which I take the liberty of reproducing here. (Fig. 1).

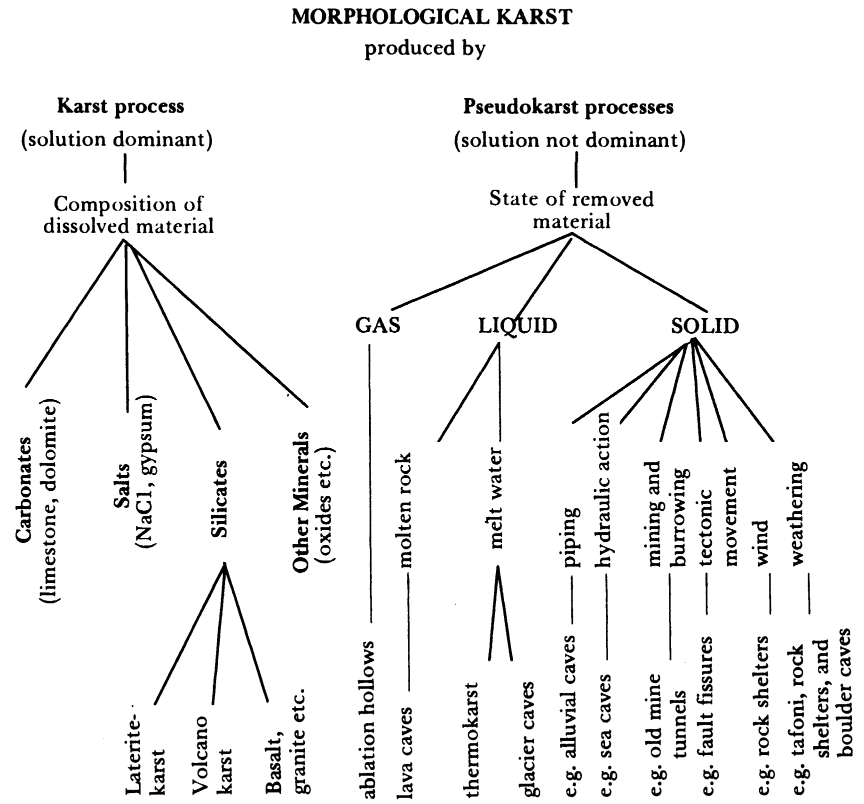

Fig. 1. : Classification of Karst and Pseudokarst
(after Grimes 1975).

Now this immediately raises some very interesting questions for us. Let me list two of them:–

1. Obviously the class named 'carbonates' within the phylum 'Karst' includes most of Australia's recorded and described caves. How can this be divided into useful sub-classifications?
2. The taxa of piping caves is one of several which raises some extremely interesting problems. We have an immense number of such caves in Australian Laterites, but very few have been been described.[15] At present, such caves are not generally seen as "significant", but if the National Estate is to be representative, then they certainly have a place on the register; the remarkable paucity of data on such caves in other countries suggests that we may well have a responsibility on world scale! Similarly, what about the remarkable tafoni of some caves in the Hawkesbury Sandstone of New South Wales? So, you see the importance of this new game – it draws our attention to previously neglected fields of speleological study, and hence poses a considerable information problem to us.

It is perhaps also important to raise the historical context of "signifcance". Places which were once seen as "significant" enough to be enshrined in state reserves may now be seen as of little or no importance. For instance, Dickson's Caves, Buchan, Victoria, are the subject of a reservation, yet on any comparative scale would today rate very low vis-a-vis almost any other caves in the region. Perhaps some of the caves which we now perceive as most significant will similarly fade into obscurity in the eyes of a future generation, or others which we now see as unimportant (even Dickson's Caves) will assume a new significance in future.

To follow the above example, perhaps our laterite caves will one day be accorded a major significance. A little closer to our present perception, I believe it can be argued that the lava caves of Western Victoria and the Einasleigh region of Queensland are greatly under-valued by virtually all Australian speleologists.

This leads me to the position that the representation framework is perhaps more valid than the significance framework. In practice we may end up trying to combine both considerations, but this is obviously a question of real substance.

A further issue is that any one cave may not only be significant for a number of reasons, but it may also be representative on a number of dimensions. Leaving aside the spectacular examples such as Exit Cave, Tasmania, let me just example Cloggs Cave, East Buchan, Victoria. This insignificant little hole of some thirty metres length is an interesting example of a cave contained within an anticlinal fold; it has proved an extremely valuable archeological and palaentological site;[17] it was (but regrettably is no longer) a maternity site for the relatively rare (in Victoria) bat *Myotis australis*[18] and houses an interesting population of living invertebrates.[19]

Cases like this are probably relatively easy to place within a significance framework, although there are some practical questions about the relative weighting assigned to particular aspects. However, the determination of its place within a representation framework does pose some nice problems in sampling design!

Assessment of Significance

Reference has already been made to the progress of the Federation's study on assessment of significance. However, one immense gap can be identified in our work to date, namely, ways in which we might quantify such subjective characteristics as beauty.

It is relatively easy to establish some kind of framework within which to assess the significance of, for instance, the occurrence of rare animal species or rare minerals within a cave, and to give that framework a reasonable appearance of objectivity. Certainly, this apparent objectivity may well be nothing more than a high level of agreement amongst recognised "experts" within a discipline, and according to the criteria of that discipline. Inevitably, these criteria are to some extent arbitrary, but they are generally accepted.

When we come to beauty, or the subjective experience of a good "sporting" cave, then we find it very difficult to specify criteria, and even difficult to conceptualize a framework within which beauty and excitement can be assessed. These are highly personalized judgements, and subject to immense variation.

Obviously, one approach would be to take an opinion poll and abide by the majority view. Regrettably, all this means is that some of the most visited and best-known caves will rank most highly, while little-known caves will be neglected.

There also seems to be an odd anomaly here, in that the concept of beauty generally evokes a response in terms of the quality (and sometimes the quantity) of cave decorations. Basic form seems to be overlooked, and such features as the geometric perfection of the arch in Anticline Cave, Murrindal, Victoria; the white walls and clear lake of Weebubbie Cave, Nullarbor Plain, the remarkable fretwork roof of Aiyennu Cave, Stockyard Gully, Western Australia; the majesty of the Gunbarrel, Wyanbene Cave, New South Wales; the massive rockfall at the entrance of Koonalda Cave, Nullarbor Plain; or the sculptured passageways of Mammoth Cave, Jenolan, New South Wales, rarely rate a mention.

Unfortunately, these subjective aspects are perhaps some of the most important ones. The very notion of some overall significance is in itself seeking a subjective judgement. Moreover, it is the beautiful and exciting places which will capture public imagination, and hence, support for the preservation of the national estate – a very important political reality.

Implications of Registration

There are three relatively obvious and quite direct benefits of registration. The first is that any place which is registered is protected from thoughtless action by Federal government authorities or departments.

In the words of the Chairman:

> *"Protection for a site on the Register (which applies equally to sites on the Interim List) is related to Federal actions and authorities only. All Ministers and heads of Federal departments or authorities must take no action which would damage that site unless there is no feasible or prudent alternative; if there is deemed to be no such alternative, they must only take such action as would minimise damage. They must not act at all without first informing the Commission. An action is defined to include the granting of moneys, the issuing of licences, and the taking of a decision".*[20]

Secondly, the registration of any place will confer an identification and recognition of its significance which surpasses any parochial considerations. Thirdly, it seems clear that future financial assistance in respect to the National Estate is likely to primarily flow in respect to those places which are registered. Registration therefore opens an avenue to potential financial resources to assist in conservation and management.

Obviously registration does not of itself confer any direct protection other than from Federal government action as outlined above. It does not necessarily mean protection from action by State governments, private land owners or lessees, such as mining companies.

However, the Federal government has expressed its hope that State governments will establish equivalent commissions with comparable functions at the State level. At least one State has announced its intention of doing so,[21] and consideration is being given to this matter in at least some other States.

Where such State bodies are established, it seems likely that they will accept registration on the National Register as a basis for their own program.

Finally, the very existence of registration may certainly act as some deterrent to private land owners and lessees who might otherwise destroy a site. Moreover, registration will provide valuable evidence to support conservation action in any area of conflict.

At the same time, there are doubtless some disbenefits of registration. The first of these is that the public attention attendant upon registration may well attract visitors in excess of the available management capacity. Fraser Island provides an interesting example of this situation. The publicity of recent years has greatly increased visitor traffic to the Island and the resultant environmental damage is considerable. It again highlights an inherent problem of the National Estate legislation in that registration is not integrated with provision for management.

Almost by converse, registration may well increase pressure upon un-registered sites. This may happen in either of two ways. Where registration results in more adequate and more tightly controlled management, visitor pressure may well be diverted to other sites in the same way as caver pressure in New South Wales has been diverted to Bungonia and Wee Jasper, much to the detriment of the latter site in particular. The other is that developmental interests such as mining companies might well be deterred from destroying one area and turn their attention to another.

The implication of this is obvious from our point of view. Every effort must be made to ensure registrations of all sites of importance rather than a limited selection.

Although perhaps an extreme possibility, there is always the likelihood that initial steps towards registration might well result in a vindicitive land owner taking action to destroy the site concerned.

Again, the implication is relatively clear and any intention to seek registration of a site on private property should be carried out in conjunction and, if possible, with the full co-operation of the owner.

Defining a Place

It is now possible to return briefly to the issue raised earlier of the way in which a place might be defined and delimited.

From an ecological point of view, it is highly desirable that boundaries should be natural ones relating to total ecosystems rather than arbitrary ones. In some cases this will also mean the incorporation of a buffer zone area which protects the ecosystem. Obviously this can pose some considerable practical problems. In the example of Easter Cave, Western Australia, referred to above, we do not really know the scope of the functional ecosystem involved. In some other cases we may know this but it may be extremely difficult to argue and justify for registration purposes. As a simple example, the watershed which influences the Buchan/Murrindal Karst of Eastern Victoria, is the total watershed of the two rivers concerned encompassing many thousands of hectares.

A further practical question is the extent to which a place as defined for purposes of registration provides a viable land unit from a management perspective. It is obviously desirable that any registered place should be under a single ownership or management and not fragmented into a variety of holdings. In practice, this will not always be possible but it clearly is a factor to be considered when arguing for registration.

Finally, one important argument for registration of relatively large areas rather than single features is that it may help to off-set at least one of the potential disbenefits of registration, namely, the extent to which visitor pressure may increase. Thus, if Kubla Khan Cave, Mole Creek, Tasmania, were registered as a single cave it is virtually certain that visitor pressure upon the cave would increase. However, if a large section or all of the Mole Creek limestone area were registered, it would not necessarily increase visitor pressure upon any one feature within the area.

Conclusion

I trust this paper and the issues raised in it will be discussed at length, both during this conference and subsequently. The extent to which the Federation can move towards a better solution to the problems posed here is important for the future of Australia's caves.

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A BASIS FOR CAVE MANAGEMENT

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Abstract

As part of its charter to protect and conserve natural phenomena, the New South Wales National Parks and Wildlife Service has the responsibility of managing a number of cave areas. Because of the unique values of caves and the ever increasing demand on them for recreational usage, the Service proposes to implement a cave management plan which will provide a basis for protecting the caves under its control. This paper introduces a cave classification which will be used to categorise individual caves into management groupings. Five levels of cave management are recognised and the caves will then be managed according to these groupings.

Introduction

As part of its charter to protect and conserve natural phenomena, the New South Wales National Parks and Wildlife Service has the responsibility of managing a number of cave areas. Because of the unique values of caves and the ever increasing demand on them for recreational usage, the Service proposes to implement a cave management plan which will provide a basis for protecting caves under its control.

The two basic aims of the management plan are:-

(i) to establish appropriate protection for the spectrum of cave resources administered by the National Parks and Wildlife Service.

(ii) to establish a uniform approach to cave management throughout all Service-controlled areas.

To achieve these aims, the cave management study has:—

(i) determined the criteria to be used to document and evaluate (in terms of management) the importance of natural cave resources.

(ii) grouped the natural cave resources into management categories based on their relative scientific and recreational importance.

(iii) determined a cave classification which orders the management categories into a scheme which is applicable on a Service-wide basis.

The Cave Classification

The management of all Service-controlled caves will be according to the cave classification shown in Fig. 1. The classification is organised so that the most important cave resources are given the most protection. The scheme not only considers the individual cave but it also considers:—

(i) the cave in relation to the area surrounding it.

(ii) the importance of the cave and cavernous area relative to the rest of the park or reserve.

(iii) the importance of that cave and cavernous area relative to the state, national, and world-wide sphere of importance.

Similarly, the classification enables the appropriate management of individual chambers or sections within the cave.

The classification will also provide the basis for determining the adequate sampling of the Service-controlled cave resource, since documentation of the cave resources at the Service estate level will enable the comparison of the conservation area's resources against the state's cave resources. This aspect is especially important in relation to maintenance of cave biological resources, in particular, bats. Access and permit systems will also be determined relative to the cave classification.

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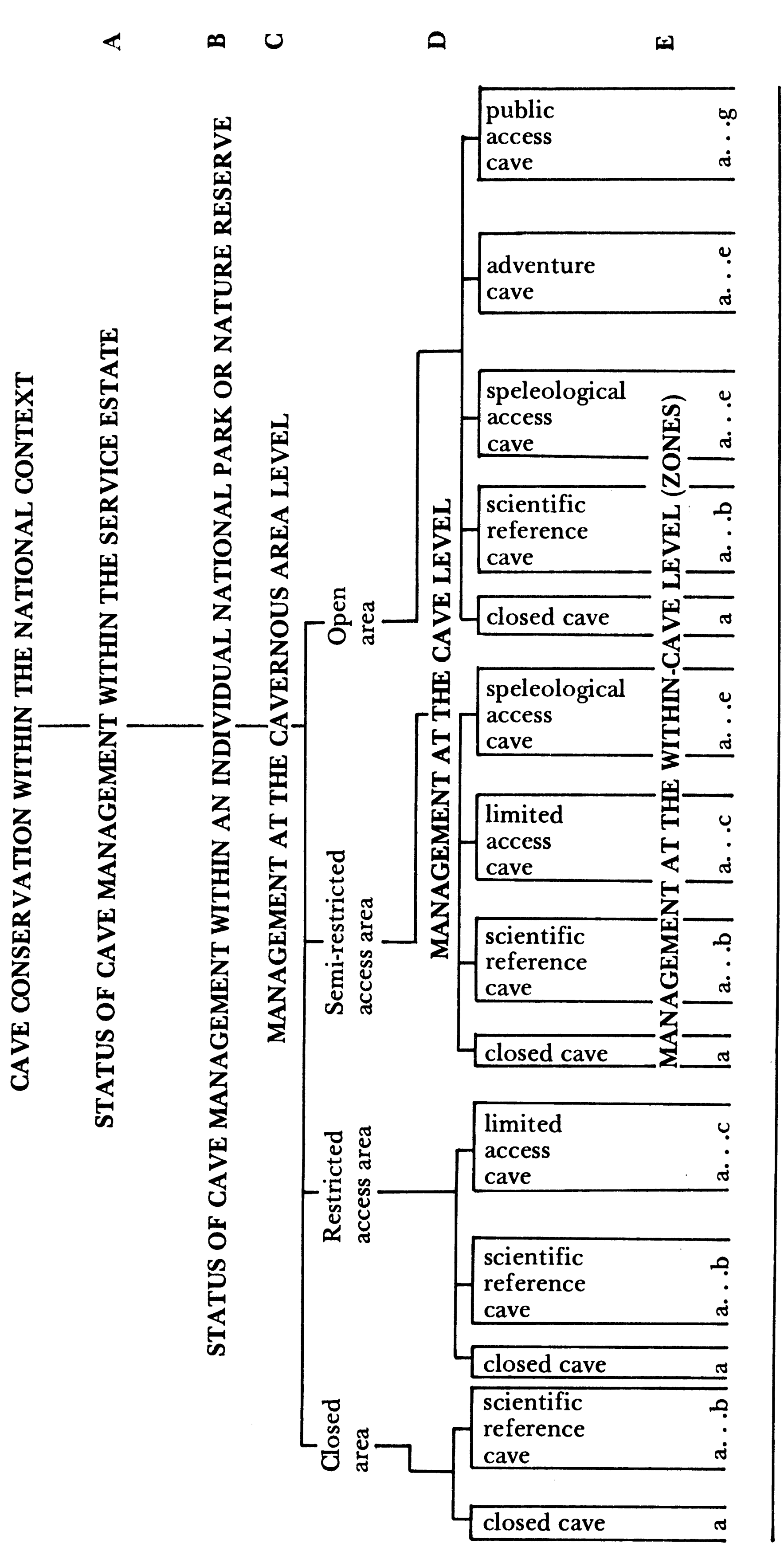
Fig. 1. The Cave Classification.



Key to zones: a — closed; b — scientific reference; c — limited access; d — natural passages; e — partially developed passage, no electric lighting; f — developed passage, with electric lighting; g — intensive use area.

The cave classification recognises five levels of cave management:–

A. the Service estate level

B. the individual national park or nature reserve level

C. the cavernous area level

D. the cave level

E. the within-cave level

Generality increases from the detailed within-cave classification to the Service estate level, which assesses the status of cave protection on a New South Wales, nationwide, or world wide basis.

The classification works on the following basis (for a typical national park):–

(i) Cave areas within the park are recognised.

(ii) All of the available resource information on the area is collated and the importance of each area is determined at the Service estate level.

(iii) This decision immediately determines the management of all the caves within the individual area since it determines access. If, for example, a cavernous area is extremely small but scientifically important, management would consider it as a restricted access area (or a more stringent classification). As shown in Fig. 1, this classification only considers access to speleologists who are experienced, or those that enter the area on a scientific permit basis.

Thus a management decision at the cavernous area level immediately imparts the minimum qualification required by persons entering the area. However, the cavernous area classification still retains the flexibility for management to impose even greater access restrictions to individual caves above that minimum level. This is particularly important at the open area classification, where scientifically important caves might be individually recognised, or reference caves might be established in an area that might otherwise have a recreational emphasis.

(iv) The caves are classified according to their individual importance and the minimum standard predetermined by the cavernous area classification.

(v) Where necessary, individual chambers within a cave are classified according to the minimum standard established by the cave's classification. This within-cave management level may be particularly important for the protection of bat breeding chambers in a large cave system or for retaining "reference sections" of cave in public access caves.

The cave classification thus overcomes the major problem of surface management classifications that have been used to protect cave areas in the past. That is, it accounts for the variability and individuality of caves within a cavernous area, and manages the individual cave according to its inherent values. The details of the individual levels of the cave classification are outlined below:–

A. The Service estate level

Controlled at head office, the Service estate level represents the master planning, co-ordinating, and controlling level of the cave management plan. Service-administered cave resources will be managed on a state-wide basis to obtain the ultimate balance of preservation, conservation, and recreation, relative to the importance of the resources and the degree of protection afforded to other cavernous areas. The adequacy of the Service's present sampling of cavernous areas will be assessed. A single permit system will be controlled at the Service estate level, although access to individual caves will be controlled at the park level.

B. The national park or nature reserve level

The national park or nature reserve level of management considers the management of cavernous areas in relation to their geographical position within the park or nature reserve, the significance (physical and biological) of the areas, the external influences and resource pressures on the areas, and historical influences. The minimum level of management, however, will be somewhat determined by the policies of the Service estate level. Management emphasis will be placed on the "greatest protection of the most important cave resource", and will therefore require an evaluation of the resources of the cavernous areas. Specific considerations have been documented as guidlines, and are presented below:–

Criteria used to evaluate the importance of the cave resource at the national park or nature reserve level.

(i) Geological considerations

Rock type, structure, stratigraphic relationships, palaeontological rarities, minerals present etc., may make a cavernous area unusual or unique. For example, caves are generally associated with limestone, but may also be associated with lava flows, evaporite deposits, dolomite, sandstones and other rock types, and may as a result be unusual.

(ii) Geomorphological considerations

Surface and sub-surface landforms in a karst area are often the most important features for management to consider. Underground features such as extensive caverns, unusual phreatic or vadose passageways, and extensive speleothem displays; or surface features such as cliffs, gorges, large cave entrances, natural arches, dolines, uvalas, minor solution features (flutes, grikes, funnels), blind valleys, semi-blind valleys; and so on, may make an area geomorphologically important.

(iii) Hydrological considerations

Surface drainage patterns and sub-surface drainage patterns may determine the significance of an area. For example, the sinking or rising of streams and their underground movements may be unusual. Large underground lakes and waterfalls may be present as might natural or thermal springs, thus making the area important.

(iv) Biological considerations

Hamilton-Smith (1971) presented a seven-category system for the classification of cavernicolous fauna:–

(a)	Parasites	– obligate parasites
(b)	Accidental	– not regularly inhabiting caves
(c)	Threshold	– inhabit twilight zone
(d)	Trogloxene	– does not complete its life cycle in cave
(e)	1st level Troglophile	– known from epigean and hypogean habitats
(f)	2nd level Troglophile	– known only from caves, but not exhibiting any modifications to the cave environment
(g)	Troglobite	– living total life cycle within caves and modified to the cave environment

The classification is an indication of the diversity of cave fauna. Cave flora is generally restricted to the entrance and threshold zones of the cave; ferns, algae, mosses and liverworts being the dominant groups.

Thus a cavernous area may be biologically significant where it supports unique, rare, or unusual life forms. It may also be significant as one of the few bat breeding areas in the state. Specific examples of unique areas in the biological sense may also include those that maintain relict fauna or flora. In nearly all cases where cavernous areas are biologically diverse, they should be considered as important.

(v) Meteorological considerations

Some cave areas may lend themselves, as a result of their morphology and geographical setting to unusual conditions of air movements, temperature, humidity, and air composition. These meteorological effects may be sufficiently important to warrant special protection measures.

(vi) Archaeological, fossil, and sub-fossil considerations

Anthropogenic influences, the presence of fossil fauna and flora, and presence of deposits or accumulations of sub-fossils (bone deposits), may make a particular cavernous area significant.

(vii) Historical influences

Past access, cave development, vandalism, usage patterns, etc., may have altered or affected the values of a cave area. The present management of an area may be dictated by these influences.

(viii) Geographical setting

The location of a cavernous area may assist in the management of a cave resource just as it may increase the problems of management of an area. Physiographically isolated cavernous areas with natural or easily imposed access restraints will be afforded protection because of natural limitations on their use. Only the keener, and generally conservation-orientated, speleologists would be interested in venturing to such isolated localities. Conversely, many significant cavernous areas are located in areas of easy access and topographical settings which make management difficult. Generally these areas are either prone to abuse by a wide spectrum of users, or have already been affected by such users. Similarly, cavernous areas located close to large areas of population may be affected by heavy visitation pressures. Thus, in assessing the importance of an area, management must also consider the influences of the geographical setting and the visitation pressures for its effective protection. The recreational importance of the cavernous area must also be considered.

C. Cavernous area level

A decision made at the national park or nature reserve level will impose one of the following management classifications over all or part of the cavernous area :–

(i) Closed cavernous area

(ii) Restricted-access cavernous area

(iii) Semi-restricted-access cavernous area

(iv) Open cavernous area

Management at the cavernous area level reflects the degree of importance of the caves, landforms, and other natural features found within the cavernous area. It represents a surface planning concept that directly controls sub-surface (cave) access. Thus surface management aspects such as the protection of landforms, vegetation communities, and stream catchments are important considerations at this level. The sub-surface (cave) minimum access requirements are defined by the cavernous area classification. (However, individual caves may have more restrictive access controls within that area). Two or more classifications may be required over any one cavernous area. That is, there may be a need to divide the management of a cavernous area into sub-areas into which influences such as development, visitation access points, and general recreation areas, are considered along with the protection of the resource. The classifications defined above would be used to define the sub-areas. (For example, Yarrangobilly Caves within the Kosciusko National Park could be defined as partly an open, and partly a restricted-access, cavernous area because of the development area at the southern end of the limestone and the natural caves to the north of the development area). The areal extent of the management sub-areas within a cavernous area must be precisely defined. Details of the four cavernous area classifications are presented below.

(i) Closed cavernous area

An important bat maternity site or breeding colony would be sufficient justification for managing an area as a closed cavernous area. Similarly, a closed cavernous area may be important scientific reference area, or the site of scientific studies which may warrant its management classification. Two types of cave classifications are envisaged for the area and include closed caves and scientific reference caves. Access to the area would be subject to a scientific permit being granted by the Director.

(ii) Restricted-access cavernous area

Where a cavernous area is considered, by the nature of its inherent values and resources, to be significant for special management protection, then access to it may be designated as "restricted". Three types of caves may be found in the area, and include closed caves, scientific reference caves, and restricted-access caves. The minimum access restrictions to the area are determined by access to the restricted access caves. Such areas would include all cavernous areas within the Service estate deemed as being "significant for the preservation and protection of the cave resource".

(iii) Semi-restricted-access cavernous area

A cave area is defined as a semi-restricted-access area when the nature of the area's physical and/or biological attributes does not warrant special protection as a closed cavernous area or a restricted-access cavernous area. Geographical and sociological pressures may influence the designation of an area as a semi-restricted-access cavernous area. The minimum access requirement is as indicated by the requirements of the speleological access cave. Four types of "management caves" may be found in the area. These include the closed cave, scientific reference cave, the limited-access cave, and the speleological access cave.

(iv) Open cavernous area

All cavernous areas that are either of little scientific value or have, because of historical factors, been altered or developed in such a manner as to have lowered their scientific values; or those cavernous areas that have been opened to general visitor access; are defined as open cavernous areas. Six types of caves may be found in an open cavernous area; that is, closed caves, scientific reference caves, limited-access caves, speleological access caves, adventure caves, and public access caves. This allows for the preservation and protection of important caves in a development area.

D. The cave level

As for the cavernous area level the cave level classifications are based on restriction of access. Six cave classifications are envisaged and are documented below:–

(i) Group 1 – closed caves

Closed caves are those caves in which access is not permitted. They may be caves that are dangerous (e.g: bad air or unstable caves), or caves that are awaiting further classification. The principal management aims are to protect caves from speleological visitation pressures while they are awaiting classification, and to close access to dangerous caves. Access will only be granted to experienced cavers undertaking a Service-approved cave classification study.

(ii) Group 2 – scientific reference caves

Scientific reference caves are defined as caves that are best representative of geomorphological, geological, biological, and/or speleothem attributes of the caves in the area. Preference for this classification will be given to those caves in which man's disturbance has been minimal, and where the physical qualities of the cave and its biological content are essentially in a natural condition. The principle management aim is to preserve the caves in their natural state so that a reference set of caves and cave life are available for the future. A gate is a necessary prerequisite for the establishment of a scientific reference cave. Access to these caves will be strictly controlled and restricted to detailed research work only. Entry will only be granted to experienced cavers on the basis of the standard scientific permit. The scientific permit will indicate the nature and value of the detailed research work and the possibility of any physical disturbance to the cave. If inexperienced cavers are to be granted a permit they must demonstrate that they have the qualifications and ability to undertake the research work and they must be accompanied by a team of experienced cavers. At all times, parties entering scientific reference caves will be under the leadership and deputy leadership of experienced cavers who will be responsible for the safety of the party and the protection of the cave. A maximum and minimum number within the cave at any one time will be designated according to the cave's characteristics.

(iii) Group 3 – limited-access caves

Those caves which have such a quality in their physical and/or biological attributes that they warrant special protection, even though these attributes are already represented in scientific reference caves in the area, or for safety reasons, those caves which have a degree of difficulty which limits cave exploration to experienced cavers only, shall be classified as limited-access caves. The principal management aims are to preserve the high quality of limited-access caves and/or to maintain a high safety standard. Access to these caves will be restricted to experienced cavers only, and a maximum number within the cave shall be designated according to the individual cave's characteristics. The installation of a gate is a necessary requirement where the physical nature of the cave permits. Where necessary to minimise damage to a particular cave the frequency of visits may be restricted. Detailed speleological research is to be encouraged.

(iv) Group 4 – speleological access cave

A speleological access cave is defined as a cave where the nature of the cave's physical and/or biological attributes does not warrant special protection as a scientific reference cave or a limited-access cave and where the degree of difficulty is suitable for cavers and novices. The speleological access caves also include those caves not suitable as adventure caves or public access caves, and those which may be suitable as training caves. The principal management aim is to maintain the cave's natural features and to provide the appropriate exploration opportunities for cavers. The installation of a gate is an essential requirement where the physical nature of the cave permits. Access will be granted to cavers in the speleological access caves provided that the group has an experienced leader and deputy and that the ratio of experienced cavers to cavers ideally does not exceed 1:3. The number of cavers within a cave at any one time will be restricted according to the nature of an individual cave. The individuality of the cave may also lower the ratio of experienced cavers to cavers. Novices will be restricted to 25 per cent of the total number of the party.

(v) Group 5 – adventure caves

An adventure cave is defined as a cave that has little or no inherent value other than its morphological form, and which would be suitable for exploration by inexperienced but properly equipped parties, such as organised youth groups. The principal management aim is to permit cave exploration by non-speleological groups in caves where the degree of difficulty and the potential damage factors are low. The installation of a gate is recommended where the physical nature of the cave permits.

(vi) Group 6 – public access cave

For the purposes of this study, public access caves include those caves in open areas that have been developed or are suitable for development as public inspection caves. Public access is with a ranger unless the cave is especially designed otherwise. No special equipment or clothing is required unless specified by the ranger.

Cave description checklist

To assist with the evaluation of the natural values of individual caves, a checklist of important aspects to be considered has been prepared. The checklist also includes topics that will assist management to estimate carrying capacities and frequency of visits to the caves.

- Location and external relationships
- History of the cave
- Cave map, preferably of standard better than CRG 4D
- Geology
- Morphology
- Mineralogy
- Hydrology
- Biology
- Meteorology
- Sub-fossils (bones)
- Archaeology
- Other special features
- Vandalism
- Potential gate site – environmental impact of gating
- Maximum and minimum limit to the number of cavers for the cave
- If a group 4 cave, the ratio of experienced to inexperienced cavers for the cave
- Minimum amount of user equipment needed for the cave
- Recommended frequency of visits to the cave

E. The within-cave level

The within-cave level of management recognises the need to manage the resources of the particular cave. It provides the basis for the recognition and effective management of extensive and variable cave chambers and passageways within the cave. For example, bat breeding chambers, sections of a cave that exhibit rare and delicate speleothems, or chambers that are archaeologically or palaeontologically significant. By zoning parts of caves according to this concept, it may be possible to allow recreation and/or exploration activities within the greater part of the cave whilst protecting the remainder as a reference section. Similarly, public access may only be permitted for part of the cave, the remainder of which may be managed according to the within-cave management plan.

The within-cave classification will be related to a detailed evaluation of the resources of an individual cave, and a cave map of standard not less than CRG 4D will be required to compile the management plan. For this reason, the Service will rely heavily on the assistance of concerned and expert speleological groups for the compilation of effective management proposals for individual caves. A within-cave classification prepared for the management of the Mammoth Cave system by the United States National Parks Service has been adopted as the basis for the within-cave classification used here; zones are designated by the letters "A" through "G" in order of use and development.

(i) Zone A – closed passages

These passages may be closed by gate for either safety or scientific reasons.

(ii) Zone B – scientific reference

The scientific reference zone relates to a part of a cave which may be an excellent representative of the geomorphological, geological, biological and/or speleothem attributes of the cave or caves in the area. It may be used as a measure of the effect of variable visitor usage on the remainder of the cave, or it may protect important biological sites, etc. Whenever possible, zone B passages will be closed to access from the rest of the cave by a gate, and access will be granted on the basis of a scientific permit.

(iii) Zone C – limited-access

The limited-access zone of a cave relates to passages or chambers whose physical and/or biological attributes warrant special protection, and/or those passages which have a degree of difficulty which limits exploration to experienced cavers only. Where possible, access to the limited-access zone will be restricted to experienced cavers by the use of a strategically placed gate.

(iv) Zone D – natural passage

Only those speleologists properly equipped and experienced in caving techniques may traverse those passages which have not been improved in any way. Access along natural passageways will be as for speleological access caves.

(v) Zone E – partially developed passage (no electric lighting)

This zone relates to those passages which are partially developed or were once developed and are now abandoned. Trails range from good to somewhat primitive. Other development is limited to that essential for visitor safety, and as there is no electric lighting, such passages provide a "wild" cave experience for visitors without training in caving techniques. Lighting is by hand-held lanterns.

(vi) Zone F – fully developed passage (electrically lit)

This zone includes all those passages provided with electric lighting aesthetically arranged and developed with trails, bridges, steps, stairways, landmarks, etc. Except where otherwise stated, (e.g.: the self-guiding cave, Glory Hole, Yarrangobilly) guides accompany all parties and a fee is charged – parties will not exceed the "limit" placed on the individual cave, and the frequency of visits will also be dependent on the management of the individual cave.

(vii) Zone G – intensive use area

Limited to those areas where people assemble; a concept more specifically orientated to Mammoth Cave (U.S.) where underground lifts and visitor facilities are provided, and as indicated by the text, "such places, essential to the comfort and convenience of the visitor, are located in sections of cave passages which have low aesthetic and/or scientific value". It is not envisaged that many such zones will be designated in New South Wales caves.

Conclusion

A cave management plan using an approach based on a "recognition and evaluation of the scientific and recreational importance of the cave resource" has been prepared as the basis for the effective and systematic management of caves within areas controlled by the National Parks and Wildlife Service.

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Reference

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APPENDIX: Terms used in the classification

A. Experienced caver

An experienced caver is one who can satisfactorily demonstrate that he/she has achieved the standard of caving proficiency defined by the list below, or is a caver who can demonstrate that he/she has reached an equivalent standard.

(i) He/she shall have the necessary temperament and sense of responsibility to ensure the safety of the party, the protection of the cavern, and the well-being of the society.

(ii) He/she shall have attended ten or more official caving trips.

(iii) He/she shall be proficient in the following:–

Knots – bowline, clove hitch, prussik
Belaying – preparation and care in the use of a safety rope and holding 75 kg in a simulated fall.
Abseiling – from an overhang of 10–20 m with or without a karabiner.
Coiling and care of ropes and wire ladders.
Ladder climbing techniques.
Prussik slings – their use in the ascent of a single rope.

(iv) He/she shall have taken part in lectures and discussions or should otherwise prove that he/she is familiar with topics such as:–

(a) safety in caves
(b) surveying and mapping techniques
(c) basic first aid
(d) trip organisation

B. Caver

A caver is one whom the experienced caver considers to have the necessary sense of responsibility to ensure the protection of the caverns; who has had training in cave safety and caving techniques, but who has not yet achieved the standard of experienced caver. He/she will, upon entering a National Parks and Wildlife Service controlled cave, have the minimum amount of equipment consistent with personal safety and adequate protection of the cave.

(i) *Personal equipment*

All persons entering caves must have a minimum amount of personal equipment which includes:–

(a) helmet – suitable approved lightweight miner's-type helmet – pudding basins and similar substitutes will not be allowed.

(b) three independent sources of light – e.g: caplight, hand torch, and candle. Carbide is permitted, only on the condition that the spent carbide is removed completely from the limestone area and placed in a suitable depository (e.g: a garbage bin).

(c) overalls in preference to normal old clothes

(d) suitable footwear without nails.

(e) waistloop or equivalent

(ii) *Group equipment*

The group equipment is the responsibility of the leader. Ideally each cave will have listed with the classification the minimum equipment needed for its safe exploration.

C. Novice Caver

A novice caver is one who has no previous caving experience; or has not, in the opinion of the experienced caver, had sufficient caving experience to be familiar with the basics of cave safety and caving techniques.

D. Cavernous area

For the purpose of this paper, a cavernous area is defined as the actual area (defined on the surface) that contains caves. The limits of the cavernous area are defined by the extent of the surface and sub-surface expressions of the caves. (For limestone karst areas, the extent of the limestone may be defined as the cavernous area).

KARST RESOURCE MANAGEMENT

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Abstract

Karst is a complex natural resource which can be used and abused in a vast number of ways. Resource management techniques provide a basis for reconciling the different needs of the various uses competing for the same resource. This paper offers a perspective on the rationale for management and conservation of caves and karst landscapes.

Resource management, at a national level, is a strategy of optimal use, or non-use, of resources. Its elements include the analysis of resources and potential uses, the definition of resource use options, and ultimately the selection of appropriate management or exploitation regimes. It is essentially a long-term planning process, and one which assists in the progressive definition of socially (and environmentally) desirable goals. One of its basic objectives is to minimise conflict for resources between various uses.

Resource management has not yet been applied to Australian karst in any systematic way. This paper is concerned with the philosophy and principles of national management of karst resources, rather than with a description of current resource management practice.

Karst, as Jennings (1971) defines it, is: "terrain with distinctive characteristics of relief and drainage arising primarily from a higher degree of rock solubility in natural waters than is found elsewhere"; the term thus embraces far more than caves alone. The central concept of karst is essentially an ecological one — it is part of a dynamic natural system. It happens to have particular characteristics that are of significance to speleologists. As a matter of perspective, it is important to appreciate that caves are just one component of this complex system. Even if caves offers outstanding opportunities for research and similar activities (Poulson and White 1969), their unique characters are frequently dependent on the surrounding karst. Although there are cases where conservation of individual cave sites is called for, deliberative management of caves and karst as a collective resource is a fundamental ecological necessity (Dwyer 1976; Hamilton-Smith 1974; Legrand 1973; and Poulson 1976). External Factors of climate, geology, topography, hydrology, vegetation, and numerous others, clearly have critical relevance to an understanding of the cave component of karst.

I emphasise all this for an important reason: that speleologists in general are very often preoccupied with caves, without necessarily taking much notice of other components of karst. So it is without apology that I shall continually refer to karst, rather than caves, in the context of this paper. Conservation of caves is a very short-sighted preoccupation unless it is accompanied by energetic attention to conservation of karst as a whole.

It should be noted that although discussion in this paper is confined to karst environments, similar principles would apply as readily to basalt caves, sea caves, or any other cave environments. Decision-making about such caves without reference to their environmental context is likely to be extremely hazardous.

Before examining principles and problems of karst resource management any further, discussion of some more basic considerations is justified. Dwyer and Harris (1973) have drawn attention to the fact that most of our conservation problems have their origin in continuing disequilibrium of the human species with global ecosystems; perhaps this should be a more urgent preoccupation for us than narrower interests such as karst. Nevertheless, an awareness of process and problems at a global level has implications which are relevant even for short-term conservation strategies. Our rationale for cave conservation has long been somewhat preservationist in outlook, with some justification, but it seems likely that the need to safeguard evolutionary processes is a more logical rationale for karst resource management (Harris and Williams 1975).

Too often speleologists expect that caves can and should be preserved at all costs. This approach contrasts with the reality that caving itself is a threat to the preservation of caves (Hamilton-Smith 1968; Davey 1976). Such an attitude also fails to acknowledge that our modern technological society (of which cavers, with their sophisticated equipment, are often spectacularly a part) depends

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on exploitation of material resources. Until our society undergoes fairly radical change, there will continue to be a need to commit karst resources to many different, and at times conflicting, uses.

Resource management is not the responsibility of speleologists, but rather, of governments and society in general; however, speleologists should be aware of the advantages and hazards of the process, and its potential for karst conservation. In most cases, it will first be necessary to see that an adequate resource management framework is established. Advocacy by speleologists for the application of such an approach is not in conflict with an activist conservation role so long as the different functions of government and conservationist are kept in mind (Clark 1974).

For karst, resource management would require a definition of use options in advance of conflict occurring between particular uses. The desired outcome is that resource use strategy which minimises such conflict. To take the most obvious of the conflicts which might arise in a karst context – that of quarrying – as an example, this approach would require a detailed knowledge of the distribution of suitable limestones, and of the alternative uses of the various resources. A decision then requires a knowledge of national priorities and values, so that the options which minimise conflict can be chosen. In this way it should be possible to direct prospective quarriers to limestone deposits which can be utilised with minimum conflict with other values. Compromise on both sides will clearly be necessary – the quarrier may have to accept a material which is not as close to his requirements as is available, and the conservationist may ultimately have to accept that some karst features will be disturbed.

This kind of process is already taking place. The best example, on a regional scale, is for the Mendip Hills area in the UK (Somerset County Council 1971 & 1973). The outcome is necessarily a compromise, but within the confines of historical, legal, and political contexts, it can be argued that even such a compromise is quite an achievement. An examination of alternatives is surely a better approach to compromise than political expediency alone.

Another of the conflicts which is amenable to resolution in this way is the separation in space of different forms of recreation. Recreation users with differing and conflicting resource requirements must inevitably compromise somewhat, but at least there might be a systematic framework for defining potential conflicts and settling on planning and management strategies which minimise that conflict. Technical inputs to this process can be defined fairly clearly; by survey techniques it is quite feasible to establish the physical limits of resources and to document features in particular places. What is difficult is the process of value judgement which must inevitably accompany the trade-off between various competing uses. My earlier preoccupation with ecosystems and the dynamics of karst is justified here because an awareness of the system nature of karst is essential to this value judgement phase; one cannot isolate particular features from their system context.

It should not be assumed that a resource management approach is necessarily capable of producing technically desirable outcomes. One must progress from each politically acceptable state to the next. Faced with this incremental characteristic of decision-making, even an ability to accommodate detailed resource and use analysis in the process is open to question (Libby 1974). Despite this, the value of resource management is as a systematic frame-work for identifying alternatives. Particularly when the choice is between preservation and development, conventional approaches to the optimal use of natural resources are not likely to succeed (Shefer 1974).

There are numerous problems associated with adoption of a resource management approach for karst conservation. In the case of resource analysis, it is clear that some progress has been made in Australia, but that there are some crucial deficiencies. We have only a very incomplete knowledge of the distribution of karst rocks, let alone sufficient information of their chemical and physical characteristics to permit a national assessment of their usefulness for various purposes. On the karst features side, however, the picture is a little more encouraging. Australian speleologists can be justly proud that this country is relatively advanced in the documentation of its karst features, and the ASF Handbook Commission, assisted by a grant under the National Estate Programme, has now developed methodologies which will aid in the provision of an authoritative input into resource management processes. Perhaps the major deficiency in knowledge of karst features is of the more specialised attributes of the resource – palaeontological and archaeological sites, for example. This problem highlights the need to ensure a degree of flexibility in decision-making which allows the incorporation of new specialist information as it arises, and the subsequent modification of resource use strategies. Even if we are ultimately in a position to reasonably assess the dimensions of our resources of karst features, we must still maintain a perspective relative to such resources internationally. The inescapable conclusion is that karst is relatively scarce in Australia (Jennings 1975).

By contrast, use analysis in the Australian karst situation is not nearly so far advanced. Of the various uses which exploit the materials of karst, the industries themselves have not as yet clearly defined their resource requirements even under specified economic and transport conditions. To take the cement industry as an example, it is clear that the industry is so market-based that the actual chemical and physical characteristics of the raw material are of secondary importance. This makes it rather hard for a government to conduct a predictive survey of suitable resources for that industry.

For the various uses which do not physically exploit karst – recreation, for example – use analysis is a more difficult task still, but I can report that we seem to be making some progress. The current National Heritage Assessment Study (Hamilton-Smith 1976 a & c), which like the documentation project referred to earlier is funded under the National Estate programme, will provide a much better basis than has hitherto been available for defining the values and preferences at least of speleologists and others with an interest in karst. The most serious deficiency remaining in the use analysis of karst is an understanding of the relative contribution this particular resource makes to the recreation, tourist, and conservation uses which are based on it in part only.

Having suggested some of the analytic tasks ahead, it remains to emphasise the subjective nature of the ultimate decision-making. With specialist advice, it is possible to define where some of the resource use options lie, but the decisions themselves remain subjective because they involve elements of social preference. Emotions, conflict, and demands are the substance of planning as a process of reconciling human preferences (Libby 1974). This subjectivity inevitably means that the process is political. There is, then, a responsibility on the part of specialists to respond to this political situation in a constructive fashion, and in a way relevant to the needs of the decision-making process (Jeffers 1973).

In most Australian situations, there is usually inadequate public involvement in resource management decision-making. As Weisbrod (1976) asserts, people who have been allowed to effectively participate in a decision are much more likly to accept the result, even if they don't completely agree with it. Because of this particular deficiency, a concentration on the substance and implications of environmental law at all levels of government is essential if every opportunity for influencing public preference (and amending the decision-making process) is to be exploited. And, as Clark (1974) points out, it is essential that conservationists learn and understand the processes and capacities of government. One deficiency here is that conservationists and others very frequently fail to respond early enough to opportunities to contribute information and opinion. In that sense at least, a major responsibility for bringing about active and deliberative management of karst resources by government lies with the speleologists themselves (Hamilton-Smith 1976 b).

Decision-making processes in resource management vary enormously (for a discussion emphasising public involvement, see Lassey and Ditwiler 1975). Political reality is that any given system will not necessarily fit well into a local political context without extensive modification (Clark 1974). Perhaps the most realistic way to achieve public involvement (in a favourable political climate) is to evolve several progressively refined proposals each of which is subject to comment and criticism. Governments must inevitably reserve the final say; politics is such that clearly defined technical solutions to resource conflicts will not necessarily be acceptable. At least a resource management approach enables options which may not otherwise have been considered to be given adequate assessment. That in itself is an achievement.

An aspect of the resource management decision-making process which is often overlooked is the need for it to be incorporated into the machinery of government. There are many examples of excellent inquiries which have produced wide-ranging and useful reports but which have not directly influenced government decisions, because they were not a formal part of the decision-making process. The Report of the National Estate (Committee of Inquiry into the National Estate, 1974), an innovative and tar-reaching document, almost certainly falls into this category. By contrast, the operations of the Land Conservation Council in Victoria *(Land Conservation Act,* 1970) are an example of a process which achieves political acceptance on account of its incorporation into the workings of government. The difference is that virtually every one of the recommendations made in the latter case are actually implemented; an important difference indeed.

It is rather doubtful that the various environmental impact procedures now emerging in some states can ever be a substitute for a wider approach to resource use planning. Bambrick (1975) points to the deficiences inherent in a system which requires a project to be well planned and fully documented before the environmental impact assessment procedures are capable of coping with it. The investment of entrepreneurial resources to take a project even to this stage often becomes a very powerful factor in pressure for development-oriented outcomes from the ultimate deliberations. A further problem is the difficulty of providing any systematic basis for isolating impact as a discrete phenomenon in the dynamic context of a karst system (Lapping 1975). Also, Weisbrod

(1976) suggests that environmental impact procedures have serious limitations in the assessment of values, as distinct from facts, and that adequate new techniques have yet to be applied.

It is depressing to note that little of what I have said here is new. Our most immediate task remains the education of the very people who have the most active interest in caves and karst – the speleologists. Then we must turn our attention to analysis of our karst resources and uses, and reform of decision-making processes to ensure reasonable consideration of all resource us options.

In the meantime, there must still be a readiness on the part of speleologists to fulfil an activist role in the conflicts over karst resources that will inevitably arise while there is no resource management basis for karst conservation.

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SOME USER IMPACTS ON CAVE ENVIRONMENTS AND THE CONCEPT OF A CAVE CARRYING CAPACITY AS A CENTRAL MANAGEMENT PRINCIPLE

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Abstract

Impact of human use of cave environments is considered in terms of flora and fauna, cave atmosphere and the physical and chemical conditions. Management principles are discussed and include the concept of a cave carrying capacity.

Introduction

I propose to do two things. Firstly, to make a quick review of the broad parameters of the human use impact on cave environments mostly in relation to cave tourism; and secondly, to speak about the concept of a cave carrying capacity as a central cave management principle.

1. Human Use Impact on Cave Environments

A review of the rather limited material available on user impact in the cave tourism situation suggests three broad areas where visitors may significantly disturb the natural parameters of the caves concerned. These are:

. disturbance of cave fauna,

. disturbance to the cave atmosphere including contamination by algae, and

. impact on physical and chemical conditions of caves.

Although each is considered separately it is important to remember that they are really interconnected. This should become evident as these are discussed.

Disturbance to Cave Fauna

Few studies have been carried out with respect to the whole range of cavernicoles (cave animals) and the impact that human visitation has on them. Those that have been made normally relate to the more obvious animals such as the bat.

Cave fauna have a precarious existence under natural conditions because they are completely dependent upon the surface for all food and because of the extremely low reproductive potential that adaptation to the cave environment entails. This means that cave animal life is extremely fragile and if disturbed cannot quickly recover. However, with the exception of bats, little is known of the actual impact of visitation, mainly because the need for monitoring this impact is only a recent phenomenon. As a result the principles upon which management of cavernicoles in general should be based have not yet been developed.

Bats are one of the most important means by which cave life is provided with food. At Blanchard Springs Caves in north central Arkansas, noticeable declines in the bat populations are expected as a result of recent development of this cave for visitation. This may have repercussions on the cave life that is dependent upon bats for food.

In the United States and Australia and also in Eastern Europe, bat populations have been given some protection through Federal and State government legislation. However, their supervision poses major administrative problems particularly when connected with caves in private ownership.

Studies of the bat's seasonal and daily behaviour suggests that visitation should be well away from them. Even the quiet tread of visitors over rocky cave surfaces has a highly disturbing effect on their hibernating. A more generally recognised effect of even slight disturbance – sound, lights

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and especially heat from lights – is to onset arousal, which inevitably continues to complete arousal and flight. Significant losses in body weight have been reported by studies in the U.S.A. and Canada due to disturbance of this nature. These disturbances can lead to a decline in the bat population of the cave affected if not their total departure from it.

Disturbance to Cave Atmosphere and Contamination by Algae

This form of visitor impact on the cave environment has received some study though mainly in connection with the growth of unsightly algae which has been reported from show cave locations all over the world.

Fodor (1965) recently argued that visitors to Dobsina Cave in Hungary have destroyed the natural equilibrium of its microclimate. He goes on to claim that this effect was increasingly apparent in many caves in Eastern Europe and should serve as a warning that careful monitoring of the changes induced by visitation on the microclimate of caves must be carried out since this was likely to help off-set the consequent diminished growth of decorations and unsightly algae.

The importance of cave atmosphere disturbance by visitation may also be closely connected with the growth of algae in show caves. This has been demonstrated by Lefevre and Laporte (1969) in their studies at Lascaux Cavern in France, famous for its paleolithic art. More recent examples of this have come from Spain.

The Lascaux Cavern, discovered in 1940, had by the late 1950's received more than 175,000 visitors per year. At certain periods, conditions became extremely uncomfortable in the cave. Subsequent analysis revealed increases in carbon dioxide, relative humidity and temperature. These together with the cave lighting provided suitable conditions for the development of algae mats on the cave walls, some of which had begun to creep over the cave paintings. The result of the studies indicated that algae were carried into the cave via visitors' footwear and that development for visitation had significantly altered the air circulation in the cave. This was the means by which the algae reached the cave walls from the visitors' shoes. The alteration of cave atmosphere parameters provided the right conditions for growth. As a result, the cave was closed to visitation, airlocks were installed together with elaborate air conditioning designed to maintain specified atmospheric conditions. Monitoring of temperature, relative humidity and carbon dioxide levels is continuous and visitation is strictly controlled and limited by a permit system.

Today the few visitors who are allowed must stand in a tray of disinfectant before entering the cave.

Studies on algae growth in show caves have been carried out in Eastern Europe, Britain and the United States.

These studies have indicated a relationship between the intensity of light, constant temperature and high relative humidity and the growth of algae mats. Two broad methods have been used to deal with the algae problem:

1. Preventive measures such as reducing the light intensity; chemical application of disinfectant to kill the algae on visitors' footwear before they enter the cave; minimising the operational periods of lighting; and providing only that light necessary to do the job.
2. Eliminating the existing mats by chemical means. Many methods have been adopted here, including steam cleaning and plain scrubbing with brush and water; however these methods are either ineffective or too expensive. The reduction of light intensity by shading and the use of U.V. – clear bulbs appear to provide successful control over algae and moss growths.

A final note on cave atmosphere concerns bats which require special microclimates for nursery colonies and for hibernation. Any human activity at either time may alter special wind, moisture and temperature conditions necessary for their activity and may either cause death in the colony or cause it to leave the cave. This highlights the important interaction between different biological and physical subsystems of a cave environment.

Impact on Physical and Chemical Conditions in Caves

Only a few references have been made about the impact of visitors on the physical and chemical aspects of limestone show caves. Problems concerning this have been raised in Britain, the United States and Europe. Most of the references are confined to the physical aspects of visitor impact. Physical damage has generally been defined in terms of litter, graffitti and the breaking, damage or removal of cave mineral decorations.

In a survey of damage to caves in Britain carried out by the National Caving Association (NCA), it was found that some 20% of all cave resources were either damaged, lost or vulnerable to this and in particular that show caves were probably less susceptible to certain forms of damage caused by graffitti, littering etc. However, at the same time, it considered that for the whole of Britain, over 40% of show caves were already severely damaged and that a further 15% were vulnerable to further damage.

Studies by Hill (1975), in the United States claimed that an unintentional form of physical and chemical damage resulted from the addition of lights, heat and visitors to the cave. The consequences included drying up or dessication of cave mineral decorations, development of algae mats and greying of surfaces through dust and lint particles brought in by visitors. These affect the mineral surfaces and destroy the natural crystalline exterior of mineral decorations. Confirmation of these general comments is provided by the cave management experiences of the United States National Park Service. Here developments in both the Carlsbad and Mammoth Show Caverns have brought about irrevocable changes to their physical and chemical character.

In Europe, and particularly Eastern Europe, Lavaur (1973) has argued that many tourist caves exhibit extreme degradation of their physical and chemical character. He claimed that, despite considerable management efforts, the general problems of visitor impact remained because management methods did not appear to be translatable from cave to cave and because all the theoretical elements of the processes operating in limestone caves and the impact of visitor developments on them were not understood.

Where damage to cave decorations and formations has been particularly acute, legislation has been resorted to, for example, the *Cave Protection Act* of West Virginia lays down heavy penalties for acts of vandalism, littering and the sale of cave mineral decorations. However, it is freely admitted that enforcement is difficult, particularly at caves in private ownership. In Austria, there is also protection against damage under the 'National Cave Law', which places all limestone caves, public or private, under strict control as National Monuments. In Britain some of its show caves have been classified as Sites of Special Scientific Interest (SSSI) by the Nature Conservancy.

But as the NCA report *Caves and Conservation* points out, the law is almost totally inadequate in so far as much of the damage is concerned.

Specific studies of some of the key variables thought to be responsible for damage to caves in general are scarce. In Britain, the NCA attempted to do this with respect to three key variables:

i. accessibility,
ii. degree of usage, and
iii. length of time over which the cave had been utilised.

When these variables were compared to the damage index based on a rating scale incorporating physical damage to decorations, littering and graffitti, a significant correlation was found between the degree of usage and the degree of damage. No significant associations could be demonstrated between accessibility and the length of time over which the cave had been open for use though it was suggested that there were some problems with measuring the length of time variable which may have affected the result. The inference to be drawn from this, however, is that if usage or visitation increases, then there will be continued damage to the caves concerned. This therefore raises the question of the methods by which damage can be controlled.

2. Cave Carrying Capacity

This concept has occupied the minds of some public recreation managers for a considerable time. If, however, it is accepted that the future of a limestone cave rests on balancing the use of visitation with that of conservation then the concept of a carrying capacity would seem to be equally relevant. The concept should therefore be a fundamental consideration in managing the flow and distribution of visitors to limestone caves.

Brotherton (1973) in some work connected with the Countryside Commission in England considered the concept of a carrying capacity to have four major dimensions. The first is the ecological capacity which he defines as the maximum level of use that a particular ecosystem can support without unacceptable change. This change is determined by visitor or management perception of the state of the site which itself is a function of the processes operating there, its management history and the cumulative effects of previous visitation.

Perceptual capacity is the next dimension considered by Brotherton and he defined this as a function of the degree of crowding at the site that an individual would accept. Brotherton suggested that different sites such as wilderness areas and urban fun-fairs have different tolerances for the same individuals. For example it could be argued that the crowding tolerance as measured by the level of use and the degree of satisfaction derived by users would be much lower at show caves than at urban fun-fairs. This is particularly relevant to show caves where the self-regulating character of perceptual capacity cannot operate as it does for beach, picnic and camping sites, where visitors can adjust their spatial position to what is comfortable for them.

The next dimension that Brotherton discusses is the economic one. This relates to situations of multi-purpose use such as cave inspections, kiosks, cafe, restaurant and accommodation provisions. The object is to obtain the maximum aggregate benefits from the combinations of these at the site. Finally, Brotherton considers a physical carrying capacity which is the relationship between usage and the facilities required to accommodate it. The predicted rate of demand and average turnover time per user are the main variables used in determining the physical capacity of a facility. From the points of view of management, Brotherton claims that the recreational carrying capacity of a site can be taken as either its ecological or perceptual capacity, whichever is the lower.

Material on 'cave carrying capacity' is extremely scarce. there is little evidence that the concept even in its physical sense as defined by Brotherton is utilised in private or public cave management. The cave carrying capacity is defined as the maximum number of people who in a given time frame can beneficially utilise the cave resources without causing any harm to them.

This concept is akin to Brotherton's ecological carrying capacity although researchers in the USA tended to emphasise more the physical characteristics of the resources such as cave decorations and formations. It has been suggested that the cave carrying capacity can be altered by changing to different management methods. For example the physical carrying capacity of Carlsbad Show Cavern operating under guided tours had been exceeded by 1952 when an average of nearly 3,000 persons per day were visiting the cave. With the introduction of self guided system coupled with adequate manpower to protect cave resources the carrying capacity of the cave has been increased considerably without apparently further increases in manpower and further reductions in quality. Capacities were determined and elevators were installed to operate so that now more than 1,100 persons per hour could be carried into the cave. How's that for solving your environmental problems. Details concerning the nature of the capacity so determined in the case of Carlsbad are not available and it is strongly suspected that it is really a physical capacity in the cave based on the number of interpretive units and the supervisory manpower to which the elevator capacity has been matched.

There is some question about the use of the concept of carrying capacity in cave management. The concept of a carrying capacity as applied to caves differs in two important ways from its normal conception. Firstly the concept was initially developed for paddock management, such as the number of sheep to the acre where the resource 'grass' was renewable. Here, if sheep began to eat the roots (or the non-renewable part of the grass resource) then the carrying capacity of that land would decline. In the case of caves, however, if not all of the resources are essentially non-renewable and, therefore, damage to these resources will continue even if the carrying capacity determined by whatever means, is not exceeded. Secondly, it can be argued that while in the paddock example where damage to the non-renewable resources decreases the carrying capacity, in the case of caves exactly the reverse happens. For example, the presence of rare cave mineral decorations would imply a low carrying capacity; if, however, these were to be destroyed by vandals, then the capacity of the cave would in fact be increased if the capacity is dependent upon the visitor perception of quality as Brotherton has suggested.

The rate and volume of visitation should be determined both by the physical, chemical and biological features of the cave and by the character of the user groups. This conception should incorporate the ecological and perceptual dimensions of the concept developed by Brotherton. One useful approach for management suggested in the available literature that also seemed more practical, was to determine which features of a cave were most sensitive to visitor use. The capacity of the cave could then be matched by this, thus avoiding some of the complicated procedures that have been suggested by others in determining capacity. This places great emphasis on the concept of a limiting factor in caves, an analogy which has been drawn from the silvicultural principles taught in forestry schools. This is that there are many factors which can affect tree growth but in any given situation there are seldom more than one or two factors which limit growth.

An attempt has been made by Brucker (1975) to provide a cave carrying capacity decision making model based on work carried out by Bross (1956). This model has four major components:

1. An alternative probability system which contains a list of factors pertaining to visitor de-

mand, staffing resources, budgets, cave resources as well as other limiting factors and alternatives to which probabilities may be assigned.

2. A value system which contains a list of values in order of importance for the situation, such as degree of visitor solitude, visual remoteness, minimal physical damage, minimal algae growth and contamination, safety, education and entertainment.
3. A decision criterion system which determines the choice of the best alternative based on the purpose of management e.g. conservation, visitor use, etc. All purposes must be listed.
4. Recommendations, which flow out from components 1 to 3.

Fig. 1 illustrates this model conceptually.

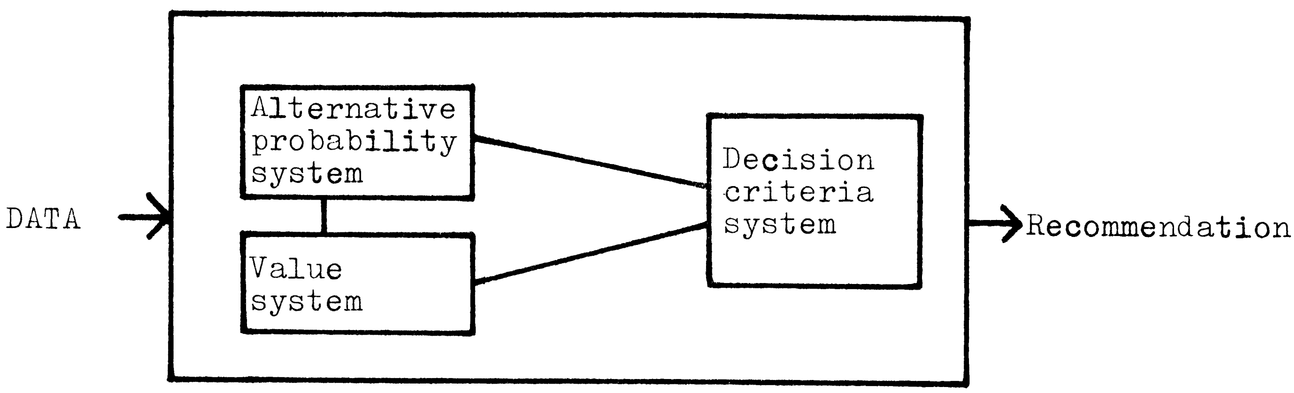

Fig. 1. Carrying capacity decision maker model. Source – Bross (1965).

The major problems with such models is that the necessary data pertaining to ecological and perceptual carrying capacity determination are not available. In addition to this the model requires clearly set objectives and awareness of values.

It would seem that if the idea that the cave resources needs to be protected from the impact of visitors is conceded, then since cave attractions concentrate visitor use, particularly where there are only one or two entrances, then the number of visitors that can be accommodated may not simply be a function of limited manpower, vehicle and cave space, but rather of a cave carrying capacity based on ecological and human perception principles.

If we are to realistically determine carrying capacities, we need a good understanding of cave features, and of the impacts of use upon these. Existing management agencies seldom have this type of knowledge or expertise, while those who have cave expertise typically lack experience in management. There is therefore a great need for the two groups to come together.

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POLLUTION OF MOONS CAVE, BUCHAN, VICTORIA: A CASE STUDY IN CAVE RESERVE MANAGEMENT

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Abstract

Moons Cave is a former tourist cave in the main reserve at Buchan. It is downstream of the camping area; effluent from toilet and shower blocks flows through the cave. This paper summarises the history and management of the Buchan Caves Reserves, and describes investigations into this and other management problems. Legal and practical aspects of reservation, management, pollution control and cave protection are discussed.

Introduction

This paper describes pollution of Moons Cave (B2) in the Buchan Caves Reserve. This is only one aspect of a whole range of management problems which are evident. These problems are not new or unique and many relate to management decisions made in the past. They are noticeable now due to the increasing numbers of people utilizing the Reserve. Development decisions and expenditure in recent years have been directed largely towards rewiring the caves and to various camping amenities. However, past decisions which did not take into account the particular properties of limestone and cave processes are proving to have shortcomings. With this in mind we will discuss the history of cave discovery and subsequent reservation of Cave Reserves as background to current problems.

History of Cave Discovery and Reservations

The caves of Buchan were probably known (to the white man) from the earliest days of settlement in the 1830s. The first geological map appeared in 1866 (Taylor), and a few years later Howitt was able to describe the geology of the area in some detail, with general reference to the numerous surface karst features and caves (Howitt 1876). The value of these caves must have been recognised from the outset, for by 1889 there were reserves at Spring Creek, Wilsons Cave and Dicksons Cave. It was realised not only that the caves had tourist potential, but that they were of considerable scientific importance as well (Stirling 1889).

Unfortunately, this early awareness of the value of the caves was not matched by adequate management; Ferguson (1898) reported that vandalism had extensively damaged some of the caves. A few years later, Dunn (1907) described extensive vandalism to Spring Creek Cave, and concluded that any new caves should be properly protected and developed; scrupulously preserving them from vandalism from the outset.

Just after the turn of the century, a fairly comprehensive survey of the cave areas was undertaken, and a considerable expansion in the area and number of cave reserves was recommended (Kitson 1907). This included the reservation of a considerable area of unoccupied Crown land as well as the conversion of several existing reserves (two of them mining reserves!) to cave reserves, and the excision of several areas from land already selected for agriculture.

Kitson clearly envisaged that the Buchan area would be of considerable interest to tourists:

> "The known limestome caves of considerable extent are so rare in Victoria that it is very desirable to retain for the Crown all areas where there is any reasonable probability of discovering caves, expecially when remembering the great number of tourists who annually visit the Jenolan (Fish River), Yarrangobilly, Wombeyan, Wellington, and other caves in NSW, and the Chudleigh caves in Tasmania."

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To its credit, the government accepted the recommendations, and a series of seven areas around the district were reserved "for public purposes, and the protection of natural features." These included Buchan, The Potholes, The Pyramids, Murrindal, Dicksons Cave, Wilsons Cave, and Slocombes Cave. Unfortunately, there has been little change in the area reserved in the seventy years since, and more recent discoveries have located numerous substantial and important caves which are not within any reserve. A summary of the reserves as they now stand is contained in the table (appendix 1).

Not long after gazettal of the main Buchan Caves Reserve, Frank Moon was appointed caretaker. In the next few years he was to discover and explore some of the most important caves in the reserve: Moons Cave, B2 (September 1906); Kitsons Cave, B8 (December 1906); as reported by Thorn (1907) and Teichert and Talent (1958).

Moons Cave was evidently popular with early visitors. As Heath (1907) described it:

> "The Moon Cave is hardly less beautiful than the Kitson, and certainly more accessible, with the exception of the part known as "Across the Creek." In this creek there is a fair flow of water, and at the crossing-place, which leads to some of the most beautiful portions of the cave, is the pool where the sightless fish may be seen; also eels which look suspiciously like small, black snakes, and make one dubious of making the necessary plunge through this icy-cold water waist high. This, especially if you have a camera under one arm and clothes under the other, dodging the hanging stalactites and stepping occasionally on a loose stone on the shingly bed of the creek, is rather an experience.
>
> After again donning one's clothes there is a torturous crawl, after the manner of the serpent, through what looks like an impossible opening leading through to the "Fairy Chamber." The spectacle amply rewards the difficulties in reaching this beautiful chamber. Here one can comfortably stand erect and admire the sparkling jewel-like effect of the tiny stalactites encrusted onto the roof of the cave, gradually getting larger as they extend to the side where they taper down in long candle-like formation. Beyond this again the creek is lost in a fissure where the stalactites hang down in a Medusa-like formation almost touching the water, which reflects them with mirror-like clearness, when the light of the acetylene lamp is brought to bear on them."

Moons Cave was developed for use as a tourist show cave and was open for a number of years, but it was over-shadowed by the Royal and Fairy Caves, and its use eventually discontinued.

Moons Cave has been considerably vandalised over the years. Decoration has been broken and sampled by indiscriminant visitors and has also been muddied. The steps and railings have been allowed to deteriorate. In recent years a gate was installed by the Victorian Speleological Association (VSA) but this has been broken. Nevertheless, the cave entrance is situated in a quite impressive bluff known as Spion Kopje around which visitors can walk.

Reserve Tenure and Management

The land comprising the various reserves is "permanently reserved" under Section 14 of the *Land Act* 1958 and earlier equivalents. This is as secure a form of tenure as it is possible to provide in Victoria, in that it requires an Act of parliament to revoke or amend a reserve.

Under the *Mines Act* 1958, reserves of this kind are exempted from mining, but the Minister for Lands has the power to allow exploration. This is quite a reasonable provision; it allows research into mineral resources, but would require a specific act of parliament to allow mining. However, under the *Extractive Industries Act* 1966, there is no exemption of reserves from quarrying for limestone. (Limestone is not a "mineral" under the *Mines Act;* rather, it is covered by the provisions of the *Extractive Industries Act* with respect to quarrying of building stone, sand, gravel, aggregate etc.) The consent of the Minister of Lands is required before an extractive industry lease can be granted on a reserve.

Nevertheless, this situation could lead to considerable conflict. Worse still, the public involvement provisions in the decision-making processes of the *Extractive Industries Act* (and, for that matter, the *Mines Act*) are so inadequate that the public may not ever find out about quarrying proposals until they are already a reality. As far as conservation goes, Victoria's earth resources legislation is (still) something of a disaster.

Despite all this, the provisions of the *Land Act* are a reasonably effective vehicle for deliberative land management. At Buchan, this management has, in the past, been far from enlightened, or particularly active, but there are now many encouraging signs. Despite the shortcomings in the commitment of resources to the management task, at least the framework is there; the Act has teeth.

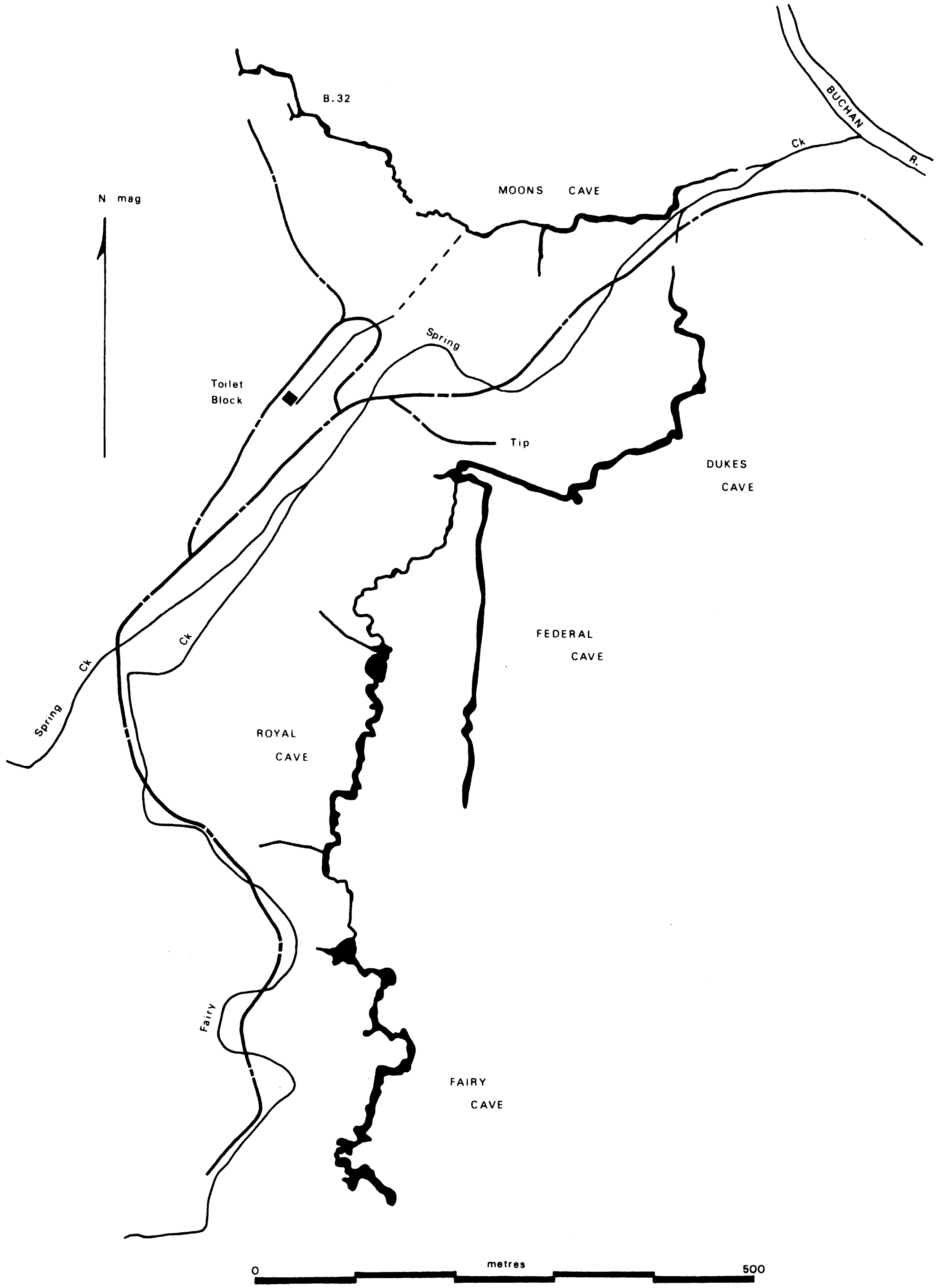

Fig. 1. Plan of the Main Buchan Caves Reserve

At present the reserve is directly administered by the Department of Crown Lands and Survey, with a resident Superintendent responsible for the day-to-day management. An Advisory Committee (chaired by the Deputy Secretary for Lands, and comprised of representatives of the Departments of Tourism, Public Works and Mines) assists with reserve planning and development.

Caves Pollution

Moons Cave pollution problems were first noticed in the late sixties when it was claimed the cave stream smelt and appeared as if it had raw sewage in it. (Anon. 1969a and b) The first attempt to prove this was in 1969 when a methylene blue dye reduction test was attempted. This test was inconclusive due to technical problems. In 1974 further tests were carried out. These relied on differential bacteria counts at 22°C and 37°C and coliform differentiation using McConky Agar Medium. Once again, the results were inconclusive but for different reasons. Certainly faecal coliforms were found but the pattern was not interpretable as both Moons Cave and Dukes Cave water had high counts whereas the Buchan River was clear. Both caves have bat colonies and the testing was not such that it could differentiate the source. The finding that Dukes Cave water had high counts was inexplicable at the time and remains so. This highlights the problem of bacteriological water testing; valid and conclusive testing relies on the facilities of a water testing laboratory with qualified personnel.

In the January and February 1975 tourist season another series of samples was taken and this time they were analysed by a microbiologist at the University of Melbourne. These conclusively showed human type 1 *Escherishia coli* in the outflow from the septic tank and high coliform counts in Moons Cave waters.

This finding was confirmed by subsequent fluorescein tracing carried out by Adrian Davey and Rudy Frank which connected the septic tank outflow and a sidestream which enters the main stream in the upstream section of Moons Cave.

We viewed these findings with considerable concern. The cave is part of an important and significant system within the Reserve. Such pollution made it an unpleasant, if not unhealthy, cave to be in. At various times of the year the cave is inhabited by bats (*Miniopterus schreibersii*). The effect of human faecal pollution on the bats is unknown. Further, the cave efflux runs into Spring Creek within the Caves Reserve and then into the Buchan River within the township area.

The findings were then made known to the Committee of Management in which we outlined the problem, and whilst not insisting that they rectify the problem immediately, we suggested a series of official water sampling tests at times of high and low usage of the reserve. These tests have confirmed our findings and plans are now being drawn up to modify facilities.

It should be noted that pollution control in Victoria is achieved by the issue of a waste discharge licence under the *Environment Protection Act,* 1970. The requirements of the Act bind the Crown and there is an obligation by the Lands Department as manager of the Reserve, not only to obtain a waste discharge licence for its facilities, but to undertake appropriate alterations so that the licence conditions and standards are met. The Environment Protection Authority, in consultation with the Health Department and other agencies sets the effluent standards which are the basis for the licence conditions. The existence of this system is providing added impetus to the controlling of pollution in situations like this.

One of the other aspects of this case was that the superintendent found that the septic tank had not been adequately maintained by the contractor and all the baffles had rotted away. These have now been replaced. It is not known how much this contributed to the pollution. However the system was not designed for the numbers of people now using the Reserve. Cave visitors numbered 53 000 in 1968, 66 000 in 1972 and have exceeded 100 000 in each of the past two years.

The Public Works Department is now drawing up plans to treat the effluent from all the toilet and shower blocks in the Reserve. A sewage treatment plant is not a viable proposition due to the very seasonal nature of the load and what is proposed is a pumping station and treatment of the effluent in lagoons. This work will be expensive but is fully warranted and will be a wise investment in the long term.

Other Management Problems

Apart from the pollution problem described above, there are other management problems, some of which are mentioned below.

For many years garbage from the reserve has been disposed of in a sinkhole on the hill above and between Dukes and Royal Caves. Over the years it has been pointed out to the various superintendents that this was an undesirable practice. During 1976 VSA has resumed exploration in Dukes Cave and passed the rockfall and connected Dukes Cave and Federal Cave which in turn is connected to Royal Cave. Frank Moon recorded this connection 60 or 70 years ago but there has been little systematic exploration since this time and there was also rockfall which blocked the connection. Federal Cave entrance was bricked up a few years ago as a result of the gate being broken and some vandalism. This entrance was opened up this year to assess the cave for reopening as a tourist cave. About this time a strong smell of burning rubbish began to be encountered in the tourist section of Royal Cave where the Federal Cave connection comes in. This was of immediate concern and Federal Cave was bricked up again and VSA was asked to see if they encountered any such smells in the new sections of Dukes Cave. Nothing could be detected and it cannot be concluded that our exploration or sump lowering activities have changed the cave breathing pattern to cause these unpleasant smells. The best explanation is that the smell was entering via some of the tiny holes in the vicinity of Federal Cave and then wafting through to Royal Cave. The upshot of all this is that the tip in the doline will be covered with dirt and the management will purchase a garbage truck which will then take rubbish to the shire tip.

The shire tip is also an anachronism in terms of karst management as it is on the headwaters of Fairy Creek which flows into Spring Creek in the Reserve and must be connected to the stream in the Tourist Cave Complex although we have not demonstrated this. The Reserve Management may yet regret the siting of this shire tip.

Other management problems associated with the Reserve relate to vandalism in the caves. VSA has installed gates on Spring Creek Cave, Moons Cave, Dukes Cave and Root Cave at the request of the Reserve Management. Both the Spring Creek Cave and the Moons Cave gates have been broken. Despite bans on unauthorised caving in the Reserve, and despite active management supervision, uncontrolled caving still exists. The decision to gate Root Cave was a negative approach to a management problem. This cave has an entrance which overlooks a medium sized rockfall chamber. Tourists had worn a track up to it and the cave was being used as a repository for soft drink cans and the like. Instead of gating the cave an alternative approach would have been to use the entrance balcony as a self-guided feature. With a minimum of expenditure, a signposted track, a hand rail balcony at the entrance and tourist-operated floodlights could have been installed. This would have been more in keeping with the obvious need for further interpretive and educational facilities within the Reserve.

Summary and Conclusions

We have written in considerable detail about the history and reservation of the caves of the Buchan area in order that the background of management can be looked at as a whole. We have described direct management problems within the Buchan Caves Reserve which demonstrate a lack of understanding of karst resources. We have indicated that the framework for deliberative management of the reserve is generally found, and given the allocation of sufficient management resources, has considerable potential for solving these and other problems.

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APPENDIX 1

RESERVES IN THE BUCHAN DISTRICT

Reserve	Area	Location	Feature	Comments
Main Buchan Caves Reserve	289 ha	In the Buchan township	Principal tourist caves, several disused tourist caves, and numerous other caves; some interesting surface karst features; vegetation on limestone cleared but reserve includes extensive remnant of bushland on volcanics; Spring Creek Falls; camping area.	Caves area and camping park actively managed and extensively developed. Numerous inadequacies; heavy visitor pressure.
Wilsons Cave	Approx. 8 ha	East Buchan adjoining road	One well-known spacious cave extensively damaged; minor cliffs; mainly cleared with some regeneration.	Not managed; extensively vandalised; noxious weeds.
Slocombes Cave	3.6 ha.	The Basin, on a good track west of the main road.	One extensive cave; cleared land; a few dolines.	Not managed; damage to cave not too extensive.
The 18 Acre Reserve	7.3 ha	The Potholes adjoining main road.	Numerous dolines and potholes; relatively undisturbed bushland.	Not managed; periodically burned and grazed; rubbish, vegetation. Landscape and caves are particularly important.
Part Allotment 22A	2.4 ha	"	Numerous dolines and potholes, cleared.	Not managed; grazed; some caves heavily visited and deteriorating.
The Pyramids	35 ha	Murrindal River 1 km walk or drive across paddocks from main road.	Cliffs, pinnacles, caves, numerous surface karst features; important palaeontological sites; good remnant jungle and forest on limestone; spectacular and interesting views.	Not managed; grazed, damage by rockhounds; surface vegetation, landscape, and to a lesser extent, the caves, are particularly important.
Murrindal	3.2 ha	Murrindal adjoining main road	Murrindal and Lilly Pilly tourist caves; several other caves; some original vegetation.	Limited management – main caves protected, part developed, and used for occasional tourist parties. Numerous inadequaces; considerable tourist potential.
Dicksons Caves	1 ha	Between the Potholes and Murrindal close to main road.	Two well-known and easily accessible caves; cleared.	Not managed; extensively damaged; rubbish.

MOUNT ETNA CONSERVATION

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Abstract

The Mount Etna, Limestone Ridge and Karst Glen karst areas in Central Queensland contain more than 150 known caves. Many of the caves in the Mount Etna area are threatened by quarrying operations. A brief history of a fifteen year old conservation conflict is given with special emphasis on interpretation of government and public responses to tactics used. In particular, attention is focused on the local response to a land use plan developed for the Mount Etna region and on the Queensland Government's response to an economic report stating that mining at Mount Etna is uneconomic.

Introduction

The Mount Etna region, just north of Rockhampton on the Central Queensland coast, consists of three karstic areas:

1. Mount Etna contains 46 documented caves on its northern face and is perhaps the most densely cavernous area in Australia.
2. Limestone Ridge contains over 80 documented caves including Johannsens Cave which is the seventh longest known cave in Australia.
3. Karst Glen with 26 documented caves.

The region, which is relatively small, has a history of limestone and guano mining, the latter dating back to early this century. Mining has now ceased on Limestone Ridge and all mining leases on this area have been relinquished, pending gazettal of a national park covering a major portion of the Ridge.

Unfortunately the Limestone Ridge national park proposal has been used as an excuse by the Queensland Government to justify continued mining of mount Etna, possibly leading to its eventual destruction. Such action is wrong as major bat colonies occur in Mount Etna caves including the Bat Cleft maternity cave which is critical for the survival of an estimated 300,000 Little Bent-winged Bats *(Miniopterus australis)*. Also an important portion of the region's population of the extremely rare Ghost Bat† *(Macroderma gigas)* uses caves at Mount Etna as maternity sites. The Ghost Bat is currently being studied by John Toop under a grant from the federal Department of Environment, Housing and Community Development.

Mount Etna's northern face and a major portion of Limestone Ridge are covered with a rare semi-evergreen vine thicket broken by well developed karren-fields often of spectacular proportions. The vine thickets are believed to be crucial for the foraging flights of young bats.

For a more detailed survey of the resources of the Mount Etna region see Sprent (1970) and Hamilton-Smith and Champion (1976).

History

A detailed history and interpretation of the Mount Etna conflict was presented at a previous ASF conference (Brown 1975). I refer you to that paper and to Sprent (1970) and Hamilton-Smith and Champion (1976) for further information.

Important facets of Mount Etna's history are summarized below:

1. Mount Etna was gazetted as a Recreation Reserve in 1920. The spirit and perhaps the letter of

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† The Ghost Bat is currently under consideration for inclusion in the official endangered species list. The application is expected to be successful.

this gazettal have been breached by the granting of limestone mining leases to the Central Queensland Cement Company and to others.

2. In 1968 a Queensland Government interdepartmental inquiry, which included representatives from the Mines Department, recommended that 31 acres on the cavernous face of Mount Etna be gazetted as a national park. Little, if any, effort was made to implement the recommendations of this inquiry.

3. Limestone mining leases were granted over large limestone deposits at Bracewell south of Rockhampton early in 1976. A geological report of the limestone deposits in the Central Queensland region prepared for the University of Queensland Speleological Society (UQSS) suggests that alternative limestone deposits to Bracewell, and indeed to Mount Etna, may exist. The significance of the Bracewell deposits will become apparent below.

Economic Report

The Capricorn Conservation Council applied for and received a $2000 federal Department of the Environment grant for the preparation of "An Economic Study of the Queensland Cement Industry" by Mr J. Ware, Lecturer in Political Economy at Griffith University, and by Dr M.M. Metwally, Reader in Economics at the University of Queensland. The report, released late in 1976, revolves around a new large-scale clinker plant to be constructed at Gladstone, 100 km south of Rockhampton, to be supplied with limestone mined at Bracewell. Clinker will be shipped to the Bulwer Island (Brisbane) plant where the clinker will be crushed and made into cement. The new operations are owned by Queensland Cement and Lime Company or its subsidiaries. Currently the central Queensland region is supplied with cement produced at Rockhampton from limestone mined at Mount Etna, these operations being under the control of Central Queensland Cement Company. Due to the economies of scale in cement production the proposed Gladstone plant, which will optimally produce two million tonnes per year, will be able to produce cement at a much lower price than the Rockhampton plant which optimally produces only 200,000 tonnes per year. This means that the

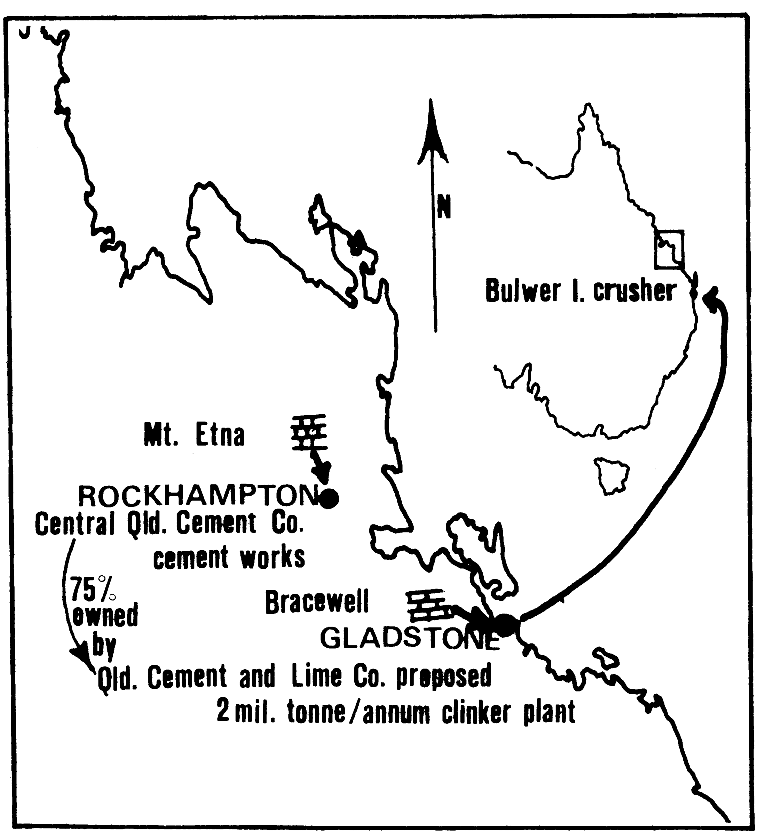

Fig. 1. The Central Queensland Cement Industry.

Rockhampton plant will not be economically viable once the Gladstone plant becomes operational. Even with the Gladstone plant operating below capacity it is estimated that it will be able to produce cement $7.00 per tonne cheaper than the Rockhampton plant.

But the story goes deeper than that. The economic report has also revealed a monopoly in the Queensland cement industry. Central Queensland Cement Company, operator of the Mount Etna-Rockhampton plants, is 75% owned by Queensland Cement and Lime Company, which will operate the Bracewell-Gladstone plants. This means that the Rockhampton cement production complex need not be forced to close by economic pressure as capital can flow into Central Queensland Cement Company from its owners, the major one being the Queensland Cement and Lime Company.

Central Queensland Cement Company has made public statements that it will not close down its operations and that the proposed Gladstone plant will have no effect on its operations. In fact the Company may be planning to close down after the Gladstone plant begins production but it has made the above statements for several possible reasons:

1. To maintain confidence, in a financial sense, in their company (so that the Company need not close prematurely).
2. To avoid any outcry from employees if they were to learn that they would lose their jobs in a few years.

At this stage it is still impossible to predict what the Company is planning.

Neither the Mines Department nor the Company, in my opinion, have been able to deny, satisfactorily, the conclusions of the economic report. After the Queensland Mines Minister (Mr Camm) was sent a copy of the report he replied . . . "Any decision on the future of operations by Central Queensland Cement Pty. Ltd. on economic grounds is, of course, a matter for that Company. In the meantime, I must reiterate that it is this Government's policy to allow the Company to continue its operations at Mount Etna in terms of its legal entitlements on those mining leases granted to it." (Even the Company's entitlements are questionable.) In other words, he is saying that the Mines Department's only interest in the issue now is to protect the leases which it originally granted irrespective of the damage such mining is causing.

The Bracewell leases cover many farms in the district and the outcry from the landowners developed into quite a controversy when they learnt of the lease proposals. Of course the leases were granted just the same. The Mines Department has attempted to turn the farmers against the Mount Etna cause by saying that we want to see mining go ahead at Bracewell so that Mount Etna can be saved. This is untrue. In fact UQSS has objected to mining at Bracewell because of the social disruption it will cause. We have pointed out that any decision to mine limestone at Bracewell is the responsibility of the Queensland Government and the Company. If mining at Bracewell and cement production at Gladstone are allowed to go ahead then there is no reason why mining at Mount Etna and cement production at Rockhampton should continue.

The publicity given to the economic report and the fact that State Parliamentarians were petitioned three times during 1976 has placed considerable pressure on the Company and the Mines Department. The pressure will hopefully work to our advantage.

Mount Etna and the Caves

Fifteen years of conservation activity at Mount Etna by UQSS has seen the accumulation of files several feet thick and the production of many publications including two books. The first was *Mount Etna Caves,* edited by J.K. Sprent, published in 1970. The second book was produced in response to a need for a more updated and integrated approach to survey the resources of the Mount Etna complex. The book, entitled *Mount Etna and The Caves,* was written by professional planning consultants Mr Elery Hamilton-Smith and Mr Randall Champion. The study was financed by a $9500 National Estate grant and was published at the expense of UQSS early in 1976.

The logical and organized nature of the study culminated, at the end of the book, in a set of proposals for the development of the Mount Etna karst region for recreational purposes. This included suggestions for park boundaries, management proposals, recognition of fragile sites and even went to the extent of proposing walking paths, picnic areas and scenic drives.

The book was a very valuable addition to our campaign and indeed was the first time we have had a well organized set of proposals for the protection of the area. We can now place the onus back on the Queensland Government to investigate these proposals.

However one small section of the book created more interest than anticipated. This section is only several pages long and covers acquisition of land for park purposes. A huge stir appeared in the Rockhampton press over the mention of compulsory acquisition of freehold land. I will make it clear that the study did not recommend compulsory acquisition but mere mention of these words caused a hypersensitive reaction amongst landholders involved.

The emotional arguments of these landholders struck a strong chord in the local community. At one stage it was estimated that 50% of the landholders involved were against the proposals presented in the book. As the issue developed it also became apparent that some of the landholders opposing the proposals were on-side with the Company. This would seriously question the motives of these people.

After several months of bitter struggling over the issue, opposition died out or at least went underground. Eventually I think that the book came out on top and it has been pointed out that the publicity given to the incident probably did us a world of good. However at one stage it was touch and go whether we could successfully fight the opposition and, at one stage, one of the landholders involved threatened and then actually bulldozed vine thicket on his property so that his land would no longer be worth incorporation in the proposed park.

In a letter to a local paper one Rockhampton resident aptly pointed out that the Company was the one doing the damage and that fighting amongst ourselves could only work to the advantage of the Company in the long run. The despoiling of the local landscape should have been more of a threat to local landholders than a set of park proposals.

In any event, the issue has highlighted a possible problem area and the lesson learnt will be of value should a similar study be undertaken in the future.

As a closing remark I would like to mention that now that the Texas Caves have been lost (flooded late 1976) caves are even scarcer in Queensland and hence the decision to allow continued mining of Mount Etna is even more irresponsible.

Acknowledgements

Thanks are due to Jeff Simmons of the Central Queensland Speleological Society and to the Capricorn Conservation Council for their untiring efforts in the campaign to save Mount Etna. In particular, thanks are due to Lex Brown of UQSS for the assistance that he has given me over the past year.

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CONSERVATIONISTS – AND THEIR BLIND SPOTS

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Abstract

Society has moved towards a situation of increasing uncertainty about the future – the turbulent environment. Although this presents problems to conservationists, it is argued that it may also provide a positive opportunity for action. A number of issues concerning the strategy of conservationists are discussed:

* *the suggestion that conservationists should distinguish themselves from preservationists is rejected,*
* *conservationists should pay attention to the long-run implications of present events,*
* *although development interests may have much greater power resources than conservationist movements, the uncertainty of the future will render them much less willing to invest in projects which may invite conflict,*
* *more attention must be paid to developing wide public support, or to not alienating existing public support, and to clear statements of conservationist issues,*
* *in developing one's case, it is vital to see the overall picture of any area or feature, to not under-rate public attitudes and values, and to think in ecosystem terms rather than single feature terms.*

Introduction

This paper seeks to indicate ways in which conservstionists might achieve greater impact upon decisionmaking than they do at the present time. Before entering into the major issues of the paper, it may be useful to outline my rationale for deciding to write on this topic at the present moment.

The conservation movement has enjoyed a great deal of limelight and even some success over the last several years. Governmental funds have been made available on a relatively generous scale for both governmental action and in grants to non-governmental bodies concerned with conservation. There has been a generally sympathetic attitude to conservation by the Australian and some state governments.

This situation has perhaps lulled some conservationists into a false sense of well-being, and has perhaps dulled the drive and energy of others.

However, the situation has now changed drastically. Not only have funds been severely reduced, but there is now a considerable back-lash against conservationist trends being voiced throughout the community. Governments are forced to hear this backlash, and there are many indications that they are heeding it when making decisions.

Perhaps I should stress that I do not see this merely as a result of change of government at federal level. I believe that much of this would have happened even if the 1975 change of government had not occurred. The impact upon conservationist movements might have been a little more moderate, but it would have been significant.

Partly, as a result of these economic and political pressures, governmental policies have vacillated, and the term "stop-go policies" has become familiar. Critics of government describe this as irresponsibility; governments describe it as necessary flexibility. Irrespective of one's perspective, the conservationist, with his inevitable commitment to the long-range view, to planned use of resources and to a notional state of equilibrium finds this a disturbing phenomenon and one which is difficult to handle.

Again, I suggest that we are likely to continue in this apparently unstable economic, social and political environment for some time. Futurologists do not agree about very much, but they do generally agree that:

* society will become increasingly varied and complex
* there will be increasing change of all kinds
* it will become increasingly difficult to make forecasts of any kind.

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In simple words, society is moving towards increasing uncertainty – or to what has been labelled the "turbulent environment". Attempts to develop new patterns of social organization to cope with this emerging environment have mainly followed three major lines:–

- decentralization of authority and control
- decreasing specialization and segmentation
- more open systems of planning and decision-making.[1]

The conservationist today is therefore facing an uncertain future, which by its very nature will be somewhat antithetical to his basic commitments. At this point in time, he is not only doing so from a relatively powerless position (as always), but one which is particularly vulnerable.

Conservationist or Preservationist?

A popular bit of rhetoric which strikes me as a dangerous one, particularly when conservationists themselves really believe it, goes something like this:

> *"Conservation is to do with the balanced use of resources; we are therefore going to be reasonable at all times and see the other viewpoint as well as our own; we recognise and accept the need for compromise; we are not nasty negative people like those we label preservationists".*

Obviously, there is some truth in this statement. After all, it is often heard from the Hydro-Electric Commission of Tasmania, mining interests, the timber industry, building developers and a multitude of others. All those people cannot be wrong.

Unfortunately, it also clouds the real issue. Conservation-oriented decisions grow out of two circumstances – either something is of no conceivable economic value, e.g., the Simpson Desert National Park, or there has been a resolution of conflict. It is not the responsibility of the conservation activist to start from a compromise position, but rather to unashamedly start from a preservationist stance, leaving compromise to others as much as possible. Conservation interests are almost inevitably in conflict with development's interests. We should not be ashamed of seeking to *preserve* elements of our natural environment, nor frightened of adopting an extremist position. In our own field of interest, caves are a non-renewable resource – each compromise which removed a cave reduces our resource stock for all time.

At this stage I am not discussing strategies, but only our basic position. In practice, strategies will have to be developed quite separately for each situation, but they will be strengthened if we are sure of our basic position. Naturally, we will have to accept compromise at times, because one principle of our kind of government and society is that nobody wins every round. But one sure way to lose every round is to start from a compromise position.

Good Management and Wicked Plots

Many development interests are playing for high stakes in major projects. This leads to three important factors:

- development interests employ very highly skilled negotiators who really understand power and negotiation.
- major projects demand a long "lead-time" and considerable planning, e.g., the decisions necessary for the introduction of the STD telephone system to Australia were all made by 1960; the legislative basis for introducing the wood-chip industry to Victoria was laid down in 1961.
- this, in turn, means that the turbulent environment creates big problems for the development interests even more than for conservationist interests.

Development interests are often accused of hatching plots in secrecy, and of only announcing plans when it is too late to fight effectively against them.[2] I suggest this is an over-simplification. It is often more a question of the long lead-times involved and the lack of community awareness at the time. Few conservationists could foresee at the time the implications of the Victorian Forests (Wood Pulp Agreement) Act of 1961, and still fewer members of the general public could have been stirred at that time.

In this context, it therefore concerns me deeply that the purchase of freehold land in the Buchan area by mining interests commenced over six years ago.[3] The crunch will probably come within the next ten years, and as yet, there are too few signs of our preparedness for action in this area.

However, although the odds are against us in terms of resources for planning and negotiation, I would argue the stakes are weighted in our favour. Development interests cannot afford to lose too heavily; future uncertainty presses very heavily upon them, and the risks inherent in over-investment in a project facing conflict with conservationist interests can be extreme.

Basically, therefore, there are two potential blind spots in this situation:

* We fail to perceive the significant long-run implications of present events, and hence may well find ourselves acting too late.
* We may also fail to recognise the extent to which future uncertainty may, in fact, represent a source of power to the conservationist movement.

A Power Base for Conservation

It has often been said that a statesman is concerned primarily with the good of his country, while a politician is concerned primarily with the next election. Even though some politicians may cause us to wonder whether they are motivated by either, the fact is

(a) that it is probably a reasonably accurate statement; and

(b) Western countries are governed by politicians.

In other words, the power of the conservation movement is largely dependent upon the extent to which governments see conservation issues as likely to concern a significant number of voters.

There is, in fact, considerable research evidence to show that legislators are more likely to vote in agreement with what they perceive is the attitude of their electors than on the basis of their personal preference and belief. This is influenced by a few other factors, for instance, a parliamentarian from an uncertain seat is less likely to be influenced by the official party line than one from a safe seat. Similarly the greater the division of community opinion, the more likely it is that the parliamentarian will adhere to the party line.[4]

Without going into too much detail on the social science research evidence, let me try to summarize its practical implications. It is vital to convince decision-makers that our interests are held and/or supported by a large number of citizens. It is important to not only communicate this but to communicate a clear perception of the issue under consideration – in other words, arguments for conservation are much more likely to succeed if they are put in simple clear terms. There is also extremely good evidence that an image of respectability is much more successful than a more radical stance and that the capacity to form alliances with other interests can contribute immensely to one's success.

A specific practical example of general failure in conservation has been the conservationists insistence upon the pure wilderness concept. I am personally convinced that this has alienated community support because the conservation message comes across as one of excluding people – no one wants to be excluded.

There is a strong community support for conservation in general and for wilderness. This is demonstrated quite clearly in the relevant research in Australia, e.g., Rinkis[5] and McKenry[6]. The latter asked a sample of the Victorian population their opinions regarding a number of statements and his results include the following:

59% of Victorians disagreed with the statement:
"We have sufficient national parks to meet our needs".

76% disagreed with the statement:
"Too much emphasis is placed on preservation of the environment".

95% agreed with the statement:
"We have a duty to our grandchildren to preserve some areas as nature created".

80% disagreed with the statement:
"The preservation of wilderness is a waste of time".

These are merely some examples of opinions expressed. The overwhelming impression from the research evidence is that the general population are very positive towards conservation and even positive towards the wilderness concept.

McKenry's respondents saw wilderness as being valuable, inspiring, challenging, beautiful, exciting, good, unspoiled, unique, restful, free and natural. Very few saw wilderness in negative terms. However, only 18% saw it as being roadless and when asked the location of their last visit to a wilderness area, the majority mentioned locations which would not be considered wilderness by most conservationists. All this leads me to the position that we have very great potential public support for wilderness preservation but that support could very easily be reduced by campaigning too hard for exclusion of motor vehicles. I believe that in making exclusion part of the conservationists campaign we are confusing objectives and management. The major fight surely is about objectives and the management fight can follow upon that.

Unfortunately it is not just in alienating general public support that conservationists encounter problems with their own lack of understanding power issues. Far too many conservation organizations have torn themselves apart or made themselves impotent by endless wrangle between themselves which, in turn, has been communicated to the public and the decision-makers.

Again, too much of this has grown out of a concern with detail rather than with simple principles.

Defining One's Case:

This now leads to some of the issues and problems associated with defining what it is for which one should fight. It seems to me this has been perhaps the greatest difficulty for many conservation campaigns. There are simple practical reasons why this is so, yet if we are genuine about conservation we must overcome these inherent problems. Let me simply outline a few of these problems:

1. There is all too often a lack of time to see the overall picture. Without any discredit to the remarkable campaign fought for Mt Etna and the surrounding area by Queensland speleologists, part of the problem of this campaign was that after a long and agonising drive from Brisbane, there is little time to do other than focus on the caves which were the object of the visit. In the course of our own studies there last year[7] we found very few speleologists who had visited the remarkable series of rimstone pools in one of the efflux creeks, the summit of Mount Etna with its splendid panoramic view of the region, the forest on the southern face of Mount Etna, or a number of other features which make this a very attractive and valuable area.

   This is very much a lack of time problem, but it is also a matter of close identification with our own specific interest, i.e., caves, and a lack of appreciation of some of those features which might appeal to other members of the public.

2. A strong identification with one's own cause and interest may well blind one either to other people's perception or to an objective test of priorities. I find it very odd that in spite of the immense concern and campaign for South Western Tasmania, virtually never a voice is raised about the potential loss of the central plateau area – an environment probably even more unique in the southern hemisphere than the South West. I know I am leaving myself open to furious attacks from lovers of the South West but I am sure that my point is a very important one. Moreover, similar examples could be cited all around Australia.

3. One of the very strange aspects of this when one turns to speleology is the extent to which conservation thinking is focused upon beautiful decoration and not upon other features. I am well aware this is not universally true but it happens all too often. I believe that at least on some occasions this under-rates the intelligence of the general public. We fall into this kind of campaign because we feel the public will identify with it. Yet I am certain that the millions of Australians who have visited show caves now realize that lots of caves have pretty decoration, it is not at all unusual or unique, and that there may be some other things of far greater value.

4. It is all too easy to think of one specific feature, e.g., a single cave, and forget the extent to which that is part of a wider system. Single feature thinking has been responsible for literally thousands of tiny reserves around Australia upon each of which a piece of rock, a cave or some other natural feature is now left in glorious isolation from the wider system of which it was part. This is a mistake we cannot afford to go on repeating. Obviously it is a mistake of decision-makers but those of us concerned with conservation should not reinforce this pattern or lead to its further repetition.

In summary, this particular group of problems can lead to poorly developed or wrongly directed campaigns. At the worst it may well lead us to neglect and even sacrifice features which are of greater value than those which we are fighting to save.

Notes and References

1 This discussion has been based upon the very useful summary in *Telecom 2000* (Australian Telecommunications Commission, 1975) pp. 44-55.

2 There is sometimes a real foundation for this belief. See for instance, *The Future of Lake Pedder* (Report of Lake Pedder Committee of Enquiry, reprinted by Lake Pedder Action Committee, 1973, p.12).

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CAVES AND ABORIGINAL MAN IN TASMANIA

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Abstract

The survival of archaeological evidence in Tasmania owes much to the suitable preservational environment found in shelter caves and, to a much lesser extent, in limestone caves. Cave art is almost unknown although hand stencils have been recorded. Recent work suggests that they may be the work of mainland aborigines. Extensive excavations of ancient sea caves at Rocky Cape have revealed an occupation history of some 8,000 years, while excavation of Cave Bay Cave on Hunter Island has yielded an archaeological record dating back nearly 23,000 years. Archaeological evidence from limestone caves is also increasing. In 1975, following the exploration of Beginners Luck Cave, investigations of bone deposits led to the discovery of an underground archaeological site. Dating of charcoal from the site has provided the first clear evidence of the presence of Aboriginal Man in the interior of Tasmania during the last ice age.

The survival of archaeological evidence in Tasmania owes much to the suitable preservational environment found in shelter caves and to a much lesser extent in limestone caves.

Cave painting was not characteristic of the Tasmanian aborigines although there are some historical references indicating that they painted on bark (Stockton 1976). The only cave art recorded consists of a number of hand impressions outlined in red ochre and found in two sandstone shelters in the Derwent Valley near Hamilton. The first shelter was reported by De Teliga and Bryden (1958) and has since been flooded by the Hydro-Electric Commission's Meadowbank Dam water storage. A second shelter in the same area (Meg's Mit Rock Shelter) has been reported recently by Stockton (1975, 1976) who states that "the paintings consist of three clear but faded hands stencilled in red ochre and several indecipherable lines in yellow, while on other parts of the walls of the cave red ochre marks are found, mostly in the form of irregular blobs". Examination of some three hundred other rock shelters in the area adjacent to the site has yielded no recognisable paintings although in some cases blobs of red ochre were found adhering to the walls.

The hand stencils appear to be identical to those found throughout mainland Australia. Jim Stockton has suggested that the stencils may be of post-European contact origin as a group of aborigines were brought from the Sydney area in the 1830's and used in an attempt to hunt down and capture the local natives. Hand stencils are prolific in sandstone caves in the Sydney region. It is quite feasible that Meg's Mit Rock Shelter was used as a camp by the mainland visitors as they are known to have spent some time in the general area.

The Rocky Cape Caves are ancient raised sea caves eroded in Precambrian quartzites. Several of them contain stratified archaeological deposits and two caves on the eastern side of the cape – North Cave and South Cave – have been excavated by Rhys Jones in 1964-65 (Jones 1968, 1971, 1975). He found that in both caves some three metres of midden deposit had accumulated. Aboriginal occupation began about 8000 years ago as the rising postglacial sea began to approach its present level. In North Cave at least, intermittent occupation continued until the time of European settlement. In South Cave progressive infilling gave rise to a room problem and the cave was abandoned about 3,500 years ago.

In early 1967 three children were exploring in South Cave when they discovered an additional chamber ('The Enclosed Chamber'). This enclosed chamber preserves a 'living floor' which was last occupied about 6,700 years ago after which time access was effectively prevented by the growing accumulation of shells in front of the entrance. The floor of the chamber revealed a number of small circular hearths, heaps of discarded shell, pieces of rock, bones and human faeces. Even some fragments of vegetable material had survived. Under the sloping roof, in a crevice at one end of the chamber, two pounding stones were found – one still in position on top of the other. The walls and roof of the chamber were stained by smoke and soot. The discovery was a highly significant one and caused considerable excitement at the time.

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The 8,000 years of archaeological record at Rocky Cape has yielded evidence of interesting changes in the nature of the coastal economy of the area. According to Jones (1975) it saw "the slow but steady attrition of the importance of seal which declined from contributing 95% down to 45% of the non-shellfish meat at opposite ends of the sequence, and the sudden disappearance of fish from the diet 3,500 years ago, a situation which persisted into historical times and for which only a cultural reason can be given".

Bone tools are found throughout the earlier part of the sequence but for unknown reasons their use was abandoned about 3,500 years ago. The sequence of stone implements shows an increasing emphasis on the use of exotic materials for the manufacture of tools – some of the raw material having come from as far as 80 km away from the site.

Of outstanding significance in recognizing the antiquity of Man in Tasmania has been the excavation of Cave Bay Cave on Hunter Island off the north-west coast of the state by Sandra Bowdler of the Australian National University (Bowdler 1974a,b, 1975).

The main period of Pleistocene occupation of Cave Bay Cave was between 23,000 and 18,000 years ago with an isolated hearth dated at 15,500 years BP. During this time the last Ice Age was still in full swing and sea level was much lower than it is today. Hunter Island was not then an island but connected to Tasmania which itself had a land connection with the Australian mainland. At that time the site would have looked out across extensive plains instead of the waters of Bass Strait as it does today.

After the island had been cut off by the rising sea it was still visited by the aborigines from time to time using bark canoes. Holocene shell middens which overlie the older Pleistocene deposits have been dated at approximately 2,500, 4,000 and 7,000 years ago (Bowdler, pers comm).

The Pleistocene deposits have yielded significant amounts of bone materials – both mammals and birds are represented. Well made and beautifully finished bone points have also been recovered. Some of the mammals recorded from the deposits are no longer present on Hunter Island but are still found on the Tasmanian mainland to the south. None of the bones belong to extinct species despite the considerable age of the lower layers of the deposit. This is all the more curious since a non-archaeological cave bone site, recently excavated by Peter Murray and the author near Montagu in northwestern Tasmania, has yielded remains of no less than six extinct species (Murray and Goede, in press). The site appears to be significantly younger than the basal deposits at the Cave Bay Cave site on the evidence available so far. This raises interesting questions about the relationships between early Man and many extinct Pleistocene marsupials (Jones 1968).

Another reason for the importance of the Cave Bay Cave site is that it is the first cave in Tasmania from which a pollen stratigraphy has been obtained (Hope, pers comm). This has given valuable information about the vegetation at the time when early Man was living in the area.

Archaeological evidence from limestone caves is limited but increasing. Gill (1968) recorded a bone implement from a cave fill, exposed in a limestone quarry at Flowery Gully. Unfortunately no stratigraphic information on this site has been recorded. Carbon 14 dating of the deposit was carried out on a mixed sample of bone and charcoal and suggested an age of some 7,000 years. However, bone is a notoriously unreliable material for carbon 14 dating and often yields a date significantly younger than the true age.

In 1975, following the exploration of Beginners Luck Cave in the Florentine Valley, investigations of bone deposits by Peter Murray and the author have led to the discovery of an underground archaeological site (Goede and Murray, in press). Finds included one probable bone point and four stone artifacts (Plates 1 and 2) associated with charcoal and charred bone fragments as well as spirally fractured and butcher-marked bones. The bone material identified belongs to eight species of mammals and two of birds. Figure 1 shows an interpretation of the evolutionary sequence of cave development and depositional phases that appears to have occurred at the site.

Carbon 14 dating of the associated charcoal has provided a date of 12,600 $\pm$ 200 years. This is the first clear evidence of the presence of Aboriginal Man in the interior of Tasmania during the last ice age. The find is of considerable significance since it had been widely believed that during late glacial times the interior of Tasmania was inhospitable and probably uninhabited (Jones 1968, Davies 1974).

Recent evidence from pollen profiles (Macphail 1975) indicates that Tasmanian vegetation in late glacial times was much more open than it is today. It now appears that the broad valleys of the interior of Southern Tasmania were much more accessible to Man at that time than they have been ever since and probably contained a more varied fauna. The present day natural vegetation of the Florentine Valley is a dense wet sclerophyll forest poor in animal life. There is no evidence that the area was visited by the aborigines at any time during the Holocene. Late Pleistocene excursions

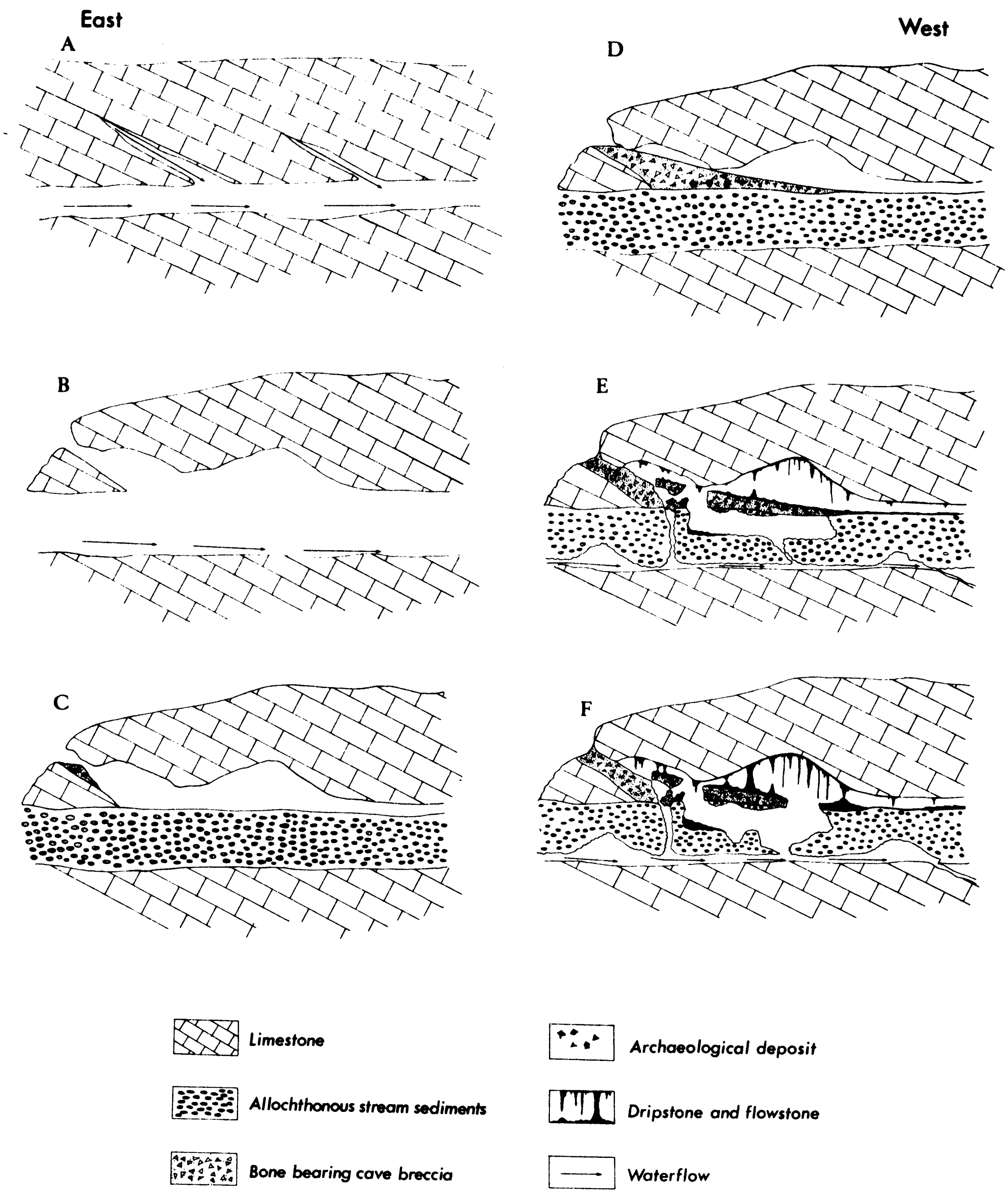


Fig. 1. An interpretation of the evolutionary sequence of cave development and depositional phases at site P, Beginners Luck Cave, Florentine Valley.

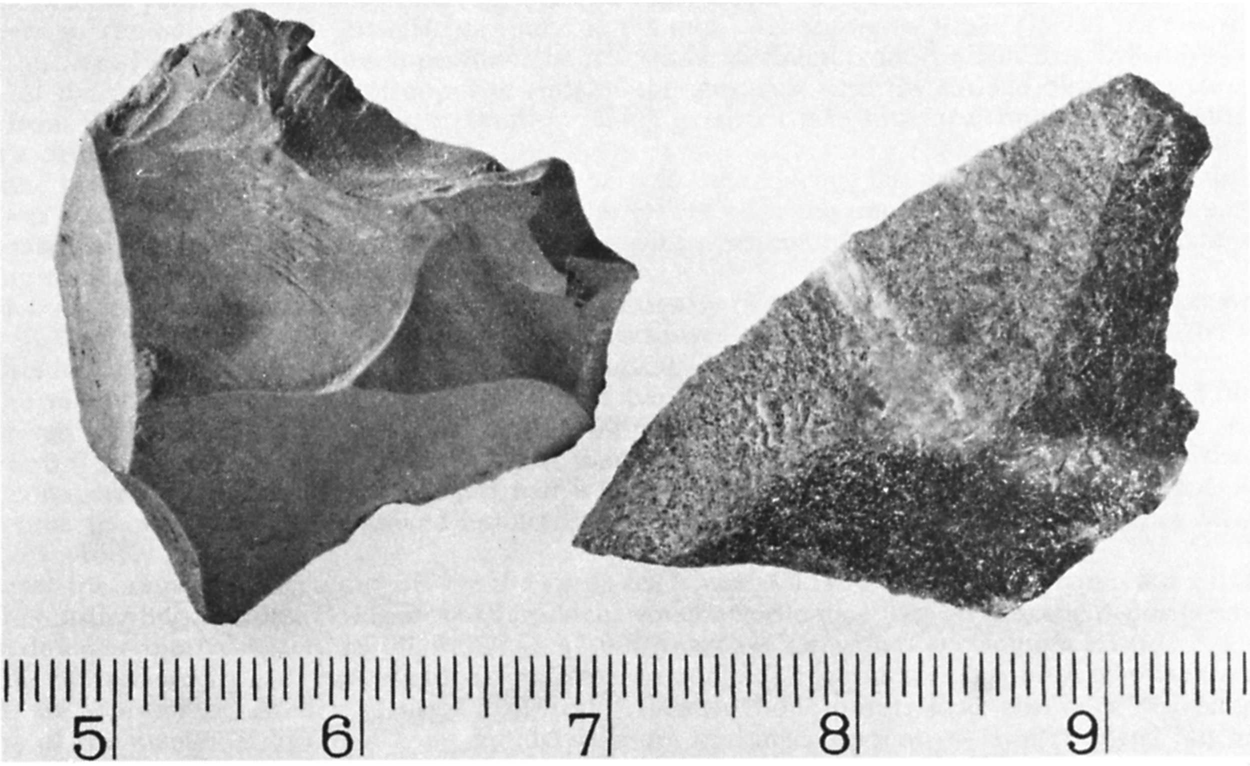
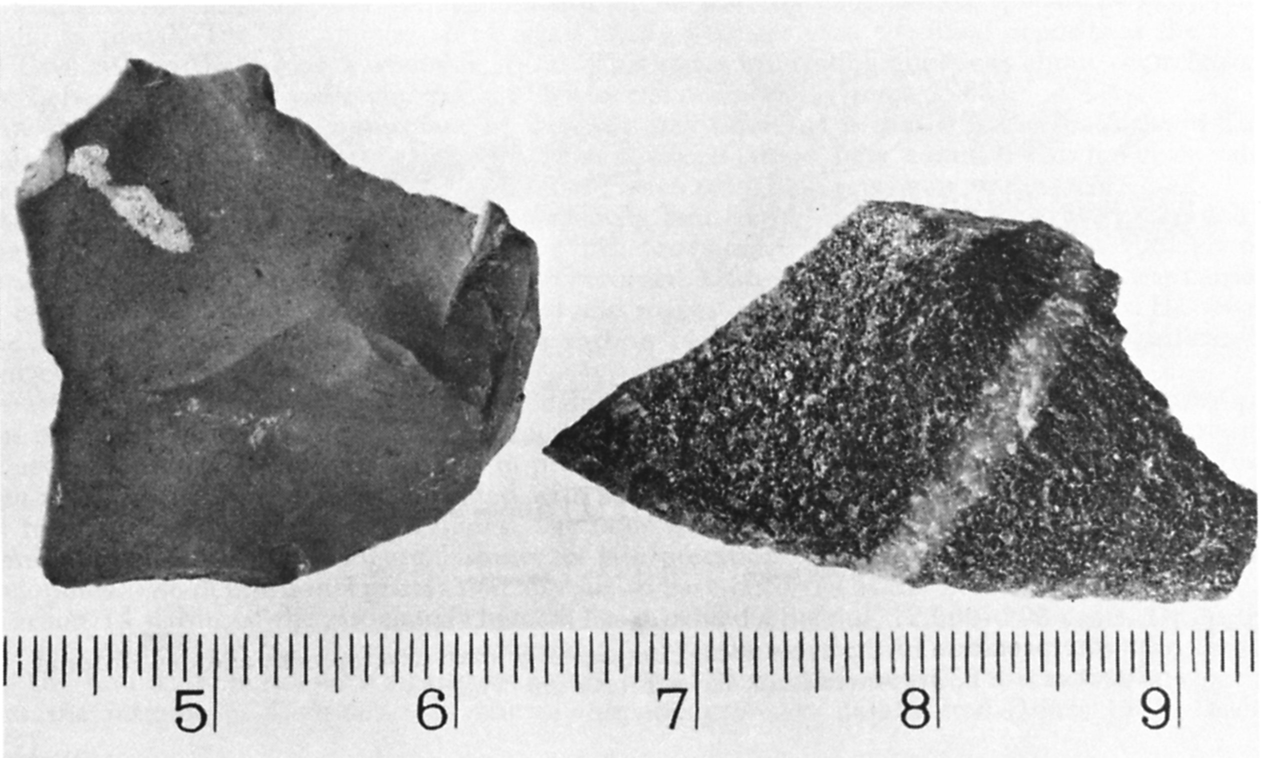


Plate 1



Plates 1 & 2. Two of the Pleistocene stone artifacts recovered from site P in Beginners Luck Cave, Florentine Valley.

inland were probably made by small hunting parties making use of spells of fine weather during the summer months.

A particularly interesting discovery supporting this idea was made when bird bones recovered from the Beginners Luck archaeological site were identified by Jerry van Tets of the CSIRO Division of Wildlife Research (Van Tets, in prep.). They included two bones belonging to the Sooty Shearwater *(Puffinus griseus),* popularly known as a mutton bird. Van Tets believes that the most likely explanation for its presence is that it was picked up on the coast by Man and carried to the cave as food, or the bones may have been used as ornaments.

The discovery of the Beginners Luck site suggests the possibility that archaeological sites may be found in limestone caves in other inland areas in Western Tasmania despite the fact that such areas do not appear to have been occupied and exploited by Aboriginal Man since the Pleistocene.

Speleologists in Tasmania can be of considerable assistance in adding to our archaeological evidence from caves by reporting the presence of bones, charcoal and artifacts in cave deposits. However, such evidence should *never* be removed from a site by amateur cavers since the position of archaeological material within the deposit and the nature of the sediments surrounding such material can yield information of archaeological value.

Exploration of sea caves could also be very rewarding as it is becoming clear that most of our larger sea caves, whether active or abandoned, predate the last ice age. Many of them would have been located considerable distances inland during the times of low sea levels associated with cold climate conditions. Some would have provided suitable shelter for Aboriginal Man. Where sedimentary deposits are exposed in such caves they should be closely inspected for the presence of archaeological material.

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STRUCTURE AND FUNCTION WITHIN THE TWILIGHT ZONE

GLENN D. CAMPBELL*

ABSTRACT

The twilight zone of a cave, while showing a microclimate intermediate between the surface environment and the cave aphotic zone, often has its own characteristic fauna. Thus, this zone becomes an ecological entity and can be described in relation to its structure and function. The basic ecophysiological factors of light, temperature, humidity and wind direct or influence the biological activity within this zone. A comparison can be made between the faunas of the surface, cave twilight zone, and cave aphotic zone based on responses to these factors.

Introduction

In addition to studies in other areas of the world, recent investigations into the ecology of Australian cave animals by Harris (1973) on the bent-winged bat guano ecosystem, and Richards (1971b) on the cave ecosystems of the Nullarbor Plain, have focused attention on the importance of surface and cave environmental conditions in governing the distribution and abundance of cave fauna. While Poulson and White (1969) have alluded to the stability of cave climate and the simplicity of cave communities, Harris (1970) emphasizes the complexities of the cave environment.

Because of the reality of these complexities, it is often convenient to divide a cave into zones, to study each one separately, and then to investigate their interrelationships. Instead of using combinations of varying environmental conditions, zonation should be based on a single, biologically significant, measurable, and recurrent environmental factor, and then the fluctuations of other factors should be qualified individually for each cave (Graham 1967). When using light as the deciding parameter, one can conveniently divide the cave into 3 basic zones:–

1. Entrance Zone – While being more similar to a 2-dimensional plane than a 3-dimensional zone, this region is exposed to the immediate light conditions of the surface.
2. Twilight zone – This region of the cave displays a reduced light intensity compared to the surface in a physiologically detectable range – above 10^{-7} lux (Kenagy 1976) – at sometime during a 24-hour period.
3. Aphotic zone – This is the region of constant darkness. The boundary between the twilight and aphotic zones would be determined for any 24-hour period at the maximum extent of the photic tide.

Twilight Zone

The twilight zone exhibits temporal and spatial differences of temperature, humidity and air movements, as well as light. These variations will be intermediate in extent between the great fluctuation on the surface and the relative stability of deep sections of the aphotic zone. In regards to the fauna, Culver and Poulson (1970) have characterized this zone as an ecotone – a transition between two or more diverse communities. The twilight zone complies with the definition of an ecotonal community by containing many of the organisms of each of the overlapping communities, in addition to organisms which are characteristic of, and often restricted to, the ecotone. The number of species is often greater in an ecotone than in the communities on either side, and the twilight ecotone is no exception. The specific faunal elements present in the twilight zone may be of 3 types:–

1. Surface forms – Many surface forms are adequately pre-adapted in utilizing this zone as a continuation of their normal range of ecological tolerances.
2. Aphotic forms – The deep cave's contribution would be troglophiles and troglobites of the familiar Schiner-Racovitza classification of cavernicoles (see Hamilton-Smith (1971) for discussion on cavernicole classification). Periodically, the environmental conditions of the apho-

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tic zone will extend towards the entrance and, as a result, cave restricted species may be found in the twilight zone.

3. Twilight forms – The majority of the animals found in the twilight zone will be those forms that are distinctly its own. Animals belonging to the cavernicolous classifications of trogloxene and troglophile will be present, along with other animals which are difficult to categorize under the Schiner-Racovitza scheme.

Hamilton-Smith (1971) acknowledges that the twilight zone is a complex ecological domain and chooses to separate the threshold dwellers from the cavernicolous classification scheme until there is a "satisfactory overall conceptual framework" for their study. I propose in this paper a physiological approach to the study of twilight animals that should contribute to the initial development of such a framework. The physiological nature of the animals commonly found in the twilight zone will be reflective of the microclimatological structure and fluctuation of the zone. Graham (1967) suggests that the microclimate alone is not sufficient to define the biological role of a species of animal, because of the added dimensions of movement and activity. It is my contention that the daily and seasonal extremes of the twilight microclimate will dictate both temporally and spatially the movement and activity of the animals in this zone. As a result, the twilight zone becomes an ecological entity.

The following will be a cursory look at the basic general ecophysiological factors of the twilight zone, and a review of the demonstrated physiological responses of the animals that frequent the zone in comparison with the corresponding responses of surface and aphotic zone dwellers. It is hoped that such an approach to the study of cave animals will find application in the current analysis of Australian cave ecosystem and cave animal evolution.

Ecophysiological Factors

1. Light

Within any particular cave, the light intensity of the twilight zone will vary daily and seasonally depending upon the angle of the sun, cloud cover, and the state of vegetation about the cave mouth. In addition to these factors, the amount of light that enters a cave will depend upon the static factors of the cave's orientation, number and dimensions of openings, and internal cave morphology. There is an exponential decay in light intensity as one progresses into the twilight zone from the entrance. The low light intensity and resulting low diurnal variation is attractive to many photonegative animals. By being photonegative, the animals that normally reside in the twilight zone can utilize both the food supply of surface environments during nocturnal foraging and the security of the twilight zone during resting periods.

Light is considered the most important environmental cue used by animals to synchronize their activity periods (Aschoff 1960). With only low intensity diurnal variation experienced by twilight zone dwellers, emphasis is on a highly entrained circadian rhythm that initiates movement under constant darkness or extremely low light conditions. If the animal is sensitive only to high thresholds of light, synchronization can occur only during the day at the entrance during light sampling as demonstrated in bats (Twente 1955). At the entrance to a forest cave, multiple peaks and drops in light intensity may occur during the day due to vegetation cover. Thus, sampling of light in this situation might give a false indication of surface crepuscular conditions. In forest caves, an alternative would be an entrained rhythm sensitive to the lowest thresholds of light only at night, while ignoring extraneous stimuli which are delivered at inappropriate times.

Surface animals have a wide range of reactions to light and can show photopositive and photonegative responses. Photopositive surface animals might venture into a cave during foraging periods during the day, or in search of a secluded resting area at night. A photonegative surface animal could be directed into a cave as a result of its normal response away from light. For those surface animals in which an endogenous circadian rhythm (internally synchronized) has been demonstrated, it is characteristically highly entrained and maintained under constant conditions for periods slightly different than 24 hours.

For an aphotic zone dwelling animal that is geographically likely to venture onto the surface, a photonegative response is selectively advantageous. But along with the morphological regression of eyes, some aphotic animals have either lost their physiological response to light altogether, or at least their reactions are much less pronounced than twilight zone relatives. Likewise, the endogenous circadian rhythm of some aphotic dwellers has undergone regressive evolutionary changes and aperiodic activity is evident (Barr 1968). Even in those aphotic animals that would occasionally venture into the twilight region of the cave, the advantage of a well entrained circadian rhythm would be of no selective advantage due to the rhythm's characteristic deviation from 24-hour periods. Thus, for those aphotic animals in which a rhythm is demonstrated, it is likely to be only weakly entrained and not persist under constant conditions.

2. Temperature

Temperature within the twilight zone often varies directly with the surface temperature. But, as seen in Fig. 1, temperature fluctuations in the twilight zone become extremely reduced as compared to the surface variations. In caves with multiple entrances, extreme temperature variations are evident in the aphotic zone due to stream and air currents. Vertical thermal gradients are often established in the twilight area of caves with the formation of hot and cold air traps dependent upon the number of openings, tunnel morphology, and tunnel inclination. In the remote calm areas of a cave, the temperature will be stable at the approximate annual mean temperature for the surface locality. But even in these calm areas, Harris (1973) has demonstrated that biological factors may induce cave temperatures to fluctuate. He showed that cave air temperatures will fluctuate more than 10°C over a year in the nursery caves of the bent-winged bat due to their occupancy and departures.

Twilight animals reflect the same basic preferences and tolerances with respect to temperature as surface forms. There are two basic alternatives for adaptation to extreme temperatures – morphological and behavioural. Morphological adaptation would involve the development of mechanisms that would allow the animal to tolerate broad ranges of temperatures. A behavioural adaptation would emphasize detection of temperature extremes and co-ordination of activity with respect to the narrow favourable limits of temperature. Even though the daily and seasonal temperature fluctuations in the twilight zone are greatly reduced compared to the surface, twilight animals are potentially susceptible to lethal extremes because of their feeding tie with the surface. Thus, morphological and/or behavioural adaptations would have a selective advantage.

Mechanisms for perceiving environmental variability and for surviving in extreme conditions, as illustrated by narrow preferences and high tolerances to temperature, would be of little selective advantage for those animals that are geographically isolated in a stable environment. It is not surprising that certain aphotic zone dwellers (e.g., cavernicolous marine relics) have lost these responses in the interest of energy conservation (Elliott and Mitchell 1973). Other aphotic animals that have the potential for moving to the surface have retained their acute detection responses as mechanisms restricting them to their subterranean environment (Bull and Mitchell 1972, Mitchell 1968).

2. Humidity

As opposed to temperature, relative humidity within the twilight zone does not often vary directly with the surface fluctuation. For a small cave without a true aphotic zone (Fig. 1) the general fluctuation of humidity can follow the surface variation, but multiple peaks in humidity may occur throughout the day as a result of surface wind deflections through humid cracks. Fig 2 shows that the humidity fluctuation in the twilight zone of a larger cave can lose all synchronization with the surface due to cave airflow reversals. Prediction of surface humidities by twilight animals is complicated by occasional wind direction changes, and as a result, activity rhythms are not normally synchronized with humidity levels.

While surface forms show the same flexibility in dealing with humidity variation as with temperature, twilight zone dwellers characteristically show a very narrow preference range around the saturation point, and show low tolerance to subsaturated air, as reflected by high water loss, in dry air flow. Water loss is determined by temperature and humidity (i.e., saturation deficit) in combination with airflow. Those cryptic animals that lack the morphological adaptations to preclude water loss are attracted to areas of water infiltration, condensation, and high atmospheric moisture which are commonly found in caves.

Humidity preference and detection strategies of aphotic dwellers will reflect the generalizations made concerning temperature responses. The variation in humidity-discriminating abilities of aphotic animals centers on what range the particular species has the potential to experience and the selective advantage of its perception.

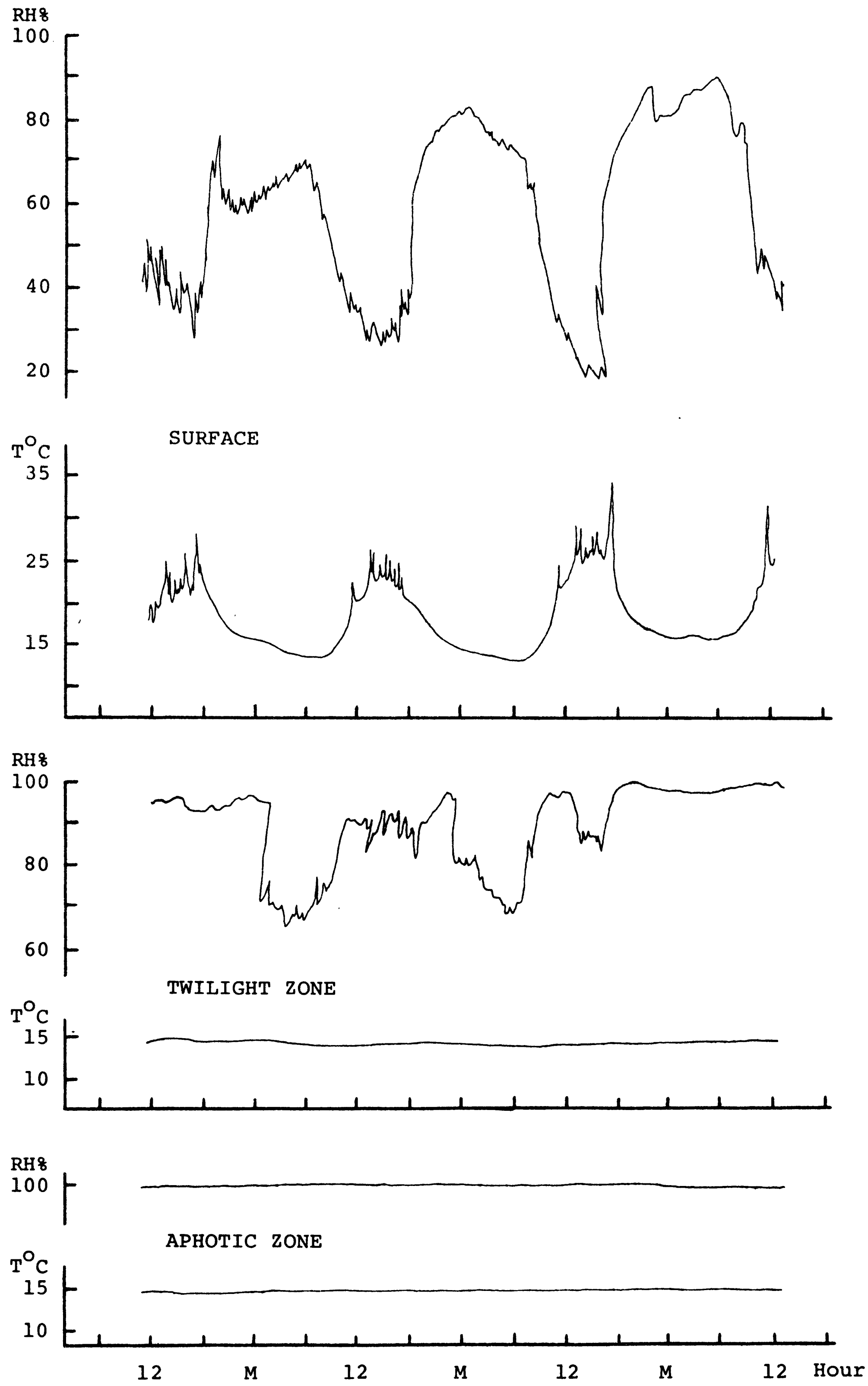

Fig. 1. Relative humidity and temperature fluctuations of the surface and twilight zone of Pipeline Cave, Tibooburra, NSW, from 30 March to 2 April 1976. The first thermohygrograph was placed in front of entrance overhang; the second placed 7 m into cave. An aphotic zone was absent in this cave.

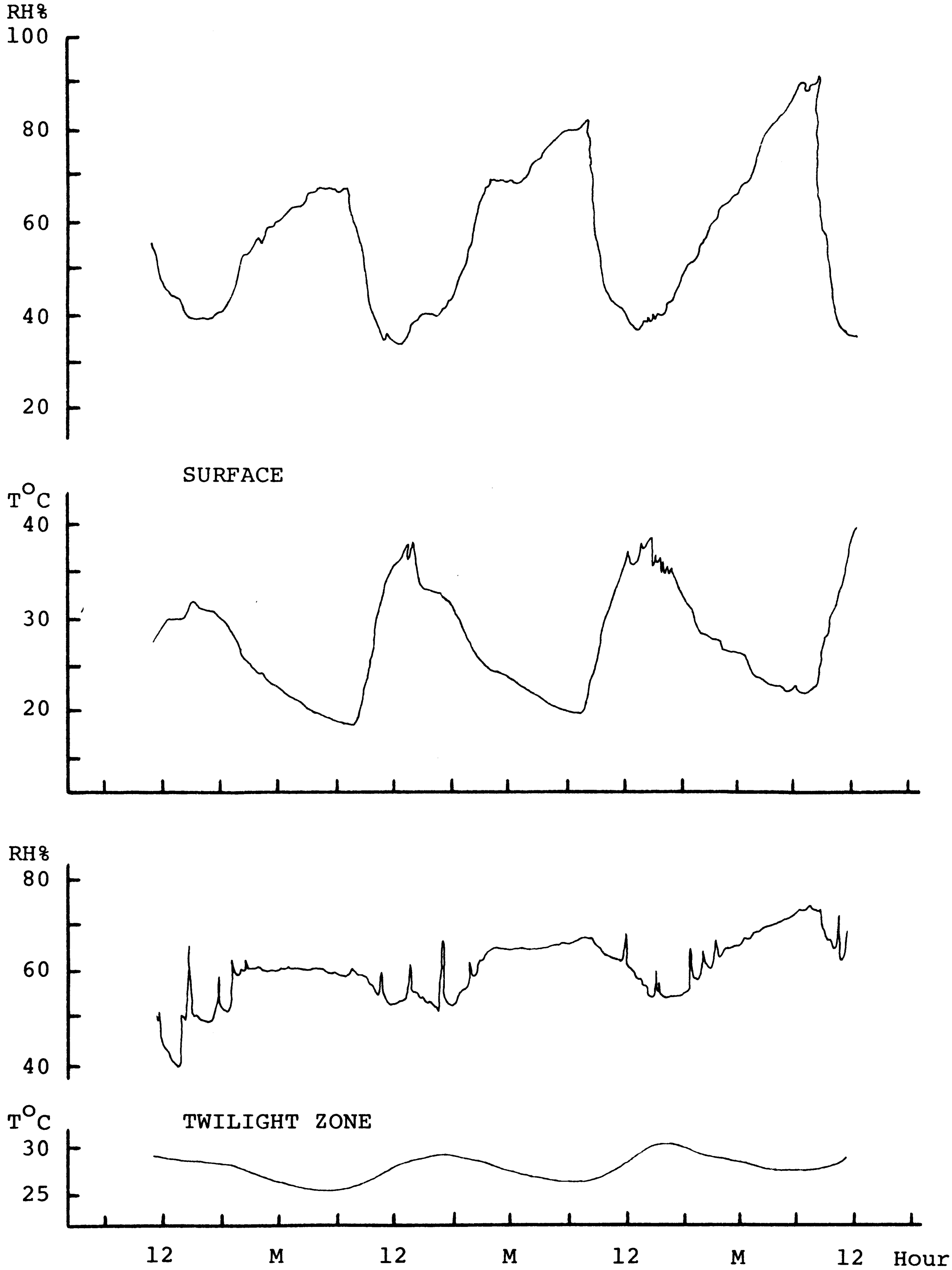

Fig. 2. Relative humidity and temperature fluctuations of the surface, twilight and aphotic zones of Barnett's Cave, Kempsey, NSW from 22 November to 25 November 1976. The first thermohygrograph was placed on the surface 1 m from entrance; the second was placed 3 m into cave; the third placed 15 m into the cave.

TABLE 1: SUMMARY OF DEMONSTRATED ECOPHYSIOLOGICAL RESPONSES

(References are intended to be representative not exhaustive)

ENVIRONMENTAL FACTORS	ECOPHYSIOLOGICAL RESPONSES Surface	Twilight	Aphotic
LIGHT Preference	photopositive (Gelderloos, 1976) photonegative (Kenagy, 1976)	photonegative (Twente, 1955)	photonegative (Ginet, 1960) photoneutral (Breder, 1944 in Vandel, 1964)
CIRCADIAN RHYTHM Entrainment	highly entrained (Thines & Ermengem, 1965)	highly entrained (Voute, Sluiter & Grimm, 1974)	weakly entrained (Lamprecht & Weber, 1975) not entrained (Ginet, 1960)
TEMPERATURE Tolerance	high (Cloudsley-Thompson, 1962) low (Spotila, 1972)		high (Ginet, 1960) low (Ginet & Mathieu, 1968)
TEMPERATURE Preference	broad (Gardefors, 1966) narrow (Toye, 1966)	broad (Thibaud, 1970*	broad (Elliott & Mitchell, 1973) narrow (Mitchell, 1968)
HUMIDITY Preference	broad (Gunn & Cosway, 1938) narrow (Spotila, 1972)	narrow (Spotila, 1972)	broad (Bull & Mitchell, 1972) narrow (Derouet, 1960)
WATER LOSS Rate	high (Herreid, 1969) low (Loveridge, 1968)	high (Packer, 1963)**	high (Derouet, 1960)

* edaphic form
** burrowing form

Conclusions

This simplified review of the environmental structure of the twilight zone shows the complexities with which the twilight animals must contend. Cave environmental studies by Roussett (1967), Andrieux (1970 a,b,c) and Barr and Kuehne (1971) give excellent descriptions of the conditions of diverse cave systems. The physiological responses by twilight animals, while being no less complex, reflect their adaptations to the cave environment. Table 1 summarizes the range of a few ecophysiological responses exhibited by surface, twilight zone, and aphotic zone animals. The references included in the table serve as examples of studies that have demonstrated these responses. Surface and aphotic zone znimals exhibit a wide range of physiological responses; the former as a result of their susceptibility to gross environmental extremes, and the latter as a result of the evolutionary adaptations to different selection pressures. Twilight animals appear to be more homogeneous in their responses. Perhaps this is only a reflection of the paucity of physiological studies on ecotonal animals. I am certain that physiological studies on cavernicolous animals will be an important tool for modern biospeleologists. The following are a few of the immediate areas in which physiological studies may contribute:

1. How similar are twilight animals to "pre-adapted" animals of epigean environments (see Barr 1968)?
2. Are morphological characters regressed before physiological characters under the same selection pressures (see Wiley 1973)?
3. Are Australian second-level troglophiles (Hamilton-Smith 1971) physiologically troglobitic?
4. To what position(s) in the cavernicolous classification scheme should species of the Family Rhaphidophoridae be relegated (see Hamilton-Smith 1971, 1972 and Richards, 1971a)?

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MICRO-ORGANISMS ON CAVE WALLS IN THE DEEP TWILIGHT ZONE

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Abstract

A greenish tinge is often observable on cave walls well into the 'deep twilight zone', where human vision requires considerable dark adaptation. To study the organisms responsible for this colouration a site in Hennings Cave, Jenolan, where daytime illumination does not exceed 0.002 lux was chosen. In the surface layer of rotten limestone four photosynthetic micro-organisms have been recognised. Electron microscope studies reveal that two of these show extreme modifications for photosynthesis in this very low light intensity. Various non-photosynthetic organisms are also found in the colonies. A fungus is occasionally seen, and there is a range of gram-negative and gram-positive bacteria one of which also forms extensive colonies on limestone and mud in the dark zone. Another resembles no type previously described, and may have evolutionary significance. These organisms together represent a complex ecosystem which has never previously been studied.

Introduction

Cave entrances harbour a variety of shade and damp-loving plants. Flowering plants (angiosperms) are found only in the outermost area, being succeeded by ferns, which often form a luxuriant growth just inside the cave entrance. Where soil is sparser or light intensity lower mosses succeed the ferns, and here the classical ecologists' sequence ends. In the totally dark region making up the larger part of most caves, whitish or yellowish patches are often seen on the walls. These have been assumed to be colonies of fungi or bacteria, but do not seem to have received much study. (Cubbon (1976) suggests that they are actinomycetes – fungus-like bacteria). Between the entrance zone and the dark zone is a region of deep twilight where human vision needs a lot of dark adaptation, and where nobody seems to have looked for plant life. Yet it has been known for a long time that blue-green algae (cyanophytes) can live in very low light intensities, and also that they have a special affinity for limestone – some species deposit it, while others dissolve it.

The entrance chamber of Henning's Cave, Jenolan, NSW, is a large boulder collapse, behind which is a chamber lit very dimly by light filtering through the boulders. A greenish tinge is noticeable on the walls, suggesting the possible presence of photosynthetic micro-organisms, and this prompted the present study.

Collection Sites

All the 'deep twilight' material described here was collected from one site in the Hennings entrance chamber. The illumination at the site was measured around midday in bright sunshine, using a sensitive battery-powered photometer, and the maximum level recorded 0.002 lux. The surface few millimetres of rock at this site were relatively soft and friable; a similar green tinge was, however, also seen on more solid rock.

Samples of the white microbial colonies of the dark zone were also taken, from both mud and solid rock.

Techniques

Fresh material was examined using both light and scanning electron microscopes. Most work, was however, carried out on sectioned material. Samples were fixed in glutaraldehyde and osmium tetroxide, with the addition of Na EDTA to remove some of the limestone, dehydrated in ethanol series, centrifuged and embedded in epoxy resin. Sections were cut at 1 μm thickness for light microscopy, and 0.07 μm thickness for electron microscopy. Electron microscope sections were stained with lead citrate and uranyl acetate.

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Photosynthetic Organisms

Green alga.

A unicellular green alga was the only photosynthetic eukaryote (organism with a true nucleus) present. Cells were small (around 6 μm diameter) with an irregular 'castellated' shape and dense contents (Fig. 1). The cell wall was up to 1 μm thick. The most interesting feature was the structure of the chloroplasts, with thylakoids (the membranes that carry out the light reaction) packed extremely closely together (over 100 per μm), as seen in Fig. 2. These cells were isolated in culture (by Dr H. Marchant, at ANU) and identified as a species of *Chlorella*. When grown in culture, under lighting approximating to cloudy daylight, the chloroplasts still showed very densely packed thylakoids. By comparison, *Chlorella fusca* grown in culture has a thylakoid density across the chloroplast of only 15-20 per μm. Clearly the cave *Chlorella* has adapted considerably for an existence in minimal light, and cannot revert to a more normal structure in higher light conditions (though, at least in pure culture, it grows well under high light levels).

Blue-green algae.

Blue-green algae (cyanophytes) are not algae in the true sense of the term. They are allies of the bacteria; prokaryotes with no true nucleus or cell organelles. A range of types was seen, but only three were sufficiently distinctive and common for detailed study.

Type 1. Cell diameter 1.2 μm approx., cells solitary or in small colonies. Thick (0.1 μm) cell wall or sheath, which appeared very dense in the electron microscope, suggesting impregnation with lipid or other non-carbohydrate material. The thylakoids (photosynthetic membranes) are 4-6 in number, arranged concentrically around the cell. This is a common arrangement, found in many cyanophytes and characteristic of the often-studied *Chlorogloea fritschii* when grown in *high* light intensity (Peat & Whitton 1967). When the cells form colonies, the colony is not bounded by a single capsule or slime layer. No name has yet been assigned to this type.

Type II. Cells ovoid in shape, 2 x 4 μm in diameter in colonies of 4 or more cells together, bounded by a common capsule, 0.3 – 0.5 μm thick. Thylakoids are much more numerous than in Type 1, and are arranged in whorls filling much of the cell. This is again a typical cyanophyte pattern, and is seen in *Chlorogloea fritschii* grown in low light intensity. (Though the low intensity used was around 200 lux – 100,000 times higher than the illumination in the cave!) Type II has provisionally been assigned to the genus *Gloeocapsa* following Stanier and others (1971).

Type III. Very small cells, 0.5 - 1 μm in diameter, which occur in spherical colonies (c. 2 μm diameter) of 4 – 8 cells enclosed in a common sheath, of microfibrillar structure. The shape of each cell tends to show the plane of last division. Fig. 1 shows three such colonies living in association with a *Chlorella* cell, and apparently linked by a slime layer. The most striking feature is the unusual thylakoid arrangement, with the membranes densely (50 per μm) packed in parallel arrays (Fig. 3). Such an arrangement has not been reported before, and must be an adaptation to the extremely low light intensity of the deep twilight zone. This species seems to belong to the genus *Chroococcus,* following Stanier and others (1971).

Heterotrophic Organisms

A varied heterotrophic (non-photosynthetic) community is present. The only eukaryote seen is a fungus, but there is range of bacteria of which two merit individual mention.

1. One bacterium found in the zone (Fig. 4) resembles no organism previously described. (A note describing it is in preparation at present). It appears to be a gram-negative bacterium, occurring in colonies with a fibrillar sheath surrounding each cell and a layer of tubular scales surrounding the whole colony. The spiral arrangement of DNA in the nucleoid is particularly distinctive; this resembles closely the pattern seen in the most primitive eukaryotes (cells with nuclei) so that this organism may represent an evolutionary 'missing link'.

2. The bacterial colonies of the dark zone consist solely of one gram-positive bacterium (Fig. 5); this is also found as a 'stray' in the deep-twilight zone. The colonies consist of short chains of irregularly-shaped cells with spiky cell walls and dense granules (probably polyphosphate) in the cytoplasm. The nutrition of this bacterium is an interesting problem – the other bacteria of the deep-twilight zone presumably live saprophytically on the remains of the algae, but this forms pure colonies in the dark and must presumably survive on some component of limestone or cave mud.

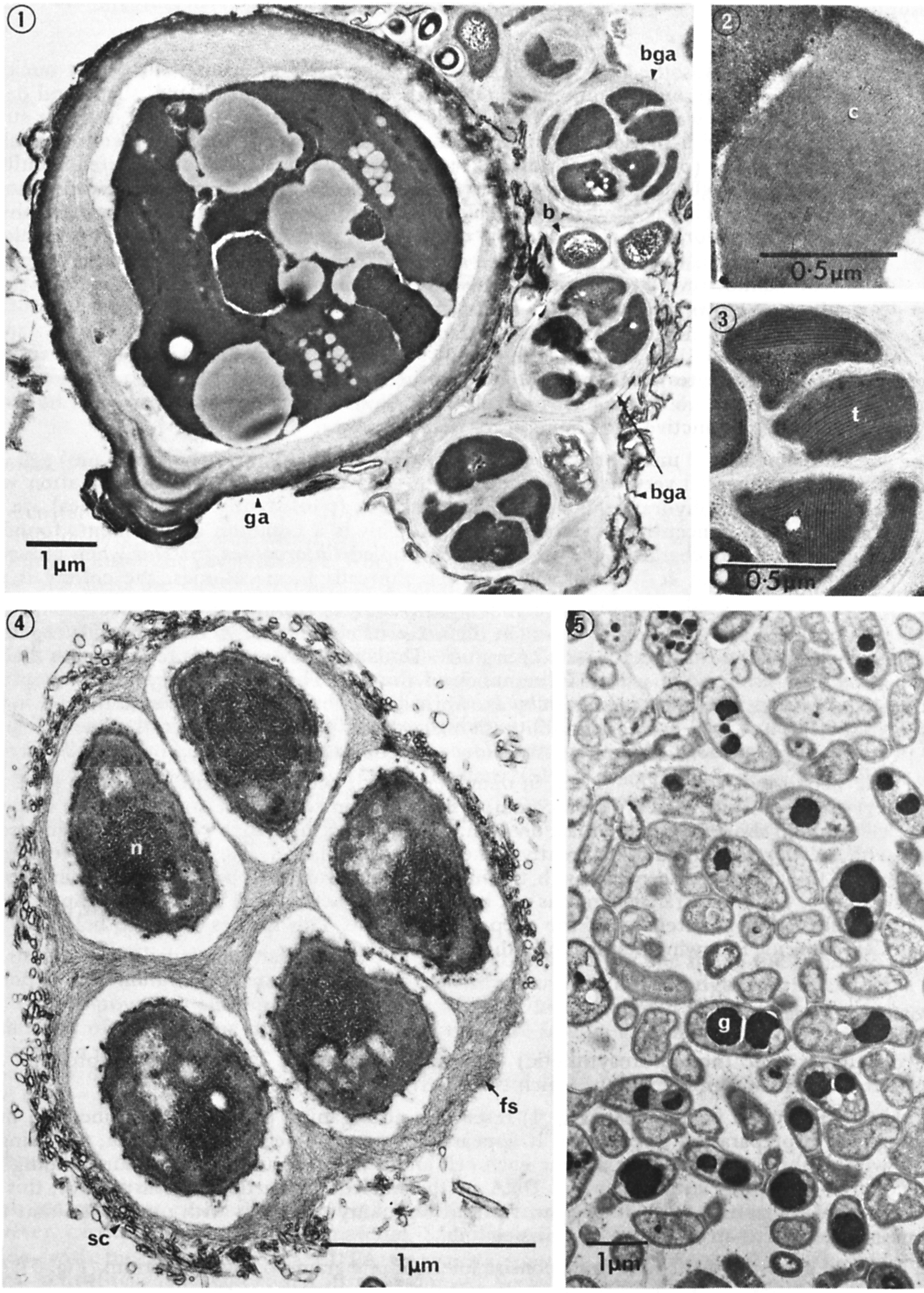

Fig. 1. A single green algal cell (ga) with attached colonies of blue-green algae (bga) and bacteria (b). x 12000

Fig. 2. Part of the green alga shown in Fig. 1. Part of the chloroplast (c) is shown; the photosynthetic membranes are very densely packed. x 45000

Fig. 3. Part of one blue-green algal colony from Fig. 1. Each cell contains close-packed thylakoids (photosynthetic membranes) (t). x 35250

Fig. 4. Bacterial colony from the deep-twilight zone. Cells have spiral-structured nucleoids (n) and are embedded in a fibrillar sheath (fs) which is surrounded by scales (sc). x 32250

Fig. 5. Bacteria from the dark zone. Many show large dense granules (g) which are probably polyphospate. x 10500

All figures are transmission electron micrographs of thin sections.

Conclusions

The little-studied deep twilight zone supports a varied, but probably slow-growing, flora. A green alga (*Chlorella* sp.) and a blue-green alga (*Chroococcus* sp.) seem to be highly adapted to the low-light environment; other blue-green algae may be casual strays from better-lit regions of the cave entrance. Bacteria form a second step in the food-chain; those marked 'b' in Fig. 1, for example, seem to be living saprophytically on the blue-green algal slime. The dark-zone bacterium, however, must either live saprophytically on the organic content of cave limestone or be a chem-autotroph. The whole represents a fascinating ecosystem in an exceedingly minimal environment; adaptation to this limited environment may also have provided an ecological haven from some evolutionary relics.

Acknowledgements

I am very grateful to Dr H. Marchant for culturing the *Chlorella* sp. and to Dr K.Y. Cho for culturing various bacteria from the site. My thanks go also to Helen Scott for sectioning some particularly difficult material.

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SILVERFISH IN AUSTRALIAN CAVES

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Abstract

Silverfish as part of the world's cave fauna are briefly described. Cases of silverfish in Australian caves are given along with discussion of their status in the ecology of the cave. A comment is made on assessing an organism's adaptions to living in a cave when the entire family is normally depigmented and eyeless. Specimens of the Bungonia Caves silverfish are used as a case study of these animals and their behaviour.

Silverfish form only a small portion of the world's cave fauna.

As no machilids have been found in Australian caves and those found overseas are covered in Vandel (1965), I will restrict discussion to the Order Thysanura. With this restriction the only family of interest is the Nicoletiidae which has been reported from caves in Europe, Australia and North and Central America.

Vandel reports a species of *Nicoletia* was described from a cave in the department of Var (South France). Two others (genus *Nicoletia* and *Troglodromicus*) were described from caves in Karst. Ulrich (1902) described *Nicoletia exensis* from Texas (USA) but this was redescribed by Wygodzinsky (1973) under a new genus *Texoreddellia.* This is the most widely distributed troglobite in the southern states and Mexico. It exhibits little variation within a cave population but wide variations between caves. Vandel records another species, *Lepisma anopthalma,* from Mexico but believes this is better considered as Nicoletia. Mitchell and Reddell (1971) record 5 thysanurans from Texas. Three of these being accidentals, one *N. texensis* and the other an undescribed Nicoletiid of the genus *Trichatelura* (a South American genus). Reddell and Mitchell (1971) also record in their Checklist of the Cave Fauna of Mexico that the family Nicoletiidae is well represented by troglobites and troglophiles in the Sierra de el Abra, but definite generic assignment is awaiting revision which has not been completed.

A review of the Australian records also reveals that silverfish are not common. To date I have records of silverfish from six cave areas in Australia.[1]

Two of these were collected from the Nullarbor by Dr A. Richards in Murrawiginie No. 3 Cave (N9) and Lynch Cave (N60). These specimens have yet to be examined. The Murrawiginie caves are little more than rock shelters but Lynch Cave is well inland and perhaps one of the oldest of the Nullarbor Caves and the specimens may prove to be of much interest (Hamilton-Smith, pers. comm.).

V. Ryland collected a silverfish of the genus *Heterolepisma* (Family Lepismatidae) from the doline of Dingo Cave WA (N160). This has not been examined but I believe this is unlikely to be a cave dweller. A specimen of *Trinomura novaehollandiae* was collected by S. Lowry in Kinnenabbra Cave, Cervantes WA (SH40). This species was originally described by Silvestri (1908) from the material collected under rocks near Perth and hence is best considered as an accidental. J. Lowry writes that "despite extensive searches in caves north of Perth and in the Nullarbor she has only ever found the Kinnenabbra specimen" and so doesn't feel they will form a significant part of the cave fauna of that area.

The two remaining species are known only from caves. The first of these was collected from Russenden Cave, Texas, Qld by J. Toop. Only a few specimens were collected and I have no details of their habitat within the cave. They are small with very long antennae compared to all other Australian Nicoletiids. Their bodies are broad and have comparatively few setae. Unfortunately

[1] Since this paper was presented two further records of cave silverfish have come to light. A second species is recorded from Bungonia, NSW and an indeterminate species occurs at Naracoorte, SA.

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unless these are found as surface dwellers we may never see living specimens as Texas caves are currently being submerged by the waters of Pike Creek Dam. Without observations of live material no comment can readily be made on their ecological status e.g. troglobite, troglophile.

The last Australian cave species was first discovered in Phoneix Cave, Bungonia NSW (B60) (Smith 1976a) and later in Argyle Hole (B31) and UNSWSS Hole (B43) (Smith 1976b).A report by R. Reid of one in Grill (B44) is yet to be confirmed. It is also a Nicoletiid, of the genus *Nicoletia.*

From the above records it would appear that the Family Nicoletiidae is more suited to cave environments than other families. All members of the family are non-pigmented and anopthalmic. They are generally found free-living or in association with ant or termite nests. In appearance they are elongate parallel-sided insects, usually with long antennae, cerci and medium dorsal appendage. The legs are long and simple and the jaws are simple chewing types. The family is generally vegetarian.

Other families in Australia are eyed and pigmented or entirely restricted to sharing nests with termites and ants.

The Bungonia Caves Silverfish

This specimen is about 9mm body length with antennae, cerci and median dorsal appendage all about body length. The antennae are held apart and moved alternately up and down while the median dorsal appendage is carried appressed to the ground with the cerci held aloft as in the photograph.

The male of the species has a row of sensory structures along the inside ventral surface of the cerci. I believe these could be pheromone detectors or transmitters enabling location of the female. These structures are not known on any other silverfish.

In Phoenix Cave they appear to be restricted to below 8 m depth, which by coincidence or otherwise is the greatest depth at which the numerous cave crickets have been found. Their numbers decline markedly at greater depths (50-60m). Only one has been found at this depth and this was after recent heavy rains. In these regions the habitat appears suitable, but the levels of CO_2 are nearly always above 1–2%. Dr J.A.L. Watson has indicated to me that repeated doses of CO_2 on Lepismatid silverfish inhibited breeding and so this may put a limit on the spread of the population down the cave. They have not been found in the cave catchment area.

These insects are commonly found free roaming across gravel, sand and bedrock, or underneath rocks. Usually they are found singly but on two occasions pairs (♂ + ♀) have been found together under rocks. They can be observed in cracks in the walls or with just their antennae protruding beyond the edge of a rock as they cling upside down. None have been seen on the roof or in the isolated piles of organic debris throughout the cave.

Normally individuals appear to avoid one another but those that were together followed each other around when disturbed.

Determining the ecological status has presented problems in this case as the entire family is normally eyeless and unpigmented. J. Reddell writes that "A few species in Mexico and the Texas species are considered to be troglobites since their overall facies is unlike the usual termitophile or soil dwelling species. These are extremely large, slender, completely unpigmented, usually somewhat elongate and their habits include free-roaming across clay banks, rock wall, etc. We get many species under rocks or among organic debris and these usually look no different from epigean species," and with his work on japygids found heavier setation and more sensillae than in epigean forms. The Phoenix specimens are certainly larger, they are often found free-roaming and contain new sensory structures, but preliminary observations show that they are not more seteated than some epigean forms although much more so than the Russenden Cave species. Probably only physiological studies will enable status to be determined.

This population would benefit greatly from restriction of human access to the cave. On one trip several specimens were found in the cave on the way down to the deeper regions but after a party of cavers moving through after us had left, only two could be found. Their habit of living on the passage floor makes them very vulnerable. The populations in Argyle Hole and UNSWSS Hole are extremely small, probably due to heavy trafficking. This is not likely to decrease.

Overall, it is obvious that silverfish are not predominant in caves either in Australia or overseas. However, at Bungonia there appears to be a well established population existing in a number of caves. Despites its success, however, no real assessment of its adaptions to cave life can readily be made.

Acknowledgements

I would like to thank Dr G. Cox for preparation of Scanning Electron Micrographs and Dr J.A.L. Watson for his guidance and access to ANIC collections. Also to E. Hamilton-Smith for the references, specimens and literature reviews he provided.

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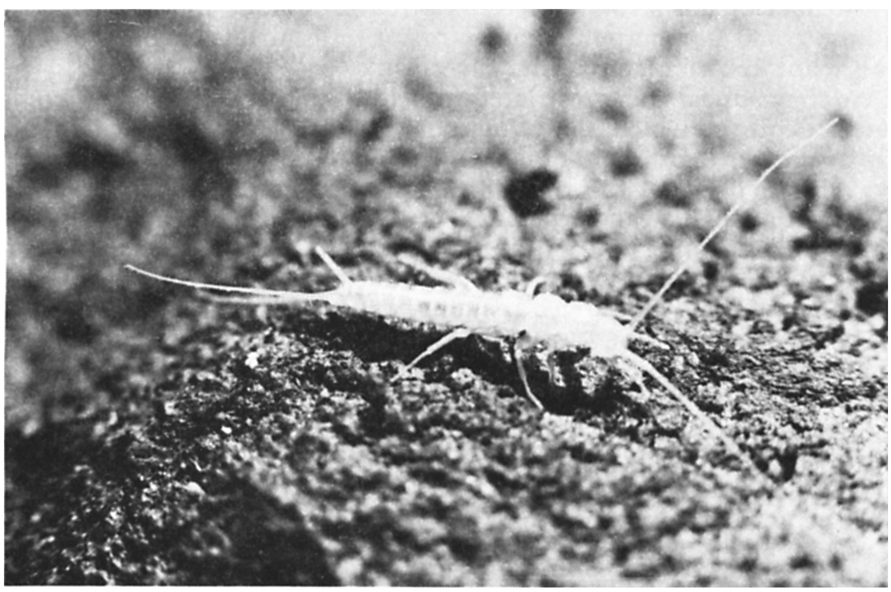

Plate 3. The Bungonia Caves silverfish.

A REVIEW OF THE BAT BANDING WORK OF BARBARA DEW

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Abstract

Barbara Dew died in 1968 and her last entry in her field notes is dated 4/5/68. Her first entry is the 30/10/60 where she banded 14 bats in the North Sydney Railway Tunnel. Over these 8 years she banded at Wombeyan, Bungonia, Jenolan, and Wellington all well known sites, but other areas such as Woni Tunnel, Katoomba Coal Mines, Seven Hills, Hill End and other areas are mentioned. This paper summarises all the areas visited by Barbara with details of banding, and subsequent recoveries.

THE SAFETY OF VERTICAL CAVING EQUIPMENT

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Abstract

Vertical caving techniques are now widely used in caving. However, vertical caving remains a potentially hazardous occupation, because of the relative absence of any back-up devices. The person who claims the perfectly safe vertical caving system can be built is, at best, using his terms loosely, at worst, woefully ignorant of the limitations of his equipment. The task of the designer of vertical caving equipment is to develop a system where the chances of failure are reduced to an acceptable level. Up to now the philosophy has been: "if it looks okay, give it a go". Unfortunately, intuition does not produce the safest system. It is time the design of vertical caving equipment was placed on a more scientific footing. This paper explains, in non-technical language, the principles governing the safety of vertical caving equipment. It describes the factors which determine the maximum forces which can occur, and provides guidelines for the design and testing of vertical caving equipment.

Introduction

Vertical caving techniques are becoming increasingly popular. Unfortunately, knowledge of the performance and safety of vertical caving systems (i.e., devices enabling vertical movement in caves) has not grown proportionately.

The design and implementation of vertical caving systems has been accompanied by much woolly thinking. It is not unusual to hear that a certain vertical caving technique is "perfectly safe". Claims such as this are dangerously misleading.

Perfect Safety

Perfect safety in vertical caving is impossible. To use the old axiom, a vertical caving system is only as strong as its weakest link.

For example, suppose you are abseiling on a single rope. The karabiner you are using may have an ultimate load capacity of 2000 kg, the whaletail a capacity of 4000 kg, the rope a capacity of 2200 kg, and the webbing a capacity of 1400 kg. However, if the anchor for the rope has an ultimate load capacity of 250 kg, then it is the anchor that governs the load carrying capacity of the system as a whole – it is the weakest link.

Using this concept, I'll explain why perfect safety is impossible.

Suppose we had an infinite number of people and each person is abseiling using a rope tied off to a different rock projection. If we tested the ultimate strength of the rock projections we would obtain a distribution of strengths as shown in Fig. 1.

All those rock projections with a strength less than the minimum safe strength (those in the hatched area) are capable of causing an accident.

In order to make our rock projection "perfectly safe" we must eliminate the hatched area, i.e., avoid using all projections that fall within this zone. This is not easy. Some possible courses of action are:

(i) We could test all projections with our body weight before abseiling off it. This won't help us much because the minimum safe strength required is much greater than one body weight, probably at least four times one body weight.

(ii) We could tie the rope off using two rock projections. This will modify our strength distribution graph as shown in Fig. 2.

The hatched area has been reduced, but it still exists, i.e., accidents can still occur.

The vertical caver is moving in a world of many unknowns. It is not possible for him to test every item of his equipment up to a minimum safe load capacity every time he is about to use it. Every

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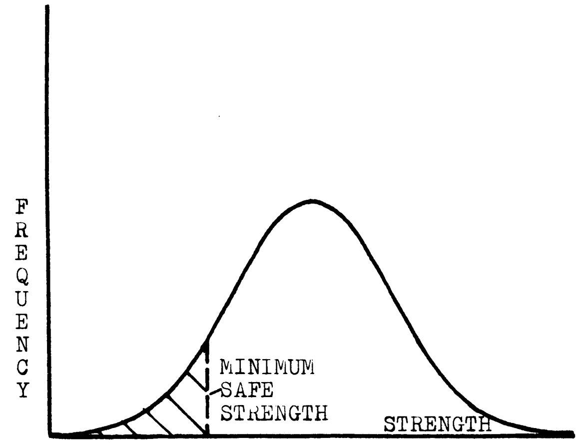

Fig. 1 Strength of rock projections.

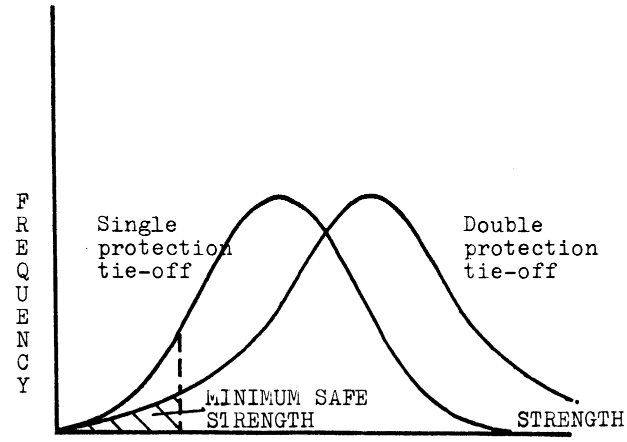

Fig. 2 Strength of double tie-offs.

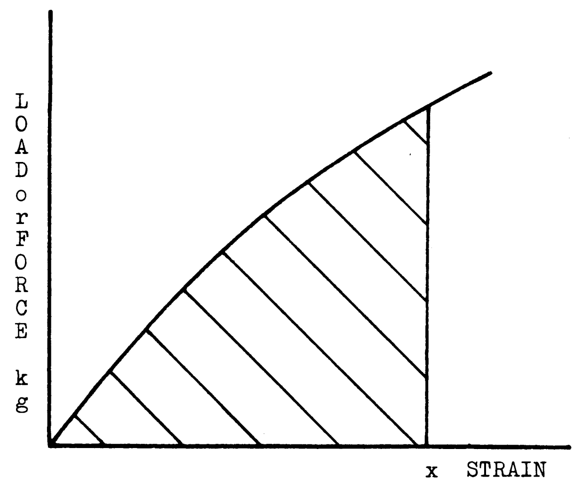

Fig. 3 Typical load vs. strain curve.

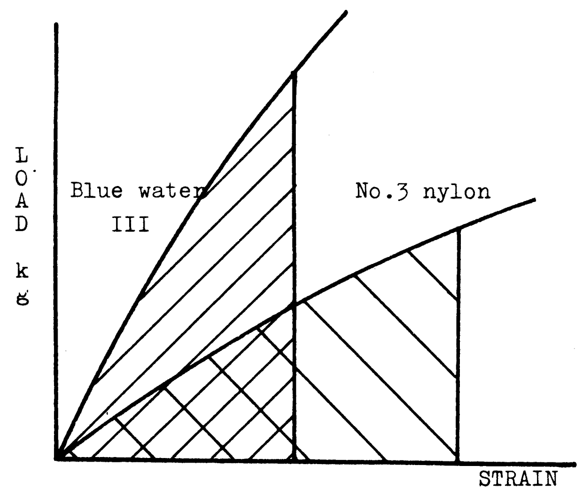

Fig. 4 Comparison of Blue water III and No. 3 nylon.

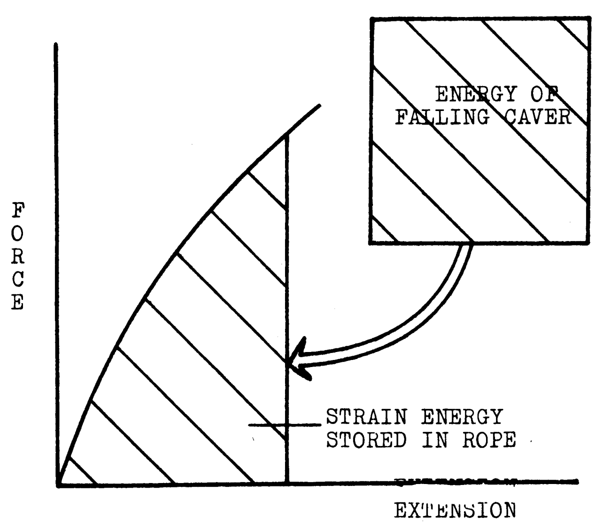

Fig.5 Conservation of energy.

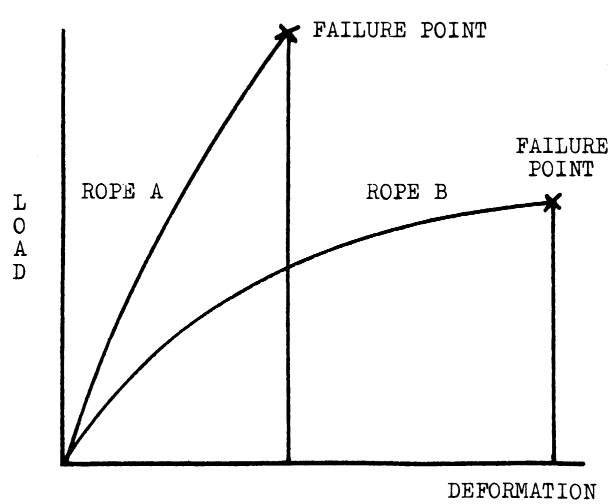

Fig. 6 Comparison of load vs. deformation curves.

time he uses an item, its strength may be reduced by abrasion or chemical attack.

The vertical caver must reconcile himself to the fact that he is playing a risk game, and approach his sport accordingly.

Safety Factors

Rather than dream about perfect safety, the designer of vertical caving equipment should direct his efforts to attaining an acceptable level of safety. But, what is acceptable safety?

Technicians love to talk about safety factors. A safety factor is a non-dimensional number obtained by dividing the ultimate strength of a device by the maximum load that you intend to put on the device.

For example, suppose we wanted to design a device to carry a maximum load of 100 kg. If we wanted the device to have a safety factor of 2, then we would design it to fail at not less than 200 kg. For a safety factor of 3, it would need to fail at not less than 300 kg.

The actual safety factor that we choose will depend upon:

(i) the certainty with which the maximum working load can be determined;
(ii) the consequences of the ultimate load carrying capacity being exceeded.

As an illustration of the second point, consider a steel bridge, held together by a large number of bolts. If one bolt snaps then usually the load that was being carried by that bolt, will be distributed to the numerous bolts surrounding it, and the bridge will continue to stand. Contrast this with a caving situation where you are using just one bolt as a tie-off for your abseil rope. The consequences of the bolt failing in the latter case are obviously more disastrous.

If the bridge engineer uses safety factors in the range 1.4 to 2.0, it is obvious that the caver should be using safety factors of at least 2.0.

Forces in Vertical Caving

The safety factor tells us by what factor to increase our maximum anticipated loads to obtain an ultimate load capacity. Hence, before we can design our equipment we need to have some idea of what our maximum anticipated loads are going to be.

As an illustration I will outline two potentially dangerous situations that could arise in vertical caving. Both situations involve a caver weighing 70 kg (The technical calculations are contained in Appendix C.)

Situation A:

A caver is climbing a ladder. The belay rope is a number 3 nylon, and belaying is done by means of a jumar at the top of the pitch. The pitch, which is free-hanging, is in excess of 80 metres. Forty five metres from the top the climber stops for a rest and then starts climbing again. The belayer is inattentive and does not recommence taking in the belay rope. Thirty metres from the top the climber loses his grip and falls 15 m vertically before the slack in the belay rope is taken up. The maximum force in this fall will be 330 kg.

Situation B:

A caver is jumaring on Bluewater III, a low stretch nylon rope. Unbeknown to the caver, the rope is caught on a small projection at the top of the pitch. When he is 0.9 m from the top of the pitch the rope comes free from the projection and he falls 0.3 m vertically before the slack in the rope is taken up. The maximum force in this fall will be 570 kg.

How did these forces arise? Why is the force in Situation B much greater than that for Situation A?

Two factors interact to govern the maximum forces arising in a fall, they being

(i) the fall factor, and
(ii) the stretch factor.

Fall Factor

The fall factor is the height of the fall divided by the length of the rope above the falling body. For a given rope, the greater the fall factor the higher the force in the rope. (An analytical proof of this hypothesis is given in Appendix B.)

Consider the following example:

Case 1: Caver falls 10 m on 30 m length. The fall factor is $^{10}/30 = {}^{1}/3$.
Case 2: Caver using same rope falls 2 m on 4 m length. The fall factor is $^{2}/4 = {}^{1}/_{2}$;

Case 2 will generate a greater force in the rope.

However, if we look at our two situations we obtain

Situation A: Fall Factor = $\frac{15}{30 + 15} = {}^{1}/3$

Situation B: Fall Factor = $\frac{0.3}{0.3 + 0.9} = {}^{1}/_{4}$

We would expect that Situation A would give the highest force, but we already know that it does not. Hence, there must be second factor affecting the forces arising in the rope.

Stretch Factor

The stretch factor can be stated as follows: for a given fall factor, the stretchier the rope, the lower the force.

Consider the following example.

Case 1. A 7.6 m fall on a 30 m rope length above the falling body. For a number 3 nylon, the maximum force will be 295 kg.
Case 2. If the same fall occurs on Bluewater III, the maximum force will be 570 kg.

The relevance of the stretch factor can be explained graphically.

For any rope, we can obtain a load versus strain graph as shown in Fig. 3. The strain is a non-dimensional value obtained by dividing the extension of the rope by its length, i.e., it is the extension of the rope per unit length. (The terms "load" and "force" are synonymous in this paper.)

The hatched area under the curve is a measure of the energy stores in the rope per unit length, when it has a strain of *x*.

In Fig. 4, the load versus strain curves for both number 3 nylon and Bluewater III have been plotted on the same axes. For the same fall factor on each rope the area under each curve must be the same. Hence, the Bluewater III rope must carry a higher force.

The Failure Criterion

The ultimate criterion for failure of every vertical caving system can be stated simply as follows: the system will fail when the energy input, (i.e., the energy of the falling caver) exceeds the capacity of the system to absorb energy.

Using this criterion it can be shown that the breaking strain, (a misnomer, it should be called the ultimate tensile load) when quoted without supportive data is almost meaningless.

A falling caver tied to a belay rope will have a certain energy (kinetic and potential) indicated by the square hatched area in Fig. 5. If the caver is to be stopped by a rope, then virtually all of his energy must be converted to strain energy stored in the stretched rope. The maximum force in the rope will be reached when the energy of the falling caver is equal to the hatched area under the curve in Fig. 5.

The total area under the curve when a rope is loaded to failure is the energy absorption capacity of the rope. Different ropes have different load versus deformation curves, and different energy absorption capacities. Consider two ropes with load versus deformation curves, as shown in Fig. 6. Rope A has a "breaking strain" approximately twice that of rope B. However, rope B has a greater energy absorption capacity than rope A and, hence is a safer rope. The "breaking strain", by itself, tells us little about a rope. What we really want to know is the energy absorption capacity.

The "breaking strain", by itself, tells us little about a rope. What we really want to know is the energy absorption capacity.

Equipment Design

Anyone who designs vertical equipment is shouldering a heavy responsibility.

It is not intuitively obvious what the worst loading conditions are going to be. Sometimes, seemingly innocuous events can lead to a heavy load being placed upon an item of equipment. It is the duty of the designer to foresee what the maximum loads on his equipment might be and to design his gear to withstand these loads with an adequate safety factor. If the equipment cannot withstand certain types of loading with an adequate safety factor, then it is the designer's responsibility to ensure that these loading conditins can never be applied to the equipment.

Experimental evaluation of equipment performance is not a simple matter. The strength of every item of equipment is approximately normally distributed as shown in Fig. 1. It is the responsibiity of the designer to develop, where possible, a testing procedure which will eliminate every item having less than the minimum safe strength.

The development of proper testing procedure should be the province of a skilled technician. Too often I hear of testing procedures which consist of taking one or two specimens from a large batch, and testing them to destruction under one type of load, in conditions which barely duplicate the field conditions. Using this scanty data, sweeping claims are then made about the performance of the entire batch. This sort of procedure is far from adequate.

A good procedure includes proper sampling techniques and multiple testing across a wide range of loading conditions, duplicating the field conditions as nearly as possible. Where relevant, mean values and standard deviations should be determined.

These techniques are not quick, nor are they cheap. However, they are a rational method of attaining an acceptable level of safety when playing the risk game of vertical caving.

APPENDIX A

DERIVATION OF MAXIMUM FORCE ARISING IN A FALL

It is possible to derive an equation for the forces arising in a rope when it is required to hold a falling caver.

Let W = weight of caver

L = unextended length of the rope between tie-off point and caver

d = vertical distance the caver falls before the slack in the rope is taken up (i.e., before the rope starts stretching)

x = extension of the rope

x_{max} = maximum extension of the rope

k = stiffness of the rope, which is defined as the force required to cause a unit extension of a length L of the rope. Hence stiffness has units of force/distance.

F = the force in the rope

F_{max} = the maximum force in the rope

The energy equation for a falling caver is,

Potential energy of caver about to fall = Strain energy stored in the rope at its point of maximum extension 1

Equation 1 ignores the small amounts of energy which are lost through heat, sound, etc.

In the absence of any firm data to the contrary, we assume that rope obeys Hooke's Law, i.e.,

$$F = k.x \qquad ..... 2$$

The strain energy stores in the rope under extension x is

$$S.E. = \tfrac{1}{2} . F . x$$
$$= \tfrac{1}{2} . k . x^2 \qquad ..... 3$$

Using as datum the level the caver reaches when $x = x_{max}$,

Eq. 1 can be expressed as

$$W(d + x_{max}) = \tfrac{1}{2} . k . x^2{}_{max} \qquad ..... 4$$

Solving Eq. 4 we obtain

$$x_{max} = \frac{W + \sqrt{W^2 + 2kWd}}{k} \qquad ..... 5$$

Substituting in Eq. 2

$$F_{max} = W + \sqrt{W^2 + 2kWd} \qquad ..... 6$$

APPENDIX B

PROOF OF THE FALL FACTOR HYPOTHESIS

It can be proved, that, for a given rope, the maximum force in the rope is a function of the fall factor.

Using the Notation of Appendix A, consider two lengths L_1 and L_2 cut from the same rope. Under the action of a body weight, W, the extension for each rope will be

$$x_1 = cL_1\ 100 \qquad \ldots\ldots 7$$

$$x_2 = cL_2\ 100 \qquad \ldots\ldots 8$$

where c is the stretch of the rope expressed as a percentage of its length.

The stiffness of each rope will be

$$k_1 = \frac{W}{x_1} = \frac{100W}{cL_1} \qquad \ldots\ldots 9$$

$$k_2 = \frac{W}{x2} = \frac{100W}{cL_2} \qquad \ldots\ldots 10$$

Rearranging 9 and 10 we have

$$100W = k_1\ L_1 = k_2L2 \qquad \ldots\ldots 11$$

Hence for a given rope, kL is a constant.

Equation 6 of Appendix A can be rewritten in the form,

$$F_{max} = W + \sqrt{W^2 + 2(kL)\ .\ w. \frac{d}{L}} \qquad \ldots\ldots 12$$

Terms W and kL are constant, hence F_{max} is a function of (^{d}/L) alone. The term ^{d}/L is the Fall Factor.

APPENDIX C

CALCULATION OF MAXIMUM FORCES

SITUATION A

Assume that number 3 nylon has approximately 5% stretch under a load of 70 kg.

Using the notation of Appendix A:

W = 70 kg

d = 15 m

k = 70/(45 x 0.05) = 31.1 kg/m

$$F_{max} = W + \sqrt{W^2 + 2kWd}$$

$$= 70 + (70^2 + 2 \times 31.1 \times 70 \times 15)$$

$$= 330 \text{ kg}$$

SITUATION B

Assume that Bluewater III has approximately 1% stretch under a load of 70 kg.

Hence

W = 70

d = 0.30 m

k = 70/(1.21 x 0.01) = 5785 kg/m

$$F_{max} = 70 + /(70^2 + 2 \times 5785 \times 70 \times 0.30)$$

$$= 570 \text{ kg}$$

ADVANCES IN VERTICAL TECHNIQUES

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Central Queensland Speleological Society

Abstract

With the introduction of Petzl gear in early 1976 we have had to change our ideas on the application of vertical caving equipment. Of all the Petzl gear we have imported, the outstanding pieces have been the handled ascender and the Shunt. The attachment point of the ascender is directly below the rope channel and a cam locking mechanism is incorporated, these features greatly facilitate its use. The Shunt is an abseil protection device. It is held with the trailing hand when moving down the rope. If it is released the device locks onto the rope. A device has been developed in Central Queensland called the Etna descender as it was felt that a safer device was required.

Ascenders

The original Petzl ascender has been recently modified in several ways to make it easier to operate. It is pressed from high tensile aluminium with a cast aluminium cam. Handles have been provided, the bottom attachment point is directly below the rope channel and there is no horizontal twisting of the rope. These improvements are certainly effective for people who still use the "bicycle" method of prussiking. However, certain problems are encountered when using the "frog" method as the ascender does not sit right on the chest and becomes clumsy. We thought that we would overcome this problem with the introduction of the Croll ascender but this has not proved to be the case. Both the Petzl and the Croll ascenders have a load limit of 400 kg.

The cam in both the ascenders has also been modified and it is similar to the cam in the Jumar ascender with two exceptions:

1) there are many fewer teeth and they face downwards,
2) a mechanism is provided so that the cam can be locked in or out, passing knots becomes a one hand operation and the device can be operated by a gloved hand.

A number of people have experimented with the use of a handled Petzl as the top ascender and a Jumar as the bottom one. The Jumar follows more easily as it has a smaller rope channel. I have set up an ascender system using two of the new Petzls and a Croll. The system works well but has the disadvantage that tapes have to be tied to replace karabiner chains.

Descenders

The Shunt is a recent development in the abseil protection field much needed as most descending devices, once released, provided no protection in an uncontrolled descent. The Shunt is made from the same material as the Petzl ascender and is basically a channel through which a hole is drilled to take a pin. The pin carries a spring loaded lever. A piece of bar, which acts as a cam, is placed on the level and is forced against the back of the channel by the spring tension.

The weight of the operator is loaded onto the lever with the rope under the cam. This locks the device up. To release it the top of the Shunt is pulled down. During the abseil the device is held down by the trailing hand. A tape is attached to the end of the lever and tied to a Whillans or similar harness. As one slides down, the attachment tape is held loosely by the trailing hand. As soon as the Shunt is released the spring pressure holds it stationary on the rope, as one's weight goes onto the attachment tape the device locks up and stops the uncontrolled descent.

Two members of the Central Queensland Speleological Society have recently developed a device called the Etna descender as it was considered that no safe abseil device was then available. It is based on the design of the Stich plate but the mode of operation is completely different. To move, the end of the Etna remote from the rope is pulled down, normally by one hand only (Plates 4 and 5); to stop, one merely releases the device. The production version has the same limitations on the length of the pitch as does the Stich plate. The dimensions of the device, for which an Australian patent application has been made, are shown in the figure (Fig. 1).

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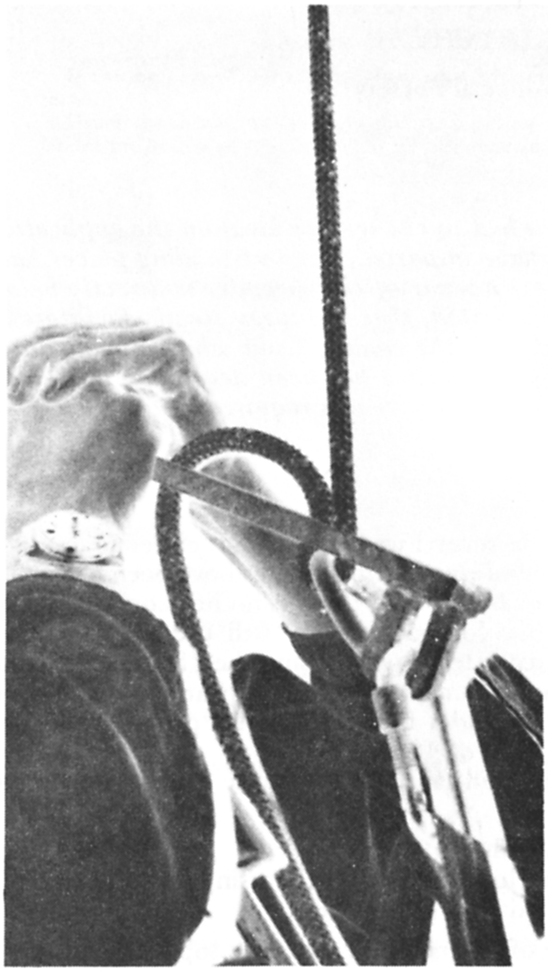

Plate 4. The Etna Descender; descending.

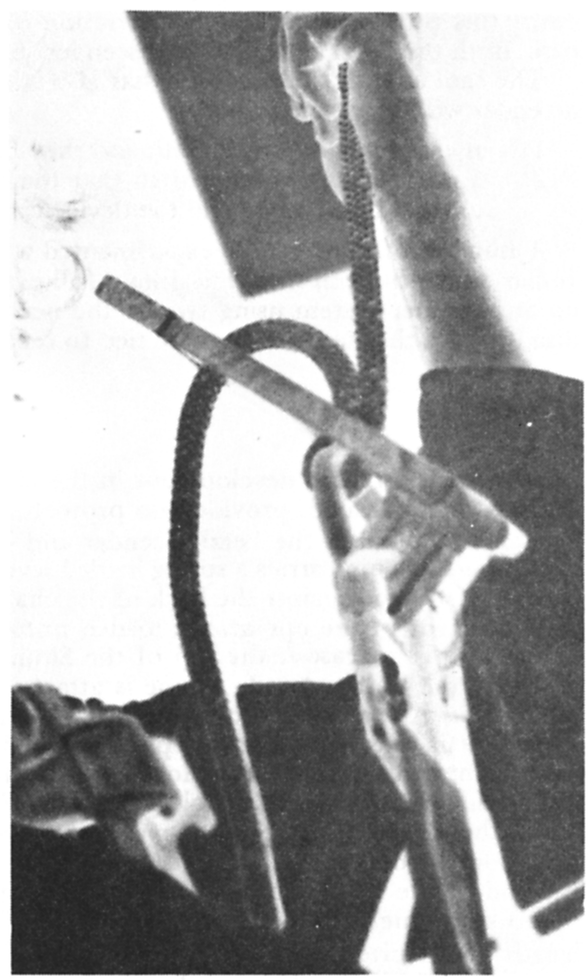

Plate 5. The Etna Descender; stationary.

The Etna descender is constructed from a medium tensile aluminium alloy (BS083 TH321). The ultimate tensile strength (UTS) of the alloy is 40 000 psi and it has a yield point of 18 000 psi. The original version was welded to make the T section, the weld used has a UTS of 38 000 psi and a yield point of 18 000 psi. The alloy is, however, available as a T section in the required dimensions but the availability of strip or section is unknown. It is used to make some railway waggons in Queensland! Sophisticated equipment such as M.I.G. argon arc welders, ultrasonic flaw detectors and other uncommon equipment are necessary to produce the welded version.[1]

Editors note:

[1] The reader is encouraged to note Bosler's comments (p. 65, this volume) on the safety of amateur construction of vertical caving equipment.

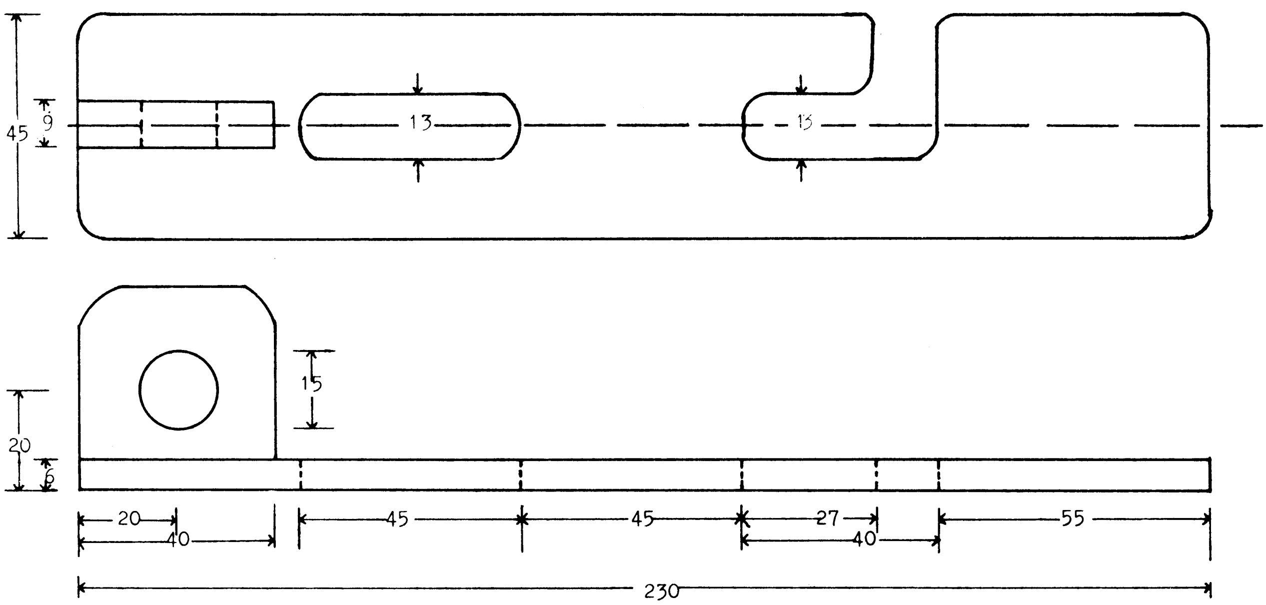

Fig. 1. The Etna Descender (all dimensions in millimetres).

HIGH ALTITUDE PHOTOGRAPHY IN CAVES

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Abstract

This paper describes equipment and techniques in photographing "inaccessible" places in caves such as the upper levels of high caverns or avens; the Gunbarrel aven at Wyanbene being an excellent example. A full description is given of constructing the lightweight equipment used. An operational run-down of taking a high level photograph and the people involved is described with problems and pitfalls discussed. Attention is given to various methods employed to aim the camera in the desired direction. The types of film used and the problems encountered in developing them are described. Finally, improvements to existing equipment and more ambitious additions are discussed.

Introduction

Following the measurement of the height of the Gunbarrel Aven in Wyanbene Cave, NSW by the Illawarra Speleological Society (ISS) using helium from a high pressure cylinder to inflate a larger than normal balloon, a lighted candle was lifted to the top of the aven. Some observers thought that the candle flame was affected by air currents during the ascent. The society later decided to equip a helium filled balloon with a large flashbulb (PF-100), that was to be fired after it had been lifted to the top of the aven, with tripod mounted cameras on the floor of the aven directed upwards to record what the flash illuminated. Photographic results of this led to the society's more ambitious project of lifting a specially constructed camera and ancillary equipment to various heights in the aven. The equipment described is designed with the wet conditions and access difficulties of the Wyanbene aven in mind. A further dampening influence on a too ambitious project is that every time the balloon and load is lofted it could be lost (i.e. cord becoming fouled, broken etc.).

Balloon

To keep the balloon weight to a minimum, 350 mm dia. by 0.0254 mm (0.001") thick polythene tube as used by dry cleaners has so far been found to be the most satisfactory. An important consideration in selecting balloon material is that it requires as little pressure as possible to inflate it (i.e. does not have to be stretched by gas pressure to size). The ends of the balloon are sealed by means of a wet cloth and a household smoothing iron; a small filling hole being left at one end. To lift 112 m of thread and a 440g payload a 6.1 m (20 ft) long balloon is required. On some ascents a second 3.05 m (10 ft) long balloon is added to:

(a) speed up the ascent.
(b) overcome the problem of water droplets collecting on the balloon which reduce its lifting capacity.
(c) speeding the balloon past cross-draughts.
(d) breaking the fall of the load should a balloon become ruptured on a high ascent.

A 40 Denier polyester thread is used to maintain the all important link between the balloon and ground party. A new thread is used for every session.

Lightweight Camera

Apart from pertinent aspects it is not the intention of this paper to delve into the workings and theory of cameras as this subject has been well documented in photographic publications. Further, with the type of photography described it is not the intention to produce portfolio type photographs but merely obtain an image that is recognisable.

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The two cameras constructed are of the single plate type for use with cut sheet film. Two major advantages steered us to this type of film:

(a) As each photo is taken it is recovered before the next photo is taken so that any loss of equipment on a 'flight' will not take all the photos with it as it would with roll film.

(b) each photo can be developed individually.

With little hope of directing the camera at high levels the wider angle of lens coverage the better; the ideal being the ultra wide angle lens. However, with most lenses likely to be used for such a project, a larger size film format can be utilised than for which the lens was originally designed with acceptable results. This in effect gives a wider coverage of the subject.

The first camera constructed was a fixed focus camera built around a single element meniscus lens with no shutter. Although this camera weighed only 30 g posed obvious difficulties in use. In spite of operational problems the first photographs of the upper levels of the Wyanbene Gunbarrel were obtained.

At a cost in weight, a second more advanced camera was constructed to suit an f3.5, 90 mm double element astigmatic lens as recovered from a Dehel folding camera of 1945 vintage. This lens was complete with an adjustable diaphragm and a between-lens leaf shutter with variable speeds including a "time" (T) setting. As the lens had a screwed barrel a mating threaded ring was fixed into the lensboard, allowing the camera to be focused. All unwanted mechanisms in the lens housing were removed. In the interests of reliability the flash contacts were replaced with a Honeywell ISX subminiature micro-switch. To trigger the shutter a Speed Graphic shutter solenoid was modified to fit into the cable release holder. The internal shutter trip mechanism had to be modified to allow it to be triggered by the solenoid with minimal power. During its first use, under wet conditions, the shutter became sluggish; it was later dismantled and clearances on pins and pivots relieved to make the shutter operate more freely.

Before manufacturing a camera body the size of film to be used and the lens to film distance at infinity needs to be determined. These dimensions can be taken off the original camera if available; if not, they can be determined with the lens and an etched glass screen. The use of a bellows type plate camera is a help. In choosing a size of sheet film to use the supply position was checked; a number of sizes are not readily available. Cutting sheet film down in size is not easy.

Basically the camera body consists of a lensboard supporting the pyramid shaped sides with a removable back; the whole being constructed of sheet balsa wood glued together with a waterproof epoxy resin. A light trap between the camera body and back is achieved by glueing velvet material to the rear of the camera body. Support brackets are glued to two opposite sides and two metal slides are fixed into the inside of the back to hold the sheet film. The thin balsa wood sheet used is not light-tight. To overcome this and to assist with waterproofing the balsa wood parts are painted with a wood sealing paint; the outside is finally painted with white enamel and the inside with a flat black enamel (i.e. as used to cut reflections from musical instruments in T.V. studios). Other refinements are additional light trappings on the removable back and supports for the rubber bands which secure the back to the camera body.

Electrical Pack

The electrical control equipment and battery pack are housed in a thin polythene bag in the interests of weight and waterproofing and consists of the following:

(a) six volt battery pack made up of four 1.5 volt 'Eveready' size N. No 904 batteries connected in series.

(b) miniature on/off switch connected in the battery supply.

(c) 2,500 µf, 25vw electrolytic capacitor to operate the camera solenoid.

(d) Light Emitting Diode (LED) indicators to assist in locating the equipment in flight and to indicate the state of the camera shutter.

(e) repetitive electronic timer as used with time lapse movies with a timing range from one second to five minutes; plug-in timing slugs being used to vary the time cycle.

(f) card relay to switch the solenoid.

Lighting

Due to the heights involved, subject illumination has to be carried aloft with the camera. For distances up to 20 m a small electronic flash unit is generally used (Hanimex TX 265). Where the subject is beyond 20 m expendible flash bulbs are used (PF-38, PF-45, PF-60, PF-100). A crude reflector is constructed on site from aluminium wire, aluminium foil and rubber bands for use with flash bulbs. A bulb holder is hung in the dome of the reflector.

Support Frame

The main frame is formed of 5 mm dia. aluminium wire in a coathanger shape with the exception that the join is made in one of the bottom corners; after twisting the ends together two prongs are left which are used to support the camera. A strong rubber band is used across the prongs to clamp them to the camera. Additional mountings for the electronic flash unit are formed of 2 mm dia. aluminium wire.

Operational Description

When all the equipment has been transported to the site, the frame and reflector are constructed and the components to be used are mounted on to the frame; the flash being mounted on the opposite end to the camera to achieve a modelling effect. After connecting the electrical wiring the completed outfit is given a test. All hands are used to unroll the balloon and to keep it off the floor while it is being filled with helium from the cylinder. During the filling process, a close inspection is made for any leaks in the balloon; any found are repaired with durex tape. When fully inflated the end of the balloon is tied off with a clove hitch using a short length of small flexible electrical wire. The position of the equipment is dependent on what photos are to be taken. With downwards or sideways photos the bracket is tied off with two ties directly to the balloon. This position is less susceptible to movement and is best if expendable flash bulbs are to be used. For upwards photos the bracket is suspended about 12 m below the balloon; being tied into the main thread rather than suspended by a separate thread from the balloon. The balloon will appear in these photographs and can be used as a scale. The electronic flash unit is usually used with this arrangement; its speed countering the spinning of the bracket. Until the thread is tied on to the bracket care is exercised to see that the balloon and load is not accidentally let go. To avoid thread tangles the thread has to be taken off the bobbin in the same manner as it was put on (not pulled off an end). The balloon is let go to the top to achieve this. On retrieving the balloon the thread is allowed to gather on the floor as it falls.

A sheet of cut film is removed from its light-tight container and loaded into the camera; all lights being extinguished during the operation. While the camera is reasonably light-tight care is taken not to direct any strong light towards it; the emergency lamp in the standard Oldham miners lamp causes no problems. The support frame is balanced by adjusting the position of the electronic package and then the shutter is cocked. After a signal from the stop-watch operator the power is switched on and the outfit let go. In places subjected to air currents no braking is applied to the thread until it is finally brought to rest. Progress is estimated by the amount of thread remaining on the floor. On high "flights" the balloon and load attains a speed of up to 5.5 ms^{-1} and at this speed, braking is started when about 10 m of thread remains on the floor. Hands are protected by gloves to avoid cuts from the fine thread. If the speed of lift and timing have been judged correctly, the camera should not operate for at least 15 seconds after it has stopped. This allows time for the load to stop spinning. As the count-down nears zero most look upwards to catch a fleeting glimpse of the upper levels as the flash goes off. At this stage the second leg of the timer is initiated and after a five second delay triggers the shutter a second time to close it; this being indicated to those below by the LED indicators. As soon as the LED's indicate that the shutter is closed the load is retrieved: minimal light being used until the unit is checked to see that the shutter is closed. All lights are once again extinguished while the exposed film is removed from the camera and replaced with an unexposed film. The exposed film is stored in a cut-film developing tank; the slots in the tank being a ready means of separating the various exposures. Two or three shots are taken from each position and stored together.

The camera and flash can be directed as desired, although at present we have no control over the orientation of the side-facing shots. With down-facing shots the five second shutter delay allows a manually operated flash to be used to illuminate the floor before the shutter closes. This enables the photo to be oriented. A person with quick reactions is needed to fire the second flash.

Film Processing

Since most shots are underexposed, development times are pushed well beyond those recommended by the supplier. With a number of shots taken from each position only one at a time is developed so that after examination of the exposure, the development times of the rest can be adjusted to suit. Due to weight considerations, only a small electronic flash unit can be used. The resulting photos therefore, are more underexposed than those exposed by flash bulbs.

Future Improvements

Improvements that could be made in the future include:

(a) use of colour film,

(b) means of directing the camera for high-level side-facing shots,

(c) use of a reeling device and counter so that heights photographs are taken from are more accurately known, and

(d) use of hydrogen instead of the more expensive helium.

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ISS unpublished Wyanbene trip reports.

Plate 6. The Gunbarrel, Wyanbene Cave, looking down from an altitude of about 60 m. The round dots near the bottom are toy balloons tethered about 8 m. above.

ELECTROMAGNETIC UNDERGROUND POSITION LOCATION

GREG HURST*
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Abstract

The technique of electromagnetic underground position location using induction coupling (often referred to somewhat incorrectly as radio direction finding) has been tried and used with varying degrees of success by a few people over recent years. However, it appears that the full capabilities and limitations of this technique have not always been appreciated. This paper outlines the theory and problems with the technique and will attempt to show how optimum performance and full use of the techniques capabilities may be achieved. A recently constructed apparatus with the capability of accurate position location through at least 250 m of limestone will be described. This sort of range renders this instrument very useful indeed as a means of externally closing long survey loops as well as other obvious and not so obvious applications.

Introduction

One of the main purposes of underground surveying of caves is to enable the spatial relationships between passages and surface features to be determined. Electromagnetic devices which enable such relationships to be determined through solid rock without line of sight are undoubtably useful tools in the study of speleology. This paper examines the principles involved in underground electromagnetic position location (often referred to as radio direction finding or RDF) and describes new position location apparatus with a useful underground location range of 500 m.

Basic Principles

Consider two coils of wire placed side by side on a common axis. If an alternating current is passed through one of the coils, the primary, an alternating magnetic field will be set up and this will induce an alternating current in the second coil, the secondary. This principle of electromagnetic induction is of course the basis of the transformer. Now if we rotate the plane of the secondary with respect to that of the primary, the secondary coil will intercept less of the magnetic field and thus less current will be induced in it. Finally, if the secondary is rotated until it is perpendicular to the primary (though still on axis) no magnetic field passes through the secondary coil and thus no current is induced in the secondary.

Location Principles

Now consider the shape of the alternating magnetic field set up at a distance from a horizontal primary coil carrying an alternating current. Figure 1 shows the lines of magnetic flux set up in a vertical plane through the centre of the horizontal coil. Several features of this magnetic field are of particular interest.

Firstly, it is noticed that the magnetic field is vertical at any point directly above (or below) the primary coil. Thus if a secondary coil is held vertically, then at a point directly above the primary coil no current will be induced in the secondary. This forms the basis of a position location apparatus. If a detector is connected to the secondary coil, then it is simply a matter of moving the coil (held vertically) around until the null is located. As it lies on the steepest part of the sine curve, this null is very sharply defined and thus easily determined and is obviously quite independent of distance between the two coils. It should be noted that the discussion has thus far been confined to one plane. In three dimensions a null will occurr whenever the plane of the vertically held secondary coil passes through the centre of the primary coil. To pinpoint the position directly above the primary coil it is therefore necessary to find the position where a null exists independent of

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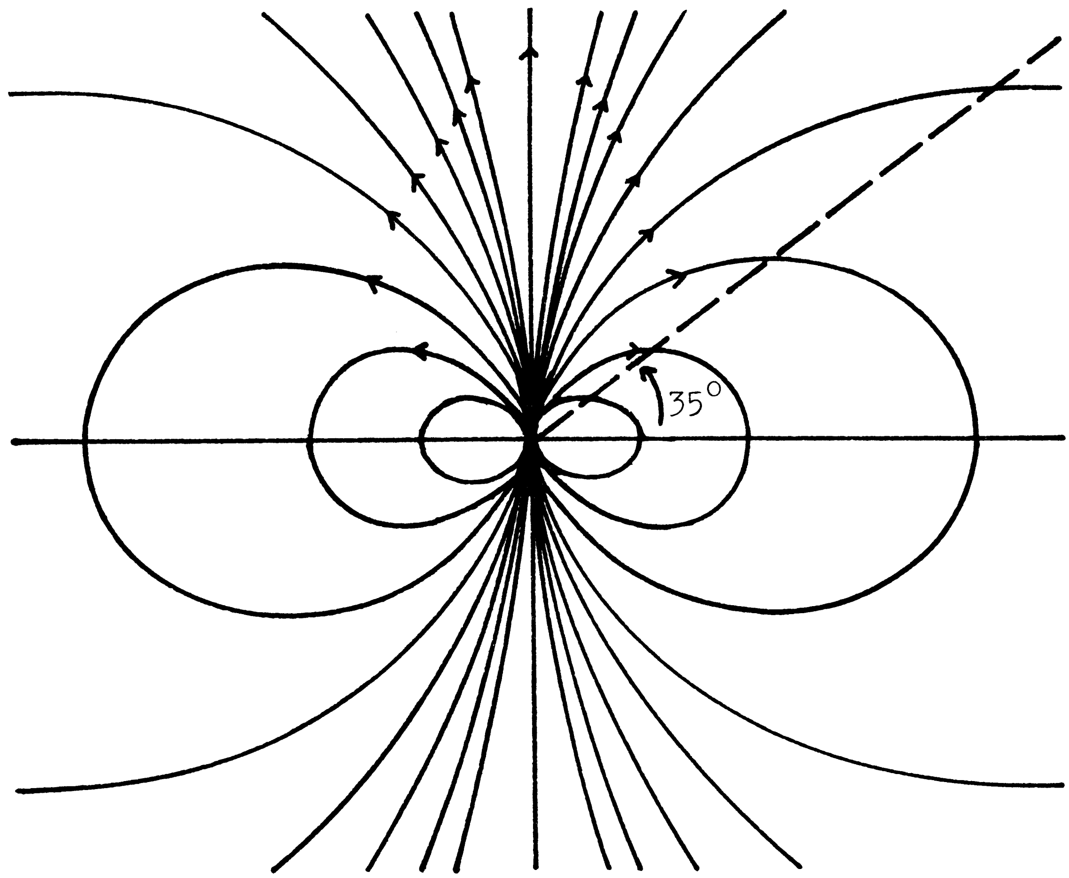

Fig. 1. Magnetic field shape.

angle of rotation of the coil about a vertical axis. The direction in which to move to get to this complete null may always be determined by rotating the coil until a null appears at one particular angular orientation. The plane of the coil then points in the direction of the primary coil below.

It will also be apparent from figure 1 that the magnetic field lines are also vertical anywhere in the horizontal plane containing the (horizontal) primary coil. Thus we may use a similar procedure to detect when the two coils are at the same level.

Finally, figure 1 shows that the magnetic field lines will be *horizontal* at any point such that the angle of inclination between the two coils is approximately 35 degrees. Thus by holding the secondary coil horizontally and locating a null, the distance between the two coils may be found with the aid of a little rudimentary surveying between this null and that found directly above (or beside) the primary coil.

Many other procedures to accomplish specific tasks may be devised involving different orientations of one or both of the coils, however, those described above form a most useful basic set of underground position location procedures.

One interesting further feature of the magnetic induction field should be noted. It will perhaps be apparent from figure 1 that if the primary coil is not placed exactly horizontally (i.e. levelling error) then the point where the field lines are vertical is not now directly above the primary coil. However, the point is not on the axis of the primary coil either. The null in fact will occur on a line at an angle from the vertical equal to 1/3 the levelling error angle for small (less than 30 degree) angles. The primary coil may thus be considered to be partially self-levelling (or "2/3 self-levelling" perhaps).

Electronic Design Considerations

The aim of any good design of electromagnetic position location apparatus is to gain maximum useable range at maximum accuracy and precision. Unfortunately many factors make the achievement of these objectives difficult.

The first problem lies in the fact that the medium through which we wish to transmit an electromagnetic signal is conductive. This means that any signal suffers attenuation, particularly at high frequencies. In order to minimize attenuation and eliminate the guiding or channelling of the signal through cracks, voids and other discontinuities in the inherently non-homogeneous medium, it is necessary to choose an operating frequency in the mid audio range. At such frequencies a directional antenna has undesirably immense dimensions and thus we are forced to use the induction principle previously outlined. This has the unfortunate disadvantage that the received signal strength is inversely proportional to the cube of the distance between transmitter and receiver. Thus any improvement that doubles transmitter output or receiver sensitivity gains only 25 percent improvement in usable range.

Many position location apparatuses in the past have suffered from inadequate range due to a lack of appreciation of the optimum design procedures. I shall start by considering the transmitter end. The most important aspect of transmitter design lies in the design of the coil. The transmitter itself should consist simply of a square wave oscillator and fully driven class B power amplifier. The coil should be connected to the transmitter output via a series capacitor such that the combination forms a series resonant circuit at the operating frequency. The design of the coil is based on three constraints. These are maximum permissible weight, maximum permissible size and maximum permissible battery drain. The strength of the transmitted magnetic field is proportional to the number of turns times the current times the area of the coil (NIA). If we wish to maximise this product it is easy to show that for a given allowed weight of copper we want a circular coil of as large a diameter as possible wound with as heavy a gauge of wire that transmitter current drain will allow. (For a given area of coil it should be obvious that doubling the wire cross-sectional area and halving the number of turns will leave the weight unchanged but will reduce the coil resistance by four times thus increasing current by four times and doubling the NIA product.) The maximum current drain is in turn based on the maximum weight and hence capacity of battery allowed and the minimum operating time required. Most of these constraints are based upon what the underground party is prepared or is able to carry through the cave.

Design of the receiving (or search) coil is based on the same principles. In order to intercept as much of the magnetic field as possible the coil should be as large as possible. To further maximize the induced signal voltage we want a maximum number of turns. The limit to the number of turns possible is determined by the self resonant frequency of the coil. As the number of turns is increased, both the inductance of the coil and the capacitance between turns increases thus lowering the self resonant frequency. We want a coil whose self resonant frequency is just above the system operating frequency so that the coil may be tuned to resonance at the operating frequency with a small tuning capacitor in the receiver. Finally, the gauge of wire will be determined by the total copper weight that can be tolerated; bearing in mind that the coil must by easy enough to support in one hand for reasonable periods of time. It is important that as heavy a gauge of wire as possible be used as the copper losses have a significant effect on the magnitude of the received signal.

The receiving coil designed as above will have a considerable peak in its response at its resonance frequency thus providing a useful degree of pre-selectivity: In order to preserve this selectivity and sensitivity the coil Q must not be damped significantly by the input resistance of the receiver front end. The receiver should thus consist of a high gain, low noise, high input impedance amplifier plus a band-pass filter to remove noise outside the narrow band of interest. It is of paramount importance that the input stage of the receiver be painstakingly designed for minimum noise as it is receiver input noise which ultimately limits the detection range of the equipment.

One major problem with high gain, high input resistance amplifiers lies in their susceptability to capacitive feedback. This problem can only be solved by very careful shielding of the input from the output and requires considerable attention to system layout.

A Practical Design

Figure 2 shows a block diagram schematic of an electromagnetic underground position location apparatus designed along the above lines.

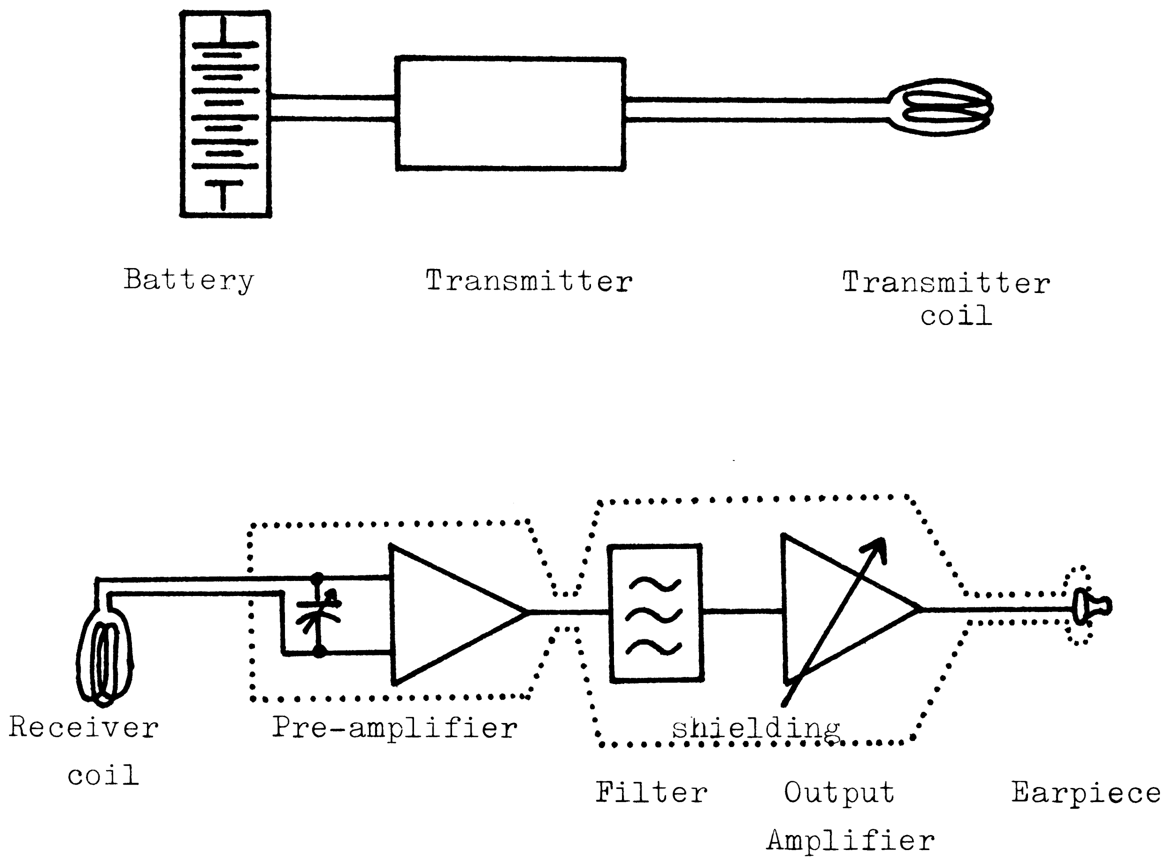

Fig. 2. Block diagram of a practical system.

The transmitting coil consists of 230 turns of 15 B&S gauge wire wound around a wooden former 35 cm in diameter. The former is supported on three brass bolts which function as levelling legs. Levelling is achieved with the aid of a surveyors bubble level mounted on the coil former. The transmitter is a simple square wave oscillator and fully driven power amplifier driving the coil via a series capacitor. A fine tuning control is provided to tune the transmitter frequency to the resonant frequency of the load. To aid tuning, a Light Emitting Diode (LED) level indicator is incorporated to detect maximum coil current. The whole unit is powered by a 12 volt motorcycle battery. Resonance occurs at about 2 KHz with about 600 volts peak-to-peak developed across the coil. The battery drain is about 1 amp and this allows about 6 hours of continuous operation. The total transmitting system weight of 9.7 kg is made up predominantly of 5 kg for the coil and 4.5 kg for the battery.

The receiving coil consists of 2200 turns of 33 B&S gauge wire wound on a 55 cm diameter wooden former. The coil, which weighs 4 kg, is suspended from a handle by two cords such that it hangs perfectly vertically. The receiver consists of a low noise pre-amplifier with a gain of 500 and an input resistance greater than 50 megohms. A tuning capacitor is incorporated at the input to tune the coil to resonance at the transmitter frequency. The pre-amplifier is followed by a band-pass filter with 2 KHz bandwidth and 18 dB/octave cutoff slopes. A final variable gain stage with a maximum gain of 1500 is used to drive a shielded crystal earpiece which constitute the detector. The receiver is powered by two pairs of 9 volt transistor batteries which provide for a battery life of about 30 hours of continuous operation.

The set-up has been tested and used successfully at Yarrangobilly. It has a maximum usable range of 500 m through limestone. With the transmitter 60 m below the surface, position location precision was plus or minus 5 cm, at 170 m precision was ±50 cm. This range and precision is considered quite adequate for use in any Australian mainland caves, however, improvements are being developed to further enhance performance. An experiment in level detecting in the Yarrangobilly tourist caves was considerably less successful due to the presence of high levels of interference from the locally generated power for the cave lighting. This remains the main bugbear with this type of equipment. At reasonable distances the magnetic induction signal is very small and sensitive receivers are easily overloaded with any extraneous signals such as invariably occur near civilization. This is no problem in the isolated caving areas that hold most of our interest, however, significant areas do occur close to interference sources and in these areas this severely limits the effectiveness of position location apparatus of the type described. But then, life wasn't mean't to be . . . . !!

In response to several requests, a complete constructional description of the unit described will be published at a later date.

CAVES AROUND CANBERRA

J.N. JENNINGS*

Abstract

The purpose of this paper is to illustrate, primarily for the beginning speleologist, fundamental ideas about limestone cave origins and evolution from caves around Canberra. First, important generalities about the nature of the tiny, impounded karsts involved are set out. Then follows a summary of the relevant hydrodynamic contexts with their related cave morphologies, in which two new terms are introduced to help avoid some misconceptions which arise from present terminology. Next some of the ways, in which these different types of speleogenetic action may combine over time and spatially, are exemplified from local cases. In this the importance of rejuvenation of drainage and relief is apparent but it is stressed that the intervention of very localised factors, especially details of geological structure, tends to be neglected. Some indication of the part that Pleistocene climatic changes may have played in the caves' development is given and the need for more work in this direction, in which cave sediments provide vital evidence, is underlined. Finally, the problems of cave chronology are touched upon, with particular reference to the very difficult case of Bungonia.

Introduction

At the 11th Biennial Conference of the Australian Speleological Federation an account of certain caves around Canberra to illustrate the basic principles relating to the origin and evolution of limestone caves was incorporated in the conference guidebook (Jennings 1976a). In so far as the area close to Canberra was inadequate for this purpose, reference was made to places farther afield in Australia (though the nearest caves that could provide the necessary examples were chosen). So that this discussion will reach more Australian speleologists it has been decided to include it in the proceedings of the conference. Some changes in writing style have been made for this different kind of publication and certain sections have been revised to accommodate subsequent discussion and further field work.

Regional Characteristics of Importance for Cave Formation

The caves around Canberra belong to tiny, impounded karsts, that is the body of carbonate rock is entirely surrounded by impervious rocks. So what goes on in the limestone is very much affected by surrounding areas. Large amounts of water are poured onto and into the limestone from outside, with particular chemical characteristics and with loads of foreign sediment of varied sizes. Generally these waters are aggressive towards limestone because they have carbon dioxide in solution which was not used up in reacting with the surrounding rocks such as the igneous rocks which commonly abut upon or surround limestone in the area. However, in dry spells so much water loss takes place by evaporation and transpiration that these incoming waters may be rich in solutes and not very aggressive towards limestone since they already have much calcium and magnesium in solution. Nearly all the caves have deposits of quartz sand and foreign rock fragments which either are being carried through the caves currently or formerly were so entrained. Therefore mechanical attack on the rocks may be more important in our caves than in those of larger limestone areas.

Precipitation is unreliable, both seasonally and from year to year, even though this is a part of Australia with a lesser degree of such unreliability than most. There are prolonged droughts, which may last several years, and prolonged and heavy rainfalls cause floods at any time of the year. Yarrangobilly and Cooleman Plain are also liable to occasional long periods of snow cover, the chief importance of which may be big flows of water if heavy rainfall combines with their melting as is sometimes the case.

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All the areas are made up of strongly crystalline and highly compacted limestone or even more crystalline marble, generally of high calcite purity, all of low intergranular porosity but highly jointed and sometimes cleaved. It is on this fissuration that passage of water through these rocks depends. With this secondary permeability any notion of a watertable has to be a highly qualified one.

The limestones are of Silurian and Devonian age and they have been caught up in earth movements of Late Silurian and of Middle Devonian age, which have folded and faulted them considerably. Practically nowhere do they lie horizontally. This has the distinct investigatory advantage that more or less horizontal parts of caves are not likely to be a consequence of rock type and arrangement.

Despite the mechanical strength of the limestones here they are more subject to attack and removal by geomorphic agents than many of the rocks which surround them, primarily of course, because of their greater solubility in natural waters. Therefore they are eroded differentially and tend to form lower parts in the relief than the surrounding impervious rocks. At Wombeyan and Cooleman, the Silurian carbonate rocks occupy small basins surrounded by higher plateaus or ranges in igneous rocks. At Cooleman there is also an extension of limestone down the gorges of Cave Creek and the Goodradigbee River valley. This extension resembles the situation at Wee Jasper where Devonian limestones crop out along the bottom of the Goodradigbee valley and that of its tributary, Wee Jasper Creek, even though it does form the well-known but modest protuberance of Punchbowl Hill. Silurian limestone at Yarrangobilly again follows the valley line, recessed relative to igneous rock on one flank and other sedimentary rocks on the other. At Bungonia the relationships are less obvious because the local relief on the plateau is small; nevertheless the limestone strike belts are overlooked by gentle hills of more resistant siltstones, sandstones and quartzites belonging variously to the same Silurian rock formation, to the underlying Tallong Beds and to the overlying Devonian rocks.

Combine this recessiveness in the general relief with the impounded nature of the karsts and with the nature of the precipitation and the result is that these patches of limestone are subject to extremely variable amounts of water and erosional attack, both chemical and mechanical.

A fifth generality which has to be borne in mind constantly is that in all these areas an essential characteristic of the geomorphology is the rejuvenation of the drainage by tectonic uplift of the plateaus in which these tiny bits of limestone are set. The incidence of river incision is crucial. Its effects are most striking at Bungonia and least at Wee Jasper where the river has cut only a little below the limestone. At Yarrangobilly the limestone forms a broad and high shelf or strath on one side of the valley; this was the former valley floor but a gorge has been carved more or less along the western side of the limestone. The basins at Cooleman and Wombeyan differ somewhat in that a strikingly planate surface of erosion in the limestone largely survives at Cooleman though encroached upon by gorges whereas the Wombeyan marble was reduced to hilly relief before gorges developed through later rejuvenation. There are indications that it was similarly an enclosed plain in the past.

Active tectonic movements may be involved in speleogenesis in places like New Guinea, even creating voids and certainly affecting the development of erosional voids. In southeastern Australia the earth's crust has been much more stable for a long time. Some faulting has taken place in the Tertiary and shifts may still be taking place along faults such as the Berridale Wrench Fault and the Jindabyne Thrust Fault (White and others 1976). The Lake George Fault appears to have been reactivated in the Tertiary, though recent work (Coventry 1976) proves there has been no movement in the last 20,000 years. As yet no faults have been demonstrated to have been active in young geological times in the karst areas around Canberra and the most to be attributed to this factor is that earthquakes may act as triggers to rockfall from roofs and walls of caves when solution along joints and bedding planes has already prepared blocks of rock for detachment by gravity. But, of course, the structures of the rock inherited from earlier earth movements exert great influence much later on the course of active agents of cave formation. An outstanding local case is Narrangullen Cave, Taemas. A small body of Middle Devonian Limestone survives there in a downfold due to Taberabberan (Middle Devonian) earth movements. The cave passes through this inlier of limestone along the axis of the syncline; in detail the cave switches from one side of this structural axis at the upstream end to the other at the downstream end.

It follows from the generalisations already made that the karsts around Canberra fall into the category of 'fluviokarsts' of Roglić (1960) as Sweeting (1972) has already recognised. Fluvial processes are as important as distinctively karst processes. Surface river valleys, especially gorges, dominate the landscape; streamsinks, blind valleys and dry valleys are usually more important than dolines. One character frequently found in fluviokarsts does not apply however. The rivers do not

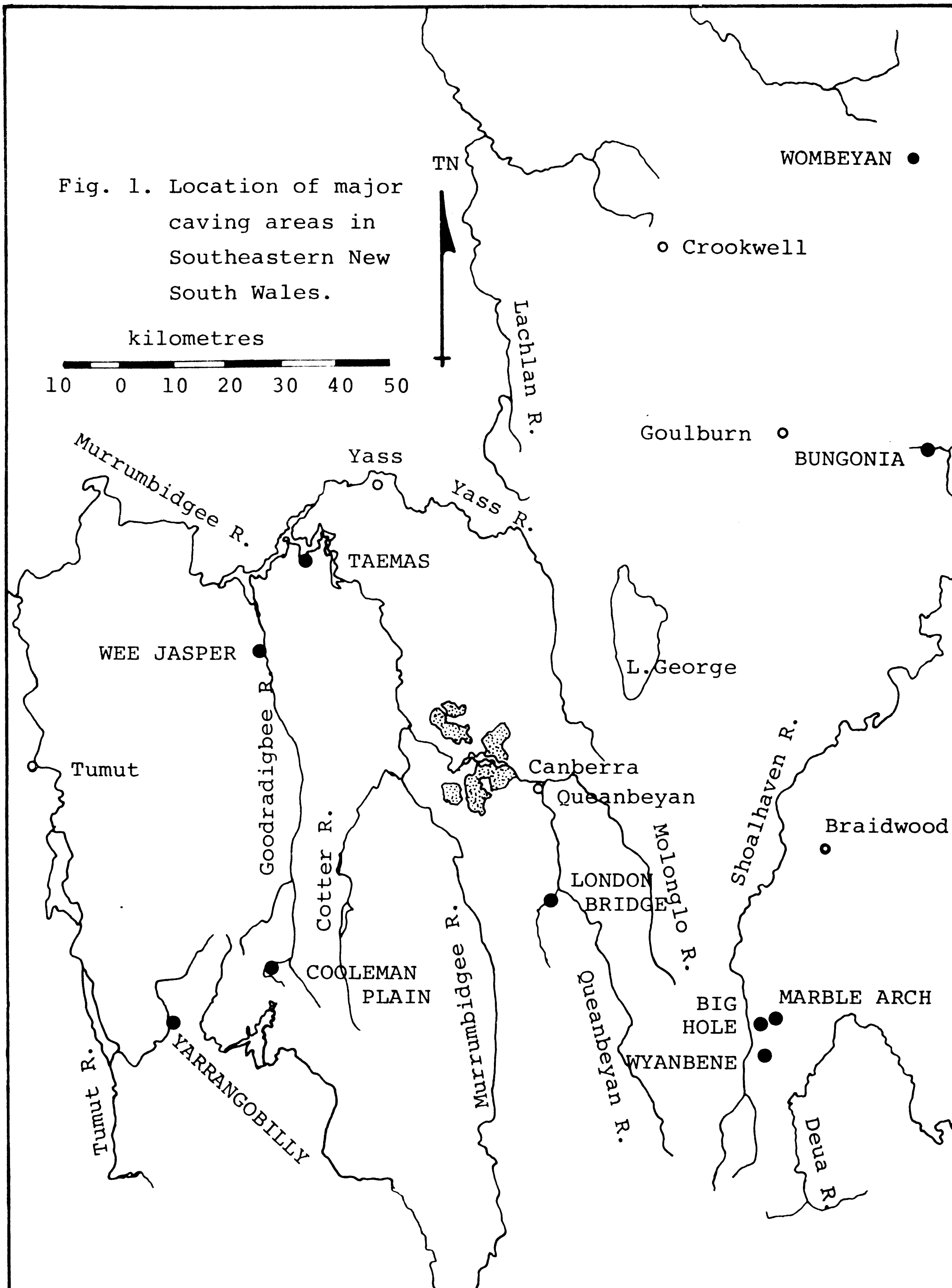

Fig. 1. Location of major caving areas in Southeastern New South Wales.

cut down through the karst rock and compartment it into blocks with impervious basement between. Instead the carbonate rock reaches deep below the lowest associated drainage lines.

Some Elements of Speleogenetic Theory

Most of the general systematic ideas held about the development of karst caves are relevant for the karst areas around Canberra.

Solution is the prime process, though it is true that for a long time there has been neglect of the mechanical aspect of water erosion in caves. Newson and Smith's quantitative work in the Mendip Hills of England has shown this to be a greater factor than has latterly been overtly recognised. Though in total removal of material, mechanical erosion remains subordinate to chemical erosion in the Mendip, (Newson 1971, Smith and Newson 1974), they tend to operate at different times and places within the system. The importance of the mechanical aspect with regard to caves is undeniable and in Mendip there are only small inliers of non-karst rocks to supply durable tools to the cave streams whereas, as mentioned already, in the karsts around Canberra much larger supplies are available to our caves surrounded as they are by other than carbonate rocks. So it is the hydrodynamic circumstances in which solution, and in certain phases mechanical erosion, operates underground that primarily concerns speleogenetic theory.

The contexts relevant to the understanding of the caves near Canberra are those of (a) vadose seepage, (b) vadose flow, (c) the nothephreas and (d) the dynamic phreas; other contexts such as the artesian will be disregarded here. Simple cases will be employed to illustrate the different process regimes at first.

Vadose Seepage

In practically every caving area near Canberra there are numerous simple shafts or rifts leading down from the surface more or less vertically. They commonly express strong structural guidance, joints and joint intersections usually, but it can be bedding where the rocks are on their side as, for instance, in Jap's Hole on Punchbowl Hill at Wee Jasper. Igneous dykes may encourage their development as for instance in an example at Wombeyan. They may open from level or sloping planar surfaces, from hollows or even from gentle convexities. The Putrid Pit at Bungonia illustrates very well how a series of pitches succeed one another downwards, not quite precisely above one another, in different joints. Their walls may be vertically scored by long grooves with sharp ribs between, in German they are called *Höhlenwand Karren,* which can be translated as cave wall solution runnels. They are commonly wider and longer than solution flutes *(Rillenkarren)* on surface outcrops.

These shafts are usually the result of solution by rainwater or soil water seeping downwards through the rock under gravity in a zone where voids are only intermittently or partially filled with water. They may narrow downwards, remain more or less uniform in plan or widen downwards, ending in a blockage of rock fragments, clay, earth or other debris more commonly than in bedrock closure.

As it is known that this vadose seepage often reaches saturation levels for calcite solution at shallow depths, downward closure of the bedrock walls is the easiest form to understand as regards process. The other modes may be due to organic matter in the seepage water, which may generate carbon dioxide biologically during descent to maintain or even enhance aggressiveness towards calcite (Jennings and others in press). Both these explanations imply development from the top downwards. However, it may be that vadose seepage shafts often develop from below upwards, water percolating through planes of weakness for some distance before the process of solutional widening begins. If solution begins below and extends upwards, then greater length of time for solution below could produce forms widening downwards.

Of relevance to this view are blind shafts, which extend upwards from caves but do not reach the surface. Sometimes these features are known to reach nearly to the surface; indeed open shafts often have blind shafts in close conjunction. Some former blind shafts have certainly punched through to the surface, no doubt with a certain amount of help from collapse of blocks, partially detached by solution.

The finest blind shaft near to Canberra is undoubtedly the Gunbarrel in Wyanbene Cave, 105m high and beautifully ornamented by solution runnels. It is, however, a special case since it reaches through the Silurian limestone, which walls it, to overlying, unconformable Devonian conglomerate. When the Gunbarrel was discussed previously (Jennings 1967a), this circumstance was not known for certain, though neighbouring blind shafts in the cave were proven to do this. However, N. Anderson searched more vigorously than had been done before and found a cobble of unmistakable purple Devonian conglomerate beneath the shower bath that prevails in the Gunbarrel. Burke & Bird (1966) regard diffuse input of aggressive acidic water from overlying jointed sandstone into the Carboniferous Limestone of South Wales as highly conducive to the formation of blind shafts by vadose seepage waters.

Vadose Flow

The cave context where cause and effect are most obviously related is that where a stream equipped with sand and gravel similar to a surface stream with an air space above is rushing through a cave over rapids and even waterfalls. For instance, if the gorge of Mares Forest Creek at Wombeyan is compared with Creek Cave through which Wombeyan Creek penetrates some 250 m of marble, many features are found to be in common because the same processes are operating in the same way. All the mechanical actions of a river are obvious, especially in flood time, and also the invisible action of solution, for which chemical measurements may often be necessary as proof, is evident from scallops or current markings. Circular depressions in the bed, a result of rotary motion, are here a product of solution as well as of abrasion and so they are best called swirlholes, rather than rock mills and certainly in preference to potholes (a most confusing term in the speleological world). Plunge pools at the bottom of waterfalls can be regarded as special cases of swirlholes. Rounded channels and chutes in the stream bed along the line of flow and asymmetrical horns between swirlholes are other characteristic features.

Underground streams tend to meander as do those on the surface so winding passages develop with meander niches in the walls where lateral erosion accompanying channel deepening leaves a succession of curving bevels like an inverted arena. Similarly inverted equivalents of meander spurs or cusps may be left in the roof. However, without such sideways swinging, a free surface stream often makes a series of semi-circular recesses along the walls one above the other, which can be called channel incuts. If deepening proceeds much faster than lateral solution, a canyon may be produced, sometimes meandering though it may not always escape straightening by structural control, but usually leaving some signs of former streambed levels which have been occupied at different stages in its formation. Scraps of fluvial sediment left in niches and incuts are sometimes misinterpreted as evidence for a stage of drastic filling of the cave.

Vadose flow in the small areas of limestone near Canberra is prevailingly associated with streams from the surrounding rocks disappearing underground. A typical case is Cormorant Cave in the Goodradigbee valley near Cooleman Plain; a small stream comes off the steep granite slope of Jackson and enters a cave almost as soon as it encounters the limestone through which it falls in a rather direct vadose passage to the Goodradigbee. However, vadose streams can gather together from seepage water and be quite independent of streamsinks. Originally diffuse flow in the limestone becomes concentrated. Lack of large areas of karst near Canberra militates against clear cases of this kind though the process contributed to all the underground streams. However, the stream in Wyanbene Cave falls into this category. No streamsinks have been found on the limestone outcrop or on the cap of Devonian conglomerate and sandstone on the ridge behind so it must simply be a gathering of seepage from above, exemplified in the shower of drops that one experiences in the Gunbarrel already mentioned.

Seepage waters rapidly become much richer in calcium and bicarbonate ions than streamsink water does. Such seepage waters commonly form stalactites and other speleothems, even stalagmites, in active vadose stream passages, though of course this goes on more freely, with less liability to removal, in passages abandoned by stream flow. A corollary should be that rimstone dams are more likely along a vadose stream channel fed by seepage water than one fed by streamsink water. This is not well evidenced in Wyanbene Cave. Base flow in Black Range Cave at Cooleman Plain is also a collection of seepage water, though it is possible that this is supplemented after a heavy rain by some overland flow entering its entrance doline. Where flow is first met in this cave, there is a good development of flowstone floor and small rimstone dams. Farther in, however, there is a normal streambed so additional water forming the stream may be less rich in solutes.

This contrast between vadose flow derived from sinking surface streams and from seepage is relevant to the outstanding hydrogeological problem at Wombeyan. None of several water tracing exercises there has yet revealed the source of the stream in the Bouverie-Bullio-Mares Forest Creek Caves system (James and others in press). This aligned system heads in the direction of Wollondilly Cave and the geomorphology suggests that some Wombeyan Creek water is diverted into the right bank of its valley, though most goes into the Fig Tree-Junction Caves system in the left bank. Nevertheless no such connection has yet been proven. There is more rimstone dam development in Bullio Cave than in other active river caves at Wombeyan and the calcium and bicarbonate content of Mares Forest Creek cave water is much higher than that of Junction Cave, though both are depositing tufa where they emerge. Nevertheless this content is not significantly greater than those of W47 Spring and some other springs in Wombeyan Creek gorge known to have streamsink water feeding them. Moreover the problematic underground stream seems to have too much water for the area of seepage supply (likely on topographic and geological grounds) to be adequate (Jennings and others in press). The answer may be that it has a larger proportion of seepage water than other underground streams yet it is also fed by a streamsink supply which has still to be identified.

Vadose flow caves are characteristically dendritic in pattern, that is one stream passage joins another to form a larger one like branches of a tree ultimately fusing to form a trunk. Again the small size of the karsts around Canberra militates against much development of this kind, the simple case cited of Cormorant Cave being typical around Canberra. There is a short confluent tributary stream passage in Barber Cave, Cooleman Plain, but it is likely that this is only another line of entry of the stream which flows into the Wet Entrance of the cave from Black Mountain. When in rare occasions in flood time Murray Cave (Cooleman Plain) functions, it receives a tributary along the branch to the north, probably of seepage origin. But Murray Cave is going out of action as a stream cave and even this is not a very good example. Of course, cases are known of separate vadose inflow caves feeding the same spring, e.g. the drainage system of Coppermine Cave at Yarrangobilly; nevertheless dendritic patterns of active vadose passages have not yet been explored there.

The Nothephreas

A turbulent underground stream with airspace above cannot form a cave; it can only enlarge what has been produced in some other way, though it may be only a small thoroughfare penetrating the rock which it inherits. The chance that tectonic activity or erosional offloading or gravitational slip has not only created a connected chain of voids large enough for such flow but created them where one end can collect a surface stream and lead it down to another lower end where it can be disgorged is rare. Therefore most caves inevitably start from tiny tubes and half-tubes that have been dissolved by water saturating the rock mass and developing minuscule threads of flow which take advantage of any planes and other loci of weakness, including such initial voids as there may be. These tiny tubes form anastomosing patterns, forking and rejoining in complex ways, not simply in single planes (though this is the manner in which they are seen most frequently as for example in the Opera House in Fig Tree Cave, Wombeyan) but three-dimensionally.

The phreas is the name for the hydrological zone in rocks where all voids are filled with water. Although this zone takes on a very different character in compacted rocks of low intergranular porosity such as occur around Canberra from that which it possesses in deposits of sand and gravel, for example, the term is used for both. A very important characteristic common to both situations is that water does not simply move downward from a high point to a low point as in a surface channel over impervious rocks but can follow all manner of courses, downward and later upwards, from a high part in the phreas to a lower one.

Because of this a cave can take on a distinctive style if solution continues to go on in phreatic conditions after connected ways through have been established, but without rapid flow being established. Spongework caves develop with irregular cavities of various dimensions interconnecting to form a complex maze. Only diving can reveal such caves in their active state and none have yet been discovered in the Canberra area in this way; the southeast of South Australia is a better hunting-ground for them. However, they may survive in large measure to be still recognisable after being emptied of their water and becoming inactive. Much of Basin Cave at Wombeyan is of this nature. In some of the Walli caves there is the same aspect though joint and bedding control of the pattern is much more evident there. Dip Cave at Wee Jasper has suffered so much breakdown and secondary deposition that its origins are not as clear as might be wished though its set of parallel passages strongly governed by nearly vertical bedding bears no obvious relationship to relief and drainage, and seems to be dominantly due to slow phreatic solution (Jennings 1963). Spongework is limited, however, and more common are symmetrical hollowings on bedding plane surfaces indicative of eddying flow but no substantial current.

Caves of this type, the phreatic caves of W.M. Davis and J. Harlen Bretz, have latterly tended to be called deep phreatic or true phreatic caves to distinguish them from shallow phreatic caves to be discussed next. However, any phreatic cave is truly phreatic if the interpretation that development took place in a water-filled state is correct. Nor do caves of this type require very deep circulation. In some circumstances they can form close to the surface and within a narrow vertical zone as, for instance, caves such as Easter Cave near August, W.A. in Quaternary aeolian calcarenites, which are dominantly spongework caves. Therefore the terms 'nothephreas' and 'nothephreatic flow' are proposed in this connection, "nothes" being the Greek for 'sluggish' or 'torpid'.

The Dynamic Phreas

If there is an appreciable head of water tending to drive water through a developing phreatic system at some speed from higher to lower levels, there is a strong tendency for a few routes, indeed ultimately a single route, to grow at the expense of others. As a tube gets larger, the effect of frictional drag on its surfaces becomes proportionately less, so the speed of flow increases and the mass transfer of solutes from the rock-water interface proceeds faster also. There is positive feedback in the system.

In these conditions, pressure conduits develop of circular or elliptical cross-section, with solution attacking all surfaces. If the ellipse is disposed horizontally, there may or may not be structural control; if it is vertical or inclined, such control is operative. Because of hydrostatic head, pressure conduits can rise and fall along their length and such loops in long profile are likely to be structurally controlled. A common arrangement as Ford (1971) stressed some time ago from Mendip examples is for conduits to descend in dipping bedding planes and rise in chimneys in joint planes. Ford and Ewers (pers. comm.) distinguish between 'bathyphreatic' (a term originating with Glennie) and 'multiple loop' caves. In 'bathyphreatic' caves, the pressure conduit describes one big downward loop to considerable depth, though this may be complex in detail; in 'multiple loop' caves, there are many down and up loops reaching to a common level, the rest level of water in the cave system or the watertable of general hydrological literature.

Dynamic phreatic action of these types is even more difficult of exploration in the active state than the nothephreatic state just described and once again no local instances can be provided. Even relict, abandoned systems of this type are rare. The best instance seems to be in Odyssey Cave at Bungonia where James and Montgomery (1976) have demonstrated with the aid of current markings a former phreatic loop of 45 m amplitude, now eliminated by a horizontal shortcut of the stream which formerly fashioned it. It is interesting to note, however, that this dynamic phreatic loop has as great a depth as any that can be demonstrated in the Canberra area for nothephreatic action, once again indicating that the adjective 'deep' should be avoided for the latter.

The mention of current markings in this connection is salutary because some speleologists have tended to associate scallops with vadose flow only. Ceiling scallops are commonly observed in pressure conduits, demonstrating that this restriction is false. Likewise mechanical action is not restricted to vadose passages. Sand and gravel can in fact do a great deal of work in pressure conduits.

Known phreatic lift in the Canberra area is usually much smaller than the example cited from Odyssey Cave, and is typified by the 6.5 m amplitude of the inverted siphon of the first watertrap in Murray Cave, Cooleman Plain, still intermittently in action (Jennings and others 1969). This is in keeping with the fact that in the Canberra area the dynamic phreatic action is what has been called that of the water table stream by Swinnerton, epiphreatic by Glennie and shallow phreatic by Davis. With this there is development of a more or less horizontal pressure conduit at or close below the level of the spring which it feeds. In the absence of structural conditions forcing downward loops in the phreatic circulation, action concentrates at the top of the phreas. Here the shortest route can develop with dynamic advantage. There are many abandoned examples in the area to some of which reference will be made below and there is good reason to think that active examples as yet unexplored link such points as Eagles Nest Cave and Hollin Cave at Yarrangobilly and Odyssey Cave and The Efflux at Bungonia. These links are at the bottom of the deepest cave systems in the Australian mainland so care must be taken not to be misled by use of the term "shallow phreatic action" in this connection; 'shallow' refers to the narrow amplitude of the dynamic phreatic action involved.

Cave Breakdown and Offloading

Another process in cave development – cave breakdown – has been referred to already but it needs further comment. The inward fall of blocks from cave roof and walls cannot by itself enlarge a cave because the fallen material occupies a substantially larger volume than the space it previously took up. For a cave to be stoped upwards by this process there has to be progressive removal of material from below, mainly of course by solution though there is also some traction of material along a cave stream.

It has been proposed that a favourable circumstance for cave breakdown is when a cave ceases to be waterfilled, e.g. when phreatic conditions are replaced by vadose ones. This is no doubt so but there is plenty of evidence from the successive incorporation of speleothems into rockpiles that it can be a protracted process persisting long after such draining of a cave. A vadose stream undercuts walls to this effect. Additionally, Renault (1970), amongst others, has stressed the importance of residual stresses in the body of the rock which will tend to be released by movement of rock into the voids created by erosional processes. Again there is positive feedback in this effect, the enlargement of the cavity makes more breakdown possible than before as long as material is removed for its accommodation.

A related point of Renault's is that offloading through loss of material from valley walls, mainly by solution, can cause sheeting joints more or less parallel to the valleyside, which promote cave formation in such locations. This needs to be considered with regard to some of the caves around Canberra such as Cooleman-Right Cooleman Caves and Wyanbene Cave. Some means of testing this idea needs devising because both of these linear caves paralleling a neighbouring valley also run along the strike.

The locations of pronounced breakdown within cave systems also call for explanation. At Yarrangobilly, for instance, big rockpiles are encountered shortly after entry into several of the more important inflow or streamsink caves such as East Deep Creek Cave. Is it simply that the sinking streams are most effective in their erosional action here, and bring about most collapse by undermining?

Combination in Time and Space

In the past the tendency was to lay stress on one or other hydrodynamic context as favourable to cave formation and the result was controversy in which one such context was set against another as the locus of cave genesis. These attitudes have long seemed quite mistaken to many speleologists. Their persistence has eventually led to overt criticism. In the Speleo Handbook (1968), I wrote about cave theories "that each of the mechanisms envisaged does operate and that nearly all caves are composite in origin. The problem is to determine the relative importance of each kind of action in producing the present form and pattern of each cave system". Monogenetic approaches have been attacked by White (1969) and Ford (1971), each identifying a variety of modes of cave evolution applicable to different circumstances. Relying mainly on his knowledge of karst areas in central and eastern United States, White based his types on overall geological structure. Ford (1971) and Ford and Ewers (pers comm) depend on examples from N. Canada to Mexico in N. America and from Britain for their scheme which incorporates a wider range of controlling factors. It will be useful to relate the caves around Canberra to their findings.

Meander and In-and-Out Caves, and Natural Bridges

Simple cases are much rarer than the selection made to illustrate the main hydrodynamic contexts would suggest. This can be illustrated by reference to the small caves closely associated with the rivers which dominate the local fluviokarsts. Meander caves such as are found at a number of points along the Yarrangobilly River constitute one of the few types of cave which are perfectly plain and straightforward. Even then Verandah Cave at Borenore (Jennings 1970a) is a double-decker due to the river cutting down more rapidly for a time or swinging away from that river flank for a while.

Short in-and-out caves are also common along our rivers, though they can vary very much within a single area. Thus at Cooleman Plain in its northern part, only shallow valleys a few metres deep occur and here only two caves are known; they are similar to one another where a stream has branched through a low, horizontal passage across a slight bend in a valley side. There is a sand and gravel bed and normally air space through most if not all of it. The rocks are dipping and there is no joint control in long or cross-section, though there may be some in plan. Most enlargement will take place during flood when they will be full of water. They are short watertable stream caves. Anabranch Cave (Montgomery 1971) though fulfilling a similar function is very different in character. It takes a substantial part of the flow of the Goodradigbee River in its deep valley below the junction of Cave Creek in almost a straight line through a steep spur end. It consists mainly of a tall oblique passage in a bedding plane like a tilted canal tunnel, though it has a watertrap near its upstream end. It may be objected that Anabranch Cave is not in Cooleman Plain proper. However, the cave in the right bank of Cave Creek at the Blue Waterholes has similar tall fissure passages. It does belong to Cooleman Plain but to that part of it where gorges have been cut into it.

Many natural bridges are formed where rivers breach meander spurs. London Bridge on Burra Creek was originally classified as a simple case of a karst meander cutoff (Jennings 1971). Later work showed at least two complications (Jennings and others 1976). The lesser of these lay in the role of the alluvial fan which now largely fills the abandoned meander channel. The nature of buried soils in it indicates it belongs in the main to the Late Pleistocene when fan building seems to have been going on widely in the Southern Tablelands because of colder climate and its geomorphic effects (Coventry and Walker in press). The role of the fan may therefore have been a dynamic, not simply a passive one. After part of the base flow of Burra Creek started to go through London Bridge Cave, the independent tendency of the tributary to dump a lot of sediment in the meander channel may have helped to round off the capture by blocking flood flows and forcing them also through the enlarging cavern in the root of the meander spur. None of the earlier cave breaches of the spur here reached completion of capture in this sense.

The second complication at London Bridge is witnessed by the longitudinal profiles of the older, inactive caves at London Bridge; Douglas Cave has a steeply dropping profile down valley and it is evident that Burra Cave formerly had a similar one. The conclusion was that the only satisfactory way to explain this drop was to postulate that a waterfall or rapid, retreating up the river through erosion, was held up in the meander by a resistant greywacke found there. Whilst it was held there, caves developed, descending through the limestone of the meander spur in a manner resembling the presently active Fish and Easter Caves system on Cave Creek below Cooleman Plain.

The Natural Bridge at Yarrangobilly is also not as simple as a casual inspection might suggest. There is a good deal of Quaternary tufaceous breccia in its construction and there are indications that there may have been a surface cutoff at one stage here, which was barred by fallen blocks of bedrock and by tufa building. This may have returned flow to the meander bend, which is now only followed in flood with the development of the present underground cutoff through the blocking materials. The geological structure needs mapping in detail to prove this. A collapse doline exposes part of the cutoff course beyond which the underground stream forks into a major and a minor arm. On steep slopes in the valley here, there are vegetated, fixed screes which belong to a past phase of much more active weathering of the limestone faces; once again the cold period of the Late Pleistocene in the Snowy Mountains comes to mind.

Thus major themes for cave study around Canberra emerge by reference even to these very simple kinds of cave.

Alternation of Vadose and Epiphreatic Activity

The mention of waterfall retreat in connection with London Bridge leads to one of these themes, namely, the effects of rates of valley incision. The larger caves owe much of their complexity to this as is well exemplified in the Punchbowl-Signature and Dogleg group of caves at Wee Jasper (Jennings 1964a, 1967). In the dry Punchbowl-Signature system, mainly from flat solution roofs in nearly vertical beds and from remnants of elliptical tubes, four levels of epiphreatic or watertable cave development can be recognised whereby a stream passed through Punchbowl Hill. In the intervals between, vadose downcutting took place. In the lowest part of the system nearest to Dogleg, spongework and related features prevail where nearly stagnant water enlarged the cave for a time whilst its former dynamic role was being taken over by Dogleg Cave, the active river cave. When the 7 m inverted siphon at the Opera House in Dogleg comes into action, much of the forward, low meandering part of the cave can fill to the roof so that it is intermittently epiphreatic in nature now. Phases of vadose flow before and after these peaks of erosional activity are separated by low stages when a lower, impenetrable route to the outflow comes into sole use.

This theme of alternation of different kinds of cave development through time as surface rivers cut down their valleys in or close by the limestone repeats itself through the area (e.g. at Marble Arch, Nicoll and others 1975). Epiphreatic cave development is much more common than other kinds of phreatic development. There may not be so many levels in the one cave as in the cave cited. For example, Barber Cave at Cooleman Plain has only two. Both of these exhibit the dominance of vadose activity at the inflow end of this through-cave with epiphreatic activity taking on a greater role in the morphology at the outflow end. Cave enlargement seems to have been propagated from the spring end upwards in the manner envisaged by Rhoades and Sinacori (1941). Slight further incision of Cave Creek has turned the lower epiphreatic level into a vadose state.

Another arrangement is one where one epiphreatic cave is replaced by another. There can be little doubt but that there is an active epiphreatic cave behind the Blue Waterholes at Cooleman Plain similar to the abandoned one upstream now constituting the dry Cooleman-Right Cooleman Caves system some 10 m higher than it but quite detached from it (Jennings 1970b). Study of the characteristics of the various springs at the Blue Waterholes indicates that the normal flow at any rate comes from the one conduit (Jennings 1972). A short phase of increased rate of incision has here been accompanied by a sideways jump in the point of outflow but the cause of the displacement, structural or otherwise, has not been perceived as yet.

Other variants on this theme are plentiful in the area as the guide to the excursions will reveal. Therefore the question arises as to why epiphreatic (watertable) caves as distinct from bathyphreatic or multiple loop caves are prevalent in the area. Ford and Ewers (pers comm) point out that for obvious reasons in steeply dipping rocks developments of the latter kind are favoured whereas gentle dips promote the former type. The Canberra area would tend to contradict this. Another thesis of Ford's helps out, namely that if the drainage from inflow to outflow tends to be mainly along the strike, this in its turn favours horizontal development along the strike. The Punchbowl-Signature and Dogleg Caves are elongated along the strike (though there is meandering along substantial sections). Again at Bungonia, the long Fossil Cave – Hogans Hole Extension has much epiphreatic passage along the strike, whereas the big loop in Odyssey Cave occurs where the chief underground stream is descending the dip in accord with the Ford/Ewers concept.

Nevertheless many of the epiphreatic cave passages run in the sense of the dip and cross the strike, e.g. Coppermine at Yarrangobilly, as must the link between Eagles Nest and Hollin Cave there also (Pavey 1974). To help with these instances and for perhaps the overriding factor generally there is another factor in the Ford/Ewers general theory, namely fissure frequency. With increasing fissure frequency in low or in steep dips, hydraulic conductivity increases also and this permits the most direct routes down the hydraulic head to develop readily. So as fissure frequency increases, the favoured sequence is from bathyphreatic through multiple loop to epiphreatic caves. There is no doubt that highly fissured rocks (even in the case of the Wombeyan marble) are prevalent as a result of a long tectonic history, the proximity of igneous intrusion in many cases, and also the nearness to valley walls which results in offloading joints.

This stress on the various modes of dynamic phreatic action must not lead to disregard of the role of the nothephreas. In this respect White's system is more useful than that of Ford and Ewers who do not retain a place for it as a significant cave-forming hydrodynamic context. This latter standpoint may be justified against a canvas of large karst areas and very big cave systems. With the small karst areas around Canberra it occurs sufficiently frequently to warrant it being classed as a normal case. White's diffuse flow category approximates to what is here termed nothephreatic but his restriction of it to impure limestone and coarse dolomites does not apply in the Canberra area where the instances cannot be differentiated on this basis. Some of the caves placed in this class appear to relate to an early and different stage in the relief development. Durins Tower Cave at Wombeyan is in the top of a knoll which is one of the highest points of the karst there (Jennings and others in press). It probably formed when the present ridges belonged to a former basin plain. The Wellington Caves also relate to a time when the limestone there formed a valley floor instead of a low ridge (Frank 1971). Clown Cave at Cooleman antedates the gorge it overlooks. These and others correspond to the classic Davisian situation of phreatic development beneath a planation surface; subsequent rejuvenation of drainage has left them high and dry, unrelated to present relief. However, not all cases are explained in this way. Basin Cave at Wombeyan is best interpreted as the result of a blind input from Mares Forest Creek, which may have developed a certain degree of throughflow initially but failed to keep pace with faster incision of the creek and eventually lost sufficient supply for even nothephreatic growth. Fred Cave still taps the river water and must still be enlarging slowly.

Rejuvenation in General

Rejuvenation of drainage and relief lies behind much of the previous discussion and it is useful now to look at this in more general terms in relation to the caves.

At Cooleman Plain there is a pronounced contrast between the slight dissection of the limestone planation surface over the northern part and round the margins of the southern part and the pronounced dissection above and below the Blue Waterholes (Jennings 1967a). Caves are insignificant in the first context; Devil Hole is probably the largest and it is only a short inflow cave for one of the largest of the many streams flowing off the igneous rim onto the karst. All caves of appreciable length and size are associated with the gorges. Circulation was promoted here, hydraulic gradients increased and probably fissure frequency also, though this may not have mattered so much as that frequency is generally high. The caves are mainly outflow caves such as Murray Cave and between-caves such as River, Frustration and New Year Caves.

Caves are more frequent and larger at Yarrangobilly because the main river runs for the most part along the side of the limestone outcrop and has cut a deeper gorge than Cave Creek; favourable conditions for cave development reach more widely and more strongly. Substantial inflow caves occur as well as outflow. At the downvalley end where the depth of incision below the old valley floor is greatest, there is a fine sequence of replacement of higher caves by lower caves functionally (Jennings 1964b). Jersey Cave, the two Glory Caves, River and Federation Caves represent a sequence of the former and present outflow caves of the sinking Rules Creek over a height range of 120 m. The shortness of the tunnel which had to be cut for the North Glory self-guided circuit indicates how near it was to becoming a through-cave at one stage. Indeed collapse may have blocked off such a cave. Jillabenan and Harrie Wood Caves are former outflow points of Mill Creek. That creek now sinks in Mill Creek Swallet whereby it flows towards River Cave to join Rules Creek in that vicinity. So Jillabenan, Harrie Wood, River and Federation Caves also form a descending sequence.

To add to the interest here Castle and Grotto Caves must also have let out Mill Creek water at certain stages so Mill Creek has had a very complex history, which should become clearer when the careful surveys now well on the way to completion are interpreted.

In all the instances so far, cave development seems to have kept pace with valley degradation or nearly so. The active outflow caves of today are either right at river level, e.g. the Blue Waterholes at Cooleman Plain and Bubbling Spring at Yarrangobilly, or nearly so, e.g. Federation, Hollin and Coppermine Caves at Yarrangobilly and Zed Cave at Cooleman.

Along valley bottoms, even with an unreliable climate allowing rivers to dry up, there is likely to be water in planes of weakness in the rock persisting with embryonic speleogenetic preparation so there is a strong chance that fresh outflow cave development will soon accompany the downcutting of the streambed. For example Federation Cave and the lower level of River Cave soon developed to fulfil the function of the upper level of River Cave when the Yarrangobilly River put that out of action by lowering its bed. The interval is of small amplitude. Junction Cave Spring at Wombeyan has to drop down a little fall of 7 m to Wombeyan Creek; its replacement has yet to form.

The possibility that pace of incision may be too great for cave formation to match valley deepening on a greater scale is a real one. At Bungonia, the water from Main Gully Springs drops steeply nearly 100 m down to Bungonia Creek and limestone crops out between the two. The Efflux, which drains most of the caves on the southern side of Bungonia Gorge by a low gradient, probably mainly waterfilled passage from Odyssey Cave, feeds Breton Creek which then falls about 190 m down to Bungonia Creek. Although Breton Creek flows mainly over impervious rocks interbedded with limestone, previous geological mapping suggested there was no structural impediment to the development of caves in limestone along the strike for water to emerge at or close to the level of Bungonia Creek. On this basis it was thought that incision had been too rapid for cave formation yet to have taken place in the lower levels of the limestone strike belts (Jennings and others 1972; Jennings and James in press). However, more recent mapping (James, Francis and Jennings in press) indicates that faulting may have cut out part of one of the limestone belts near The Efflux and this may have caused its perched position. Whatever the final answer is in this regard, there can be no doubt that rapid incision has had an important effect on cave development at Bungonia because here vertical development is more pronounced than in any of the cave areas around Canberra which have been mentioned, and this is matched by the depth and narrowness of Bungonia Gorge. Of these vertically developed caves, the greater ones such Odyssey, Drum and Grill Caves have small catchments feeding them with surface runoff so they have vadose flow into them. However, some of the other deep shafts here rely on seepage water only for their formation as has been mentioned earlier.

Co-existence of Different Speleogenetic Actions

In the previous section the idea of one phase of cave development being succeeded by another of a different kind and so on in the evolution of the cave over time was stressed. It is important to be well aware, however, that different kinds of cave enlargement go on at the same time both in caves which are near together and within the one cave.

The great difference in nature between Dip Cave and the Punchbown-Signature and Dogleg group at Wee Jasper has already been underlined yet they occupy much the same position in the general relief of the Goodradigbee valley and must have formed at much the same time (Jennings 1967). The same is true of Basin and Bullio-Mares Forest Creek Caves at Wombeyan (Jennings and others in press). There also the active level of the long Fig Tree-Junction Caves system includes alternating vadose flow and epiphreatic sections along the streamway. Again this applies to the River-Murray Caves system at Cooleman Plain (Jennings 1969). As a model for interpreting cases of this kind there is an excellent account by Palmer (1972) of Onesquethaw Cave in New York State, United States, where the detail of the geological structure can be shown to be responsible for lengthwise variety of this kind. It is true that obvious structural controls are not evident in the Canberra caves of ours cited but this direction of detailed geological mapping is one which badly needs pursuing more rigorously here.

Palmer also stresses the important role of floodwaters in Onesquethaw and other caves, which really masks the differentiation between vadose flow and epiphreatic. This has already been emphasised with regard to caves around Canberra so liable as they are to large, rapid changes in discharges; cave rivers readily developed three-dimensional anastomosing complexes of passages (Jennings 1967a, 1968a). A surface stream is free to braid into many channels over its flood plain thus reducing rise in stage level; passages fill to capacity in caves in flood, forcing levels up to maintain high level passages in intermittent action along with lower ones carrying base flow. Palmer (1975) calls these floodwater mazes. One of the best active ones in Australia to my knowledge is in the Honeycomb Caves at Mole Creek in Tasmania.

Palmer's work in general draws attention to local factors of various kinds within active caves, inducing areas of different hydrodynamic development from that prevailing generally within each cave. This theme is particularly relevant in southeastern Australia as a result of various of the regional characteristics set out above. For instance, rockfalls and big inputs of allogenic gravels (which of course are especially liable to jam up at rockfalls) can bring about small sectors of phreatic action and of phreatic features in a prevailingly vadose cave, not only of epiphreatic action but also nothephreatic, as for instance in Old Inn Cave (Y10) at Yarrangobilly.

All this means that in working out the evolution of a cave, reliance on one or two scattered geomorphic features for inferring particular hydrodynamic contexts for the whole of a cave at a given stage of development must be avoided. Simple situations are and have been rare.

Effects of Climatic Change

The impact of climatic change on cave development in the Canberra area has been touched upon already once or twice. This again is a factor which needs exploring more thoroughly than has been done so far. Pursuing this will be helped by the reconstruction from other sources of the climatic history of the area (Bowler and others 1976). Study of glacial and periglacial geomorphology and pollen analysis of organic materials in the Snowy Mountains have demonstrated the occurrence of a colder period than at present starting at a little before 30,000 B.P. and lasting till around 10,000 B.P. There probably were earlier colder periods but no positive evidence survives. Since 10,000 B.P. there hasn't been much change in temperature though it was probably a degree or two lower about 3,000 – 2,000 years ago.

The direct effects of lower temperatures in the caves were probably slight, though angular material in the Antechamber of Murray Cave, Cooleman Plain, may have been due to frost wedging reaching into that chamber at the time there were glaciers in the Snowies. However, lowered temperatures resulted in reduced vegetation cover over some higher parts of the Southern and Central Tablelands and exposed soil and rock slopes to more rigorous weathering and mass movements of materials. At Wombeyan angular debris was fed by accelerated slope processes into the lowest entrance of Basin Cave (Jennings and others in press). Another consequence was that more material was fed into the rivers and this indirectly affected caves.

But perhaps the greater impact of temperature change on local speleogenesis was by its influence on evaporation, which altered the amounts of water available for cave formation substantially. Undoubtedly there were also variations in precipitation causing direct variation in water amounts for geomorphic action. The evidence, which survives for reconstruction of past climates, largely reveals changes in amounts of water in rivers and lakes; it is a much harder task to determine the extent to which these changes are due to alterations in evaporation or in precipitation, in other words in effective or in absolute precipitation. For cave study, this difference could be important because the two climatic elements may have different effects on stream inflow and percolation into karst rocks. For instance evaporation may reduce input of streams from surrounding rocks more than it reduces percolation of rain falling directly into the limestone. For the Snowy Mountains, Galloway (1963) has inferred that the small size of the glaciers which formed there in the main cold period, coupled with the estimated substantial temperature drop, implies reduced precipitation at that time. Nevertheless streams in the area probably had higher peak discharges and shifted bigger loads of sediment then (Ritchie and Jennings 1955). About this time also Lake George was much larger and deeper than at present (Coventry 1976) but water balance estimations show this was due to reduced evaporation, not to increased precipitation. Singh's pollen work at Lake George (Bowler and others 1976), though in an early stage, gives a preliminary picture of paleoclimatic history back to 50,000 – 60,000 years during which time temperatures were varying but always lower than they have been in the last 14,000. Effective precipitation was also varying and Lake George alternated between long periods of high level and of drying out.

Little or no work has yet been done to determine what effects these changes had on the caves around Canberra. The deposits in a dry valley on Cooleman Plain have been investigated (Jennings 1976b). It was formerly a blind valley, in form much like that of River Cave nearby, but then it was filled up to its threshold level by a mudflow from the igneous slopes above, which nowadays do not suffer such mass movements. This behaviour can be related to periglacial activity in the cold period of 30,000 – 15,000 years ago which also gave rise to periglacial blockstreams elsewhere on the plain. This fill blocked up the cave which must formerly have taken the stream that cut down the valley to produce the threshold. The stream, now flowing down the whole length of the valley, proceeded to sort the very mixed mudflow materials, redepositing first loose gravels, then a fine loam. Eventually the stream sank through superficial deposits at the head of its valley over the limestone. Close by, the South Branch of Cave Creek has buried, with coarse gravels, its main sink into the limestone; base flow still sinks here though at a higher level than previously and this may have increased the likelihood of flood flow travelling farther on into Ev's Cave, the overflow streamsink. Goede (1973) has described similar happenings in the Junee karst in Tasmania and caves at Mole Creek have been partially filled with outwash gravels from the ice-capped Lakes Plateau there (Jennings 1967). Such developments as these have drastic effects on developing cave systems, rerouting water flow significantly.

There was probably also the tendency to develop new caves through new points of input and augmentation of that input, i.e. there was the development of 'invasion' vadose caves (Malott 1937) as distinct from the normal 'drawdown' vadose caves such have already been described (Ford and Ewers (pers comm) There are peripheral channels along the sides of glaciofluvial and periglacial fluvial fans below the Great Western Tiers, which pumped water into the limestone alongside (Jennings and Sweeting 1959). Goede (1969) considers part of Exit Cave to be of similar origin. So there appear to have been contradictory effects in cold periods, filling and blocking some cave passages, opening up new ones. Permafrost which would have prevented the latter event was apparently absent from both the southeastern mainland and Tasmania. At Jenolan Caves there is evidence that both excavational and depositional effects of cold periods in the Pleistocene are involved significantly in the development of caves such as Mammoth.

It will have been evident from the preceding discussion that study of cave sediments is the main key to elucidating such climatic effects on cave development. The most detailed work on cave sediments so far in Australia has been that of Frank in the western Central Tablelands a little beyond Canberra's ambit. Some climatic history conclusions were derived from the cave sediments (Frank 1975) but perhaps of more direct relevance to the present theme is part of the story he established for Tunnel Cave at Borenore where a dry period around 28,000 B.P. permitted flowstone and dripstone to build right across a stream passage as a result of its reduced flow. Stream flow has been restored through it in wetter conditions since.

Speleochronology

There is great difficulty in giving ages to the caves around Canberra; this is part of the wider problem of the general denudation chronology of the Canberra district about which most divergent views have been held. Reliable dating means were just not available and one was forced mainly to proceed by dint of rather speculative inferences. Many of the methods for speleochronology set out by Ollier (1966) either have not been applied or were not applicable in this area. The situation is improving but there is a long way to go as yet.

The host rocks are very ancient and their age has little relevance for cave dating here since the voids in them were created very much later. Generally the area has been a land surface since before Permian time (c.280 million years) though the eastern margin including Bungonia was under the sea for a time within the Permian. Again this upper limit is well beyond the times in which the caves formed.

Dateable materials within the caves set minimum age limits for the spaces they partially fill but sometimes the cave geomorphology shows some chambers or passages to be younger than the dated deposits. Radiocarbon dating of charcoal and other plant material, animal bone and even bat guano in flowstone, as well as of flowstone itself, has been the chief absolute or physical dating method employed so far in Australian caves, unfortunately not yet within the Canberra area. It will be useful nevertheless to refer briefly to Frank's work on cave sediments from the western Central Tablelands by way of illustration. In the last 30,000 years, deposition has been the rule in Douglas Cave at Stuart Town, though one entrance has become blocked by this fill and another small entrance has opened (Frank 1969). Wellington Caves appear completely to antedate extensive fills, much of them mined out for phosphate; the sediments range back to 40,000 to 50,000 B.P. (Frank 1971). The Walli Caves failed to yield dateable material but the interesting sequence of sediments is effectively subsequent to the formation of the caves (Frank 1974). At Borenore two new cutoff passages have developed since sediments dated at 27,000 B.P. accumulated in an earlier one and Tunnel Cave was extended significantly headwards to a new entrance and its passages were deepened since 28,000 B.P. (Frank 1972, 1973). In both cases, however, the earlier phases of their development go back much further in time than the dated sediments.

Animal bone and human artefact assemblies from caves have been rendered useful as means of dating now that many sequences of cave deposits containing them have been radiocarbon-dated. It now appears that all extinct species belong to the Pleistocene so that deposits with such bones and so the containing caves are at least about 14,000 to 15,000 years old. A case in point is (or rather was) a cave at Wombeyan, practically sediment-filled and exposed in quarrying there, which included the bones of several extinct species (Hope in press).

As already mentioned, some superficial deposits at Cooleman Plain can be attributed by correlation, not by dating, to the last Pleistocene cold period established in the Snowy Mountains. They permit other inferences. For example, Barber Cave has two levels low down in Clarke Gorge which has a periglacial blockstream not far away, reaching down to about 15 m from its bottom (Jennings 1968b). It is likely that at least the upper level of Barber's had formed before this time. At Cooleman also, River Cave entrance lies in a dry valley with a threshold and with coarse aggradation deposits farther up which make it resemble the neighbouring dry valley with its threshold buried by a mudflow probably emplaced in a periglacial environment. Thus it is inferred that the tributary passage of River Cave leading down the main river passage is likely to be older than the last Pleistocene cold period also (Jennings 1969). Murray Cave, Cooleman Plain, exhibits three phases of development in its forward part (Jennings 1966). The middle appears to be related to a coarse aggradation terrace in the valley outside, again referable to colder conditions and the third phase includes at a late stage the frost-wedged gravels in the Antechamber. So it appears the two later phases of Murray Cave probably belong to the late Pleistocene. It is evident, however, from these examples that certainty and precision are rapidly diminishing when compared with Frank's results where cave deposits were dated.

In the future, however, a firmer basis can be expected reaching farther back into cave history when uranium/thorium dating of speleothems, particularly in conjunction with oxygen paleotemperatures, comes into use in southeastern Australia. This has proved itself in N. America and New Zealand already. Results of this kind will soon be forthcoming from Tasmania (Goede pers comm). Preliminary experiments with speleothems from Murray Cave, Cooleman, and from Fossil Cave – Hogan's Hole Extension show there are suitable materials for this kind of attack (James pers comm).

Much of the local cave history will, however, go back beyond the 300,000 year range of uranium/thorium dating and beyond this limit chronology of caves becomes much more difficult. For example, only very broad conclusions have been published about the age of the Wee Jasper caves (Jennings 1963, 1964). They formed subsequently to the time when a valley bench about 60 – 70 m above the present level of the Goodradigbee formed the valley floor. This valley bench is some 300 m below nearby plateau surfaces which carry basalt remnants only ascribable on stratigraphic evidence to the Tertiary as a whole.

However, recently potassium-argon dating of the Tertiary basalts here and elsewhere is helping to sharpen up the denudation chronologies of which cave developments form part. In the ranges west and southwest of Canberra the dated lavas all belong to the Snowy River lava province dated at 22–18 million years; the undated ones within the same area are assumed to be of the same age at present.

A few kilometres up the Wee Jasper Creek from the caves, basalt within 40 m of the valley floor and overlying river terrace deposits has been dated in this way and belongs to the Lower Miocene. Thus the oldest caves at Wee Jasper belong to the period since then but may well be of considerable age within it. Much erosion has taken place since, for example, the uppermost level of Punchbowl Cave formed.

There are problems in relating the lavas to the geomorphic history however. Thus at Yarrangobilly there are lavas on the limestone shelf in which the caves have formed. This suggests a close relationship between the date of the lavas and the beginning of cave formation. However, there is the difficulty that covering rocks on limestone are very liable to solution subsidence so that these lavas may have been lowered along with the limestone shelf through solution. The shelf surface may in part be younger as a geomorphic feature than the lavas forming as a rock. Solution subsidence disturbs the rocks lowered in this way and this provides a tool for resolving this issue.

The nearest basalt to Cooleman Plain is a cap on the top of Peppercorn Hill some 250 m above the Long Plain which is separated from Cooleman Plain by the ridge of the Cooleman Mountains. There are other hill caps in the area which suggest that they are residuals and the valley plains around have developed subsequently. But there are also valley fills such as have been described from Yarrangobilly so that this evidence is ambiguous about the age of the planation surface in the limestone at Cooleman Plain. A closer analysis of the geomorphology of the sub-basaltic surface in the whole area is needed. The oldest caves relate to the planation surface but most belong to the phase of incision of the gorges into it, indeed to late in that period. The evidence of dating from Wee Jasper Creek farther down the Goodradigbee valley has a bearing on developments here, since it shows that a good deal of the valley incision had taken place before the Lower Miocene (Rieder, Jennings and Francis in press).

At the present stage of investigations it is at Bungonia that the greatest chronological problems are found and further work is in progress at the present time. To do more than outline the nature of the problem would be inappropriate here. On the one hand evidence is accumulating that the uplift of the plateau which set in motion most of the cave development is very old. From their datings of basalts and the geomorphic relationships of the lavas, Wellman and McDougall (1974) consider there were two major phases of uplift, one in the early Tertiary and one ending some 10–15 million years ago. Young (1970, 1974) has argued that uplift was completed even earlier, some 25 – 30 million years ago, and additional evidence can be brought in support of his standpoint (James, Francis and Jennings in press). In discussion of Jennings (1975), Wellman pointed to a lava-filled valley along the Endrick River valley well upstream of Bungonia (Craft 1931); this is at a level which makes it likely that much of the Bungonia Gorge incision must have taken place before these lavas were emplaced and these are Eocene lavas, 45 – 40 million years old.

On the other hand, the gorge at Bungonia has the appearance of being a youthful geomorphic feature and it is only 80 km from the margin of the plateau. The Blockup in the Slot at Bungonia is the product of a huge but young rockfall and is emphatic evidence that widening of the gorge is actively in progress. One or two million years is the sort of length of time most geomorphologists would have thought necessary for headward erosion to have retreated from the edge of the plateau to the waterfalls and rapids at the head of Bungonia Gorge. Apart from some shallow cave development of phreatic aspect close below the plateau surface, the main cave development is active and vadose down to a more or less horizontal level of active, epiphreatic nature roughly 120 – 150 m below the plateau. Once again this cave development is youthful and no great age seems acceptable for it.

There is a very stern conflict here and though some suggestions have been put forward to mitigate it – Young (1974) relies on great resistance to erosion of the Permian sandstones of the lower Shoalhaven gorge to slow down headward retreat of erosion; James, Francis and Jennings (in press) point out that erosion may proceed much more slowly up small tributaries such as Bungonia Creek compared with the major rivers such as the Shoalhaven River – , more work will be needed to resolve it. Dating of more speleothems from the lower levels of the Bungonia deep caves should provide additional evidence to constrain theorising and may be rebuff some preconceptions about rates of gorge development and cave evolution.

Dating the caves around Canberra more precisely and reliably and determining the rates at which they have been excavated is one of the great fields for future speleology in this part of Australia especially.

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PRELIMINARY REPORT ON DRAINAGE MODIFICATION IN THE DEEP CREEK–EAGLES NEST BASINS, YARRANGOBILLY, NSW

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Abstract

To account for the present distribution of cave systems in the Deep Creek-Eagles Nest area of the Yarrangobilly Cave Area significant modification of drainage patterns must have taken place. The size of drainage basins has changed significantly in the past 22 m.y. The drainage basins now feeding the North and East Deep Creek cave systems have decreased in size, but the West Deep Creek drainage basin has greatly increased in size. Three upper level cave systems, Janus, Restoration and East Eagles Nest, are identified and are correlated with the One Tree Hill Erosion Level developed in the Yarrangobilly River valley. Lower levels of North Deep Creek, East Deep Creek and Eagles Nest Caves appear to be related to the present level of the Yarrangobilly River.

Introduction

The caves of the Eagles Nest-Deep Creek drainage basins form the largest integrated cave system in the Yarrangobilly Karst Area. The system is composed of four inflow caves – Eagles Nest (Y1–2), East Deep Creek (Y5), West Deep Creek (Y6), North Deep Creek (Y7); two dry high-level caves – Restoration (Y50), Janus (Y58); and the common stream resurgence – Hollin Cave (Y46). There are additional caves in the area which may be related to the system but these have yet to be accurately mapped and plotted.

This paper attempts to examine the origin of these caves in terms of successive development of cave levels and looks at stream piracy in the drainage basins to explain some of the observed variation in passage size and the size of the active cave streams. It must be noted that this is a preliminary study and that subsequent work, based on more data, may indicate that there are alternative explanations as to the origin of some of the features that are here related to stream piracy.

Geomorphology

A summary of our present knowledge of the recent geomorphic history of the Yarrangobilly Karst Area is presented in Table 1. The only fixed dates that have been obtained are for two basalt samples. One was collected from the basalt outcrop along the Bullock Track near its junction with the northern access road and gives an age of 21.9 + 0.5 m.y. The second sample was collected from Gravel Hill near Yarrangobilly Village and gives a date of 22.4 ± 0.5 m.y. The dates are in agreement with dates, obtained by Wellman & McDougall (1974), for the Snowy Province which range from 22 to 18 m.y.

These dates represent the age of the partial filling of a broad proto-Yarrangobilly Valley, formed in this area mostly on limestone, by basalt flows that probably originated on the surrounding highlands. As can be seen in the Bullock Track exposure, there was considerable relief on the limestone and the thickness of the basalt is variable but is estimated to have been in excess of 10m in some places.

Following the basalt flows in the early Miocene, the Snowy Mountains area was subjected to slight uplift and a period of rapid downcutting took place that initiated the development of the limestone gorge at Yarrangobilly. It should be noted that the present course of the river is strongly controlled by structural lineations in the steeply dipping Silurian sediments and is not a random meander pattern developed from a meandering stream superimposed from a flat basalt plain. It is possible that the basalt flows covered only part of the old valley floor.

The initial period of downcutting in the middle or late Miocene led to the development of cave systems that are presently preserved at high level on the limestone plateau, including caves such as Restoration, Janus and Jillabenan (Y22). These caves were graded to a river level that is thought to have been at an elevation of about 990 m in the Deep Creek area. At that elevation a short halt in the downcutting led to period of lateral erosion in the river valley. Only three or four remnants of this period are still preserved as bedrock notches, as at Funnel Pot spur and at One Tree Hill, within the entrenched Yarrangobilly Valley. This erosion level is here called the One Tree Hill erosion level.

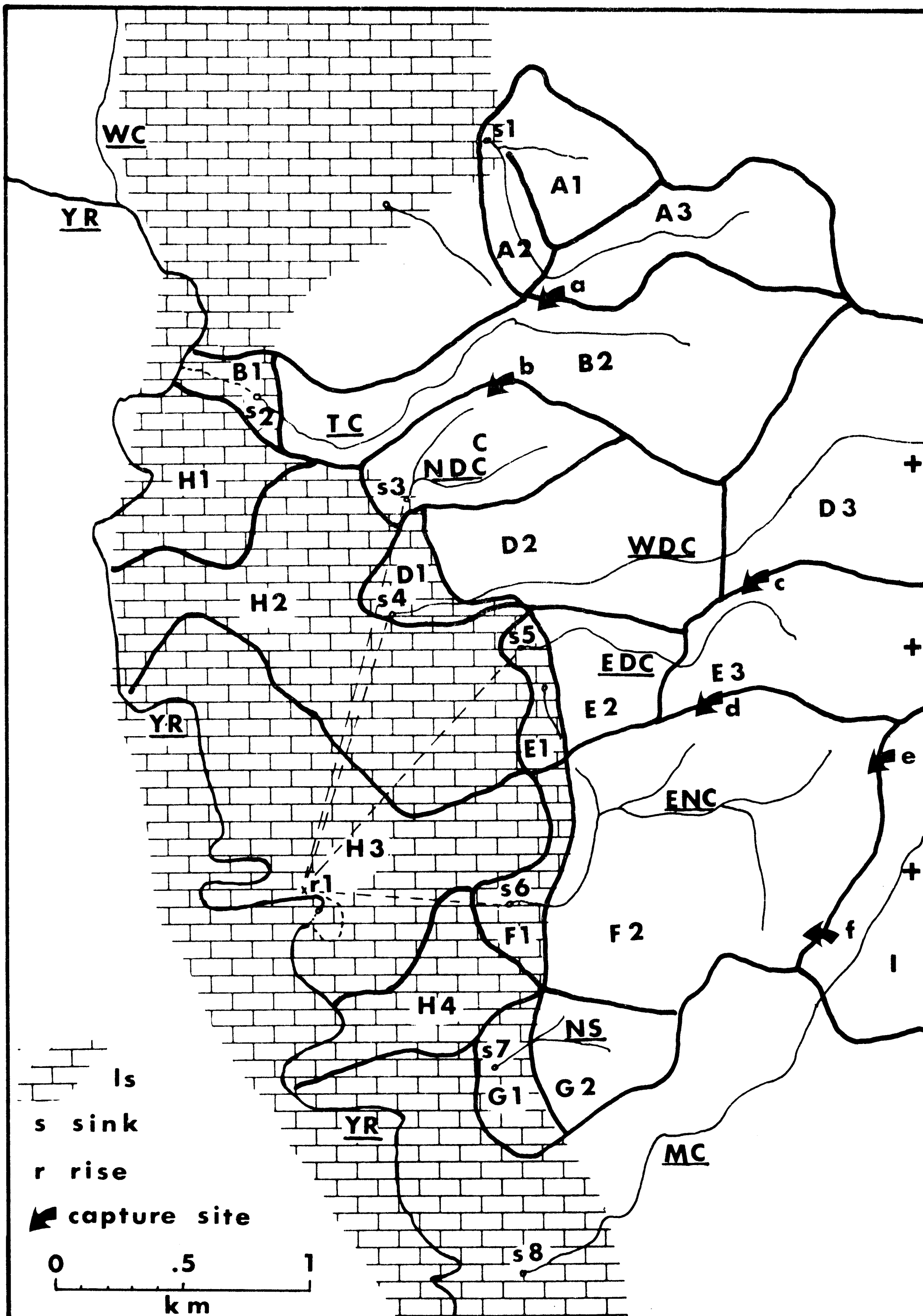

Fig. 1.
Drainage basins in the Eagles Nest-Deep Creek portion of the Yarrangobilly Karst Area, see Table 2 for identification of sinks and areas. WC – Wombat Creek, TC – Traverse Creek, NDC – North Deep Creek, WDC – West Deep Creek, EDC – East Deep Creek, ENC – Eagles Nest Creek, NS – Negative Series, MC – Mill Creek, YR – Yarrangobilly River.

Table 1. **Summary of middle Tertiary to Recent erosion history of the Yarrangobilly Region**

	Age	Development
1.	pre Miocene	downcutting and lateral enlargement of the Yarangobilly Valley, development of plateau at elevation of 1130 – 1150 m.
2.	Miocene	partial filling of the valley floor by basalt flow, dated at 22 million years.
3.	?late Miocene	uplift and renewal of downcutting, initial development of gorge and high-level cave systems.
4.		period of lateral erosion, development of the One Tree Hill erosion level at about 990 m.
5.		renewal of downcutting to present level.

Renewal of downcutting was accompanied by the abandonment of the high level cave passages for lower (middle) levels that are graded to the present river level with resurgences such as Hollin and Coppermine Caves. Recent examination of Hollin Cave by divers indicates that the stream passage is as much as 15 m below the level of the adjacent river only a few metres from the entrance. This, combined with the abandonment of middle level stream passages in caves such as Eagles Nest, may mean that active development of phreatic cave passages at a low level is now in progress.

Cave Systems

The active cave streams in Eagles Nest, EDC, and NDC caves are considered by the author to be underfit cave streams when compared with the fossil segment of the cave system. An underfit cave stream is one which is smaller than that judged to have been necessary to have formed the size of the passage now present in active or abandoned levels.

There are three major reasons for the real or apparent underfit streams in cave passages. These are changes in the size of drainage basins, changes in climate and local variability in the chemistry or physical character of the limestone. At Yarrangobilly the latter explanation is not considered because the caves generally developed across the strike of the bedding and the size variations do not seem to be related to bedding.

Variation in amount of rainfall is also not regarded as an explanation for the observed sizes of cave passages. There has been a progressive trend toward a more arid climate in Australia since the early Miocene (E.M. Kemp pers comm). However, the present size of some of the drainage basins is such that the variation in rainfall is thought not to have been enough to account for the observed change in passage dimension.

It thus seems probable that there has been a series of modifications of the size of local drainage basins, together with a general decrease in rainfall that must be examined in order to explain the relationship of size of fossil and active cave passages in the Eagles Nest-Deep Creek area.

A number of drainage basins (Fig 1, Table 2) have been delineated for the Eagles Nest-Deep Creek area at Yarrangobilly. These were generated using the preliminary edition of the Yarrangobilly 1:25 000 topographic map and the Tantangarra 1:50 000 topographic map. The size of the individual basins was calculated with the assistance of A.P. Spate. Following this air-photo interpretation and surface traverses outlined a number of potential stream capture sites on the Eagles Nest, North Deep Traverse and Bathhouse Creeks.

Table 2. **Drainage basins of the Eagles Nest-Deep Creek area** (see Fig. 1)

Drainage basin		**Sub-Division**	**Area**	**Drainage point**	**Area drained**
A	Bathhouse	A1	25.9 ha	S1-Bathhouse Cave	76.0 ha
		A2	10.3		
		A3	39.8		
B	Traverse Creek	B1	9.7	S2–Traverse Creek sink (variable)	88.5
		B2	88.5		
C	North Deep Creek			S3–North Deep Creek Cave	31.6
D	West Deep Creek	D1	10.6	S4–West Deep Creek Cave	305.3
		D2	57.3		
		D3	237.4		
E	East Deep Creek	E1	8.3	S5–East Deep Creek Cave	79.8
		E2	21.6		
		E3	49.9		
F	Eagles Nest	F1	14.8	S6–Eagles Nest Cave	137.5
		F2	122.7		
G	Negative Series	G1	14.2	S7–Negative Series Sink	35.4
		G2	21.2		
H	Plateau	H1	33.8	infiltration	258.0
		H2	101.4		
		H3	95.2		
		H4	27.6		
I	upper Mill Creek			Mill Creek	395.0

Eagles Nest Caves

The sequence of drainage modification for the Eagles Nest-Deep Creek areas is outlined in Table 3. As I have only a very limited knowledge of Eagles Nest Cave discussion of that cave is limited. Pavey (1974) has commented in a general way on the geomorphology of the Eagles Nest System but has not suggested a sequence of events relating to the development of the cave. He does, however, note that the present stream is underfit compared with the passage size of the Eastern Eagles Nest section. The Rims End-Golden Streamway passage levels seem to be at grade with the Hollin Cave resurgence but these have now been abandoned in favour of a low level, probably phreatic, route through the Deepest Dig. The Eyrie and Western Eagles Nest passages may represent a passage graded to the One Tree Hill erosion level. The lower part of the Western Eagles Nest passage was later modified to grade with the Hollin Cave resurgence.

Table 3 **Summary of drainage modification and cave development in the Eagles Nest-Deep Creek area**

Stage	Drainage	Cave Development	Area
1A	All flow to Yarrangobilly River via Deep Creek dry valley	initial development Restoration Cave	835 ha (E,D3,F2,I+lower parts of WDC)
1B	capture by Restoration Cave of upper part of Deep Creek-Eagles Nest drainage	enlargement of Restoration, initial development of Eagles Nest Cave	EDC 834.9 ha (E,D3,F2,I)
2	capture by Eagles Nest Cave of all except E1, E2 drainage	Restoration Cave abandoned Eagles Nest Cave develops, initial development East Deep Creek Cave	EDC 29.9 (E1,E2) EN 819.8 ha (F,E3,D3,I)
3	capture by East Deep Creek of E3 and D3 drainage, reduction of flow to Eagles Nest Cave	East Deep Cave develops, Eagles Nest system continues to expand	EDC 317.2 ha (E,D3) EN 532.5 ha (F,I)
4	capture by West Deep Creek of D3 drainage, capture by Mill Creek of I drainage	reduced development of Eagles Nest Cave, reduced development of EDC Cave, West Deep Creek Cave develops.	EDC 79.8 ha (E) EN 137.5 ha (F) WDC 305.3 ha (D)

East Deep Creek – Restoration Cave System

Warild (1975, 1976) has mapped EDC Cave and suggested a three stage sequence of development. However, he has not taken into consideration the relationship of Restoration Cave to EDC Cave which, because of their proximity, must be physically related to each other. By adding Restoration to EDC the developmental stages presented by Warild must be modified to account for the higher level passage.

In terms of cave development the sequence below is generalized, but takes into account the present state of knowledge. The initial development of EDC-Restoration is seen in the small high level passage at the entrance level of approximately 1085 m. This is about 5–8 m below the tags of both Restoration (Y50) and the (Y4) entrance to EDC. Both entrances are late stage collapse features. The main high level passage – the lower level of Restoration Cave and Shattered Passage of EDC – are at an elevation of about 1050 m and are thought to be at grade with the One Tree Hill erosion level. Then the sequence of stream piracy envisioned by Warild (1976) may have taken place with the stream in the lower levels at grade with the Hollin Cave resurgence.

West Deep Creek Cave

West Deep Creek Cave is a relatively recent example of karst stream piracy. Deep Creek flowing in the old dry valley, enters West Deep Creek Cave along an old structural trend and drops rapidly to a depth of 51 m (Pavey 1976). The stream probably drops another 20 to 30 m and joins with either (or both) the North or East Deep Creek cave streams.

North Deep Creek Cave

The North Deep Creek drainage basin (Table 4) is the smallest basin associated with an active cave

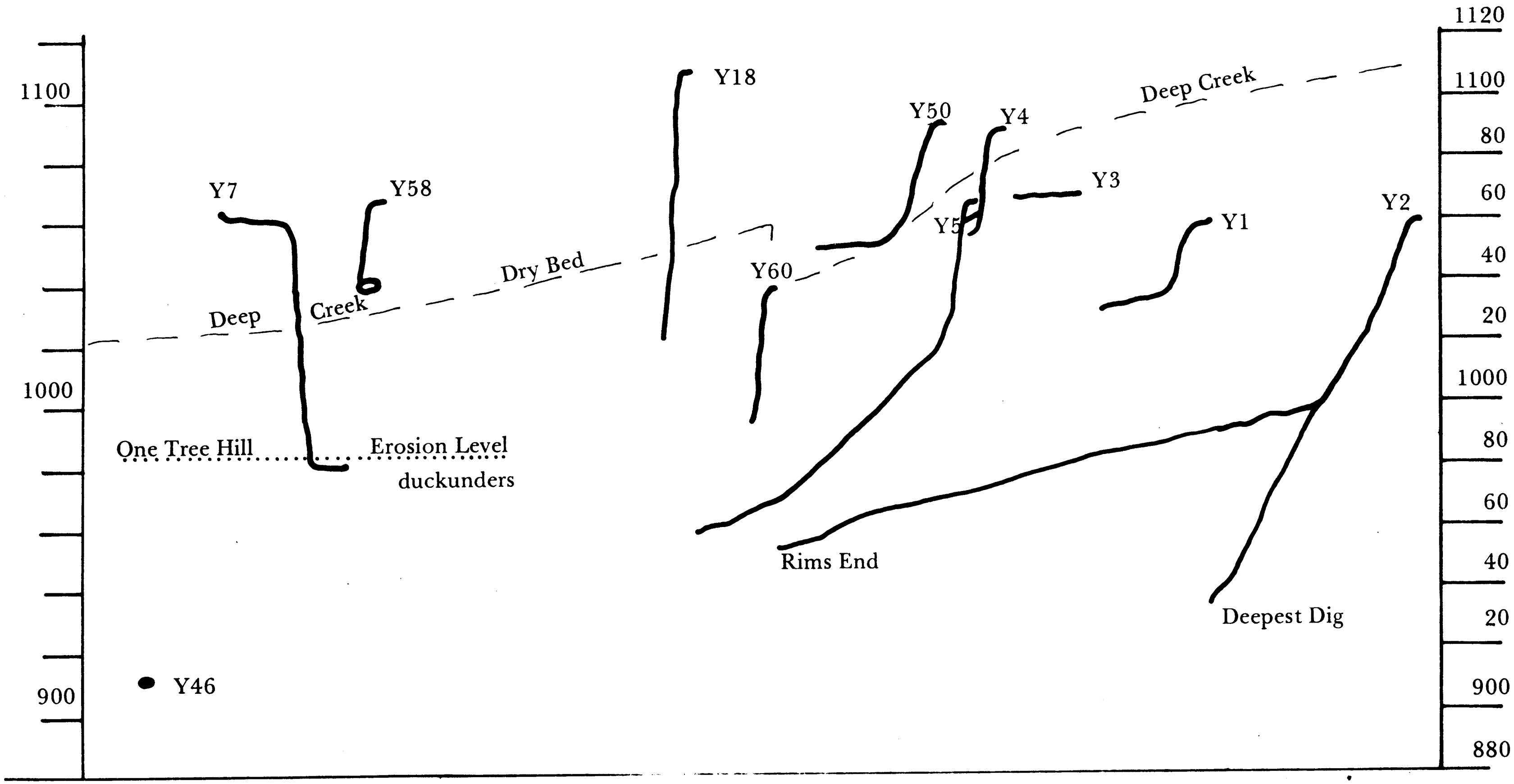

Fig. 2. East-west projected profile of cave systems in the Deep Creek – Eagles Nest area showing relationship of passage levels.

stream in the Deep Creek-Eagle Nest area. The cross-section of the active stream passage varies from a narrow canyon to a low roofed oval. This cross-section is much smaller than the collapse dominated section of the abandoned upper level of Janus Cave (Y58). This would seem to indicate that stream size has decreased from the time Janus Cave was being developed to the present.

Two basins, B2 and A3, now draining to other sinks, are thought to have originally drained into the NDC system. The stream in the A3 basin appears to be following the same structural trend as is the main part of Traverse Creek. The headward working Bathhouse drainage captured the A3 drainage. The B2 basin, which constitute the non-limestone part of Traverse Creek, is also thought to have drained into the NDC system. In this case the diversion is thought to have been caused by resistance in the volcanic rock and the diversion of the stream along a structural trend which now defines its path.

Table 4 **Summary of drainage modification and cave development in the North Deep Creek area**

Stage	Drainage	Cave Development	Area
1A	all flow to Yarrangobilly River via North Deep Creek dry valley	initial development of Janus Cave	159.9 ha + (A3, B2, C) + NDC dry valley
1B	capture by Janus Cave	expansion of Janus Cave	159.9 ha (A3,B2,C)
2	capture by Traverse Creek of headwaters	Janus Cave abandoned, initial development North Deep Creek Cave	NDC 31.6 ha (C) TC 128.3 ha (B2,A3)
3	capture of A3 drainage by Bathhouse Cave	continued development North Deep Creek Cave	NDC 31.6 ha (C) TC 88.5 ha (B2)

Negative Series

The Negative Series does not appear to have been ever related to a large drainage basin. As a result all cave development in this area is probably dependant on infiltration and the size of caves in this area would be expected to be small. An example is Hanging Spring – 1909 Cave that is a solution tube up to 1 m wide and 3 m high. Abandoned higher levels of 1909 Cave have similar dimensions.

Interpretation

This study points up several interesting exploration possibilities in the Eagles Nest-Deep Creek area at Yarrangobilly. First the high level cave systems of Restoration and Janus should be expected to continue, roughly at the level of the explored caves, toward the gorge with exit elevations of about 1000 m. Thus a two-prong study, one of an active examination for prospective entrances in the gorge, and the second of an active re-examination for leads within the caves, should be carried out.

The Eagles Nest system has not been adequately examined for the continuation of the high level passages of either the Eyrie-West Eagles Nest or the upper canyon of East Eagles Nest. The high level passage, if present, should lead to an exit at about 1000 m.

The mid-level passages in Eagles Nest, East Deep Creek and North Deep Creek Caves should be at grade with the present river level. However, cave sediments in the lower reaches of these caves may effectively block all passages when stream gradient becomes sufficiently low so that the wash load is deposited by the cave streams (Pavey 1974). This point also appears to have been reached at the deepest part of EDC Cave. Digging efforts in these passages may not be a rewarding task.

The active streams in all caves in the area are thought to drop rapidly to very low levels and new passage development may be restricted to the phreatic zone.

This interpreation also points up the need for a closer examination of the nature of all segments of the cave passage in regard to its origin at the time of exploration and mapping. In this regard most of the existing cave maps of Yarrangobilly do not contain enough information. Areas of solution passage are not differentiated from passage formed mostly by collapse. In addition most cave maps show only what is happening on the cave floor. Not enough cross-sections, long-sections and projected profiles are produced on which serious geomorphic studies could be based.

Conclusion

This paper has called upon several acts of stream piracy to explain the size and distribution of cave passages in the Eagles Nest-Deep Creek area. Stream piracy is not usually regarded as such a common occurrence and there may be other possible explanations of the features discussed above. Additional data on all caves in the Deep Creek area is needed before more interpretative work can be done.

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A TRIPLE DYE TRACING EXPERIMENT AT YARRANGOBILLY

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Abstract

Rhodamine WT. leucophor HBS and fluorescein were inserted into Deep, Eagles Nest and Traverse Creeks respectively, all sinking wholly or partly into the limestone at Yarrangobilly, as part of a programme to determine the catchment area of Hollin Cave. Hollin Cave and three other major springs, together with the Yarrangobilly River above, between and below these springs, were sampled for various periods manually or by machine. Heavy rains began a day after dye insertion. Various lines of evidence and analysis, including the plotting of regression residuals between different wavebands as time series, showed that the relevant fluorescent wavebands were affected by rises in natural fluorescence in the runoff, probably of organic origin. Green was affected most, then blue, and orange only slightly. It was possible to identify a dye pulse of rhodamine at Hollin Cave, most probably representing all the dye put in. A leucophor dye pulse was also identifiable here but a load curve could not be constructed because of probably interference by changing natural fluorescence. Tracing by fluorescein became impossible. Interference between the three dyes was demonstrated. The implications for future quantititave tracing here are discussed.

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THE COPPERMINE SYSTEM, YARRANGOBILLY, NSW

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Abstract

The Coppermine drainage area is defined as the area contributing to the resurgence at Coppermine Cave; the caves within this area are listed and briefly described. The history of cave exploration is given followed by a brief description of the geology and hydrology of the area and a proposed account of the sequence of cave development. Cave conservation activities and future work are briefly discussed.

Introduction

The Coppermine system is the most northerly of the distinct drainage basins at Yarrangobilly, in the Snowy Mountains of southern New South Wales.

The caves are reported to have been discovered in the 1830's. By the 1890's, if not considerably earlier, several caves in the Coppermine system had been entered. The Coppermine system comprises four major stream sinks and their imputed common resurgence at Coppermine Cave plus other associated caves in the drainage basin. Coppermine Cave has been mentioned in the historical literature and Bath House Cave (as a type example of a streamsink in a blind valley) in the academic literature but the remainder of the caves are known only in the speleological literature.

This paper is an attempt to briefly summarise the known information on the Coppermine system and attempts to define the problems yet to be resolved.

Watershed

We have defined the limits of the coppermine system in terms of its assumed watershed (Fig. 1). The four Coppermine Creeks rise on the high ground of the Fiery Range to the east of the limestone belt and all sink in the limestone within a short distance of the limestone/shale contact.

The southern boundary of the system is the ridge north of Traverse Creek. The closer the ridge approaches the Yarrangobilly River to the west the less certain we can be about the position of the watershed. For this paper we have assumed the watershed intersects the River south of the bluffs around (Y13) Tricketts Cave, although it is unlikely that water falling in this area close to the River actually resurges at (Y12) Coppermine Cave. Following the water tracing experiments of Jennings and others of October 1976 (page this volume) it is unlikely that Traverse Creek feeds Coppermine Cave while it is known that (Y8) Bath House Cave does feed Coppermine Cave (Jennings and Anderson 1966).

Drainage from the dry valley west of Bath House Cave could go to Coppermine Cave, directly to the Yarrangobilly River or to Bubbling Spring.

The boundary of the Coppermine system then follows the eastern bank of the River north to Coppermine Cave itself and follows the eastern bank of Wombat Creek to the vicinity of Y64. On the grounds that Y64, 34, 36, and 37 may well be associated with the development of Coppermine Cave we have taken the boundary north to the nearby hill, thence around the ill-defined "headwaters" of Wombat Creek and up the ridge north of Y45 to the high country again.

The Caves

At least 25 caves are located within the watershed of the Coppermine system. Of these, only (Y8) Bath House Cave, (Y9) Innstable Cave, (Y10) Old Inn Cave and Y45 (which is a streamsink and not

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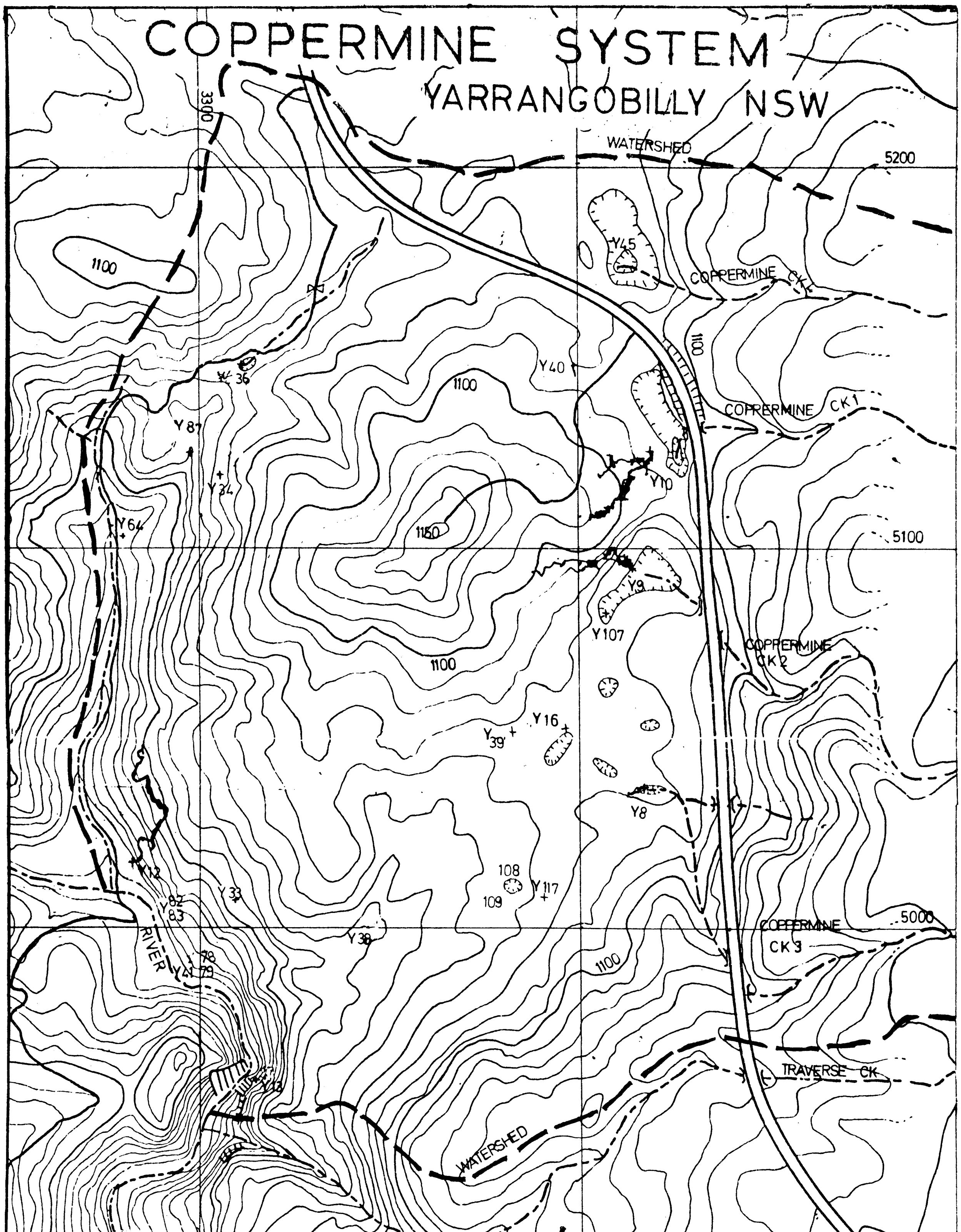

Fig. 1. The Coppermine catchment; Yarrangobilly, NSW (Base map by YRG, 1976, contour interval 10 m, 1 km grid).

a cave) are considered to be important streamsinks. (Y17) Pitch Pot and (Y36) Upper Wombat Creek Cave both lack permanent streams, however, they do show evidence of taking water in flood.
Coppermine Cave is the main resurgence and collects water from Y45 (Pavey 1975b), Bath House Cave, and presumably from Innstable and Old Inn Caves as well. Y64 is a small intermittent spring which probably represents only very localised groundwater flow.

(Y8) *Bath House Cave*
Length approx. 200 m, depth 53 m, first surveyed 1966, resurveyed 1976 by University of New South Wales Speleological Society (UNSWSS), (Warild 1976b).

It is a steeply descending and quite sporting streamway with several waterfalls. There is one 5 m pitch in a waterfall, or a dry bypass which has a 9 m pitch. The lower reaches contain brachiopod fossils, and plenty of mud. This small, tight cave ends as a squeeze into a sump. There are about 70 m of passages above the present streamway.

(Y9) *Innstable Cave*
Length 1005 m, depth 58 m, surveyed by UNSWSS 1976; published in *Spar 62.*

A fairly complex stream cave with a rockfall entrance. The active streamway is quite steep, and ends in a sump after a complex route which includes a bypass, climbs, 7 m pitch and sporting wet squeezes. Much of the length is gained by a long, straight, abandoned stream passage which eventually becomes tight at the cave's lowest point (some 6 m lower than the sump and a considerable distance from it). There are practically no speleothems in the entire cave although a large "erratic" block of old stalactite boss in the passage just before Tea Junction seems to indicate that there was decoration, or still is – but nothing yet has been found).

(Y10) *Old Inn Cave*
Length 1017 m, depth 71 m (47 m from sink to sump). Recent survey by UNSWSS to be published in *Spar,* earlier maps published in *Spar 21* and *42.*

Old Inn Cave is fairly complex. The stream sinks in an intermittent sump, after flowing for 80 m through large boulders and a joint controlled rift. Much of the cave's length is gained in two upper levels which are well endowed with speleothems. The highest level is a long abandoned high canyon with two large chambers, which ends in a massive rockfall of what appears to be basalt boulders. Slightly lower, the second upper level leads via a well decorated chamber (Strawhaven) back to the present streamway. The connection is made via either a loose 18 m pitch or an exceptionally muddy rift. The streamway then becomes very similar to those of Bath House and Innstable Caves until the final sump is reached where the stream sinks into gravel. An overflow passage leads on through a very muddy section and some squeezes to terminate in an almost impenetrable sandy floored squeeze The extra 24 m of depth is gained from the higher Y187 and Y188 entrances to the cave.

(Y12) *Coppermine Cave*
Length more than 450 m, surveyed 1974-76 by UNSWSS (to be published in Spar), best other maps; *Spar 21* and CAVCONACT Guidebook.

Coppermine Cave is a large walkthrough cave containing the resurging Coppermine Creek. Past the sump where the waters resurge there is a well decorated upper level, with some vandalism, and a tight squeeze (now gated) leading on to a rocky, muddy cavern and then to water again. A rift with a howling draft beckons. Throughout its length the cave has a low gradient.
There are five other moderate sized caves in the Coppermine system.

(Y16) *Helictite Hole*
A 15 m tube leads to small rooms and some decoration. Map by Sydney Speleological Society (SSS) (Wellings 1975)

(Y17) *Pitch Pot*
Length 50 m, depth 28 m, map by SSS (Walker and Ellis 1976)

This cave takes a fair amount of water in flood. It starts as a dipping solution tube 16 m long and then expands into a large rockpile cavern and lower down into a tall narrow, intermittent streamway which terminates in a gravel sump.

(Y33) *Mooroolbark Cave*
Length 130 m, depth 15 m, map by SSS (Wellings et al 1976)

A 9.5m pitch leads to a well decorated and very muddy horizontal passage.

(Y34)
Length approx. 200 m, depth more than 30 m, survey in progress UNSWSS

A 12 m pitch leads to muddy tunnels on two levels. The lowest part of the cave terminates in an unusual 'sink hole' in flowstone. A second entrance has been reported.

(Y40)
Depth 78 m, map by UNSWSS and SSS.

A very steeply descending pothole north of Y10. It contains a number of climbs and pitches and is rather tight and sporting. The cave ends in a gravel sump where some hopeful digging has been done without much likelihood of success.

The remaining caves are very small.

(Y36) *Upper Wombat Creek Cave*
Length 35 m, depth 9 m, map by Canberra Speleological Society (CSS)

A large earth walled doline leads to a number of muddy chambers with little hope of extension.

(Y37)
An old swallet of Wombat Creek, short crawls leads to a mud blockage. (Rose 1964)

(Y38)
A shaft 12 m deep leading to a clay blockage (Rose 1964)

(Y39)
A 13 m deep clay filled shaft, blocked by formation (Rose 1964)

(Y41)
A small pit about 50 m above Coppermine Cave, very hard to find (Rose 1964)

(Y78)
A small mud floored chamber with a tight passage leading off (Brush 1973)

(Y79)
A 3 m drop leads to an elongated chamber with holes which lead to 6 m of lower passage (Brush 1973)

(Y82)
A small cave about 7 m long (Middleton 1974)

(Y83)
A small cave about 15 m long (Middleton 1974)

(Y84) *Undernover Cave*
A high arch entrance with a 3 m long upper level and a 30 m long lower level (Middleton 1974)

(Y107)
Cave about 10 m long. (Wellings et al 1976)

(Y109)
A 10 m deep dig near 108 (Wellings et al 1976)

History

Rose (1964) suggests that Coppermine Cave was known in the mid 1800's and visited frequently by parties from the show caves at the other end of the limestone belt. Certainly a number of caves were discovered at the southern end of the limestone belt in the 1800's. Yarrangobilly Village was well established by the turn of the century and the coach road from Tumut to Kiandra must have been used well before this period giving access to the area around Coppermine generally.

Oliver Trickett (1898) reported extensive vandalism in the cave prior to 1897. Trickett says (in part)

> ". . . Following the underground stream up from its exit for 500 feet, wading through icy cold water on the way in places, and then rising about 30 feet, the remains of what has been a magnificently ornamented cave is reached, about 300 feet long as far as has been explored. Axes, crowbars, chisels and cartridges, have been used to demolish or remove the beautiful formations in this part of the cave."

Later Trickett (1917) was able to report that due to the difficulty of protecting the cave from mutilation, the attractive chambers had been closed with iron bars set in cement. Little of this barrier remains today. In the area of the climb scattered pieces of rotten wood and iron bars are occasionally encountered.

The inlet caves (Y8, 9, 10, 45) are located near the highway and not far from the location of the former "Yarrangobilly Hotel" (Trickett 1897). Trickett reported

> "The water descends rapidly after passing though these openings by channels which may be followed for some distance."

Rose (1964) reports signatures from 1891 in an extremity of Y10 but these have not been sighted by the authors.

There is little available historical record between Trickett's accounts and the first visits by members of the Sydney University Speleological Society (SUSS) in the early 1950's. SUSS members visited Coppermine Cave and descended Bath House Cave. The first recorded visit to Bath House Cave (according to Rose 1964) was in 1956 although it may have been descended in 1950-51.

Rose, Cherry, Ballard and Myers were active in the late 1950's to early 1960's and recorded some of their trips in the 'Yarrangobilly Caves Speleological Investigation Log Book No. 1' (Currently held at the Information Centre at Yarrangobilly). Rose started the cave numbering system at Yarrangobilly. The first entries in the Log are the discoveries of Y34 and 39 in November 1959.

Myers and Rose found Y16 in 1958 and Y17 in January 1960; the entrance having only recently appeared in the side of a sink. At the same time Y8 entrance was reported as having fallen in and almost buried the number.

In 1960 a party under R.A. Batchelor explored Old Inn Cave to the Strawhaven area and reported the fissures beyond as not going and of little potential. An arrow marked 'out 1891' was found nearby. According to this report Strawhaven had been first entered in 1957.

In 1962 D. Purchase lead a CSS party which broke through into the streamway again and followed it downstream for 50 feet stopping at a narrow crevice. In March 1962 a CSS party under V. Pickering discovered the Lofty Chamber/Rimstone Cavern upper level. A later trip established a connection from Strawhaven to the first sump and this has recently been refound by an UNSWSS party.

On his departure from Yarrangobilly in 1963 Paul Rose commented that the surface at Yarrangobilly hadn't yet been scratched and he was quite right. At that time the numbering had reached slightly more than 40 caves, at the date of writing this paper the number was over 190.

Y40 was greatly extended from the simple 12 m shaft known to Rose, to 78 m deep by an SSS digging party (Smith 1968).

(Y9) Innstable Cave was for many years known as 'around 600 feet of loose rockfall with a stream flowing through it'. Ballard, Cherry and Rose made a 100 foot extension to an area where progress was regarded as sheer folly. We now think this was directly below Portable Chamber. Rose

(1964) stated "All attempts to find a higher level bypass have so far failed but there is no conclusive evidence that one does not exist".

Matthew and Pavey (1974) from UNSWSS found a higher level abandoned stream canyon leading up and on from Culvert Junction to Tea Junction, Hoover Passage, Portable Chamber and Pricker Passage – an estimated length of 345 m of new passage. Further small extensions in this area followed (Pavey 1975) and then Warild et al. (Pavey 1976) discovered the Northernmost Passage which provides a dry route virtually to Portable Chamber. These discoveries pushed the known length of the cave to over 1000 m of passage in the space of 18 months.

Bath House Cave, perhaps the most sporting of the three major inlets has the smallest amount of passage, with only a short abandoned higher level discovered in 1976 (Warild 1976)*. There are good chances of further discoveries.

Geology

The geological structure at Yarrangobilly has not been well studied and we present only a brief outline. The Silurian Yarrangobilly Caves Limestone strikes approximately north-south and dips to the west. On the eastern margin there is a bed of shale separating the limestone from the underlying Goobarragandra Volcanics (porphyries and others) which form the high ground of the Fiery Range to the east. Above the limestone, outcropping on its western margin is another shale unit. The dip in the limestone varies from 70°W on the eastern margin to 30°W on the western margin.

The limestone outcrop in the Coppermine drainage area varies from just over 1 km wide at the northern boundary to 1.5 km in the central section (between Y8 and 12) and necks to approximately 0.5 km wide at Traverse Creek on the southern boundary.

The limestone is capped on Gravel Hill by some Tertiary gravels and by remnants of a Tertiary basalt flow which originally filled the early Yarrangobilly River valley (Nicoll pers. comm.)

Hydrology

The general consensus is that the water which sinks in Y8, 9, 10 and 45 resurges in Y12. Trickett (1897) and Rose (1964) have both recorded this opinion. However, no practical tests are reported before 1966.

On the 15th May, 1966 a party from CSS placed approximately 2 kg of fluorescein in the stream outside Bath House Cave which was flowing at about 0.1 cusec at that time. The colour was observed to be still entering the cave at 4.15pm on the 19th May, while colour was first detected emerging from Coppermine Cave at noon on 22nd May. This gives a time of somewhere between 4 days, 17 hours and 50 minutes and 6 days 18 hours for the underground flow between Y8 and Y12 (Jennings and Anderson 1966).

Wellings (1972) describes placing a quantity of dye into Y45 and charcoal bags into Y12 and elsewhere in April 1971. The bags were collected two days later when there was no sign of colour in the stream in Y12. Only a modest flow of water was entering Y45. There was no written report of the success of this test but apparently it was successful (Wellings pers. comm.) in proving a connection to Y12. In light of the questions raised about the efficiency of detecting fluorescein with silent watchers at Yarrangobilly due to the high background fluorescence (Spate et al page 104 this volume) this positive result must be considered to be in doubt. This argument does not hold for the Y8 to Y12 test as the colour was positively identified.

Pavey and Shannon (1974) describe a 2 kg fluorescein water tracing test from Y112 (Leak in the Creek, 3 km along the strike to the north where the Yarrangobilly River crosses the limestone.) which showed positive results at Y12 and also Bubbling Spring and Hollin Cave (Y46) (both to the south of the Coppermine drainage area). The positive result in Y46 was recorded after 6 days and that from Bubbling Spring after 30 days (Pavey 1975). This result is also in doubt due to the method of detection.

The Y8 and Y45 tests to Y12 would indicate a simple dendritic system, confirming the generally held view that the water which falls on what we have called the Coppermine drainage area drains through to resurge in Coppermine Cave. Clearly more testing with unambiguous results is required before we can positively assert that the water sinking in Y8, 9, 10 and 45 does resurge at Y12.

Just how many of the other caves in the Coppermine drainage actually feed water to Y12 rather

* During the preparation of this paper for publication we were told of a short 50 m upper level discovered by members of UNSWSS at Easter 1977

than to, say, Bubbling Spring will be difficult to establish. The majority take little water, even in flood whilst those that do take sufficient quantities of flood water may well be so choked with gravel, debris and sand as to make dye or spore tracing unreliable.

The further possibility of water from Leak in the Creek flowing under the Coppermine drainage net and resurging at Bubbling Spring clearly needs further investigation following the failure by Jennings et al. to repeat the initial test of Pavey and Shannon (1974). Recent work of diverting water into Leak in the Creek and digging nearby has produced flows of between 1 and 2 cusecs for considerable periods. This water sinks in Y112 and we have no confirmation of where it resurges*.

Speleochronology

Little work has been done on speleochronology in the area and the following is mainly speculation.

The Yarrangobilly River is thought to have had a shallow valley when the Tertiary basalt flows occurred. The basalt flow may well have sealed off the limestone sufficiently for a dendritic pattern of drainage to become solidly established. This pattern remained for a considerable period after the erosion level again reached the limestone. This resulted in the shallow broad valleys of the upper section of Wombat Creek and the now dry valley between Y8 and 9 and the River.

Stream capture through the limestone occurred as the River's base level reduced sufficiently for the water to take the easier course underground. Stream capture forming caves Y8, 9, 10 and 45 may not have taken place sequentially as the current entrances are remarkably similar in altitude. It could equally be argued that stream capture took place sequentially up the dry valley leaving successive cave remnants some of which we now see as Y16, 38, 39, 107, 108 and 109. Certainly the chain of dry channels and sinks to the west of Y8 would indicate some successive capture.

The caves themselves show evidence of successive internal stream captures; for example Rimstone Cavern in Y10 and Pricker Passage in Y9 have been abandoned in favour of the present streamways.

Y45 and Y10 have larger dolines than Y8 and Y9 and perhaps they were captured earlier in the sequence, being at that time slightly higher and due to the differential rate of erosion due to varying stream flow they have lowered at much the same rate as Y8 and Y9. The streamsinks today are at 1050 ± 5 m.

We have yet to enter cave in Y45 and are probably only seeing part of Y8 at present. The older passages in Y9 and Y10 head more directly west towards the River and with a lot lower gradient than the present streams which tend to the south-west around (but well under) Gravel Hill. No obvious earlier resurgences for the higher level passages exist although Coppermine Cave does have a well developed upper level approximately 5 m above the present stream level.

Y40 has the highest entrance in the area (1082 m) and is the deepest cave (78 m) presumably it has been formed by the stream from the gully where it is located. It follows the strike to the south towards Y10.

Y34 and Y33 probably represent an earlier level of cave which captured the headwaters of Wombat Creek before the period of rapid downcutting commenced. Y36 and Y37 may well have been prior sinks for Coppermine Number 4/Wombat Creek before the sink at Y45 developed.

Coppermine Cave's stream appears to emerge in the most part from the sump approximately halfway into the cave. The pools beyond this point although not much different in level from the flowing stream appear to be either a backwater or to be fed by much lower flow stream coming from the Y34, Y36 area.

Structural Control

A notable feature of Y8, 9 and 10 is the jumbled pile of boulders (rockpile) near their entrances. The size and frequency of these rockpiles is almost unique to Yarrangobilly on the Australian mainland at least. Rose (1964) suggests that these have been formed by the cave streams undermining limestone cliffs and causing large blocks to break away on dip joints. Certainly in Y10 there are at least six large chambers aligned north-south with dip slope roofs and rubble or soil floors, although this feature is not present in Y8 and Y9. Once past the entrance in Y8 and Y9 the cave form is basically streamway, with some minor collapse features present.

* Flow measurements made on a post conference field trip by Shannon (1977) seem to indicate that the Leak in the Creek water is flowing past the Coppermine system and resurging further downstream at Bubbling Spring.

The current lowest section of streamway in Y10 is a jumble of mud coated boulders with little evidence of substantial passage in bedrock. This in contradistinction to the abandoned upper levels which have formed substantial canyons in bedrock.

Coppermine Cave shows distinctive alignment along the strike of the beds throughout its length.

Speleothems

In the main part there is very little speleothem development in the caves of the Coppermine drainage area. The notable exceptions are Y33 and the upper levels of Y10 and Y12. It may be these are the two oldest caves and hence the best decorated but that does not explain the relative lack of speleothems in Y8, 9 and 34 which by the above discussion are probably contemporaneous.

Conservation

"I have the honour to report on the mutilation of the Copper Mine Cave, Yarrangobilly" (Trickett 1897) — so starts the first report of vandalism in the area and of the attempts to stop it. Not long after this report a gate was placed on the entrance to the Coppermine Cave upper level. It was, however, easily bypassed and being made in part of wood, soon rotted away. Thus for many years the upper levels of the cave were prey to wandering vandals. After some considerable pressuring from Australian Speleological Federation (ASF) members over the preceeding 10 years a substantial gate was finally placed on the upper level, but this time at the squeeze some two-thirds of the way along the upper level. This site is much better as the squeeze was originally chipped out and is quite tight. It quite effectively keeps out unwanted visitors but protects only a small proportion of the cave. No other caves in the Coppermine area have been gated.

The passage beyond Lofty Chamber in Y10 is well decorated and delicate and could be easily trampled out of existence. A gate would be out of the question in this section due to the tall narrow passage shape, but by common agreement we are hoping to keep purely 'tourist' parties out of this section. Some track marking and signs have been erected to this end.

The remainder of the caves and their passages do not need this sort of protection. For the most part they could do with some keen explorers who might well find some decorated sections. The only exception is Y33 which is well decorated and extremely muddy. Any party in here could do extensive, albeit unwitting, damage. The cave has a measure of natural protection in that it has a difificult-to-locate entrance, and is one of the few caves in the area which requires a ladder for entry.

Conclusions

There is still a lot of cave to be found in the Coppermine drainage area. Considerably more exploration needs to be undertaken especially in Y8 and Y9. The hopes of finding a 'master' cave leading from the inlets to Coppermine Cave should not be totally dismissed. There is still a good kilometre of limestone between the known furthest reaches of Y8, 9 and 10 and Coppermine Cave.

Further work is required in geological mapping and water tracing to establish more precisely the extent of the limestone and the area which feeds water to the resurgence in Coppermine Cave.

Acknowledgements

Much of the work reported in this paper has been carried out by many individuals from ASF member societies during past Convention field trips and under the auspices of the Yarrangobilly Research Group. Particular mention should be made of members of UNSWSS who have contributed the largest part of the task of surveying the caves. R.S. Nicoll supplied the basic geological data. We would also like to thank the NSW National Parks and Wildlife Service who have given permission for these activities to be carried out, and to the Rangers at Yarrangobilly who have assisted us from time to time.

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KARST AT NEW GUINEA, SNOWY RIVER, VICTORIA

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Abstract

One of the features of the Snowy River Gorge northeast of Buchan, Victoria, is a small but spectacular area of karst, at New Guinea. This is developed in an isolated occurrence of massive limestones of the Early Devonian Buchan Group, downfaulted into the Lower Devonian Snowy River Volcanics; and is one of several small outliers of the Buchan basin. The limestone occurs as a dissected bench along the gorge and is characterised by substantial cliffs, well developed dolines, and a number of interesting caves. Speleological investigations at New Guinea in recent years indicate that the geomorphology, hydrology, cave biology, and surface vegetation of the area are of considerable interest. This paper summarises the discovery and exploration of the area and describes the main characteristics of the karst and associated features. A number of issues in land use planning and management of an area such as this are discussed.

Introduction

The name "New Guinea" is applied to an area on the Snowy River just south of the Tulach Ard Gorge and some 25 km northeast of Buchan (Fig. 1). The area probably gets its name from the relict rainforest communities in the gullies, and the rugged terrain. It includes a small area of karst which is part of a larger and discontinuous belt of limestone outcrops which extends from Buchan to Jacksons Crossing and New Guinea. This paper is concerned with the northern end of this belt.

Geology

The limestone at New Guinea is of Early Devonian age (VandenBerg 1976) and is dense, dark to light bluish in colour, massive, well bedded, and often highly fossiliferous. It is one of several small outliers of the Buchan Caves Limestone along the Snowy River to the east of the Buchan Basin (Teichert and Talent 1958). In outcrop, it appears as a roughly rectangular block, some 1.5 km wide and 6 km long, extending from New Guinea in the north, to Jacksons Crossing in the south.

During the late Devonian, the limestone was subjected to complex faulting and tilting down into the unconformably underlying (Bradley 1969) Early Devonian Snowy River Volcanics (Howitt 1876; VandenBerg 1976). The general structure is of a roughly north-south strike and a 10-30° westerly dip. A number of faults have been identified along its margin but, due to poor outcrop and severe dissection, the exact nature of the limestone/volcanics boundary is rather obscure (Bradley 1969; VandenBerg pers comm).

Talent (1956) and Teichert and Talent (1958) correlate the limestone at Jacksons Crossing as equivalent to the Buchan Caves Limestone of the Buchan Basin; it is similarly dolomitic at the base and has a somewhat richer fauna. Talent describes a sequence of about 200 m of limestones and dolomitic limestones, commencing with over 30 m of calcitic dolomite and dolomite limestone, and passing upwards successively through pure limestones, muddy limestones, mudstone, and pure limestone. The upper portion of the Buchan Basin sequence – the Taravale mudstones and Murrindal limestones (Teichert and Talent 1958) – is unrepresented in the area.

The underlying Snowy River Volcanics comprise a thick and massive sequence of acid volcanics including rhyodacites, rhyolites, andesites, tuffs, agglomerates and occasional sediments (Ringwood 1955; Bradley 1969). An interesting feature of the volcanics is an outcrop, near the base of the limestone on the northern side of New Guinea spur, which shows strong columnar jointing (Ferguson 1899).

River gravels and cobbles occur in a number of scattered places, especially capping ridgetops

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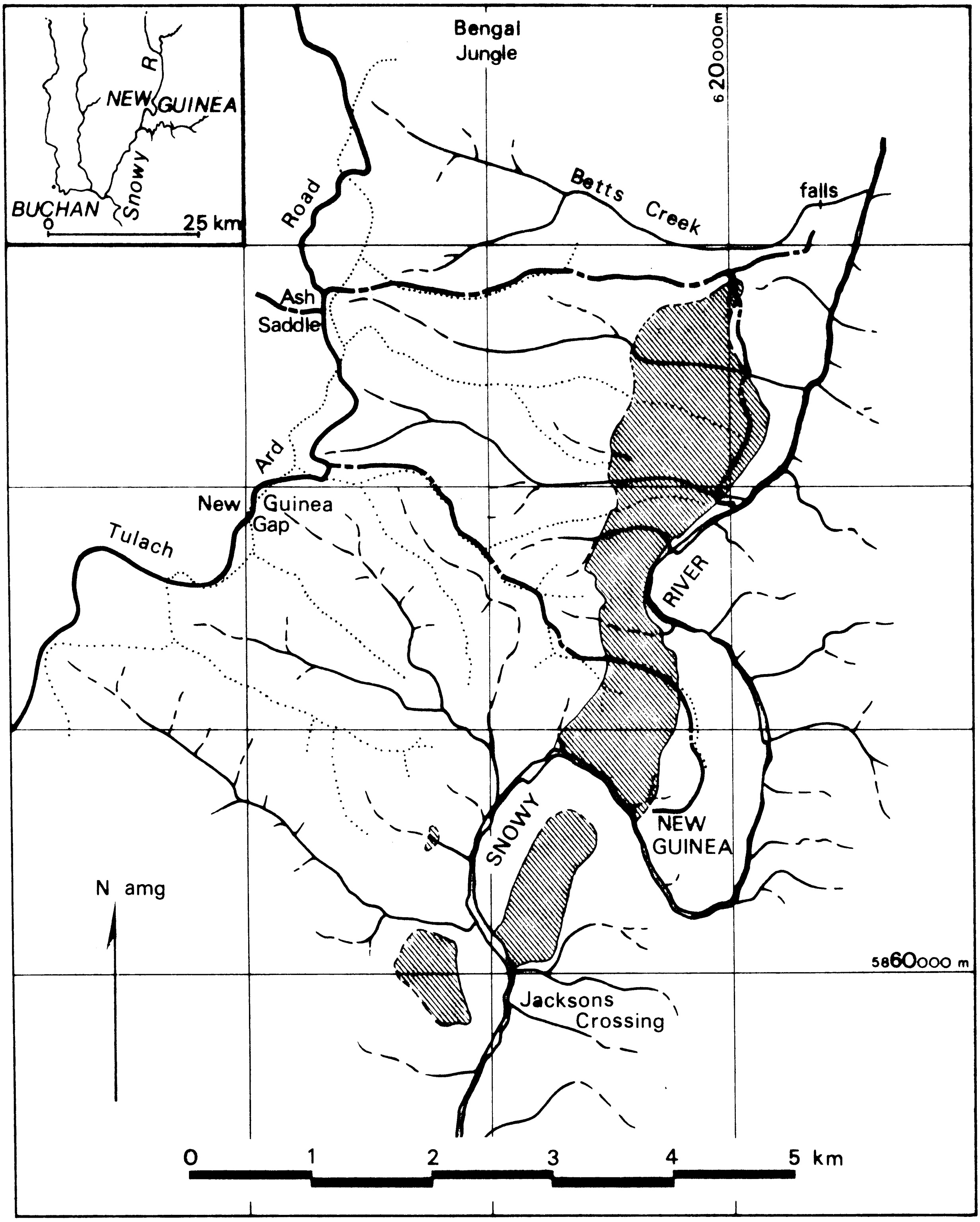

Fig. 1. Approximate extent of the limestone at New Guinea, showing the catchments which drain across the outcrop to the Snowy River.

along the gorge. These are most likely to be of Pleistocene age (VandenBerg pers. comm.) although Ferguson (1899) regarded them as Pliocene. These sediments are indicative of a broad valley floor in an earlier stage of downcutting the Snowy valley. One such deposit outcrops on top of the limestone on New Guinea spur.

Topography

The setting of the New Guinea area is of a probable Tertiary erosion surface uplifted in the Pliocene or early Pleistocene and deeply dissected by the highly active Snowy River to form an impressive tract of gorges, steep valleys, and rugged terrain. The general relief of the area is about 800 m, ranging from 80 m at the Snowy to 900 m elevation on plateau remnants to the west.

The limestone outcrops as a bench in the western side of the gorge. The Snowy initially flows parallel and a little to the east of the outcrop, but then cuts a broad bend into it (at some high limestone cliffs) and swings east to flow round New Guinea spur before heading back west across the limestone and then away to the south. It is interesting to note that the Snowy has incised this great meander in volcanics, rather than cutting directly through the more readily eroded limestone of New Guinea spur. The gravels on top of the spurs, and the broad former valley that their setting implies, suggest that this meander is a superimposed drainage feature.

Three major spurs, New Guinea spur being the southernmost, descend steeply from the plateau to the limestone. At the contact of the volcanics with the limestone, there is a marked break in slope, characterised by a small saddle. The limestone on the spurs is fairly level and they then drop relatively steeply to the Snowy River.

Drainage

The northern section of the New Guinea limestone is dissected by three gullies. These are partially filled with coarse gravels and have dry stream channels. The channels probably flow only after exceptionally heavy rain, since the surface streams normally sink as they approach the limestone/volcanics contact. In the case of the northernmost gully on the limestone, it is uncertain whether the stream enters an underground karst drainage system, or merely seeps through the deep gravels in the gully floor.

The next two gullies south apparently sink and enter the NG5-6 and NG2 systems respectively. It would appear that these systems developed only after the gullies were cut to their present level. Downcutting of the gullies has kept pace with the downcutting of the Snowy River and there has clearly been no underground capture until relatively recently. It would appear, especially from evidence in NG1, that there may have been considerable phreatic preparation of the limestone prior to downcutting.

Climate in the area is temperate, with cool winters and hot summers. The rainfall varies considerably with topography. Stands of Mountain Ash (*Eucalyptus regnans*) occur at 700-900 m in the heads of the main gullies, and these indicate an annual rainfall of about 1500 mm. However, the Snowy valley is considerably drier and the rainfall decreases rapidly down to river level (at 80 m). The woodland and open forest on the limestones (from 80 m to 300 m) is indicative of annual rainfall of about 400 mm.

This rainfall pattern is significant, since it means that the runoff on the karst area itself is likely to be considerably smaller in volume than the runoff flowing onto the limestones from the volcanics. Although summer flows may be as low as 0.1 $1s^{-1}$, these streams from the volcanics are virtually perennial, and would carry higher flows (typically in the 1-10 $1s^{-1}$ range) for most of the year.

Caves and Karst Features

To date, three cave systems and one small spring have been found at New Guinea. The only other obvious karst features are two substantial limestone cliffs, a number of dolines, and a few apparently minor caves.

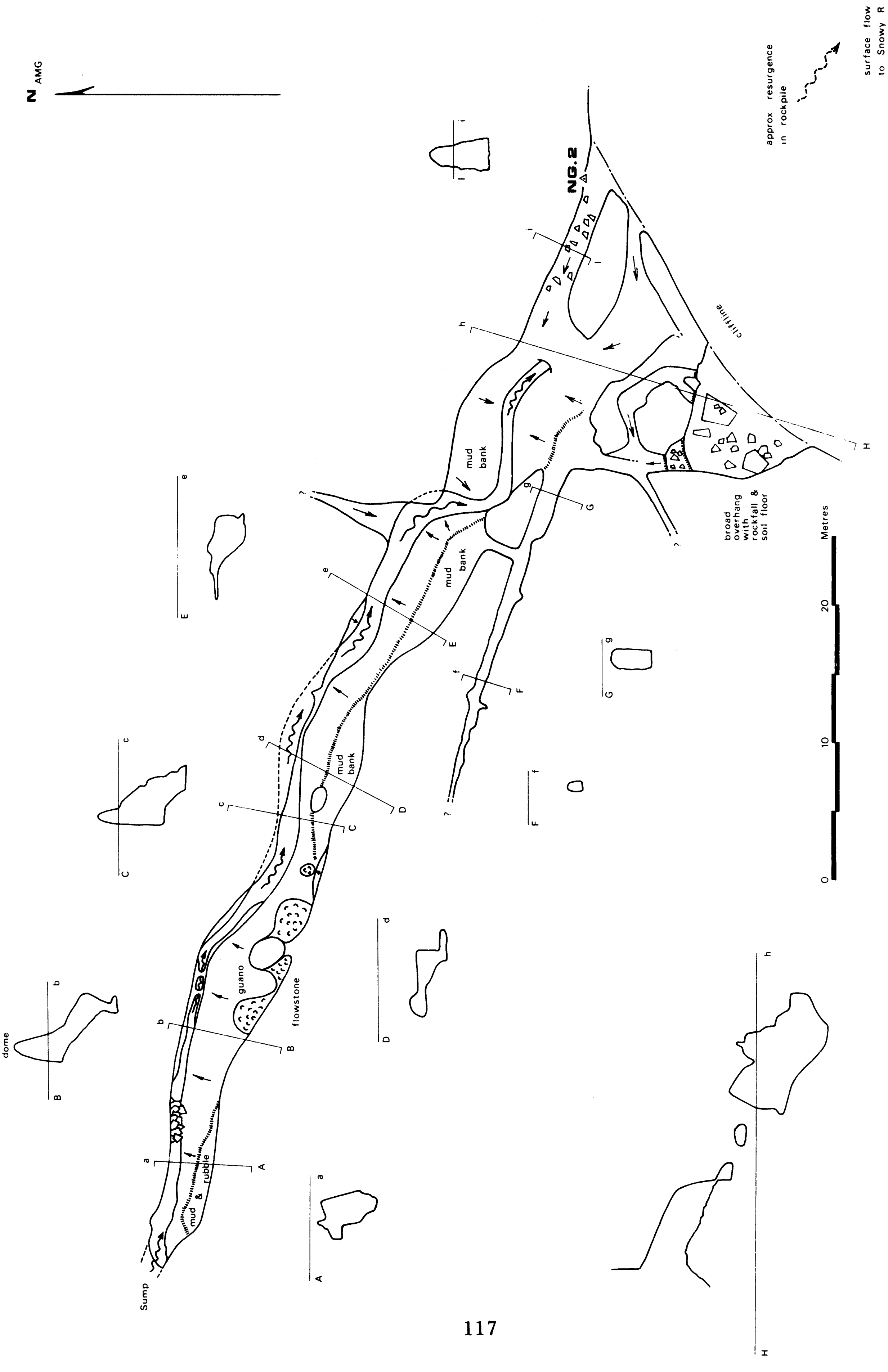

Fig. 2. Plan of NG 2 cave, as far as the sump.

NG2 cave (un-named)

This cave is the outflow of a relatively substantial (1-5 ls^{-1}) permanent stream. Its entrance is in a short section of low cliff about 100 m back from the Snowy River. The cave consists of a large chamber with several entrances, and a roomy stream passage with several dry side passages; all joint-controlled (Fig. 2). About midway, the stream sumps off and the inner section can only be reached through it by excavation of gravels and a very low wet crawl. The termination of known cave is a substantial rockfall; total length of the cave is about 150 m.

Near the entrance, the cave is partly developed along bedding planes, with collapse creating a large balcony looking out towards the river. This has a floor of large fallen blocks and earth. From the evidence of shell, bone and stone fragments, it would appear that this balcony and the large bank above the stream in the entrance chamber were occupied at some time by aborigines.

The source of the water flowing from NG2 is not known. Its volume is too substantial for it to be solely derived from a catchment on karst. It probably originates from the surface stream in the gully to the north, which has its headwaters to the west of the cave, and sinks just 50 m or so upstream of the contact with the limestone. However, this is a substantially smaller (and lower, and drier) catchment than that feeding the NG5-6 system (which has a flow comparable to that of the NG2 system). It seems likely that NG2 depends on other, as yet unknown, surface catchment areas as well.

Nuigini Namba Faiv Cave (NG5), and NG6 (un-named)

NG5 and 6, together with an un-numbered resurgence, form an interesting underground drainage system. Nuigini Namba Faiv is an extensive (500 m) stream passage cave (Fig. 3) which is more or less parallel to, and only a few metres below, the surface flood channel in a gully which crosses the limestone. The surface stream sinks into fractured volcanics some 50 m upstream of the contact with the limestones (about 500 m upstream of NG5). Between these two points there are several dolines quite close to the flood channel.

The cave has a tight rockfall entrance and the stream passage is generally low and rather wet; it meanders considerably, mainly controlled by jointing, and alternates from bedrock to frequent sections of rockfall. At the upstream end of the cave is a large chamber (approximately 60 m long and 25 m wide) which extends at the far end to about 25 m above stream level. The stream is blocked by a massive rockfall.

At the downstream end of the cave, the stream likewise disappears in rockfall. It almost certainly reappears in NG6, which consists of a large doline with a stream flowing out a short section of tight cave on one side of the doline, and promptly disappearing into rockfall on the other. A substantial resurgence on the surface flood channel some 100 m downstream is presumably that of the NG5-6 system. Total underground course of the stream would be about 1.5 km ("as the crow flies").

New Guinea Cave (NG1)

New Guinea Cave has a surveyed length of 400 m, and is 70 m deep (Fig. 4). It appears to be essentially joint-controlled in that the initial 250 m is north-south along strike joints, and the last 150 m is east-west down dip joints. Although the general trend in these two sections is straight, the cave is occasionally offset, or minor chambers developed, along joints more or less at right angles to the trend of the main passage.

Generally the stream passage is a high (up to 20 m), narrow, vadose canyon, and has upper levels along most of it. These run parallel to and at times slightly offset from the main stream passage. The upper level passages are frequently modified by rockfall and are normally partially infilled with clayey gravels, mud, and guano. Higher level phreatic development also shows a marked north-south and east-west structural control; it consists of low passages, blocked by heavy clay fill.

The cave stream is a small trickle between occasional pools, and presumably flows only after very heavy rains. The gravelly stream bed falls at a fairly consistent gradient, bounded by occasional banks of cemented gravel and silt. In one section, along the east-west leg, the gradient steepens for 25 m or so, where a narrow sinuous passage in bedrock has been sculptured into a series of short falls and splash pools.

The initial phreatic development of NG1 probably took place when the Snowy River was at a level above the present spur and the gravels had not yet been deposited. As downcutting proceeded, the phreatic system would have progressively drained, allowing the present vadose stream system to

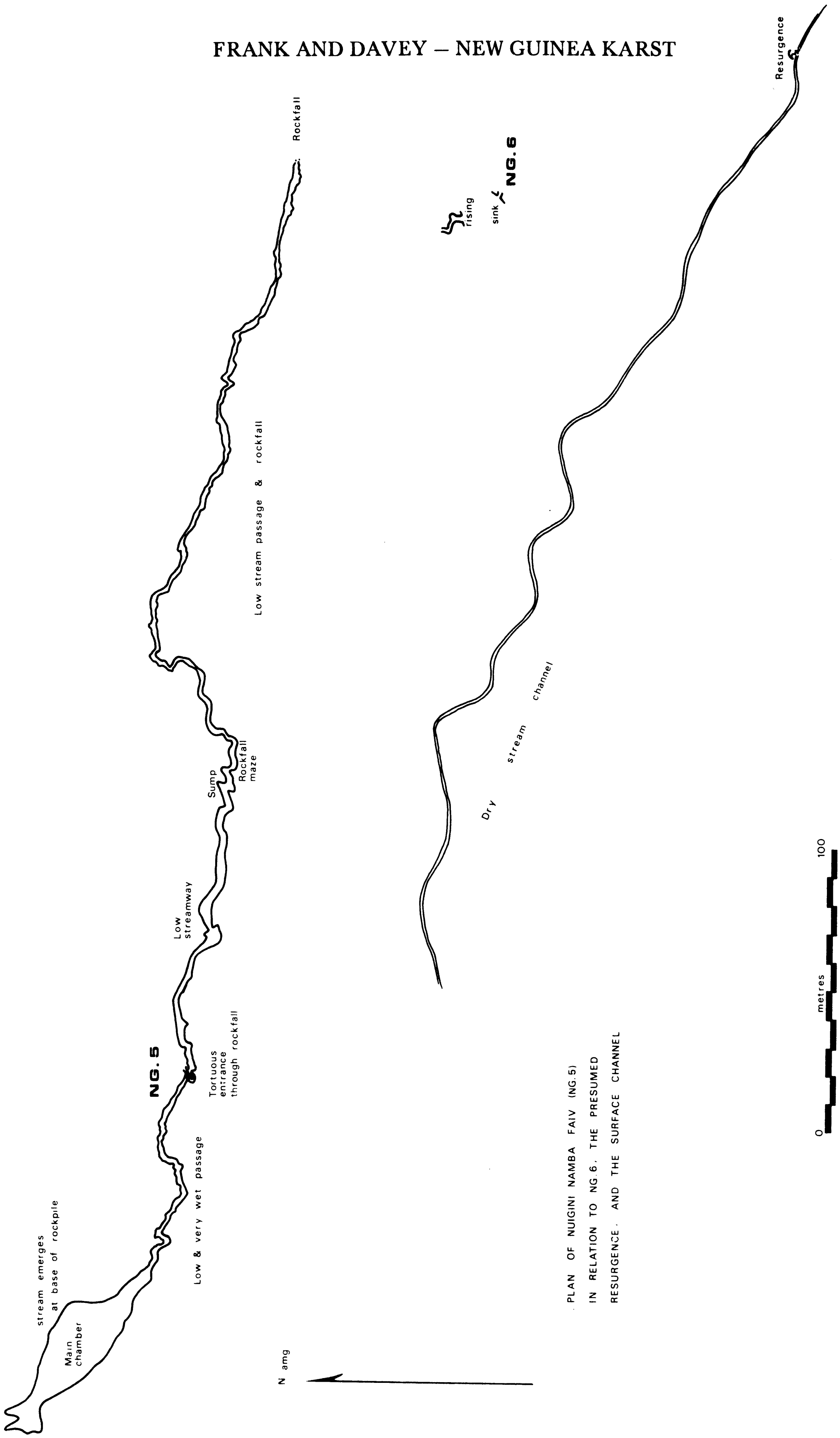

Fig. 3. Plan of Nuigini Namba Faiv cave and NG 6 in relation to the dry surface channel and the presumed resurgence.

develop. The solution doline must also post-date this downcutting. It is interesting to note that had the spur been slightly narrower – even by 100 m or so – it is unlikely that any more than the initial phreatic phase would have developed, since all drainage would have been run directly off one side of the spur or the other, instead of draining into the large entrance doline. As it is, the surface catchment to the doline is not only small, but is directly on top of the spur. The old gravel beds, permitting rapid infiltration in an otherwise small catchment, may have been an important factor in cave development.

The ultimate rising of the stream at NG1 is unknown. Its sump is about 150 m above the level of the Snowy, and gullies with small streams in them occur on both sides of the spur. Neither has any obvious springs.

Other Features

Just south of the New Guinea Cave doline, a small valley of degraded dolines and small limestone outcrops heads south in the direction of the Snowy. One of these dolines contains a small cave formed in large corroded boulders of limestone.

A small spring with an estimated average flow of about 0.2 ls^{-1} rises on the main cliffs just north of New Guinea spur, at about 150 m above the river. The stream from this spring has deposited a large bank of tufa at the base of the cliffs.

The northernmost of the gullies crossing the limestone has not yet been adequately investigated, but a preliminary reconnaissance over just part of the area revealed several blind dolines, and a fairly substantial catchment without any surface stream flow. Like the streams associated with NG2 and NG5-6 in the gullies to the south, the surface stream sinks into the gravels and/or fractured volcanics at or just upstream of the contact with the limestone. A major tributary gully in limestone, and a doline area identified from air photos, have yet to be investigated!

Vegetation

Vegetation communities at New Guinea include tall open forest, open forest, woodland, and remnants of closed sub-tropical rainforest in the lower gullies.

The gully heads contain tall wet forest of Mountain Ash (*Eucalyptus regnans*). At slightly lower elevations, and more exposed sites, the vegetation is an open forest dominated by Silvertop (*E. sieberi*) and Messmate (*E. obliqua*). In drier sites still, the forest is more open and dominated by White Stringybark (*E. globoidea*) and associated species.

On the limestone, and on other dry sites in the gorge, the vegetation varies from open forest to woodland, and is dominated by Red Box (*E. polyanthemos*), But But (*E. bridgesiana*), and Yellow Box (*E. melliodora*). Other species of interest include Kurrajong (*Brachychiton populneum*) and Austral Grass Tree (*Xanthorrhoea australis*), both of which are locally characteristic of the limestones, and occur on the volcanics very rarely. Groundcover on the limestones is generally more grassy than on the volcanics.

The relict rainforest gullies are dominated by pittosporum (*Pittosporum undulatum*) and Lilly Pilly (*Eugenia smithii*), and are characterised by a diverse assemblage of lianas.

Much of the limestone was once partially cleared (at the turn of the century) and then abandoned. All but a few areas have now regenerated, though not necessarily to their original condition.

Cave Fauna

New Guinea Cave and NG2 both frequently contain larger number of the Bent Winged Bat (*Miniopterus schreibersii* Kuhl). In both cases, the bats tend to congregate in relatively large chambers well inside the caves, near the terminal sump. These bats are almost certainly part of the population based at Nowa Nowa, 20 km to the southwest (Hamilton-Smith 1965). New Guinea Cave is regarded by Hamilton-Smith (pers. comm.) as one of a few caves in the Buchan area used by pregnant females, prior to the birth season, for acclimatisation.

The guano piles in both of these caves support a characteristically rich invertebrate fauna, including guano mites, beetles, and spiders. Elsewhere in the caves, several spider species and wetas are fairly common.

Invertebrate species of interest which have been recorded from New Guinea Cave include the troglophiles *Notospheophonus castaneus consobrinus* Moore, and an as yet undescribed species of

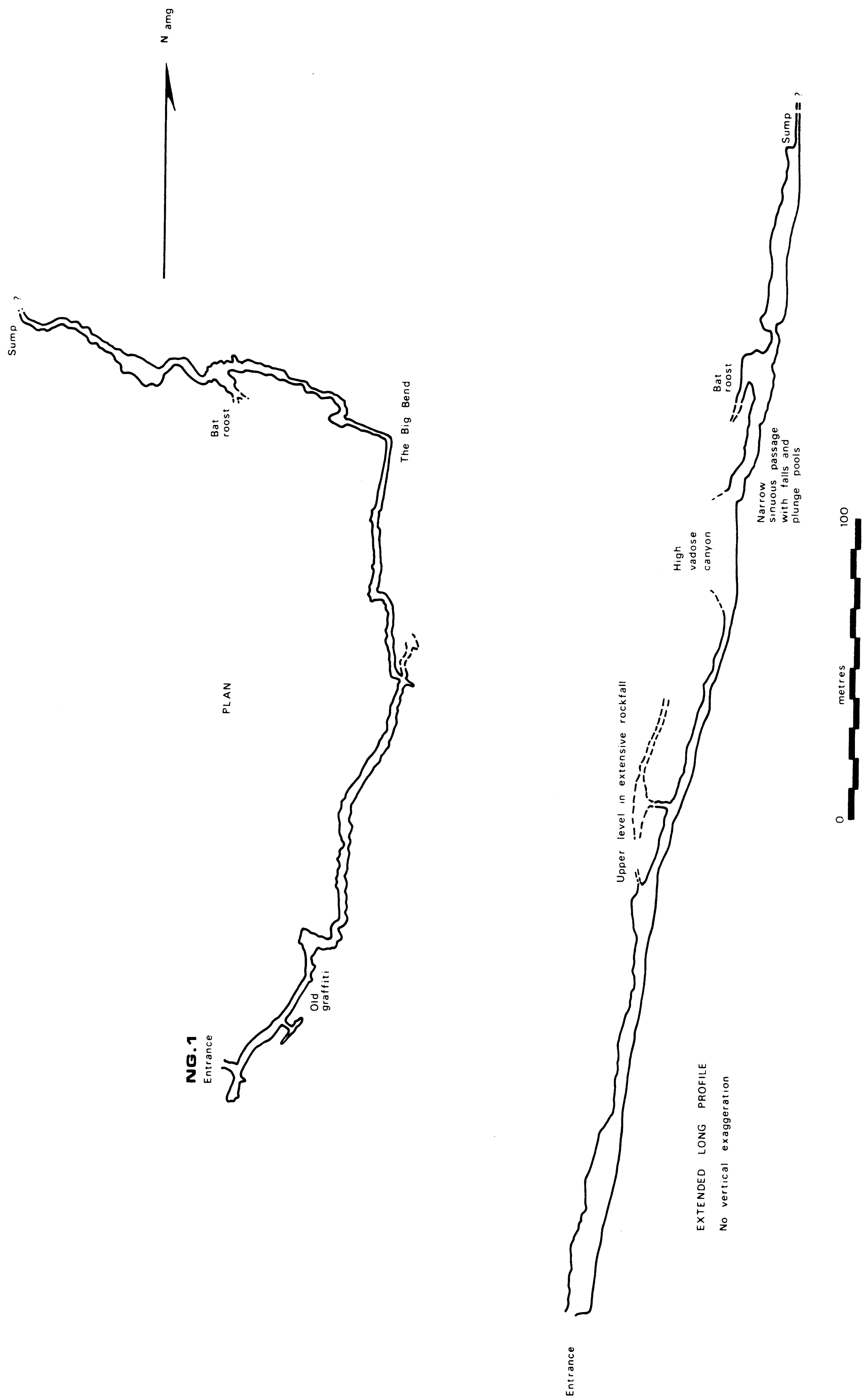

Fig. 4. Plan and profile of New Guinea cave

Triaenonychid harvestman, which are both endemic to the Buchan area; and an interesting mollusc, *Elsothera funerea* Cox, which is only recorded from caves in two other localities – East Buchan, and Bungonia, N.S.W. (Hamilton-Smith pers. comm.).

History

The first recognition of the limestones of the Buchan area appears on a geological map produced by Taylor in 1866. Soon after, Selwyn and Ulrich (1867) and McCoy (1867) established the age of the limestones; but it was not until the work of Howitt (1876) that the geology of the Buchan district, including the limestone and some of the outliers along the Snowy River, was first described. Later, Howitt (1878) described some detailed stratigraphic sections for the limestones; Whitelaw (1899) also provides a description of the Buchan limestone.

First specific description of the limestone in the New Guinea area was in 1899, following a survey of the Snowy River gorge by Ferguson. An unpublished Geological Survey of Victoria map, which includes the New Guinea area in some detail, resulted from this survey.

Initial selection of land at New Guinea took place around the turn of the century. Three allotments, totalling 270 ha, were surveyed between 1897 and 1902. These covered approximately one third of the total limestone outcrop area, and little other country. Commenting on the scope for further settlement, a Lands Department surveyor reported in 1901 that ". . . the Crown lands adjoining are rocky slopes almost precipitous, impossible to fence, and absolutely useless to any grazier" (Department of Crown Lands and Survey 1901). As it turned out, the only other settlement in the area was to be that further south, at Jacksons Crossing and on the Rodger River.

Freehold title was never granted for the leases at New Guinea, mainly, it seems, because of objection from the Mines Department on grounds of potential for mining (Department of Mines 1911). It seems that, apart from periodic leasing of the area for forest grazing, the area has steadily regenerated since being abandoned ten or fifteen years after selection. Several old fences in the area presumably date from this later grazing.

The early surveyors and lessees were certainly aware of the extent of the limestone, and of the existence of the big cliffs, but there seems to be no early reference to the large doline at New Guinea Cave, or the major spring at NG2. However, New Guinea Cave at least must have been known from about the time of first selection, as there are dates in the cave from 1906 to 1920. Interestingly, none of the names in this early graffiti are those of the surveyors or lessees.

Speleological Investigation

Caving trips to the area commenced in the early 1960's with visits to New Guinea Cave and some surface exploration. The mid sixties saw several bat-banding trips to New Guinea Cave, but little other exploration until 1967, when much of the central area was investigated. The section of NG2 upstream of its sump was first entered at this time. More recent investigations, particularly between New Guinea Cave and NG2, confirmed that there was not likely to be any connection between the two, and failed to locate a resurgence for the New Guinea cave drainage.

In 1974, the northern part of the limestone was explored for the first time, and Nuigini Namba Faiv and NG6 discovered, together with the resurgence of that system, and several dolines upstream. A major extension of Nuigini Namba Faiv Cave, downstream of the sump, was first entered in 1976. Considerable further investigation is warranted; for example, a survey party in New Guinea Cave late in 1976 discovered new upper levels which extended the known cave by 50 per cent or so! As mentioned above, the northern section of the limestone awaits systematic exploration.

Land Use Planning and Management

The New Guinea area is currently unreserved Crown Land administered by the Forests Commission as "protected forest" (*Forests Act* 1958). Apart from canoeing and bushwalking along the river, caving on the limestone, and some infrequent recreational use of the tracks by four-wheel-drives or trail brikes, the only active land use is (or has been) logging.

The Mountain Ash forests and the taller of the "mixed species" forests above an altitude of about 500 m are the only timber resources here of interest for commercial sawlog production. Most of the commercial timber within the catchments of the New Guinea karst has been cut during the last five or so years. Some limited production could continue for another few years.

The logging has not been a serious conservation problem, apart from the usual landscape effects. Perhaps the main cause for concern is that regeneration of the mixed species forests under a low-intensity cutting regime is not easy to contrive. There is no evidence that the caves have been affected by siltation.

As a land use issue, however, it was unfortunate that logging ever took place here. The scenic and wilderness qualities of the area are such that there is good reason to suggest that the timber should never have been cut. The timber resource within the main valley of the Snowy is both small in volume and scattered in nature, so it must have been far from the most valuable of the various resources available to the timber industry in the region.

As long ago as 1899 it was proposed that New Guinea and the rest of the Snowy Gorge should be a National Park:

> "The scenery is wild and rough and grand in the extreme. In no place else in Victoria are there such dizzy precipices, such sheer bluffs, or gorges with such vertical sides . . . The gorge between the Broadbent River and Campbells Knob is perhaps the finest in Australia ... For miles along the Snowy River the land is not likely to be in request for settlement purposes, and it would make a splendid National Park. If the place were made accessible by a track along the river, and the native animals and plants protected the year round, it would be an ideal recreation reserve for generations of Australians as yet unborn." (Ferguson, 1899).

Ferguson's sentiments have been echoed many times over the intervening years, but the gorge and associated wild lands have still not been reserved.

There are now indications that this situation might change. An agency of the State government, the Land Conservation Council, recently released new regional land use proposals for public land in East Gippsland, including the eastern side of the Snowy valley (Land Conservation Council 1976). The Council makes recommendations to the government after a process of investigation which successively involves publication of a descriptive report, receipt of submissions from the public, publication of proposed recommendations, and receipt of additional submissions from the public. Only then are the final recommendations published and submitted to the government. It is a system which has gained a substantial degree of political acceptance, and, elsewhere in the state, has already resulted in a considerable increase in the number and extent of National Parks, Wildlife Reserves, and so on.

For the Snowy Gorge, the Council's proposals involves a new land use concept – that of Wilderness Area, to be reserved in its own right. This concept is similar to that of National Parks, but more specialised. Use of such an area would be by walking and canoe only. It is not known whether the final recommendations will be the same as the proposed – there may yet be adjustments to the policy or boundaries. Although New Guinea itself is not actually within the area of the recommendations – the boundary was down the Snowy – the outcome of the East Gippsland study area will almost certainly influence the outcome for the western side of the gorge, when it is reviewed in a year or two.

So, 75 years or more after the first description of the gorge, it is still not reserved and still gets no deliberative management. When (if?) its significance is finally recognised by reservation, the New Guinea karst will be a valuable and interesting component of this larger national asset.

Acknowledgements

We are indebted to a large band of speleologists who over the years have explored and documented the New Guinea area. In particular, we are grateful for the patience of those who have assisted with surveys. Peter Matthews and Elery Hamilton-Smith assisted with information of early exploration, and cave fauna, respectively. Cliff Beauglehole gave us access to his botanical records for the area, and A.H.M. VandenBerg provided details of Ferguson's geological work.

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Note added in press:

A preliminary reconnaissance by the Victorian Archaeological Survey has now confirmed that NG2 is an important aboriginal site. There are several areas on the walls and roof with linear markings similar to those of Koonalda Cave on the Nullarbor; this is the first such occurrence recorded in Victoria.

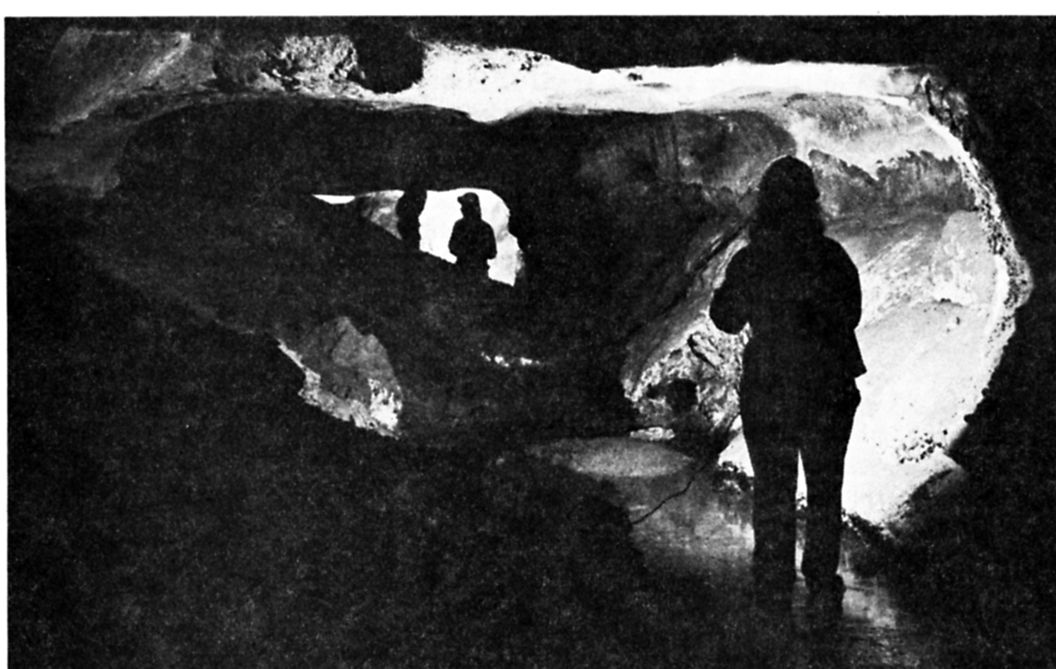

Plate 7. Main stream passage in NG2 cave.

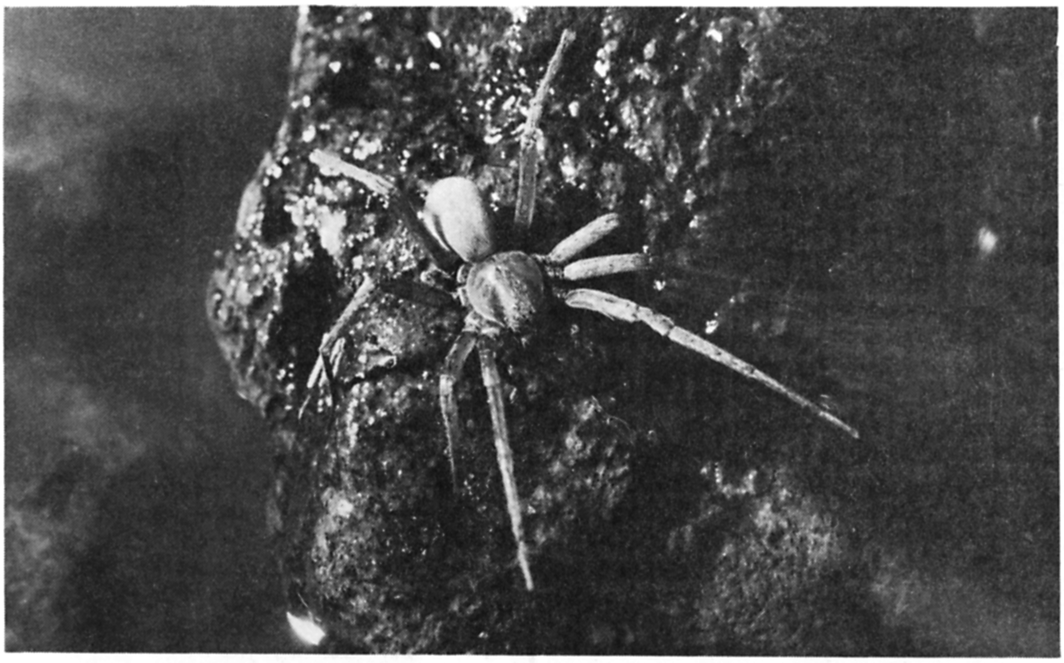

Plate 8. Spider (unidentified) near stream in Nuigini Namba Faiv cave.

Plate 9. Cave pearls, Nuigini Namba Faiv cave.

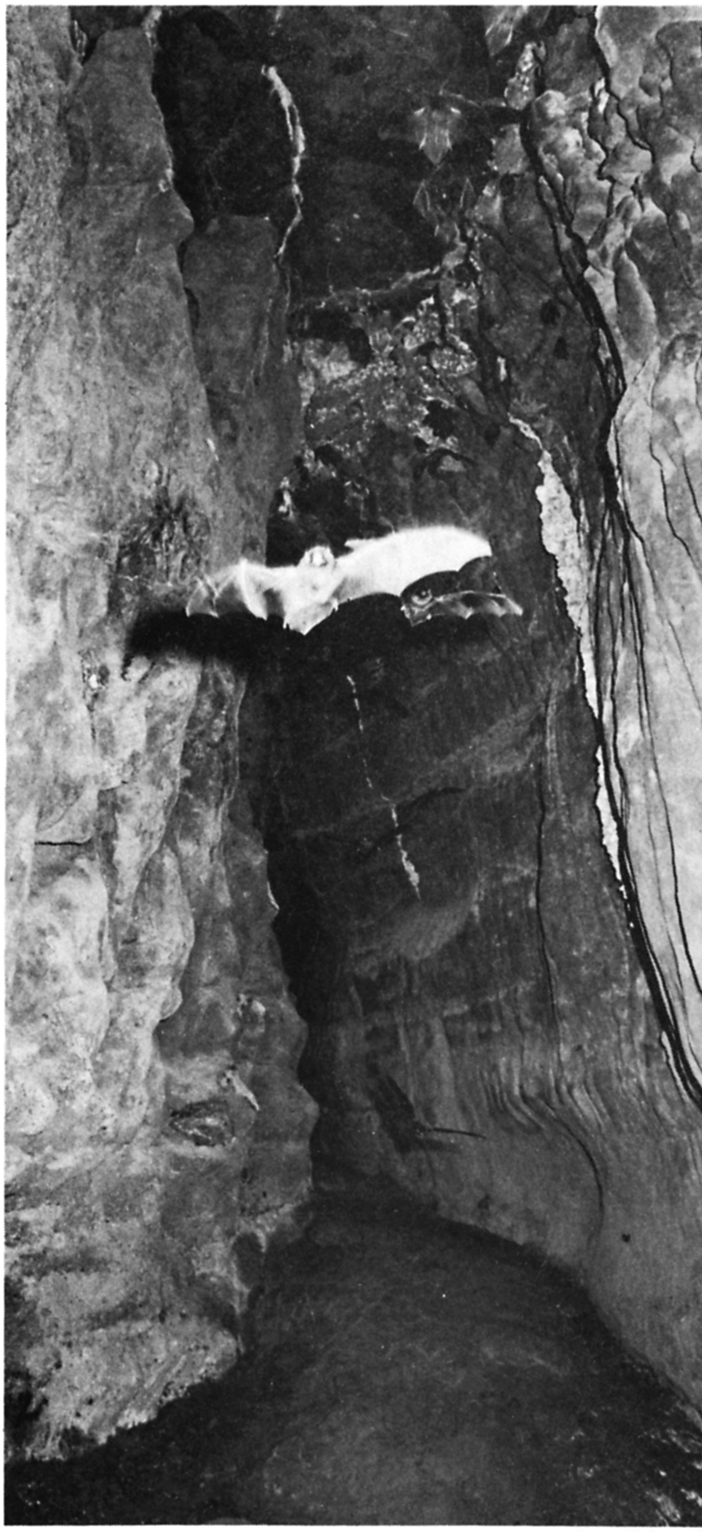

Plate. 10. Bent-winged bats *(Miniopterus schreibersii)* in NG2 cave.

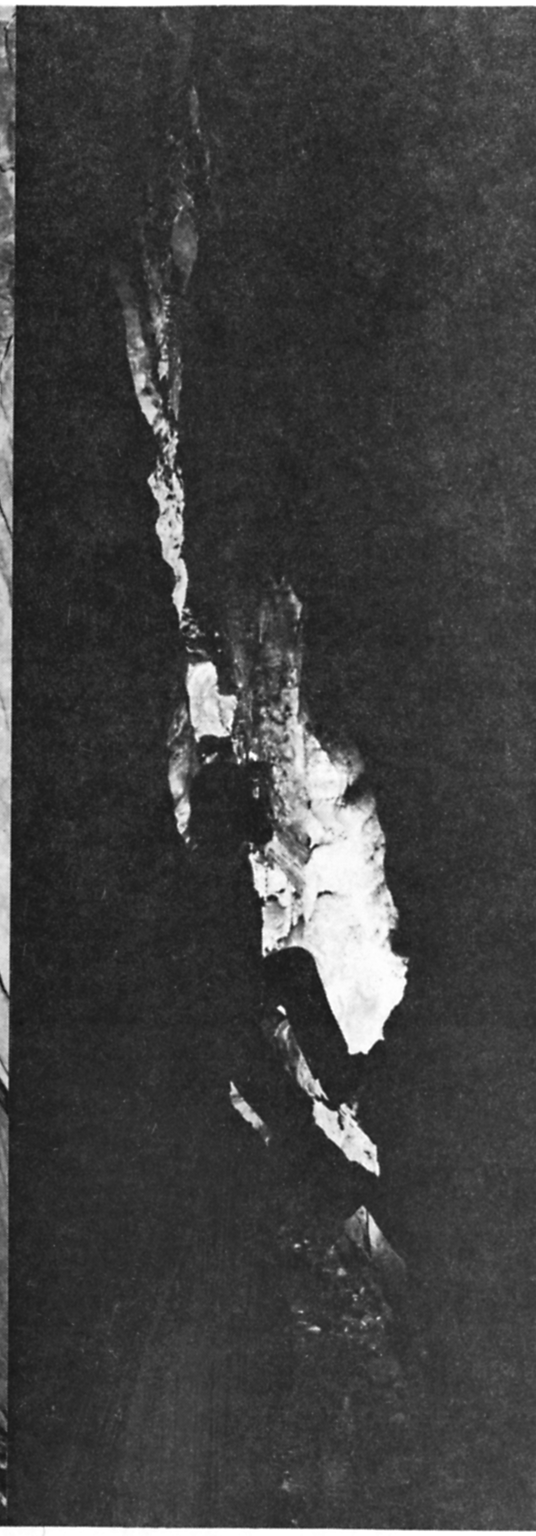

Plate 11. Vadose canyon in the east-west section, New Guinea cave.

QUATERNARY KARST AT BAT RIDGES, VICTORIA

MILES PIERCE* AND SUE WHITE**
Victorian Speleological Association

Abstract

Bat Ridges is an area of Quaternary calcareous dunes near Portland, Victoria. The dunes have karst development which appears to be syngenetic, as the karst processes have occurred concurrently with the consolidation of calcareous sand into aeolian calcarenite. Features related to syngenetic karst development such as solution pipes, cap rock, horizontal development, low solutional ceilings, roof collapses and secondary features are described. The Victorian Speleological Association is currently engaged in detailed exploration ana documentation of the area.

Introduction

Bat Ridges is an area of calcareous dune ridges approximately 10 km N.E. of Cape Bridgewater near Portland. About 300 ha (800 acres) of this is a Fisheries and Wildlife Division Reserve surrounded by Crown land and private property. There are about 40 caves known, many of which occur in a fairly small area and are probably interrelated.

The land use of the area is primarily a wildlife reserve and the Land Conservation Council in its Final Recommendations for the South West Study Area District 1 (April 1973) recommended that the reserve be extended to include all the adjacent Crown Land. Surrounding the reserve is cleared farmland used mainly for cattle raising. Although this is similar geologically to the area on the reserve, not many caves have been found except in the uncleared area (Mr Davies' property).

These limestone dunes support a complex mosaic of coastal heathland communities as well as Brown stringybark *(Eucalyptus baxterii)* and Manna gum *(E. viminalis)*, open woodland and acacia scrub. The heathland communities are dominated by epacrids such as *Astroloma* sp, Xanthorrhoea and Banksia. Acacias, Leucopogon and Leptospermum form the majority of understorey vegetation in the open woodland. Evidence of burning can be seen e.g. Xanthorrhoea and Banksia.

The Reserve has been subjected to grazing – evidence can be seen in the vegetation – and the presence of the old lime kiln indicates the limestone has been quarried for lime, probably only for local use.

The existence of the caves in the dune ridges has been known to the locals for many years. Coulson(1940) reports visiting a number of caves and makes reference to their particular character. Whilst the area has occasionally been visited by cavers, systematic exploration and documentation by the Victorian Speleological Association (VSA) was not commenced until late 1973.

Geology

The entire area lies in the Otway Basin, a trough filled with a maximum of 7,500 m of Mesozic and Tertiary sediments extending across the southern portion of southeast South Australia and western Victoria, and separated from the similar Murray Basin to the north by the Dundas High of Palaeozoic rocks. The oldest sediments of the Otway Basin overlie the eroded surface of folded Palaeozoic strata of the Tasman Geosyncline. The Tertiary stratigraphy starts with Cretaceous non-marine sediments which are overlaid by series of marine sediments. At the end of the Miocene the sea receded in stages due to the upwarping of the continent, and at the end of the Pilocene renewed activity along the Kanawinka Fault to the northwest resulted in further marine recession. Over these predominantly marine Tertiary sediments the Pleistocene series of calcareous dunes were deposited. The Pleistocene sea level adjustments related to the formation and melting of large ice caps which meant that shelly Tertiary beds were exposed to vigorous wave action, breaking them down into bioclastic sand similar to that on the present coast. As the coastline receded, dunes of calcareous sand up to 30 m high marked the position of further strand lines. These dunes were then subjected to terrestial weathering conditions which, in the case of Bat Ridges, has meant the calcareous

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material was dissolved, seeped downwards and redeposited as a secondary limestone layer, leaving a residual surface layer of unconsolidated silica sand. This has, during arid periods, been transported by prevailing winds to the lee of the dunes. The limestone dunes are called the Bridgewater Formation, of which the Bat Ridges dunes are an example, and the unconsolidated sands are the Malanganee Sands.

Syngenetic Karst

Karst terrain can be defined as one which is underlain by a dominantly calcareous rock to the virtual exclusion of other kinds, and whose surface and subsurface features are determined by the characteristic responses of soluble rocks to weathering and erosion. These features include caves as well as surface features.

Cave genesis, that is the development of caves, is the subject of many papers and research. We do not propose to discuss it here except by defining the concept of syngenetic karst.

Syngenetic karst was defined by Jennings (1968a) as karst landforms which are developed concurrently with the consolidation and compaction of limestone itself. The phenomenon occurs in calcareous dunes which lithify to aeolian calcarenite.

The calcarenite is cemented by the formation of a cap rock in dunes which have been fixed by vegetation. The caprock forms by the solution and subsequent redeposition lower in the profile, cementing the loose bioclastic sand grains in a calcite matrix. This hardened layer forms the necessary structural conditions for the removal by water of the underlying softer limestone and the formation of shallow linear caves.

Characteristics of Bat Ridges Caves

At Bat Ridges the caves are characteristically shallow and linear (Bastion 1964), often with extensive areas of low unsupported solutional ceilings. These ceilings are an expression of the hardened caprock which provides sufficient structural strength to permit the removal by water of the softer material underneath. The floors beneath these areas are typically covered with insoluble residues of the solution process together with sediments probably carried in from outside.

Collapse breakdown has been a significant part of the development of most caves. A majority of the caves have collapse type entrances downslope from the crest of the dune. Domed roof structure due to collapse (Jennings 1968a) is in evidence to varying degrees, however, in some places cross-bedding of the limestone appears to have influenced an inclined ceiling structure.

Another common feature of syngenetic karst is the development of solution pipes. A number of theories have been advanced for their formation (Blackburn and others 1965; Jennings 1968a & b) of which the case hardening of caprock material around tree roots appears to be favoured. A well formed example gives rise to the local name of Chimney Cave for BR1. It is one metre in diameter and drops some 7 metres into the cave below (see Fig). A number of other caves in the region have similar features including and interesting 'window' into cave BR8 due to collapse between two adjacent solution pipes.

Also of note are a number of blind shafts or foibes similar in appearance to the solution pipes but not opening to the surface. Big Cave (BR6) has such a feature with a diameter of about one metre and rising up several metres from the passage ceiling to a hemispherical closure. (Lowry 1967; Jennings 1968b).

Although Speleothems are not the most prominent feature of the caves, they do commonly occur. These fall into two major groups which imply two periods of active calcite redeposition in the caves. The older more massive form is in general no longer active but the younger still active series of helictites, straws and rimstone pools are maintained by minor surface water. Chimney Cave (BR1) has an attractive example of the latter where a small surface soak above appears to maintain its activity. Other secondary calcite features include large areas of moonmilk and cave coral.

Surface Features

A notable feature of the surface karst in the exposure of the large areas of caprock near the crest of the dunes. This exposure related to the removal of the Malanganee Sands after formation of the caprock with redeposition in the lee of the dunes.

Other clear surface exposures of the caprock appear at most of the collapse entrances to the caves as mentioned previously.

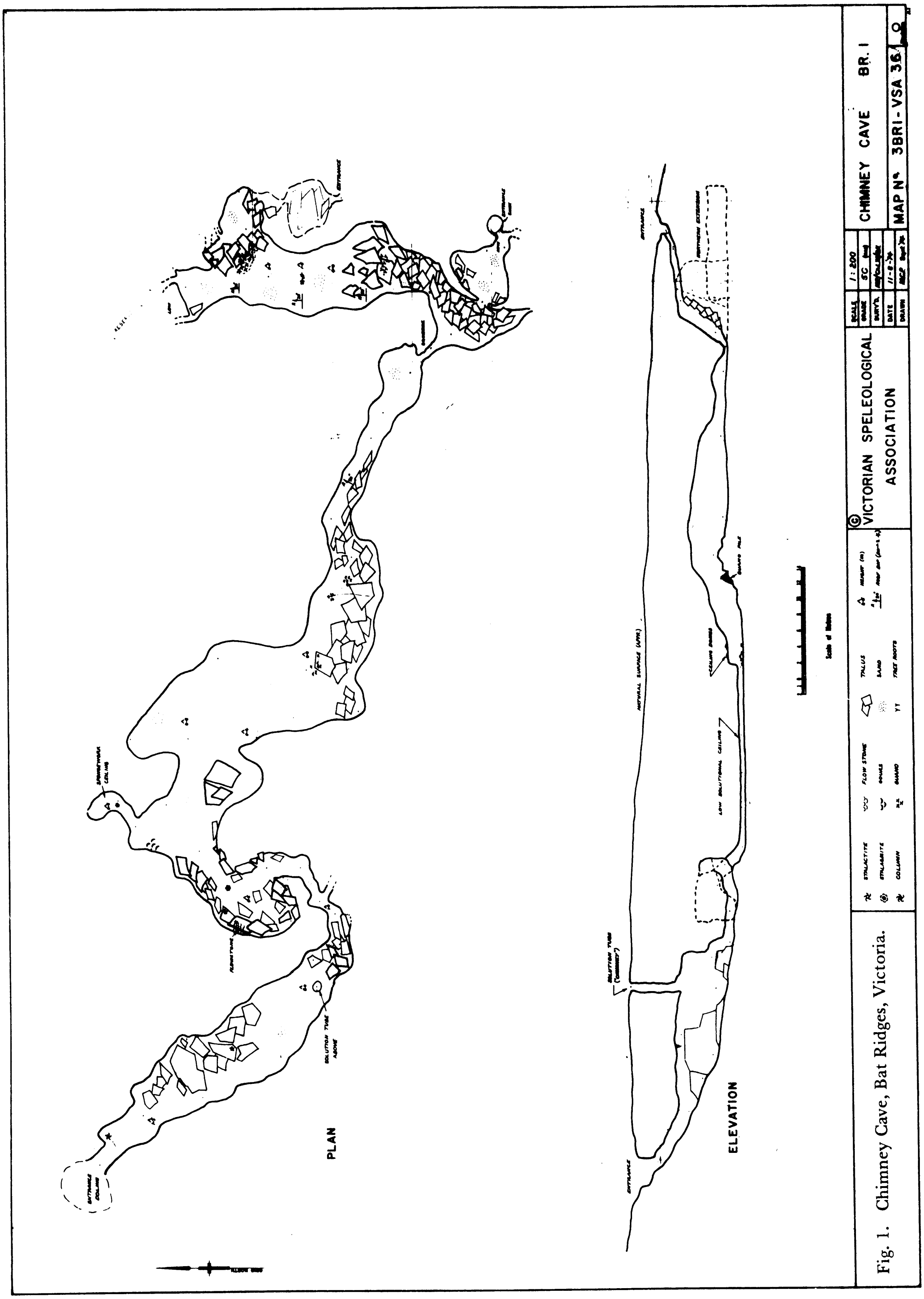

Fig. 1. Chimney Cave, Bat Ridges, Victoria.

The exposed caprock exhibits varying degrees of secondary surface solutional features such as rillenkarren and mottling. These are not in evidence on the more unconsolidated limestone elsewhere.

Drainage

The area to the north is low lying, and in places swampy, draining seawards via the dunes. This water has undoubtably been important in the hydrology of the caves. However, in recent years the artificial Bat Ridges drain on the northern boundary of the reserve has significantly altered the natural drainage pattern making it difficult to assess the details of the past hydrology.

Some water now enters the north of the reserve from the drain during winter and fills the shallow impounded lake area. At this time River Cave (BR4) becomes an active inflow cave and its waters ultimately appear to resurge into the southern reaches of the lake. Other nearby caves, particularly BR5 also become inundated when the lake level is high. Southward drainage of water from the lake itself appears to take place very slowly. Existing caves to the south of the lake are shallow and no evidence of flow through them has been observed in recent times.

Conclusion

Further mapping and detailed documentation which the VSA is undertaking as a continuing program should permit a more comprehensive understanding of the karst processes of the area. Many of the caves are interconnected, for example River Cave (BR4) has a current surveyed length of about 1.4 km and five entrances. With further exploration this cave will probably be linked to other nearby caves in the same dune ridge.

The whole area illustrates the ability of calcareous dunes under suitable conditions to develop caves during lithification by syngenetic karst processes. Whilst cave formation has been extensive the dunes are far from completely and/or uniformly lithified.

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THE BORDER RIVERS KARST REGION, QLD & NSW

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Abstract

The Border Rivers Karst Region includes three known cave areas: the Texas, Riverton and Ashford Caves. Development of the Texas Caves involved several epiphreatic (nothephreatic) solutional levels related to the development of Pike Creek. The Glenlyon System is a subterranean cut-off of a meander spur; there stream passage development and collapse of large areas has modified an original phreatic system. On Viator Hill there is no definite evidence of a throughflowing stream system and the caves are mainly shallow phreatic at several levels. Here there are two major phases of deposition of speleothems and soil derived sediments. Erosion and deposition within the caves is thought to be related to similar phases in the evolution of Pike Creek and to climatic fluctuations. The main Ashford Cave is dominantly phreatic but may have been a stream cut-off of a meander spur at one stage in its development. It now contains soil derived sediments. Riverton Cave is high on a spur and may be older than the other cave areas.

Introduction

The Border Rivers Karst Region lies astride the Queensland – New South Wales border on the western slopes of the divide. It consists of a series of small limestone lenses within the Upper Devonian to Permian Texas Beds, a part of the New England Fold Belt (Olgers and others 1974). The limestones contain early Carboniferous (Visean) corals. Most of the limestone lenses are small (Seimon 1973) and are non-cavernous, though well developed karren fields can be seen on most outcrops. Only three of the larger lenses contain caves. These are the Texas, Riverton and Ashford Cave areas. The Texas Caves have recently been flooded by the Glenlyon (Pike Creek) Dam. This paper summarises some results of a survey made for the Geological Survey of Queensland (Grimes in prep).

The Texas Caves, Qld.

(1) Development of the Viator Hill Caves

On Viator Hill there are two large caves (Russenden and Main Viator – see Fig. 1) and a number of smaller 'potholes'. The latter are basically vertical shafts and fissures formed by rainwater infiltration, though some have horizontal epiphreatic development in their lower parts. The two large caves are basically horizontal systems, Russenden has two levels of development, Main Viator has only one. This horizontal development together with the presence of flat roofs and horizontal wall undercuts suggests that the main development of the caves was by epiphreatic solution at and immediately below a water table which subsided in a series of stages. The hill is in a vertical lens of limestone with the channel of Pike Creek abutting on each side (see inset in Fig. 1) so the main control on water levels would be the level of the stream channel and the concept of a water table seems permissible in this case. The highest caves would have formed first and progressively lower caves would have developed as the creek cut down beside the hill. Thus The Joint would be the oldest cave on the hill and it contains the oldest bone deposits in the area (Archer in prep.).

The sequence of development deduced for these caves is based on an elaboration of Butler's (1967) K-cycle model of valley development and of Frank's (1972) model of non-fluvial cave development. In humid climates there is a strong vegetation cover which stabilises slopes; stream incision and cave development can then occur. With a deterioration of climate – either towards colder or more arid conditions, or both – the vegetation cover will be disrupted and slope erosion will occur. Sediment will be delivered to the streams which will build up their beds to form terraces (Butler op cit). Sediment may also enter cave entrances and with time will eventually fill any non-fluvial caves (Frank op cit). However, if the climate returns to humid conditions the slopes will be stabilised and

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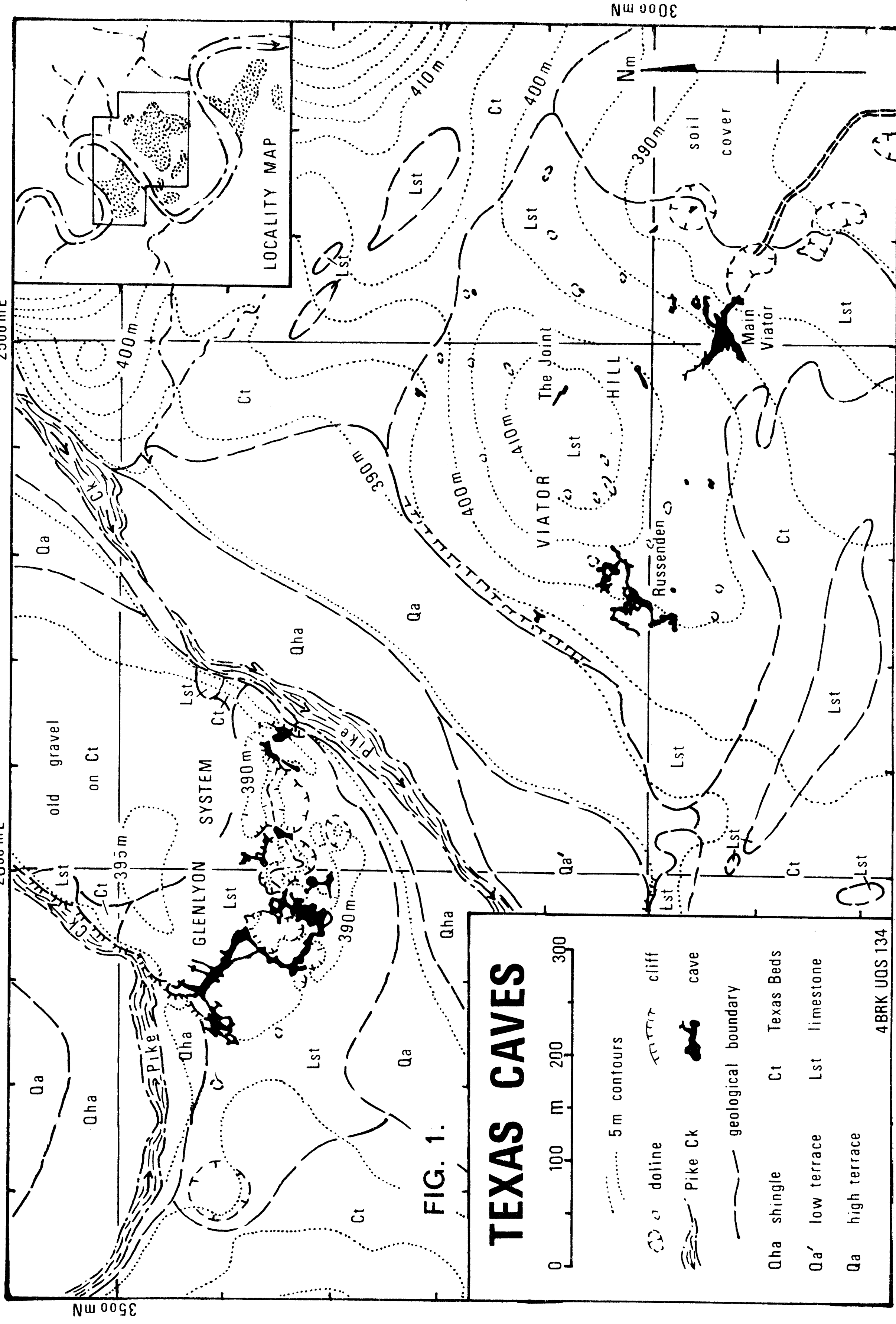

FIG. 1. TEXAS CAVES

the streams will once again begin downcutting. Increased circulation of ground water will allow further cave enlargement to occur. If the stream incision is sufficient the cave development will be at lower levels and the earlier cave sediments will subside or be washed into these levels. If stream capture occurs with the formation of a throughflow system then the sediment may be removed from the system entirely.

In the larger Viator Hill caves there is evidence for two ages of sediment, both younger than the bone beds in The Joint. Formation of the upper levels of Russenden Cave, which have a horizontal roof level, may have occurred when Pike Creek was at the similar level to the old gravels on the Glenlyon meander spur. Main Viator Cave may have commenced its development at much the same time. Draining of the upper level was probably a result of continuing stream incision. Removal of hydrostatic support would have caused some ceiling collapse and this, coupled with surface denudation, would have opened the caves.

With the appearance of an arid phase of surface instability rubble, soil and bone material were washed into the caves. These deposits have been cemented to form the 'red earth breccias' and old coarse grained speleothems are associated. This material contains the older of the two Russenden faunas (Archer in prep). This instability could also have caused aggradation of the creek bed but no terraces have been recognised from this period.

The subsequent erosion of the red earth breccias and older speleothems is probably related to a return to a humid climate and further cavern development at lower levels. The Foul Air Section in Russenden and probably some low extensions of Main Viator Cave would have formed at this time. A line of shallow depressions leading southeastward from Viator Hill towards Pike Creek could indicate a low level system which drained water from the hill. The stream cliffs on the northwest side of the hill may have been cut at this time and there is a possibility of partial stream capture and the existence of a throughflowing system beneath the hill. There is no direct evidence for this, however, and augering in the caves did not intercept any stream sediments. The wall features in the Foul Air Section suggest sluggish epiphreatic conditions – nothephreatic in the sense of Jennings (1976).

The next stage in the development of the caves was one of aggradation of the bed of Pike Creek to form the Qa terrace (Fig. 1) and the formation of a further series of cave sediments and speleothems. The sediments suggest instability and a deteriorating climate once again. The younger Russenden fauna of Archer (in prep) comes from these deposits and is sub-recent in age. The soil of the Qa terrace is of the red-brown earth type which if correlated with dated terraces elsewhere would suggest an age of about 4000 years BP. Deposition in the caves appears to have continued up to the present but the occurrence of a lower Qa' terrace on the surface could indicate a minor break.

The younger deposits include a considerable quantity of clay aggregates, especially in Main Cave. These range in size from one to ten mm or more and come in a variety of colours. They appear to be soil particles and their preservation argues for minimal water transport: mass movement would seem to be the main process. In Russenden the earthy deposits are interbedded with an entrance scree and an old guano mound. Peter Bridge (pers. comm.) has identified a number of unusual phosphate minerals from this guano mound. A section in one locality consists of – from the top down – 10 cm of hard nodular cemented material; 10 cm of soft powdery gypsum; about 60 cm of dark brown earth with some almost black bands which contains whitlockite, taranakite, and apatite in guano dust. Below this was a basal unit more than 75 cm thick which extends into the nearby subsidence pit. This is composed of hard buff to white material containing taranakite, with minor leucophosphite, quartz and apatite.

In Main Cave the upper parts of the sediments are acidic with pH values as low as 3, but with depth they become alkaline with pH up to 8½. The acidity may be due to recent organic material, guano, and/or bat urine which becomes neutralised with depth. The entrances to Russenden Cave were only reopened with the cave's discovery in 1967 so recent organic material could not have entered this cave: here the deposits are uniformly alkaline (pH 7– 8) with the exception of the old guano mound which is acidic.

(2) Development of the Glenlyon System

This sytem differs from the Viator Hill caves in being all on the one level, and in having captured a part of the flow of Pike Creek fairly early in its development. Throughflow stream passages have modified the original phreatic network and in addition, the system has suffered from a series of major collapses of large chambers. These have formed large dolines which have disrupted much of the downstream part of the system. The continuing history of collapse also restricted the stream flow through the system and it appears that complete capture of Pike Creek never occurred. The surface stream channel has therefore been able to develop independently of the underground system.

The initial phreatic development of the system may have been contemporaneous with the development and draining of the upper levels of Russenden and Main Viator Caves. Collapse of the older dolines may have commenced shortly after the initial stream capture as these contain small terrace deposits which may correlate with the Qa terrace. The depositional sequence found on Viator Hill does not occur in the Glenlyon System. Instead there are fluvial silts, with minor sand and gravel.

The most recent collapse was that of the upstream cliffs which blocked the cave stream at its inflow point. The present cave stream appears to be underfit: it meanders between large silt mounds and the wall scallops do not appear to be in equilibrium with the present hydrology.

The Ashford Caves, NSW

Only a quick reconnaissance study was made of this area. There is only one large cave known, located on a meander spur of a medium sized creek. It is basically a horizontal epiphreatic system. Old stream cliffs similar to those of Viator Hill occur next to its upstream entrance and it is possible that some stream capture may have occurred. The cave sediments are similar to those of the Viator Hill Caves and there has been some guano mining. The northern wall of the main chamber follows the limestone – volcanic rock contact. This cave is a maternity site for *Rhinolophus megaphyllus* (Dwyer 1966).

Riverton Cave, Qld.

This is in one of the largest limestone lenses in the region but only one sizeable cave is known. This is high up on a ridge and could be older than the caves at Texas and Ashford. No detailed study has been made but it appears to be a phreatic system with soil derived sediments and guano. Guano mining has occurred and the cave is the maternity site for the *Miniopterus schreibersii* population of the region (Dwyer and Hamilton-Smith 1965) and is also a breeding site for *Rhinolophus megaphyllus* (Dwyer 1966).

Some form of protection and a definite management plan is urgently needed for this cave as visitation pressure is likely to increase now that the Texas Caves have been destroyed. A complete embargo should be placed on visitation during the summer bat breeding season.

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A BRIEF REVIEW OF THE LIMESTONE RANGES, WESTERN AUSTRALIA

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Abstract

A series of low limestone ranges extend for 275 km along the northern margin of the Canning Basin in northern Western Australia. To the north of the limestone ranges lie the mountains and plateaux of the Kimberley Block. The limestone ranges are exhumed reef complexes of Late Devonian age. They extend in a discontinuous belt, rarely over 15 km wide, from 175 km NW to 100 km SE of Fitzroy Crossing. In some areas the ranges may stand as much as 200 m above the surrounding plains. Karst features are abundant in the region but very few major caves have developed.

Introduction

The limestone ranges of Western Australia consist of a series of low limestone hills that are located along the southern margin of the King Leopold Range. The ranges extend for about 270 km with a northwest-southeast trend. About midway along, and just south of, the ranges is the small village of Fitzroy Crossing.

The ranges are traversed by a number of major streams including the Lennard, Fitzroy and Margaret Rivers. There are also a number of small rivers and creeks that cut through the ranges. In the wet season even small streams carry large volumes of water and have been important in the geomorphic development of the region.

In this paper the ranges have been divided into five areas (Fig. 1), running from the northwest they are:

1) the Napier Range.
2) the Oscar Range – Oscar Plateau – Geike Ranges area
3) the Horseshoe – Hull – Horse Spring Ranges, north of the Margaret River
4) The Pillara – Home Ranges; and
5) the Emanuel – Lawford – Laidlaw Ranges area.

The latter two are south of the Margaret River.

Environment

The climate is a semi-arid type with strongly seasonal rainfall amounting to 450 – 650 mm, 85% of which falls between December and March often very intensely. Temperatures are high exceeding 38° C for more than 100 days a year; evaporation is likewise high and is estimated to exceed 2500 mm. Soils vary from non-existent on the Ranges themselves to deep, heavy textured soils on the surrounding plains which carry Mitchell and other tussocky grasses. Some alluviated areas have an open eucalypt woodland community which becomes denser in the protected valleys. The dissected surface of the Limestone Ranges carries very little vegetation – scattered spinifex and other tussock grasses with some acacia scrub and an occasional baobab (*Adansonia gregorii*) and other trees.

Geology

The limestone ranges have been the subject of numerous geologic studies because the area has been considered as a classic example of an exhumed reef structure (Playford and Lowry 1966) and as a model for the study of potential oil accumulating strata in the subsurface to the south. The most popular geologic interpretation of the limestone ranges is that of Playford and Lowry (1966). They have put forward the hypothesis that the ranges are preserved reef structures of Devonian age (350

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million years old). Three types of limestone have been associated with the reef interpretation. They are a thin to a thick bedded, flat lying limestone representing the backreef facies; the massive inter-bedded limestone of the reef proper; and the steeply dipping interbedded limestones and clastics representing the forereef beds.

Logan and Semeniuk (1976) have recently proposed an alternative interpretation that depends on micro-solution to form the steeply dipping beds that have been assigned to the forereef; and they have dismissed the reef interpretation of Playford and Lowry. To date most workers have rejected the Logan-Semeniuk hypothesis and follow a modified Playford-Lowry hypothesis.

Caves in the ranges are usually developed in the steeply dipping forereef beds (eg. Old Napier Downs Cave, Tunnel Creek Cave) but the Cave Springs Cave system is developed in the backreef beds.

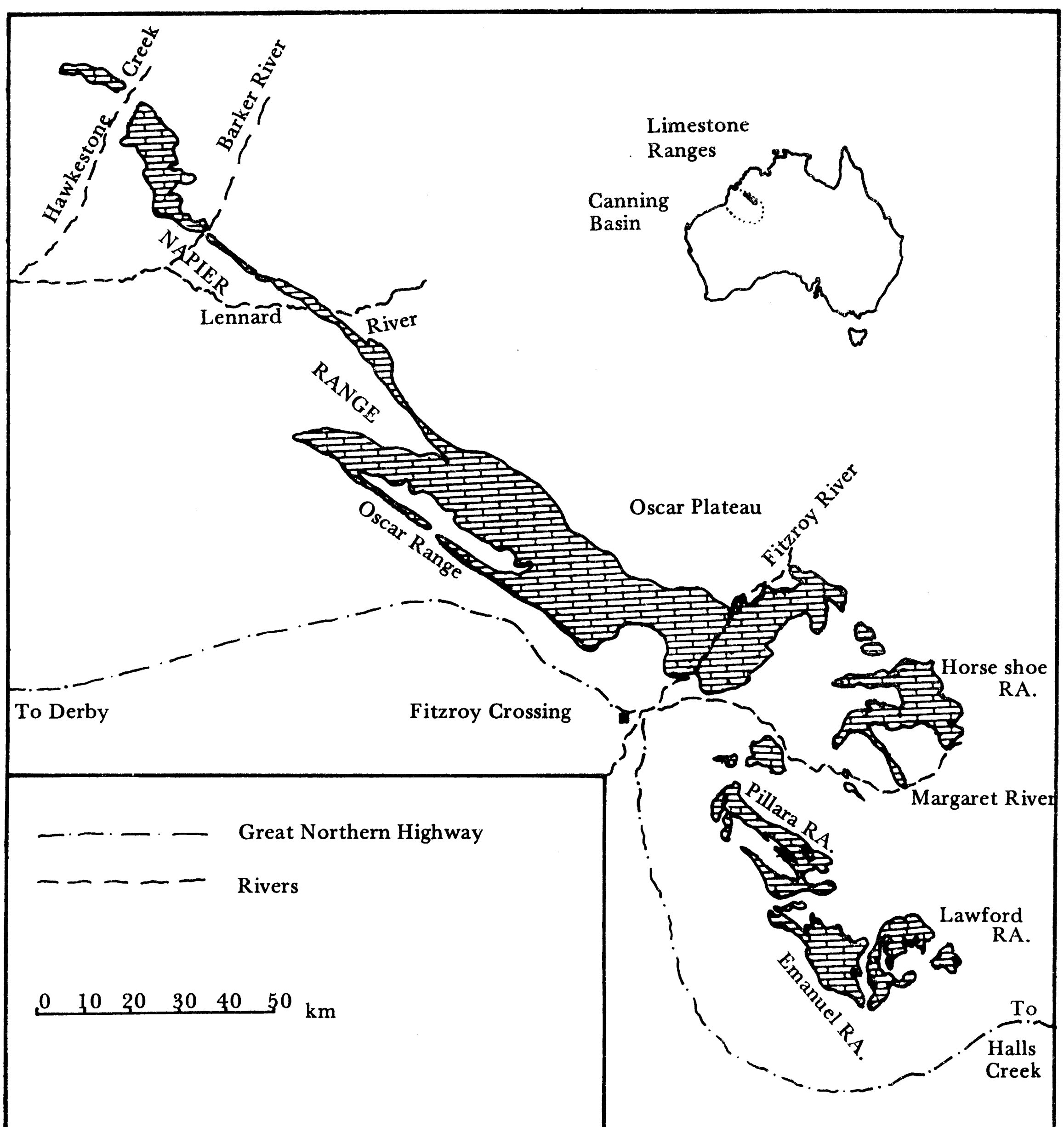

Fig. 1. The Limestone Ranges of Western Australia.

Karst Features

A wide range of karst features is found in the Limestone Ranges. These range from rain pits and rillenkarren to caves and marginal amphitheatres. These features have been enumerated by Jennings and Sweeting (1963a) and will not be discussed here.

Only a few large caves have been developed in the region. This may, in part, be related to the lack of concentration of water into confined channels in the limestone, as would occur in a sinkhole. The thin to non-existent soil cover means that most of the rainwater falling on the rock surface enters the nearest joint or bedding plane. This does, however, mean that a great number of minor caves have developed some of which are geologically very interesting.

Aboriginal Sites

Many of the caves and rock shelters of the Limestone Ranges contain material associated with aboriginal culture. These include burials, paintings and artifacts. Extreme care should be taken so that no damage occurs to any of these sites. If possible a photographic record should be made of all sites. The burials consist of the skull and some other bones, usually limb bones, that were originally wrapped in bark and placed on a ledge in the cave. The paintings may be simple monochromes or very complex works in three or four colours. Artifacts include points and tools.

Napier Range

The Napier Range is the best studied of all the Limestone Ranges (Basedow 1918; Jennings and Sweeting 1963a, 1963b, 1966). The major caves, such as Old Napier Downs Cave and The Tunnel, have been mapped, as has one of the larger cliff-foot caves near Barnett Spring. There are, in addition, a number of caves known to the author that have not been discussed in the literature. All the caves will be briefly discussed by following the trend of the range from north-west to south-east.

The westernmost cave of the Napier Range is located in the gorge where Alexander Creek cuts through the range near Limestone Spring. A small entrance passage, a few metres in length, in the south wall of the gorge intersects a large transverse passage. This passage is blocked at either end and contains relatively abundant speleothems. When entered in July of 1972 the larger passage contained a bat population, species undetermined, estimated at between 50 and 100 specimens. There is an aboriginal burial in an alcove near the cave entrance.

Barnett Spring is located near the end of a spur that juts out about 3 km from the trend of the range. Jennings and Sweeting (1963b) have described a major cliff-foot cave located on the north-west side of the spur. There are also a number of caves located on the west side of the gorge that runs up the centre of the spur. These caves are solution passages that run for short distances parallel to the trend of the gorge. There are additional small caves around the margin of the spur on the south and east sides.

Old Napier Downs Cave (Jennings and Sweeting 1966) is located near the eastern end of Chedda Cliffs. The cave is small, about 110 m long, but interesting as it has the best decoration of any of the caves in the area. The cave has exploration potential as it was not fully mapped by Jennings and Sweeting.

There are a number of caves in the immediate vicinity of Windjana Gorge. Most are small but exploration has not been thorough. About 2 km west of the gorge there is a complex of small cave entrances associated with a travertine deposit at the base of the cliff. A large sinkhole is located on top of the range above these caves and there may be a connection.

In Windjana Gorge there is a prominent cave entrance close to the top of the downstream end of the west wall. The entrance is at least 5 m in diameter and extends for more than 10 m. Observation of this cave has only been from the ground and from a helicopter as it is at least 40 m above the floor of the gorge. There is also a rock shelter with an unexplored lead just east of the upstream entrance to the gorge.

Three kilometres east of Windjana Gorge, behind the ruins of Lillimilura Police Station, there is a small cave at the base of the cliff. In July, 1972, a small stream was flowing from the cave which is about 2 m high, 2 – 3 m wide and extending 5 – 7 m into the cliff, the water enters from the ceiling. Above the cave, on top of the range, are two major sinkholes one of which was investigated and a shaft located but not explored.

The Tunnel is the largest (but not the longest) cave in the Limestone Ranges, it has been described in detail by Jennings and Sweeting (1963b). The Tunnel is 675 m long, up to 15 m high, averages 20 m wide and carries the waters of Tunnel Creek through the range. There is a major collapse doline (karst window) about halfway through the cave. Speleothems are present but most are dry.

Jennings (1962) reported a cave in a spur in Dingo Gap, no description or exact location is recorded but it contained a bat colony.

Oscar Range

The Oscar Range has not been examined as thoroughly as the Napier Range has been; caves have been investigated in three areas – Morown Cliff, near Stumpy Soak and at Brooking Yard.

Morown Cliff extends for about 8 km along the NW tip of the Oscar Range. The cliff is up to 60 m high rising abruptly from the adjacent plain. There are numerous cliff-foot caves as well as several large entrances part way up the cliff. One of these caves in the cliff-face was entered; a steep upward climb over talus, bedrock and clay fill, possibly old guano, to a large chamber at the top. Speleothems are present although scarce but the abundant small vertebrate material on the floor is of interest and the cave is potentially an important study site.

There are numerous small caves in an area about 3 km southwest of Stumpy Soak. These include some cliff-foot types but some multi-level solution caves with multiple entrances also occur. One small cave is an anastomosing passage developed within a steeply dipping bed of the forereef beds. The largest of the caves has large angular passages 2 – 3 m in diameter plus a couple of larger chambers. One of a number of smaller crawl size passages leads up to an upper level entrance. The cave also contains a short side passage that has been used as a multiple burial site by aborigines. The passage only goes a few metres and should not be disturbed.

Brooking Yard is a large marginal amphitheatre located adjacent to Brooking Creek at the south eastern end of the Oscar Range. There are a number of cliff foot caves in the yard. A larger cave is located in a spur at the southern side of the entrance to the yard.

Pillara Range

The author visited the Pillara Range only briefly. The only cave observed was a small shelter cave in Menyous Gap that contains some poorly preserved aboriginal paintings.

Horsespring – Hull – Horseshoe Ranges

These ranges, located in the relatively inaccessible northeastern part of the Limestone Ranges, were not visited by the author and the extent of karst features in the area is not known.

Emanuel – Lawford – Laidlaw Ranges

These ranges represent the southeastern end of the Limestone Ranges; the only described cave in this area is the Cave Spring Cave system located in the Lawford Range (Lowry 1967). There are a number of shelter caves throughout the area especially around the north end of Paddys Valley between the Laidlaw and Emanuel Ranges.

The Cave Spring system consists of three separate caves located on Mimbi Creek as it flows through the southern end of the Lawford Range. The Lower Cave is about 60 m long and contains a large pool even during the dry season. Middle Cave is about 150 m long with pools of water in the main passage. The Upper Cave has over 2000 m of passage, again with pools. Speleothems are relatively abundant in the three caves. The Middle and Upper Caves are the only caves described from the Limestone Ranges that are developed in the flat lying backreef limestone. The development of these caves was controlled by prominent joint sets that are developed in this limestone. The result is a maze type plan with most passages intersecting at right angles. The tendency is toward rectangular cross sections usually about 1 m wide and 3 – 4 m high but some passages are up to 12 m high. The main passage is about 4 m wide. Most of the system is subject to flooding during the wet season.

Conclusion

The Limestone Ranges represent one of the largest karst areas in Australia and has not been examined in detail for caves. It is probable that most of the major caves have been located but numerous caves and cave systems with lengths between 10 and 100 m may be expected during systematic exploration. Aerial photo interpretation and field observations indicates that the smaller cliff-foot caves tend to be located beneath shallow depressions on the tops of the ranges.

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MEASUREMENT OF RELATIVE AND ABSOLUTE WATER TABLE LEVELS IN NULLARBOR CAVES

EDWARD G. ANDERSON*

Abstract

Several specially conducted trips to the Nullarbor Plain have been made over the period December 1968 to January 1970 with the aim of measuring the differences in height between the water table levels in a number of major caves. In addition, by connecting the surveys to the national levelling network, the water table heights with respect to mean sea level at Esperance and Eucla have been determined. The water table level was assumed to be indicated by the free standing surface of the lakes which occur in some caves. Minor diurnal and longer period fluctuations in these levels are also reported. Special surveying techniques, devised to cope with the difficult condition in the caves, are explained and results are presented for Mullamullang (Oasis Valley), Cocklebiddy, Weebubbie (Weebubby), and Murra-el-elevyn Caves.

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THE WAITOMO STREAM, WAITOMO GLOW-WORM CAVE, NEW ZEALAND

DAVID HAWKE*

Abstract

The Waitomo Stream, draining a catchment of approximately 45 square km, flows through the Waitomo Glow-worm Cave. A rapid increase in the rate of sediment deposition in the cave has been noted in recent years, threatening both the cave and the unique faunal assemblage. Ongoing research is aimed at quantifying the erosional and depositional aspects of the stream flow so that conservation measures may be established. This paper will describe the current programme, and present preliminary results.

Introduction

New Zealand's Waitomo karst has long been a focus of speleological and tourist interest, and its caves have deteriorated as a result. Recently, a growing awareness of the problems being experienced in the tourist caves has occurred, and a preliminary conservation study of these caves was initiated by the New Zealand Speleological Society (NZSS) in 1974-75. The results of this study (Williams 1975) indicated a need for further research in three main fields: glow-worm ecology, the growth and influence of Lampenflora, and the hydrology and sedimentation of the Waitomo Stream. The Tourist Hotel Corporation, which administers the tourist caves, has made funds available for graduate study of these topics, and this paper describes work being undertaken regarding the hydrology and sedimentation of the Waitomo Stream.

The Area

The Waitomo Stream drains an area of approximately 43 km^2 upstream of the Glow-worm Cave, and flows through the cave before reaching the Lower Waitomo Valley (Fig. 1). The basin's maximum relief is 400 m, and a number of component sub-basins may readily be distinguished. Oligocene crystalline bio-clastic limestones crop out over approximately 40% of the area, and are characterised by dense polygonal doline networks. Multi-level phreatic and vadose caves are common, and the streams which frequently occupy the lowest levels are an important component of the drainage network. The remaining 60% of the catchment is dominated by the surface exposure of younger sandstones and siltstones, with rare remnants of recent ignimbrite capping the hills. Volcanic ash mantles the catchment, and probably contributes much of the finer material carried by the streams.

The lithology is disrupted by a number of major faults, resulting in a stepped repetition of stratigraphy (Fig. 2). This repetition has a marked effect on the drainage system, since the streams are typically underground on limestone, and sub-aerial over the remainder of the basin. The underground portions are characteristically free air surface streams, although numerous sumped sections occur; that of the Glow-worm Cave (Fig. 3) being of particular significance due to its influence on the stream's hydraulic characteristics.

The Problem

The results of the preliminary study by NZSS indicated a rapid rate of sedimentation and hence stream floor build-up in the Glow-worm Cave. The current sedimentation rate was estimated as 57 mm per annum, approximately 4 m of sediment having been deposited in the last 50 years, and it was suggested that the submergence air space may be lost within the next 50 years if deposition continues at this rate. The present project aims to examine the sedimentation occurring in the Glow-worm Cave, having particular regard to its dynamics, mechanisms and sources. Hence it is concerned with establishing a sediment 'budget' for the catchment, and with the hydraulic factors which influence sediment transport and deposition. Since sediment transport is intimately linked

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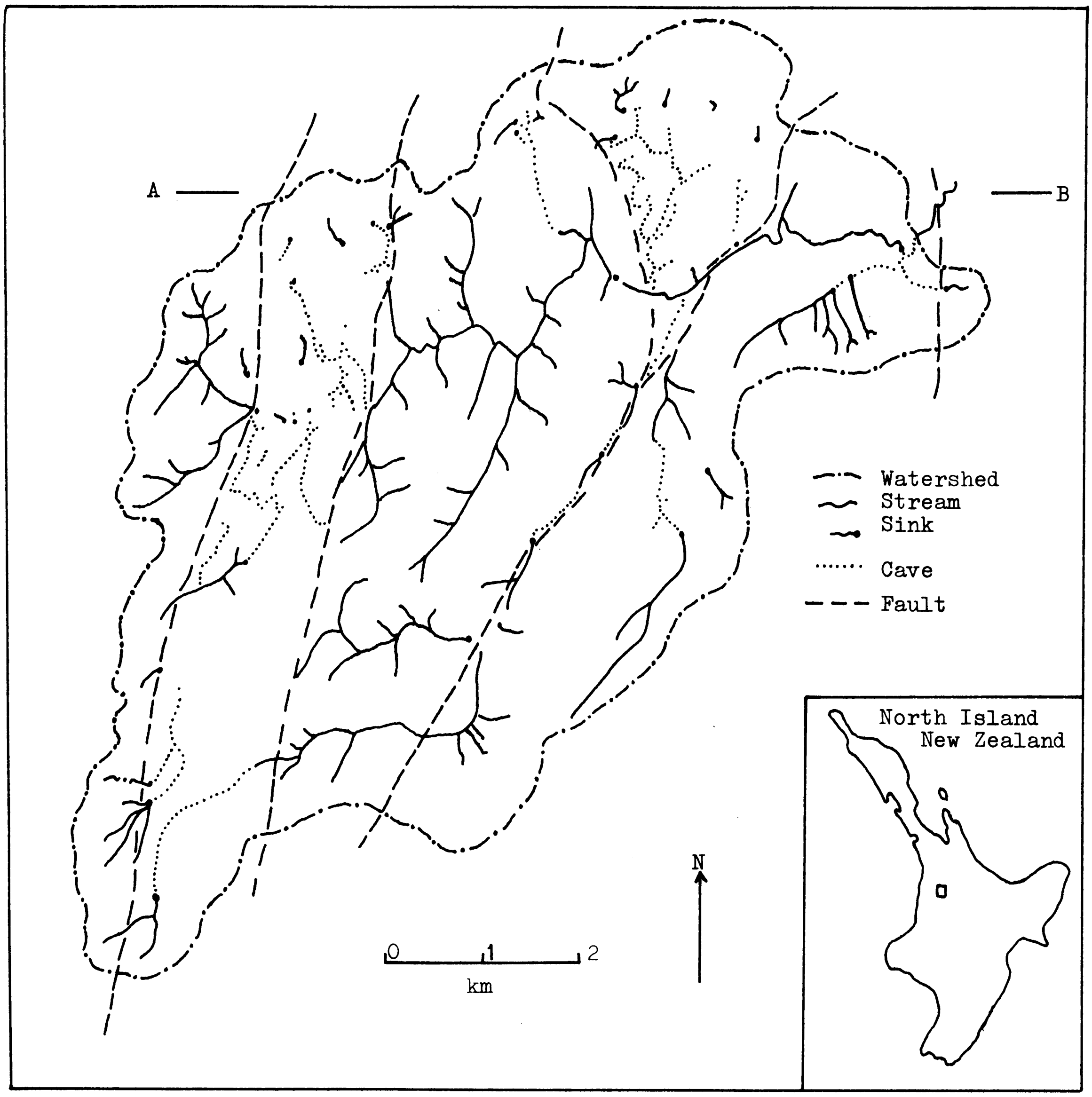

Fig. 1. The Waitomo Drainage Basin (after Kermode 1975).

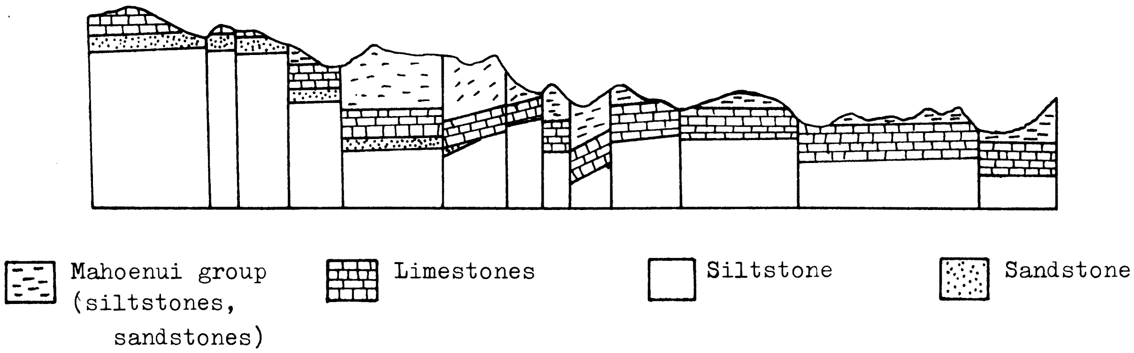

Fig. 2. Simplified geologic cross section (after Kermode 1975).

with the hydrological characteristics of the system, the hydrology of the Waitomo basin must also be examined, with particular attention being paid to the separation of karst and non-karst influences.

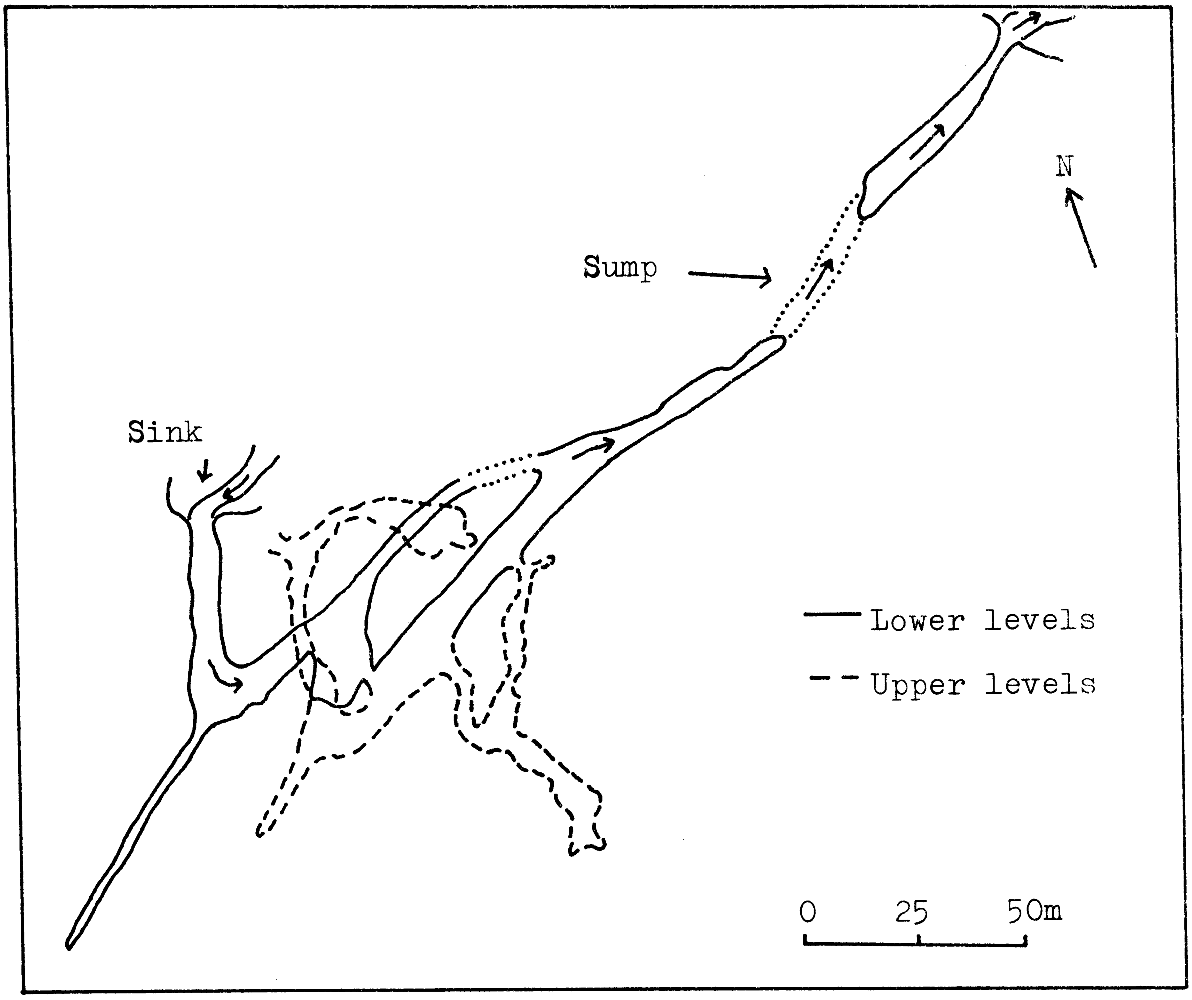

Fig. 3. The Glow-worm cave, Waitomo.

Research program and preliminary results

The data collection program has only recently been initiated, and is concentrated on the temporal and spatial variations in water and sediment discharge within the system, monitoring being conducted on an event rather than a regular basis. To enable the establishment of a sediment 'budget' for the system, a number of sampling points have been established (Fig. 1) where discharge measurements and sediment samples are taken. Stage-discharge and stage-sediment yield rating curves will be established for each site to enable comparison to be made between sites. The temporal variation of parameters will be established by correlating stage readings for each site with those of a master site where a continuous water level recorder is being maintained. Other characteristics of the study relate to the physical properties of the sediment, in particular the variation of bed material size throughout the catchment, and to the rate of transport of particular size fractions. The Glow-worm Cave is the subject of further attention regarding the changes in hydraulic parameters through the cave, and their influence on deposition.

Little data is as yet available on the operation of the system. Preliminary observations indicate that the system responds rapidly to rainfall inputs, and that the main sources of sediment are likely

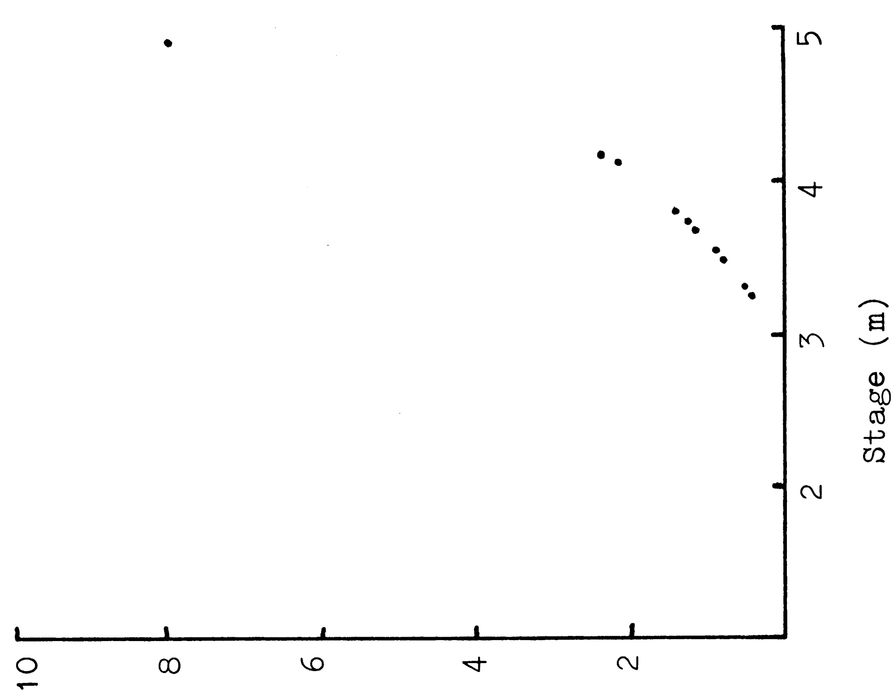

Fig. 4. **Stage-discharge relationship, Waitomo master site.**

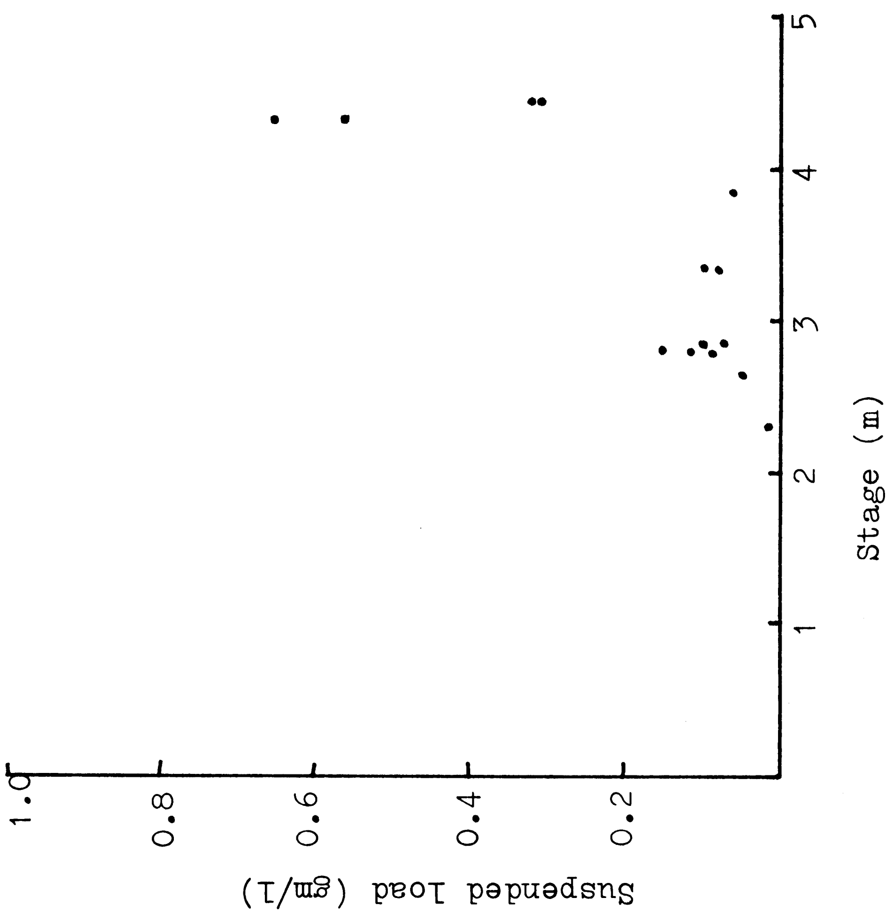

Fig. 5. **Stage-suspended sediment load relationship, Waitomo master site.**

to be bank scour and erosion, and major road works located at the head of one tributary. Quantitative observations have thus far been mainly confined to the master site, and a preliminary stage-discharge rating curve has been established for this site (Fig. 4). The discharge of the system varies between 0.5 $m^3 s^{-1}$ at low flow and an estimated 15-18 $m^3 s^{-1}$ in high flow conditions, and there is a seasonal variation in baseflow discharge (0.5 $m^3 s^{-1}$ in summer, 1.5-2$m^3 s^{-1}$ in winter).

Suspended sediment concentrations in the system are generally low, the highest so far recorded being 840 mg per litre at 10 $m^3 s^{-1}$. It is notable that a great scatter of points occurs on the state-suspended sediment plot (Fig. 5), indicating that the sediment load may not be related directly to discharge, but may be influenced by factors such as season, antecedent conditions, limb of the hydrograph and source, particularly if bank collapse is dominant. Preliminary observations in the Glow-worm Cave indicate the need for concentration on that section of the system since as much as 50% of the suspended load may be deposited in the cave at moderate flows (2-4 $m^3 s^{-1}$).

Conclusion

The work thus far has indicated a number of avenues which require closer examination. It is hoped that as a result of this project, proposals may be developed to aid in improving the water flow through the Glow-worm Cave so that sedimentation is limited and the valuable glow-worm assemblage may be maintained.

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ATEA KANADA

JULIA JAMES*, RANDALL KING † and NEIL MONTGOMERY††

Abstract

The Atea Kanada, located in the tropical rainforest of the Southern Highlands of Papua-New Guinea was investigated during the 1976 Muller Range Speleological Expedition. In the course of the expedition, 4 kilometres of cave passage in the Atea Kanda were mapped, a 5½ kilometre survey between the Atea sink and its resurgence undertaken; and a preliminary speleological study was made of the Atea system. Various results of this investigation : area physiography, hydrology, cave map and description, geology and the cave's future potential as a contender for the Southern Hemisphere depth record are discussed.

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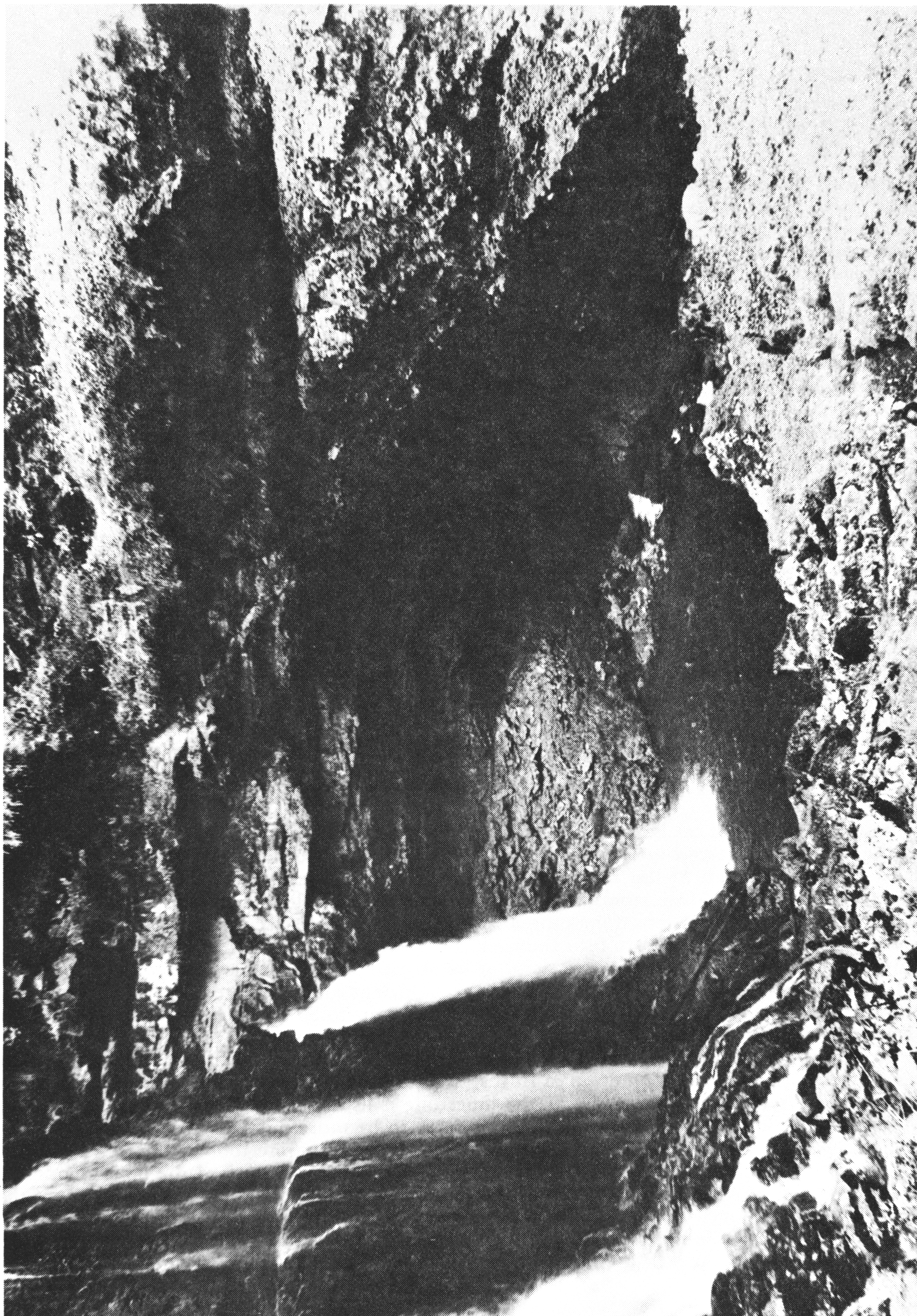

Plate 12. Atea Kanada entrance doline.

CAVES IN THE QUATERNARY RAISED REEFS OF EASTERN MANUS, PAPUA NEW GUINEA.

GEOFFREY FRANCIS*

Abstract

There are least 18 known caves in the raised reefs of Eastern Manus. They range from small single chambers to complex multi-level systems. Cave forms are controlled largely by the distinctive geological structure but there is little relationship between surface and underground karst morphology. All caves appear to be of phreatic origin and most developed without penetrable entrances and have only become accessible after collapse or backwearing of slopes. Cave development was initiated when the sea stood at higher levels and has been influenced by eustatic and tectonic sea level changes. As percolation waters are usually saturated or supersaturated, cave genesis under these conditions requires processes by which water that has entered the limestone can regain aggressiveness on reaching the water table. The available evidence suggests that "rejuvenated aggressiveness" caused by mixing of ground and percolation waters with different Ca/Mg ratios may be involved. Other possible complimentary effects are undersaturation produced by the mixing of waters with different chloride concentrations and the "mixing corrosion" proposed by Bogli. These phenomena could be responsible for development of solutional forms such as bellholes. Limited data obtained from water analyses suggests that brackish and saline waters are sometimes capable of limestone solution.

Introduction

Manus Island is situated on the Outer Melanesian Island Arc at latitude 2°S and longitude 147°E. The raised reefs are found in an area which extends northeast from Bunai to Los Negros Island (Figs 1, 2 & 3). Here the topography consists of northeasterly trending volcanic ridges with raised reefs on the southeastern seaward side. The largest raised reef extends northeast from Loniu for 4 km and is up to 800 m wide. There are two other sizeable reefs at Lolak and Bunai as well as a number of smaller reef patches in adjacent areas. In some places estuaries and backswamps lie between the volcanic ridges and the raised reefs.

Geology

The oldest rocks exposed on Eastern Manus are middle Miocene andesitic lavas and pyroclastics. In places these are disconformably overlain by upper Miocene to Pliocene basalts or clastic sediments. The caves have developed in the lower Pleistocene Naringel Limestone which is largely an algal-foraminiferal biomicrite. Most samples contain high magnesium calcite and a few have been dolomitised. The porosity of the limestone ranges from 4 to 13% but is accentuated on weathered surfaces where filamentous algae bore into the rock. Primary voids up to 1 m in diameter have been infilled with coarsely crystalline sparry calcite or lined with saw-toothed layers of calcite and dolomite. Bedding is not usually visible in the limestone though at some localities dips to the northwest or southeast, of usually less than 10° though occasionally up to 30°, have been observed. The dips vary considerably over short distances and appear to be largely depositional.

The most prominent structural feature of Eastern Manus is a set of strike-slip faults trending northeast which controls the orientation of ridges, valleys and estuaries. Another less well developed set of faults bears northwest. Jointing in the limestone is usually parallel to the faults though in many cases the field evidence does not allow fractures to be more precisely classified as joints or faults. The Naringel Limestone was deposited over irregular submarine topography in a period of rising relative sea level. Subsequent uplift accompanied by faulting has raised the limestone up to 80 m above sea level. Although the crests of the raised reefs vary from 20 m to 80 m in height the uplift appears to have been relatively uniform within each reef. Extensive deposits of younger coral and alluvium were laid down in the late Pleistocene or Holocene when the relative sea level was about 4 m higher than the present.

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Fig. 1. Manus Island – Location of study areas.

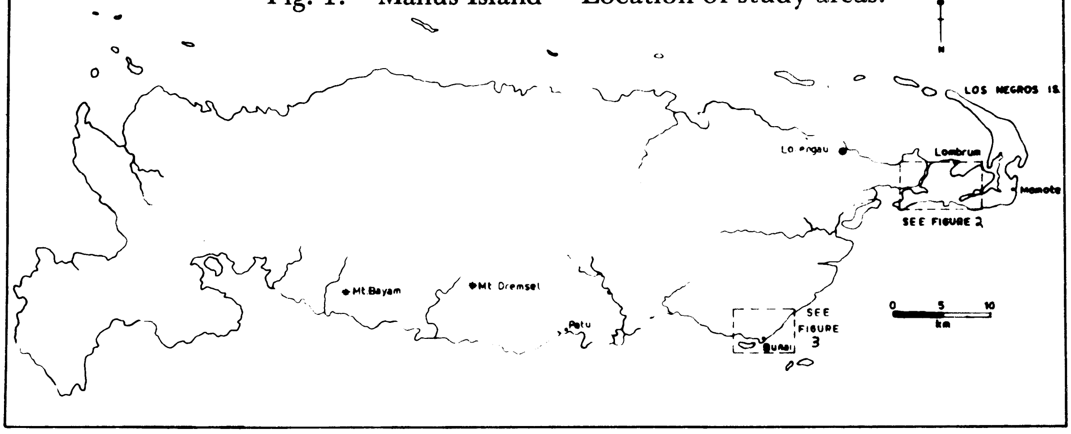
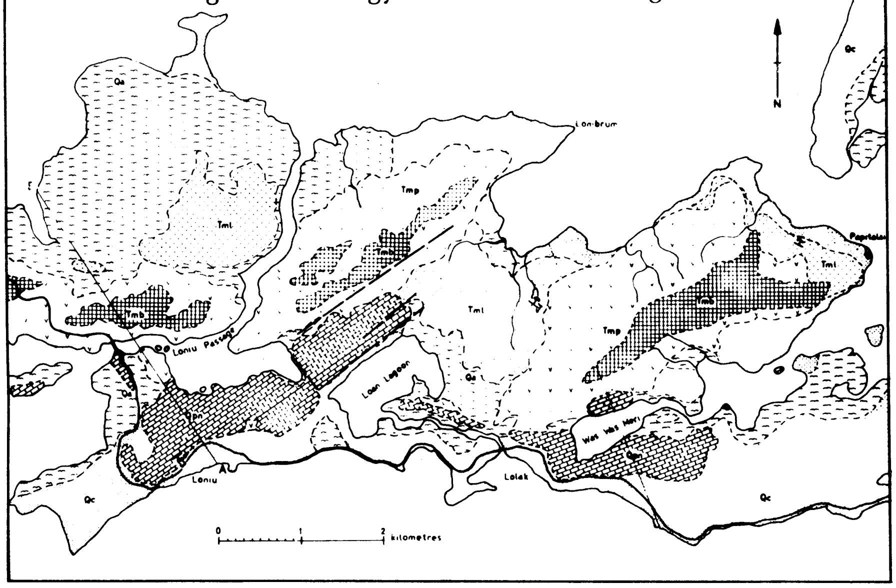


Fig. 2. Geology of southern Los Negros Island.



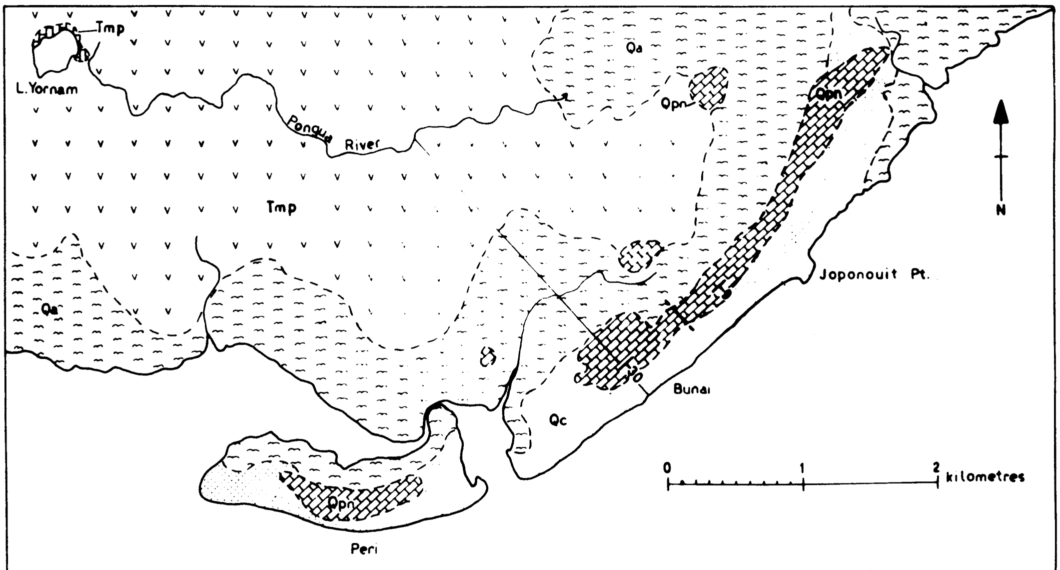


Fig. 3. Geology of Bunai.

Topography

Slope forms on the raised reefs are variable ranging from 25° soil-covered slopes to near vertical cliffs. At Lolak and Loniu there are extensive areas of relatively level ground on the crests of the raised reefs. Scattered dolines are present usually less than 50 m in diameter though occasionally much larger. Some areas are dissected by regular networks of crevice karst with fissures up to 13 m deep.

Hydrology

Because the northeastern trending faults exert such a strong influence on topography, the drainage usually runs northeast or southwest parallel to the raised reefs. Therefore streams rising on the impervious rocks do not flow into the karst areas and river caves are absent. Along the margins of the raised reefs there are a number of small risings fed by percolation water. Some are located in the intertidal zone while others lie on the contact between the Naringel Limestone and the low-lying deposits of coral and alluvium. All risings have formed on fractures in the limestone.

Observations on groundwater levels in caves and at risings suggest that there is a fairly continuous water table which lies less than 5 m above sea level in the centre of the raised reefs and slopes gently down to estuaries or the sea. However, waters emerging from risings only a few metres apart can vary considerably in total hardness, indicating that there are dominant lines of flow with only limited interconnections. In the narrower reefs the groundwater is usually brackish or saline, whereas in the more extensive ones it is usually fresh but may become brackish during relatively dry periods.

Caves

There are at least 18 known caves in the raised reefs of Eastern Manus. They range from small single chambers up to complex systems, with as much as 500 m of passages, developed on more than one level. All caves appear to be of phreatic origin but in some cases their bedrock morphology is obscured by earth fill, speleothems or breakdown. In the Ngai-Loso Caves bedrock is rarely visible and in Poywih Cave only occasional bedding controlled ledges formed in limestone can be seen (Figs. 4 and 5; morphological symbols for all cave maps are shown in table 1).

Loniu Cave

The largest of the caves lies just northwest of Loniu Village and has three hillside entrances about 27 m above sea level. Much of Loniu Cave has developed along fractures which trend slightly west of north. In the southern part of the cave, chambers of various sizes are linked by narrower connecting passages (Fig. 6). From the entrance chamber a solutionally enlarged fissure extends up to the surface connecting with a crevice karst corridor (cross section B). There are two sets of joints in the main chamber, bearing 355° and 080° respectively. The chamber is elongated in the direction of the latter set. Although some joints have been conspicuously enlarged by solution to form wall and ceiling cavities, others have been recemented by medium to coarsely crystalline calcite. This material is more resistant to solution than the rest of the limestone and forms projections on the cave walls. Large pods of sparry calcite originally precipitated as void fillings stand out in a similar way. A line of massive stalactities, stalagmites and columns has developed where calcite has been deposited by water seeping down through a fracture which bears slightly west of north. The main chamber has been formed almost entirely by solution with only minor rockfall. Contrasting with this is the collapse chamber where an extensive rockpile has formed by breakdown from the roof (cross sections J and K). At the northern end of this chamber two collapse blocks exceeding 10 m in length have fallen away from a bedding plane that dips gently to the west (cross section K). Rockfall is also present in the passage that leads down to the lowest part of the cave (cross section J). Near cross section I, the base of the rockpile extends down several metres below the water table. The water in this pool flows slowly into a narrow cleft on the northern side.

The most common bedrock solution forms in Loniu Cave are joint wall and solution cavities, wall pockets and bellholes. Thin tree roots hang down from some of the bellholes. There are also symmetrical hollows averaging 70 cm in diameter and 30 cm deep which are transitional between wall pockets and scallops. Spongework is present near cross section E but has largely been covered by flowstone and earth fill.

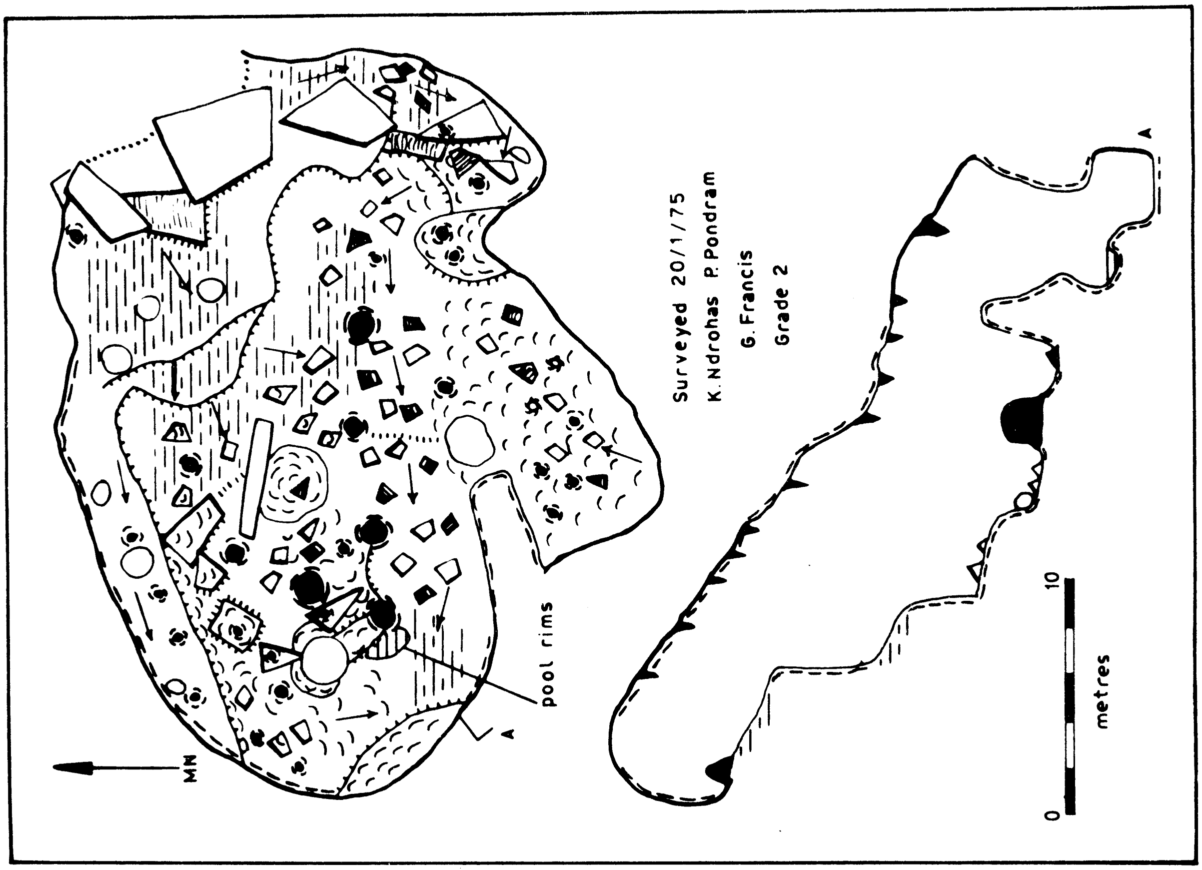


Fig. 5. Poywih Cave.

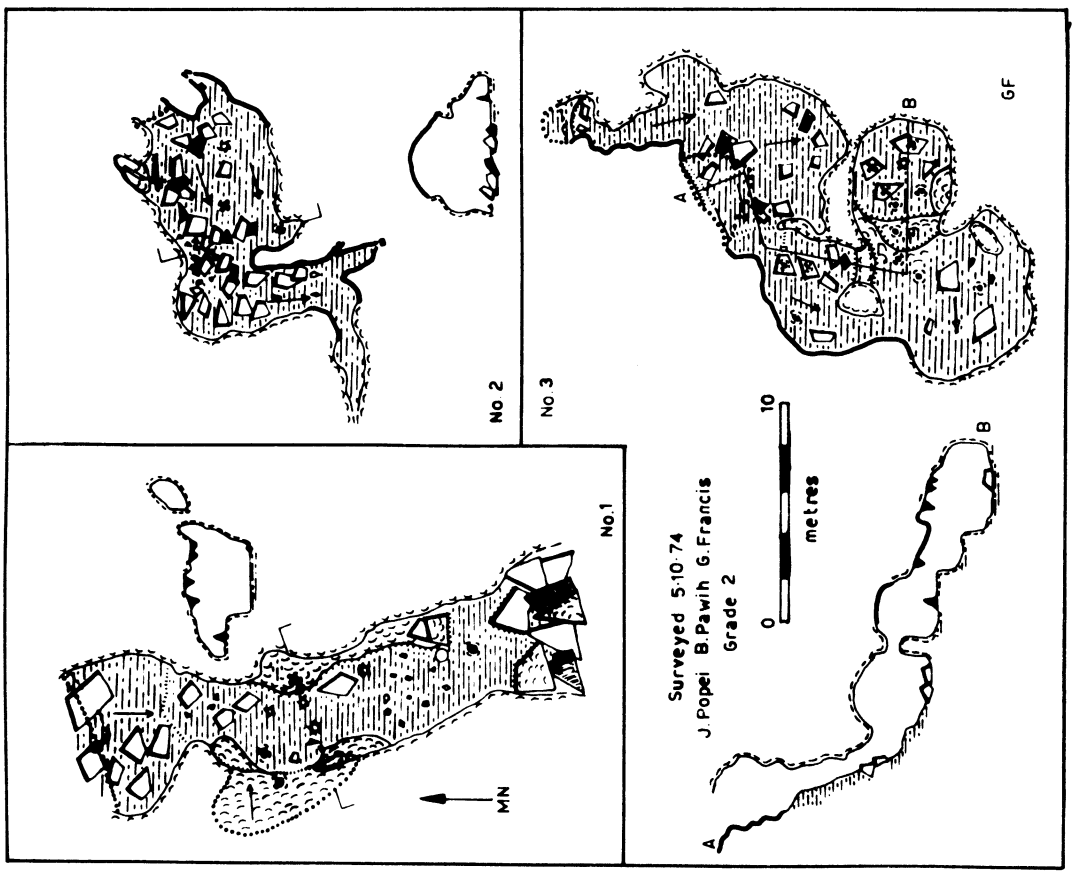
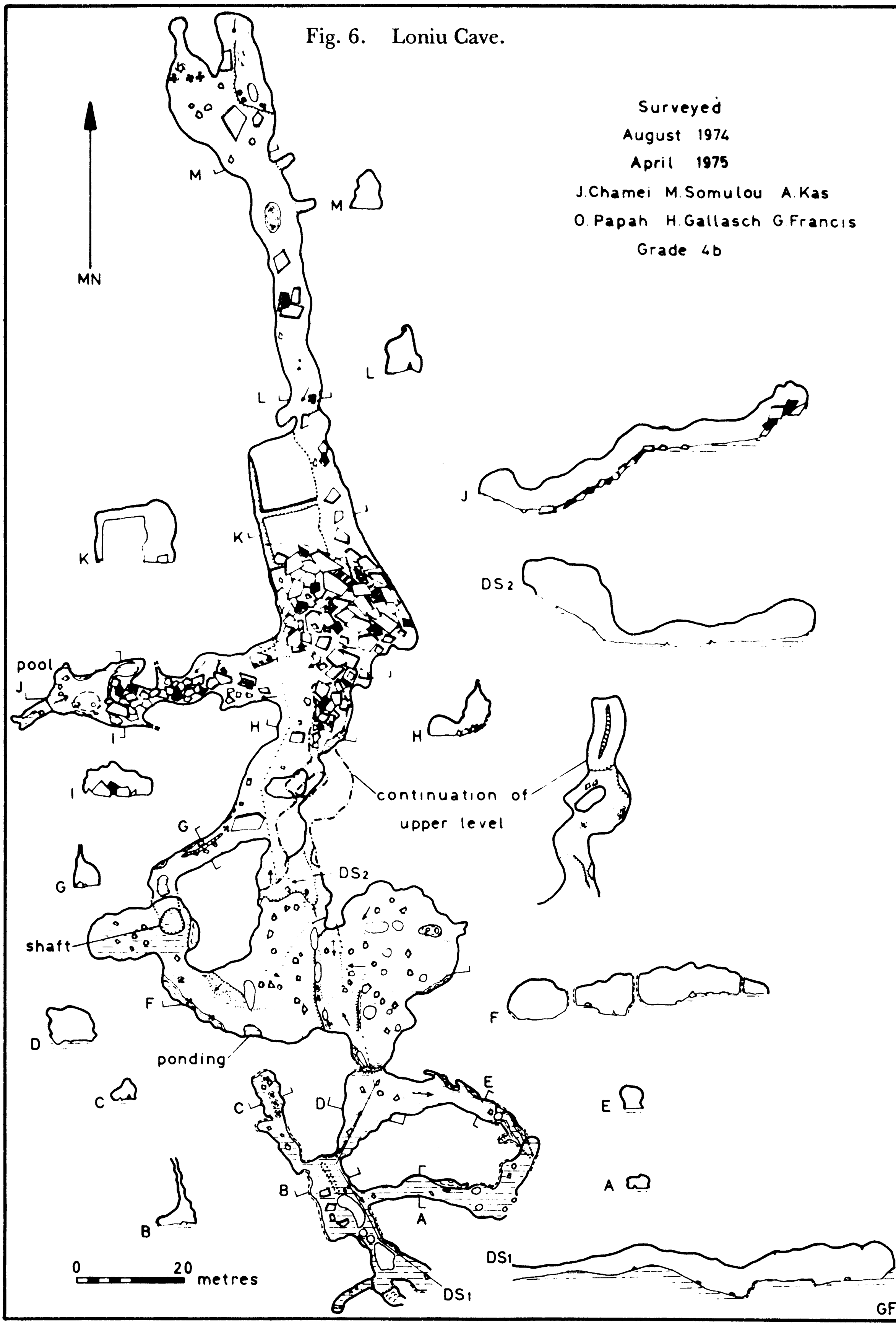


Fig. 4. Ngai-Loso Caves.

Fig. 6. Loniu Cave.



The main chamber and some of the passages to the north contain brown ferruginous phosphate deposits which are often indurated. These deposits are almost entirely phosphosiderite though a 1–2 mm outer crust of goethite is sometimes present. The material is extremely porous and varies in consistency from friable to hard. Some of the phosphate occurs as loose floaters which have broken away from the main deposits. In the narrow passage west of cross section I, the ferruginous phosphate contains small lenses of cherty mudstone. Since such lenses are often found in the Naringel Limestone, this would normally be interpreted as evidence for the replacement of limestone by iron phosphate prior to the development of the cave. However, it is clear from the conformation of the phosphate deposits that these formed as fill in pre-existing passages. The limestone contains small quantities of ferruginous minerals such as magnetite and pyrite which have sometimes been concentrated along fractures and partings by pressure solution. This suggests a complex evolution for the phosphates, involving:

(a) selective removal of carbonates from the limestone leaving concentrations of less soluble ferruginous minerals along fractures and partings,

(b) solution by groundwater forming caves along these planes of weakness and,

(c) chemical reactions between phosphates and ferruginous cave fill producing phosphosiderite.

The phosphate may have been derived from bird guano originally deposited on the surface or from bat guano which accumulated in the cave. Less extensive phosphate deposits occur in Kohin and Nge-Pelimat Caves.

Nge-Pelimat Cave

Nge-Pelimat Cave is situated just east of Lolak Village. Entry to the cave is gained through a collapse doline, the rim of which lies about 30 m above sea level. Much of the cave consists of high but narrow passages developed along a fracture system which bears between 335° and 355° (Fig. 7). There has been minor development of lower roofed passages along fractures which trend about 065° (cross sections D and G). The main forms of bedrock solution sculpture are joint wall cavities, wall pockets, symmetrical scallops, bellholes and spongework. In one chamber there is a vertical rock partition which rises up to 5 m above floor level.

Prominent features of Nge-Pelimat Cave are the abrupt passage terminations in bedrock and abrupt variations in the height of the cave floor. Sometimes these variations have been caused by the deposition of flowstone in the lower part of a fissure passage, but elsewhere the variations result from irregularities in the bedrock floor of the cave. At the southern end of the cave is a deep fissure which is partly filled with groundwater. The fissure extends down below the water table for at least 20 m and is separated from another deep pool by a rock partition which rises up to within 50 cm of normal water level. No water movement is discernable in the fissure but the groundwater flows southwest through the constriction created by the partition at rates of 20–40cm min^{-1}. From the pool the water passes southwest through a sump into a water-filled passage.

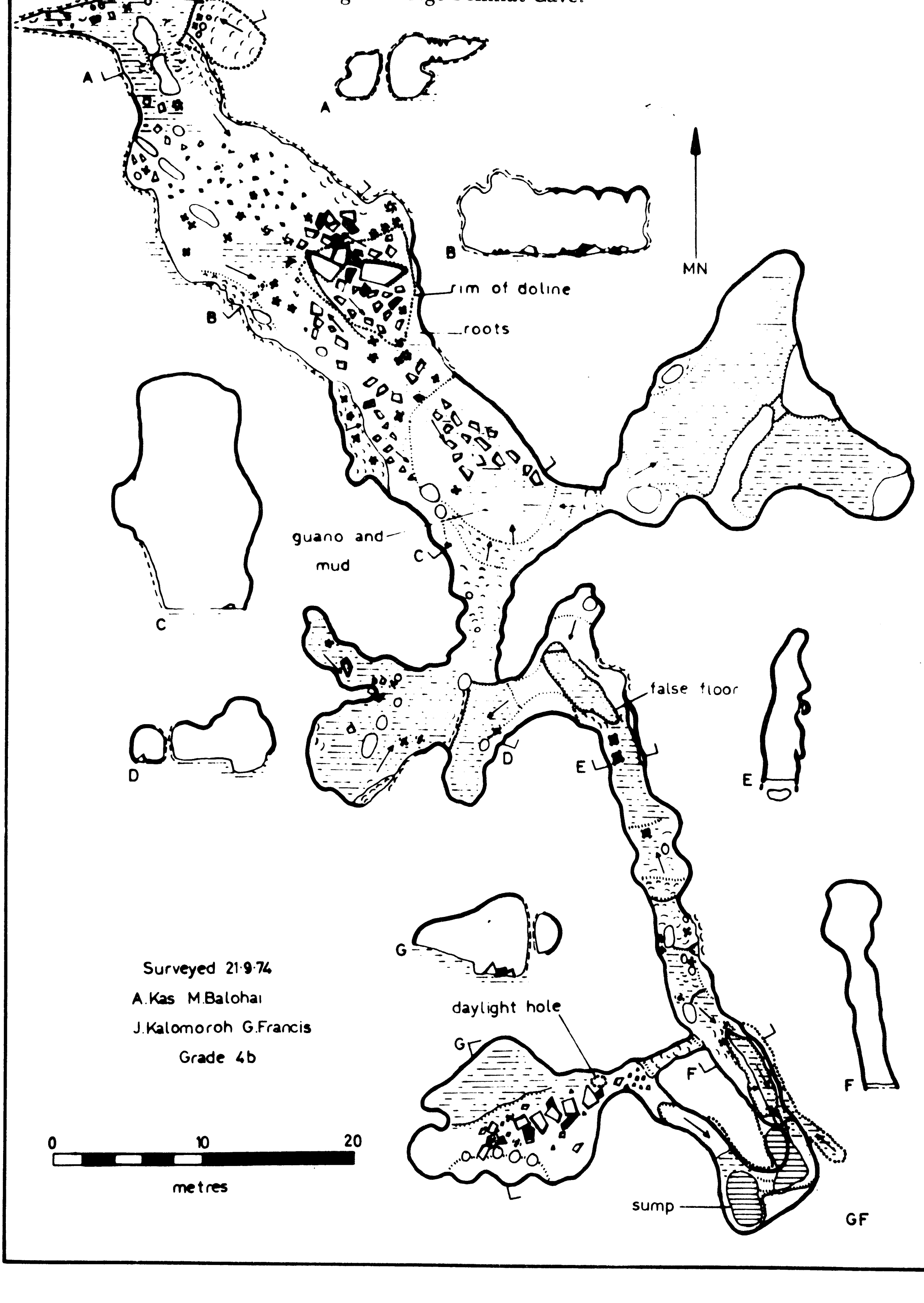
Ndran Akohau Cave

Ndran Akohau Cave is situated near the southern end of Was Was Meri Lagoon about 350 m east of Nge-Pelimat. Like Nge-Pelimat Cave it consists largely of vertical fissures passages though the middle section has a lower bedding plane roof (Fig. 8, cross section B). There are two branches in the cave, the larger one having a dog-leg form with passage segments developed alternately along fractures which run south and southeast. Solution pockets and spongework are present on the walls of these passages. Near the entrance there has been substantial breakdown, but much of the collapsed rock has been recemented by flowstone (cross section C).

Kohin Cave

Kohin Cave has formed in the landward side of the raised reef behind Bunai Village. It has two entrances about 14 m above the level of the brackish backswamp. There are three other entrances in a collapse doline on top of the reef (Fig. 9). The northern part of the cave is a large daylight chamber which has been formed mainly by solution with only minor collapse (cross section H). In the roof of this chamber there are complex cavities with smaller bellholes nestled within larger ones. The walls display well developed spongework and subhorizontal bedding controlled ledges. A few flat projections of the type that Ollier (1975) has termed 'salients' are also present. In the southern branch of the cave roof pendants occur in association with spongework (cross section C).

Fig. 7. Nge-Pelimat Cave.



Towan Cave

Towan Cave is on the eastern side of the raised reef about 60 m northeast of Kohin. (Fig. 10) It was initiated as two low roofed chambers, one on top of the other. The intervening limestone was partially breached by collapse into the lower level, leaving a horizontal bedding controlled rock bridge which extends across the chamber. This breakdown has continued until fairly recent times, fracturing some of the stalagmites and flowstone. The upper level of the cave contains spongework and solution pockets.

Cave Genesis

The bedrock solution sculpture in caves of Eastern Manus indicates that the caves were formed through solution by slowly moving water in the phreatic zone. Forms such as joint wall and ceiling cavities, wall pockets, bellholes, spongework and rock spans are typical of solution below the water table (Bretz 1942). Other features thought to be characteristic of phreatic solution are large chambers linked by narrow connecting passages and blind passage terminations in bedrock. A number of authors have attempted to distinguish between two zones of groundwater solution, the shallow phreatic and the deep phreatic. The shallow phreatic zone was thought to be characterised by fairly rapid flow at or slightly below the water table, producing forms such as planed horizontal ceilings and assymetrical scallops (Davis 1930). The deep phreatic zone below was believed to contain slowly moving water which gave rise to forms such as solution pockets and spongework. The main solutional features in the caves of Eastern Manus are types which have been ascribed to deep phreatic solutions, yet the field evidence indicates that a number of these features developed close to the water table. In parts of Nge-Pelimat and Kohin Caves, bellholes and wallpockets can be found only 4 m below the ground, and it is unlikely that there has been more than few metres of surface lowering in the limited time available for karst development. Moreover there is no discernable flow in the large pools of groundwater that now lie in the lower cave levels. It is only where the water passes through constrictions less than 1 m in width that flow rates of 20 – 40 cm min^{-1} can be observed. Ollier (1975) has noted a similar phenomenon in caves of the Trobriands.

The occurrence of phreatic solution forms at levels up to 30 m above the present water table indicates that the caves were formed at times when groundwater levels stood much higher in the limestone. In Bermuda there are phreatic caves which formed when groundwater levels were at least 15 m higher than the saltwater pools now found in the caves. Bretz (1960) attributed this phreatic solution to low sea level stands during the Pleistocene which greatly enlarged the land area and allowed the formation of a water table steeper in gradient than the one which now exists. An explanation of this type cannot be applied to cave development in Eastern Manus. Because of the steep submarine slopes on the southeastern coast of Manus, the land areas at Bunai, Lolak and Loniu would not have been significantly greater during sea level stands 100 – 120 m below the present one. Also it is doubtful whether the porous and fractured limestone would allow the formation of a moderately sloping water table even during the earlier stages of cave development. Consequently the evidence indicates that the caves of Eastern Manus formed when relative sea levels were higher than the present and have been largely drained of phreatic water as the reefs were uplifted. The withdrawal of hydraulic support caused by this lowering of the water table has probably been the main cause of cave breakdown and the formation of collapse dolines, though the breakdown in Towan has continued until recent times.

Since reef limestones often contain large primary voids, Ollier and Holdsworth (1968) suggested that raised reefs might contain caves inherited from marine conditions, but could find no evidence for this in the Trobriands. On Eastern Manus, cave formation was initiated only after substantial diagenetic changes had taken place in the Naringel Limestone. The larger primary cavities in this rock have been wholly or partly filled with sparry calcite. Even in the case of partial fill the layer of calcite which lines the cavity is more resistant to solution than the rest of the limestone. This prevents the voids from serving as a focus for cave development.

In low lying areas of Eastern Manus there are outcrops of very porous Quaternary coral which has been locally recrystallised and cemented but generally remains relatively friable. Tectonic jointing is present in the reef rock with individual joints spaced about 1 m apart and rarely extending for distances of more than 15 m. This is in marked contrast to the Naringel Limestone where the spacing of joints in the Quaternary coral is caused by the lower shear strength of this weakly lithified rock. Since the caves in the Naringel Limestone have formed along joint fractures they postdate the fracturing of this rock. Thus the Naringel Limestone must have been substantially lithified before cave development began. However, the recemented joints found in Loniu Cave and in several other areas suggest that cave formation may have accompanied the later stages of diagenesis.

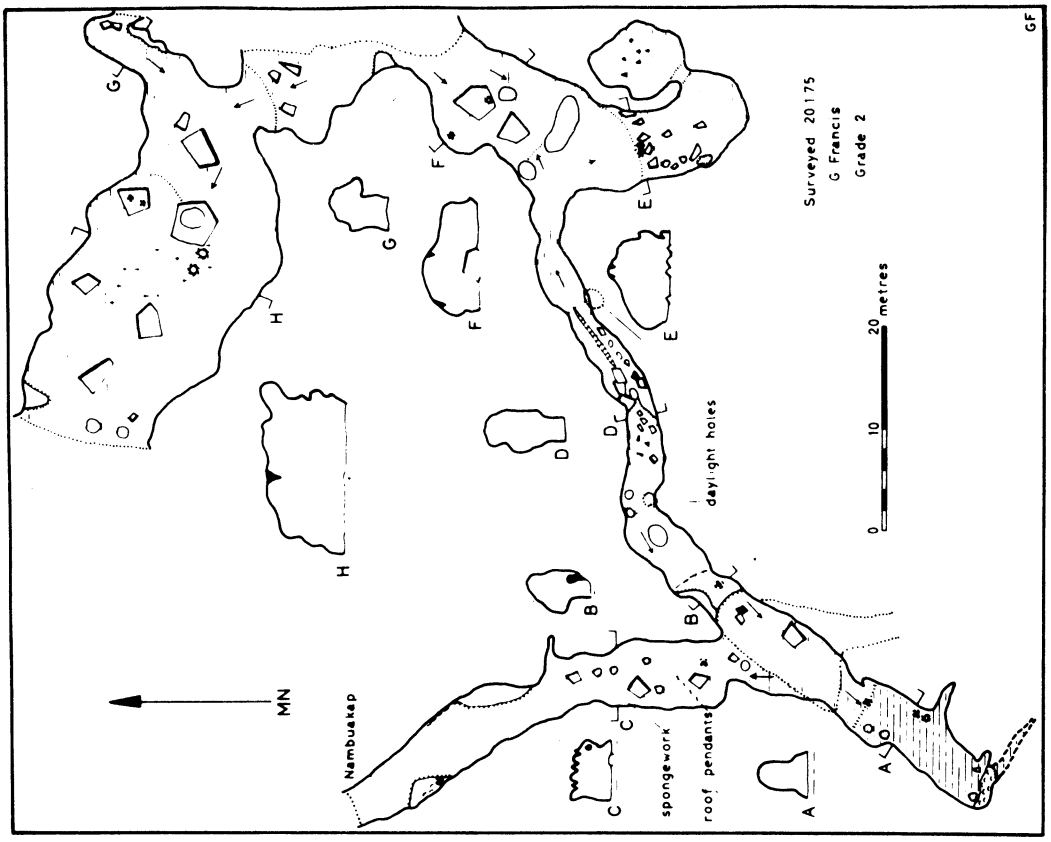


Fig. 9. Kohin Cave.

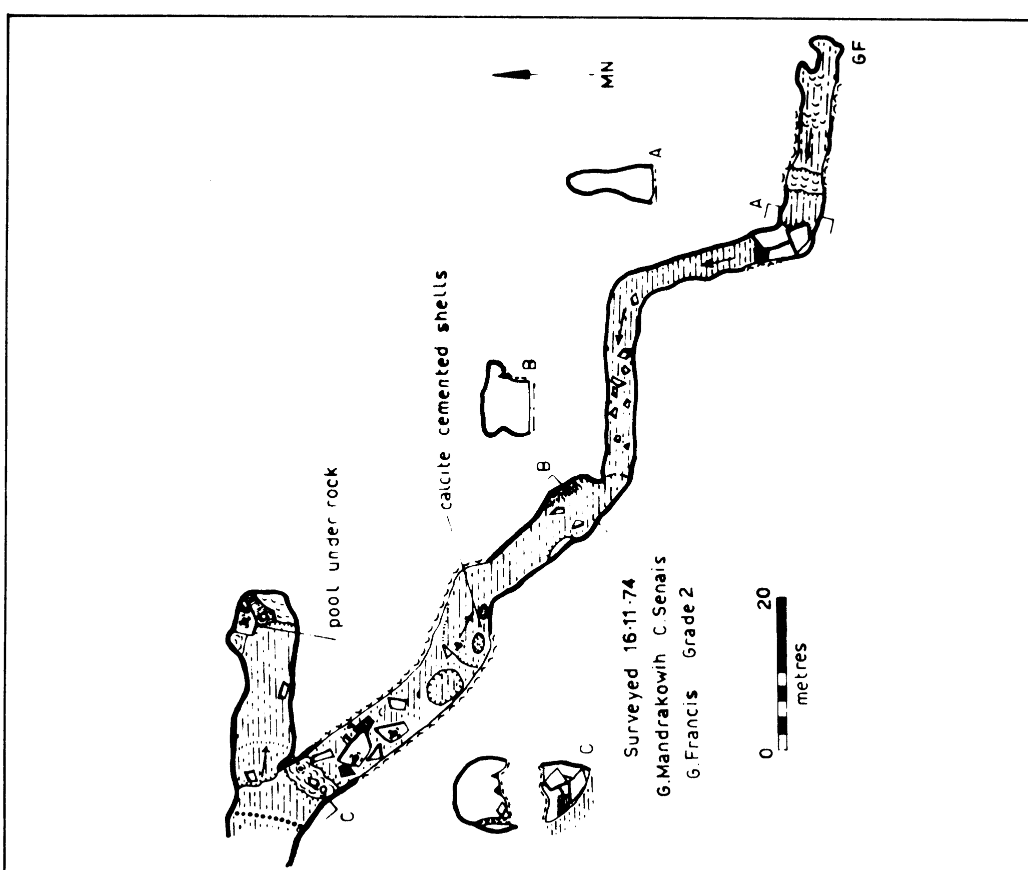


Fig. 8. Ndran Akohau Cave.

The caves in Eastern Manus are well adjusted to geological structure. The orientation of passages is controlled largely by the main fracture systems, though where bedding is present this often influences cave cross-sections. If bedding is absent the passages are usually the vertical fissure type formed by the solutional enlargement of fractures. Typical examples are found in Ndran Akohau, Nge-Pelimat and parts of Kohin. An interesting feature of the raised reefs is the lack of solutional development in the vicinity of risings. The largest outflow passage found was Lower Kohin Cave, a solution tube about 40 cm in diameter situated directly below the daylight chamber in Kohin. Lower Kohin extends back into the limestone for at least 20 m and is floored with a porous breccia of shells and limestone pebbles in a muddy matrix. At the other risings water emerges from impenetrable clefts.

The absence of outflow caves in the occurrence of numerous blind passage terminations in bedrock suggest that the caves originally developed without penetrable entrances and have only become accessible through being partially unroofed by collapse or vadose solutions, or exposed by backwearing of the limestone slopes. The fact that several large solution dolines have no cave entrances in them also indicates that there is little relationship between cave and surface karst development.

The solution processes responsible for the formation of caves in raised reefs are not well understood. Because saline and brackish waters in the tropics are usually supersaturated with respect to calcium. Bretz (1960) assumed that the phreatic caves of Bermuda formed at a time when the island held a body of fresh groundwater. However, Ollier (1975) has drawn attention to phreatic caves formed in small islands of the Trobriands which could never have held a body of fresh groundwater. On this basis he argued that brackish and saline waters were sometimes capable of limestone solution.

A limited water sampling programme was carried out in the karst areas of Eastern Manus and the results of this study will be presented more fully elsewhere. However, some of the analytical data is relevant to this problem of cave genesis. One sample of brackish water from a rising at Loniu had a total hardness of 272 ppm (expressed as $Ca\ Co_3$) and 785 ppm of dissolved chlorides. It dissolved a further 6 ppm of calcium carbonate to reach equilibrium. Another sample from a tidal pool connected through a rockpile to Was Was Meri Lagoon was saline with a chloride concentration of 39 000 ppm. It had a total hardness of 15 550 ppm and dissolved a further 1 400 ppm of calcium carbonate to reach equilibrium. Although the data is limited it does indicate that brackish and saline waters are sometimes aggressive. One possible mechanism to produce undersaturation is the mixing of waters with different chloride concentrations. This alters the ionic strengths of the solutions and the solubility equilibria for carbonates. Runnels (1969) has suggested that these mixing effects may play an important part in the diagenetic solution and reprecipitation of carbonates.

Some mechanism of the type appears to be necessary for cave development since percolation waters are usually supersaturated after passing through only 10 – 20 m of limestone. Another possible means of producing undersaturation is rejuvenated aggressiveness caused by mixing of waters with different Ca/Mg ratios. Picknett (1972) has shown that the solubility of calcium carbonate is increased by the addition of magnesium ions in small quantities, but inhibited when large concentrations of magnesium are present. Since the Ca/Mg ratios of percolation waters ranged from 1.2 to 155 and those of groundwater samples ranged from 0.5 to 1.9 it is possible that aggressiveness could be rejuvenated by mixing of waters with different Ca/Mg ratios. In one experiment supersaturated samples of groundwater and percolation water were mixed to form a solution with a Ca/Mg ratio of about 6, which proved to be aggressive. In other cases, samples mixed to form solutions with lower Ca/Mg ratios remained supersaturated.

The results of these experiments should be treated with some caution, since it is impossible to duplicate conditions of natural mixing. It is also uncertain whether the change in saturation was caused by alterations in the chloride concentrations or the Ca/Mg ratios. Another possibility is mixing corrosion caused by variations in the CO_2 partial pressure, which Bogli (1971) has postulated as a major cause of phreatic solution. This effect considered singly appears to be very slight, but the three mechanisms for producing undersaturation may well be complementary. Bogli has shown that forms such a joint wall and ceiling cavities can readily be explained by a mixing effect which renews aggressiveness, though he was thinking specifically of mixing corrosion rather than the other two processes. Features such as wall pockets and bellholes can also be explained by mixing effects, provided that the limestone is porous. In view of the evidence from bedrock morphology and water chemistry in caves of Eastern Manus the question of phreatic solution by mixing effects should be further investigated.

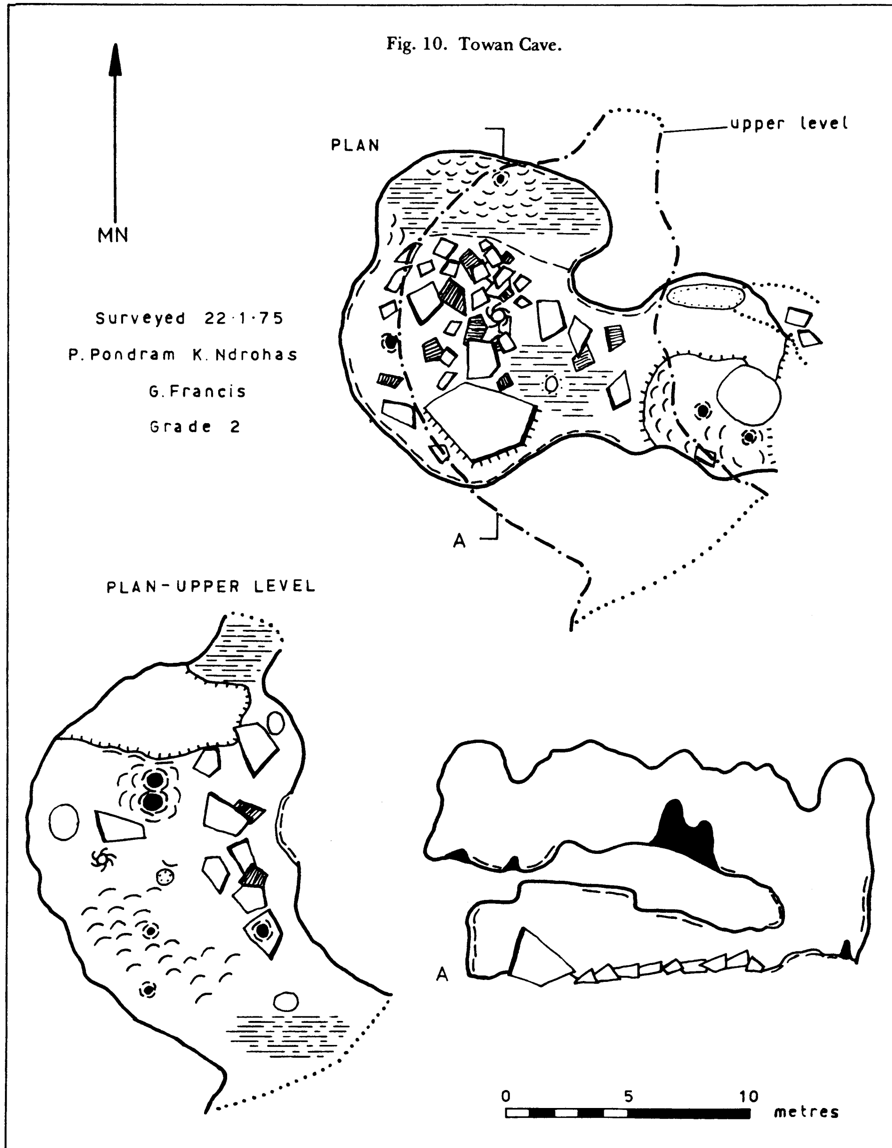


Fig. 10. Towan Cave.

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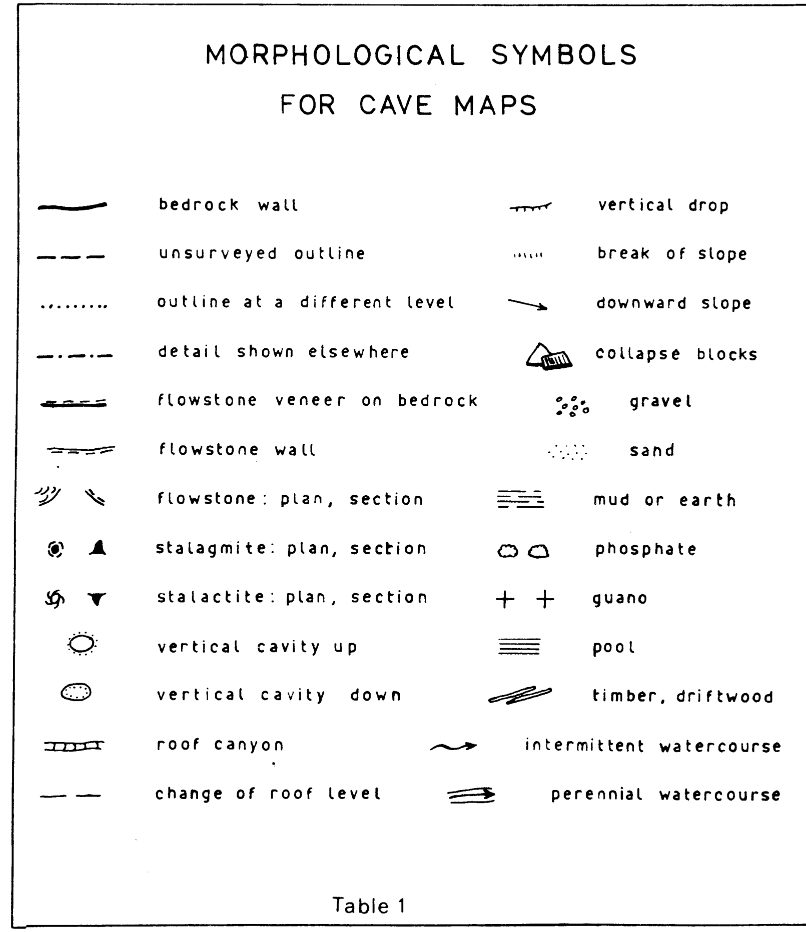

Table 1

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