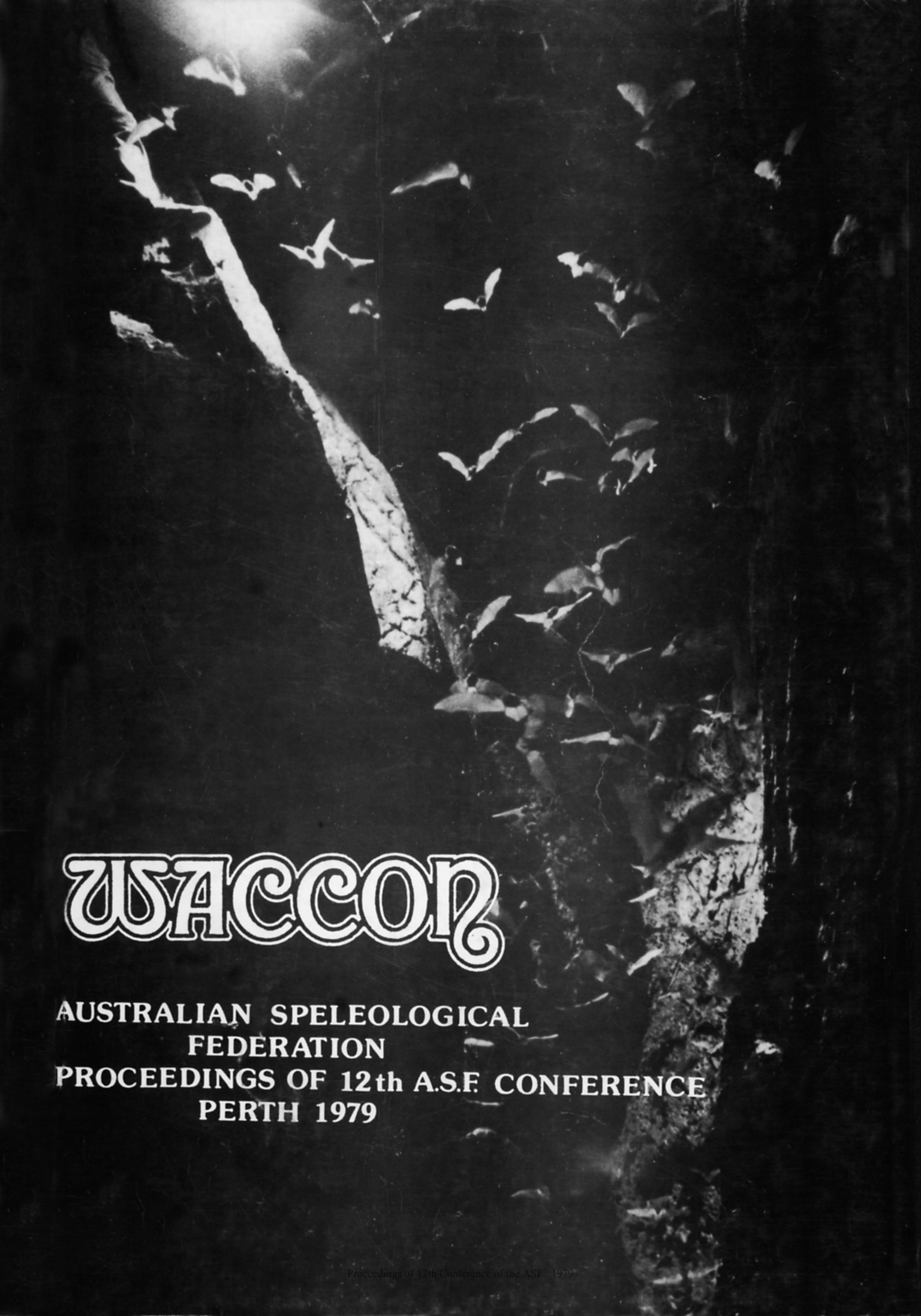

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Proceedings of the Twelfth Biennial Conference

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Foreword

These Proceedings are the result of many months of labour on the part of the editors. Due to the high cost of typesetting it was decided to type the papers ourselves. As some papers were not submitted until 18 months after the Conference this proved a lengthy and laborious job.

On top of these problems, the small budget with which we were forced to work barely enabled us to offset print and bind the completed Proceedings.

With these points in mind I wish to strongly suggest to the A.S.F. that all papers presented at future conferences be submitted to the journal "Helictite" for publication as a single issue Proceedings or as the editors see fit. I'm certain that authors, with the knowledge of where their paper is to be published, will submit manuscripts that are befitting of the aforementioned journal.

My sincere thanks to my co-editor Alex Saar for his efforts on these Proceedings and also to Ken Lance, Kevin Beckham, Ev Tulp, Joanne Webb and Peter Bell all of whom lent a hand at various times.

I hope that all those who read these Proceedings are encouraged by what they read and that speleologists in Australasia continue to work on the many facets of speleology, only some of which are included in these Proceedings.

Rauleigh Webb

CAVE CONSERVATION IN AUSTRALIA: FIGHTING FOR THE IMPOSSIBLE?

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Abstract

An examination will be made of problems facing cave conservation in particular and conservation generally in Australia. Attention will be focused on avenues open to conservationists for tackling issues and their effectiveness. Some discussion will centre on the lack of access to courts and exclusion from governmental decision-making processes which face many Australian conservation issues today. Examples will be cited where possible. A comparison with conservation in the United States of America will be made.

There appear to be some promising trends appearing on the Australian scene although the overall situation is still rather poor.

INTRODUCTION

The term cave conservation implies that the cave is under some sort of threat to its integrity or to the integrity of its associated ecosystem. Such threats range from wholesale destruction by mining activity through to unwitting abuse by excessive visitation to the fragile cave system by speleologists. The latter threat is a subtle one and one with which we are only just learning to come to grips. My discussion will centre on ways of tackling the more obvious sorts of threats, such as those posed by mining activity.

In particular, I will examine the legal avenues available which can be used to tackle conservation issues. The laws in Australia, and the liaison with governments that resulted in their formulation, are a far cry from those in the United States of America.

THE LAWS IN AUSTRALIA

Of necessity, I must discuss laws relating to conservation of the environment generally, simply because I am not aware of the existence of any law in Australia designed specifically for the protection of caves.

The first thing that one strikes when looking at environmental law is the great variation in legislation between different states. However, there are a few similarities in the laws. For example, all states have laws which are generally inadequate or useless! In this regard I mean that the laws are open to abuse by the administering government, for example, the process of protecting a site by declaring it a national park. Such decisions are made behind the veils of secrecy in the cabinet room and as such, the cabinet ministers can abuse their responsibility with little fear of public reprisal. I could cite examples here of states with such a cabinet, but I will leave it to your imagination.

In Queensland, there are four laws involved to a significant degree with

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protection of the environment. First, there is the *Fauna Conservation Act*. This statute provides "protection" to all native fauna on a temporary or permanent basis. It provides protection from the killing or taking of an animal, but says nothing about the protection of the habitat of that species. In relation to caves, protection of habitat is protection of the particular cave. An obvious example is the protection of bat maternity caves.

Next is the *Native Plants Act* which has not been amended since the 1930s. This Act provides for the protection of a select list of native plants, which includes things like orchids, from destruction on Crown Land only. A person can do what he likes provided the particular plant is on private land.

Third, there is the *Forestry Act* which provides for national park-type protection, except that forestry activity of any kind, including clear-felling, is allowed.

The fourth of these laws looks a little more promising. This Act deals with environmental safeguards for public and private developments, and includes provision for preparation of environmental impact statements (E.I.S.). It works like this. The Co-ordinator General's Department is notified of private projects requiring State approval or public projects which are in planning. The Co-ordinator General selects an advisory council made up from representatives of various government departments likely to be affected by the project. The council first decides whether or not the project is likely to have major environmental consequences and if it does, an E.I.S. must be prepared by the proponent. After the E.I.S. is completed, public comments are sought and the advisory council then examines these and recommends any necessary restrictions which it thinks should be placed on the project. It is then up to the head of the department with which the project is most closely associated to make a final decision, taking into account all factors of relevance including environmental factors. The important part of the legislation is contained in an amendment made in October 1978. The amendment places a legal responsibility on the particular departmental head making the decision, to ensure that environmental factors are taken into account. The departmental head can be held legally liable if he does not do so. While I can see major problems in the policing of this provision, I think the amendment is a major step in the right direction.

Many of the provisions of the E.I.S. legislation are repeated in the *Local Government Act*, that is, local authorities are required to pay due attention to environmental factors when assessing the merits of a project.

With regard to local governments and protection of the environment, local authorities have land-zoning powers which enable them to afford some protection to environmentally significant areas. However, there are problems. For example, land which is zoned for public recreation does not pay rates. I personally know of one council which could not care about protection of the environment for this reason alone. Another problem with local authorities is their lack of power such that the state government can override many of their decisions. Pardon me for not using a cave example but in the case of Moreton Island near Brisbane, the Queensland Local Government Minister, Rus Hinze, modified Brisbane's town plan to suit the State Government's own wish that sand-mining should go ahead on the island.

There are two Federal laws of relevance to this discussion. The first is the *Environment Protection (Impact of Proposals) Act* passed by the last Labor Government. This Act is similar to, but less effective than, the

Queensland E.I.S. law which I referred to earlier. A project requiring Federal approval is assessed for a possible effect on the environment. If the Minister thinks there will be a significant effect, he informs the proponent that an E.I.S. must be prepared. Once the E.I.S. has been prepared, comments from the public are sought. The E.I.S. is amended in line with these comments and the final statement is placed before the Minister, who makes the decision. It is clear that this legislation, while having the capacity to be a powerful law, is open to abuse by the excessive provision for discretion on the Minister's part. A recent example of abuse of this discretion, again non-cave, was the Iwasaki project. In this case the E.I.S. was prepared and some serious deficiencies were brought to light via public comment on the Statement. However, the Federal Government apparently ignored even the right of the public to comment by making a Cabinet decision to give the all clear to the project, before the deadline for public comment closed.

The other piece of Federal legislation is the *Australian Heritage Commission Act* 1975. The Act called for the establishment of an Australian Heritage Commission whose task was to prepare a register of the National Estate, that is, a list of places of environmental and historical significance in Australia. Places on the register are afforded protection, under this Act, from Federal Government action likely to damage these places. However, the Act does provide for development to occur on places on the register when the Minister is satisfied that 'there is no feasible or prudent alternative'. The Act states that under these circumstances 'measures that can reasonably be taken to minimize the adverse effect will be taken'. While the powers to protect places on the register are limited, again by the excessive provision for ministerial discretion in the Act, the independent recognition of the significance of a place, by its inclusion on the register, is of considerable political value. Another value of the legislation is the direct contact it provides between the Government and the public, via the process of nomination of a place for inclusion on the register. A necessary function of the Commission is obviously the assessment of nominations, so that selection of places to be included on the register can be made. This has required a considerable amount of expert opinion. The Australian Speleological Federation was asked to supply such expert opinion by the Australian Heritage Commission and funds were supplied for this purpose. This has been a major breakthrough in having caves, and the environment generally, recognized by our administrators and is the first step in the effective management of caves in Australia. Such liaison between governments and private groups or individuals is a new thing in Australia, with regard to environmental matters, and there are still many administrators to be convinced of the value of such liaison. To illustrate, I spoke to a Queensland Liberal parliamentarian recently about the need for independent opinion on environmental matters. He clearly had not given the subject much thought and came out with the instant reply: 'but you don't have any say.'

After the Australian Heritage Commission legislation was introduced, some states followed suit by introducing similar laws. One of the most effective laws introduced was that in New South Wales. This law is regarded as potentially more effective than its Federal counterpart simply because many more projects come under State jurisdiction than under Federal jurisdiction.

USING THE LAW IN ENVIRONMENTAL MATTERS

Here comes the crunch! At the moment, all of the laws involved with protecting the environment can be policed only by governments. Clearly, if for its own convenience a government wishes to see a project go ahead, then despite a significant environmental effect, the project can not be stopped in the courts because the government obviously will not take the necessary legal action. There is provision for individuals to take action under two circumstances. The first is when an individual can show that he will be affected by a project, to a greater extent than a member of the general public. The circumstances under which this can be proved are almost non-existent in environmental cases and where recourse is possible, court costs are generally prohibitive. I do not know any case where action was successfully taken under these circumstances. The other situation is when an ordinary citizen wishes to pursue an environmental case, or any other public interest case. Under these circumstances, the person must first obtain the Attorney-General's "fiat", as it is called, and legal precedent has been set to establish this requirement. "Fiat" is a legal term meaning that the action proceeds in the Attorney-General's name, that is, in the government's name, although court costs etc. are the responsibility of the person proceeding with the action. The Attorney-General's fiat is required because the person proceeding with the action does not have the legal standing, or *locus standi*, to take the case to the courts. This system was designed around the English system. However, in England, the Attorney-General is an independent public servant whereas in Australia, the State and Federal Attorney-Generals are party-political Cabinet Ministers. The Attorney-General is useless in this situation because when a government decides not to take legal action on a particular environmental matter, it certainly is not going to allow a member of the public, via its Attorney-General, to take such legal action. This is what happened in the case of the Mt Etna caves near Yeppoon in Queensland (Pure, 1978). Grounds were established for a legal challenge questioning the granting of mining leases over Mt Etna. Of necessity, the State Attorney-General's fiat was sought so that the challenge could proceed. The Attorney-General refused to grant his fiat and would not detail the reasons for his refusal. We will be left to ponder whether the Queensland Government's entrenched opinion that mining will be allowed to continue on Mt Etna had any influence on the Attorney-General's decision.

Fortunately, the problem of members of the public being unable to take such public interest court action is receiving attention. Recently, the Australian Law Reform Commission has examined this problem (Australian Law Reform Commission, 1978) and has recommended a change in the present regulations to allow greater public access to the courts in such cases.

There is one instance I know of which may indicate a trend towards greater access to the courts in public interest matters. There is provision in the Federal *Trade Practices Act* for any member of the public to take legal action on the matters, essentially of public interest, which the law covers. Furthermore, this provision of the Act has recently been successfully tested in a public interest suit (R. Phelps, pers. comm.). However, it seems that a trend in greater court access will be slow in coming, first, because governments will be loathe to give up their powers in this regard and second, because the courts in this country are already working to capacity and any increase in traffic which would result from a change in the present provisions could not be coped with.

THE SITUATION IN THE U.S.A.

Not only is there an impressive array of conservation laws in general and cave conservation laws in particular in the U.S.A., but the U.S. public have virtually full access to the courts in public interest suits. For a detailed comparison of Australian and U.S. conservation generally, with particular reference to use of the law, see Miller, 1978.

To look at the effectiveness of the laws, take for example the *Endangered Species Act* 1973 which seeks to:

> provide a means whereby the ecosystem upon which endangered species and threatened species depend may be conserved, to provide a program for the conservation of such endangered species and threatened species, and to take such steps as may be appropriate to achieve the purposes of the treaties and conventions . . . .

Then compare this with the Queensland Fauna Conservation Act's flimsy provisions that I described earlier. Furthermore, many Federal departments affected by the U.S. Act have initiated their own programs to ensure its effective implementation (Mohr, 1976). This law has been effective in the protection of animals and their environments. For example, this legislation was used to stop local authorities from removing water from the surrounds of Devil's Hole cave because this would have resulted in the destruction of the extremely rare pupfish in this cave (Anon., 1976).

In relation to specific cave conservation laws in the U.S., the first law was gazetted in 1883. By 1974 there were twelve separate statutes, covering eleven states and five statutes in the process of being gazetted. The more recent laws are fairly comprehensive and cover cave vandalism, littering, and protection of cave fauna. I have appended the text of one of these laws, which was introduced in Maryland in 1978. While these laws are fairly powerful, considerable difficulty has been encountered in trying to police them. Perhaps less than five convictions have been recorded in the whole of the U.S., although no accurate records have been kept on this. The laws obviously must have some deterent effect though (Stitt, 1976).

Many government departments have provisions for protection of caves and their ecosystems. For example, Godfrey (1977) reports that the Bureau of Land Management goes to considerable lengths to preserve caves under its jurisdiction. Also, Manges (1976) indicates that the National Parks Service has several specific rules dealing with caves in national parks. Another example is the Scout Mountain Nature Preserve in Indiana which is run by the Division of Forestry. This Preserve was gazetted to protect a bat wintering site (Keith, 1976).

Generally speaking, liaison between the U.S. Government and cavers seems to be excellent. A further example here is the signing of an agreement for preservation of the Marble Mountains wilderness area caves by the Klamath Mountains Conservation Task Force and the Forest Service (Sims, 1977). On the state level, activity by cavers prompted the establishment of a committee in Virginia to look at ways to protect the State's caves (Strong, 1978). A major breakthrough has been the recognition of the concept of "underground wilderness", thus allowing caves to be covered by the *Wilderness Act* (Stitt, 1975).

To conclude this section, I will quote from a letter I received from Tom

Strong who is Conservation Committee chairman of the National Speleological Society:

> Attempts by cavers to influence Government policies have generally been most successful on the local level with personal contact. For example, cavers active in a particular national forest or a unit of the National Park Service have frequently been able to work with the unit supervisors or resource management personnel to influence cave management. This is especially true in the western United States because of the extensive Federal ownership of land.
>
> The National Speleological Society is also on the mailing list for Environmental Impact Statements prepared by various agencies, particularly the Forest Service, Park Service and Bureau of Land Management. The main function of the Environmental Impact Sub-committee of the Conservation Committee is to respond to or provide input on these Statements where caves might be affected.

CONCLUSIONS

The advanced state of cave conservation law in the U.S. has grown out of liaison between cavers and governments at the various levels. Small activities such as lobbying politicians on particular cave conservation projects has created interest about caves generally amongst the politicians, and the government agencies that serve them, to the point now where cavers not only comment or collaborate with government agencies on particular projects but supply expert opinion on cave management matters (Curl, 1976).

Promising trends are appearing on the Australian scene in this regard and I mentioned the example of the A.S.F. Australian Heritage Commission study earlier. These trends have been slow in appearing probably because of the relatively short time which the Australian caving fraternity has been in existence.

To look at a few achievements, a caver was appointed to the Queensland National Parks and Wildlife Service to prepare a management plan for the Chillagoe caves, and recently, another Queensland caver was appointed to the Service so that he could continue his research on the Ghost Bat. In other states, liaison with national parks services and other government authorities is occuring. An example here is the Nullarbor caves management strategy prepared by the A.S.F. for the Western Australian Government. The long term result hopefully will be sufficient awareness of caves by our administrators that specific legislation can be introduced to protect caves, as has happened in the U.S.

ACKNOWLEDGMENTS

I am indebted to P.L. Ellis of the Co-ordinator General's Department (Queensland) and Mike O'Brien of the Australian Heritage Commission for informative discussions on some of the material presented in this paper. Also, thanks are due to Tom Strong of the National Speleological Society for information on U.S. cave conservation.

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APPENDIX

MARYLAND CAVE LAW

Subtitle 14. Caves

5-1401

(A) In this subtitle, the following terms have the meanings indicated.

(B) "Cave" means any naturally occurring void, cavity, recess, or system of interconnecting passages beneath the surface of the earth or within a cliff or ledge, including natural subsurface water and drainage systems. The word "cave" includes or is synonymous with cavern, pit, pothole, sinkhole, grotto, and rock shelter.

(C) "Commercial cave" means any cave with improved trails and lighting utilized by the owner for the purpose of exhibition to the general public as a profit or nonprofit enterprise, wherein a fee is collected for entry.

(D) "Gate" means any structure or device located to limit or prohibit access or entry to any cave.

(E) "Person or persons" means any individual, partnership, firm, association, trust, or corporation.

(F) "Speleothem" means a natural secondary mineral formation or deposit occurring in a cave. This includes or is synonymous with stalagmites, stalactites, helectites, anthodites, gypsum flowers, needles, angel's hair, soda straws, draperies, bacon, cave pearls, popcorn (coral), rimstone dams, columns, palettes, flowstone, et cetera. Speleothems are commonly composed of calcite, epsomite, gypsum, aragonite, celestite and other similar minerals.

(G) "Owner" means a person who owns title to land where a cave is located, including a person who owns title to a leasehold estate is [sic] such land.

(H) "Speleogen" means a solutional feature of the bedrock, and includes or is synonymous with anastomoses, scallops, rills, flutes, spongework, and pendants.

(I) "Sinkhole" means a natural depression in a land surface communicating with a subterranean passage or drainage system.

(J) "Cave life" means any life form which normally occurs in, uses, visits, or inhabits any cave or subterranean water system.

5-1402.

(A) A person may not, without express, prior, written permission of the owner, wilfully or knowingly:

(1) break, break-off, crack, carve upon, write, burn, or otherwise mark upon, remove, or in any manner destroy, disturb, deface, mar, or harm the surfaces of any cave or any natural material therein, including speleothems and speleogens;

(2) disturb or alter in any manner the natural condition of any cave;

(3) break, force, tamper with, or otherwise disturb a lock, gate, door, or other obstruction designed to control or prevent access to any cave, even though entrance thereto may not be gained; and

(4) dispose of, dump, store, or otherwise introduce into any cave, sinkhole, or subterranean drainage system any litter, refuse, dead animals, sewage, trash, garbage, or any chemical or biological contaminant which is potentially dangerous to man or any form of cave life.

(B) Any person violating any provision of this section is guilty of a misdemeanor, and upon conviction thereof, shall be fined not less than $150 nor more than $500, and in addition thereto, may be imprisoned for not less than ten days nor more than six months.

5-1403.

A person may not sell or offer for sale any speleothems in this State, or to export them for sale outside the State. A person who violates any of the provisions of this section is guilty of a misdemeanor, and, upon conviction, shall be fined not less than $150 nor more than $500 and in addition may be imprisoned for not less than ten days nor more than six months.

5-1404.

(A) A person may not remove, disfigure, kill, harm, disturb, keep, restrain, or in any manner alter the natural condition or environment of any plant or animal life which normally lives or occurs within any cave or subterranean water system.

(B) Notwithstanding the provisions of subsection (A) of this section, scientific collecting permits may be obtained from the Secretary. Gates

employed at the entrance or at any point within any cave shall be of open construction to allow free and unimpeded passage of air, insects, bats and aquatic fauna. A person who violates any provision of this section is guilty of a misdemeanor, and, upon conviction thereof, shall be fined not less than $200 nor more than $500 and in addition thereto, may be imprisoned for not less than 15 days nor more than six months.

5-1405.

(A) A person may not excavate, remove, destroy, injure, deface, or in any manner disturb any burial grounds, historic or prehistoric ruins, archeological or paleontological site, including relics, inscriptions, saltpeter workings, fossils, bones, or any other such features which may be found in any cave.

(B) Notwithstanding the provisions of subsection (A) of this section, a permit to excavate or remove archeological, paleontological, prehistoric, and historic features may be obtained from the Secretary. The permit shall be issued for a period of two years and may be renewed at expiration. It is not transferable but this does not preclude persons from working under the direct supervision of the person holding the permit.

(C) A person applying for a permit shall:

(1) provide a detailed statement to the Secretary giving the reasons and objectives for excavation or removal and the benefits expected to be obtained from the contemplated work.

(2) provide data and results of any completed excavation, study, or collection at the first of each calendar year.

(3) obtain the prior written permission of the Secretary if the site of the proposed excavation is on State owned lands and prior written permission of the owner if the site of the proposed excavation is on privately owned land.

(4) carry the permit while exercising the privileges granted.

(D) A person who violates any provision of subsection (A) of this section is guilty of a misdemeanor, and upon conviction shall be fined not less than $100 nor more than $500, and may be imprisoned for not less than ten days nor more than six months. A person who violates any of the provisions of subsection (B) of this section is guilty of a misdemeanor, and, upon conviction, shall be fined not less than $100 nor more than $500, and the permit shall be revoked.

5-1406.

(A) Neither the owner of a cave nor his authorized agents acting within the scope of their authority are liable for injuries sustained by any person using the cave for recreational or scientific purpose if the prior consent of the owner has been obtained and if no charge has been made for the use of the cave.

(B) An owner of a commercial cave is not liable for an injury sustained by a spectator who has paid to view the cave unless the injury is sustained as a result of the owner's negligence in connection with the providing and maintaining of trails, stairs, electrical wires, or other modifications, and the negligence is the proximate cause of the injury.

SECTION 2. And be it further enacted, that this Act shall take effect July 1, 1978.

RESTORATION, STABILISATION AND GATING OF THE CHRISTMAS STAR EXTENSION OF CRYSTAL CAVE (WI-62), WITCHCLIFFE W.A.

NORMAN POULTER*
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Abstract

Crystal Cave (WI-62) is located in the Witchcliffe region of the Leeuwin-Naturaliste ridge some 290 km south of Perth, W.A.

The Christmas Star Extension was first entered in 1968 and by 1972 considerable sand-staining damage had occurred to the flowstone floor throughout the Extension despite the use of plastic pathway. Most damage was around the clothes-changing area where a sand bank had been spread across the floor and into a dry crystal pool.

During 1973, S.R.G.W.A. undertook a major restoration program in the Extension consisting of scrubbing the floor, laying new pathways and the construction of several walls.

Time out was taken through the program to stabilise the entrance area where a strategic rock, if dislodged. threatened to initiate a major rockslide.

At a later date a gate was installed over the entrance to the Extension.

This paper will describe the restoration methods, design and construction of various walls as well as the design and construction of the gate.

INTRODUCTION

Crystal Cave is a small cave of 610 m passage length (see Fig. 1 for map), formed in coastal limestone, located in the Witchcliffe region of the Leeuwin-Naturaliste ridge some 290 km south of Perth. The cave is in the form of several chambers connected by passages of varying dimensions, a small stream is present. The average ceiling height of the chambers is 20 m while the average chamber roof thickness is 7 m. The Christmas Star Extension leads off from the Helium Chamber and is low roofed for the first third of its area, persons being unable to stand up along the pathway. The remaining tracked area presents little difficulty except that the pathway, by necessity, passes within close range of delicate decoration.

A report by the Chief Inspector of Lands, published in the 1900 Parliamentary Papers attributed extensive damage in the entrance chamber and stream passage to "marauders" and timber felling before the turn of the century (Shoosmith, 1975). Chief Inspector C. Erskine May recommended that Crystal be closed so that ".. it may, in the course of 20-30 years, restore itself from the hacking about it has received with a timber 'jack' which I found in the cave."

GENERAL

The Christmas Star Extension was first entered during Christmas 1968. Access was apparently gained by breaking some decoration thus creating the First Squeeze

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which led into a small decorated chamber. At the other end of this chamber, the Second Squeeze led into the main section of the Extension. Once through the Second Squeeze, visitors came out onto a sandbank, the source of future decoration damage. The passage that led off from this sandbank over a white flowstone floor is heavily decorated with straw stalactites, helictites, crystals and an outstanding crystal pool. A gate was installed near the Entrance Chamber shortly after.

Despite the laying of a plastic pathway throughout the Extension and a policy of removing boots and overalls at the Second Squeeze sandbank, by August 1972, the pathway was broken in several places and footprints had soiled the flowstone in numerous places. Most damage that occurred during this four year period was at the clothes-changing area beyond the Second Squeeze where the sandbank, under pressure of use, moved across the flowstone and into a dry crystal pool. The damage to this Extension can only be attributed to cavers' indifference and lack of foresight.

Following the formation of S.R.G.W.A. in December 1972, a restoration program based, but later expanding upon, Poulter's recommendations of August 1972 (Poulter, 1972) was started in March 1973 continuing through until October of the same year. Minor additions were added during 1974.

Part of the restoration program entailed removing the original pathway, scrubbing the floor with water and laying new pathways using slightly stiffer plastic. The outcome of this exercise was not as successful as expected. The deeply ingrained footprint stains could only be made less obvious by "blending in" so to speak. In places the new pathway was widened to cover possible sources of soil contamination. A disadvantage with plastic sheeting as pathway is that it is quite slippery and with use across slopes, crimples (reducing its width) or breaks up altogether. It is hoped to replace "problem areas" of pathway with heavier gauge non-slip clear plastic "carpet protector" type pathway in the near future.

The "Crystal Walls" as they became known presented a different problem. Soon after work began it became obvious that one low wall, as originally suggested, would not be enough. Another, larger retaining wall to completely isolate the sandbank from the chamber was necessary. This presented a logistical problem as all building materials used had to be transported through the two squeezes.

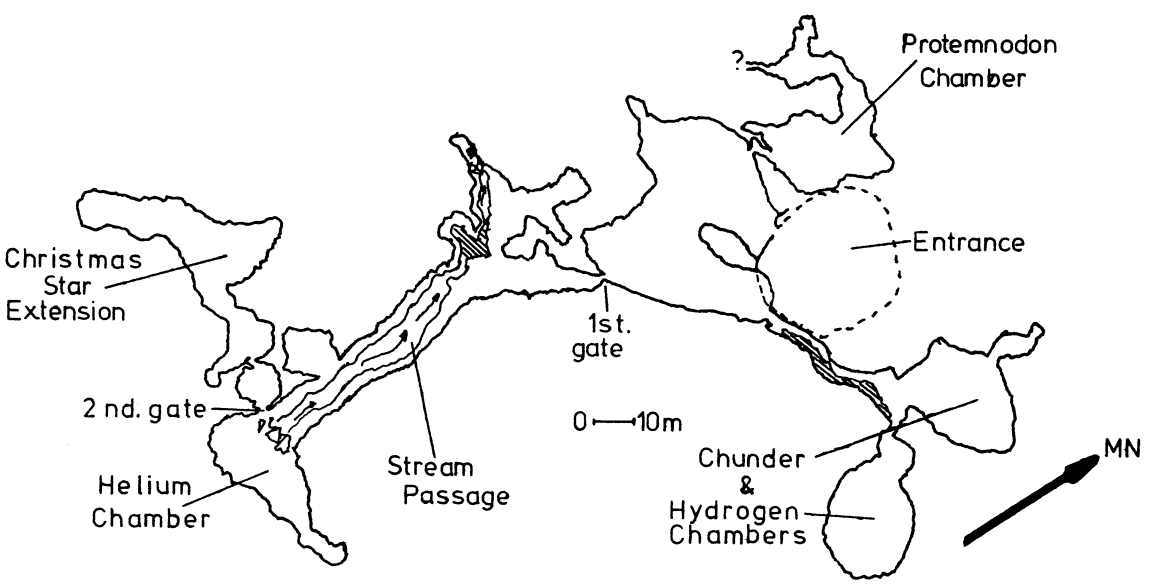


Fig. 1 Reduced outline of the Loveday (WASG) map of Crystal Cave Wi 62

During the course of the program, to make maximum use of available time and increase overall efficiency, a camp was established in the Entrance Chamber of the cave, close to the First Gate. People confined their camp activities on large groundsheets with no observable effect to the cave environment.

A typical work weekend on the "Walls" was preceeded by removing suitable rocks from the adjacent Helium Chamber and moving them in batch lots through the squeezes to the work site. Watercarriers then started a relay to bring water in 4.5 L containers from the streamway to the cement mixing site. The mixing of cement took place on a steel sheet in the area between the two squeezes (Fig. 2). Mixture used was three measures of sand (taken from an adjacent sandbank) to two of lime to one of cement. The lime and cement powders were premixed in Perth and transported into the cave in small double polyester bags. The mixed cement, usually of a soupy consistency was moved to the work site in 2.25 L buckets; the only size capable of fitting through the Second Squeeze upright.

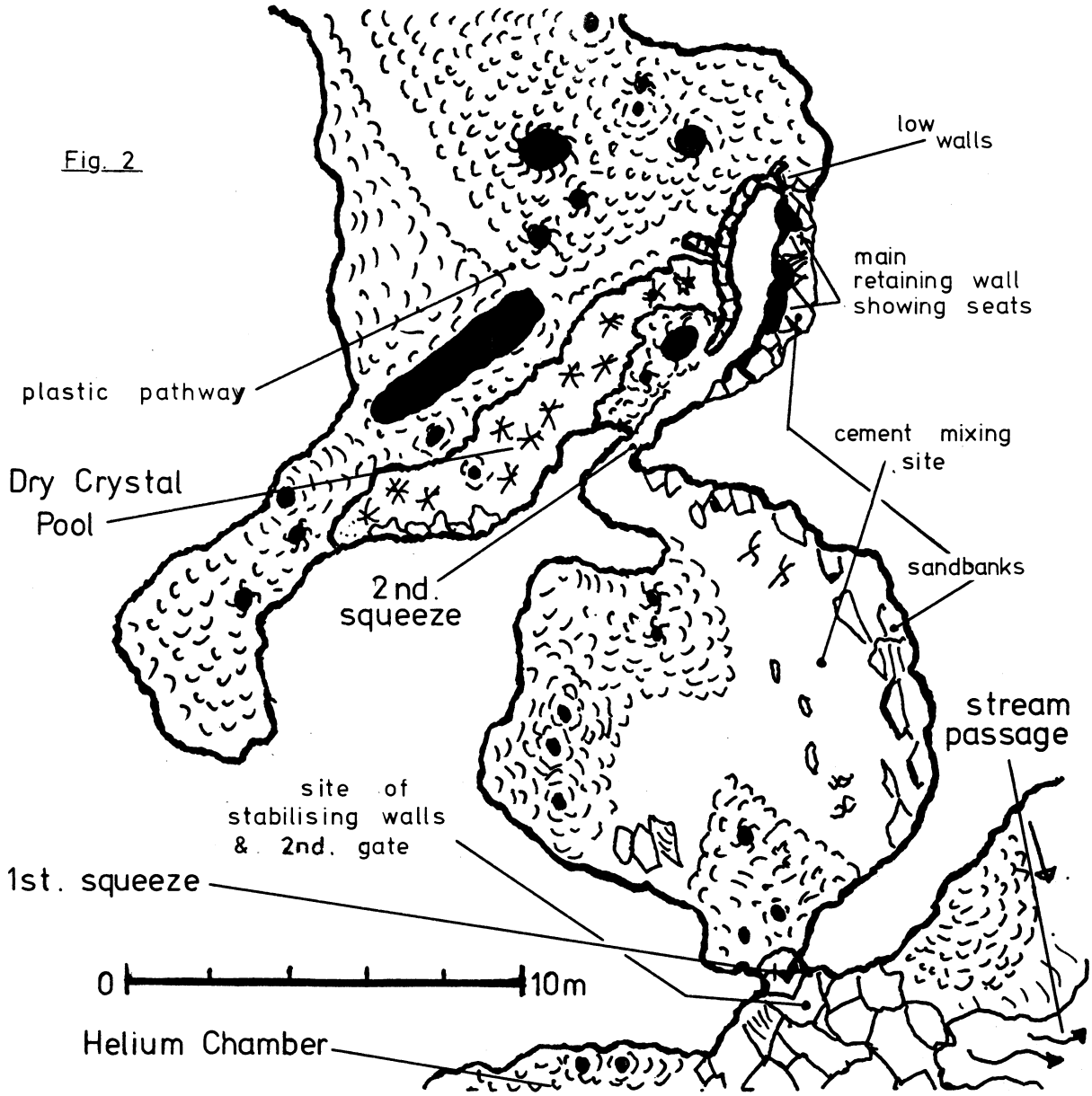
An unfortunate aspect of the wall construction was that initially, traditional grey cement was used which, due to its colour was not very compatible to the decidedly yellow colour of the native rock. Shortly afterwards, the colour advantage of the more expensive white cement was observed and all subsequent construction used this cement; in some situations it is difficult to see the joints.

Altogether, 200 hours were spent constructing some 10 m of walls. The low wall is approximately 4.2 m long and 0.2 m high whilst the larger retaining wall, incorporating seats to accommodate five to six persons is approximately 3.6 m long and 0.6 m high (Plate 1) with loose rocks sloping back to the chamber's wall to completely isolate the sand, allowing clothes and equipment to be placed on top without fear of becoming contaminated with sand again. In its roughest sections part of the intervening floor was covered with cement to facilitate cleaning. A bend was placed in the low wall after the discovery, during site cleaning, of a steady drip of water from the ceiling near the Second Squeeze. The runoff from this seepage flows over badly stained flowstone and into the dry crystal pool. It is hoped that in time nature will heal at least some of the damage.

The entrance to the Christmas Star Extension, immediately above the First Squeeze has always been in a dangerous condition, due in part to the frailty of the ceiling rock and the unstable nature of the rockpile forming the actual entrance; some of the rocks on the downslope side being flowstone cemented together. At least one ceiling collapse has been recorded in recent years (Willock, 1976). The main danger of the entrance lay in one strategic rock, in a natural hand-hold position that, during restoration work, was noted to be in danger of falling if dislodged from its precarious position. If it had been dislodged then a chain reaction rockslide would have resulted.

Work on the restoration project was halted while stablisation of the entrance area took place (Fig. 3). Cement mixing, using the same techniques described above, took place in the Stream Passage, with the 2.25 L buckets again being the best way to transport the mixed cement. The main retaining wall is approximately 1.5 m long and ranges, with backfilling, from 0.6-1.5 m high and utilises a 5 inch R.S.J. beam. On the other side of the entrance, a pier has been built on another 5 inch R.S.J. to support a cluster of rocks above it. One hundred hours were spent stabilising this section.

Fig. 2



Section of Christmas Star Extension

Reproduced from the Loveday's (WASG) map of Crystal Cave Wi 62

Plate 1. Christmas Star Extension seat and retaining walls.

POULTER - RESTORATION OF THE CHRISTMAS STAR EXTENSION

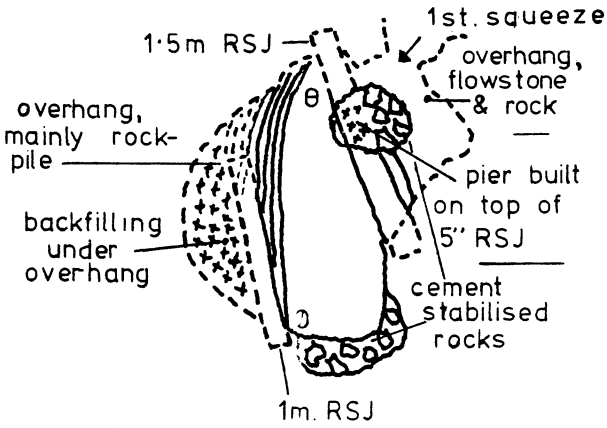


Fig. 3

Stabilising Wall detail

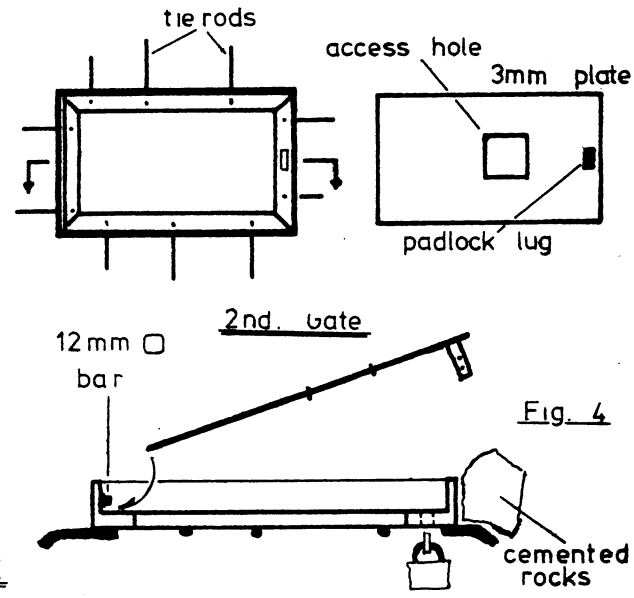


Fig. 4

NOT TO SCALE

During 1974 an access dispute arose over Crystal Cave. The Christmas Star Extension is generally regarded as being for cavers only while the main cave has been used to show speleological features to scout and youth groups. These "tourist trips" of youth groups etc. increased during 1973/74 although they have since subsided. In order to remove the temptation to take such groups into the Extension, a second Gate, covering the Extension only was proposed and accepted.

The gate, (Fig. 4) consists of an angle iron frame with welded tie rods of various lengths to fit the aperture of the stabilising wall section of the Extension entrance. A rectangular slot was cut in one of the short side bases to allow a padlock lug to pass through. A 12 mm square rod was welded to the opposite end, slightly above the base to allow the lid to slip into the slot created. The actual gate-lid is a sheet of 3 mm plate with a padlock lug welded on one side and a square hole cut in the middle of the plate to allow two arms to pass through to get at the lock. The lid is then lifted clear of the entrance.

The gate, installed during September 1975, could be considered to be almost tamperproof as the lid itself is recessed well below the level of the angle iron and the padlock is underneath the gate and therefore is not exposed to open attack by "intruders". Close proximity of rock around the padlock and the closeness and fragility of the ceiling above the gate combine to make unauthorised entry to the Extension a difficult and hazardous proposition.

The cost of materials for the gate and stabilising wall were jointly funded by the Western Australian Speleological Group and the Speleological Research Group Western Australia while all work on the restoration, gating and stabilising of the Christmas Star Extension was carried out by members of S.R.G.W.A. and staff and PhD students of the Physics Department of the University of W.A.

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A PRELIMINARY NOTE ON THE BLACK SPELEOTHEMS AT JERSEY CAVE, YARRANGOBILLY, N.S.W.

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Abstract

Black to grey flowstones and other speleothems occur commonly in Jersey Cave and, to a lesser extent, in other tourist caves at Yarrangobilly. Preliminary investigations indicate a carbonaceous nature for the material that produces the dark coloration. The deposits occur both as a surface layer and deep within the calcite masses. An account is given of the investigations into the nature of these deposits and hypotheses are advanced for the mode of formation.

The black speleothems of Jersey Cave, Yarrangobilly, N.S.W. have been of interest to visitors since the original description of the cave in 1891. The deposits are regarded as part of the attraction of the cave:

> The beauty of the caves is undoubtedly enhanced by the great variety of colours possessed by the various formations. This is particularly the case with the black surfaces, which set off to perfection the many beautifully white isolated forms, . . . which relieves to a wonderful extent the monotony there would otherwise be if the entire chambers were coated with pure white calcareous growths (Anderson & Leigh, 1891).

The origin of black deposits has been attributed by local hearsay, apparently based on little evidence or indeed examination of evidence within the cave, to manganese, carbon or the 'exuviae of bats'. The deposits occur as a layer on upper surfaces, becoming thicker as the surface becomes more horizontal. Small patches of black material may be found on stalactites but only where upwards-facing surfaces occur or where material has been washed from above. Restriction of the deposit to upper surfaces of flowstone and stalagmite is consistent with the hypothesis that the material has an aerial origin. Broken formation or breakdown often has a black upper surface with a normal coloured underside. The surface on which such pieces lie also have normal coloration suggesting that protection from airborne particles occurs under these circumstances.

Deveson (1969) observed that the material occurs only in the upper 3 mm of flowstone cross sections. Our observations indicate a surface layer and up to three layers of similar thickness deeper in the flowstone (to a maximum depth of approximately 30 cm). Examination of the surface layer under a microscope reveals a thin black line (≃ 0.1 mm) overlying an apparent grey staining in and between the calcite crystals with decreasing greyness until the next layer of colourless or red-brown calcite occurs. The black material gives the impression of encouraging 2-4 mm thick layers within the (more usually) massive flowstone.

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Extraction of the black material by solution in hydrochloric acid was attempted by Deveson (1969) for the surface layer and by the present authors for both the surface and subsurface layers. In both sets of analyses the resultant solution contained negligible quantities of iron, manganese or other cations considered likely to produce dark discoloration. The acid-insoluble residue was a dark grey flaky material with fine grains of sand-like material; the entire residue was insoluble in boiling aqua regia. Deveson (1969) heated the residue in an ignition tube until a white ash identified as silica remained. Carbon was qualitatively identified from another sample of the residue.

Our samples of acid-insoluble material were boiled in hydrofluoric acid and then digested in hydrochloric acid. The resultant solution was then subjected to atomic absorption spectrophotometry for a number of cations. No manganese was found but relatively high percentages of iron (expected), potassium and sodium (unexpected) were determined. A possible source for these latter two ions is the basalts which overlie the limestone.

Organic carbon was determined at 7.7% by a modified Walkley and Black method in a surface sample. We suggest that the hypothesis that the black speleothems of Jersey Cave are produced by carbon originating in bushfire smoke settling out in the cave environment, seems reasonable in view of the above evidence. The presence of silica in bushfire smoke is to be expected. Evans, King, MacArthur, Packham & Stephens (1976) report levels of "mineral ash" at up to 60% of the particulate content of smoke; the mode of deposition and its episodic nature all tend to favour such an explanation.

The whole investigation has provoked rather more questions than it has answered and further investigations are being pursued.

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NOTE ADDED AFTER CONFERENCE

Similar deposits were observed in Drovers Cave, near Jurien Bay, on a post-WACCON field trip and A. Goede (pers. comm.) reports occurrences in Exit Cave, Tasmania. Examination of some small caves on the Upper Murray (Indi) River, N.S.W., has revealed surface deposits exactly analagous to those at Yarrangobilly. In Drovers Cave the layering of both dark and "white" calcite is much thinner than at Yarrangobilly in all stalagmite cross-sections examined, perhaps reflecting the stronger seasonal rainfall in Western Australia.

THE FUTURE OF AUSTRALIA'S CAVES

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Abstract

The conservation status of Australia's karst resources is reviewed in the context of three main themes: planning, management, and use.

One of the most difficult problems in karst conservation is to reconcile use of caves with their conservation. We must face up to the challenge that some of the most significant of the damage being done to our scarce cave resources is caused in various ways by cavers and speleologists.

Discussion of planning problems centres around the land use conflicts affecting caves and karst features, and the adequacy of decision-making processes.

Karst is a specialised natural resource which offers many unusual and exciting opportunities for nature conservation and scientific research, and for recreation and tourism. Some of our karst is of considerable international significance, but karst generally is a relatively scarce and vulnerable resource in Australia (Jennings, 1975).

The continuance of the special opportunities which karst provides is at risk from physical destruction of cave and karst environments by incompatible uses, and by degradation from uncontrolled or unplanned use. Those who value caves and karst for their special natural values and recreation opportunities have a responsibility to work towards better procedures for resource management of them.

It must be recognised that there is ultimately a conflict between conservation of an essentially non-renewable resource, and recreation or other uses based on it. Virtually any use of caves will modify them to some degree. In the long run, gradual deterioration and inadvertent modification of caves is probably a far more serious challenge than the obvious threats of vandalism and suchlike. This kind of conflict is as much a problem in remote caves visited only infrequently by relatively responsible speleologists as it is in our tourist caves and other heavily visited caves (see for example, Stitt, 1977).

There needs to be more than a recognition that this is happening and that it is a real problem. All of us must face the challenge of reconciling this situation with the long-term responsibility for resource management. In an earlier paper (Davey, 1976), I explored some of the ethical and ecological problems of recreation in the cave environment, in the context of underground wilderness as well as in other situations; I also provided a tentative analysis of the sources of damage to caves - inadvertent, avoidable, and deliberate - by cavers and speleologists. The point I wish to reiterate here is simply that the credibility of speleologists will be suspect in any karst conservation controversy if they cannot demonstrate a commitment to resolution of the conservation contradictions arising from their own activities.

We should be quite wary of the justification for further exploration of caves. Until we can demonstrate a capacity to properly manage those caves we have already exposed to the depredations of investigating humans, we should

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curb our own curiosity. And surely we have as much responsibility for leaving opportunities for discovery and exploration to future generations as we have a responsibility for conserving the resource itself?

The ecological nature of the karst concept is of crucial importance. There needs to be a greater concentration on the system context of caves than on the individual cave site. This has important implications for the kind of information we should be seeking to manage karst better, but it should be remembered that even research may have unanticipated or undesirable effects on karst systems.

Our objectives for karst resource management should take account of the relative capacities of different parts of our total resource stocks to provide opportunities for:

- nature conservation
- scientific research
- aesthetic appreciation
- recreation and
- economic development.

We should not seek to preclude mining and quarrying and other destructive resource uses from karst under all circumstances, but rather to ensure that society adopts decision-making processes which give proper attention to all of the alternative values of such scarce irreplaceable natural assets (Davey, 1977). The biggest problem here is that in making the necessary trade-offs in such resource allocation decisions, we have only a very limited capacity to quantify the values of intangible aspects of these resources.

The challenge in providing for better management of karst is thus essentially three-fold:

- providing an understanding of the values and dynamics of karst resources
- protecting important resources from destruction by incompatible uses, and
- protecting the resource from gradual deterioration.

The future of our karst resources can only be safeguarded if there is a systematic approach to all these aspects of karst resource management. The mechanisims needed for planning and management in this context fall into four categories:

1. Public resource allocation procedures.
2. Land tenure and resource ownership arrangements (the two do not necessarily coincide) which best safeguard resource allocation decisions and give adequate management powers.
3. Management planning procedures which, through consultation with the public, seek to identify the resource values and management objectives, and the means of achieving them.
4. Recognition by users of the contradictions involved in recreational use of caves.

In a so-called democracy, there can be no more permanent protection of karst resources from incompatible use than an Act of Parliament. The legal phrase "permanent reservation" means only that the reservation will remain in effect until such time as it is revoked. This situation may seem contradictory, but there is no real alternative. If the future status of karst is to be safe-guarded, what matters is that decisions taken about karst resources (or, for that matter, any other resources) are fully public, and carefully considered. This applies to all aspects of the management of karst resources - be it at the regional land use planning level, or in mineral or water resource

development, management planning, or tourism and recreation development.

Ownership of resources is one of the key questions. The depth dimension of karst raises all sorts of difficulties which do not arise as significantly in other land use contexts. Depth of title is an important consideration - many pastoral leases and freehold allotments in Australia do not extend below the surface very far, or at all. Possibilities for better management of karst beneath such titles deserve careful exploration. It is difficult, however, to find realistic means for adequate protection and management of caves and karst unless such resources are fully under public control. There are cases where the most practical protection in the short-term is to rely on responsible private owners, but it is ultimately inescapable that the responsibility for protection of such public resources be vested in governments.

Another major complication with karst resources is that land ownership (or reservation) does not necessarily imply full control of mineral, energy or water resources. This would not be a problem if Australian legislation in this field provided for a reasonable level of public involvement in decision-making. If the future of Australia's limited karst resources is to be protected at all, this is a crucial area for conservation action.

In many nature conservation initiatives, there has been too little attention given to the protection of habitat as well as species, and this certainly applies to many of the important animals in cave environments. The species can only be conserved if there is adequate habitat protection. The strong functional link between individual caves and their surrounding karst context is another example of the need for protection to extend far beyond the feature of immediate concern. There are obvious political and practical difficulties in the case of karst areas with very large catchments (for example, the vast Nullarbor karst, or the small fragmented Buchan karsts within an enormous drainage basin) but the principle involved needs to be kept prominent in land use and resource management decision-making. One of the problems here is that we often know so little about the precise nature and extent of karst drainage systems. If anything, this increases the responsibility for conservative management.

We need both permanency and flexibility in our land utilisation decisions. We are certainly not in a position to make any precise prescription now of the conditions which will prevail in the future, so our resource management mechanisms should recognise the necessarily incremental nature of decision-making. Within such constraints, there is still a need for expectations about use and management of resources to be safeguarded until there is a public decision for change.

The implications of all this are that the future of Australia's caves and karst may best be safeguarded if we work energetically towards the following ideal, rather than concentrating exclusively on particular resource use conflicts:

> As much as possible of the functionally-related system of which any important karst area is part should be reserved by Act of Parliament; there should be explicit public procedures before such reservation, and before it can be amended or revoked; and there should be active management by a responsible agency with clearly specified powers and in accordance with a regularly updated management plan which is arrived at after explicit public procedures. Within the framework of management controls, users must be able to demonstrate that their activities are fully consistent with long-term retention of the characteristics for which the resources are being protected and managed.

Cave conservation is not just about opposing quarries or dams; unless there is a move to much better public procedures and systematic planning, there will always be the kinds of conflicts which plague us at present. The future of our caves will be much better provided for if we are able to make a rational assessment of the values and objectives of all of our karst resources than if we concentrate on responding to each crisis arising from someone else's initiative.

The real dilemma here is that people's energies are much more readily harnessed for tangible and obvious conflicts involving resources that they personally can relate to, than is the case for a long-running strategic campaign aimed at changing the way we make decisions about the use and management of our irreplaceable natural assets. This paper, and two earlier contributions on related themes (Davey, 1976 & 1977) are in response to this need; too often, in our attitudes to cave conservation, we cannot see the karst for the caves.

The preceding discussion should not be taken as suggesting that legislative protection and management by a responsible agency will be enough to secure the future of our caves. They are an essential beginning, but as I stressed at the outset of this paper, the contradictions of continued use of caves for recreation and other purposes needs careful attention also. Australian speleologists, having formally adopted a Code of Ethics, should start actually applying its principles, and take active steps to encourage all persons who visit karst areas, for whatever purpose, to do likewise.

Education of all cave users, whether in organised caving groups or not, about the full range of values associated with karst is one of the most pressing challenges. The Australian Speleological Federation has a responsibility to better organise itself to undertake this daunting task, and to assist management agencies in natural resource oriented education and interpretation programmes. Such co-operation with government departments needs considerable development for wider purposes as well. For far too long there has been considerable suspicion on both sides. As long as the necessarily different functions of government agencies and special interest groups are recognised by both parties (see Clark, 1974), in the long-term it can only lead to better understanding and better karst management. The more professional the input from speleologists the better.

In short, the future of Australia's remarkable but limited karst resources is as much dependent on the ability of concerned speleologists to contrive better decision-making mechanisms about those resources (and to contribute substantially to those processes, both technically and politically) as it is on the ever-present necessity for activism. Australian speleologists have responded with quite remarkable skill and energy to serious conflicts at such places as Mt. Etna, Bungonia, Precipitous Bluff, and many more. But let us make sure that such essential battles do not overshadow the higher purposes and greater difficulties of safeguarding all that is valuable about our karst resources for the future.

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OVERUSE OF CAVES – AVOIDING AND REPAIRING : A CASE STUDY

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Abstract

Moondyne Cave (Augusta, W.A.), a former tourist cave, was studied to assess the potential for avoiding and repairing damage due to "normal wear and tear." The potential for repair is limited and it is necessary to avoid damage before the repair stage is necessary. This conclusion is applied to the more difficult problems of cave management in wild caves.

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RECREATIONAL CAVING IN W.A. : SOME HARD DATA

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Abstract

The annual number of visits to caves in W.A. has been estimated for paying tourists, the adventurous public and speleologists. The high number of visits to wild caves by the public presents some serious problems of management. This is contrasted with the problems of less intensive but more extensive use of caves by speleologists.

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RESOURCE MANAGEMENT OF THE NULLARBOR CAVES

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Abstract

The Western Australian Environmental Protection Authority recently commissioned a study team from the Australian Speleological Federation to carry out a resource management study of the Nullarbor region of W.A.

This paper summarises some aspects of the study. It reviews the remarkable natural resources of the Nullarbor, especially of the caves, and identifies some of their special values. The challenge of achieving conservation and active management of these resources is considerable. Some of the conflicts and management problems are discussed.

THE NULLARBOR KARST

The natural resources of the Nullarbor Plain and its caves have probably been more completely documented than any other karst area in Australia. The extensive literature on the natural resources of the region is analysed in some detail in the Australian Speleological Federation (A.S.F.) report (Davey, 1978), and a fairly complete listing of all the literature is contained in Davey and Lewis (1978).

The Nullarbor Plain is one of the most impressive outback landscapes of Australia - a vast and nearly flat expanse of treeless shrubland surrounded by sparse mallee country and scrub. Beneath its semi-arid surface are some very remarkable caves, often characterised by enormous rockfalls, large roomy passages, clear lakes, rare mineral formations, and many other interesting features.

The Nullarbor is one of the world's three or four largest karstlands, and the only arid and semi-arid karst of any great extent. Its seaward margin includes two substantial lengths of tall unbroken sea cliffs facing the Great Australian Bight; in between, the emerged continuation of the sea cliffs forms the prominent escarpment of the Hampton Range - the most obvious landscape feature at the southern margin of an otherwise gently undulating plateau. Considering the size of the Plain, caves are not numerous, although over 200 caves, blowholes, and dolines have been documented, mainly in the less arid area near the coast.

The caves are quite diverse in character. They range from simple blowholes, through complex networks of low passages at one or more levels, to extensive roomy collapse passages. Some of the deep caves have a compelling beauty and majesty - not to mention sheer size - of a kind unknown elsewhere in Australia or the world. Submerged passages extending off the lakes in three or four of the caves offer outstanding cave diving challenges. The considerable variety of caves contain numerous features which are of scientific importance; these include prehistoric art and archaeological sites, fossil bird and mammal sites, troglobitic invertebrate fauna, rare mineral deposits, and a surprising range of beautiful and rare speleothems. Studies of many of the caves and other karst features of the Nullarbor have contributed significantly to better understanding of environmental processes and aboriginal prehistory elsewhere in Australia.

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At present, most visitors to the Nullarbor merely cross it on the Eyre Highway or transcontinental railway, spending as little time on the Nullarbor as possible. Most of the commercial activity in the region centres on servicing the highway traveller. The Nullarbor certainly has a widespread image as a vast flat expanse of uninteresting scenery. In many respects, however, this image is deceptive - the Nullarbor is in very many ways quite beautiful and contains a remarkable diversity of interesting natural features. More attention to interpretation of the natural features of the region will not only contribute to a much more positive tourist experience, but will make the task of managing the natural resources of the region a much easier one.

An analysis of visitor patterns on the Nullarbor suggests that a diversification of tourist opportunities would be of considerable interest. One of the major constraints at present is the general inadequacy of the tourist service facilities.

Unfortunately, Australians have only recently begun to appreciate that resources of the kind represented by the caves of the Nullarbor require active protection and careful management. For example, apart from widespread problems of rubbish, vandalism and disturbance, two of the most beautiful and scientifically important of the caves are disfigured by totally unnecessary pipes and pumping equipment. Erosion caused by stock and people goes unchecked in some cave entrances and dolines. In many of the caves, careless or thoughtless visitors have unintentionally (perhaps in some cases deliberately) contributed to a general deterioration of the condition of the caves by treading a multiplicity of paths, walking on sand dunes, damaging crystal deposits at lake edges, walking on rare mineral crusts, disturbing bats, breaking speleothems, and so on.

At present, the only industry other than tourism is grazing. The continued economic viability of the industry is open to serious question, and there is substantial evidence that carrying capacities have been (and still are) exceeded to the extent that range conditions have declined seriously. This has important nature conservation as well as resource management implications.

THE MANAGEMENT CHALLENGE

Many of the caves on the Nullarbor are deteriorating seriously. The main problems are a proliferation of camping and erosion near cave entrances, rubbish and graffiti in the caves, and inadvertant or deliberate destruction or disturbance of important natural and cultural features (for example, fossil sites, aboriginal art sites, troglobitic fauna).

In other parts of Australia, the conventional response to this kind of problem is to arrange for active resource management, usually by some public authority. The sheer size and remoteness of the Nullarbor Plain makes this very difficult; there are over 200 important karst features scattered within an area larger than 750 km by 200 km!

Only a few of the Nullarbor caves or other karst features are in reserves. In the Western Australian sector, Cocklebiddy Cave (N-48), Murra-el-elevyn Cave (N-47), Tommy Grahams Cave (N-56), Pannikin Plain Cave (N-49), and a few other features are all within the large Nuytsland Wildlife Reserve, and Weebubbie Cave (N-2) is within a water reserve. In South Australia, Koonalda Cave (N-4) is a declared prohibited area under the (S.A.) *Aboriginal and Historical Relics Preservation Act* (1965), but there are no caves there within reserves as such. The vast majority of significant karst features on

the Nullarbor are within pastoral leases or on vacant Crown land.

Despite the existence of a few reserves, there is no cave or karst feature on the Nullarbor which is the subject of responsible management. Even the very strict legal "protection" of Koonalda Cave has not yet contributed significantly to its actual protection, because it is not backed up by active management; this valuable archaeological and prehistoric art site is steadily being subjected to vandalism and disturbance. Another example is Weebubbie Cave, where its status as a water reserve may actually have encouraged the disfiguring of the cave and lake by totally unnecessary pumps and piping. One has to conclude that the challenge in an area like the Nullarbor is not in achieving reservation of important features so much as in achieving an active management input.

In some cases (for example, the Nuytsland Wildlife Reserve), the lack of management is partly attributable to the daunting task of managing huge tracts of Western Australian backcountry with extremely limited resources. In other cases (for example, Koonalda Cave), it is hard to escape the conclusion that, despite legal protection, there has never been a realistic commitment to achieving practical protection and management of such a priceless site.

Even if reserves or national parks are a practical option for the future, land tenure of important parts of the Nullarbor karst, it should be recognised that workable arrangements for actual management are ultimately a far more important concern. Any means of achieving active management, even if quite different from the arrangements which would normally be desirable for more accessible karst areas, should be given very careful consideration.

MANAGEMENT OBJECTIVES

The Nullarbor Plain and its caves are of considerable international interest. The caves and other karst features are of scientific importance, and they provide many significant opportunities for nature conservation, aesthetic appreciation, recreation, and tourism. The report (Davey, 1978) identified six basic objectives for resource management of the W.A. Nullarbor:

(1) To provide for the preservation of the Nullarbor caves and other karst features in as near to a natural state as possible.

(2) To provide for the preservation of viable examples of the natural ecosystems of the Nullarbor region in as undisturbed a condition as possible.

(3) To secure the preservation of rare, unusual or endemic cave-dwelling fauna or mineral formations and other scientifically interesting natural features of the Nullarbor caves and Plain, and to foster research into them.

(4) To provide opportunities for visitors to experience and appreciate the remarkable subterranean environment beneath the Nullarbor Plain, with its magnificent chambers, lakes, and mineral formations.

(5) To provide opportunities for education and interpretation about the Nullarbor caves and karst and to increase awareness of other interresting aspects of the Nullarbor environment.

(6) To provide opportunities for pastoral production on a carefully controlled sustainable-yield basis, consistent with the achievement of the primary objectives above.

IMPLICATIONS

Station managers are in no position to guarantee that important sites which happen to be within pastoral leases will be protected. Even if it were reasonable or practical to rely on station managers, and even if they were concerned to protect caves, they have no expertise of cave management and have no statutory powers of enforcement.

The public responsibility for protection and active management must be accepted. The evolution of workable management arrangements will be time-consuming, but a greater contribution by public authorities is essential. There may already be the beginnings of a management presence as the result of previous recommendations of the Environmental Protection Authority (E.P.A., 1975) for a new national park in the Eucla area. That recommendation was not related to karst features, but the proximity of the park to a base at the developing tourist and government servicing complex at Eucla Pass, may make it easier for the National Parks Authority to find a workable arrangement for active management of features elsewhere in the region as well.

Whatever the land tenure (for example, reserve, national park, vacant Crown land, or pastoral lease), it is essential that there be on-ground management for all the caves and other karst features on the Nullarbor, and that there be systematic management plans for each major site or group of sites (or reserve). Particularly for the well known and accessible caves, it is desirable that there be a specific plan for each, with careful attention to such things as littering, smoking in caves, disturbance of cave fauna, damage to mineral formations, and disturbance of sediment, bone, and archaeological deposits. The main components of the management programme needed are:

- An active management presence on the Nullarbor with responsibility for management of caves and other karst features.
- Legislative protection for all caves and karst features.
- Reservation of all the most important caves and groups of caves.
- The development and implementation of management plans for each major cave or group of caves.
- Provisions for active management of other caves beneath pastoral leases and other tenures.
- Declaration of cave invertebrate fauna as protected species.
- Restoration and protection works at sites which have been disturbed.
- A programme of public education and interpretation about karst resources, their values, and their vulnerability.
- Selective development of specific sites for carefully managed tourism.

Until the Environmental Protection Authority has had time to consider the proposals, the other specific recommendations of the report will not be discussed here. In summary, they involve, among other things, restoration works and closer supervision at Cocklebiddy Cave and Murra-el-elevyn Cave; the development and implementation of a management plan for Mullamullang Cave (N-37); management protection of the palaeontological and archaeological

site at Madura Cave (N-62); a major new reserve or national park including the complex of karst features centred on Abrakurrie Cave (N-3); and the possible development of Weebubbie Cave for very carefully managed tourism. This latter proposal will be the subject of detailed further investigations.

The study represents an interesting achievement in co-operation between a specialist interest group and government. It remains to be seen how much of the recommendations of the report can be realised, but it does at least seem to have provided a valuable stimulus to achieving better resource management of the karst on the Western Australian Nullarbor.

ACKNOWLEDGMENTS

This paper is drawn from a report which is the result of the energy and initiative of very many people. The study team consisted of Jim Cundy, John Dunkley, Elery Hamilton-Smith, Ken Lance, Ian Lewis, Kevin Mott, Bob Shoosmith, Nicholas White, and Kerry Williamson, with the present writer responsible for co-ordination and editing. George Kendrick (W.A. Museum), Richard May (National Parks Authority), and John Watson (Department of Conservation and Environment) also made major contributions, and numerous others in Perth and on the Nullarbor gave assistance in various ways. The generous help of numerous friends and colleagues is also much appreciated: Ted Anderson, Peter Bridge, Bill Crowle, Fred Elliott, Ross Ellis, Rudy Frank, Joe Jennings, David Lowry, Jackie Lowry, Duncan Merrilees, Greg Middleton, Bob Nicoll, Andrew Spate, and Rauleigh Webb.

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DEUA - A NEW CAVING AREA IN NEW SOUTH WALES

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Abstract

A cave with a 12 m high entrance has been discovered in a previously unknown limestone lens in rugged country between the Wyanbene and Bendethera caving areas in south-eastern New South Wales. It was discovered by B.M.R. geologists during a field mapping programme early in 1978. However, it was not until mid-November of that year that cavers were able to visit the area. In this paper the area and the cave are described.

INTRODUCTION

A new caving area has been discovered in south-eastern New South Wales. It is situated on a tributary stream of the Deua River, approximately 100 km south-east of Canberra. This paper is a preliminary report on the area which so far, has been visited only once by cavers. That was in mid-November 1978 when a party, made up of members of the Canberra Speleological Society and the Capital Territory Caving Group, paid a fleeting three hour visit during which the only known cave was explored and mapped.

The name proposed here for both the area and the cave is Deua, after the Deua Trigonometrical Station approximately 2 km south-west of the area.

THE AREA

The Deua area lies at an altitude of approximately 550 m on the lower eastern slopes of the Minuma Range between the Wyanbene and Bendethera cave areas. It lies within the proposed Deua-Tuross National Park. The limestone is covered with thick "rain forest". Eucalypt forest occurs along the top and upper slopes of the Minuma Range, but along the valley floors and on the limestone, "rain forest" with fig trees, lawyer vines and stinging nettles predominates.

Deua joins the list of cavernous limestone lenses, situated between the Shoalhaven and Deua Rivers, which comprise the Upper Shoalhaven Karst Region (Nicoll & Brush, 1976). The most northerly of these is Cheitmore, followed to the south by Marble Arch, Wyanbene, Deua and Bendethera. Further areas of limestone are inferred by the presence of shallow, grassy depressions and springs near Cheitmore and Wyanbene, scarn mineralisation approximately 3 km south of Marble Arch (Johnson, 1964), the Big Hole, which is thought to be the result of subjacent karst collapse (Jennings, 1966) and an occurrence of limestone float in a creek bed 3 km north of Deua.

The Deua limestone occurs near the base of a Silurian volcanic sequence (M. Owen, pers. comm.). It is underlain by black cherty siltstones, probably of volcanic origin, and is unconformably overlain by tuff, agglomerate and lava. Conodonts recovered from the limestone have indicated a late Silurian age, similar to other limestones in the region. The Silurian sequence is unconformably overlain by Upper Devonian terrestial conglomerate, sandstones and siltstones which crop out in a north-south strip along the Minuma Range

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The limestone crops out over an area of approximately 200 m by 100 m and has a thickness of about 50 m. It has been folded into a tight anticline which gives the impression that the thickness is much greater than it really is. The rock has been recrystallised and slightly dolomitised, and according to the Folk classification for limestones (Folk, 1959) it is a biosparite (M. Owen , pers. comm.).

HISTORY

Caves in the Upper Shoalhaven Region have been known for approximately 150 years. They were first referred to in 1832 in a report of a trip to the area by the New South Wales Surveyor-General at the time, Major Thomas Mitchell. According to Carne and Jones (1919), Mitchell was shown the Big Hole and a cave at Cheitmore.

For their report, *The limestone deposits of New South Wales*, Carne and Jones painstakingly compiled all information known at the time. All major deposits are referred to in the text, while many more insignificant lenses are shown on accompanying maps. In the area south of Braidwood however, only Cheitmore, The Big Hole, Variegated Marble (now known as Marble Arch), Wyanbene and Bendethera are shown.

It is possible that the Deua area was found long ago but the discovery not recorded. The area is near the Majors Creek, Araluen and Snowball goldfields, and also in the general area are a number of old copper prospects. It does seem likely that early prospectors would have at least passed close to the limestone - even if the cave was not noticed.

The first known visit to the area was in April 1978. During the course of field mapping work by geologists from the Bureau of Mineral Resources for the Araluen 1:100 000 Geological Series, a party led by Mike Owen discovered limestone float in two creek beds in rugged country on the eastern side of the Minuma Range. Aerial photographs were used to locate likely areas from where the material could have originated and these were subsequently investigated in the field. Three possibilities around one occurrence were checked out without success. However, near the other 3 km to the south a small lens of limestone was found. Soon after, a cave was found in the limestone by Ken Mitchell, one of the party (see Fig. 1).

The B.M.R. also found a lens of limestone about 200 m long on the western side of the Deua River, approximately 4 km east of Bendethera Cave. Karst features such as rillen-karren, joint widenings and solution pits have been found, but no caves.

HYDROLOGY

Deua cave contains a small stream (little more than a trickle) derived from a shallow valley immediately to the west of the entrance. The stream sinks into its bed above the limestone contact, which is approximately 50 m horizontally and 30 m above the entrance, and re-appears in the cave near the bat chamber. The stream is seen for only a short distance before it sinks into the gravel floor.

A small spring has been found near the end of the ridge in which the cave is situated. It is approximately 80 m from the junction of two small creeks

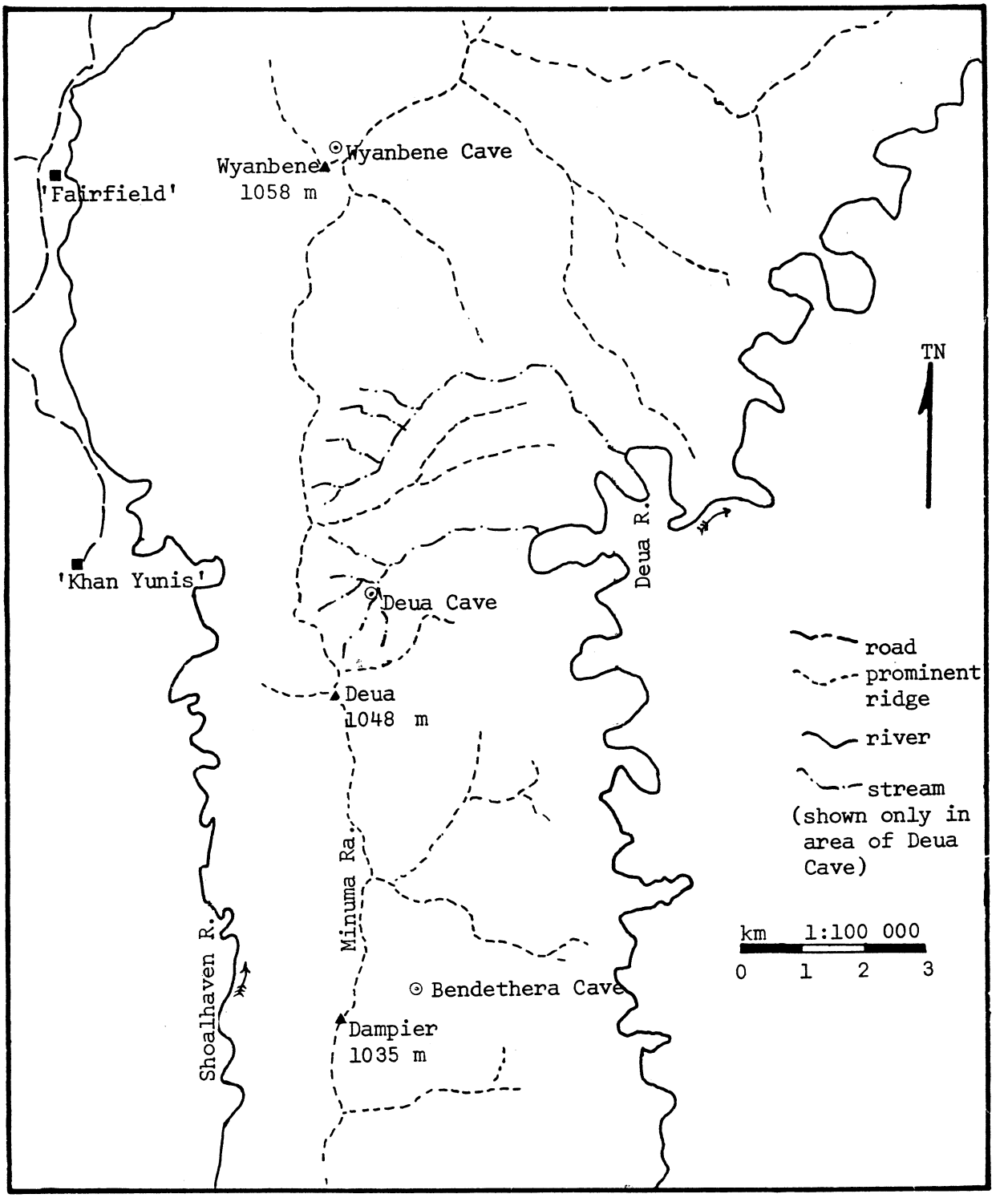

Figure 1. Deua Cave location.

north of the cave. As well as being the probable rising for water seen in the cave, it may also be the rising for the stream east of the cave, which also sinks into its bed near where it crosses the limestone.

THE CAVE

The cave is about 80 m long and consists of a tall meandering stream passage, developed along joints, with an upper level chamber adjacent to the entrance. The bedrock walls are pale grey and have a soft chalky appearance, while the floor, in general, is composed of coarse angular gravel (see Fig. 2).

Despite the large size, the 12 m by 3 m entrance is not obvious more than a few metres away. It is effectively hidden by the thick vegetation.

The steeply sloping earth floor at the entrance terminates in a short pitch, at the base of which is a shallow pool of water, fed by a small stream. This can be followed for about 8 m to where it emerges from between breakdown material. One entrance to the upper level bat chamber is directly above this point.

The chamber is about 6 m by 8 m and contains a large accumulation of guano, evidence of a long history of occupation by bats. On the November visit there were estimated to be more than one hundred bats - probably *Rhinolophus megaphyllus* -present. A continuation of the chamber connects back to the main passage via a series of holes, the largest of which can be free climbed.

At the foot of the entrance climb, the passage is about 2 m wide and more than 20 m high. Some 20 m further in the passage widens and some decoration is present - much of it being guano-stained and brittle. Beyond this "hall", roof height decreases sharply and the passage continues through a flowstone-coated room. One wall and most of the rubble floor have been flowstone coated. At one end, a number of gours about 10 cm deep and 20 cm wide occur. These, and the flowstone below them, are a dull yellow-brown colour and have started to re-dissolve.

The cave beyond here consists of a dry, rubble-floored meandering passage which steadily decreases in height and width. At the limit of exploration the passage is down to crawl-size, and after a few metres may become impassable.

CONCLUSIONS

Our current knowledge of the area is limited. Several features have not yet been thoroughly examined. The sinking points of the two streams and their joint resurgence, for example, have not been closely looked at.

No outcrop has been found north of Deua to account for the limestone float found in a creek bed there. The outcrop may only be very small, but its location would be of some interest. In addition, the recently discovered lens near Bendethera does warrant further investigation.

Although the Deua area is small, and only one cave is known, the discovery demonstrates that new areas of cavernous limestone can still be found in south-eastern Australia; an area thought to have been fairly well explored during the past 150 years.

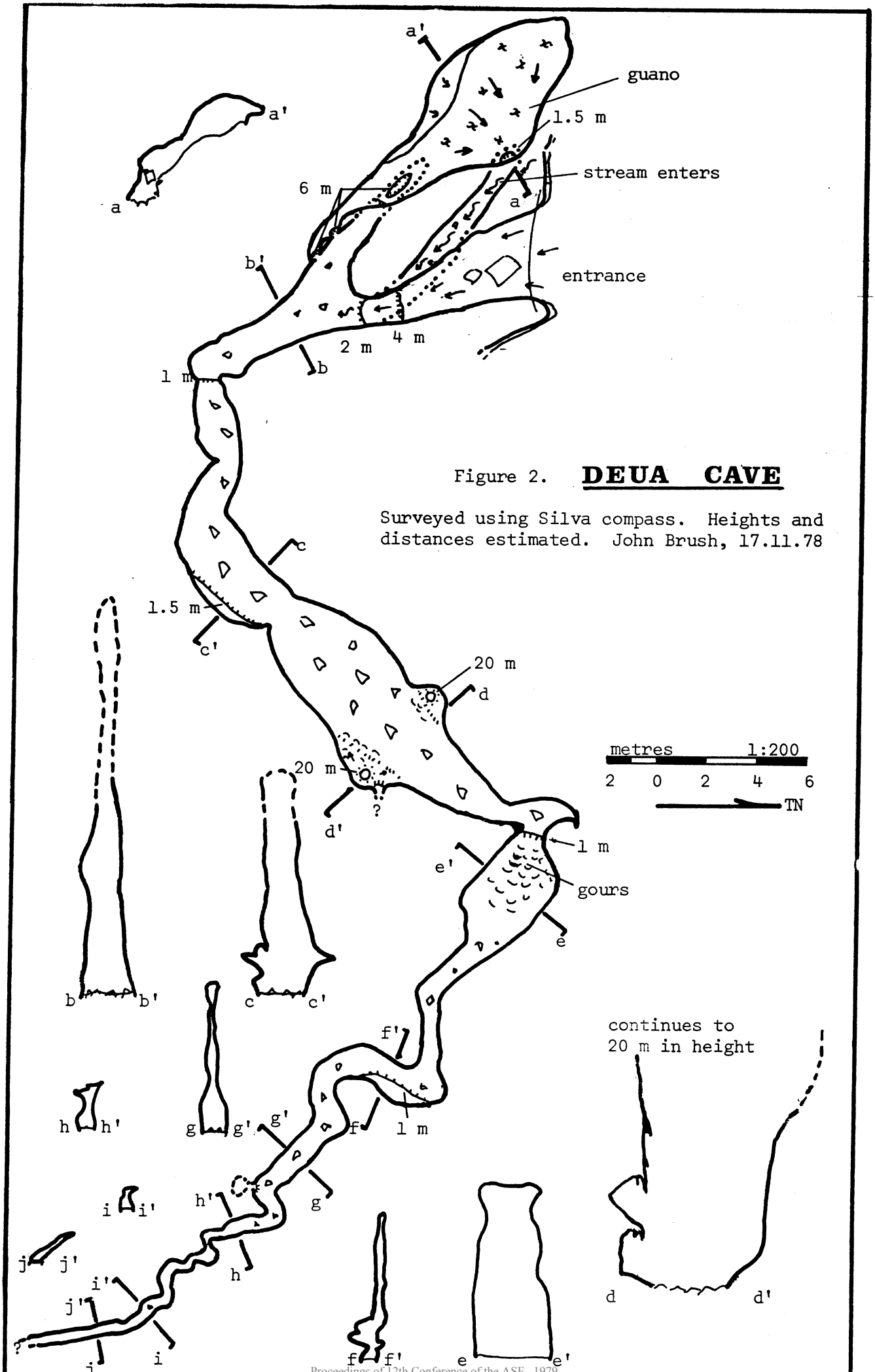

Figure 2. **DEUA CAVE**

Surveyed using Silva compass. Heights and distances estimated. John Brush, 17.11.78

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NOTE ADDED IN PROOF

On a combined Canberra Caving Clubs/National Parks and Wildlife Service visit to the area in August 1979, cavers from NUCC pushed the terminal squeeze and more than doubled the length of the cave. Total depth is now more than 50 m.

A second small cave to the east of the main cave was also found on this trip.

ATEA '78

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Abstract

The Atea Kanada is located in the rainforest of the southern highlands of Papua-New Guinea. The cave was partly explored in 1976 but further investigation by the 1978 expedition extended the mapped length to thirty kilometres, making it the longest cave in the southern hemisphere and Asia. Initial hopes for the southern hemisphere depth record were not realised.

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THE FLINDERS RANGES

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Abstract

The landuse history of the region is outlined and the geology described. Four separate caving areas are identifed and characterised. The palaeontological significance of the Flinders Ranges is indicated and some comments made about the impact of present landuse patterns in the absence of an overall management strategy.

INTRODUCTION

The Flinders Ranges in South Australia are a series of thrusted uplands stretching in a boomerang arc, 500 km long, from Melrose in the south to Mount Hopeless in the north. The Willouran Ranges, although detached, are a related offshoot.

First sighted on 7 March, 1802 by Matthew Flinders from his ship Investigator they were not to be named Flinders Ranges until 1839 by Governor Gawler.

Exploration began in 1840 when Edward John Eyre set out to make his famous trip to King George Sound. On 27 June, 1840 he made this journal entry:

> From our present encampment a very high and pointed hill was visible far to the N.N.W. this from the lofty way in which it towered above the surrounding hills, I named Mount Remarkable.

At that time the area was occupied by several tribes of aborigines, notably the Adjnamutana, who were fearless and jealously guarded the Ranges, obviously due to the relative abundance of food and water.

Within ten years the white European settlers had moved in building homesteads and bringing with them their domestic animals.

The next fifty years saw a great influx of pioneer families, farmers, graziers and miners. They suffered many hardships with lack of medical care, bad roads, slow communications and hostile aborigines.

During the 1870's wheat crops were planted with good returns. Then came the Great Drought. Small holdings and towns which had flourished were deserted and now remain as stark ruins, reminders of shattered dreams. Once fertile soil, which supported many varieties of native grasses and wildflowers, was eroded away.

By the turn of the century a stable industrious population was formed but economic pressures were brought to bear on the farmer who strove to make his land once again fertile and as profitable as possible. Dry and seemingly arid land was seen to be productive with the aids of "scientific farming", by additives to the soil, either organically or chemically. Chemicals were readily available but expensive and sometimes complex in composition. What the farmer needed was cheap, organic and easily available fertilizer. "Farmyard" fertilizers were most readily sought after and farmers who drove to the cities with their produce, re-loaded with horse manure obtained from city stables. This often had to be carted long distances and was not always available in the quantities needed.

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Bat guano contains appreciable quantites of nitrogen which gives the highest degree of fertilizing power. It was found that one ton of bat guano was equal in manurial value to 21 tons of stable manure! Was it any wonder this was a prize highly sought after?

For forty years one lone prospector (Montague) worked several small guano deposits without great success until Mr W.G. Hardy of Pamatta Station informed him of the Buckalowie Creek caves. A limited liability company named Nitrogen Limited was officially set up on 10 January, 1922 to mine the deposits in Clara St. Dora, buying out Angus Mair owner of the Mairs Cave claim. First estimates on the deposits (sufficient to keep the works at full blast for fifty years) were greatly overestimated.

The search for guano brought to light many caves and it was a report of the activities in an early Mining Review that inspired the first official Cave Exploration Group of South Australia (C.E.G.S.A.) trip in December, 1955.

GEOLOGY

The topography of the Flinders Ranges is the result of sedimentation, orogenisis and subsequent erosion of what is termed the Adelaide Geosyncline. The time interval represented in this area spans the crucial Pre-Cambrian-Cambrian boundary which is a major break in the rock record throughout the world. Major faulting or metamorphism is minimal or moderate and enables a relatively uncomplicated history of this area to be determined.

The crystalline basement rocks of Archaean to Late Proterozoic age (1 500 million years ago) were eroded away and deposited in an adjacent long shallow marine trough. Depositional environments ranged from shallow marine (less than 200 m) to marginal marine. Slow subsidence of this trough enabled great thicknesses of sediments to be deposited, in some places to 10 km deep. Table 1 gives the broad outline of deposits and the approximate depositional areas.

The oldest sediments in the sequence are the Callanna Beds (inferred age 1 400 million years) consisting mainly of quartzites, siltstones, stromatolitic carbonates and basic volcanics. These lie unconformably over the crystalline basement rocks and outcrop near Mount Painter and Arkaroola.

The Burra Group, which began approximately 900 million years ago, is characterised by conglomerates, quartzites, dolomites and sandstones which show mud-cracks, salt-casts and cross-bedding suggesting tidal flat or fluvial environment.

The Skillogalee Dolomite contains distinctive stromatolites and some black cherts containing algal filaments.

Two important glacial periods are represented by the Sturtian Tillites (over 5 000 m thick) which underly the shales and carbonates of the Umberatana Group and the Marinoan Tillites (over 6 000 m thick) which underly the Wilpena Group. Radiometric dating suggests 660 to 680 million years for the Marinoan Tillites and as they occur over a very large area they act as key marker beds.

The Wilpena Group, consisting of sandstones, quartzites and siltstones, completes the Adelaidean where warm to tropical climate conditions prevailed. The world famous Ediacara fossils occur in the Upper Wilpena Group in the Upper Pound Quartzite.

A period of erosion, followed by basin subsidence and subsequent sea transgression led to extensive carbonate deposition during the Cambrian Period with

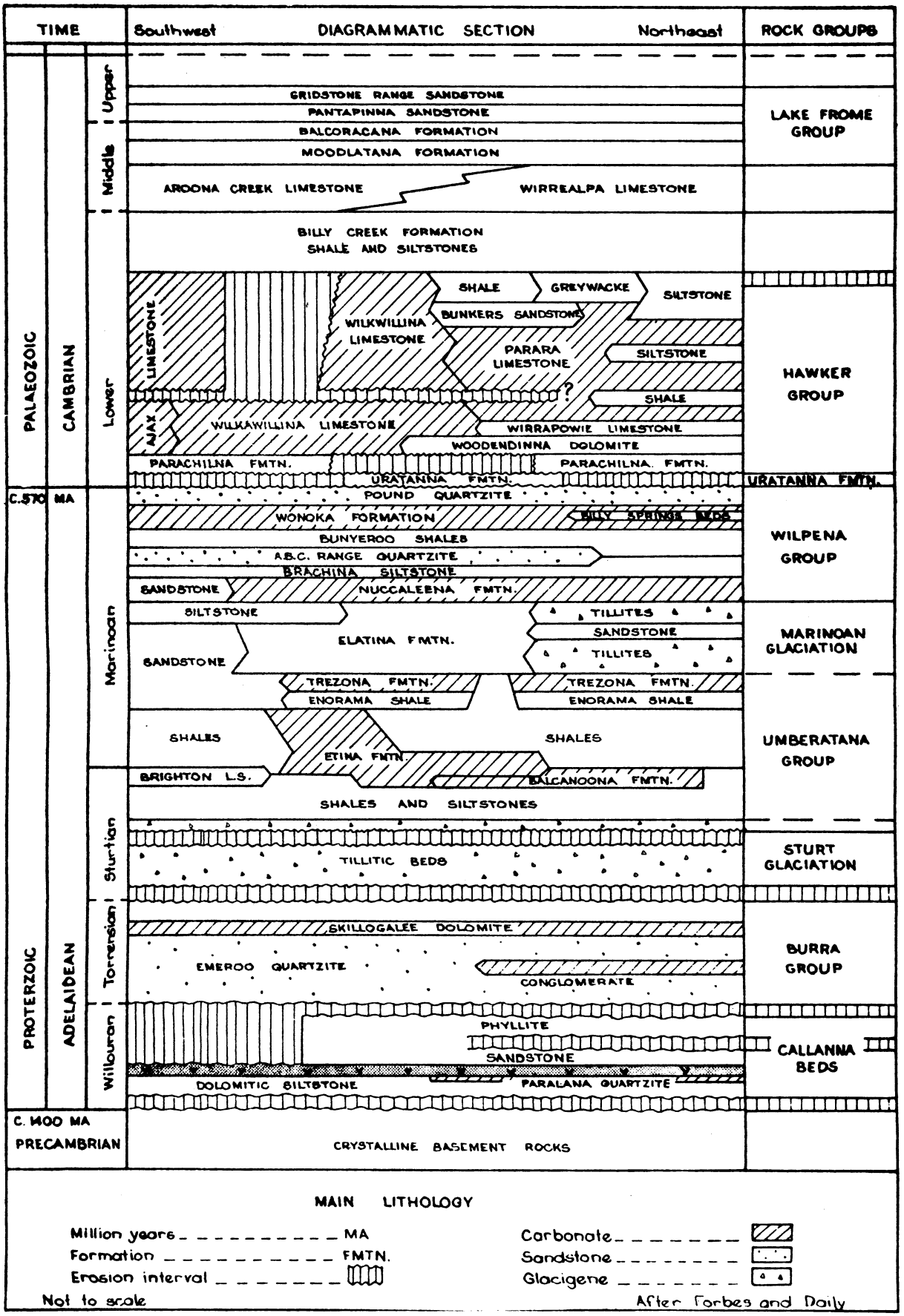

Table 1. Sedimentation - Adelaide Geosyncline.

the Uratanna and Parachilna Formations rich in trace fossils occurring in the Lower Cambrian Period. Shelf deposits such as the lighter coloured Ajax and Wilkawillina limestones reflect tidal environments grading to warm clear waters of the neritic zone. Dark coloured limestones appear to reflect increased water depth. The Hawker Group includes the Woodendinna Dolomite and the Wilkawillina and Parara Limestones.

Fossil fauna becomes increasingly varied including Archaeocyatha, trilobites, hyolothids, brachiopods, gastropods and stromatolites.

Sedimentation gradually exceeded subsidence and the carbonates gave way to clastic sediments of the Billy Creek Formation containing trilobites and gastropods, followed by marginal marine "red bed" sedimentation. The final capping sediments of the Lake Frome Group are similar carbonate clastics, the final phase being the Gridstone Range Sandstone.

Conversion of this thick bed of sediments to a mountain range took place about 520 to 460 million years ago during the Late Cambrian to Early Ordoivician Period. Lateral compression of the trough by the enframing basement landmasses produced the basically concentric fold pattern, typified by narrow anticlines separated by broad, almost flat-bottomed synclines. Wilpena Pound is a classical example which is most easily seen from the air. Structural complications occur due to the "plastic" injection of brecciated basement material contemporaneous with sedimentation, forming the "diapirs" of the Flinders Ranges. A very long period of erosion followed and renewed lateral basement compression in the Tertiary Period (65 to 2 million years ago) raised the sediments again allowing weathering agents to etch out the present day awe-inspiring topography.

THE CAVES

This large area has relatively few known caves and they occur in the carbonate sediments of dolomite and limestones. Cave development is impeded by the rapid run-off with little seepage essential to the making of large cave systems. For simplification I have divided the area into six regions where the greatest number of caves occur. For separate descriptions of these caves see C.E.G.S.A.'s Occassional Paper Number 5, pages 34-38.

The Lower Flinders contains five known caves (F-1, F-2, F-20, F-21 and F-22). F-1 and F-2, at Melrose, occur in local sandy pink and grey dolomite of the Umberatana Group (? Brighton Limstone equivalent) with thin interbeds of granule sandstone. The term "Blowhole" which is locally applied to F-1 is misleading as there appears to be no appreciable air movement.

F-21 and F-22 are interesting as they occur in the Emeroo quartzite of the Burra Group and follow an obvious jointing pattern.

F-20, apparently an isolated incidence of a cave, is formed in oolitic limestone of the Etina Formation and is situated in the basin of a syncline. A joint-controlled cave, with some decoration, it has an unusually high humidity.

The Buckalowie area has four known caves (F-3, F-4, F-27 and F-28) all having vertical entrances. This has proved the most popular caving venue in the Flinders. The caves are contained in a narrow steeply-dipping (85° E) outcrop of dolomite (suggested correlation with Brighton Limestone), which is bounded by easily weathered shales. All these caves were mined for guano and F-4 has had an adit driven for easier access. F-3 and F-4 both had large workings. In F-3, this almost vertical dip has a strong influence on the development of

the cave where the walls are frequently the bedding planes. During the 1960's a palaeontological dig was undertaken in F-3 to remove bone material. This will be commented on later. F-4 has some particularly beautiful calcite crystals which unfortunately have been subject to some abuse by rock collectors. F-27 and F-28 are both 10 m deep fissures ending in rubble chokes which, in spite of enthusiastic investigations, failed to develop further.

The Holowilena Syncline contains five caves (F-5, F-6, F-7, F-14 and F-17) in sandy oolitic limestones of the Etina Formation (Umberatana Group) bounded by dolomitic Shales of the Enorama Group. All the caves are formed by solution following the joints and planes creating extensive mazes of passages. The most extensive of these are F-5 and F-7 and, although all were mined for guano, these proved the most profitable. Remnants of mining days still remain with screens, buckets, explosives and shovels being left behind (the explosives have now been removed).

The Central Flinders area has isolated occurrences of caves and although bats occur in some of them only F-8 has been mined for guano. There are seven known caves (F-8, F-13, F-15, F-16, F-29 and two unnumbered caves). F-8 is quite extensive, mazelike and very dusty, occurring in Wilkawillina Limestone of the Hawker Group which is rich in Archaeocyathids and brachiopods. F-15 and F-16 occur in the Trezona Formation of the Umberatana Group which underlies the Marinoan Glacial sequence hence making it a key marker bed. F-29 and the two unnumbered caves occur in Brachina Gorge in flaggy limestone of the Wonoka Formation of the Wilpena Group interbedded with grey calcareous shale. They are joint-controlled, following bedding planes and at present are roosts for bats. F-13 also has bats and hopefully will remain a safe haven as the entrance is not easily discernible. It occurs in dark flaggy Parara Limestone of the Hawker Group interbedded with shales.

Eight caves occur in the Narrina area (they are F-10, F-11, F-12, F-18, F-19, F-23, F-24, and one unnumbered cave). F-10 is formed in a synclinal basin in oolitic limestone and pale grey dolomite of the Balcanoona Formation (Brighton Limestone equivalent). A sporty four-wheel drive track leads to this cave of exceptional dog-tooth spar calcite decoration. The unnumbered cave occurs in the Nuccaleena Formation of the Wilpena Group, a flaggy dolomite, overlain by reddish Brachina Shales and is encountered on this same track. The rest of the caves occur in Cambrian fossiliferous Wilkawillina Limestone of the Hawker Group.

F-11 is of particular interest having permanent water which lies above the watertable. It has been dived and recently the South Australian Museum expressed interest in the cave to ascertain if any life was present, in particular the *Milyeringa veritas*, Blind Gudgeon or Blind Cave Fish which can be found in Western Australia. Three museum representatives, three divers, a teacher and the author visited the cave in May 1978. The divers took capture nets and bottles to collect anything of interest and to take water samples. A thermometer was taken to the bottom and this registered 22°C. Cave air temperature was 23°C and the very high relative humidity was estimated at 85-90%. Water samples were obtained from a local creekbed for comparison (Table 2), and there appears no substantial difference in the breakdown. After analysis John Glover the Curator of Ichthyology, South Australian Museum, thought that although no lifeforms were found it was possible they could survive under present conditions. It was disappointing not to have found anything, although we expected it, and we can quell future rumours with confidence.

The Northern Flinders encompasses the Arkaroola-Wooltana area and westwards to Lake Torrens. There are numerous small holes not yet explored or given

Chemical composition	Narinna Lake Cave		Brachina Creek	
	Milligrams per litre mg/L	Milliequivalents per litre me/L	Milligrams per litre mg/L	Milliequivalents per litre me/L
Cations				
Calcium (Ca)	160	8.0	108	5.4
Magnesium (Mg)	78	6.4	78	6.4
Sodium (Na)	260	11.3	260	11.3
Potassium (K)	18	0.5	5	0.1
Anions				
Carbonate (CO_3)	nil	nil	nil	nil
Bicarbonate (HCO_3)	391	6.4	348	5.7
Sulphate (SO_4)	288	6.0	206	4.3
Chloride (Cl)	525	14.8	500	14.1
Nitrate (NO_3)	nil	nil	nil	nil
	TOTALS AND BALANCE		TOTALS AND BALANCE	
	Cations me/L	Anions me/L	Cations me/L	Anions me/L
	26.2	27.2	23.2	24.1
	diff.Δ 1.0 sum Σ 53.4 % $\left(\frac{\Delta \times 100}{\Sigma}\right)$ 1.9		diff.Δ 0.9 sum Σ 47.3 % $\left(\frac{\Delta \times 100}{\Sigma}\right)$ 1.8	
Derived and other data		mg/L		mg/L
Conductivity (E.C.) µS/cm at 25° C	2500		2260	
Total dissolved solids (based on E.C.)		1450		1310
Total hardness calc. as $CaCO_3$		721		591
Carbonate hardness calc. as $CaCO_3$		320		285
Non-carbonate hardness calc. as $CaCO_3$		401		306
Total alkalinity calc. as $CaCO_3$		320		285
Sodium adsorption ratio	4.2		4.7	

Table 2. Water analysis report - comparison of water samples.

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locations in the Arkaroola area. F-9 and F-26 are the two caves known in C.E.G.S.A.'s records. F-26 occurs in flaggy dolomite of the Wonoka Formation (Wilpena Group). This formation has been subject to large scale slumping which can be seen in several places in the Flinders. F-9 is the best known cave of this area occurring in Balcanoona Dolomite of the Umberatana Group. A spectacular vertical entrance drops 70 m to the floor of the cave where it bells out into a large chamber. Reserves of guano were estimated to be over 900 tons in 1924 before mining commenced. A mummified specimen of *Macroderma gigas*, a carnivorous bat now extinct in the Flinders, was found in 1925.

Some mention must be made of the Yourambulla Caves which are located near Hawker. They are essentially Aboriginal rock shelters where painting can be seen. They occur in Pound Quartzite and have been subject to conchoidal weathering and are of archaeological interest rather than speleological interest.

FOSSILS

There are several caves that have recorded incidences of fossils, the most notable being F-3. An extensive dig was begun in the 1960's by P. Rose but unfortunately it was never finished and has since been inundated by the 1974 floods. Recognised species that have been recovered include a predominance of carnivores such as *Thylacinus*; *Thylacoleo*, marsupial "lion"; *Sarcophilus*, Tasmanian Devil, *Dasyurus* sp., tiger cat; and numerous rodents. Kangaroo, wallaby and some bird bones have also been identified and *Trichosurus*, the Brush-tailed Possum have been found in several caves.

Other fossils unearthed in open sites include the famous Ediacara trace fossils. This fauna, preserved by sand burial on a muddy shoreline, evolved in a protected, low-energy "lagoon" type of environment. They were found in 1947 by a government geologist. Most of the fauna consists of coelenterates (jellyfish) and worms. Coelenterates make up nearly 70% of the fossils discovered and include *Cyclomedusa*, jellyfish and *Pennatulaceans*, sea pens.

Dickinsonia costata and *Spriggina floundersi* are polychaete worms (segmented worms) and make up 25% of the faunal assemblage.

Trace fossils from the Cambrian Period include the U-shaped burrows of the *Diplocraterion* and Trilobite tracks. Many species of Trilobite include *Redlichia*, *Balcoracania flindersi* and *Balcoracania dailyi*.

The phylum Archaeocyatha lasted for only a few tens of millions of years during the Lower to Middle Cambrian Period (a short time geologically speaking) but many genera have been recognised.

Post-Cambrian vertebrate fossils are not common but the Lake Callabonna area north of the Flinders Ranges has yielded *Diprotodon*; *Sthenurus*, giant short-faced kangaroo; *Protemnodon*, giant wallaby; *Phascolonus* giant wombat; and *Genyornis*, giant bird. Species found in other areas include *Nototherium*, *Macroderma* and Dingo. Once unearthed bones deteriorate very quickly and it is possible many have been lost through ignorance of what they might be.

CONCLUSION

The Flinders Ranges have many other aspects equally as interesting as those already mentioned. More than 100 000 tourists visit the area each year and mineral exploration companies spent more than $3 million searching for minerals during 1970. Unfortunately this huge influx has left its mark on the natural

drawcards of beautiful scenery, flora and fauna. Tracks have been randomly worn by vechicles, and trees around campsites have been stripped of wood for campfires. Recovery from this barrage is slow or non-existent and further deterioration is imminent unless some form of control can be maintained. The National Parks cover only a small portion and the remainder continues to be subjected to abuse. It is still well worth visiting both for the scenery and for caving and I may be a little optimistic in hoping that in the future we could have a Flinders Ranges National Park.

ACKNOWLEDGMENTS

The advice and help of Mr Neville Pledge and Mr John Glover of the South Australian Museum is gratefully acknowledged, also the assistance of Dr Brian Daily of the Geology Department, University of Adelaide. I would also like to thank Mr Athol Jackson for presenting this paper in my absence and Mr Kevin Mott for drawing up the tables.

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ENTRANCE TYPES IN QUATERNARY DUNE KARST, BAT RIDGES, VICTORIA

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Abstract

Quaternary dune limestone develops caves with marked similarities in morphology. However there are three distinct entrance types: collapse under cap rock, solution pipe and stream passage, which indicates that variety in morphology is not completely lost in such an area.

Bat Ridges is a small area of Quarternary dune limestone near Portland, Victoria. The area has been worked on by the Victorian Speleological Association since 1973 although it was known to have caves much earlier. The caves appear to have developed concurrently with the lithification of the calcareous dunes.

The area is interesting for a number of reasons.

1. It is an example of syngenetic karst development which has not been thought of in relation to other Victorian karst areas.

2. It is very different from the main caving area at Buchan and so has widened many Victorians' concepts of caves.

3. Despite being a small area (8-10 km^2), it has 40 numbered caves and about 20 unnumbered ones.

4. It shows that even within such a small area with a relatively uniform lithology, big differences in karst forms can occur.

5. In reference to this Conference and W.A. it appears to be similar to caves in the Quarternary limestone of the south-west of W.A.

Some things are constant in terms of the area and its caves. First, all caves in the area are dependent on the formation of cap rock as a primary process. The calcarenite cap rock is formed by solution of calcareous bioclastic sand grains of the dunes and the subsequent redeposition of secondary calcite lower in the profile, cementing the loose sand grains in a calcite matrix. This hard layer has sufficient structural strength to support a cave roof and without it caves do not form in any size. Second, the caves generally can be described as linear and shallow, often with extensive areas of low flat ceilings. Collapse breakdown is an important process. Solution pipes and foibes are common. These features generally fit descriptions of caves in syngenetic karst areas.

However, although the area is small and there are these marked similarities between caves there are quite noticeable variations in land form, for example, cave entrances. In general cave entrances show evidence of cap rock ceilings and show collapse breakdown downslope from the main ridge. Within this generalisation there are a number of variations; cap rock and collapse (by far the most common), solution pipes and stream passages. All of these are closely related to processes of cave formation.

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WHITE – BAT RIDGES ENTRANCE TYPES

Cap rock and collapse type. The solution of calcium carbonate in calcareous dunes by percolating water moving down through the rock is an on-going process, but the calcium carbonate is redeposited as a hardened secondary calcite cap rock with sufficient structural strength to support the cave roof and the caves form under this layer. The cap rock is often expressed inside the cave by low uniform, relatively flat ceilings. However this cap rock has finite strength and is subject to collapse. Entrances form where the roof has collapsed. Collapse also results in dome or arch forms due to the tensional and shear components of the compression from collapse. At Bat Ridges, dome forms do occur, but relatively infrequently in comparison to areas such as Kangaroo Island and Naracoorte. Collapse does occur in the main part of the cave, for example, Hut Cave (BR-6), but is often confined to entrance areas, for example, Big Cave (BR-5) and Chimney Cave (BR-1). When a cave is very close to the surface, the roof tends to behave like a beam which sags into the void and eventually collapse occurs resulting in the opening. The dolines tend to be rather small.

Solution pipes. These are present as cylindrical forms of varying size and are generally surrounded by a secondary calcite layer. The pipes narrow downwards and accumulate debris piles beneath them, primarily of soil and surface debris rather than rock collapse debris. An example is the chimney entrance to Chimney Cave. This is 1 m in diameter and drops about 7 m into the cave. Collapse between two adjacent solution pipes, for example, BR-8, can show an interesting "window" form. Some caves, for example, Bat Cave (BR-9), have more than one such entrance.

Two main theories are put forward as to the mechanisms of formation of such pipes. These are not the only theories for the formation of pipes but seem to be the most applicable for consideration in this area. First, the solution of cap rock after its consolidation and second, the development from top to bottom during lithification by a combination of leaching along a descending water thread through the sand and the associated cementation of the pipe surround. Such formation is often associated with plant tap roots either as the tap root follows a pre-existing soil-filled pipe or that the growth of the tap root proceeds with the downward extension of the pipe and the root guides water down the developing pipe. BR-35 shows the close relationship between such pipes and tap roots. This is a small cave, dome-shaped with a large debris pile. However the 3 m deep, 1 m diameter small pipe entrance still had most of the tap root of a now dead tree *in situ* when the cave was first entered. Finally it is important to note that the solution pipes in such limestone are the result of secondary calcite deposition along the walls of leached passageways through the sand, and tree roots although being important, may not be the only agent involved.

Stream entrances. At Bat Ridges these are actually streams formed from the overflow from the Bat Ridges Lake. Water enters the lake from the north during the wetter winter months and during this time River Cave (BR-4) becomes an active inflow cave, whose waters resurge into the southern end of the lake. The inflow entrances show more typical stream inflow characteristics than any other caves of the area.

Many caves are multi-entrance, for example, Chimney Cave, Bat Cave and BR-4, and often show more than one type of entrance, for example, Chimney Cave has three collapse entrances and a solution pipe.

The whole area shows interesting examples of karst features. V.S.A. is currently undertaking an extensive surveying program of the caves with the immediate aim of production of an atlas of the interrelated karst forms of the area.

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KARST STYLES IN WESTERN AUSTRALIA

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Abstract

Western Australia contains several very different karst terrains. The differences can be related to contrasts in lithology, structure and climate. These three factors interact in complex ways so that often two or three of the factors are involved in the interpretation of each feature. The karst areas described are Devonian reef limestones of the West Kimberley; Tertiary open shelf limestone of the Nullarbor and Barrow Island; and Quaternary eolianite of the south-western coast.

INTRODUCTION

An outline of the different styles of karst that occur in Western Australia will serve as an introduction to speleologists visiting Western Australia for the first time. Traditionally geomorphic features have been interpreted as resulting from the interaction of three independent variables - lithology, tectonic history, and climate. Analysis of the origins of the various distinctive features of the regions shows that although lithology, tectonics and climate are the major factors determining the features, they are not independent variables but interact in complex ways. The areas discussed here are the Limestone Ranges of the West Kimberley, Barrow Island, the Nullarbor, and the South-western Coast.

SETTING AND CLIMATE

West Kimberley. The Devonian reef limestones in the West Kimberley form a belt 300 km long (Fig. 1). The climate is hot semi-arid with an average rainfall of about 500 mm. Most of the rain falls in the summer months with high intensity (10 to 20 mm per rain day, on annual averages).

Barrow Island. The island covers some 230 km^2, and lies 60 km offshore. According to West Australian Petroleum's records the average annual rainfall has been 200 mm. Onshore at Onslow the average rainfall is 265 mm with an average of 12 mm per rain day. Intense rainfall is associated with occasional summer cyclones (for example, 330 mm in 12 hours in March 1964) and whereas the West Kimberley rivers flow annually with the monsoon, river courses on Barrow Island only flood for a few days every five or ten years.

Nullarbor. Tertiary limestones of the Eucla Basin cover 130 000 km^2 in Western Australia, but only the higher rainfall area near the coast is described here. The climate is arid to semi-arid with rainfall (amounting to 200-300 mm annually) concentrated in the winter months. Average intensity is lower than in the preceding areas (3 mm per rain day at Eucla).

South-western Coast. The area considered here is a narrow belt of coastal dunes stretching from Cape Leeuwin in the extreme south-west to Dongara 600 km to the north. The belt of dune limestone extends much further north

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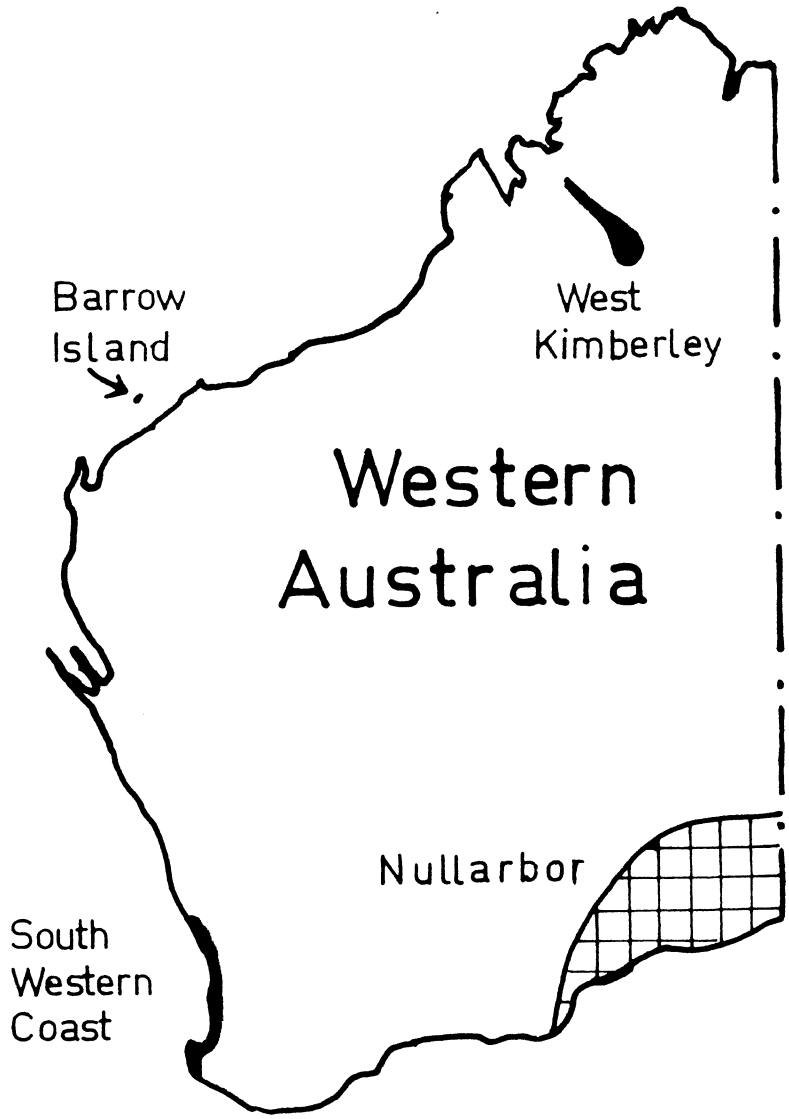
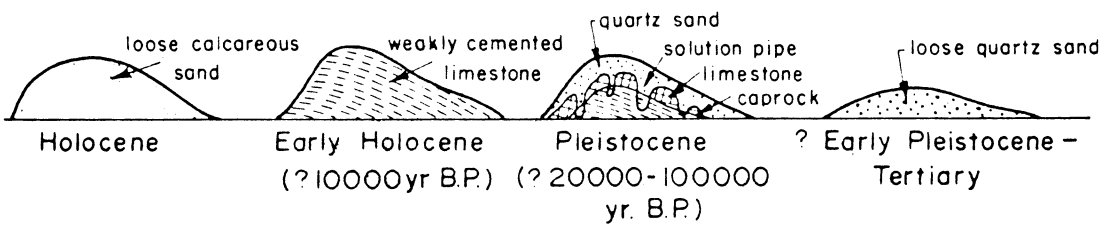


Figure 1 Location map

Figure 2

WEATHERING SEQUENCE OF CALCAREOUS DUNE SAND



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but karst features and knowledge of them are sparse. Rainfall varies from 1000 mm annually in the extreme south through 880 mm at Perth to 600 mm in the north. It is largely restricted to the winter months - at Perth 80% of the rain falls in the six months May to September.

LITHOLOGY

West Kimberley. The Limestone Ranges are the remnants of a reef complex developed along the northern margin of the Canning Basin 350 million years ago. The reef presumably grew in tropical waters and thus the lithology was partly climatically determined. The complex includes a barrier reef (for example, Napier Range) and several atolls (for example, Laidlaw Range). Limestone platforms were built up in horizontal layers of coral, algal and stromatoporoids together with their debris. The platforms were mostly rimmed by a reef margin of similar organisms in front of which was a steep talus slope leading down into deep water between the reefs. The fore-reef limestone tends to be impure and to pass downslope into siltstone brought in by rivers from the north.

Subsequent burial caused stylolitisation, recrystallisation and cementation of the limestone, resulting in a very hard limestone with negligible intergranular porosity.

Barrow Island. The island consists of Tertiary foraminiferal limestones that were laid down on a broad stable continental shelf.

Nullarbor. Limestone on the Nullarbor Plain consists of Tertiary foraminiferal, algal, and bryozoan shelf limestone similar to that of Barrow Island. The general absence of terrigenous material suggests that there were no major rivers flowing from the continental interior, as a result of low relief and low rainfall (that is, tectonic history and climate). Much of the limestone retains its high intergranular porosity, presumably because of a lack of later burial (tectonics) and the slight amount of groundwater movement (climate).

South-western Coast. A belt of limestone is formed along the western coast by the lithification of the carbonate-rich Quaternary coastal dunes. A few thousand years after the dunes accumulate they become weakly lithified. The sand commonly contains abundant quartz grains so that after some tens of thousands of years of weathering the surface of the dune develops a soil of leached quartz sand. Below the sand a layer of limestone becomes indurated and recrystallised. This "cap rock" is perforated by solution pipes and with prolonged weathering the limestone is reduced to pinnacles and finally to a heap of quartz sand (Fig. 2). Again, the very existence of carbonate-rich sand on the continental shelf is partly controlled by the low relief and low rainfall of the continent. The weathering progression described here is not well understood but the development of a cap rock with its rinds of secondary calcium carbonate ("kankar", "caliche" or "calcrete") is probably controlled by the rainfall being concentrated in a few months of the year, thus giving an annual wetting and drying.

TECTONIC HISTORY

West Kimberley. The reefs lie on a basin margin that remained tectonically active in the Carboniferous and Permian, resulting in the burial, faulting,

tilting and jointing of the limestone. The area was planed by erosion. Rejuvenation of the drainage in the Tertiary exhumed the reef limestone by eroding the soft inter-reef siltstone, so that the carbonate platforms now stand above the modern valleys almost as if the Devonian sea had just drained away.

Barrow Island. This is the crest of an anticline whose growth has continued intermittently into the late Tertiary or Quaternary.

Nullarbor. The Nullarbor Plain is an emerged sea bed that has been modified by very minor faulting and by minor stripping. Air photos indicate a regional joint pattern but the rocks are relatively soft and regular joints are not obvious in outcrop.

South-western Coast. The dune limestone is geologically very young and has not undergone any recognisable tectonic deformation.

MAJOR SURFACE FEATURES

West Kimberley. The overall trend of the reef complex is controlled by the tectonic structure of the basin margin, and in some cases the shape of individual ranges is controlled by faulting. However some features are related to the shape of the growing reef (for example, the spine at the southern end of the Laidlaw Range, and the cliffs along the front of the Napier Range which mark approximately the limit of reef growth).

The ranges are flat-topped, standing some 50-100 m above the plain, and these flat tops are the remnants of an earlier erosion surface.

Barrow Island. Most of Barrow Island displays a gently-domed planation surface that is presently being dissected. At the southern end is a low-lying down-faulted area. Coastal cliffs are developed around much of the island, particularly on the exposed western coast.

Nullarbor. The area consists of a plateau rising gently northwards from about 60 m above sea level to about 250 m inland. Coastal cliffs (in places modern; in places emerged) form an abrupt southern margin. Inland, the arid climate has developed a deep calcareous clay soil with a layer of secondary concretionary calcium carbonate ("kankar") but nearer the coast the soil has been blown eastwards leaving a stony plain. The plain is gently sculptured by solution: in some areas into circular "dongas" 1-2 km across and 2-5 m deep; in other areas into subdued parallel ridges with a relief of 5-8 m spaced 0.2-1 km apart and separated by flat clay-floored valleys.

These features probably result from a combination of low rainfall and low initial tectonic relief - runoff ponds locally and does not develop an integrated surface drainage system.

South-western Coast. The topography of the eolianite belt is basically dune topography.

DRAINAGE

West Kimberley. The intense summer rainfall has developed a fairly well integrated surface drainage system, but some goes underground to emerge in springs at the margins of the ranges. A few major rivers flowing from the Kimberley Plateau to the north have been superimposed on the limestone and

now flow in steep-sided gorges (for example, Windjana Gorge) or have suffered underground capture (for example, Tunnel Creek, Cave Spring). Much of the drainage pattern is strongly joint-controlled.

Barrow Island. Apart from the area south of the fault, Barrow Island has a well developed radial drainage pattern dissecting the domed old land surface (Fig. 3). There is no sign of drainage going underground. This is largely a climatic feature. Rainfall sufficient to cause runoff occurs only rarely and on those occasions it does, it is usually associated with a cyclone and very intense. Thus the rainfall pattern results in extensive fluvial erosion and very little solution of the limestone.

Nullarbor. On the Nullarbor plateau there is a very limited development of a drainage system and it is mostly relict. When rain is sufficiently intense to develop runoff, there is mostly local ponding followed by evaporation and some infiltration. Most of the infiltrating water is absorbed by the clay soil and later lost by evaporation, concentrating salts carried by the wind and rain. Thus a small, saline proportion of the rainfall reaches the water table. In the Madura area, the combination of low recharge and highly permeable limestone results in caves having lakes of saline (10 000 ppm) water within a few metres of sea level as much as 60 km from the coast.

Some major allogenic rivers (for example, Ponton Creek draining 70 000 km^2) pond on the edge of the plateau and probably have done so since the Miocene emergence.

South-western Coast. No surface drainage occurs on the dune limestone. The permeability of both the original dune and of the quartz sand soil that develops later is sufficient to cause complete absorption of rainfall. In a few areas the limestone belt is broken by major rivers that have maintained their course to the sea, but because of the generally low rainfall inland, many rivers have had their courses blocked by the belt of dunes, and the water seeps through, dissolving caves.

MINOR SURFACE FEATURES

West Kimberley. Where the margin of a limestone range has a few tens of metres of relief there is a lateral progression from the old undissected soil-covered land surface in the interior, to areas of bare limestone with joint openings, to areas of karst corridors where the joints are several metres wide and have flat floors, to areas of box valleys with level floors connected with the alluvial plain, to areas of marginal amphitheatres and isolated limestone towers at the edge of the range. This erosional sequence is strongly joint controlled and the near-vertical limestone surfaces are spectacularly fluted (Rillenkarren). This type of karst has commonly been thought to be the product of tropical weathering but recently it has been argued that such features can develop in any climate and the requirement is an impermeable limestone with extensive jointing; that is, the control is lithologic and tectonic rather than climatic. Nevertheless, the solutional sculpturing of outcrops points to surface solution of limestone as being a major process in the West Kimberley, despite the modest rainfall, and this may be due to the association of the rainfall with high summer temperatures.

A minor weathering agent is the spalling of crystalline limestone due to fires. The semi-arid climate restricts vegetation to spinifex (*Triodia*) which burns every few years during the dry season. The intense heat from the

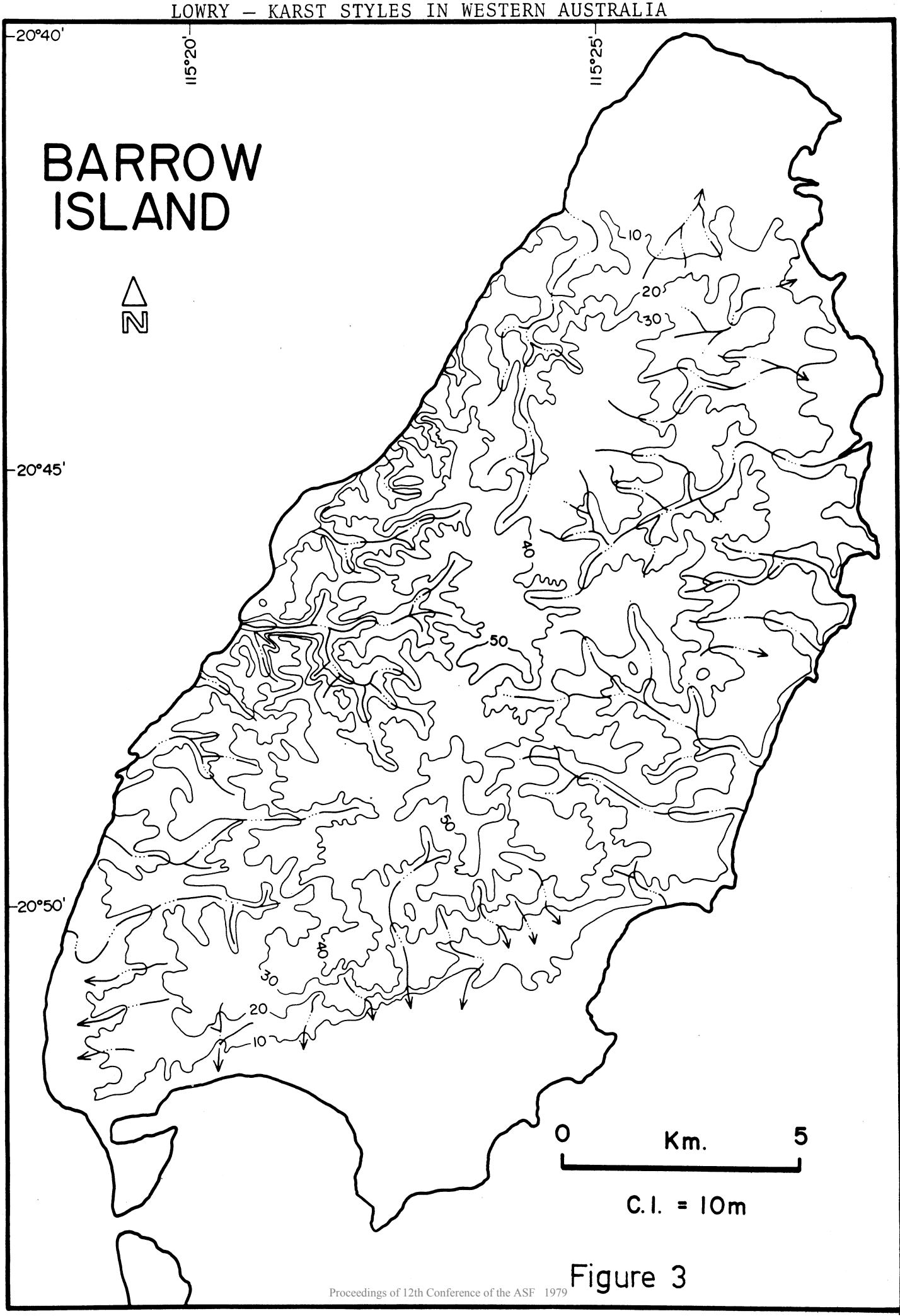
20°40'
115°20'
115°25'
BARROW ISLAND
N
20°45'
10
20
30
40
50
50
40
30
20
10
20°50'
0
Km.
5
C.I. = 10m

Figure 3

the fire causes spalling around the base of outcrops.

Barrow Island. Much of Barrow Island is soil covered. The scattered outcrops show minor solutional fluting, together with sculpturing that may have developed while covered with soil. Vertical rock faces along the coast and along some river valleys have minor rock shelters at the base. These appear to be formed by salt-wedging of flakes and grains of the porous limestone and are thus partly related to the low rainfall.

Nullarbor. Much of the Nullarbor is covered by residual and colluvial clay and silt. Limestone pavements are smooth or show only small scale solution pans. In a few places, large unjointed pavements have developed rock holes about 1 m across and 1 m deep. They hold water for several months after rain and their enlargement is probably speeded up by the biological activity of algae and decaying animal carcasses.

South-western Coast. Where limestone is exposed by deflation or coastal erosion, solutional pitting is comon but fluting is rather minor. In the northern part, smooth crusts of caliche are common.

CAVES AND DOLINES

West Kimberley. There are relatively few major caves known in the Limestone Ranges although there are a large number of short cliff-foot caves and overhangs of anthropological interest. Upper Cave Spring System with more than 2 km of passages is the most extensive mapped system. It is a striking example of a cave system developed by the opening up of a grid of joints. The Tunnel is a spacious cave developed by underground capture of a river superimposed on the Napier Range. There is a collapse doline in the centre of the cave, but in general roof collapse is not an important process in West Kimberley caves because of the hardness of the rock. Calcite cave decoration is moderately well developed. A feature of Cave Spring Middle System and of Old Napier Downs Cave is floating calcite which forms on pools that are left by the summer flood and that evaporate throughout the dry season.

Barrow Island. Just as climate and tectonics have inhibited the development of surface karst, so there is very little cave development. The largest known cave occurs in a headland on the west coast about 20 m above sea level. It appears to be an ancient cave unrelated to the present erosion processes, and to have been breached accidentally by the retreat of coastal cliffs. The cave is about 100 m long; it has a flat earth floor and massive calcite decorations. Another small cave occurs near the Barrow Fault where it has been opened by solution along a fracture parallel with the fault. The doline is about 3 m by 1 m at the surface, and the cave extends horizontally for 3 m at a depth of 5 m.

Nullarbor. On the Nullarbor there are two main styles of cave. The "deep caves" of large dimensions are developed close to the level of the present water table some 70-110 m below the plateau. The caves have stoped their way upwards by roof collapse and in places have breached the surface to form spectacular collapse dolines. There are also "shallow caves" developed in the upper 5-15 m of the plateau. This rock is often rubbly and perforated by small tubes and cavities, and this may be a weathering response of a fairly porous poorly-jointed limestone to an arid to semi-arid climate. The shallow caves often connect with the surface by way of circular blow-

holes that have probably developed by upward stoping by granular disintegration at the top of cave roof domes. Many caves are modified by granular disintegration of the roof and walls. The Dune in Mullamullang is a spectacular example. This occurs where saline water seeping through the porous rock evaporates as it reaches a cave wall. The dissolved salts are precipitated in the pore spaces and crystal growth wedges off fragments of rock. In a few caves halite crystals are extruded from the walls. Thus the presence of this rare speleothem is due to a combination of climate and lithology. Gypsum occurs in several caves but calcite speleothems are relatively uncommon.

South-western Coast. Most caves are associated with allogenic drainage that has been blocked by the dune belt. The water ponds against the dunes and seeps through, developing caves with flowing streams. Roof collapse is usually extensive and may extend to the surface, forming a collapse doline. Many dolines have overhanging lips caused by the hard cap rock. If the cap rock fails to collapse, the soil may fall through the solution pipes to give a chimney-like entrance above a soil cone.

In many caves, collapsed rock hides the stream and blocks the passage so that only short segments of dry cave are accessible. Near Augusta there are a few caves developed by solution at a water table with no perceptible gradient, and the cave consists of low anastomosing lake-filled passages of variable width. Calcite decoration is abundant in the high rainfall area in the south where thick sandy soil with dense vegetation results in aggressive water percolating into porous limestone - ideal conditions for getting calcium carbonate into solution. At the northern end of the belt, rainfall is lower, and as a result the soil is thinner and the vegetation sparser. Not surprisingly the northern caves are mostly sparsely decorated.

DISCUSSION

In a paper of this length it has been possible only to bring out the contrasting highlights of the four areas, and an attempt has been made to interpret the contrasts in terms of the complex interaction of differences in lithology, structure and climate. There is one other important influence on the morphology of the West Kimberley and Barrow Island areas - that is the dissection of a Tertiary planation surface. This has not been stressed because there is no comparable feature on the Nullarbor (the surface is still essentially that of the sea bed) or on the South-western Coast (the limestone is too young and soluble).

An attempt could have been made to extend the cause-and-effect arguments a step further by relating lithology, structure and climate to the plate tectonic history of each area and the general circulation of the hydrosphere and atmosphere, but at this level the generalisations become rather too great too be useful. For example, it could be pointed out that in the Devonian the West Kimberley was near the Equator and was therefore likely to develop reefs, but the perfection of preservation and of present exposure could not have been predicted. Similarly, the Nullarbor is tectonically undisturbed because the basin is on an Atlantic-type continental margin, yet Barrow Island is in a comparable position on the plate but is tectonically active.

ACKNOWLEDGMENTS

The bulk of this paper is derived from a mixture of my observations and those of J.N. Jennings. The paper could not have been written without his extensive documentation and interpretation; and it would not have been written without his enthusiasm and encouragement over the years. West Australian Petroleum Pty. Limited provided some drafting and typing assistance and I had helpful discussions about Barrow Island with W.H. Butler.

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In a paper as brief as this it is not possible to document previously published ideas and argue new ones. Instead, key publications are listed here to enable the interested reader to explore the subject further.

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THE AUGUSTA AREA, SOUTH-WEST OF WESTERN AUSTRALIA: THE REASONS FOR ITS KARST MORPHOLOGY

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Abstract

Within several square kilometres of Tamala Limestone, south-east of Turner Brook, are found the only known extensive nothephreatic shallow watertable maze caves in the coastal limestone of Australia. The physiography, soils, vegetation and distribution of karst features in the area are described, and an hypothesis proposed to explain the occurrence of maze caves in this restricted area.

GEOLOGY AND PHYSIOGRAPHY

The Tamala Limestone of the Augusta area is underlain by hard igneous rocks of the Leeuwin Block. This block is separated from the Perth Basin to the east by a series of faults, the principal of which is the Dunsborough Fault (Lowry, 1967; Playford, Cockbain & Low, 1976). To the west there is no fault, the Precambrian rocks of the Leeuwin Block extending out into the Indian Ocean. The small section of this block which has not been eroded by wave action, corresponds to the Leeuwin-Naturaliste Ridge. The Precambrian in the Augusta area is granite-gneiss. Also in the Augusta area are anticlines in the granite-gneiss dipping roughly north-west.

There are three sets of joints in the granite-gneiss (Williamson, Loveday & Loveday, 1976) at roughly 180°, 240° and 270°. The 240° set is the most enlarged by wave action on the present coastline. This is also the dip of the axes of most synclines and anticlines in the block. The coastline south-west of the Augusta caves is relatively straight for about 10 km along the 270° joint orientation.

The Precambrian is overlain by a series of late to middle Pleistocene marine and aeolian deposits (see Fig. 1). The aeolian deposits visible on the surface generally increase in age from west to east. The older are podzolised silicious dunes which occur on the north-east edge of the limestone belt. These may represent fore dunes as do similar deposits at Capel (Playford *et al*, 1976). These dunes are now much reduced in relief, though still visible, sloping up from the laterite plains of the Blackwood Valley and down towards the limestone.

At the contact with the limestone, a marked sharpening of the slope of the aeolian calcarenite is evident. This is the result of greater leaching of carbonate where it overlies a silicious sediment.

On the surface, the next oldest bed is the oldest aeolian calcarenite but underlying this deposit and evident in Jewel Cave and Easter Cave is a beach ridge deposit which itself directly overlies a marine erosion surface developed on the granite-gneiss. This surface shows wave-cut gutters (along 240° and

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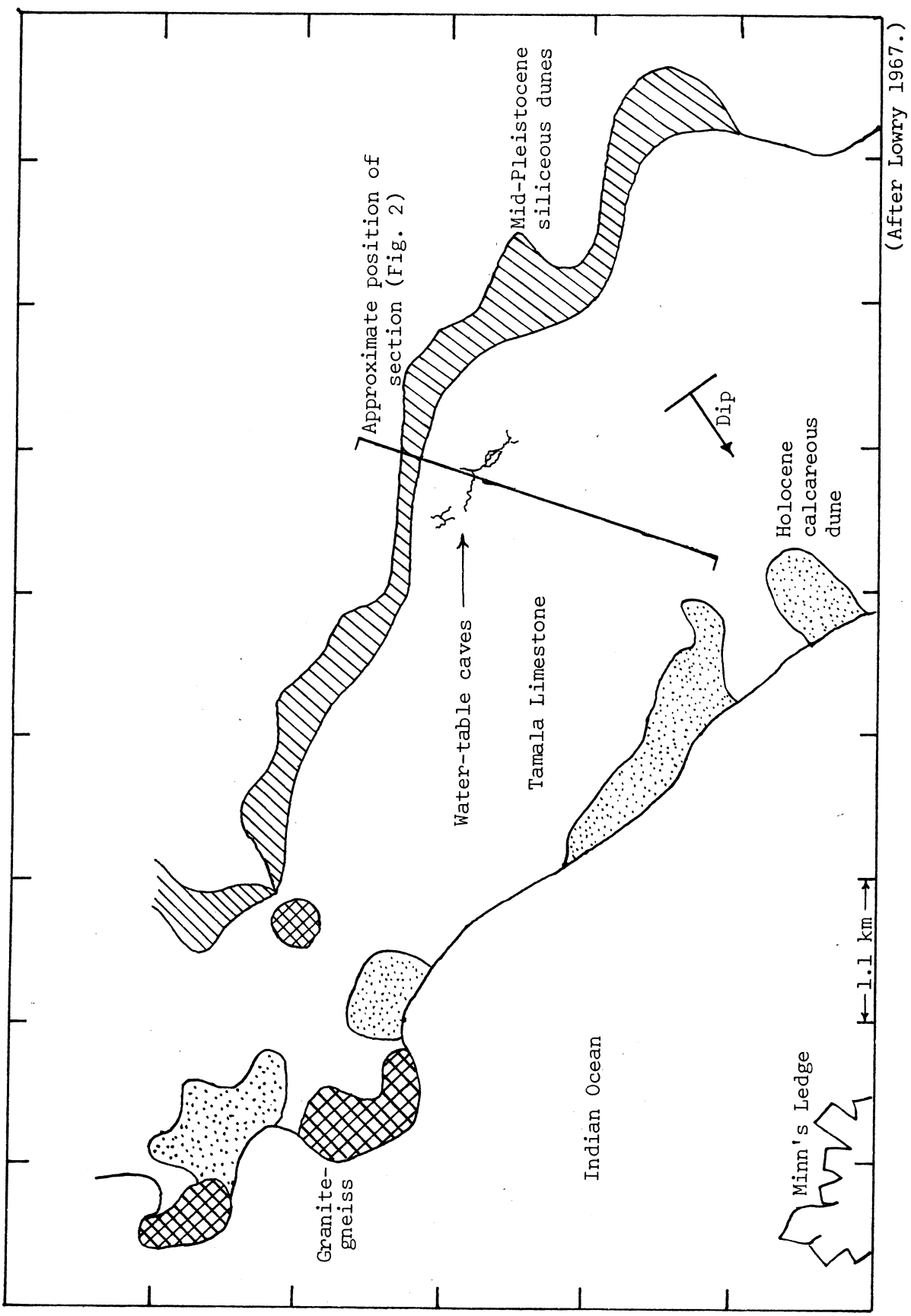

Fig. 1 Augusta area - surface geology and location of water-table caves.

270° joints) and large rounded boulders. All is very weathered and kaolinised. The beach ridge is a well laminated calcarenite with no obvious fossils on an admittedly cursory investigation. The lamination is enhanced in corrosion passages. Dips are small (10° to 12°) with in places overlying cross bedded deposits which may represent storm ridges.

The aeolian calcarenite overlies these deposits and shows the wide-spaced bedding, soil horizons, *Bothriembryon* (native terrestrial gastropod) beds of aeolianite. A terra rosa soil with bands of ferricrete is developed above the limestone. In places this ferricrete has fallen through solution pipes into caves, for example, the Gravel Grovel in Easter Cave.

Overlying and to the west of this older calcarenite is a younger aeolianite. This aeolianite has cavern collapse up into it, for example, Old Kudardup Cave, but no development of water table maze caves has been found. Similarly, there has been no development of the caves extending under the youngest aeolianite. This aeolianite is poorly vegetated, unconsolidated sand. It has a poorly developed alkaline soil. In some places down slope of the dunes, this soil has become cave fill. The large size of the calcited drip pools in Old Kudardup Cave is probably the result of the calcareous nature of the fill.

Each aeolianite has its characteristic soil and faunal association. Bain (1962) distinguished several stages in the formation of these dunes. Bain also suggested that drainage was mainly off the younger dunes and aeolianites and to the north-east. There is evidence that this is not entirely the case. Recent experiments have shown that the direction of flow in the Flat-roofed Chamber lake in Jewel Cave is to the south-west (R. Webb, pers. comm.).

At the contact of the younger aeolianite and the old aeolianite is a steep slope, almost a karst pavement, developed on the cap rock of the younger aeolianite. At the base of the slope are areas of karst pavement with very small solution shafts formed from runoff.

THE CAVES

The Augusta area is characterised by extensive shallow nothephreatic maze cave systems. Three reach down to extensive tracts of water-table development: Labyrinth (AU-16), Jewel (AU-13), and Easter (AU-14) Caves. A fourth, Moondyne (AU-11) Cave, has developed just above the present water table with some areas of maze. Other caves in the area are interpreted as collapses down onto such mazes.

Easter Cave is no doubt the most extensive with possibly 10 km of passages. Labyrinth Cave is the next most extensive with 4 km, followed by Jewel Cave with 3 km of mapped passages. Each cave is different in character. Labyrinth is characterised by a profusion of tubes along dip and strike, a relative absence of helictites and generally small passages. Corrosion passages in Labyrinth show a greater range in altitude. Jewel, near the edge of the limestone (north-east Flat-roofed section) and the Gneiss Extension of Easter Cave are characterised by wide sandy-floored flattener passages. Jewel has more tubes than Easter while Easter has massive wide corrosion chambers and collapse chambers. Also common in sections are networks of tubes and rifts, that is, tubes which have become rifts due to dropping watertable, for example, the CEGSA Extension in Easter Cave. Similar cross-sections of the same origin are seen in Nurina Cave, Nullarbor (Lowry & Jennings, 1974). Easter Cave shows a greater profusion of spongework than Jewel or Labyrinth Caves. There is also a north-east to south-west increase in spongework within Easter Cave.

The caves contain a profusion of secondary calcite forms. Forms characteristic of highly supersaturated groundwater occur in Moondyne (Lux Flakes), Jewel (Pendulites and volcanoes) and the Gondolin-Crystal Labyrinth sections of Easter Cave (Pendulites and volcanoes). The relative scarcity of helictites from Labyrinth Cave may have a lithological reason.

The passage orientations are along dip and strike (Bain & Lowry, 1964). The major overall trend of both Easter and Labyrinth is along the strike. Overall the systems are found in a narrow generally strike-orientated band between the youngest aeolianite and the old silicious dunes. Gneiss and beach-derived sediments show a south-west slope in Jewel Cave.

GEOLOGICAL HISTORY, HYDROLOGY AND SPELEOGENESIS

The following series of events is postulated to explain the existence of these large complex caves in such a restricted belt.

The first event would be a marine transgression resulting at its height in a beach plus foredunes at the edge of the present limestone belt. Such a transgression would have destroyed its own foredune and beach deposits as it progressed inland. This transgression in such a high wave-energy area would have removed most of the soft sediments in its path - foredunes, soil and laterite profiles and kaolinised gneiss - and produced wave-cut gutters in the underlying gneiss.

The regressive phase would have resulted in a strip of beach sediments overlain by beach storm ridges, foredunes and more extensive dune belts (Fig. 2). The regressive beach strip would have been laid down on a gently sloping south-west surface of gneiss with wave-cut gutters. The beach deposits would have a higher proportion of silica and molluscan carbonate fragments left behind as a lag deposit when the more platey and light fragments (for example, red algae) were winnowed out by wind action on the beach. Its dip would parallel the gneiss surface beneath. Due to the action of prevailing winds, the aeolian deposits would dip north-east and strike north-west at much steeper angles (up to 30°) than the beach sediments.

Water would move down off the silicious dunes along the slope of the gneiss basement until the present water table was reached. Initially, this movement would be down the dip of the beach sediments (south-west). Water movement would also be channelled along the paths of the buried wave-cut gutters. Such gutters are visible in the Gneiss Extension of Easter Cave and the Flat-roofed Chamber section of Jewel Cave (Bell, 1978).

To the south-west the gneiss and the overlying beach rock would eventually dip below the water table. At this stage water movement, which occurs mainly at the water table surface would be across the dip of the aeolian beds if it were to move south-west. This would result in a 90° switch in the direction of water movement, the water following along the strike of the aeolian beds - north-west to south-east. Movement in this zone would be much slower.

In the section of the limestone where water moves down the dip or the beach sediments following the path of wave-cut gutters in the gneiss, wide low sandy passages occur, oriented in Jewel mainly along the 240 joint set of the granite-gneiss and the Gneiss Extension of Easter along the 270 joint set. Further downslope strike tubes and passages start appearing at different levels reflecting different water table levels.

The greater number of tubes and greater altitudes in corrosion forms in Labyrinth compared to the two other caves to the south-west, suggest that

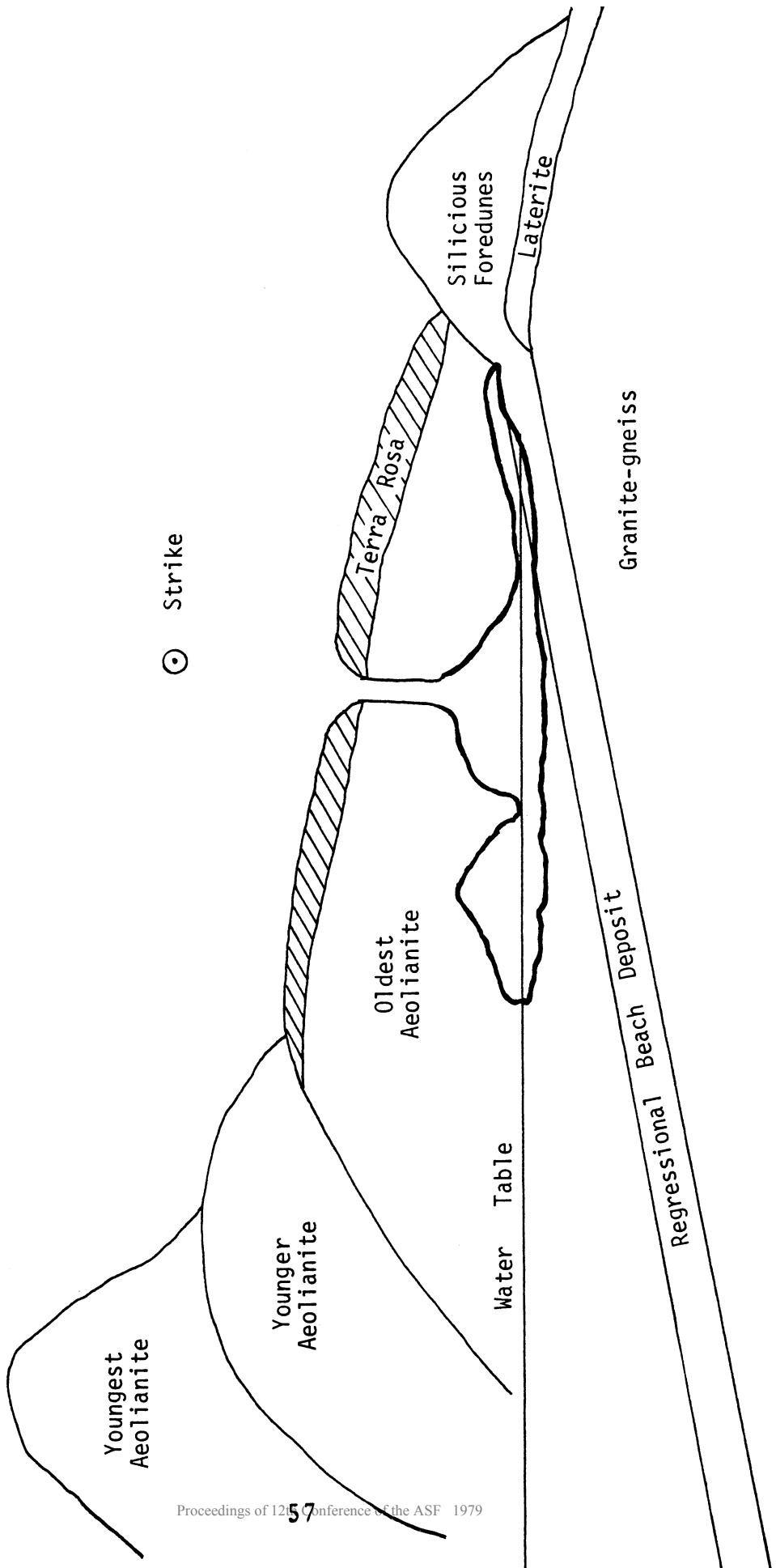

Fig. 2. Augusta caving area - north-east to south-west cross section

the slope of the water table along the strike is north-west to south-east. Tubes are typical of a fairly fast phreatic situation as postulated by Ford (1971). A reduction in the rate of movement of water would result in large spongework mazes. This is the situation in the south-west sections of Easter Cave, where movement is slow and along the direction of slope to the south-east. A rise in water table may reduce the rate of movement of water in a particular area and hence the resulting passage morphology to spongework mazes. Similiarly a drop in water table may result in tubes. In the Y Junction area of Easter, a large collapse block has a mini-cave system in it. This shows the only well-developed one level tubes in the area. In the upper sections of the water table thalweg, rises and falls in the water table will not greatly affect the flow rate and down cut tubes, as in the CEGSA Extension mazes, will occur.

It is the widening resulting from slow-flow conditions that causes over widening and resultant collapse. It is in these sections that entrances are likely to occur.

This model invokes water movement through the silicious dunes to the north-east into the limestone belt in the formation of water table caves. Water movement, from the vegetated calcareous dunes to the west of the limestone, no doubt occurs and is quite major in terms of volume. However, it seems to play no part in cave formation, probably because its waters are saturated in carbonate and low in humic and carbonic acids due to the poorly developed soil. This is supported by the abrupt truncation of caves at the edge of the new dune.

The importance of downward percolating water in the region of the old and younger aeolianites and the beach sediments, is problematic. Sections of cave such as the north end of the Flat-roofed Chamber section in Jewel are devoid of formation and virtually raining with presumably aggressive drip water in early spring. This water then moves rapidly down slope over sand covered gneiss slopes to the lakes below. It is probably only coming through a thin covering of limestone, overlain by silicious dunes. Percolation water in saturated carbon dioxide/carbonate equilibrium can be aggressive on mixing with ground water (Bogli, 1971). With low ground water levels drip water may on losing carbon dioxide to cave air, deposit carbonate, for example, calcite crystal films just past the Gravel Grovel. With high levels when water is right up to the roof, mixing of the waters will corrode the roof into nondirectional scallops and spongework.

The continuation of the Easter and Labyrinth mapping, more accurate levelling within and between the caves, geological mapping following on from the cave mapping, water sampling and analysis, air tracing and specific experiments should in the next decade subject the above hypothesis to a thorough test and no doubt modify it considerably. We have tendered it here as an incentive to such projects. In few places in the world are there maze caves of such an extent as to give access to large areas of a karst system in rocks with high intergranular porosity.

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STREAM CAVES IN THE COASTAL LIMESTONES OF MOIST SOUTH-WEST WESTERN AUSTRALIA

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Abstract

Current ideas on the formation of stream caves in the higher rainfall areas of south-west Western Australia (S.W.W.A.), Yanchep southwards, are reviewed. The effects of stream flow regime and rate of flow, topography, the underlying basement rocks, pre-limestone marine transgressions and collapse on the three parts of the stream cave hydrologic system (the insurgence area, the between cave, the exsurgence area) and on the resulting karst landscape are discussed.

In the interest of digestibility, I will consider the stream cave systems of the coastal limestone , from Yanchep southwards, of south-west Western Australia (S.W.W.A.) in three sections:

1. the insurgence
2. the "between" cave
3. the exsurgence

This initial discussion is restricted to caves from Yanchep to Augusta in the 760 to 1270 mm rainfall area of S.W.W.A. Further north from Perth the increased aridity and different underlying geology produce, due to the interaction of a large number of resultant factors, a vastly different picture of spelean hydrology.

INSURGENCES

In the 760 to 1270 mm rainfall area of S.W.W.A., present cave streams are all small (0.014 cumecs) streams with small catchment areas. Larger streams were able to maintain a path through the encroaching dunes which later became limestone (Jennings, 1968). The only exception to this would be Ellensbrook which only traverses the limestone for the short length of Meekadorabee Cave (MR-9), the only through cave in the coastal limestone (from insurgence to resurgence). In most of Witchcliffe the streams entering the limestone drain swamps to the east. There is a gradation from inflows where streams flow freely into the limestone, to those where part of the stream course is blocked by sediments (sand, collapse boulders), to those where the entire stream drainage is sand covered.

(1) Mammoth Cave (WI-38) best represents the first type of inflow: here the stream, which drains the Nindup Plain, flows freely into a large open cave. When the swamp feeding the stream is full and 50 mm or more of rain falls in a short period, for example two hours, a flood pulse will move through the cave causing rises in water level up to a metre and damage and inconvenience to the tourist operation (Yates, 1973). Only in low flow conditions does the stream flow under the sediments of its bed (sand, breccia, organic matter). The stream is very seasonal and dries up completely in Mammoth Cave in summer. Further downstream in Terry Cave (WI-47) and Conference Cave (WI-44) the stream will continue to flow even in summer (indicating sub-bed flow at the inflow), though in late summer '77/'78 the flow was only a trickle in Terry Cave.

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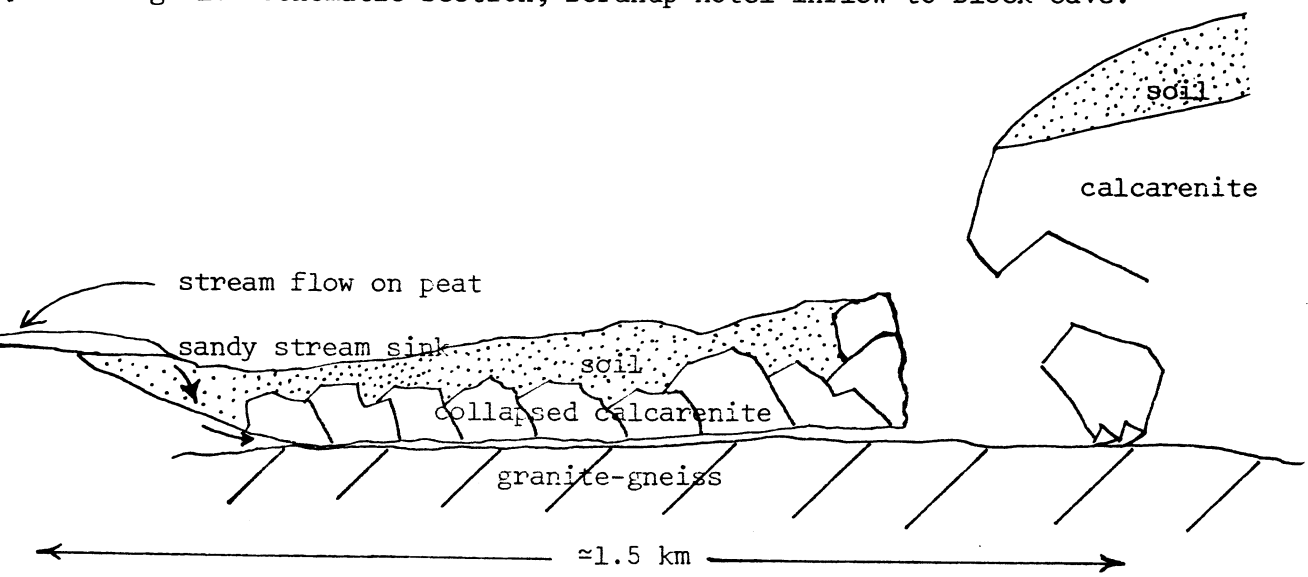
Fig. 1. Schematic section, Boranup Motel inflow to Block Cave.



(2) Breakneck Gully (WI-54), the inflow to the Arumvale system, represents the next stage in the gradation. Here the stream does not flow freely into the cave but sinks into rockpile in the base of a steeply sloping blind collapse valley. Stream flow regime in Breakneck Gully is similar to that of Mammoth. There is circumstantial evidence for flood pulses (evidence of recent scouring near the inflow point and evidence of 2.3 m high floods between recent caving trips (Hart & Williamson, 1975)) in Arumvale Cave (WI-57), downstream from the inflow. In low flow this stream also flows below its bed as evidenced by flow in Arumvale Cave and Arumvale Pipe (WI-56). Flood flow is perched on humic material above sand. There is a 3 m waterfall in this material just upstream of the inflow point.

(3) The next stage in the gradation is represented by WI-88, the inflow behind the old Boranup Motel. Here a stream which drains the swamp to the east of the old Boranup townsite flows south of the townsite to sink in a circular sandy depression (WI-88) at about the contact with the limestone. From this point to Block Cave (WI-106) there is a blind collapse valley of subdued relief (so subdued it was not noticed before the clearfell). Little outcrop or rockpile is is visible as most of the eastern slope of the roughly north-south fossil dune ridge is covered in thick yellow sand as is the blind collapse valley. Schematically the situation may be represented as in Fig. 1.

(4) The next stage in the gradation is represented by the blind valley leading to Mill Cave (WI-59). The valley is off the limestone and shows no appreciable upward slope towards the limestone except for the last 30 m where collapse limestone blocks may be found. The stream draining the west end of the swamp near the Boranup townsite flows across Caves Road and becomes lost in deep yellow sand. A subtle general depression leads in two directions: one to the inflow near the old mill site (near which water has been seen to collect in winter), the other further north to a sand filled valley (WI-76) leading to Mill Cave. No surface water has been observed in this latter valley. This all occurs within a broad westward indentation into the limestone filled with quartz sand.

The sand fill or the inflow valley in this system acts as a damper on flood pulses; rather the stream in Strong's Cave (WI-63) rises and falls in response to the general seasonal increase in runoff associated with the winter rains. The response is delayed by the sand fill and the highest flow rates are seen in early summer in distinct contrast to the Mammoth Cave system where flood pulses can occur within hours of heavy rain.

This gradation could be taken to represent a chronological sequence with the free inflow representing the youthful stage and with collapse and downslope movement of sand plus dissolution of the collapse material alternately producing the Mill Cave inflow situation. However factors other than time must be involved as all these systems are, to the best of my knowledge, of approximately similar age. The two main factors thought to be involved in determining inflow type are:-

1. flow regime of the inflow stream and
2. relief of limestone behind the inflow.

Mammoth Cave stream, although seasonal, shows a relatively large prolonged surface flow over the wet season. Breakneck Gully stream is slightly less reliable. The stream flowing into the Boranup Motel inflow is rarely seen to flow.

In southern Witchcliffe, for example Mill Cave to Breakneck Gully, there is limestone of high relief just inland of the inflow points in the form of a fossil dune ridge running from Mannup Cave (WI-60) to Breakneck Gully. Large amounts of B horizon yellow quartz sand have moved downslope off this ridge, blocking with sand the inflow of all but the large Breakneck Gully stream. In northern Witchcliffe (Mammoth Cave to Swamp Inflow (WI-87)) the relief is much reduced and even small, intermittent streams such as the Rudduck Cave (WI-51,52) stream are not blocked by sand and instead sink into a smaller version of Mammoth Cave.

The only area of the northern Leewin-Naturaliste where inflows have been investigated is the Quinninup area in Cowaramup. Here no surface streams are apparent, the water flows through soil cover off a limited catchment on a gneissic hill to the east of the limestone. The only evidence of inflows (Williamson, 1977) are two indentations into the limestone caused by collapse and dissolution with an area of dark seasonally boggy soil nearby. These two inflow points may correspond to the two streams on gneiss in Quinninup Lake Cave (CO-1) to the west of these points. Recent observations at Yallingup and Margaret River suggest leak in the creek situations may play an important role in these areas.

In the Blue Rock Cave (WI-58) area in central Witchcliffe, a series of fissure caves parallel the contact which itself is a steep scrubby cliff. Here, it is thought that, rather than a discrete stream entering the limestone, the groundwater associated with the seasonally rising and falling swamp is, under cover of sand, undercutting the limestone and causing the collapse of massive blocks resulting in the fissures. The fissures are at right angles to the direction of flow which is thought to be westward where this sheet flow collects itself up into a stream as evidenced by the more typical collapse dolines (F. & B. Loveday, pers. comm.).

THE "BETWEEN" CAVE

STRUCTURAL CONTROL BY UNDERLYING BASEMENT ROCKS

Recent underground and surface mapping of the southern Witchcliffe area by the Loveday's has shown the trends of a good sample of stream caves. Bastian (1964)

and Jennings (1968) suggested that the streams which predate the limestone are following the old valley system they eroded before the dune cover changed their style. Recent work (Williamson, Loveday & Loveday, 1976) in Strong's Cave has brought into the picture the role of marine erosion forms associated with Pleistocene transgressions determining variations in stream flow within this valley.

The pre-dune topography consists of valleys and ridges of low relief in the granite-gneiss. These were subjected to marine transgression. The high wave energy of this coast cut gutters in the granite-gneiss along the three main joint directions (roughly north-south, northwest-southeast and southwest-northeast). The southwest-northeast set display (and still do on the present coastline) the largest gutters as this is the predominant direction of wave action.

In the regressive phase the sea would cover these gutters in beach sand, then storm ridges, then foredunes. Under the sand cover the granite-gneiss was subjected to deep chemical weathering in inter-glacials. Strong's Cave represents the upper limit of the last transgression.

The deep weathering of the granite-gneiss is a post-dune phenomenon (post-recessional). There is no reason such weathering cannot occur beneath dunes and later limestones. It will resemble the lower levels of the typical laterite profile but the upper levels of the laterite profile will be absent as, under that depth of limestone and near a streamway the interstitial spaces are permanently filled with water and hence not subject to the seasonal wetting and drying necessary for the formation of a laterite profile's upper regions (microcrystalline fericrete and aluminium oxides). Any deep weathering predating the beach deposit would have been removed by the marine transgression (wave action).

STREAM DIVERSION

Thus the cave stream flows in a broad shallow valley with a system of marine gutters inside it. While its general trend and destination is controlled by the valley shape (itself joint-controlled) its smaller scale movements are along the numerous marine gutters at its disposal. If collapse, blocks a gutter an easier route may be found using another gutter. Thus abandoned segments may be left. This has occurred on a small scale in two places in Strong's Cave and, on a much larger scale, in the case of the Mammoth, Labor (WI-112), Winjan's (WI-113), Kudjal Dar (WI-114), Boya Bouka (WI-115), etc system.

These streams may be pushed around in broad valley systems with a network of marine gutters by repeated collapses. This can produce as an end result quite large collapse depressions, for example the depsession (about 0.5 km across) between Golgotha Cave (WI-13) and the main Kudjal Yolgah (WI-9), Bungle Pot (WI-117), Budjar Mar (WI-144) system.

At Yanchep there is no impervious basement, relief is still more reduced, streams smaller, more sluggish and hence, more easily deflected by collapse with the water table lying closer to the surface. Because of this, large multiple collapse depressions are common and collapse right down to the water table. Generic series, from doline chains and clusters to swampy depressions to large lakes may be recognised (Williamson & Lance, 1979). These large swampy areas and lakes serve as significant areas for recharging the aggressiveness of stream waters in the karst.

PHREATIC FORMS ASSOCIATED WITH STREAMS

When sections of low roof mainly non-collapsed corrosion passage occur in streams with fairly open inflows subject to appreciable flood pulses, spongework pendants are formed, for example Conference Cave, Arumvale Cave and Connelly Cave (WI-48). In some cases these may have formed before downcutting lowered the stream to its present level. This is an active phreatic situation. The most spectacular active phreatic situation associated with a cave stream is Witchcliffe Cave (MR-1). This will be described in detail in the next section on exsurgences.

In other cases, backing up of streams may produce situations and forms which resemble more closely those formed in the nothephreatic condition of the Augusta caves.

Streams can back up in two ways:

(1) By rockfall and constrictions downstream. The main collapse in Calgardup Cave (WI-49) has occurred at the junction of two streams. The southern stream, at present backs up resulting in back waters off to the south of the active stream. There are collapsed side passages above this backwater. A short way into the northern section is a small side passage, initially a collapse chamber which drops down in two places to sections of typical, shallow nothephreatic maze. This is thought to have been due to backing up of the northern stream. Note: Jennings (1968) quotes a laboratory determined pH value for stream water from Calgardup Cave as being pH 5.8. The *in situ* value is probably even lower, as CO_2 may have been lost. This very low pH of stream waters close to the western edge of the contact may be why backwaters can corrode phreatic mazes. The collapse passages off the southern section are thought to have formed by collapse of such a nothephreatic maze.

At Quinninup Lake Cave, the southern stream is restricted to a very small defined course in the basement rocks, there is plenty of evidence of recent flooding in this section presumably when the flow rate became too large for the restricted channel.

(2) By an outside river at the outflow point. At Blackwall Reach, cave streams are backed up by tidal and other actions in the Swan River. The results of this and the Quinninup example will be discussed more fully in the next section on exsurgences.

EXSURGENCE CAVES

Bastian (1964) and Jennings (1968) remarked on the absence of known exsurgence caves in the Coastal Limestone of S.W.W.A. This they attributed to the lack of aggressiveness of stream waters by the time they reached the outflow points. Percolation water would be saturated and play no part in corrosion. Conto Spring (WI-90) and Leeuwin Spring (AU-27) typify this situation. At both these springs water exurges through fist sized tubes in the limestone.

Since that time several outflow caves have been found and documented as well as many more springs. However two of the large stream systems of the Witchcliffe area have yet to be traced to a resurgence.

Bobs Hollow Resurgence Cave (WI-82). This cave was found in 1972 by digging at the base of a cliff where a small stream exsurged (Caffyn, 1972). This gave access to a low, though fairly wide stream passage almost blocked with roof drip derived secondary calcite. Recently the final squeeze has been pushed

(Webb, 1978) and found to open into large chambers upstream. The existance of large chambers so close to the resurgence can be explained by the closeness to the north of the limestone contact and the size of the Bobs Hollow catchment.

Bobs Hollow stream takes water from Connelly Cave and a stream 1.5 km north of Connelly Cave. This insurgence must connect with the Bobs Hollow stream at some point between the upstream limit of Bobs Hollow Cave and the downstream limit of Connelly Cave, approximately doubling the flow rate as well as recharging the stream with aggressive water. This imput would also contribute to the mixing effects of different CO_2 / CO_3 = balances and different temperatures as it would be colder in winter and coming quickly off a largely granulitic hill with little time spent in swamps, it would be chemically different from water entering other imputs of the system.

The Connellys Cave stream is fed with waters from the WI-102 inflow, Swamp inflow, Rudduck Cave, Arnor Cave (WI-93), WI-94 and the inflow to Calgardup Cave, WI-50. Most of these inflows are relatively free of sediment (exceptions WI-94, WI-102 and Arnor) and a high rate of aggressive flow may be achieved in late summer. Caffyn observed yellow stained (by inference highly aggressive) water resurging from Bobs Hollow Cave during the heavy wet season of 1973.

Quinninup Lake Cave (CO-1). This has large collapse chambers, a large steephead valley with two exurgences in the valley feeding a lake backed up behind the fore dunes of the present beach. The steephead has formed by collapse so at one stage the two streams met underground. The largest chamber in area in the cave occurs between the two streams. The southern stream, the smaller, is flowing 5 m above the larger northern stream. Both streams flow on granite occurs as evidenced by passage morphology) have produced this large chamber. The inflow points for these streams are only 1.5 km to the east; the Coastal limestone belt at this point being only one quarter as broad as in the Witchcliffe area.

Similarly the spring YA-25 at Canal Rocks which has stream sediments in its bed and much collapse just upstream is on the western end of a 1.5 km belt of Coastal Limestone.

Witchcliffe Cave (MR-1). Witchcliffe Cave is a large abandoned outflow cave with evidence of a considerable flow of water under phreatic conditions. This must have been the largest underground stream in the Leeuwin-Naturaliste. The present stream which is 2 m below the floor of the present cave is not of sufficient size to cause such a large corrosion cavity.

The cave exhibits current directed roof grooves, and spongwork, bedrock pillars and pendants at the sides of the flow channel; plus undermined and corroded flowstones. It is developed mainly in a nearly horizontally bedded calcareous sandstone so a considerable quantity of silica sand residue must have been removed by the current. This large upper level may have been a flood bypass for the lower system.

The entrance area is practically choked with columns showing that the stream has been inactive at this level for a considerable time.

This exsurgence is perched high above Boodjidup Brook. That this reflects the relief of the underlying basement is evidenced by the presence of angular feldspar pebbles in the Coastal Limestone at the exsurgence. This corresponds with marine beds in Strongs Cave 51 m above present sea level.

The inflow points for the stream are not known, mainly due to lack of looking, but most likely are east of Blackboy Hollow Cave (MR-2), a very large collapse cavern with a dry stream bed lower level (M. Dall, pers. comm.). There are several appropiate indentations in the limestone contact worth investigating in this region.

BLACKWALL REACH CAVES

On the south bank of the Swan River, at Blackwall Reach, are several lines of cliffs with three known exsurgence caves (LW-8, LW-9 & LW-10). Entrances are either on or slightly above river level with some higher collapse crevice entrances. The Swan at this point is 18 m deep in the main channel which runs near the cliffs.

Each cave has one or two small streams associated with it. LW-8 is typical. The caves are developed in closely (Laminar) bedded calcarenites/calcareous sandstones which dips consistently 11 degrees to the west (Williamson, 1973), and is most likely of marine or beach origin; with some collapse up into overlying aeolian calcarenites.

The caves show processes of wave erosion and undercutting in the entrance areas at river level. Updip from the low presently active stream flattener is a traversible passage with a floor of silicious sandy stream sediment and collapse blocks all covered in mud. The roof and walls to a height of 1.5 m (2 m above present river level) show many examples of nothephreatic spongework. Tidal range in the Perth region is only 0.3 m at most. During periods of strong onshore winds the river level may rise 0.5 m or so. At such times (Williamson, 1978) the entrance area of the cave is filled with river (estuary) water and subject to fairly strong wave action and the cave stream is backed up.

This backing up would result in a mixing of saturated (with respect to carbonate) cave stream waters and similarly saturated marine waters (which in a good wet season may be brackish and not saturated) producing ponded waters capable of nothephreatic corrosion.

Cave development is thus limited to 100 to 150 m back from the entrances, below which, as a result of stream gradient, mixing can occur and this seems to be associated with the smaller streams. The large stream below LW-9 must be able to force back the river water and prevent mixing, thus restricting the extent of cave development, that is the smallest cave has the largest stream.

The presence of stream sediment and spongework 1 m above the present river level suggest the wind assisted backup of the Swan is not the only factor involved. Higher estuary levels were associated with the last sea level maxima or backing up of the river due to barring of the mouth before the removal of the bars by europeans.

CONCLUSIONS

Caves in the moist south-west of Western Australia are not particularly young for caves though their limestones are young for limestones. However they are remarkable in that very large collapse caves have resulted from small streams (0.014 cumecs is large). This is the result of:

(1) the incoherence of the rock and its inability to support even a short span, for example the largest chamber is found in the very friable limestone around Green Cave (WI-2).

(2) the extremely aggressive nature of the streams flowing from swamps to the east of the limestone belt. This is principally the result of humic acids; pH's of 5.8 have been recorded from caves near the swamp. Similar peaty waters in Ireland have produced fast rates (in this case post glacial) of cave formation (Ollier & Tratum, 1956). In the Irish situation high flow rates and flood pulses are common whereas at Witchcliffe chemically similar waters have produced large caverns from streams with lower flow rates over a period of 100 000 years or more.

Further north in the Leewin-Naturaliste, greater basement relief, increased downcutting during the pleistocene and a slightly reduced rainfall, make peaty swamps leaching the limestone less common. Open inflows are virtually unknown and caves generally less common and of a smaller size.

ACKNOWLEDGMENTS

I wish to acknowledge the many Western Australian cavers whose exploration, mapping and documentation has greatly assisted my own investigations. I wish to acknowledge the contribution of the surface and underground mapping of Barry and Fran Loveday especially in the southern Witchcliffe area as it greatly enhanced our knowledge of stream cave form and orientation.

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SIMULTANEOUS MULTIPLE LOOP CLOSURES FOR CAVE SURVEYS: A COMPUTER PROGRAM

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Abstract

The mathematics of a new least-squares procedure for cave survey loop closures is presented. Previously-published methods are briefly reviewed and it is suggested that the new method is superior, in both single- and multiple-loop situations. Brief description is given of a FORTRAN program for survey reduction incorporating this algorithm.

INTRODUCTION

The loop closure problem will be familiar to all cave surveyors. However careful we may be in making measurements, it is most unlikely that a survey station reachable by more than one path will be positioned unambiguously to within the plotting accuracy. Before the final plot is drawn it is therefore necessary to "adjust" the survey.

Closed loops (with a good closure scheme) actually improve the positional accuracy of the survey in the same sense that the average of repeated measurements of a single quantity is more reliable than one estimate. Of course, if the closure error is large we would not (or certainly should not) attempt to perform the closure - the data needs to be checked for such gross mistakes as reversed bearings, etc., and if all else fails a re-survey may be necessary.

Methods in common use for resolving closures include simple adjustment by eye, and separate distribution of X, Y and Z errors in proportion to leg lengths. Ellis (1976) suggests distributing errors equally between legs since this is the simplest method and, he claims, as likely to produce reasonable results as any other. If there are several interconnected loops, however, the simple methods require that closures be adjusted sequentially. This has the disadvantage that the early closures may force errors onto the remaining loops over and above those due to mere measurement inaccuracies. Precisely for this reason, most surveyors choose to adjust the "best" closure first.

The purpose of this paper is to show that the closure problem may be put on a firm mathematical basis. The problems attending sequential closure are avoided because the opportunity exists for adjusting any number of loops simultaneously. At least two papers (Schmidt & Schelleng, 1970; Luckwill, 1970) have treated the simultaneous closure problem. I claim some superiority for the new method, for reasons to be discussed later. Many cave surveyors are already using computers for data reduction - why not get the most out of them?

MATHEMATICS OF LOOP CLOSURE

For simplicity, we consider at first a survey traverse of N legs forming a single closed loop, as shown in plan view in Fig. 1. The generalisation to

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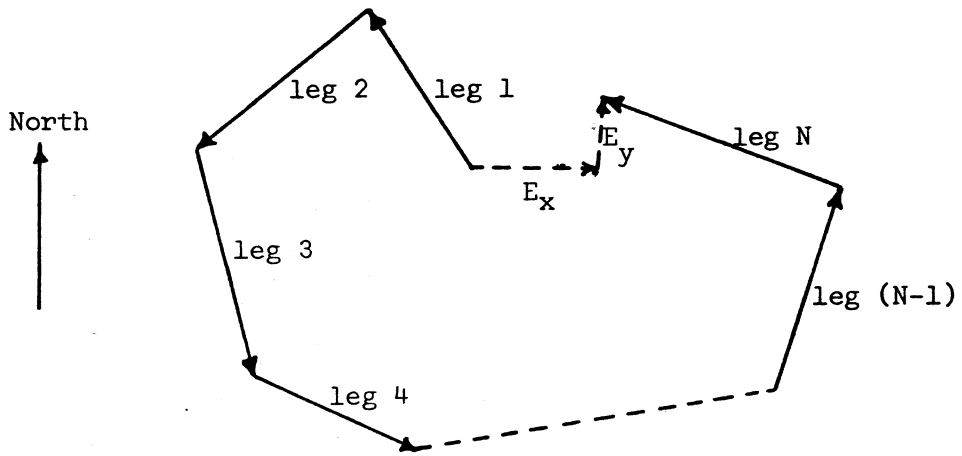
Figure 1. Example of uncorrected survey plot.



other situations is straight forward and is explained later. Due to unavoidable errors in the measurements, the last point does not coincide with the first; instead there is an error which in general has an easterly component E_x, a northerly component E_y, and (although not shown in Fig. 1) a vertical component E_z. The values of the error components may be readily calculated without plotting. Let us assume that for each leg we have measured the length L, the bearing B (clockwise from north, in degrees) and the slope or elevation S (in degrees, relative to the horizontal).

Distinguishing between the legs by a subscript i, the easterly (X), northerly (Y) and vertical (Z) components of each leg are given by straight forward trigonometry as:

$$X_i = L_i \sin B_i \cos S_i \quad \ldots\ldots (1)$$

$$Y_i = L_i \cos B_i \cos S_i \quad \ldots\ldots (2)$$

$$Z_i = L_i \sin S_i \quad \ldots\ldots (3)$$

Negative values indicate, of course, west, south or down. (More usual mathematical notation would employ r, θ and ϕ, with the azimuth θ being taken anticlockwise from east, and θ and ϕ would be measured in radians. However, the equations are just as readily derivable in terms of the "geographical" angles.)

Provided that all legs are taken in the same sense around the loop, the error components are simply the sums of the corresponding leg components, for example:

$$E_x = \sum_{i=1}^{N} L_i \sin B_i \cos S_i \quad \ldots\ldots (4)$$

Our aim in "adjusting" the survey is to introduce small changes l_i, b_i and s_i to some or all of the L_i, B_i and S_i in such a way that the error components

are reduced to zero. The smaller the changes that are required, the more appealing the adjustment will be to the surveyor. The problem is mathematically tractable if we choose these adjustments in the way which minimises a "weighted least-squares objective function" F, defined as:

$$F = \sum_{i=1}^{N} (w_{li} l_i^2 + w_{bi} b_i^2 + w_{si} s_i^2) \quad \ldots . (5)$$

The w's are weighting factors which may be freely chosen to reflect the realities of the survey. For example, we may consider an error in bearing of 1° to be as likely as a 0.1 m error in length, and make $w_{li} = 100\ w_{bi}$ so that each would contribute equally to the value of F. The appearance of the subscript i implies that different weights may be given to different legs, a useful feature if some of the surveying was done accurately with (say) a miner's dial and some only with hand compasses. Some measurements may be considered "perfectly" accurate if desired - that is, some l, b or s values may be defined as zero and simply omitted from equation (5).

Considering now any one leg (dropping the subscript i), the increments l, b and s will introduce corresponding changes x, y and z to the easting, northing and height differences. Provided that the increments are small enough, approximate formulae for these changes may be obtained by partial differentiation of equations (1), (2) and (3), that is

$$x = \frac{\partial X}{\partial L} l + \frac{\partial X}{\partial B} b + \frac{\partial X}{\partial S} s \quad \ldots . (6)$$

and similarly for y and z. Explicitly,

$$x = l \sin B \cos S + brL \cos B \cos S - srL \sin B \sin S \quad . . (7)$$

$$y = l \cos B \cos S - brL \sin B \cos S - srL \cos B \sin S \quad . . (8)$$

$$z = l \sin S + srL \cos S \quad \ldots . (9)$$

The factor r, equal to $\pi/180$, appears because b and s are in degrees. Geometrical demonstrations of these formulae are possible, and illustrate that they are more accurate the smaller the increments. For length changes only (b = s = 0) the formulae are exact.

To "close the loop" we want the net effect of the changes x, y and z summed around the loop to be equal and opposite to the original error components E_x, E_y and E_z, while simultaneously making F as small as possible. That is, we have an "equality constrained" optimisation problem, the three constraint equations being

$$\sum_{i=1}^{N} x_i + E_x = 0 \quad \ldots (10)$$

$$\sum_{i=1}^{N} y_i + E_y = 0 \quad \ldots (11)$$

$$\sum_{i=1}^{N} z_i + E_z = 0 \quad \ldots (12)$$

To solve such a problem we define a "Lagrange function" G (see any general text on optimisation theory, for example, Gottfried & Weisman, 1973), involving the objective function F, the constraints, and one new variable p for each constraint, that is,

$$G = F + p_x\left(\sum_{i=1}^{N} x_i + E_x\right) + p_y\left(\sum_{i=1}^{N} y_i + E_y\right) + p_z\left(\sum_{i=1}^{N} z_i + E_z\right) \quad \ldots (13)$$

The solution is obtained by simultaneously equating to zero the partial derivatives of G with respect to all the variables (the original l's, b's and s's, and the p's). Substituting for F from equation (5) and for x_i, y_i and z_i from equations (7), (8) and (9), and performing the differentiation, we get:

$$\frac{\partial G}{\partial l_i} = 0 = 2\, w_{li} l_i + p_x \sin B_i \cos S_i + p_y \cos B_i \cos S_i + p_z \sin S_i \quad . (14)$$

$$\frac{\partial G}{\partial b_i} = 0 = 2\, w_{bi} b_i + p_x rL_i \cos B_i \cos S_i - p_y rL_i \sin B_i \cos S_i \quad \ldots (15)$$

$$\frac{\partial G}{\partial s_i} = 0 = 2\, w_{si} s_i - p_x rL_i \sin B_i \sin S_i - p_y rL_i \cos B_i \sin S_i + p_z rL_i \cos S_i \quad \ldots (16)$$

The partial derivatives with respect to the p's yield the original constraint equations (10), (11) and (12).

We thus have a set of 3N + 3 simultaneous linear equations to solve. This would certainly be an unpleasant task by hand calculator. At first sight it would seem to tax the capabilities of most computers also - if there were 100 legs in the loop, over 90 000 memory locations would be needed just to store the matrix of coefficients. However, the situation is not as bad as that. The coefficient matrix is symmetric and (better still) is sparse. A set of very simple transformations reduce the problem to that of solving three simultaneous equations, followed by a straightforward back-substitution to produce the l's, b's and s's. In fact, hand caculation would be feasible for a single loop, even with 100 legs.

Because the equations (7), (8) and (9) are not exact, this process does not solve the closure problem exactly, but will come extremely close. An exact closure (with a very slightly sub-optimal value of F) may be obtained by a second application of the process, this time allowing only leg lengths to vary (which they will do by miniscule amounts).

GENERALISATIONS

So far we have considered a single survey loop, allowed changes in all the measured variables, and required the loop to close in all three dimensions. Very simple modifications take care of other situations. First, if we regard some measurements as much more reliable than others we can adjust the closure

Figure 2. Illustrating simultaneous loop closure.

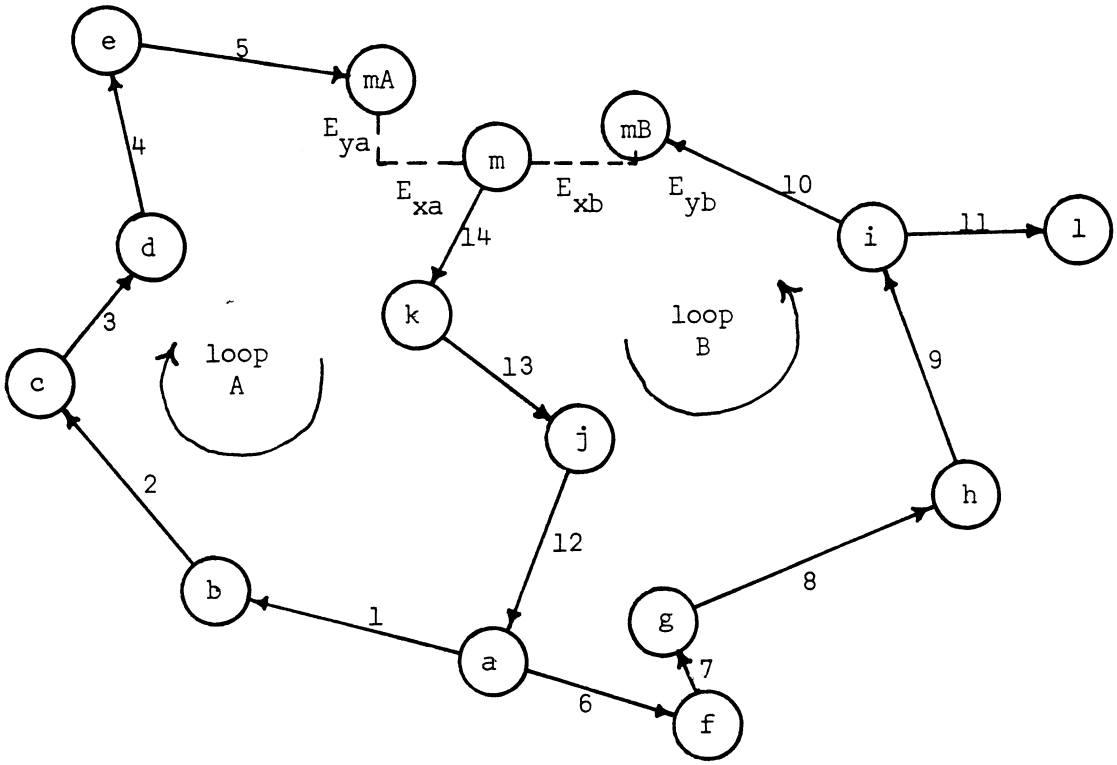
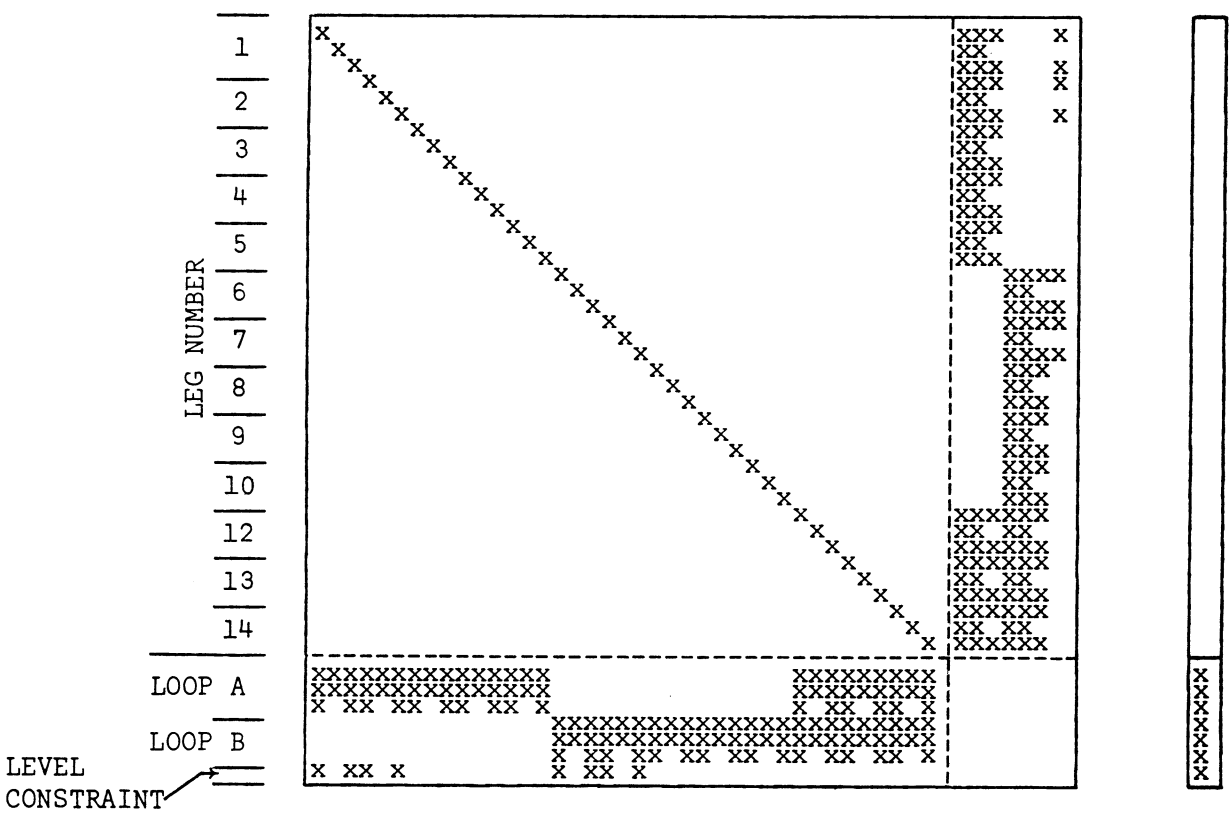


Figure 3. Example of Coefficient Matrix and R.H. Side

This applies to the two-loop example of Fig. 2.
x Denotes non-zero entry.



by varying only the latter - this leads to equations of the same form but fewer of them. Second, we may require closure in only one or two dimensions, for example, two stations may be spatially separated but both on the water table - there would be a z constraint (equation (12)) but no x and y constraints; or an electromagnetic ("RDF") measurement may constrain a station in x and y but not in z.

The generalisation to multiple loops is also straightforward and is illustrated in Fig. 2, where legs are numbered and stations identified by letters. Stations mA and mB are physically the same as station m. We still wish to minimise F as defined by equation (5), where the summation is over the entire survey and quite unrelated to the number of loops. Of course, if a leg forms part of no loop, we have no reason to adjust it at all, and so we do not include it. We now have six constraints because we wish to cancel simultaneously the errors E_{xa}, E_{ya}, E_{za}, E_{xb}, E_{yb} and E_{zb}. A change to (say) leg 10 would have no effect on the closure of "loop A" - thus the summation in the constraint equations (10), (11) and (12) is not over the whole survey but only around the relevant loop. For example, one constraint would be:

$$x_{14} + x_{13} + x_{12} + x_1 + x_2 + x_3 + x_4 + x_5 + E_{xa} = 0 \qquad \ldots (17)$$

Only legs 12, 13 and 14 are common to both loops and so appear in the equations for both E_{xa} and E_{xb}.

As a further illustration, suppose that we know in addition that stations g and c are at the same level although the raw survey would place c 0.3 metre higher. We would then have a seventh constraint, namely,

$$-z_7 - z_6 + z_1 + z_2 + 0.3 = 0 \qquad \ldots (18)$$

(the minus signs occurring because we are looking at legs 6 and 7 in the reverse sense). Fig. 3 shows the coefficient matrix for this example. Simple transformations reduce the problem to the solution of seven simultaneous equations. If we were to consider instead of "loop A" and "loop B" just one of them and the entire exterior loop, the equations would look different, but the solution would be the same.

COMPARISON WITH OTHER METHODS

Schmidt & Schelleng (1970) have published a least-squares method for simultaneous closures. They minimise not the adjustments to lengths, bearings and slopes (the actual measurements made) but the changes to the Cartesian components (X, Y and Z) of the survey legs. The authors admit that they do not have the control they would like over bearings, for example, some of which can end up in the adjusted version to be uncomfortably different from their measured values.

The method requires the solution of k simultaneous equations (k = number of stations) for each coordinate, and the authors employ the idea of a "string" of legs to reduce the coefficient storage requirements. Luckwill (1970) describes (although not fully) what is potentially a better method, because it requires only one equation for each loop. If weighting factors are introduced, Luckwill's method yields exactly the same results as Schmidt and Schelleng's but with much less effort - it solves a related "dual" problem which is easier because there are always fewer loops than stations.

The principal advantage claimed for the method presented here is the explicit formulation in terms of the actual measured quantities - length, bearing and slope. During the adjustment process none of these values can wander further from their measured values than absolutely necessary. The small price to pay is some elementary trigonometry, and the solution of three equations for each loop (once) rather than one equation for each loop (three times). The computer is not worried.

A COMPUTER PROGRAM

A complete survey data reduction program has been written (in FORTRAN) incorporating the above. It has turned out to be quite long (23 pages of listing) not because of the mathematics but because of requirements for generality in entering data and in setting up the equations for all possible constraint and weight combinations.

In summary, the first action of the program is to read in the coordinates of any stations which were finalised on earlier runs, if any. New raw survey data is then entered in the form "station from", "station to", length, bearing, slope and instrument height. Alternatively, the program can accept stadia data or any mix of the two types. Compass and clinometer calibration data, etc., is entered on special cards and applies to all raw data following until overridden by a new value indicating, perhaps, a different instrument. An important feature is that stations reachable by multiple paths must be given more than one name (as with station m in Fig. 2). To the computer, then, there are no closed loops and no ambiguities in station positions, which are calculated and printed out to allow the surveyor to decide whether immediate closure is justified or whether the data needs re-assessment.

The program then enters a "command" mode. Commands include equating stations to each other (that is,closing loops) in one, two, or three dimentions, and forcing station coordinates to assume certain values. There is no ambiguity in choosing the legs involved in the closure: to the program there are no loops and so only one path. It just "happens" that two "different" stations wind up with the same coordinates. The commandstructure allows closures to be all simultaneous, all sequential, or any intermediate combination. Another useful command produces a print-out of coordinates for a map at any scale. Plotting would be another possibility but has not been included at this stage. Commands may be stacked on the input file after the data, but if a remote terminal is available the user may enter them interactively.

Copies of this program and a detailed set of instructions for "driving" it are available for the cost of posting the card deck.

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VERTICAL CAVING EFFICIENCY: A CASE STUDY

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Abstract

This paper uses a recent exploration of a world-renowned, sporting, vertical cave in New Zealand as a case study to illustrate the factors to be considered in vertical caving. Single rope techniques were used. No account is given of personal techniques but rather this paper treats the exploration party as a team operating to maximise exploration efficiency. Outlined in the paper are the necessary considerations to be taken into account in explorations of this nature.

INTRODUCTION

In Australia multi-pitched caves are little known and rarely visited except by the more dedicated enthusiast. Even at Bungonia which is a predominantly vertical area, few cavers tackle more than one pitch in a cave. The cavers that do tackle these caves use S.R.T. because it reduces the amount of gear that needs to be transported through the cave.

Greenlink Cave, N.Z., was at the time of our exploration 283 m deep with 18 pitches ranging in size from 3 m to 20 m. The cave swallows a small stream which is a tributary of a much larger stream that is met after only three pitches have been negotiated. The cave temperature is around 12^{o}C.

Due to the sporting nature of the cave and its cold temperatures a caver is losing energy at a rapid rate from the time he enters the cave. A major factor to be considered in explorations of this nature is vertical caving efficiency such that these undertakings have an acceptable safety level.

EFFICIENCY

Efficiency does not necessarily mean speed; however, it is often the best measure of efficiency. Efficiency refers to the smooth transportation of cavers and gear through the cave such that problems do not arise or are eliminated, and such that each caver's workload is minimised.

It is clearly inefficient for one unfortunate person to be ferrying gear back and forth between pitches or worse, up and down a particular pitch because of the energy involved in performing these tasks.

If workloads are minimised and problems eliminated then speed can be increased (and thus efficiency could be measured) such that individual cavers are not exposed to a hostile environment for longer than necessary.

PERSONAL EFFICIENCY

For the team to work efficiently during an exploration each member must be self sufficient and efficient within themselves. Any factor which hinders

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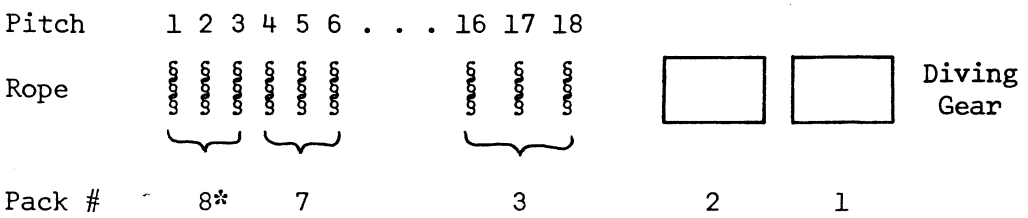
Figure 1. Greenlink - organisation of packs.



Rope packs are packed in reverse order.

*Pack # 8 will be the first pack needed in the cave.

an individual's performance inconveniences the whole party and slows the rate at which gear is transported through the cave. Each person should have:

- adequate dependable lighting.
- a well-constructed rope pack for gear carrying.
- an operational descender and prusik rig which can be used competently and rapidly with a minimum of fuss.
- sufficient warm clothing to enable comfortable movement through the cave.

In Greenlink we used carbide lights because they are easy to operate and can be continually refilled to yield many hours of lighting. These were backed up with dry cell electrics for the wet pitches. Wetsuits were worn by all. These were covered with a pair of Busy Bee water-resistant overalls to save abrasion. These also have a hood which makes for more comfortable prusiking under waterfalls.

PRE-TRIP ORGANISATION

The aim of the trip was to give a local diver, Keith Dekkers, an opportunity to dive the -283 m sump. Rope packs were used to transport gear through the cave. Eight people were required to carry this gear which consisted of six packs of rope for the eighteen pitches and two packs of diving gear.

Keith had been to the bottom of the cave several times and knew the rigging requirements of the cave. Ropes of suitable length for all the pitches were chosen and the rigging gear affixed. The ropes were then organised in the required order (see Fig. 1). Rope for the bottom pitch was packed first, on top of it was placed the rope for the second last pitch, etc., until this pack contained one sixth of the rope needed for the cave, almost a full pack load.

The last rope packed was that required for the first pitch. Spare space in the packs was filled with spare carbide, a chocolate and each caver's prusik rig which would not be required until the journey out.

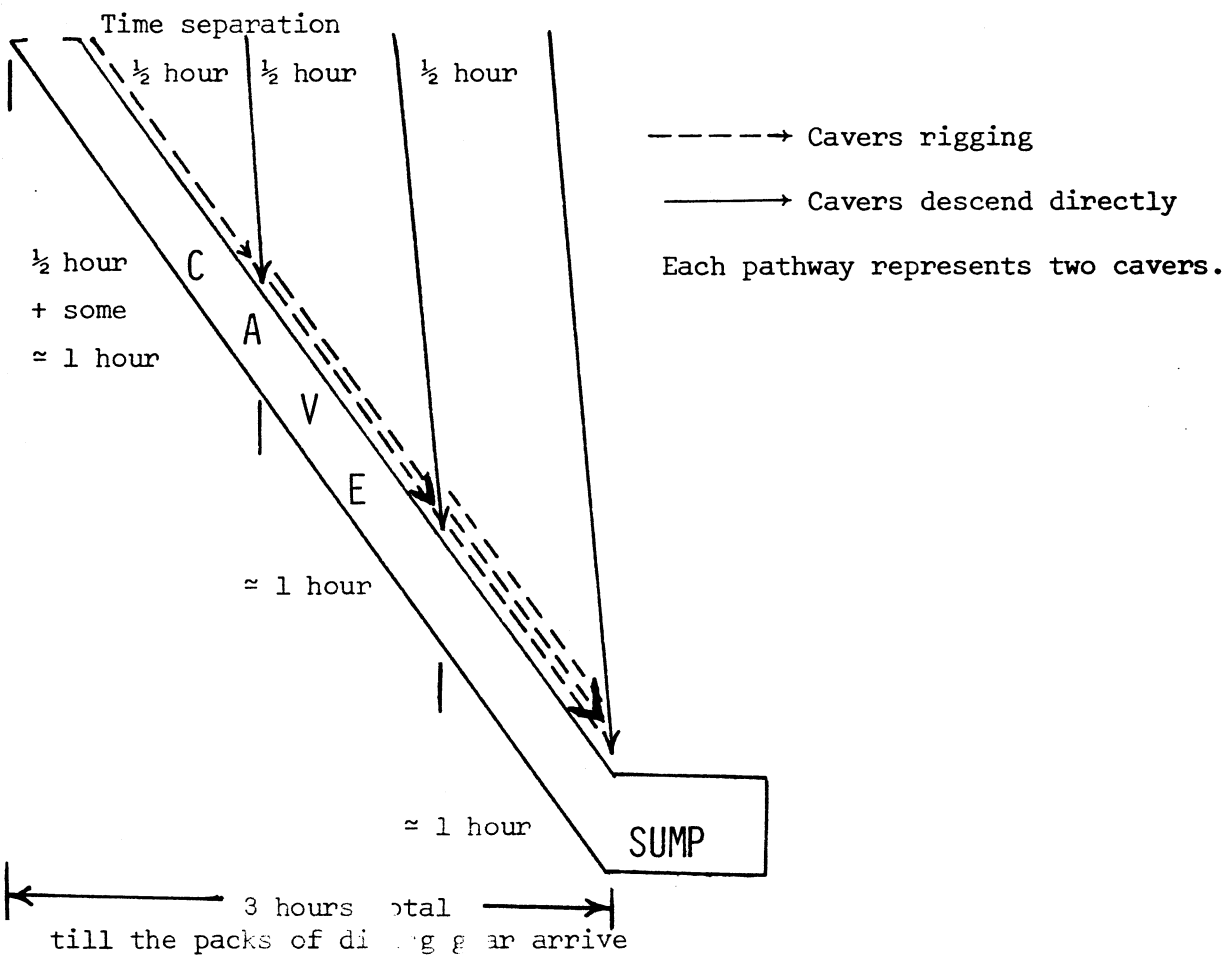
LOGISTICS

Rigging. We intended to tackle the cave as four parties. Each party would Delay themselves half an hour behind the party before them. The total separation between parties would be an hour and a half. Thus the total time afforded for the rigging of the cave was one and a half hours plus about another one and a half hours it would take for the last party to negotiate the cave and catch up to the first.

The first party would enter the cave rigging the first bracket of pitches and then be met by the second party just as they ran out of rope (a little over half an hour later). The second party would be carrying the rope to rig the next bracket of pitches. As these cavers exhaust their rope supplies they would be met by the third party with the ropes to rig the last bracket of pitches.

The last party would carry the diving gear straight to the bottom without any delay en route (see Fig. 2).

Figure 2. Greenlink logistics - rigging.



Derigging. After the diving operations at the bottom of the cave the parties would exit as soon as they had full rope packs. Those that entered first would take the diving gear directly to the surface. As other packs were filled these cavers would also head directly for the surface.

In this way the actual time spent underground by any member of the group would be minimised.

THE ACTUAL EXPLORATION

It took the cavers carrying the diving gear one and a half hours to bottom the cave. By this time the first party had spent three hours underground. Three hours were spent at the sump while Keith was diving (his dives were successful). It was then another six and a half hours before the last caver emerged from the cave after a total of ten hours underground. This was the maximum time any caver spent in the cave.

The last de-rig party will always spend the longest time underground because they must ascend a pitch, remove the rope and give it to some-one else to fill their rope pack. Eventually this person will have a full pack and make for the surface. It is only after all the other rope packs are full that this last party starts its share of the de-tackling.

To overcome this obvious bottleneck situation we initiated a leap-frog situation. The cavers in the third and fourth parties went on ahead to wait and rest in a more comfortable, less wet, less draughty place till the first de-rig party had taken their quota of ropes.

The first party to enter the cave, who were exiting with the diving gear stopped to investigate the upstream mainstream sump. This was done without interfering with the de-rigging procedures.

THE NEED FOR EFFICIENCY

After personal S.R.T. skills have been mastered and the logistic problems of multi-pitched caves appreciated and solved, the scope for exploration is boundless. By using plans similar to that which I have outlined above it becomes possible for small teams of very fit cavers to tackle some of the world's deepest caves with maximum safety.

As a response to more realistic considerations by minimising the time spent underground, the danger of exposure is lessened and mistakes and dangers arising from fatigue are eliminated.

CONCLUSION

Explorations of this nature provide a challenge to the skill and stamina of sporting cavers now and in the future. Cavers can justify to themselves the extending of their limits such that they improve themselves in response to new-found challenges. This has prompted the rise in expedition caving in Australia. Cavers should feel confident in themselves when undertaking such explorations, though possibly a little reserved. Nothing will surpass their feeling of achievement once such an exploration has been successfully completed. The only danger is in over-extending oneself. Realistic

appraisals of one's ability and a knowing of oneself is all part of sporting caving.

One may argue that in rapid caving the caver "sees" nothing and does not stop to appreciate anything. Sporting cavers may state that they "get a feeling" for the cave, and they appreciate it in that sense.

I will state that Greenlink Cave is the most impressive vadose streamway I have ever seen!

ENVIRONMENTAL MONITORING IN CAVES: PART 1

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Abstract

A summary is given of the considerations that influenced the design of a cave monitoring program.

Environmental monitoring is the systematic measurement of the environmental factors concerned with the well-being of a natural resource.

In caves the natural resources to be protected are many and varied. An incomplete list might include: fungi, bacteria, algae, plants, insects, spiders, worms, amphibians, fishes, mammals, birds, minerals, sediments, fossils, archaeological artifacts and the ever-popular speleothems. If a new cave is discovered, careful research is needed to determine what is of value in the cave, and then more research is needed to find out what conditions are important to conserve these features.

This paper is about the measurement of the physical cave environment, temperature, humidity, airflow and energy flows. Although many descriptions of the cave environment have been published over the last 70 years, it seems to me that the caves we have measured are far more complicated and varied than the simple models described (Ford & Cullingford, 1976; Gèze, 1965; Martel, 1908; Moore & Sullivan, 1978; Trombe, 1952). So here is a short description of the relevant processes that seem to control the physical cave environment. The supporting physical evidence is not complete, but at least it is based on about eight years work, involving the development of instruments and techniques to be able to measure some effects in a limited number of caves.

Caves are formed in the earth's crust which has a temperature gradient with depth called the geothermal gradient. The intensity of this gradient is about 1°C per 30 m depth but it can vary from place to place. The gradient is caused by a heat flow called the geothermal flux which ranges from about 40 milliWatts per square metre (mW m^{-2}) to 100 mW m^{-2}. Any cave formed in this temperature gradient will tend to have this increase of temperature with depth, but a volume of air with this gradient will be unstable, in the meteorological sense, and convective circulation will start to transport heat to reduce the temperature gradient in the cave. As caves are often damp, evaporation and condensation of water will often be involved in this convection of heat from the lower parts of a cave to the higher levels.

If we consider caves with just this one process occurring we will find that the temperature at any place will be constant. As convection is a very efficient process, the temperatures from place to place will be close to each other. This does not mean that the cave is meteorologically static. What it means is that the active process in the cave is steady.

The magnitude of the effects caused by the geothermal flux should not be underestimated. Although the heat that would have flowed through the floor

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of a cave is only say 60 mW m^{-2} before the cave was formed, with the heat flow in the cave there is a change in the uniformity of the thermal field and heat flows 100 times larger are probable. A simple, calculable case is a horizontal cave of indefinite length (Michie, 1977). If this cave is at surface temperature then Fig. 1 shows the distribution of temperature in the rock around the cave. Fig. 2 shows the amount of heat captured by such caves with diameters of 0.2 m, 2 m and 20 m. It can be seen from this graph that water flowing in a tube 200 mm in diameter at a depth of 200 m could collect heat at the rate of 10 000 Watts per kilometre.

To investigate the heat flows in a cave it is helpful to have an accurate vertical section map of the cave. This map should include all passageways and cracks, even if they are too small to enter. Measurements of air temperature and humidity will now reveal the vertical temperature gradient and areas of evaporation and condensation.

If the temperature decreases more than 1°C per 100 m of increased altitude, which is the adiabatic lapse rate of dry air, then the air in the cave is unstable and heat is being transferred. If the temperature decreases between 0.5 and 1°C per 100 m, the lapse rates for moist and dry air, then stability is conditional, and heat may or may not be transferred, and if the gradient is less than 0.5°C per 100 m, or if the gradient is inverted, then the air in the cave is stable and very little heat can be conducted by the air.

If an inversion is found in a cave, that is, if the bottom of the cave is full of cold air, then either there is a heat sink at the bottom of the cave, a heat source at the top of the cave or the inversion is a temporary situation.

A large number of caves are not isolated from the surface conditions but may freely convect heat to the surface. When temperatures outside the cave are low there will be convection of heat to the surface. When outside temperatures rise the cave becomes stable and no heat is transferred.

Extreme cases of this phenomenon are the freezing caves, found in many parts of the world, which fill with snow and ice in winter and which stay stable all the rest of the year while maintaining very low temperatures.

If a cave has more than one connection to the surface it may behave as a chimney cave. Fig. 3 is a diagram showing a simple chimney cave (Gèze, 1965). Included are some important features that other authors neglect: the geothermal gradient and the stored heat in the walls of the cave.

The caves that we have studied have included aspects of caves which are stable in hot weather and caves which act as chimneys. Much of the work has been monitoring the reversal conditions of multi-entrance caves, that is, the conditions for which airflow will cease. Each cave has proved as unique in its behaviour as it is unique in shape.

So the first step in monitoring a cave is to make sufficient measurements of the shape of the cave and the conditions found in the cave over the whole range of external conditions until self-consistent data have been acquired. By this stage the effect of digging new entrances or blocking old ones should be predictable.

The only guide to the quantity of data that will be required for a cave is that based on past experience. I am building an eight-channel recording system to continuously monitor a cave at Jenolan for a period which may be as long as two years to acquire a data base.

Figure 1. Calculated temperature field around a very long cave.

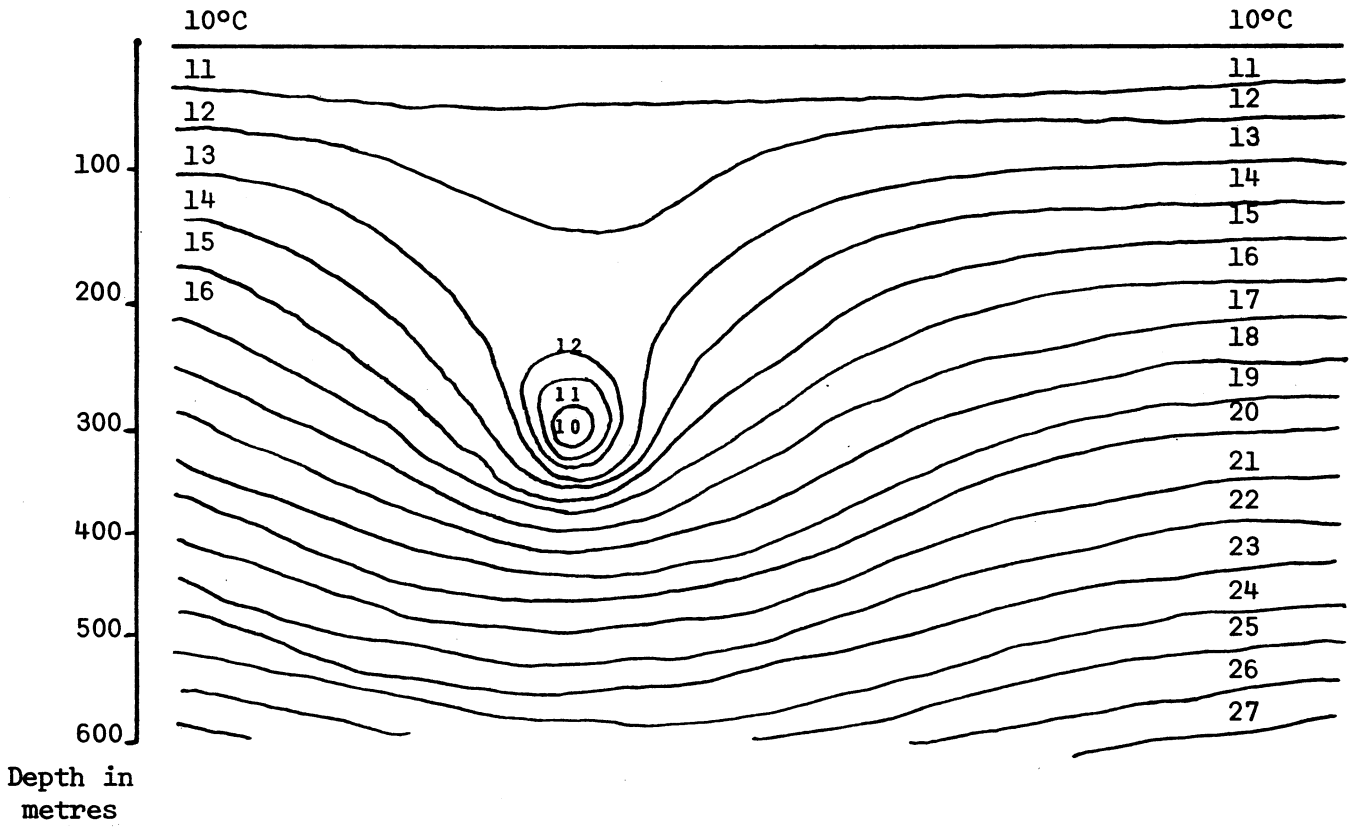


Figure 2. Heat gathered by a long horizontal cave at surface temperature.

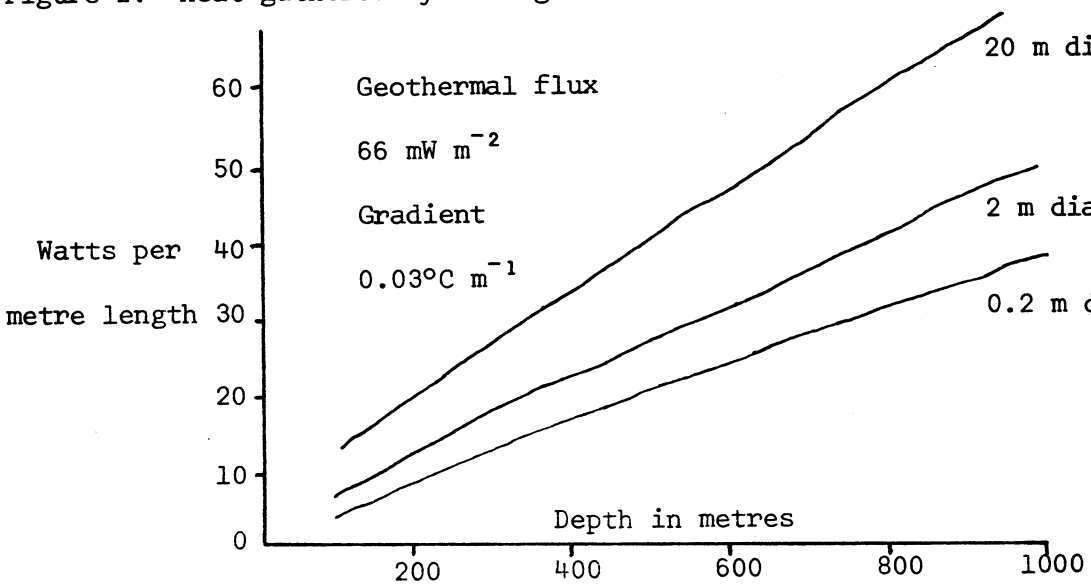
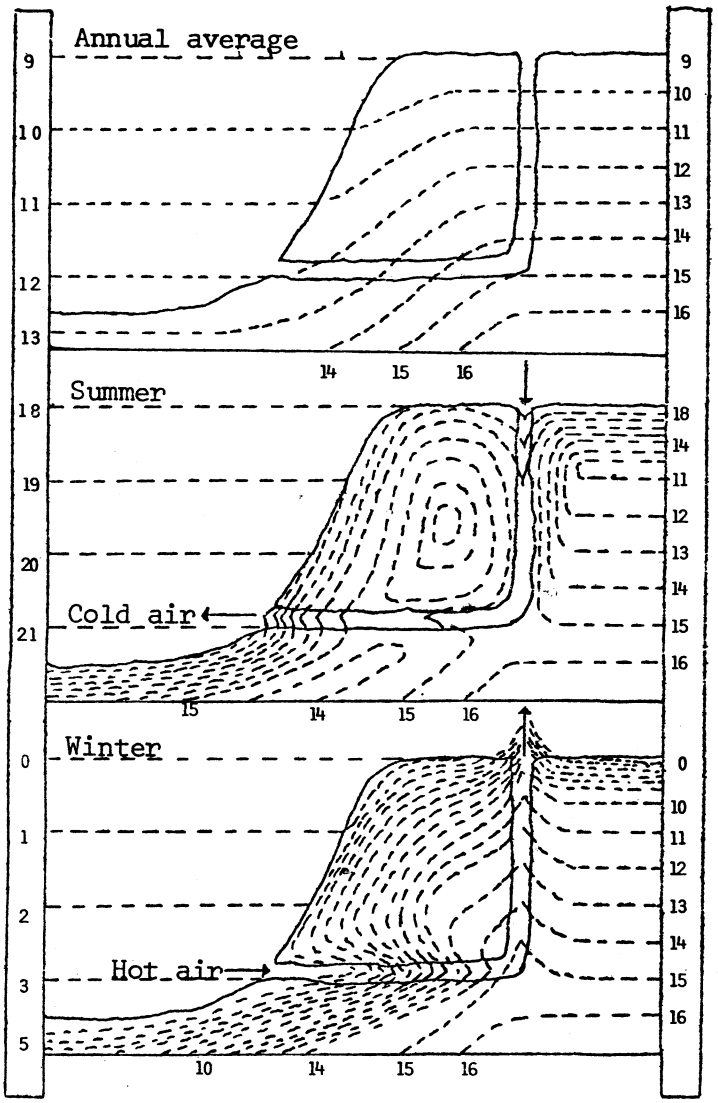


Figure 3. Simple chimney cave showing isotherms. (After Gèze 1965.)



ACKNOWLEDGMENTS

This paper was based on work done with Erik Halbert and the Sydney Speleological Society.

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ENVIRONMENTAL MONITORING IN CAVES: PART 2

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Abstract

Some techniques of measurement and the equipment used are discussed. An instrument system developed for cave work will be demonstrated.

INSTRUMENTS AND TECHNIQUES: A DEMONSTRATION

(1) Psychrometer. The most important single instrument is an aspirated psychrometer such as the Assman model. The instrument demonstrated is smaller than commercially made models and has an electric motor to aspirate the wet and dry bulb thermometers. Commercial models are larger and cost a lot of money. They usually have a clockwork motor.

To use an Assman Psychrometer in a cave with little air movement it is often easier to leave the instrument running and retire to a safe distance downwind. When it is judged (say three minutes) that the instrument has come to equilibrium it is approached and read quickly. It is very easy to get errors of greater than 1°C from operator body heat. The measurements of dry bulb and wet bulb temperatures enable the condition of the air to be measured, and its stability and directions of heat transfer calculated.

(2) Precision barometer. This is a surveying altimeter. When used in pairs they enable fast accurate levelling when vertical section surveys are required. It is also very useful for measuring barometric pressure.

(3) Titanium tetrachloride. This can be used to detect very slow airflows in caves (Halbert & Michie, 1971). I am not sure that the release of titanium dioxide in a cave is consistent with conservation. The next method may be more desirable.

(4) The cigarette. These handy flowmeters are cheap and come in convenient packets. They have some use as flow meters in low to medium rates of horizontal air flow. The smoke from a cigarette which has one end lit rises at about 100 mm per second. If a point 100 mm above the burning tip of the cigarette is taken, the horizontal distance to the smoke rising from the tip gives the velocity in mm per second. Caution: the lighting of cigarettes in caves is likely to present a health hazard if conservationists are about.

(5) Air-tracing agents. Vanilla essence and vanillin provide a non-toxic method of marking an airstream so that is can be detected with a simple sensitive instrument - the nose. Initial experiments using vanilla-tracing have been variable. They have ranged from more spectacular than fluorescein in water to quite negative.

(6) Contact thermometer. This is an electronic instrument for measuring surface temperatures. I am not sure how useful it is as I never seem to use it.

(7) The recording system. This is an electronic system that controls a modified "Rustrak" chart recorder. The system is powered by torch batteries

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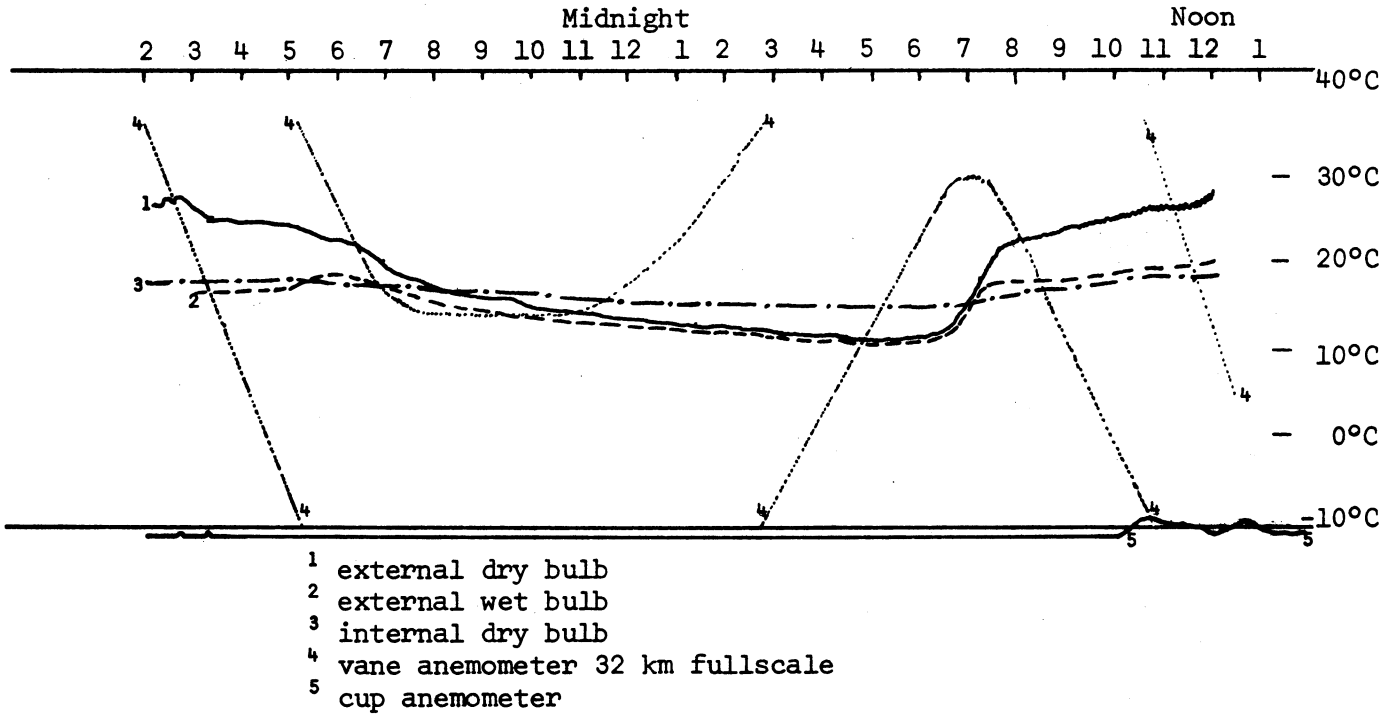

Figure 1. A recording in a chimney cave of airflow through the cave and external temperatures with internal temperature and external cup anemometer.

that can last one year. The circuitry is a mixture of analog circuits that are only operated briefly to plot a point on the chart and digital circuits using very low power. The recording system is connected to several measuring devices:

(a) The "pigeon-house" psychrometer. This consists of wet and dry bulb thermometers which are not aspirated. They are mounted in an elaborate double heat shield. This is for measuring actual air temperatures on the surface even in direct sunlight. Simple tests showed good comparisons with an Assman-type psychrometer.

(b) The cup anemometer. This rather insensitive anemometer measures the surface wind speed.

(c) Underground thermometers. These use the same elements as the pigeon-house psychrometer - selected silicon diodes.

(d) Underground vane anemometer. This resembles an engineer's vane anemometer but has two magnetic proximity detectors to sense rotation. The rotation information is fed into a bidirectional counter, the value of which is recorded. The recording of integrated flow removes much difficulty from the fluctuations of air velocity and enables more accurate measurement of heat flows.

A section of a chart which was recorded in a multi-entrance cave is shown (Fig. 1). The relation between the rate of airflow (the gradient of the vane anemometer trace) and the external dry bulb temperature can be seen.

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Halbert, E.J. & Michie, N.A. (1971). The use of titanium tetrachloride in the visualization of air movements in caves. *Heliotite* **9**(4):85-88.

THE METHODOLOGY FOR THE USE OF INERT TRACER GASES IN RELATION TO CAVE METEOROLOGY

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Abstract

An outline of the various procedures for using the inert tracer gases, Freon 11, 12 or sulphur hexafluoride, to determine air movements in caves is discussed.

Practical examples proving air connection between two previously separate cave systems are given.

Problems inherent in using these tracer gases in caves are discussed and compared with the advantages of the system.

INTRODUCTION

Air tracing in caves has to date been carried out using such crude tracers as ethyl mercaptan (Fetrow, 1960). This type of tracer is not only harmful to the experimenters but has also been shown to kill some types of cave fauna (Muir, 1968).

Titanium tetrachloride ($TiCl_4$) has also been used to visualise air movements (Hälbert & Michie, 1971). However, the authors do point out that hydrochloric acid (HCl) is produced during the hydrolysis of the $TiCl_4$. Although they indicate that HCl has no cumulative poisonous effects, its effects on speleothems and cave fauna are unknown and hence to be avoided if possible.

In view of the above problems, the use of inert tracers such as Freon 11 ($CFCl_3$), Freon 12 (CF_2Cl_2) or sulphur hexafluoride (SF_6) would allow the tracing of air movements in a cave system while having no known effect on the cave environment.

Glossop & Hamilton (1977) have outlined the procedure for the use of the above-mentioned inert tracers in above-ground tracing experiments. Using such tracers in the cave environment is a new and complex experiment.

Therefore, I report here the equipment and methodology necessary for air tracing experiments using these inert tracers in a cave system and also a discussion of the major complications that arise as a result of using tracer gases in the cave environment.

BASIC METHODOLOGY

Simply, the method involves releasing a tracer gas from a cylinder or, in the case of Freon 11, vaporising it and then collecting air samples at various times and at various points throughout the system under study. Thus the tracers can be used to determine the speed and direction of air movements in caves as well as to prove air connections between caves.

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WEBB – INERT TRACER GASES AND CAVE METEOROLOGY

INSTRUMENTATION

Low concentrations (ca 0.01 ppb) of tracer gases can be detected using gas chromatography with an electron capture detector. The detector giving the best reported result was a Nickel^{63} electron capture dececter which was capable of detecting 0.0002 ppb of SF_6 in air (Luckan & Mura, 1974).

In my experiments a tritium absorbed on scandium foil detector was used. Glossop & Hamilton (1977) report the limit of this detector as 0.018 ppb of SF_6 in air. Hence no matter which detector is used the method is obviously very sensitive.

Each tracer is best analysed on a different column: SF_6 on a 5 Å molecular sieve column, Freon 11 on a SF96/OV17 column and Freon 12 on a Porapak Q column (Glossop & Hamilton, 1977). Detection of Freon 12 requires a higher concentration, compared to Freon 11 or SF_6, when using the Porapak Q column as the Freon 12 peak occurs on the oxygen tail.

SAMPLING

A number of sample containers have been tested for their ability to contain an air sample without absorbing or diffusing the tracer gas (Glossop & Hamilton, 1977; Luckan & Mura, 1974). These range from plastic bags of varying types to aluminium cans and glass containers.

Of these sample containers, the aluminium can would be the most suited to cave use as it is unaffected by water and robust. Unfortunately they are also expensive.

The glass containers offer limited use due to their fragile nature.

This leaves the Mylar and Saran bags, of which the Saran bag has the advantage of storing low concentrations of tracer for up to two months without noticeable decrease in concentration (Luckan & Mura, 1974). However, it is available only in 12 litre and 50 litre sizes, so that when fully inflated, both the 12 L and 50 L bags are very bulky and storage and handling are problems. The cost of these bags is also prohibitive.

In regard to cost and ease of use, the Mylar bags described by Glossop & Hamilton appear to have the widest adaptability. However, these bags do suffer from one major disadvantage. The tracer diffuses out of the bag at a rate of 11% per day. Hence the bags must be analysed within two days of sampling, taking into account the relevant corrections for diffusion.

SAMPLING PROCEDURE AND PRECAUTIONS

The sampling bag (Fig. 1) is connected to a plastic hand pump which has been flushed for about 30 seconds prior to sampling. It is generally wise to remove the glass stopper a short time before the sample is to be taken as sometimes it may be very difficult to extract.

The actual sampling time (the time required to pump up the bag) can be varied by the rate of pumping and also by the use of a capillary constriction in the neck of the plastic pump.

Some important precautions when using Freon 11 or 12 are to ensure that samplers have not used any insect repellants, deodorants or aftershaves prior to sampling.

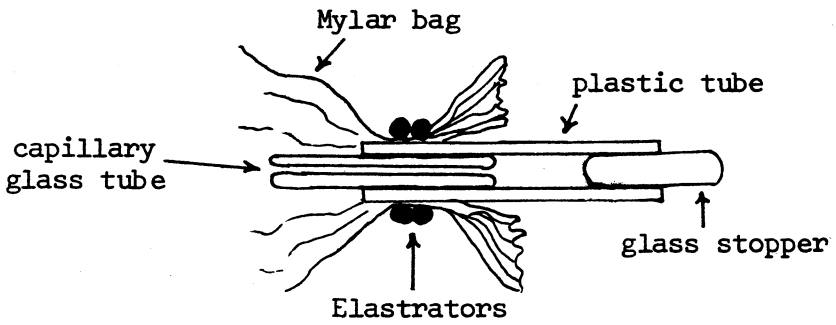

Fig. 1. Sampling Bag (not to scale).

Also ensure that the sample bottles are clearly labelled and the code explained to the samplers.

BACKGROUND LEVELS OF FREON 11, 12 AND SULPHUR HEXAFLUORIDE

Freon 11 has many known sources including propellants from spray cans such as insecticides, spray deodorants and aftershaves (varying significantly with brand). Freon 12 background is known to be 10% higher (Fraser, 1975, cited by Glossop & Hamilton, 1977) than Freon 11 but can not be detected using the Porapak Q column as the peak occurs in the oxygen tail. Freon 12 also occurs in spray cans.

A sample of ten sites in the Perth metropolitan area produced an average concentration of 1 $\mu g/m^3$ for Freon 11 (Glossop & Hamilton, 1977). Therefore background levels must be measured before an air trace is conducted.

Sulphur hexafluoride has the advantage of a background level that is not ordinarily measurable. However, to be sure, blanks should be taken to show that no SF_6 was present before release.

CHOICE AND QUANTITY OF TRACER

When choosing which tracer to use you must consider the following:

1. The possibility of high background levels of Freons 11 and 12 from industrial sources.

2. The availability of the tracer.

3. The ease of transporting the tracer (In my experiments a small "lecture bottle" cylinder was found to be excellent for underground use).

The choice of the quantity of tracer to be released depends upon the type of experiment to be undertaken and the volume of the cave in which the gas is to be released.

For example, if the cave is large or long (ca 5 km) and you are attempting to prove air connection to an adjacent system, then several hundred grams of tracer will be adequate. However if you are trying to establish an air flow chart for a long (ca 5 km) system then a release of about 10 g of tracer should provide measurable concentration gradients at sampling points, whereas the previous example is only likely to afford a positive or negative result. This presumes that some air movement is occurring in the cave.

WEBB — INERT TRACER GASES AND CAVE METEOROLOGY

A PRACTICAL EXAMPLE

THE EASTER TO JEWEL CAVE (AU-14 TO AU-13) CONNECTION USING FREON 11 AND SF_6

Easter and Jewel Caves are situated a few kilometres north of the Augusta town site in the south-west of Western Australia.

The Gondolin Extension in Easter Cave was thought to be the closest point to nearby Jewel Cave. The survey of Gondolin was not complete at the time of the experiment and hence the distance between the caves was not known.

The Freon 11 air trace. As the retention time of the tracer in the cave was not known, Freon 11 was chosen for the first trace so that SF_6 could be used at a later date in a more sensitive trace.

On 30 June 1978, approximately 200 g of Freon 11 was vaporised in the Gondolin Extension of Easter Cave. For a period of eight hours after this release air samples were collected every hour from The Dome area in the Flat-roofed Chamber of Jewel Cave. Further samples were taken from the entrances of Jewel and Easter Caves, also hourly for eight hours. The samples were then transported to Perth and analysed the next day.

The tracer was detected in all eight Jewel (Flat-roofed Chamber) bags although the bulk of the tracer reached Jewel after three hours. It was not possible to determine if the tracer in the first two samples was a true indication of the tracer levels at the time of sampling as the concentration of Freon 11 was so high after three hours that diffusion into these early samples over the remaining five hour period could have accounted for the observed levels of Freon 11. The Jewel entrance samples gave further proof that the air connection was positive, as high levels of tracer were detected after seven hours. On the other hand, no tracer was detected at the Easter Cave entrance.

During this experiment the overall cave breathing was observed to be in at the Easter entrance, away from the Easter entrance at the first duck into the Gondolin Extension, and out at the Jewel Cave tourist entrance (the natural entrance being blocked).

With the basic knowledge that a connection did in fact exist, a second air trace was designed to isolate the points of connection between the two systems.

The SF_6 air trace. To avoid the problem of diffusion of tracer into samples once they had been collected, the Mylar bags were housed in a one litre plastic bottle with a screw cap. These plastic bottles were tested to determine if SF_6 could penetrate the plastic if left in an atmosphere with a high SF_6 concentration for five days. No SF_6 could be detected in the blank air sample after the said period.

After choosing two possible points of connection in the Flat-roofed Chamber of Jewel Cave (marked 1 and 2 on Fig. 2), an attempt was made to repeat the first experiment on 9 July 1978. Samples were also collected in the Gondolin Extension at the points marked 4 and 5 on Fig. 2.

Approximately 100 g of SF_6 was released and samples were collected at three sites in both Jewel and Easter caves. Unfortunately this experiment did not have the luck of the first. Analysis revealed that the gas had reached sampling point 1 in less than *one minute*. However, then the unpredictable happened. During the first 15 minutes after release the overall cave breathing either stopped or changed direction. As a result sampling point 3 never detected the SF_6 (although they could see point 1) and point 2 had only one positive sample and that was after five hours.

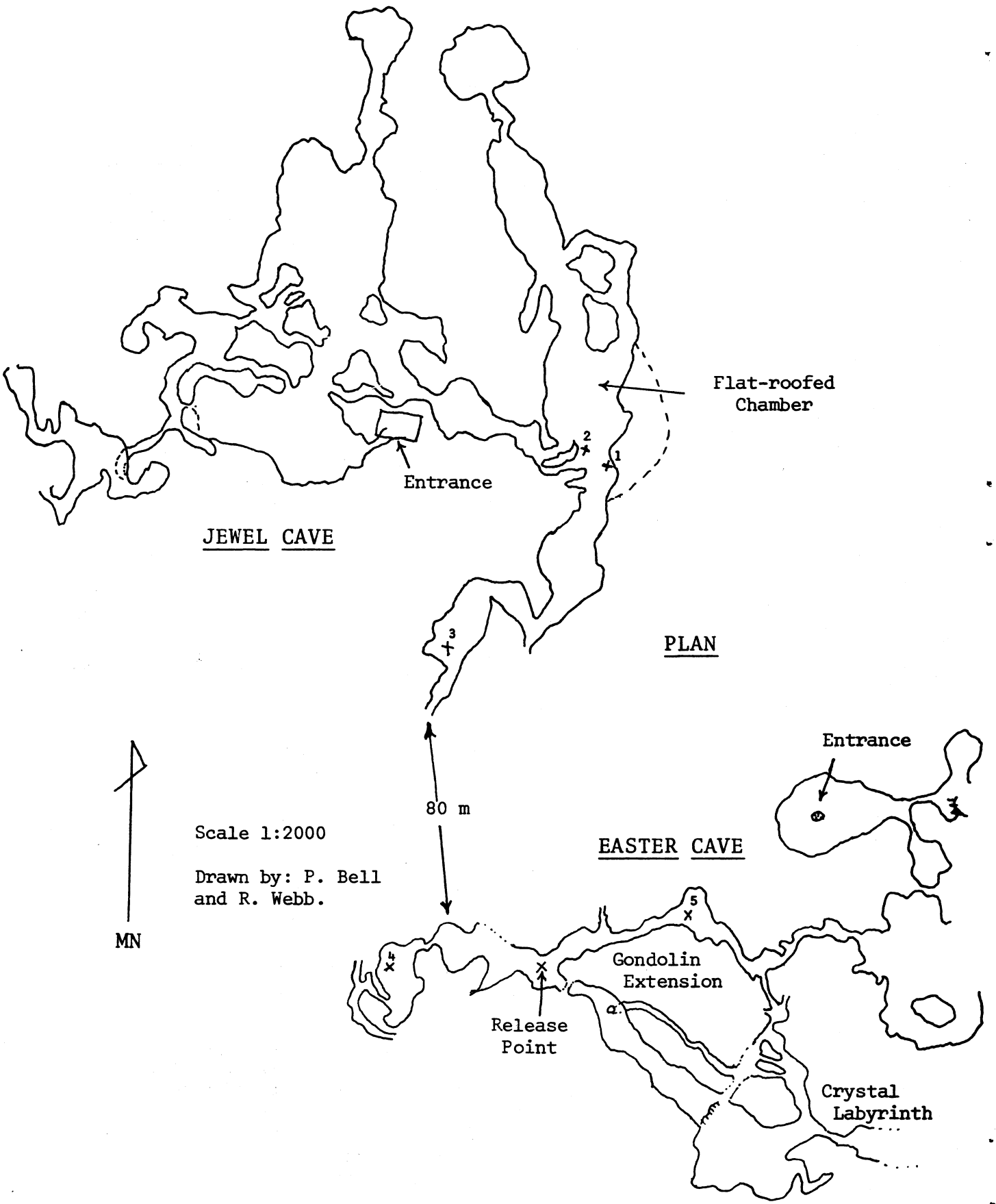

Fig. 2. Plans of Jewel and part of Easter Cave.

In Easter Cave the only valuable information that was obtained was that the SF_6 pulsed through Gondolin Chamber (point 4 on Fig. 2) during the first minute, decreased in concentration, then pulsed again at 24 minutes, most likely in the opposite direction as the cave breathing changed direction. The samples taken at Gondolin Beach (point 5 on Fig. 2) indicated that the cave was not breathing strongly as little tracer was detected but the pulse at 24 minutes was observed.

Overall these two experiments were a success in that an air connection between the two caves has been proven and a cave breathing flow chart has been commenced. Also possible points of connection have been established.

Advantages and disadvantages of the method. The major problem that was uncovered is the unpredictability of cave breathing. With studies of cave breathing patterns it may be possible to reduce the incidence of attempted air traces in periods when gross cave breathing changes are likely to occur. I envisage, however, that cave breathing changes and even internal fluctuations will always be a problem when conducting an air trace.

Another problem stems from the ease with which the tracer is conveyed in a cave. This means that once release has occurred samplers are virtually confined to a small area until sampling is complete. This can make sampling a difficult job especially if samples have to be collected for twelve hours or longer.

The choice of a time for an overall sampling period is difficult, for it will vary with each type of air trace and hence the sampling time should always be exaggerated to cover most possibilities.

The plastic bottles used as sample bag containers were of great assistance when transporting the samples through lakes and crawlways. Their only drawback is that some samples were lost through samplers overinflating the sample bags causing them to burst when the sampling neck was forced back into the bottle. Hence some care, by samplers, must be exercised here.

Following the Freon 11 air tracing experiment weekly samples were collected from Jewel Cave for one month. The concentration of Freon 11 dropped drastically over the first week and then approximately halved each week thereafter. However the final sample was still well above the background level and would have required at least another month, at the same rate of decrease, to reach it. Therefore before attempting an air tracing experiment thought must be given to the possible need for a second trace to either verify or extrapolate the results of the first. If this is to occur, with the same tracer, and the cave breathing is poor, then some considerable time period may be necessary before the tracer is expelled from the cave.

When tracing between two caves with large entrances that are in close proximity care must be taken to avoid the tracer making the above-ground connection. This can be detected by using entrance and even surface sampling points.

One final disadvantage is that the air samples can not be analysed in the cave and hence many hours may be lost on experiments which fail completely.

The major advantage of these tracer gases is that they are chemically inert and hence the chance of them having any adverse affect on the cave environment or cave speleothems is very unlikely. With regard to cave animals the effects of SF_6 are almost certainly nil (Lester & Greenburg (1950) have shown that rats can exist in an 80%:20% atmosphere of SF_6:O_2 for 16-24 hours with no detectable physiological effects). Freon 11 or 12, however, could cause suffocation if used in very high concentrations in a confined space. This

problem is virtually overcome by another advantage of these tracers and that is their sensitivity. From experience I can say that the use of small quantities of tracer (ca 10-20 g) will give the best results, even in large systems. Hence high concentrations of tracer should not occur.

ACKNOWLEDGMENTS

I would like to thank Bruce Hamilton and Laurie Glossop for their helpful discussions as well as the many W.A.S.G. and W.A.S.S.G. members who aided in the air tracing experiments. Also my thanks to the Department of Conservation and Environment for funding the program and the Chemistry Department of the University of W.A. for the use of the gas chromatograph.

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CAVING EQUIPMENT: THEORY, DESIGN, TESTING AND THE NEED FOR STANDARDS

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Abstract

Most testing reported in the literature is poorly designed and executed. The need for standards to evaluate equipment against, and for standardised methods of testing is outlined. Methods of development for standards are suggested. A review of desirable characteristics for S.R.T. ropes and reliable test data leads to presentation of a draft standard for public discussion.

INTRODUCTION

In a fairly extensive review of the speleological literature worldwide I have found that random snippets of essentially useless pieces of data, commonly called "test results", appear frequently. Amongst all the verbiage written on equipment design and testing there is very little which meets acceptable standards of testing design and reporting. The vast proportion of "testing" done by cavers and reported in club newsletters and journals is functionally meaningless. Almost every single report examined used a different test method, different equipment under different conditions, and most frequently was unrepeated. As responsible speleologists concerned about our own and others' safety, we need to be more critical of the equipment we use and particularly how we justify that feeling that "I'm all right, Jack. It won't break while I'm on it!"

It is relevant at the beginning of this paper to quote comments made by John Bosler (1977) at the last Australian Speleological Federation (A.S.F.) conference:

> The development of proper testing procedures 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.

WHY TEST?

There are three basic reasons for testing caving equipment.

1. Development. Almost all equipment progresses from an initial idea to prototype construction, then field and laboratory testing to iron out the bugs, followed occasionally by production if the idea was good and the tests gave

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satisfactory results. Depending on the nature of the particular equipment, this development testing is usually to answer questions of the nature of "how" or "why" it works. There may be several prototypes developed by trial and error and modified in accordance with test results before an item is considered to be acceptable.

2. Quality control. Once the equipment is in production and is circulated widely the question arises as to whether the items are all the same. Quality control testing requires the establishment of a norm or ideal which all items tested should meet or exceed. Wide divergence from the norm indicates poor quality control and reflects largely on the manufacturer. Large numbers of items must be tested over a period of time to ensure quality standards are met and are continuing to be met.

3. Consumer testing. Consumer testing is usually "one-off" testing, usually quite independent of the manufacturer, which seeks to determine whether a given consumer purchasing a given item, can expect that item to meet relevant standards of performance and, in particular, how it compares with similar items from different manufacturers. Assuming the testing methods are consistent, reliable, unbiassed and relevant (and that is not always the case), then consumer testing becomes for the manufacturer, and the consumer, a "luck-of-the-draw" situation. Manufacturer A may have one in 1000 items which fail to meet the test standard, while for manufacturer B the ratio might be one in 100. Providing distribution is even, a random sample of one of each item gives manufacturer A a much better chance of having a "good" item tested than manufacturer B - but this does not exclude the possibility of getting one of the few "good" items from B and the rare "poor" one from A. In order for their products to perform well under this system, then manufacturers must maintain high quality control or be lucky. From the consumer's point of view, of course, he wants the lowest chance of getting a "dud" - not only from a value for money point of view but also, far more importantly, from the point of view of safety. Consumer test methods are outlined in the International Standards Organisation (I.S.O.) guide number 12 (I.S.O., 1977).

RELEVANT STANDARDS ARE NEEDED

In order to evaluate caving equipment, we require mutually agreed upon standards of performance before we start any testing program. Standards need to be very carefully framed. It is of no use to specify performance criteria which cannot be reliably and reproducibly repeated and it is of little use to specify tests which are not relevant to the use of the item. There are currently very few acceptable standards by which caving equipment can be evaluated. Those that do exist were initially set up for other uses of the equipment and may not on closer examination be particularly relevant to caving use. A good standard for caving equipment must take into account conditions encountered in caves, be it high humidity, intermittent immersion in water or abrasion from mud as well as the manner in which the equipment is used. By now, most cavers should be aware of the clear difference between ropes designed for climbing which meet the Union Internationale des Associations d'Alpinisme (U.I.A.A.) standard and superficially similar ropes for caving which do not require high energy absorption and consequent elasticity. Similarly caving helmets worn by the vast proportion of cavers are designed for industrial use where a broad rim is useful and where constant abrasion is rare. Your helmet if tested now would be unlikely to meet the standard it was designed to meet!

INTERNATIONAL STANDARDS AND AUSTRALIAN STANDARDS

As cavers, we need to sit down and prepare our own standards for our own equipment. There are already some moves in this direction in Britain. The most logical move would be for the International Union of Speleology (I.U.S.) to set up a committee and sponsor drafting of relevant standards. This will probably take years, so A.S.F. should consider looking at its own situation and get on with the job, before more time and money is wasted in irrelevant, non-repeatable and scientifically worthless testing programs.

WHAT STANDARDS ARE REQUIRED?

Standards are required for equipment where life is directly endangered. I would propose as an initial list the following: rope for S.R.T.; descenders; ascenders; helmets and ladders.

The standards would specify what are the required minimum safety requirements for strength, durability, age or use-related deterioration, dynamic and static testing, standard practice in use and methods of testing and reporting of results.

HOW SHOULD STANDARDS BE DEVELOPED?

Anyone who has had experience with the Standards Association of Australia (S.A.A.) will tell you that standards are neither easy to write, nor easy to get agreement upon.

The S.A.A. procedure is to form a committee comprised of all interested parties - manufacturers, consumers, academics and, if necessary, government. This committee wrangles its way to a draft standard which is published for public comment and after all comment has been considered, publishes the standard in its final form. It should be noted that Australian Standards thus established by consensus have no weight in law. No-one is compelled to manufacture to such a standard until required to do so by specific direction of government or parliament.

DRAFT STANDARDS

In order to stimulate discussion, included here is a review of a number of aspects which must be considered in the drafting of standards for caving equipment.

All standards should include a preamble setting out what the standard is, how it arose and basic definitions of terms used in it. Then follows specification of the performance required, the methods to be used to assess the performance and the manner in which the results should be reported.

If special testing equipment is required, it is usually described in appendixes. Standards need not be long and involved documents, nor do they necessarily require extensive and costly testing equipment or procedures. To illustrate the procedure I will give an example.

ROPE FOR S.R.T. - REVIEW OF CHARACTERISTICS

Many properties of ropes are important for S.R.T. The most important characteristics of an S.R.T. rope are that it be sufficiently strong and have a low stretch. Other characteristics to consider are type of construction and abrasion resistance, thermal conductivity, melting and softening temperatures, shock strength or energy absorption, diameter in relation to handling characteristics, stiffness and effect of environmental factors such as sunlight, water and common chemical substances which may affect the physical characteristics of the rope.

The ultimate tensile strength of a rope is important since the stronger the rope the greater the safety factor. It is generally considered that a rope must be able to sustain a force of at least 10 kN (equivalent to the weight of 1000 kg) although such a rope would have little in reserve as a safety factor to account for degradation of physical properties with time. Knots and abrasions rapidly reduce the strength of a rope - remember it is the weakest link in the chain that will fail first (Bosler, 1977). Selection of a rope should be made keeping this is mind. Clearly, then a rope with a tensile strength of 3000 kg or greater, would give a good safety factor when knotted and no longer new, as the combination of a knot and ageing can reduce the rope's strength by over half what it was when new.

Abrasion of a rope can occur when the rope moves and rubs against a rock surface. Generally the rougher the rock or sharper the edge, the quicker the rope is damaged. However, it should be noted that abrasion can occur on quite smooth surfaces (see, for example, Eavis, 1974; Weiner & Sheehan, 1966, for detailed discussion). The more elastic the rope the more it will stretch and the more likely rope bounce set up during abseiling or prusiking will cause severe rope damage due to abrasion. A rope should be retired when the number of cut strands in the sheath reaches 50% (Penberthy, 1972). A rope for abseiling and prusiking should be judged on how little it will stretch under a typical bodyweight plus, say, a pack. It is common to quote percentage rope stretch under a load of about 80 kg.

Although an S.R.T. rope is not expected to absorb the energy of a fall, some small shock loading may occur. Cowlishaw (1978) has suggested that a figure around 800-1200 J m^{-1} is appropriate, allowing for reduction in energy absorption with age and use. It should be noted that energy absorption capacity (E.A.C.) decreases very approximately as the square of the ultimate tensile strength (U.T.S.). If the U.T.S. is halved then the E.A.C. is only about one quarter - don't fall on an old rope! In caving, a maximum likely fall factor is 0.3 and Cowlishaw (1978) suggests that a peak force should not exceed 6 kN. Limited testing to date suggests that most current S.R.T. ropes will meet this criterion (see also Hawkins, 1977).

There are two main types of rope construction - laid and "kernmantle".

Laid ropes comprise of strands twisted together, each strand being composed of many monofilaments or staples twisted together. The most common laid ropes used for abseiling are nylon climbing ropes made to BS 3104. These ropes are generally much more elastic than is desirable for abseiling and have a tendency to cause spin on freefall drops.

"Kernmantle" is a German word describing a rope constructed with a core of twisted or straight strands surrounded by one or more plaited sheaths. Depending on the details of construction, a kernmantle rope can be very elastic or very inelastic. Climbing ropes must take a "leader-fall" under

dynamic conditions and are designed to absorb a lot of energy by stretching. Kernmantle ropes specifically designed for abseiling and prusiking are quite different from climbing rope and should not be confused.

Although polyamide (Nylon/Perlon/Grilon)* has a greater elasticity than polyester (Terylene/Dacron)* as a monofilament it is possible to construct very low stretch kernmantle ropes for abseiling and prusiking. Such ropes should not be used as a lead-rope for climbing.

The sheath can act solely as protection for the core or it can contribute a significant proportion of the strength of the rope. From the point of view of abrasion affecting strength it is obviously better if the core provides the strength and the sheath provides protection. All ropes should be frequently inspected for abrasion damage.

Abseiling generates a good deal of heat, the heavier the person the longer the drop and the faster the abseil the more heat is developed. A rope with a high thermal capacity and conductivity will absorb heat better than one with lower capacity and conductivity, but this factor is less important if the rope is wet. Nylon does absorb a small amount of water, but does not swell and water does not markedly affect its tensile strength. It will withstand temperatures up to 150°C for hours without undue loss of strength.

The diameter of the rope will affect not only its strength (a linear increase with diameter) but also its handling and whether it suits commonly used descenders or ascenders. Too thick a rope is stiff and must be fed through the descender, while too thin a rope does not generate sufficient friction, giving rise to overly fast abseils - it is also much harder to grab effectively to control the descent - suitable rope diameters are in the range 10 to 12 mm with an optimum of 11 mm.

While chemically very stable, nylon is attacked by phenol, cresol and acids. No foods or drinks and very few household products contain these chemicals in concentrations high enough to cause damage. The only product of great concern is battery acid. Polyester (Terylene/Dacron) resistance is good with weak alkalais and all but hot strong acids. Battery acid has no effect under atmospheric temperatures. The only chemicals of real concern are strong alkalies such as caustic soda in the concentration found in NiFe cell caving lamps.

From the above discussion it seems desirable to require tests of ultimate tensile strength, wet and dry elongation under load of 80 kg, energy absorption, diameter of rope, abrasion resistance, and knottability.

TEST PROCEDURE - PRELIMINARY DRAFT

1.1. All tests unless specified otherwise should take place at 20°C, deviation to be noted.
1.2 A minimum length of 10 m (?) shall be presented for testing.
1.3 After conditioning at 20°C for at least one hour.

2.1 The diameter of the rope shall be measured with vernier calipers (or a micrometer?) in at least 10 places along the length of the sample.
2.2 The average of these measurements shall be reported as the diameter and the maximum deviation noted.

* Alternative brand names for basically the same product.

3.1 The test length shall be cut in half. One half will be immersed in clean water (at 20°C) for 20 minutes (?), removed and allowed to drip for 5 minutes (?).
3.2 Both test lengths to be weighed and mass per unit length (kg/m) and proportion of water absorbed (mass of water / mass of unit length rope) reported.
3.3 The "wet" rope shall be dried until it is within 1% (?) of the mass of the dry rope.

4.1 Both the ropes shall be tested in the following manner:-
4.2 Load the rope without impact with 80 kg - maintain the load for 10 minutes.
4.3 Unload - maintain the rope unloaded for 10 minutes.
4.4 Load the rope with 5 kg and mark two reference points one metre apart in order to measure the elongation.
4.5 Load the rope without impact up to 80 kg total. After 60±5 seconds, measure the distance between the reference points and calculate the elongation as a percent (U.I.A.A., 1977).
4.6 The average percentage elongation to be reported.

5.1 In each rope an overhand knot will be formed. The rope to be subjected to a tension of 10 kg for one minute after which the tension will be reduced and maintained at 1 kg.
5.2 As long as the tension lasts, it must be impossible to introduce a rod of a diameter equal to that of the rope into any part whatever of the knot without forcing it.
5.3 The test with the knot should be made in both directions (U.I.A.A.,1977).
5.4 Penetration of rod to be reported and rope noted to be "stiff".

6.1 The dry rope shall then be cut into three lengths each length to be mounted in a tensile test jig (Instron or similar machine?). The rope ends to be wound three times round a 5 cm diameter rod (clamped in the jaws) - see Eavis, 1974 - and tied off in a suitable manner.
6.2 The jaws to be expanded slowly until failure occurs and a plot of force versus extension to be kept.
6.3 The average of the three results for ultimate tensile strength and percentage extension at failure to be reported and total energy absorption per unit length (kJ/m) and shock strength (J/m) to be calculated and reported (for example, see Cowlishaw, 1978).

7.1 The "wet" rope (now dry) to be similarly cut into three lengths and each length to be cyclically loaded with a mass of 30 kg over a steel right angle, making contact with both faces of the bar (90° angle of contact). A 5 cm stroke to be used and a suitable cycle rate in the range 1200 - 3000 Hz be maintained until failure of the sheath for kernmantle ropes or 30% of strands cut for laid ropes (see Isenhart, 1977).
7.2 Nature of failure and average number of cycles to failure to be reported.

CONCLUSION

A far higher quality of testing of caving equipment than has hitherto been the case is required. A.S.F. should move to establish carefully considered and well documented standards against which caving equipment can be evaluated, by rigorous, repeatable and statistically relevant test methods. Until such time as mutually agreed upon standards are established we should be very wary of inadequately carried out "tests" of equipment upon which lives depend.

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A PRELIMINARY REPORT ON A SYSTEMATIC AND MODULAR METHOD OF SURVEYING AND MAPPING

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Abstract

Problems with incompatible and unwieldy maps caused the search for a better system. The solution being tried, and still under development, is a practical implementation of the so-called "street directory" method, perhaps better called modular mapping.

The system produces all routine maps as modules 200 mm square on A4 sheets, and at a range of standard scales chosen to suit both the particular area and the type of caves. The boundary of each sheet is fixed, and is determined strictly from a metric grid standardised on for the area, and not on the present wanderings of any cave. The grid is preferably the Australian Map Grid or close to it, but may in fact be any grid decided upon if no A.M.G. control points can be established in the area. Maps at different scales are used to enable either a close or an overall view of the caves or the area, and also to act as key sheets for the next scale down.

The set of sheets can be thought of as an "atlas" for the area. Each new survey fills another gap in the overall mosaic. Non-standard maps for special purposes are still drawn as required.

INTRODUCTION

This paper deals with a mapping technique which is currently under development and evaluation by the Victorian Speleological Association (V.S.A.). It was devised and introduced because as club records keeper and cave surveyor I was most dissatisfied and frustrated with the handling characteristics, cost, difficulty and incompatibility of existing cave maps and mapping methods.

The basic design of the method was actually done in 1972 but then shelved because of commitments to A.S.F. Documentation and Handbook. However, over the last few years V.S.A. has been fortunate to have had an influx of members who were keen on mapping. They were also interested in trying out the new technique. Its implementation and refinement has therefore now been able to proceed without making any significant demands on my own time. This surveying and mapping has been ably led by Lloyd Mill and Tom Whitehouse.

A preliminary report is presented at this time to encourage others to try out the method and hence speed up further development of what we feel promises to be a most useful technique.

WHY CHANGE?

What is wrong with the existing method anyway? Two things are mainly wrong: large map sheets and incompatible maps.

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MATTHEWS – MODULAR MAPPING

Few will deny the following problems with large map sheets.

Handling. Opening in a windy paddock; using underground; unfolding and refolding; fighting a map whose only aim is to roll up again; "Clear the whole table so we can open the map!" etc.

Copying. Large sheets will not fit on photocopiers so the tracing-and-dyeline method must be used. This restricts the number of possible copying locations, particularly free ones, and is quite expensive anyway.

Filing. Tracings should not be folded, so they must be stored either rolled or flat. Have you tried to find and replace a tracing in a roll of fifty or more when the sheets are all different sizes and the title block (if any) could be in any of the four corners? This might even drive you to try flat filing, but how do you flat-file at home sheets measuring two metres long or more? Whichever way you do it, it is likely to be a "pain in the neck", space consuming and/or costly.

Drafting. Drafting of large maps usually requires a proper drawing board set-up.

Publishing. Large maps are almost unpublishable within the normal budget. The alternative is a special re-draw to a small size. Photoreduction is usually unsatisfactory because it makes the lettering unreadable.

Incompatible maps means that although the existing maps of any given area might be quite good individually, each has been produced apparently without any awareness of the others, and as a result it is usually impossible or a great deal of trouble to integrate and use them in any report, presentation or submission on the area. The chances are you will need to draw up a special set and probably do some actual surveying, and all the while time is usually very short for the submission. Generally there will be a mix of scales (all "standard"!). You might be lucky enough to have the entrances interrelated by a surface survey, but there will probably be no clue as to the relative orientation of one cave to the other or any cave to the surface survey: they will probably all show "magnetic" north, but what they mean is "compass" north, and different compasses can easily differ by up to ten degrees. A ten degree swing at a radius of 1 km gives a positional error of about 175 m. This is a long way if you are digging a connection! It is also very discernable - even on a 1:100 000 map.

The aim then, was a mapping system which was easier to live with, and which automatically produced compatible maps.

THE BASIC SCHEME

The main characteristics of the method are:

1. All the routine mapping for a given area takes the form of an integrated set of map sheets each 200 mm square on an A4 sheet, and arranged together to form an atlas for the area.

2. The boundaries of each map sheet, that is, the ground coverage, are fixed according to a definite rule, and are determined from an agreed metric grid for the area. This grid can be any arbitrary metric grid but is ideally the Australian Map Grid (A.M.G.).

3. The set of sheets consists of several groups of standard scales arranged in a hierarchical manner. The smallest scale comes first and consists of a

single A4 sheet covering the whole area - the "top sheet". Then follow the other scales in order, finishing with the detail sheets at the largest scale. The number of different scales chosen, and their values, will depend on the type of caves and the mapping needs for the particular area. The smaller scale sheets also act as key sheets for the scale below them, for example, a complete set might consist of:

a sheet at 1:100 000 which is also a key to
a set at 1:5000 which is also a key to
a set at 1:200.

4. Because of its modular nature the atlas lends itself to being built up over a period of many years yet is useful right from the start. It can inherently cope with the fluctuating and random enthusiasm so characteristic of some caving clubs: each new survey fills one more gap in the overall mosaic. Maps eventually growing together from different starting points will automatically match up.

5. Only the squares which actually have caves or other features on them get drawn. Conversely, regardless of which way a cave extends, the mapper routinely starts a new sheet without needing any heart-rending decisions about its placement.

6. Each atlas has a single map number like an area map. Individual sheets have sheet numbers according to the coordinates at their bottom left-hand corner. Cave map numbers within an atlas follow the normal rules (A.S.F., 1974).

An example of how the sheets fit together is shown in Fig. 1. Its "highest" sheet is 1:5000:

At 1:5000, 1 mm represents 5000 mm or 5 m.
Therefore a 200 mm sheet represents 200 x 5 m = 1000 m or 1 km.

If we divide this 1 km square into a grid of 5 both ways:
each resultant square represents 1000 m/5 = 200 m.

If we now expand one of these 200 m squares on to a 200 mm sheet:
1 mm will represent 1 m or 1000 mm. The scale is therefore 1:1000.

Similarly if we divide this sheet into 5 both ways:
each resultant square represents 200 m/5 = 40 m.

If we now expand one of these 40 m squares on to a 200 mm sheet:
1 mm will represent 40 000 mm/200 = 200 mm.
The scale is therefore 1:200.

Each sheet therefore, besides being a map in its own right, is also a key sheet to the next scale down.

Although this particular example uses a grid factor (ratio of adjacent scales) of 5 in both cases, the grid factor can in fact range between 2 and 25.

The method described is obviously the "street directory" principle talked about in caving circles for the last ten years or so. All we have done is establish a clear and practical way of implementing that concept.

Two well-known maps which use a series of detail sheets with a smaller scale key sheet are Mullamullang Cave (Hill, 1966) and Mammoth Cave, Jenolan (Dunkley & Anderson, 1971). However both these differ in one important respect from the method described here - their detail sheets have a size and location uniquely selected to suit the then current shape and

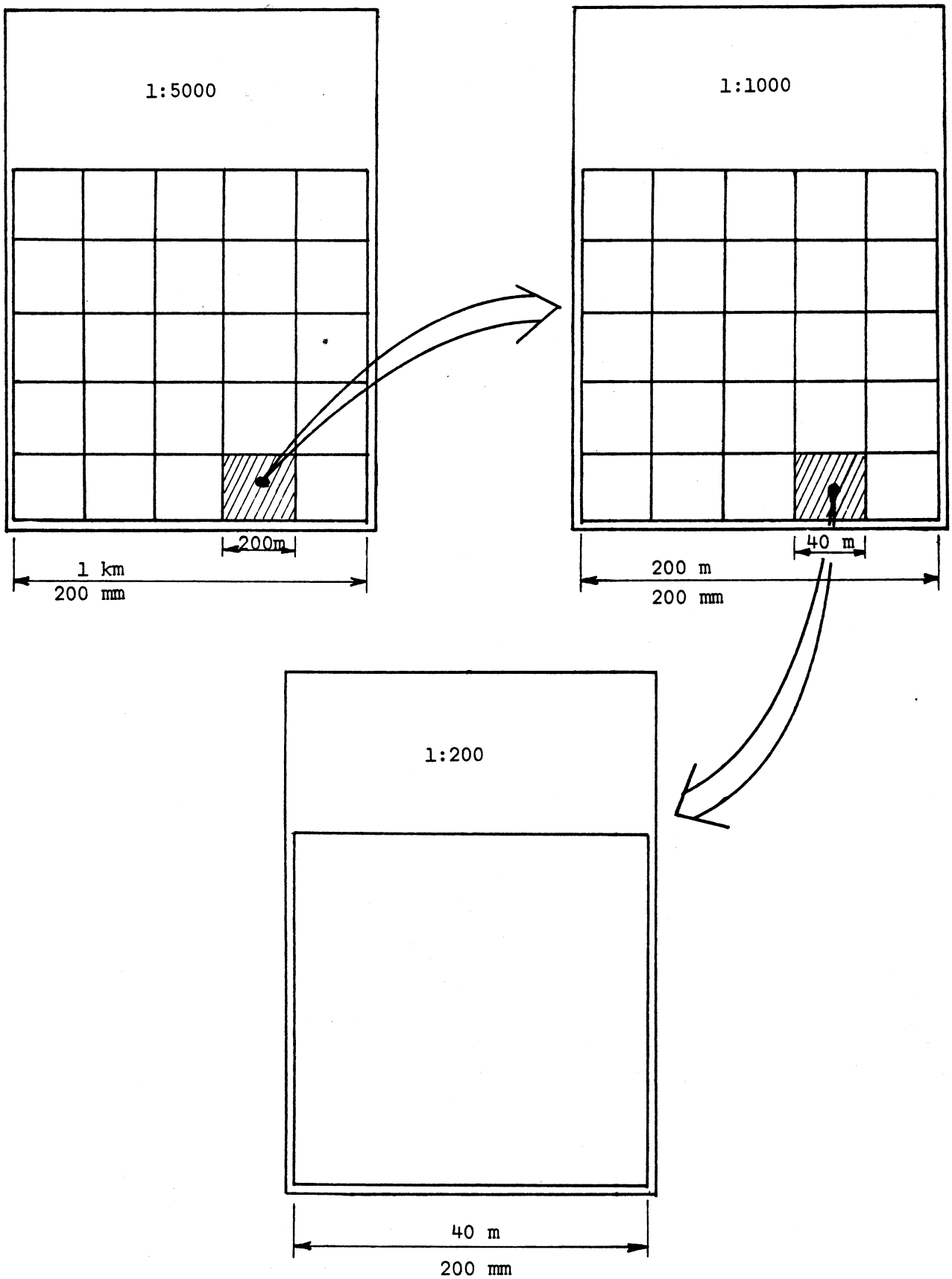

Figure 1. Example of scale relationships.

extent of the cave being studied, rather than being arrayed in a fixed and uniform grid.

While this method is more convenient and perfectly reasonable for presenting their respective cave, it is not very suitable (nor was it intended to be) for the routine long-term mapping of a whole area. The problems are:

- o future extensions and/or new caves could soon upset the careful initial placing of the detail sheets.
- o fairly important decisions continually have to be made about the placement of new detail sheets throughout the life of the project. It is certainly not automatic.
- o it becomes difficult to reference the arbitrarily placed detail sheets on an overall area basis.

When dealing with a whole area the uniform grid method of map sheets is better because all decision-making is done at the initiation of the project, and regardless of any new caves discovered or in what directions any cave develops:

- o the placement of all new sheets required is automatic and does not require reference to a central coordinator.
- o key sheets need no special notations on them to define or to reference lower level detail sheets - their existing grid automatically does this.
- o no constant maintenance of any referencing system is required.
- o adjacent maps always match up if they eventually join.

The only published example of a cave map using the uniform grid approach I am aware of is Flint Ridge Cave, Kentucky (Brucker & Burns, 1966), now of course part of the Mammoth Cave System. However that example used geographical coordinates (latitudes and longitudes) for its sheet boundaries, and hence had to use an additional and independent system for the numbering of its detail sheets. The detail sheets were 30-second rectangles (about 2400 ft by 3000 ft) at a scale of 1:3048 (1 cm = 100 ft), while the key sheet was 1:28 800 (1" = 2400 ft).

IMPLEMENTATION

There are two main stages: the initial setting up and routine use.

The initial setting up. The basic steps are:

1. Define the limits of the area. Include everything which could ever possibly be incorporated into the atlas for that area.

2. Decide on the scale for the top sheet. This should be the largest standard scale such that the whole area can be fitted on that one sheet. Standard scales will be found in Anderson et al. (1978:3). As much or as little of the A4 sheet as necessary can be used because the boundaries of the top sheet do not have to "obey" any higher sheet, that is, one is not limited to a 200 mm square. It is useful however if the boundaries align themselves with boundaries of sheets from the next lower level down.

3. Decide on the scale for the bottom (cave detail) sheets. This would commonly be 1:200.

4. Decide on the intermediate scales between these two. They should be chosen both with regard to their usefulness for that area and also should form convenient steps between the key sheets. Each scale should be a sub-multiple of the next higher scale, for example, 1:2000 and 1:5000 are not compatible but 1:2000 and 1:10 000 are. The maximum practical difference between adjacent scales is a factor of 25. Two examples of sets of scales are:

	Example 1	Example 2
top sheet	1:100 000	1:25 000
	5 000	5 000
		1 000
detail sheets	200	200

If there is also a need for a scale which is not compatible, for example, 1:10 000 in Example 2 above, then this can be inserted in the set as an auxiliary scale but it will not form a part of the main key sheet series. Note that 1:10 000 would be compatible in Example 1.

5. Decide on a grid for the area and implement it. The preferred grid will be the A.M.G. because this is the standard grid, most people are already familiar with it, and it permits the use of existing official maps directly as part of the atlas; for example, the Buchan top sheet is an A4 cut-out from a 1:100 000 map, and its normal 1 km grid represents 1:5000 sheets.

However, the decision will ultimately be based on what control points can be established in the area. "Implementing a grid" really just means having (1) some permanently marked points in the area whose coordinates relative to some starting point or origin have been found by surveying and calculation, and, (2) a permanently marked sighting line for the area to define orientation (Anderson, 1978:5). Any subsequent cave surveys taking their coordinates from a nearby one of these control points and their orientation from the sighting line will automatically be properly located on that area grid.

The control points provide a "higher" accurate network from which the cave surveys are hung, and as such should be established before the actual drawing of any cave maps. The points can be established by triangulation, by traversing, or by a combination of both, such as traverses equalised between accurate triangulated points to establish strings of lesser accuracy control points.

High accuracy, however, is not essential to this modular mapping technique, although naturally it produces better results. Surface traverses done carefully with normal cave surveying instruments are perfectly adequate, provided closed loops are employed as a check and all compasses used are corrected to a common orientation.

Some typical situations are:

- o accurate A.M.G. grid and control points established by theodolite and triangulation from official trig stations.
- o approximate A.M.G. grid and control points by using landmarks identifiable on a topographical map.
- o a purely local grid and control points of unknown relationship to the A.M.G., based on some convenient origin, and using a standardised magnetic north for orientation.

If accurate triangulation is being contemplated, a surveying textbook should be consulted to take advantage of established techniques for gaining maximum accuracy out of a given situation. *Surveying for field scientists* (Pugh, 1975) is a useful text.

Although a single sighting line with an agreed bearing is enough to define orientation of the grid, it is not enough to allow calibration and proper comparison of compasses. Some compass errors, such as pivot offset, are sinusoidal in nature, that is, the correction required depends on the direction being sighted. Because pivot offset direction will vary between compasses, comparing two compasses only on a single direction of sighting could give quite misleading results, depending as it does on the phase relationship between the two sine waves as well as the amplitudes. (We have found correction variations of up to two degrees around a prismatic and one degree around both our miners dials.)

Compass calibration stations should therefore provide several sighting lines spaced around the 360 degrees so that the correction-vs-bearing curve can be plotted and hence some intelligent decision made: one can then see what the average correction for that compass is, and either apply this average or apply the right correction per survey leg bearing. Note that reading both ends of a compass needle and averaging the two will remove the sinusoidal pivot offset error (and also bent-needle error), but in prismatic and Suunto compasses only one end of the needle is available.

6. Make up a folder for the atlas with a tab for each selected scale.

7. Prepare the initial version of the top sheet and any other high-level sheets which depend primarily on existing topographic maps

Routine use. The basic steps are:

1. Connect the cave survey to the surface control. The minimum requirement is a surface traverse to a control point or other known point. If better accuracy is required compass corrections should also be obtained, and if possible the cave survey should be strung between two or more control points, possibly with the aid of radio direction finding (R.D.F.) links. If calculated coordinate method (as opposed to the protractor and rule method) is being used, the whole cave should be calculated and equalised at this stage.

2. Mark the start of the survey in the right place on the right detail sheet. If a new sheet has to be made, see "Setting up new sheets" below.

3. Draft normally, using new detail sheets as required. If the protractor and rule method is being used any loop equalisations should be done now. If any of the detail sheets already exist from previous cave surveys, these existing sheets should be used. Elevations and cross-sections can be put on the A4 sheets either outside or inside the 200 mm square, or on auxiliary A4 sheets when necessary (use same sheet number but with dash-number added). The 70 mm strip between the title and the 200 mm square is useful for this purpose.

Normal paper can be used unless tracing or stability is specifically required. V.S.A. is trying out a polyester film with a blue drop-out grid showing 1, 5, 10 and 50 mm. It is not an expensive precision grid however. The brand is GAF "continuous sectional material" code G3002XC.

4. Transfer the cave silhouette or outline to higher-level sheets if appropriate. Generally the cave outline can be easily transferred square

by square by eye. For example, a 5 m square from a 1:200 sheet (A.S.F.'s recommended grid interval) is represented by a 5 mm square at 1:1000 and a 1 mm square at 1:5000. Most decent graph papers have 1 mm and 5 mm squares.

5. Assemble the sheets into numeric order within each scale and insert in the appropriate place in the atlas.

6. Register the existence of the new cave map in the club's set of A.S.F. Map Summary forms.

Setting up new sheets.

Sheet boundaries are determined by dividing the scale by five.

If this is strictly adhered to, all sheet boundaries will line up right through a set of key sheets.

Scale:	1:5000	1:1000	1:200
Sheet boundaries at every multiple of:	1000 m	200 m	40 m

With 40 or 400 m make sure you get the right multiples, for example:

	56 300	56 340	56 380	56 420	is wrong
but	56 320	56 360	56 400	56 440	is right.

If you are using other than 200 mm modules, then the factor to divide by is found by dividing your module size into one metre.

Grid interval is determined by dividing the sheet width by the number of times the next lowest scale fits into this scale, for example:

> If this sheet is 1:1000 and the next scale down is 1:500, then divide the 1:1000 sheet into (1000/500 =) two, both ways.

Strictly, the grid interval is determined by the sheet boundaries of the next lowest scale down, but for equal-sized modules (all 200 mm) the above rule holds.

If there are five or less grid lines across a sheet, then additional border ticks (not grid lines) should be added in accordance with, or as close as possible to, A.S.F. recommendations (Anderson et al., 1978:6).

Grid lines should be calibrated only in km or in metres as appropriate, and always including the respective "units" (km or m) digit.

Sheet numbers are given by the grid reference of the bottom left-hand corner of the sheet.

The high-order digit is always the 10's of km as is standard with map grid references, and the number of digits used is the minimum necessary to distinguish sheets within that scale, that is, the lowest order digit is the lowest one which changes from sheet to sheet, for example:

Scale	Size	Changes	Sheet number
1:5000	1 km sheet	kilometres	03.29 (3 km E, 29 km N)
1:1000	200 m sheet	100's of m	034.290
1:200	40 m sheet	10's of m	0340.2908

Different scale sheets with a common left-hand corner in any given atlas are usually distinguishable by the different number of digits, but not

always. To avoid any possibility of confusion it is best to fill in as a matter of course the sheet number block in the title like the following examples (note these would not all be in the one set):

1 km sheet	400 m sheet	200 m sheet	100 m sheet	40 m sheet
03.29	032.296	032.296	032.296	0324.2968

A typical sheet format is shown in Fig. 2. The top margin should be at least 10 mm to allow for the gripping edge needed in some photocopiers and multilith machines. Some photocopiers are also a bit vague at the bottom edge, so at least the remaining 7 mm should be left there. The title strip shown is intended as a minimum identifier for each sheet - the main title details, possibly including schedules, should be on a special sheet(s) in the set. If cutting the sheet from gridded material as mentioned above, care should be taken to cause the 200 mm square to align with the 50 mm grid lines on the material. Use the opposite side of the sheet to the printed grid so that the grid will not be affected by erasures.

OTHER ASPECTS

sub-areas
special-purpose maps
standard cave location series
location security

In some large areas it might be preferred for convenience of working to handle some sub-areas separately. In this case all the respective sheets can be extracted from the main atlas and a sub-atlas formed just for that area, with its own individual top sheet. If the top sheet is not a standard sheet from the main atlas it should be given its own map number, but all the lower sheets will retain the original number of the main atlas as they are still really a part of it. At Buchan, V.S.A. has a separate top sheet for the Buchan Caves Reserve and surroundings; it is a vertical strip 2 km E-W by 5 km N-S up the centre of an A4 sheet at a scale of 1:25 000.

If for some specific presentation or submission the sheet boundaries are inconveniently located or the scale is unsuitable, then there should be no hesitation in producing a new special map for the purpose, using the standard sheets for the basis. This new map would have its own new map number. The modular mapping technique is primarily aimed at routine mapping, and while it will also satisfy many other mapping requirements it is certainly not expected to satisfy all.

The 1:5000 series of sheets can be very useful for general cave referencing, such as for a standard cave location series in an area. The scale is a convenient one for locations (1 mm = 5 m) and can still accept cave silhouettes. The sheets are also very identifiable, being the 1 km grid squares on official 1:100 000, 1:50 000 and 1:25 000 maps. V.S.A. is at present transferring the Buchan parish allotment map to these sheets so that fence-lines can be used (when they are in the right place!) to help plot cave locations.

The question of location security is one we have not seriously looked at yet, although several possibilities come to mind - the use of an arbitrary grid or the suppression of high-order digits on an A.M.G. grid were mentioned by

V S A	Map No: 3B.VSA47	Atlas Title	1:1000	200m sheet
Rev 5: Computation 29.10.77		Subtitle for sheet or group	Grid: local	028.492

Squares are 40m 1:200 sheets.

FIGURE 2. SAMPLE MAP SHEET FORMAT.

Sheet Margins: Top 10mm
Sides 5mm
Bottom 7mm

		(cont sh) (028.494)		49400
				360
(cont sh) (026.492)				320 (cont sh) (030.492)
				280
9200mN		(cont sh)		240 49200
	840	880 (028.490)	920	960 03000

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Anderson et al.(1978:5), high-order A.M.G. digits could be replaced by an arbitrary code letter, the cave locations on V.S.A.'s 1:5000 sheets will probably be on separate overlays per sheet. This latter method will allow the 1:5000 sheets to be widely used for various purposes without revealing locations unless required. Even the very use of many sheets keeps the eggs in separate baskets.

DISADVANTAGES

1. The fixed boundaries can cause a small map to take up several sheets when it would really fit on one.

2. Modules 200 mm in size leave only a 5 mm margin at each side of the sheet. This can cause difficulties in some publications. However it is not practical to use any other module size with A4 sheets - key-sheet and other problems are caused.

3. Another consequence of the 200 mm size is that it is not possible to have formal sheet overlap; however I suspect overlap is a mythical advantage anyway on cave maps even if it is valid in street directories.

4. Drawing a cave at more than one scale is needed.

5. Some sort of surface control is needed. However this may actually be an advantage!

ADVANTAGES

1. The scheme provides a definite and simple long-term plan for club surveyors to work to.

2. All mapping is compatible. This means minimum delay when any submission has to be made.

3. It permits a rational and consistent presentation regardless of area size and level of detail required.

4. Cavers can survey where and when they like, and the results can still immediately fit into the overall scheme and eventually match up with adjacent maps - "One more square in the mosaic is filled."

5. All the A4 advantages:

- easy handling in the field and at home.
- easy and cheap filing.
- easy and cheap photocopying.
- easy and cheap drafting.
- easy and cheap publishing.
- fits on the cheaper computer plotters.
- fits in typewriters.

6. Makes infinite-sized wall-maps possible.

CONCLUSIONS

- The method does seem to be working.
- At last we feel we are on top of "the mapping problem".
- The advantages far outweigh the disadvantages.
- The method's main strength is in its ability to provide a scheme for the long-term integrated mapping of a whole area, not just of individual caves.

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VERTICAL CAVING GEAR IN ACTION

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Abstract

As well as being mentally and physically taxing on individuals, any expedition is also the ultimate test of caving equipment. The ATEA '78 expedition which spent two months in the mud of New Guinea's Muller Plateau was no exception.

This paper will attempt to show some of the weaknesses and strengths of the gear which was used on the ATEA '78 expedition.

INTRODUCTION

As Equipment Officer for ATEA '78 I was in charge of collecting, choosing and often resurrecting most of the group caving gear which went to New Guinea. Actual caving time in the field was about six weeks. Most of the gear was air-dropped except for easily damaged items such as karabiners and Jumars, which were either carried in or flown in by helicopter.

1. GROUP GEAR

(a) *ROPES*

A huge range of types and lengths of rope were taken, the main reason being that these were what could be borrowed cost free from people, the only exceptions being the 600 m of 8 mm polypropylene and the 1000 m of 8 mm polyethylene "Ski Rope".

Polyester (terylene) ropes

Most of the ropes taken were polyester with a 16 plait sheath and 10 mm or 12 mm in diameter: Marlow 12 mm staple; Marlow 10 mm staple; Kinnears 12 mm staple; Downs 12 mm staple and Downs 10 mm multifilament (smooth).

Comments. The Marlow 12 mm was too thick for easy prusiking and very heavy to carry, especially when wet (one person actually complained that it squeaks when you prusik on it). None of it sustained any damage.

Marlow and Downs 10 mm were generally preferred as exploration ropes because of their ease of packing. carrying, prusiking and low water absorption, althougn they did make difficult handlines when muddy. The Kinnears 12 mm spun badly and was very bouncy while the Downs 12 mm was excellent - being a denser weave it absorbs less water than most 12 mm ropes and also has better abrasion resistance but some problems with sheath slippage may be encountered with a new rope. Twelve mm rope was usually used for the long pitches, and heavy use pitches because of the safety factor. Four ropes were cut on the expedition. Two were Marlow 10 mm, one was 30 m down a 100 m rope at an unprotected lip, while the other was on a short handline which was so muddy that the cut was not detected until the rope was removed and washed.

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Nylon ropes

Those taken were: Bluewater II; Bluewater III; Edelrid 10 mm static; Edelrid 11 mm dynamic and Interalp 11 mm dynamic, the latter two being climbing ropes.

Comments. The Bluewater II had stiffened with age and was extremely unmanageable, hence hardly used, while the new piece was both stiffer and heavier than polyester. The Bluewater III was easier to handle and fairly bouncy (up until the time it was dropped down the doline wall and into the riverway and never seen again!).

The Edelrid static was quite popular as short, light "handy rope" for exploration trips. Abrasion resistance is excellent although stretch is astronomical. The two 11 mm climbing ropes performed well and if they had less stretch they would make excellent prusik ropes. A most spectacular rope cut occurred in a short length of Edelrid 10 mm which was used as a handline. The sharp and unprotected lip at the top stripped the sheath completely off for a length of 30 cm.

Float rope

The ropes taken were: Downs 8 mm 8 plait polypropylene; Downs 12 mm laid polypropylene; Kinnears 8 mm 8 plait polyethylene and Millers 12 mm laid polypropylene.

Comments. The Downs 8 mm was bought specifically as a handline for long swims and it performed well, being easy to see and hold although it abraded very easily and in one instance actually cut in two on a sharp rock in the streamway. The polyethylene was cheap and abrasion-resistant but very slippery and had to be used at least double thickness on handlines. It is also hard to hold when swimming but makes excellent clotheslines.

(b) *RIGGING GEAR*

Karabiners

One hundred and thirty four were taken, all aluminium alloy and 75 of them with locking gates. Most were Hiatt small Ds with a 2000 kg rating. The rest were survivors from previous expeditions. There were no problems encountered except for mud clogging up the gates and making them hard to open. For some reason the locking krabs were more prone to this than the non-locking ones. The loss rate was quite low. Of the 100 new Hiatts taken (50 locking, 50 non-locking), 52 locking and 45 non-locking krabs returned. On arrival in Sydney, 50% of locking krabs and 30% of non-locking krabs were jammed, but a few hours work with WD40 (penetrating oil) returned them all to as-new condition.

Bolts*

About 120 Ramset Terrier self-drilling expansion anchors in sizes ¼" and ⅜" and both Flush End and Snap Off styles were taken. Bolts for the anchors were ¼" and ⅜" by ¾" long hi-tensile steel and brackets of 4 mm structural grade aluminium. Some 2½" x ¼" Dynabolts and drills to suit were taken for soft rock but were not needed (Plate 1).

Comments. The bolting system was tested at Bungonia by two methods.

(i) Ripping them out with a car. In all cases the ¼" bolts snapped off flush with the anchor although the car (Toyota Corona) needed a 2 m+ running start to do it. The ¼" bolts could not be removed from a standing start. The ⅜" bolts could not be removed with a 4 m+ running start and the driver was unwilling to try harder.

*Expansion anchors have been used for many years in U.S.A., U.K. and Europe.

(ii) Slowly pulling them out with an hydraulic Porta-Power. Only ¼" bolts were tested and in all cases they failed when the casing snapped where it protruded above the rock surface. The weakest bolt failed at 1100 lbs. The brackets survived undamaged and were later found to break at 2000 lbs although a steel keyhole bracket distorted severely under load.

In practice, people did not like the look of the snap-offs, so did not use them. Of the 15 bolts placed, there was only one failure and that was where the rock into which the anchor was being put broke in half. Because our brackets turned out to be 4 mm instead of 6 mm, the ¼" by ½" bolts were slightly too long for the anchors and so poked out too far giving the bracket a slight amount of leverage on the bolt. Otherwise the bolting system seemed perfect, with ¼" for exploration, aid climbing and retreating and ⅜" for heavy use pitches.

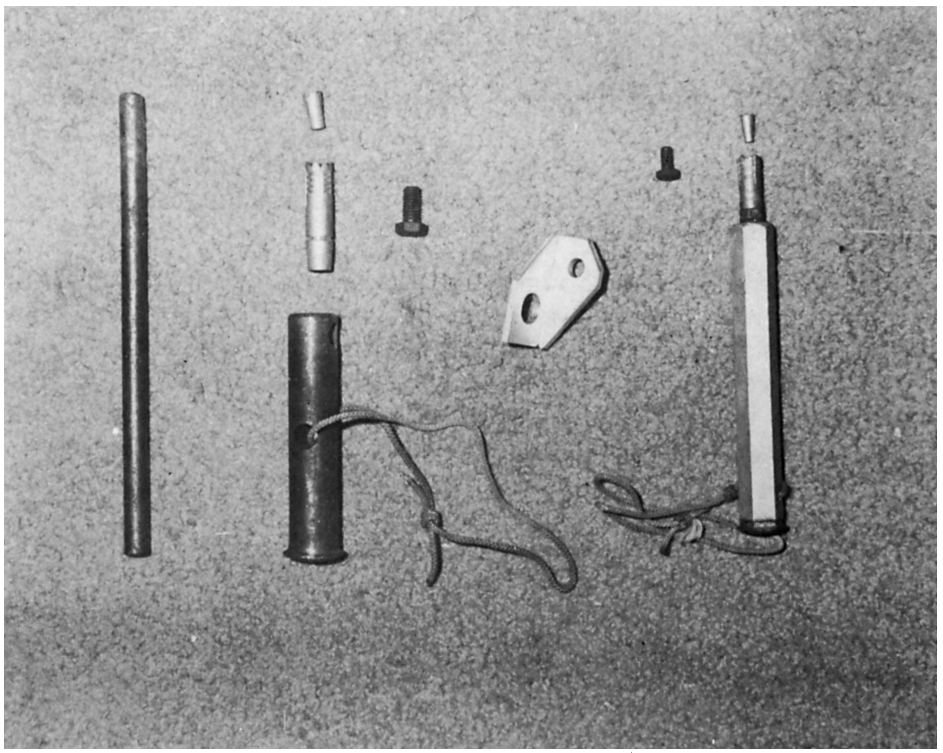

Plate 1. Terrier expansion bolt system.

Shown are a ⅜" Snap Off anchor, driver and tapered drift, ⅜" bolt and bracket, and a ¼" Flush End anchor on driver plus bolt.

Pitons and chocks

Most of the pitons were Chouinard with some Clog and Hiatt models as well. All the chocks were Chouinard. Pitons ranged from the smallest angles and short knifeblades through to a few bongs of various sizes, and nearly two full sets of leepers.

Comments. As expected, the most popular pegs were the small to medium angles, long angles and leepers. The chocks were of limited use, rarely carried and although handy for climbing they were certainly not necessary. As for "bad" pegs, two "popped" under load because of bad placement, one came loose and nearly fell out for the same reason and one small Hiatt angle actually snapped across the axis about 3 cm from the tip while under load.

Tape and traces

Fifty metres of 5 cm wide and 50 m of 2.5 cm wide nylon seatbelt tape was taken. The 50 wire traces with thimbles in each end to take krabs were in two sizes (1.5 m and 3 m) and were of 6 mm galvanised wire rope with aluminium swages.

Comments. The tape was very popular, especially amongst those who had forgotten waist loops, prusik rigs etc. The 2.5 cm tape was so popular that almost none was left for rigging. The traces were a little thick at 6 mm which made them heavier to carry but at least people were confident in them (unlike a few of the 3 mm and 4 mm ones around). Both lengths were handy but the 3 m ones were definitely the most useful. The thimbles could have been larger such that the screw gate of a krab could pass through them.

Rope protectors

Eighty-one of the Jerry Protector design were taken. They were made of Agrifab, a heavy P.V.C. coated terylene. Thirty or so split hose protectors were taken on the off-chance that all of the Jerry Protectors were lost or used.

Comments. About 50 rope protectors were used and there were no problems due to protector failure although at least one had a hole rubbed right through it. In very muddy areas the velcro became clogged and protectors were replaced by hessian sacks. The plastic hose protectors were burnt in preference to carrying them out. Only four cloth protectors were lost.

(c) *ROPE PACKS*

Thirteen group and several personal rope packs were taken, all made of Agrifab and in two basic designs. They were typically small, simple sacks 25 cm in diameter and 50 to 60 cm long with standard design shoulder straps and drawstring tops. The newer ones also had an extra drawstring closing throat, and all packs had paired 1" tape hauling tabs on the top. All performed well, but the older design with straps towards the front were easier to carry at the expense of having corners on the bottom which tended to wear through faster than the new models with their rounded bottoms. A slightly worse-for-wear version of the new design is shown in Plate 2.

2. PERSONAL GEAR

(a) *DESCENDERS*

The choice of descenders was restricted to Whaletails - both machined and cast, and a wide variety of Rappel Racks. In most cases wear was considerable with some whaletails being worn down to the centre-screw and many brake-bars being thrown away as useless. It is interesting to note that very little vertical work was done, and had the caves been vertical instead of horizontal the wear on descenders would have been quite a problem. The only device that did not wear excessively was the author's rack which had steel bars (¾" waterpipe in fact) instead of the usual aluminium.

(b) *ASCENDERS*

Types used were: Jumars; Cloggers; Gibbs and Petzel.

Jumars were by far the most popular and worked quite well except on very muddy ropes when one had to push upwards on the cams to gain any grip. It was found that a smooth multi-filament rope was slightly better than either thick or thin staple (furry) ropes. Wear on Jumar teeth was noticeable but not excessive.

Plate 2. Warild design cave sack.

Note drawstring closing top and throat with cordgrips and hauling loops (with krab in one).

Cloggers were used almost exclusively by the few British cavers on the trip, their theory being that Cloggers are more robust than Jumars and could handle much more abuse. The availability of cheap factory seconds in Britain also may have had something to do with the choice of Cloggers. Despite their low cost, Cloggers had many disadvantages: they suffered from worse slip on muddy ropes than Jumars and were prone to jamming when they were supposed to be sliding up the rope, not to mention the handling problems associated with getting them on and off the rope.

Gibbs ascenders were used by a few, and then only rarely. They were unsurpassed on the muddiest of ropes but because of their intricate design they were quite difficult to assemble in the sticky mud and generally proved to be a slower but safer alternative.

Petzels were used by very few people. Although they were quite easy to get on and off the rope, they seemed to suffer the same slip/jam problem as the Cloggers.

(c) *LIGHTING*

Small brass carbide lamps were the usual form of underground lighting. Many problems were encountered after filling them with muddy water. A useful modification was to replace the inadequate felt filter with a piece of Scotch-

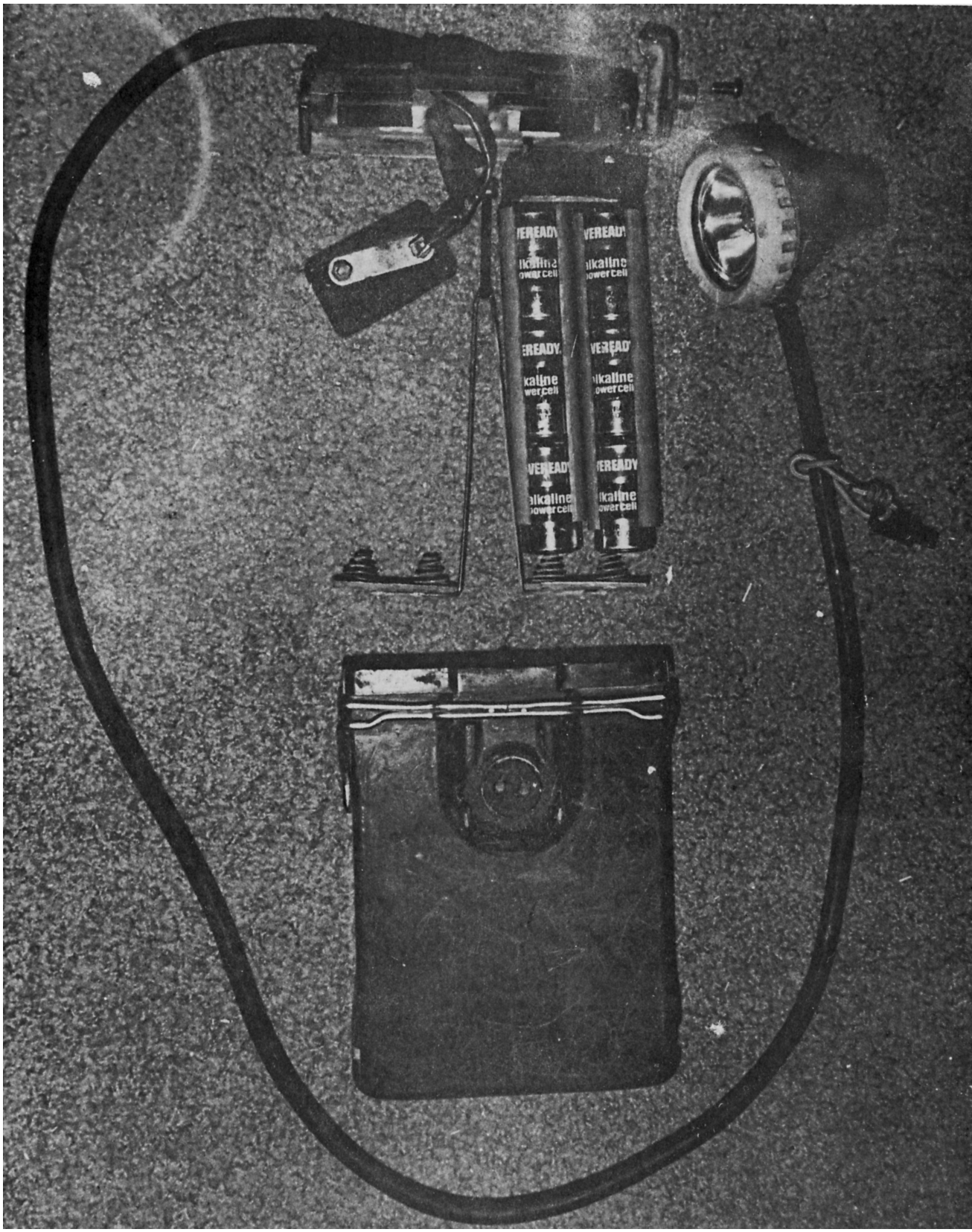

Plate 3. Rothery converted lead/acid.

Shown are six of the twelve C cells in place in PVC holders, and alligator clip for connection to each "half" of battery.

brite plastic scourer. Some lamps had their mounting brackets broken off after too many collisions with the roof of caves but these were easily fixed with a large pipeclamp.

Electric lighting was a much more complex problem than those associated with even the worst carbide lamp. Almost everybody used the Dave Rothery converted miners lights. These have had the original lead/acid plates removed and replaced with twelve C cells stacked in four rows of three in series (Plate 3).

Additionally, the cells were wired into two groups such that only six can be used at any one time, giving a reserve supply of the other six cells. The main beam bulb was replaced by a 3.6 volt bulb which gave adequate light for much longer than the standard bulb. These lamps performed extremely well under the conditions but they were high maintenance units and had to be dried out and often repaired between trips. Two other types of electric light were used. Julia James had a perspex battery case containing nine D cells (three rows of three in series) which worked well except when the cells jammed because the case was too tight. The author's unit consisted of three D cells in series, crammed into a P.V.C. junction box to make a light compact unit which was not as cumbersome as the other lighting systems. Apart from one minor short circiut it performed perfectly. Both the James and the Warild lights used standard lead/acid headpieces and bulbs.

CONCLUSION

ATEA '78 was not as technically difficult as expected, but it did give some of the equipment a hard time. Had the Atea been a deep vertical system many people may have had their gear dangerously worn.

Nevertheless, the basic trends of gear destruction were the same and expedition members were saved from nasty moments which pushing equipment to the limit can cause.

SEISMIC CAVE DETECTION MADE SIMPLE

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Abstract

Describes a practical method of cave detection using simple seismic methods and equipment. Investigations have proved that the equipment developed recently and used by the author will detect caves in various types of limestone. It has in many cases indicated passage widths and position accurately and with further investigation it may be possible to calculate depth as well.

Seismology is the study of sound or shock waves in the earth's surface and this paper looks at how these sound waves, when used in a systematic way, can be used to detect the presence of caves.

Several years ago a friend who has a property in South Australia found, after a day of ploughing, that he had picked up a number of geophones in the plough and so he tossed them into a shed for safe-keeping. Some time later while discussing caving with him, he mentioned the geophones and said I could have them to experiment with.

The first experiment was to connect them to my Hi Fi amplifier and then to listen to people walking down the street; amusing, but not the way to find caves.

The second experiment was more scientific. A storage cathode ray oscilloscope (C.R.O.) was connected this time, and recordings were made of a house brick hitting the ground (Fig. 1). This is all a bit meaningless to an untrained person and anyway what caver would want to carry a thing the size of a C.R.O. all over the countryside?

About two months ago I came across an article in a sales brochure on seismic equipment, titled *Seismic surveying made simple* and included was a sketch indicating that by timing shock waves through the ground from different points it was possible to determine the rock type and the depth of each stratum. This then gave me the clue on how caves might be able to be detected (Fig. 2).

The principle of operation is this. When a shock wave is "injected" into the ground from, say, a hammer blow it radiates out in all directions and three important waves are produced. They are:
(1) compression wave known as the P wave, whose motion is a push-pull one;
(2) shear wave known as the S wave, whose motion is a sideways shake; and
(3) Rayleigh or surface wave, whose motion is a combination of (1) and (2) (Fig. 3). It is the P wave that is most used in seismic work. As these waves radiate out from the point of impact they tend to take three different paths, being:
(1) direct path;
(2) reflected path; and
(3) refracted path (Fig. 4).

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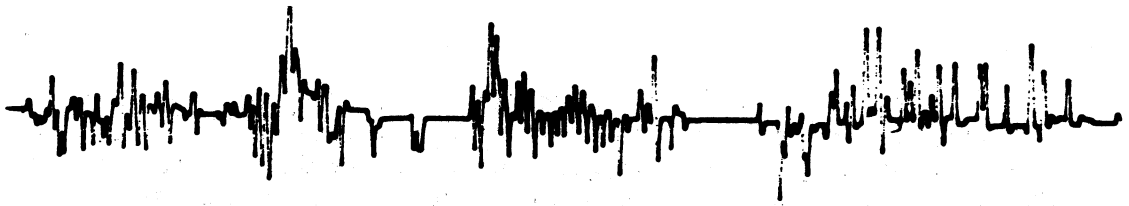


Fig. 1. Tracing taken from the output of a Geophone.

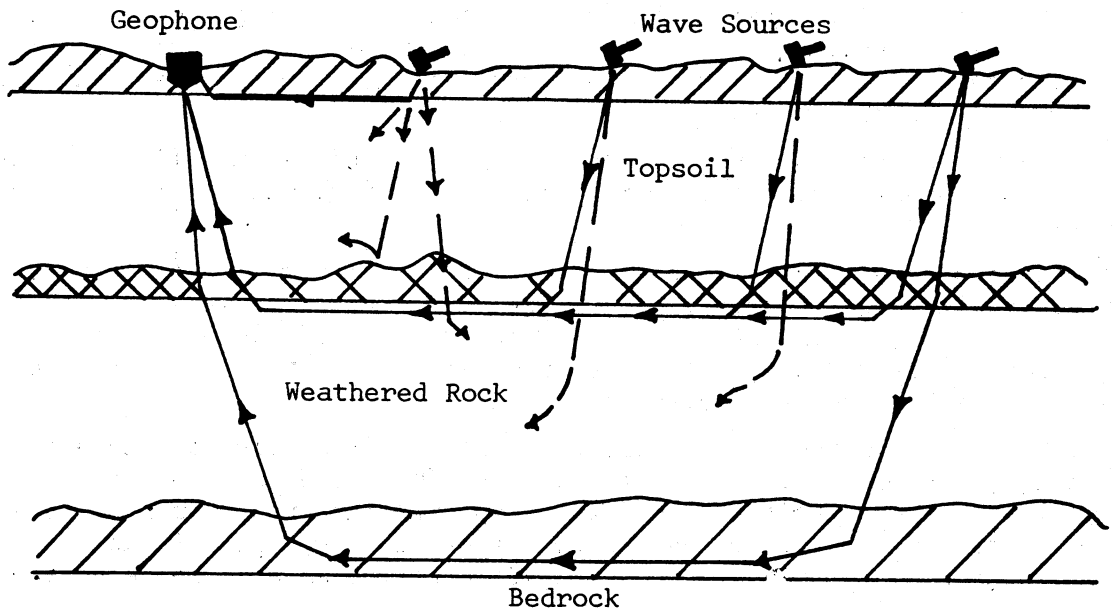


Fig. 2. Diagramatical cross-section of subsurface showing paths of seimic waves.

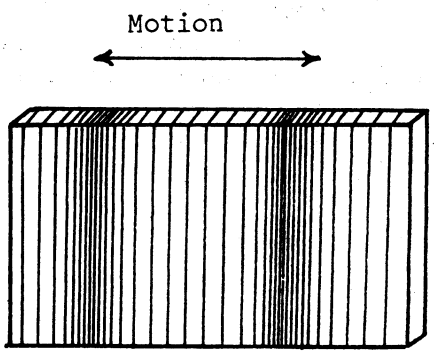
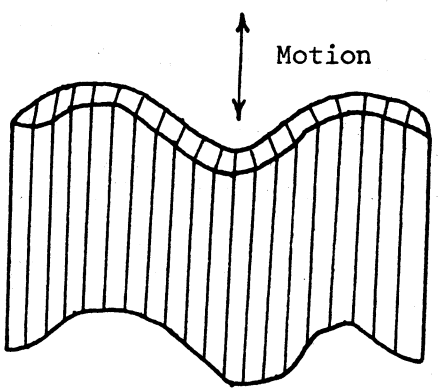


Fig. 3 Compression Wave (P)



Shear Wave (S)

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Another characteristic of the ground is that the more dense the soil or rock, the faster the shock wave will travel, for example:
(1) if the top soil is soft then the shock wave travels slowly;
(2) if in clay and sandstone the shock wave will be faster; and
(3) if in solid rock the shock wave will be very fast.
To measure the speed of sound through the ground, three pieces of equipment are required (Fig. 5):
(1) an electronic stop watch reading in milliseconds (ms).
(2) a hammer fitted with an "ON" impact switch.
(3) a geophone which is virtually a sensitive microphone connected to a high-gain amplifier driving an "OFF" switch.

The principle of operation is that when the hammer strikes the ground the impact switch closes, and starts the timer. The shock waves then travel through the ground and as they pass the geophone the signals are picked up, amplified and the timer is stopped. A digital readout indicates the time in milliseconds that has elapsed.

I will now describe how a seismic survey is conducted to obtain useful information suitable for interpreting what lies below (Fig. 6a).

The first thing to do is to lay out a tape measure over the line you want the survey to run. The geophone is then pushed into the ground at the zero end of the tape and connected to the timer. The lead to the hammer switch is also connected. Using at least two people, one using the hammer the other reading and plotting the results, the survey can commence. Using graph paper with the vertical scale indicating time, 1 cm = 5 ms and horizontal scale indicating distance 1 cm = 2 m, plot the times as they are indicated on the timer, for each station. At least three readings should be taken at each station and averaged before plotting, as false signals are recieved at times, for example, wind noise or someone moving. These errors are usually large and very random. True signals are always within 1 to 2 ms of each other.

Starting the survey at say, the 2 m point, record the time. Then move on to 4 m and record the time again. Continue this until the survey is completed over the whole line. On examination of the results, it will be seen that the line will be straight for a number of plots but then will tilt or level slightly (Fig. 6a). This indicates a change in the velocity as the shock wave gets out of the top soil and into a more dense subsurface stratum and increases velocity. Another tilt further on in the survey indicates an even deeper and denser stratum has been detected.

The plot in Fig. 6a is what may be obtained in most general surveys provided it is not cave country.

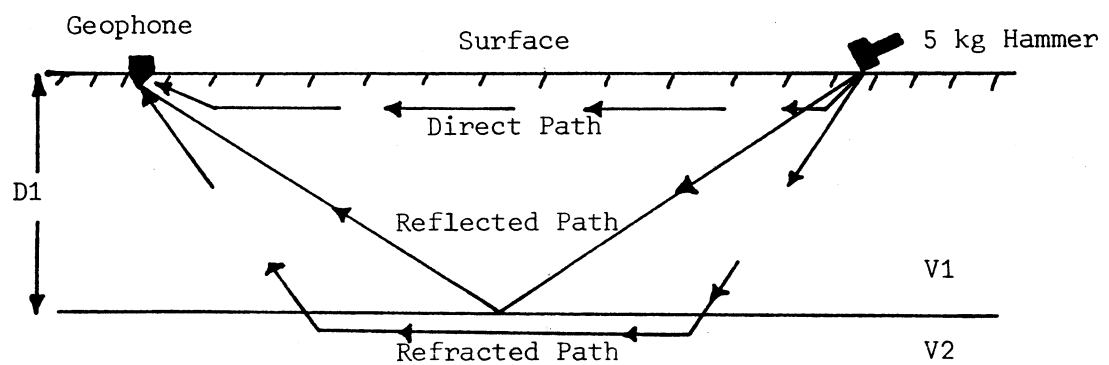


Fig. 4. Illustrates the direct, reflected, and refracted paths.

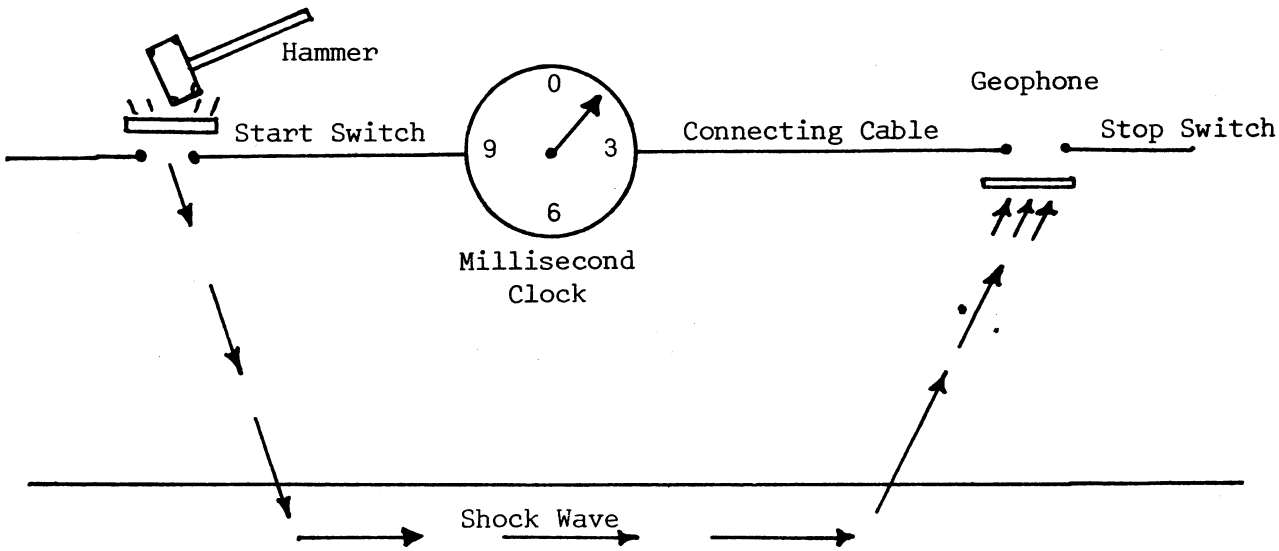


Fig. 5. Illustrates the three pieces of equipment required.

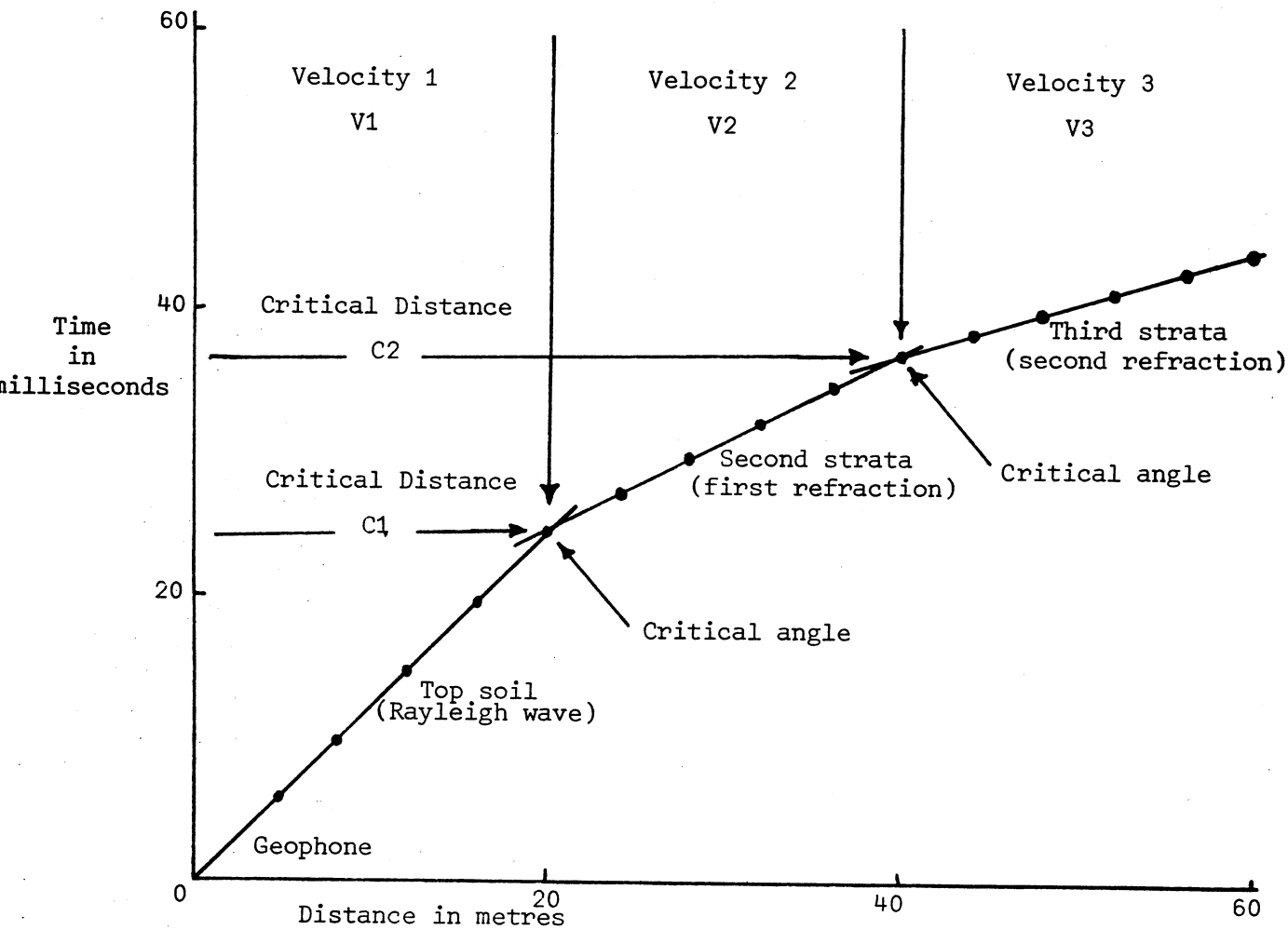


Fig. 6a. Illustrates a survey done over perfect strata and shows the meaning of each point.

If we know the rock strata to be generally level then by using the following formulae it is possible to determine the depth to each stratum (Fig. 6a & 6b).

(1) $$D_1 = \frac{C_1}{2}\sqrt{\frac{V_2 - V_1}{V_2 + V_1}}$$

(2) $$D_2 = 0.8\ D_1 + \frac{C_2}{2}\sqrt{\frac{V_3 - V_2}{V_3 + V_2}}$$

where D_1 = thickness of first layer

D_2 = thickness of layer 2 plus preceding layer

V_1 = true velocity in metres per second ($m\ s^{-1}$) of first layer

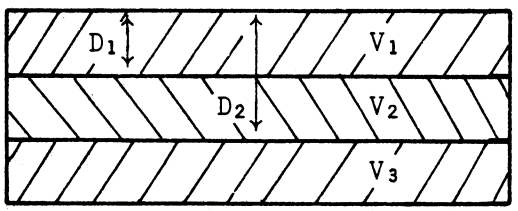
V_2 = true velocity in $m\ s^{-1}$ of second layer

V_3 = true velocity in $m\ s^{-1}$ of third layer

C_1 = critical distance from geophone to first change in slope of time-distance graph

C_2 = critical distance from geophone to second change in slope of time-distance graph.

Figure 6b. Numbering of layers for depth and velocity.



Now consider Figure 7. Suppose we insert a cave in our traverse line and carry out the same experiment. Everything will be normal until we start passing over the cave, and what will happen then? Confusion? That's right! Three things may happen:
(1) no signal will get back as it is absorbed by the cave;
(2) the signal will have to travel around the cave therefore giving a longer delay;
(3) only the surface wave will return, also giving a longer delay.
In all cases an anomaly will show. If we continue on past the cave, our original curve will follow on again but with some modification - usually a loss of range.

This was the theory on which I decided to design and build the seismic cave detector. Some of the results that have been obtained in practice over known caves in different types of limestone are given below with some annotation.

Figure 8. This was the very first plot done over a cave passage. The cave was in Buchan limestone (mid-Devonian; Exponential Cave) and the passage was accurately known as an R.D.F. survey point had been installed on the surface. The cave anomaly stands out very well. The depth to the cave would be about 6-7 m.

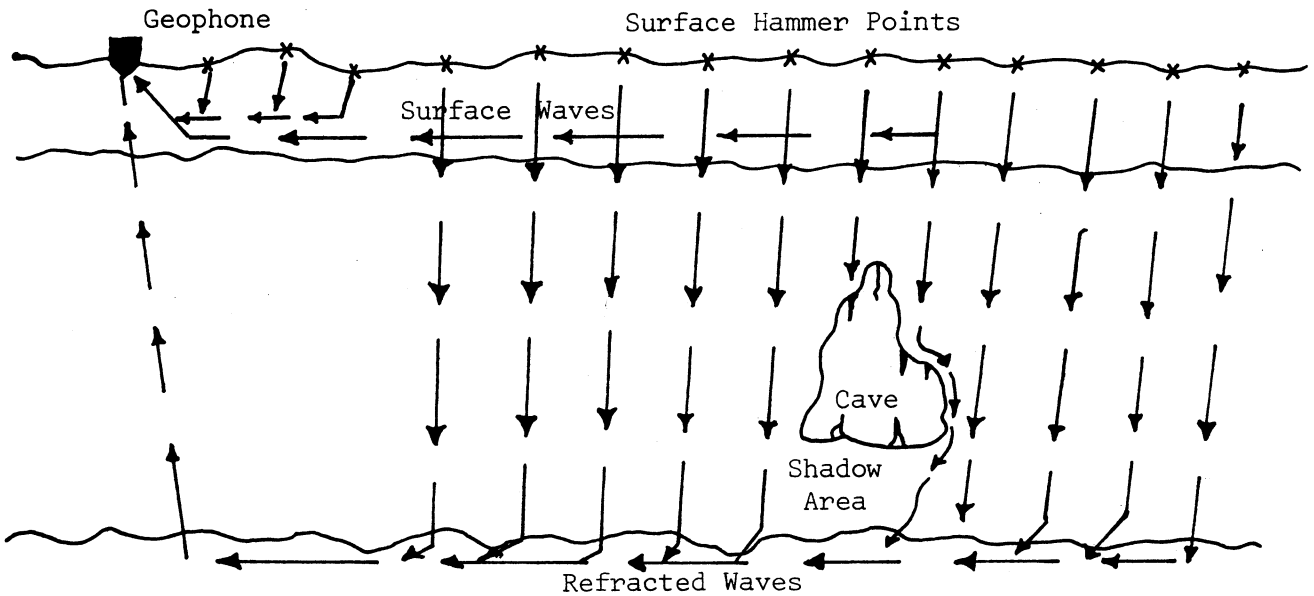


Fig. 7. If we insert a cave in our seismic survey, three things could happen; (1) No signal return, (2) Signals go round the cave, (3) Surface wave only returns.

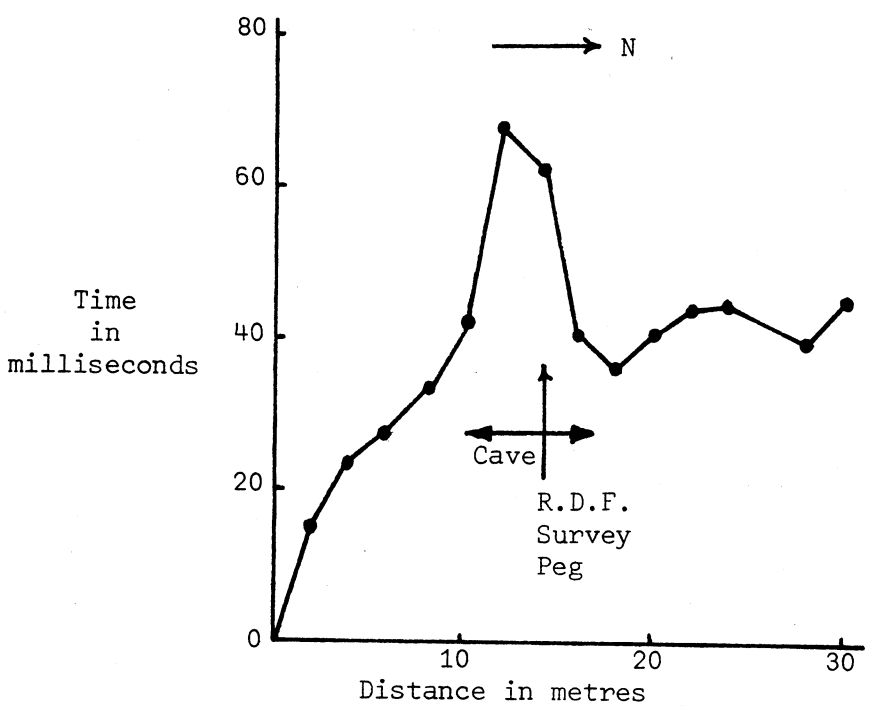


Fig. 8. The first seismic survey results.

Figure 9. This plot was over a much deeper passage of a cave in the same area (Honeycomb Cave). Again the passage stands out clearly.

This seemed to prove the system would work. The next thing to do was to collect as many results over known caves in different limestones as possible and see what could be interpreted from them.

Figure 10. This plot indicates the results obtained when a survey was done across a 60 m shaft (Jam Pot, Buchan).

Figure 11. This is the plot on a hillside containing no known caves (Buchan).

Figure 12a. This is the plot taken between two sinkholes. A portion of the graph is missing, indicating that no signals could be received.

Figure 12b. This is a closer look at the missing section by moving the geophone up to the 28 m point and doing the survey again. Note the extra detail.

Figure 13. This is a survey done over a cave in South Australia (Robertson Cave, Tertiary limestone). A plot was done in two directions using the same hammer points but moving the geophone to the other end. As can be seen, the cave anomaly can only be seen in one direction. This was probably caused by the fact that a new hammerman took over and was not hitting as hard as the first more experienced person. This only seems to be a problem with the Naracoorte limestone as the caves there have a hard capping over them.

Figure 14. This plot is a two-directional plot (over Blackberry Cave, Naracoorte) and this time a mean is plotted of the two curves thus producing a straight line plot with only the anomaly standing out.

Figure 15. This plot was done in dune limestone at Bat Ridges, Portland, Victoria. The cave was located 13 m down and on the plot is a cross-section of the cave accurately positioned using an R.D.F. point.

Figure 16. This plot was done over Nannup Cave, Witchcliffe, Western Australia in eolian calcarenite. The cave was located 20 m below and accurately positioned using R.D.F. equipment. Notice the dip in the plot over the cave. It was found on entering the cave that a column about 2.5 m in diameter had been resolved in the seismic survey.

I think I have given enough illustrations to prove that the method and equipment works. In the next few months, I intend to conduct many more tests in an effort to build up a library of reference graphs.

From what has been done so far, it seems clear that the anomaly is in fact the surface (Rayleigh) wave taking over control of the equipment as the hammer blows pass over the cave, and the deeper faster shock waves are attenuated by the cave to the point where they are no longer received. This is also borne out by the fact that quite often as the survey passes over the actual interface between solid rock and a cave it is very hard to get three consistent readings, but the next point on will be satisfactory.

It has also been found that the distance between hammer points is important, particularly if narrow passages may be present. Using, say, a 6 m spacing between hammer stations, it is possible to completely miss a 2 m passage. It seems the signals are very directional. Refer back to Figure 16: seeing the column proves this.

On several surveys, points have been reached where all return signals have been lost and only by moving the hammer station about, have returns been possible. This feature has been used to determine the size of chambers.

Another feature that stands out is that whenever a cave passage cross-section has been plotted in below the seismic survey results (Fig. 15) an offset to the right occurs. It might be possible to use this error as a means of determining depth.

By taking two or more plots over a passage but spacing them, say, 30 m apart, it is possible to determine the direction the passage runs. Taking this further as we have already done, a full grid was done over an area and the results fed into a computer which in turn produced a three dimensional contour-type plot of the cave.

Finally, the main functions I can see the seismic cave detector performing could be determining the extent of a known cave system from the surface, and being able to evaluate the resources of caves in an area where as yet no entrances have been exposed.

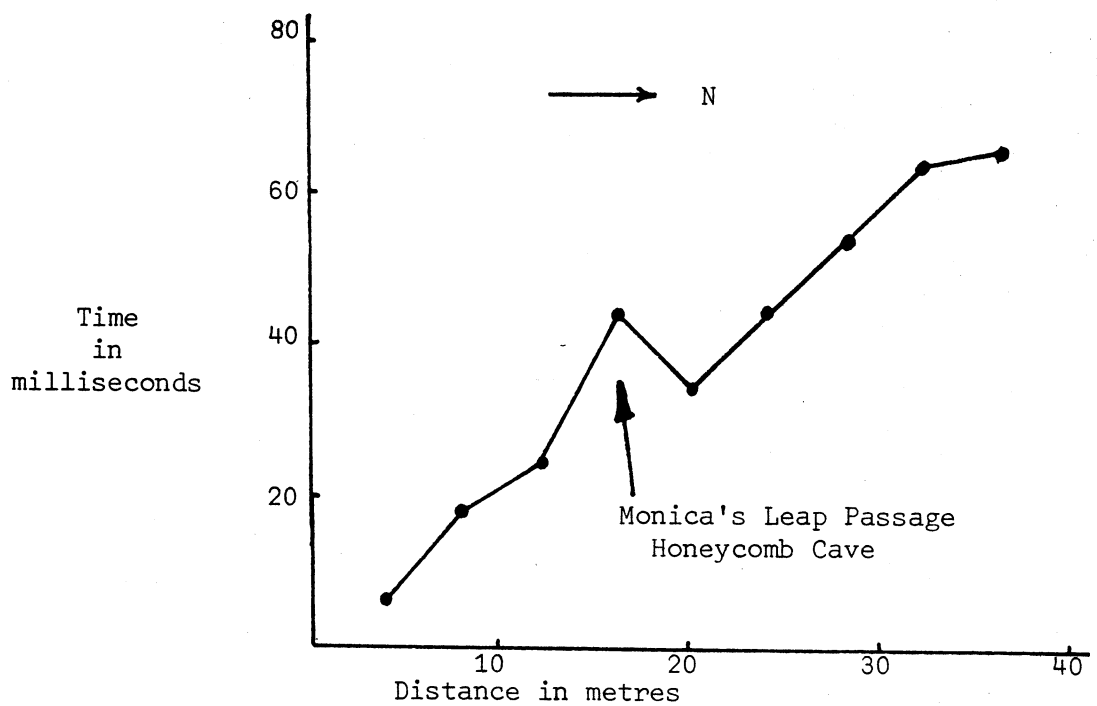


Fig. 9. This shows a deep pasage.

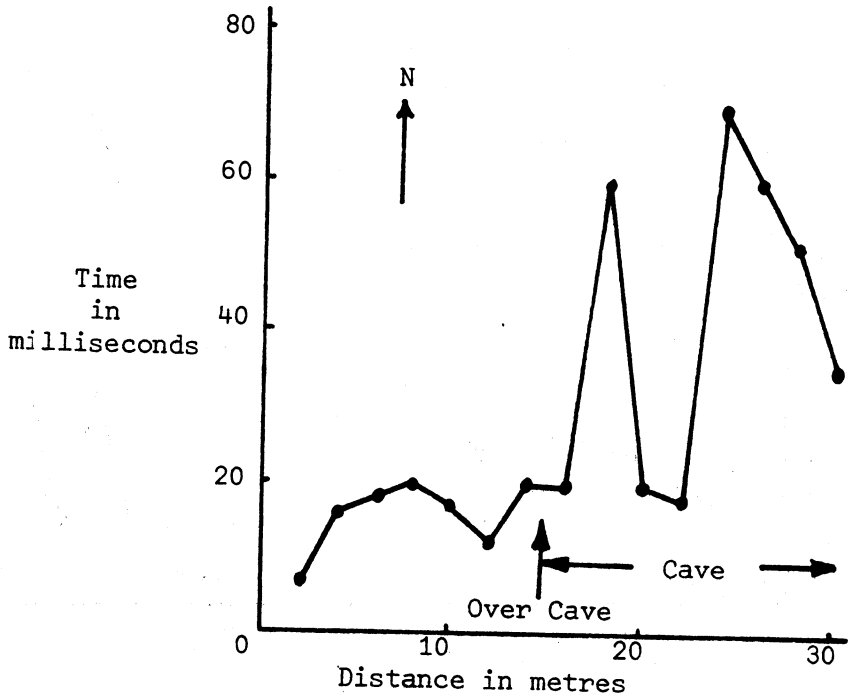


Fig. 10. Plot over a 60 metre shaft.

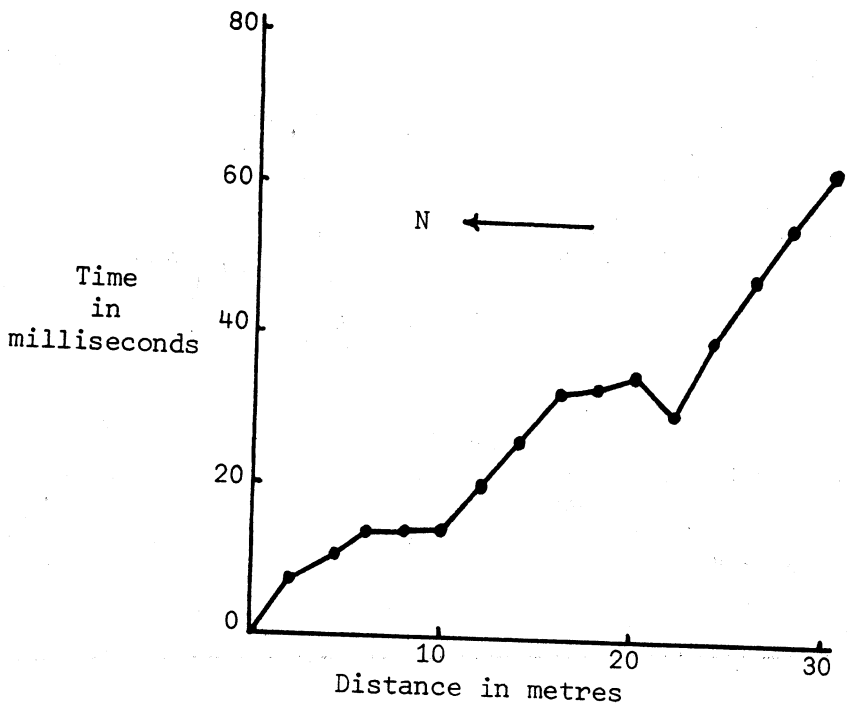


Fig. 11. This plot was on a hillside containing no known caves.

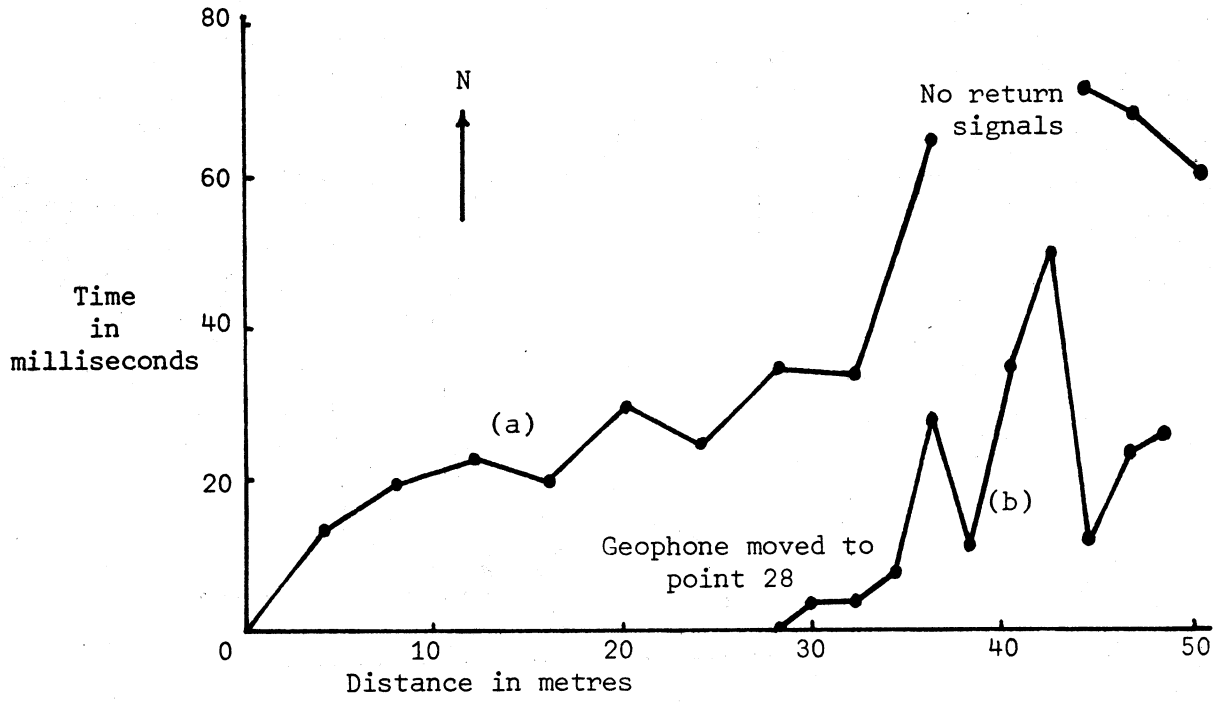


Fig. 12. (a) This plot was between two sinkholes.
(b) This is a closer look at the missing section.

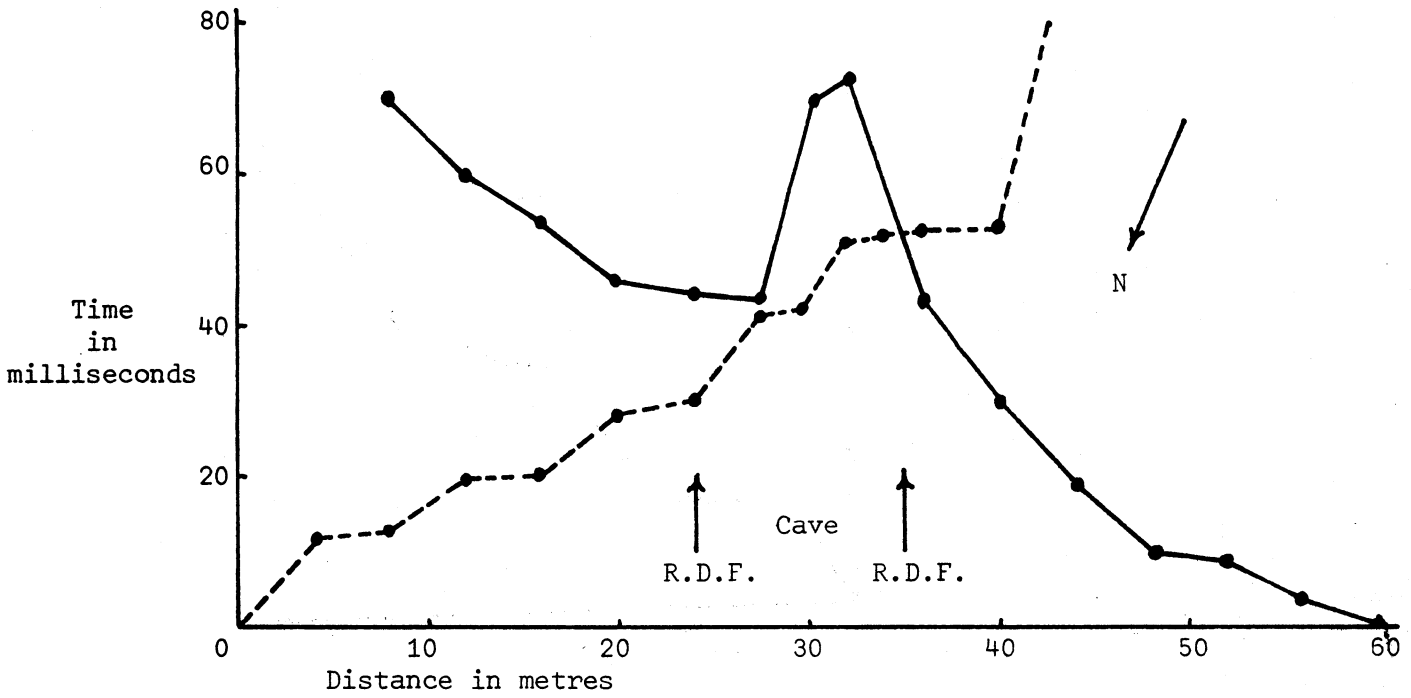


Fig. 13. This is a two direction plot showing the position of the cave relative to the plot.

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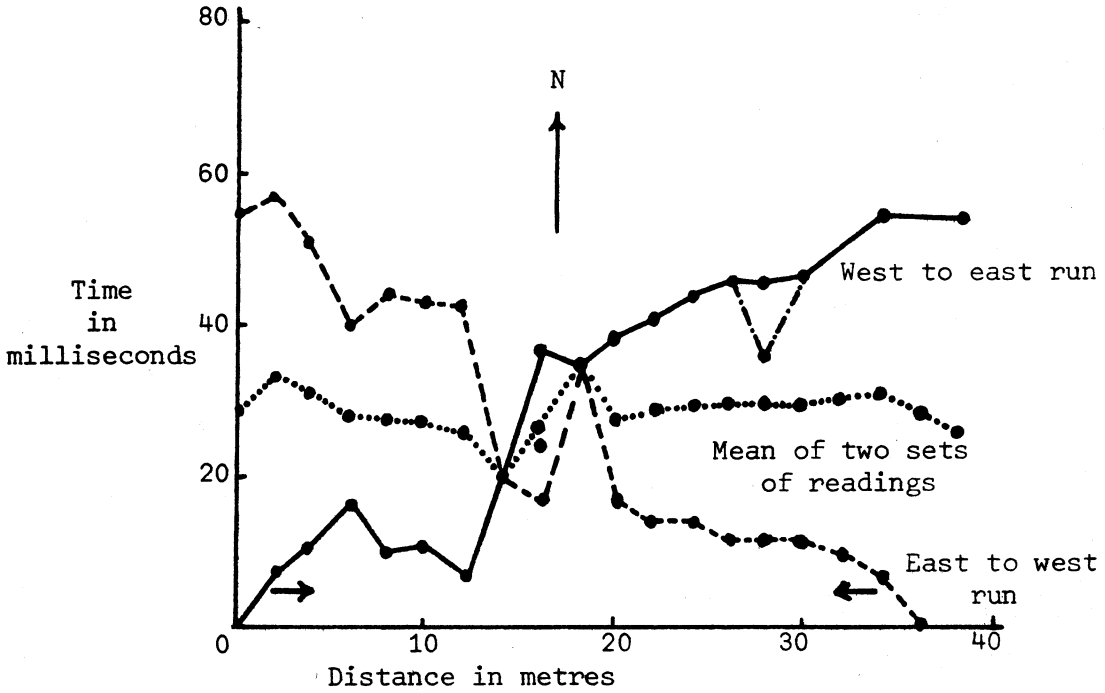

Fig. 14. A two direction plot to obtain more detail.

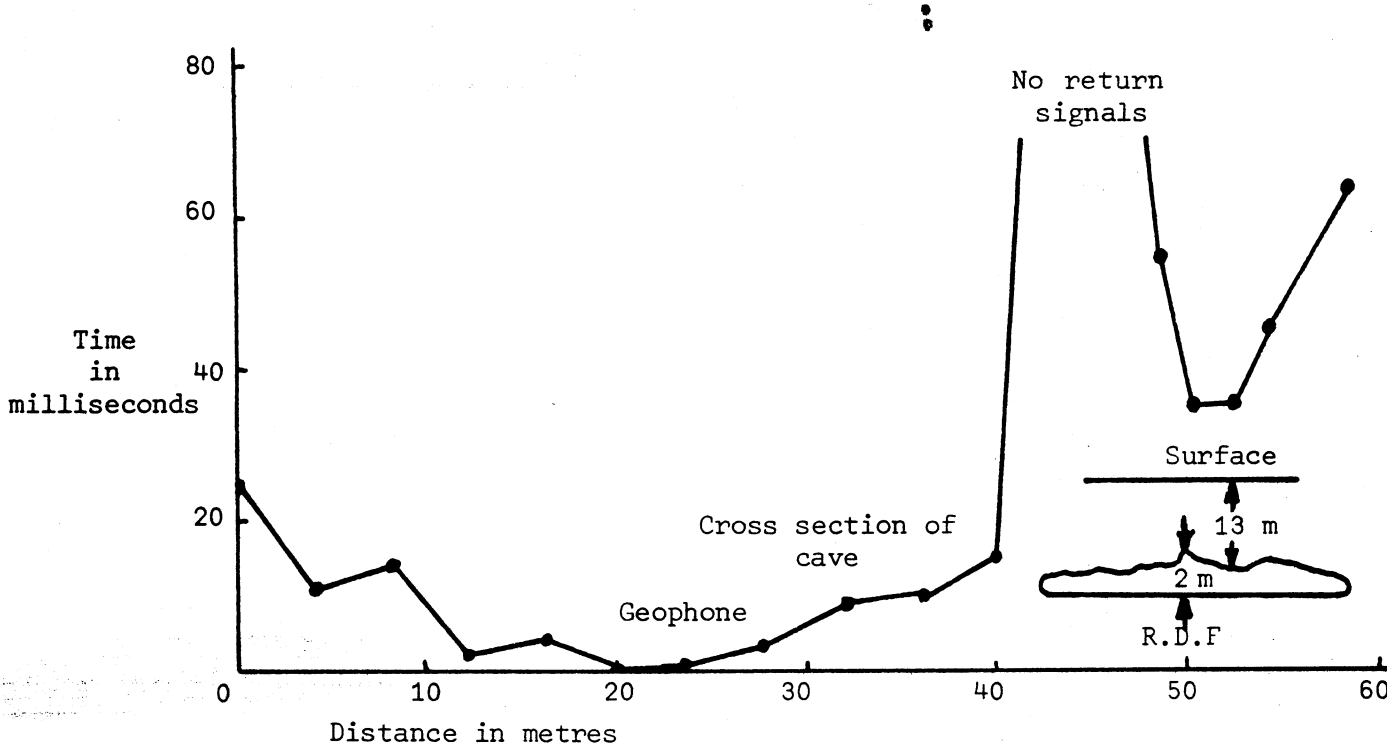

Fig. 15. Bat Ridges limestone gives clear indication of caves.

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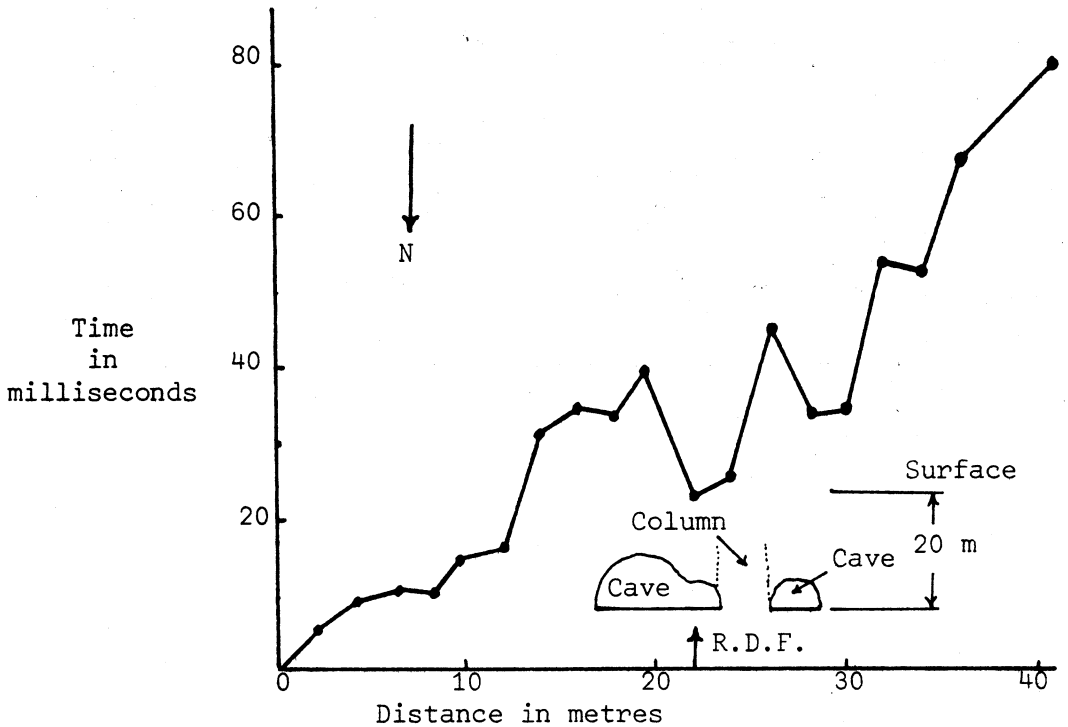

Fig. 16. Nannup Cave, W.A., plot has resolved 2.5 m column in cave.

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CAVE-DWELLING DECAPOD CRUSTACEANS OF AUSTRALIA AND PAPUA NEW GUINEA

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Sydney University Speleological Society

Abstract

Three families of decapod crustaceans are represented in the cave faunas of Australia and Papua New Guinea. One family, the Sundathelphusidae, occurs in caves in both countries while the remaining two families are recorded from the Australian cave fauna. The distribution of the families in the region is compared with the distribution of karst areas. The Australian cave decapod fauna is compared with the much better documented American cave fauna. Some hypotheses are advanced to explain the evolution of this element of the Australian cave fauna.

INTRODUCTION

The Order Decapoda includes the large commonly known crustaceans such as prawns, lobsters, crayfish and crabs. It is the largest order of crustaceans with well over eight thousand species (Chace, 1951). The group is mainly marine in habitat but several families are restricted to freshwater and a few others have some species which pass through their entire life cycle in freshwater. It is these freshwater groups which are of the greatest interest from the biospeleological point of view as they include by far the greatest proportion of decapods found in caves. Marine decapods are rarely found in caves (Holthuis, 1956; Vandel, 1965). Land crabs of the Family Gecarcinidae have been found in some caves in the West Indies (Peck, 1975; Hobbs, Hobbs & Daniel, 1977). Freshwater decapods found in caves include shrimps, prawns, crayfish and crabs.

Representatives of fifteen families of decapods have been found in caves containing freshwater (Table 1). They have been found on all continents (except Antarctica) and a number of islands including Cuba and New Guinea. They cover the entire spectrum of adaptation to the spelean environment from accidental occurrences to troglobites. Of the fifteen families, four have representatives which pass their entire life cycle in the freshwaters of Australia and Papua New Guinea. They are the Palaemonidae, Atyidae, Parastacidae, and Sundathelphusidae. Of these families, the last three have been found in Australian caves while the Sundathelphusidae is the only family so far known to occur in caves in Papua New Guinea.

CAVERNICOLOUS DECAPODS OF AUSTRALIA AND PAPUA NEW GUINEA

Order Decapoda

Suborder Pleocyemata

Infraorder Caridea

Family Atyidae

This family has over one hundred species and is very widely distributed (Kaestner, 1970). It includes at least twenty-six troglobites (Williams, 1964;

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Table 1

Decapod families with freshwater* cave-dwelling members

FAMILY		DISTRIBUTION
Atyidae	shrimps and prawns	FW only
Alpheidae	shrimps and prawns	FW + marine
Palaemonidae	shrimps and prawns	FW + marine
Cambaridae	crayfish	FW only
Astacidae	crayfish	FW only
Parastacidae	crayfish	FW only
Aeglidae	"crabs"	FW only
Pseudothelphusidae	crabs	FW only
Potamocarcinidae	crabs	FW only
Potamonautidae	crabs	FW only
Gecarcinucidae	crabs	FW only
Potamidae	crabs	FW only
Parathelphusidae	crabs	FW only
Sundathelphusidae	crabs	FW only
Grapsidae	crabs	FW + marine

*"freshwater" as used here includes slightly brackish and semiterrestrial habitats.

Monod, 1975). This high proportion of troglobitic species is regarded as a sign of the great age of the family (Carpenter, 1977). In Australia, the family is represented by six genera and about fifteen species (Riek, 1953; Bishop, 1967; Williams, 1977). These species range in distribution from North West Cape in Western Australia to Tasmania. Most species are found in the eastern states. Species from four genera have been collected from Australian caves while a fifth genus may have one subterranean species. Atyids are commonly referred to as shrimps.

Atya. This genus is very widely distributed and has one species in Australia. *Atya striolata* occurs in coastal streams from southern Queensland to southern New South Wales. It has been recorded as a "facultative troglobe" from Gloucester Caves in New South Wales (Bishop, 1967). This classification implies that this species is a first level troglophile in the system of Hamilton-Smith (1967). Other species of *Atya* have been found in caves overseas (Peck, 1975).

Caridina. This is another widely distributed genus, with several species reported from caves in other countries (Holthuis, 1956). There are seven Australian species ranging from the vicinity of Darwin down to south-eastern New South Wales (Bishop, 1967). *Caridina thermophila* is known only from the waters of a bore drain near Muttaburra in central Queensland (Riek, 1953). Although the species exhibits no morphological adaptations to the subterranean environment, it is possible that it occurs in artesian waters (Williams, 1964).

Paratya. The genus is found in the eastern Pacific area from Siberia to New Zealand (Carpenter, 1977). There appears to be only one Australian species but it exhibits some morphological variability (Williams, 1977). *Paratya australiensis* occurs in the eastern coastal regions of Queensland, south-eastern Australia and Tasmania. Its occurrence in caves is restricted to a small area in Victoria. It is recorded from Moon Cave, Buchan and Cave M-35, Murrindal (Hamilton-Smith, 1967). The New Zealand species *P. curvirostris* has also been found in caves (Williams, 1964). It seems probable that both species are first level troglophiles.

Parisia. This genus demonstrates a remarkable disjunct distribution with one species in Zanzibar, three in Madagascar and two in Australia (Holthuis, 1956; Williams, 1964; Gordon & Monod, 1968). All six species are troglobites, and all are known from a single type locality. The two Australian species are *Parisia unguis* and *P. gracilis*. The only recorded locality for both species is Brennon's Brook in Sixteen Mile Cave near Katherine in the Northern Territory (Williams, 1964). Brennon's Brook is about ninety metres below the surface and only eight metres of the brook is accessible. In both species, the eyes are reduced and lacking in pigment (Williams, 1964).

Stygiocaris. This is the only atyid genus known to occur in Western Australia, and it is endemic to that state (Bishop, 1967). There are two species - *Stygiocaris lancifera* and *S. stylifera*. They are known only from the slightly brackish waters found below the coastal limestone platform of North West Cape (Holthuis, 1960). Both species are recorded from the western side of the peninsula in various wells and waterholes on Yardie Creek station (Holthuis, 1960; Mees, 1962). In addition, *Stygiocaris stylifera* has been found in Kubura Well on the eastern coastal platform (Cawthorn, 1963). Neither of the two species has been found in the caves of the intervening Cape Range which is generally lacking in water (Cawthorn, 1963). Both species are classified as troglobites. They possess strongly reduced, unpigmented eyes. These species are closely related to *Typhlopatsa pauliani* which is known only from Mitoho Cave in Madagascar (Holthuis, 1956, 1960).

Infraorder Astacidae

Family Parastacidae

The Parastacidae are the southern hemisphere crayfish. There are some one hundred and twenty species (Hobbs, 1974a). They are found in South America, Madagascar, New Guinea, New Zealand and Australia (Riek, 1969). Of the fourteen genera, only *Cherax* is shared between two of these areas. It is found in Australia and New Guinea. This high degree of endemicity is regarded as a sign of the antiquity of the family despite the lack of pre-Pleistocene fossil material (Hobbs, 1974a; Carpenter, 1977). The family reaches its greatest diversity in Australia which contains about eighty percent of the currently recognised species (Hobbs, 1974a). Species are found in all Australian states although the majority occur in the eastern states. The family is poorly represented in the western half of the continent with the exception of the south-western corner where there are eleven species, all of which are endemic to that area (Riek, 1967).

The only recorded cave localities for this family are in Australia. They have been recorded from caves in both eastern Australia and the south-western corner (Hamilton-Smith, 1967). There is, at present, no published information on the biology of the species inhabiting the eastern caves. They are regarded as accidental occurrences only (Hamilton-Smith, 1967). *Euastacus spinosus* has been observed on several occasions in River Cave in the Windy Gap area near Kempsey during

field work by G.D. Campbell. This species shows no obvious adaptation to the cave habitat. The crayfish found in Western Australian caves have received more attention but again, there is very little in the way of published work. The crayfish found in these caves are of the genus *Cherax* (Hamilton-Smith, 1967). Research by Muir has indicated that the cave populations are isolated and they have achieved some degree of physiological adaptation to the subterranean environment (Hamilton-Smith, 1967). These animals are regarded as first level troglophiles and are presumably conspecific with the surface forms in the area. Certainly, there is a large amount of work yet to be done on the crayfish in Australian caves.

Infraorder Brachyura

Family Sundathelphusidae

As defined by Bott (1969), this family consists of some thirty-seven species which range from Sri Lanka to Fiji (Bott, 1970, 1974). The family does not occur on the Asian mainland. The fifteen species recognised by Bott from Australia and New Guinea are placed in three genera - *Rouxana*, *Geelvinkia* and *Holthuisana*. The first two genera are endemic to New Guinea while *Holthuisana* is found in Australia and Fiji as well. Although these crabs are commonly referred to as freshwater animals, many of the species are semiterrestrial in their habits (Bott, 1972; Greenaway & MacMillen, 1978). The records listed below are the first for crabs of this family from caves. The only other crab known to pass its life cycle in freshwater in either of the two countries is the crab *Halicarcinus lacustris* from the largely marine family Hymenosomatidae. It occurs in south-eastern Australia, Lord Howe Island, Norfolk Island and New Zealand but has not been recorded from caves (Walker, 1969).

Holthuisana. This genus has been divided into two subgenera by Bott (1969). The subgenus *Holthuisana* is restricted to New Guinea while *Austrothelphusa* is said to occur in Australia and Fiji (Bott, 1970). An analysis of specimens, both in the field and in museums, has indicated that Bishop (1963) has more accurately analysed the taxonomy of the Australian species than has Bott. Thus, it appears that there are six or seven species. Further specimens are required from Cape York to clarify the situation. In Australia, most of the species are restricted to Cape York but one species does not occur there. *Holthuisana transversa* is widely distributed on the continent being found in all mainland states with the exception of Victoria. There is no overlap with *Halicarcinus lacustris*. Four specimens of *H. transversa* have been collected from Niggle Cave near Camooweal in north-west Queensland. These specimens are held in the Queensland Museum - specimen no. 3179. The animals were collected from burrows near the permanent lakes within the cave. The burrows were in mud with the entrances built up above the surface of the mud. This is the characteristic burrow entrance found in the surface-dwelling specimens of *H. transversa*. In this species, the young hatch from eggs as small crabs which are retained by the female for some time in the pouch formed by the abdomen and pleopods beneath the thoracic sternites. The female collected from Niggle Cave was found to have young in this pouch. There is no information available on the distribution of this species within the cave. The specimens exhibit no morphological differences from epigean examples of this species. *H. transversa* can therefore be considered to be a first level troglophile.

Genus unknown. The biologists on the 1978 expedition to the Atea Kananda region of the Muller Ranges in Papua New Guinea collected several crabs of a species which is referable to the family Sundathelphusidae. However, the

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species cannot be placed in any of the currently recognised genera of the family. Work is currently being carried out to describe this species in relation to those already described by Bott (1974) from New Guinea. The crabs were observed in several areas within the extensive Atea Kananda system including regions at some considerable distance from the surface. They were found both in and out of water. Some specimens were found on the surface near the entrance to the cave suggesting that the animal may be distributed in surface waters also. The crabs were also collected from a cave in the nearby Mamo area. The specimens display considerable morphological adaptation to the subterranean environment in comparison to the Australian species, *H. transversa*. There is a considerable elongation of the walking legs relative to the carapace width. There is also a reduction of the pigmented area of the eyes. In some specimens, there also seems to be a shortening of the eyestalks. On the basis of these observations, it seems that the species should be classified as a first level troglophile although it seems likely that those specimens at some distance from the entrance may constitute physiologically distinct populations.

OTHER RECORDS

The above records for cave dwelling decapods include those reports and specimens which could be placed in a particular family. Quite often, lists of cave fauna are published giving only the common names of the animals concerned. This creates difficulties when it comes to a consideration of cave biogeography as it is impossible to distinguish most species of decapods on the basis of their common names. Indeed, in some cases, it is impossible to determine whether or not they are decapods. So, records of this type have been listed separately.

Freshwater crabs. The British New Guinea Speleological Expedition of 1975 collected or observed freshwater crabs in a number of caves in the vicinity of Telefomin in New Guinea (Chapman, 1976). Beck & Goulbourne (1976) were astonished to find that the only usable ledge in the shaft of Tina Bu Tem cave 'was infested with crabs'. The crab was also found at one locality on the surface (Chapman, 1976). These crabs have not as yet been examined at any taxonomic level. Attempts are being made at present to borrow the specimens. It seems likely that the crabs are first level troglophiles.

Cave "shrimps". The term shrimp is used for a great variety of crustaceans including amphipods, isopods, some decapods and a number of smaller groups as, for example, the mountain shrimps or syncarids which are found in some Tasmanian caves (Lake & Coleman, 1977). As a result, reports of cave shrimps from the Chillagoe area are recorded here as decapods with a considerable degree of reservation. Colourless cave shrimps have been reported from caves in the Chillagoe region on several occasions (Wilson, 1974; Parr, 1975; Robinson, 1975). They have been found in Christmas Pot (CH-144) in Suicide Bluff and Narahdarn Cave (CH-34) in Carpentaria Bluff (Robinson, 1975). It is of some interest to note that these are two of the three caves known to descend into the phreatic zone in this area (Wilson, 1975). The other cave is Ti-tree Cave (CH-43, CH-101).

Colourless prawns. Williams (1964) recorded an unconfirmed report of colourless prawns from deep gold mines in the Maryborough area of Victoria which are no longer being worked. No further information has been published on these animals. Other decapods have been recorded from abandoned mines overseas (Horst, 1972).

DISCUSSION

Any consideration of the freshwater decapod fauna found in caves in Australia and Papua New Guinea is plagued with difficulties. It is not simply that the cave fauna has not been examined in any great depth, but the surface fauna, particularly in Papua New Guinea, is so poorly known that is is difficult to make generalisations or comparisons. However, some points can be made, at least with regard to the Australian forms.

With the exceptions of *Stygiocaris* and *Parisia*, all of the forms currently found in caves occur on the surface in the same region. As a result, those karst areas where surface decapods are absent rarely contain subterranean decapods. The most obvious example of this situation is found in the Nullarbor which, despite the large amounts of water present in the caves, has not yielded any subterranean decapods. This does not imply that there will be subterranean decapods in all those karst areas where decapods are found on the surface. This is patently not true. Species which are found only in one or two caves in a single karst area are often found on the surface in several. The vast majority of surface forms do not occur in caves at all. This is most obvious in the crayfish. This is quite different from the situation in North America.

The surface freshwater decapod faunas of Australia and North America are remarkably similar. They are both dominated, in terms of species numbers, by crayfish with relatively small proportions of atyids and palaemonids. Australia has the added bonus of several species of freshwater crabs. In the other three continents with well developed freshwater faunas, the decapod fauna tends to be dominated by the freshwater crabs. Despite the similarities in the general composition of the two faunas, there is a considerable difference in the proportion of troglobitic decapods found in the two countries. As well as two atyids, there are three palaemonids and at least twenty-one crayfish occurring as troglobites in North America (Strenth, 1976; Hobbs et al., 1977). This represents slightly more than ten percent of the total freshwater decapod fauna. The number of other decapods associated with caves is not known (Hobbs et al., 1977). The palaemonid genus *Palaemonetes* has six species in North America and a further three in Mexico (Strenth, 1976). Three of the North American species are troglobitic. The only Australian species of *Palaemonetes* occurs in the south-west of Western Australia. As there is only one Australian species, a comparison of the two areas is difficult. Some comparison can, however, be made for the crayfish.

The North American crayfish are placed in the families Cambaridae and Astacidae (Hobbs, 1974b). The American cambarids are further divided into two subfamilies - Cambarinae and Cambarellinae. All of the cavernicolous crayfish in North America belong to the Cambarinae (Hobbs et al., 1977). As well as the twenty-one troglobites, there are twenty-three other species known from caves. This represents some twenty percent of the total number of crayfish species in North America. With the exception of *Troglocambarus maclanei*, the cavernicolous forms belong to the three largest genera in this subfamily (Hobbs, 1974b). It is interesting to note that *Cherax* and *Euastacus* are the two largest genera of Australian crayfish (Riek, 1969). The evolution of the North American cavernicolous crayfish has been complex (Hobbs et al., 1977). In each of the three large genera, there have been several invasions of the cave habitat with the possibility of some adaptive radiation once there. These incursions have been separated both temporally and spatially. Herein lies the major difference between the American and the Australian

crayfish. The Australian crayfish have not had, or have not taken, the opportunity to enter the spelean environment until relatively recently. On the basis of the available data, it is impossible to determine which of these options is more likely.

The atyids of mainland North America show a distribution pattern which is similar to that of the Australian atyids. Of the five species known from North America, the two species of *Palaemonias* are troglobites while the three species of *Syncaris* are epigean forms (Pennak, 1953; Hobbs et al., 1977). *P. ganteri* is known only from within the Mammoth-Flint Ridge cave system in Kentucky while *P. alabamae* has been found in two caves in Madison County, Alabama (Hobbs et al., 1977). The species of *Syncaris* were described from the San Francisco-Los Angeles area but it seems that only one of these Californian species is currently extant (Pennak, 1953). The subterranean forms are thought to have evolved from a common epigean ancestor which was not necessarily closely related to *Syncaris*. They now represent relict populations as do *Stygiocaris* and *Parisia*.

The relict nature of *Stygiocaris* and *Parisia* has been questioned by Mees (1962) and Bishop (1967). Mees suggests that the relationship between *Stygiocaris* and *Typhlopatsa* is a morphological similarity rather than a true evolutionary kinship. He further suggests that the two species have arisen from distinct marine ancestors. These suggestions are made without 'even the slightest knowledge of shrimps' (Mees, 1962). More recently, the family has been divided into a number of "series" including one composed entirely of troglobitic forms, although not including all troglobitic atyids (Monod, 1975). This group - "la serie typhlatyienne" - includes both *Stygiocaris* and *Typhlopatsa* (but not *Parisia*) and is considered to be a monophyletic group derived from a marine ancestor possibly during the Cretaceous (Monod, 1975). This would seem to be a much more economical hypothesis than one which would require a number of fairly recent marine ancestors which have subsequently disappeared without trace, leaving a group of freshwater forms showing a great deal of convergence. Bishop (1967) states that the *Stygiocaris-Typhlopatsa* relationship and the disjunct distribution of *Parisia* 'may not have great zoogeographical significance in view of the close relationship of *Parisia* and *Caridina*'. As neither *Parisia* nor *Caridina* is closely related to *Stygiocaris* or *Typhlopatsa*, the connection here is somewhat obscure. In addition, Holthuis (1956) considers that *Parisia* is more closely related to *Caridella* although it strongly resembles *Caridina* while Williams (1964) states that 'the generic similarities between the species described here and the previously described species of *Parisia* appear strong'. Thus, the available evidence supports the idea that both genera are relicts which are not associated with the remainder of the Australian atyid fauna or with each other. The relict nature of the two genera is a partial explanation of their origins as troglobites.

If it is accepted that both genera are relicts, it seems likely that the ancestors of both previously occupied larger areas of Australia as epigean forms. With the progressive increase in the aridity of the continent during the Pleistocene, the available habitat decreased and the animals retreated to cave systems. In the case of the Australian species of *Parisia*, there is no available evidence of the selection pressures which may have lead to the development of the two species. It is probable that Brennon's Brook forms part of a much larger freshwater system and the explanation may lie there. The ancestral form of *Stygiocaris* was presumably restricted to the North West Cape region. With changes in sea level during alternating periods of

glaciation and thawing, it is likely that the range of the species varied in this area. It may have been that, during a period of low sea level, two populations were formed, one on either side of the Cape Range. These populations changed gradually in isolation resulting in the development of specific differences. A later rise in sea level resulted in the reunion of the two habitats but the movement of only one species. The next decrease in sea level gave the present situation with one species separated into two populations, one on either side of the peninsula and the other species found only on one side. The two populations of *S. stylifera* have been separated for some time and are now showing some morphological differences although these are not sufficient to require the construction of separate taxa (Cawthorn, 1963).

The study of the Australian cave decapod fauna is still in its formative stages. There is still a great deal to be learnt. At this stage, it is important to gather basic information such as the distribution of decapods in caves and their relation to the surface.

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ARCHAEOLOGICAL FEATURES OF AUSTRALIAN CAVES

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Abstract

Throughout Australia many valuable archaeological sites occur within caves and rock shelters. These consist mainly of art sites - paintings and engravings - and occupation sites - habitation sites or places of other activities such as flint mining or burials. It seems likely that many more sites will be found and in many cases they will be in caves that have been frequently visited by speleologists and others prior to their recognition as sites. This paper endeavours to describe the features of archaeological sites most likely to be encountered in Australian caves. Hopefully this may lead to earlier identification of new sites enabling proper investigation, curation and management to protect them from any unnecessary, inadvertent or wilful damage. Some aspects of site protection and preservation including the relevant legislation and authorities are discussed. A basic outline of the sort of information speleos could usefully record is given.

INTRODUCTION

Caves and rock shelters potentially contain some of the most valuable archaeological sites within a particular area. This is because the cave environment is often well-suited for the preservation of the more perishable items in the archaeological record. For paintings, delicate engravings and stone or other arrangements, a cave may be the only place where long-term preservation will occur. In the case of occupation sites, organic habitation debris such as bone, wood, egg and mollusc shell, etc., has a far better chance for survival in a cave compared to a site exposed to surface weathering.

Frequently cave occupation deposits also contain valuable associated palaeontological material which apart from being of interest in its own right may be relevant to sorting out the associations of extinct fauna with prehistoric aborigines.

LEGISLATION AND AUTHORITIES

The protection and management of archaeological sites ultimately lies with the relevant agency set up under the "Archaeological and Aboriginal relics preservation Act" within each state. In general these acts prohibit unauthorised damage, defacing, disturbance, buying, selling, bartering, etc., of any archaeological sites, materials and artefacts. They also set up systems for recording, documenting, investigating and managing sites, undertaking public education and regulating archaeological excavations. Most provide for the declaration of "archaeological areas", which protect and restrict access to important sites.

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Any sites or suspected sites discovered in caves ought to be reported to the agency concerned (see Appendix) so that it may be checked against recorded sites, registered or noted for further investigation. Most welcome such information and although pressed for staff are usually quite helpful if anyone wishes to further their interest. These agencies usually have available a variety of pamphlets and publications about the sites in their state.

ARCHAEOLOGICAL SITES - GENERAL

The recognition of archaeological sites involves careful observation to discriminate between natural features, materials and processes (including animals, weathering, etc.), and those caused by man. Often it is a case of "picking the odd man out" or noticing something that might not have got where it is on its own, or something that is out of context.

In the past speleologists have played a useful role in discovering cave sites, often in remote areas. With increasing mobility, greater numbers of speleos and more frequent trips to outlying areas, doubtless more sites will be found. The following is an outline of useful information that speleos could record should they find any sites.

o sufficient information to accurately relocate the site preferably on a standard survey or cadastral map.

o a location sketch to fill in the finer access and location details.

o a scaled and oriented site sketch showing any relevant features or details such as its extent, location of any artefacts, hearths, disturbances, etc.

o other useful information is the site's setting, the general topography of the area, the dominant vegetation types, and its proximity to water - close or distant, permanent or ephemeral. This helps to give an indication of the sort of food and other resources that may have been exploited from the site.

o a general assessment of a site's preservation, any current degradation or threats of continuing or new degradation or damage.

In no way should sites be interferred with or disturbed nor any material be collected or removed from a site.

For descriptive purposes it is easiest to describe each type of site separately. However, this does not mean that sites will occur in isolation of each other. For example, at Koonalda Cave, a "declared" site interest was originally aroused by a surface scatter of flint flakes adjacent to the doline. This led to the discovery of flint mining and engraving sites inside the cave along with such items as hearths, burnt torches, bone arrangements and an occupation deposit in the doline. Later on it was noticed that many of the engraved boulders had been placed and oriented to indicate pathways through the cave. Similarly, many painted galleries have occupation deposits in their floors.

TYPES OF SITES

ART SITES

Paintings. Most painted galleries in Australia occur in open rock shelters with only a few known from the darker zones of actual caves. The paintings

tend to be fairly simple in style often using only one colour, chiefly reds. This is especially so for south-eastern Australia. However, further north in central north-western and northern Australia styles tend to be more intricate and multi-coloured. The subjects depicted include human figures, hand stencils, spiritual beings, mythological creatures, animals and their tracks, implements, weapons, linear markings and indeterminate figures. The pigments were mainly derived from oxides of iron, other minerals, clays and ochres. These were pounded or ground to a powder and mixed with water or animal fat. The paint so prepared was then applied either by finger, a brush made from a twig, or could be sprayed on with the mouth to cover large areas or make stencils (Plate 1). It is possible that remants of paint preparation, small grindstones and pounders, brushes, faceted or unground pieces of ochre may still be present in the galleries. Many of the sites are in a poor or degrading state of preservation often being badly faded. This is due to a variety of factors including aerial weathering, break-down and flaking of the rock surface, rain, insects, dust, lichens, algal growth and graffitists but once aboriginal traditions broke down the periodic repainting of sites ceased.

The recognition of a gallery and its full extent may take quite some time if the paintings are faded. Lighting and humidity can make a great difference: some parts may be visible under specific conditions only. Under no circumstances should anything be applied to a gallery to enhance, fill in or delineate any paintings as this can easily cause irreparable damage.

Plate 1. Hand stencils, on ceiling Murrawijinie Cave, S.A.

A variety of methods exist for recording rock paintings. These include the use of sketching grids, transparent overlays for tracing on, photogrammetry using precision survey or stereo cameras and a stereo plotter, or just using a standard camera. The latter is most suited for making a general record. Any methods involving actual contact with the paintings ought not to be used without consulting the local archaeological agency.

Colour film probably gives the best results however the type of lighting (direct sunlight, shaded, blue sky, flash, etc.), can appreciably affect the colour balance of the result. With black and white film results may be enhanced by the use of contrast filters, for example, green and blue filters will darken reds against a light background. The use of orthochromatic films has also met with some success. In some cases ultra violet photography has brought out faded paintings.

Some simple techniques exist for multiple-flash illumination of larger areas. Figure 1 uses a slave to activate a second flash under fairly bright lighting conditions. Figure 2 shows the open shutter flash painting method for use under low lighting conditions. Two methods for obtaining multiple exposure panoramas of larger galleries are shown in Figures 3 and 4 - one by rotating the camera on a tripod , the other by offsetting along a baseline parallel to the gallery.

Things that could be usefully noted are the colours used, if there is any superimposition of paintings, any styles or motifs used, comparisons with any other galleries nearby, any suspicious modern additions, the general state of preservation of the site and any threats to its preservation.

Engravings. Several types of aboriginal engravings occur throughout Australia. These vary from fine stick and finger markings on soft cave walls to designs pounded or ground into hard sandstone surfaces. The former are the most abundant in caves having now been reported from caves on the west coast of Western Australia, the Nullarbor, Naracoorte, and East Gippsland.

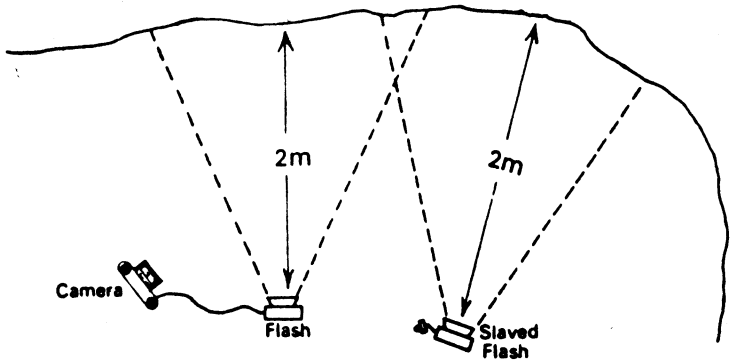

Fig. 1

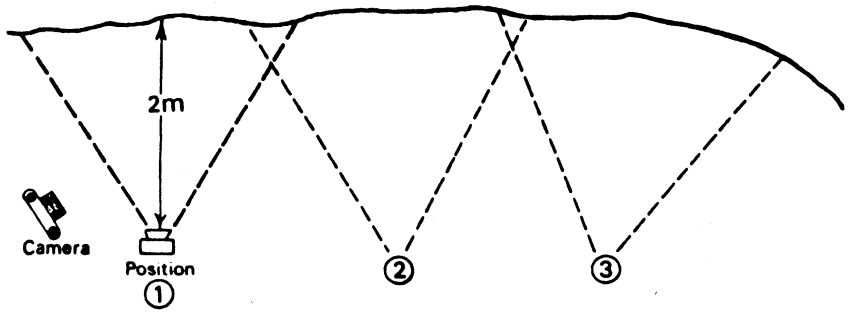

Fig. 2

Figures 1 & 2. Multiple flash lighting techniques (after Fillery 1977).

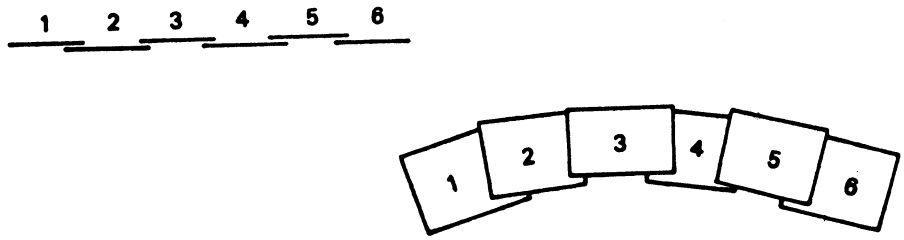

Fig. 3

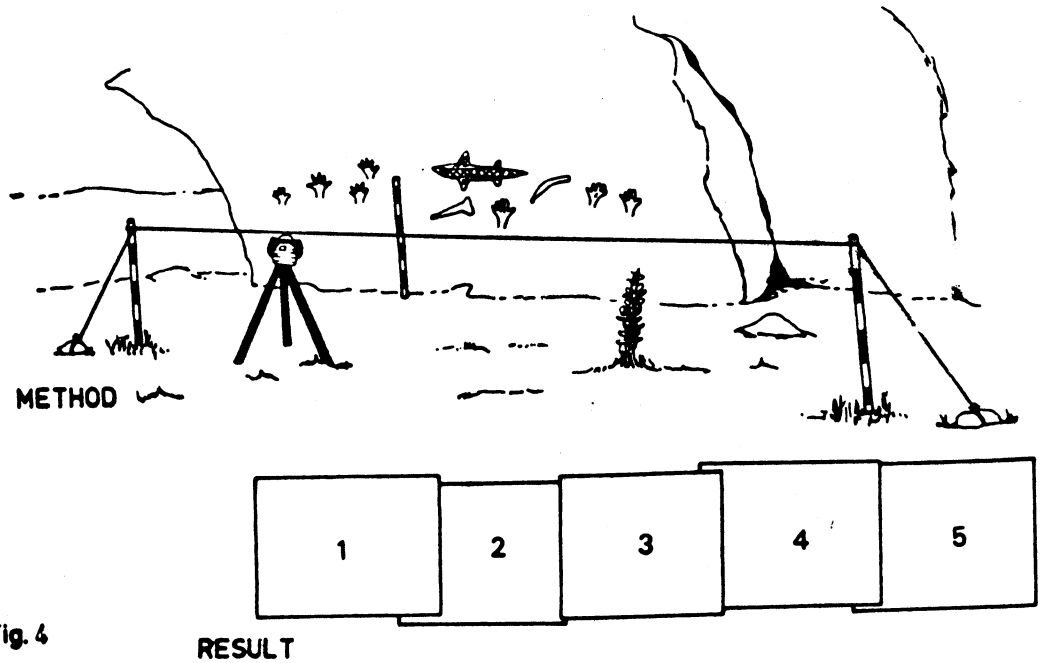

Fig. 4

Figures 3 & 4. Panoramic photographic techniques (after Fillery 1977).

Cave engravings are often difficult to detect because of both the low level of lighting used and that the lighting is fairly direct, that is, a headlamp. As most engravings are executed on a dull contrastless surface, direct lighting makes them appear quite featureless and blend in with the cave wall. Side lighting, often quite acute and from a specific direction may be the only way to see them.

Some care needs to be taken in identifying engravings as a variety of natural and modern human features may look similar. Weathering of joint and bedding features especially in dolomites can etch out nice "incised" grids and triangular patterns. Solutional features such as fine anastamosies and karren can form a variety of intrigueing patterns. Animals including birds, bats, possums, kangaroos, wombats, wallabies, goannas and dogs can leave quite a variety of markings on a soft cave wall.

Some modern human activities may unintentionally leave confusing markings in caves. Hobnailed or tricounied boots can leave incised marks on quite hard rocks. Any works that have been undertaken such as guano mining, tourist cave development, gating and digging for new caves, including the use of explosives, may also leave their mark, not to mention any casual marks as a result of routine visitation.

A variety of deliberate modern human markings may also be found. These include the blatant graffitist intent on naming and dating his activities wherever possible, the casual doodler who has just found a nice medium to indulge in, and also the intrigued discoverer who having found some engravings proceeds "in the name of science", to make his own set to work out how the originals were made and thus only confuses the issue further as in time they may be indistinguishable from the originals.

Usually a close and rational examination will determine whether engravings are likely to be genuine and the sort of implement used to make them. Things to be taken into account are whether there is any style or design to the markings, for example, figures, patterns, grids, concentric, parallel or bifurcating lines, any enhancement of natural hollows or protruberances.

Finger markings. These are made by drawing three or four fingers across a soft weathering mantle or clay deposit on the cave wall leaving a series of meandering grooves. They may cover quite a large area forming a variety of patterns (Plate 2).

Fine implement markings. These occur in similar soft material as the finger marks above but were executed with either stick, stone or bone. The designs made were largely as strokes, often as grid patterns both straight and curved and may enhance natural features.

Fine incised markings. These have similar patterning to those above but occur on harder rocks having been incised or ground in with a piece of stone. They have also been found on boulders as well as on walls. Fine grooves that occur on rocks harder than limestone may have been used as sharpening grooves.

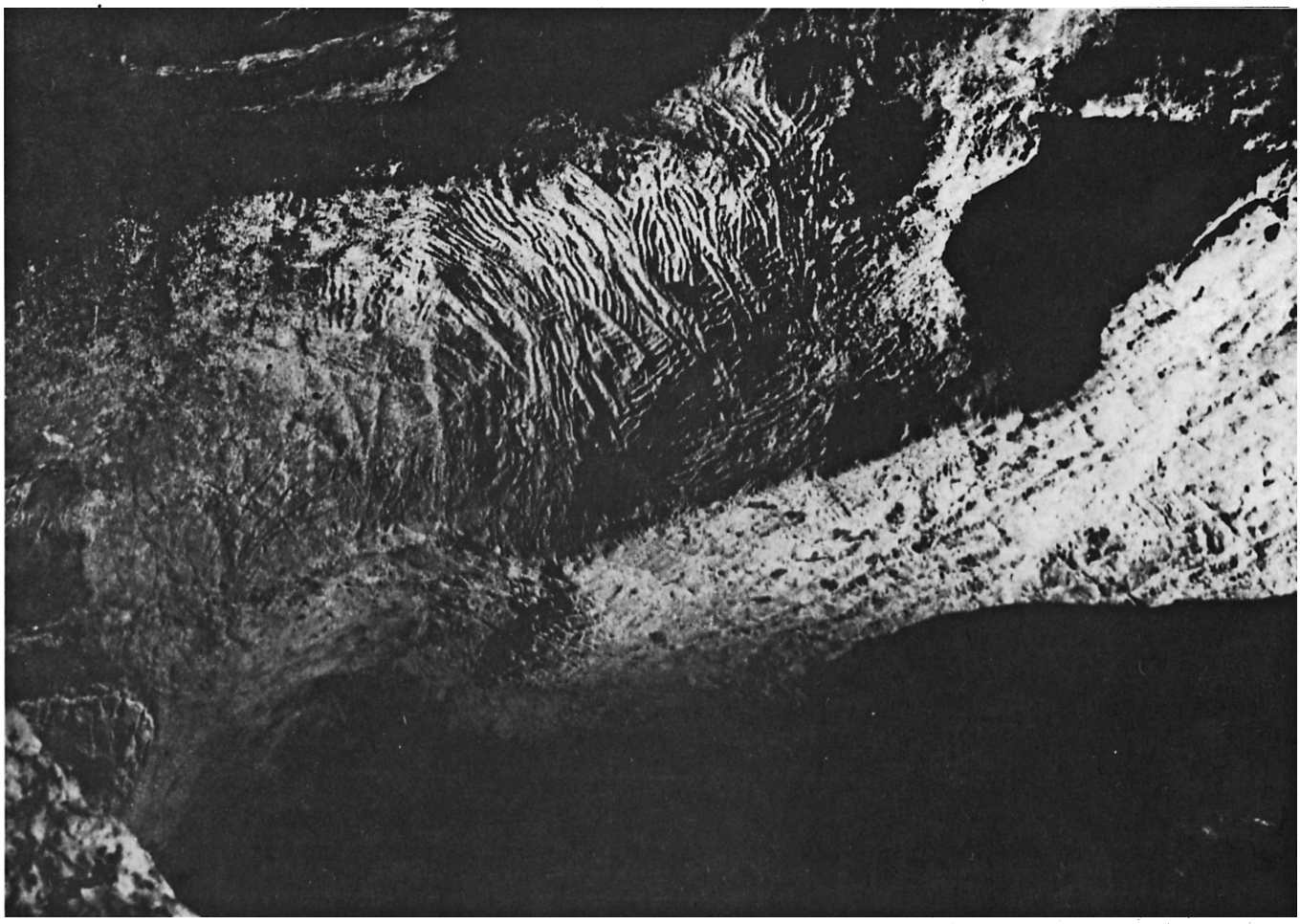

Plate 2. Finger markings, in soft mantle on ceiling N.G.-2 Cave, Vic. Note: Finer rectangular grid on left.

Other markings. The following appear not to have been recorded from caves but are included for completeness. Large abraded grooves occur, sometimes outlining animal figures several metres across or just as a series of parallel grooves, or sometimes in harder rocks as sharpening grooves. Percussive engravings or pecked intaglio are usually found on flat rock slabs having been made by pounding the rock surface with another rock so that circular spalls break off. By repeated spalling, patterns can be engraved.

For the delicate engravings in soft walls the only acceptable method for recording is photographic. The most sophisticated method involves survey or stereo cameras and a stereoplotter which enables the engravings to be accurately mapped or even contoured. Using standard 35 mm cameras a useful stereo effect can be achieved by moving the camera several centimetres in the plane of the engraving between successive shots. A good degree of side-lighting is required to highlight the engraving's relief. Under no circumstances should anything be applied to the engravings to improve their appearance.

OCCUPATION SITES

Where a cave has been regularly or intensely occupied by prehistoric aborigines a rich black occupation soil is often found. This organic rich soil was formed from the debris of the materials and food resources and its processing, which the aborigines were exploiting at that site. This includes the ash and charcoal from fires, burnt and unburnt fragments of bird, mammal, fish and reptile bone, pieces of egg and mollusc shell and any waste material from the making of stone, bone or wood implements. Of these the stone is most abundant (Fig. 5). Occasionally a stone implement may be found but it has often been discarded or broken. Other things that may be found are pieces of ochre, stones foreign to the immediate area including grinding stones and hammer stones, burnt stones and burnt clay lumps.

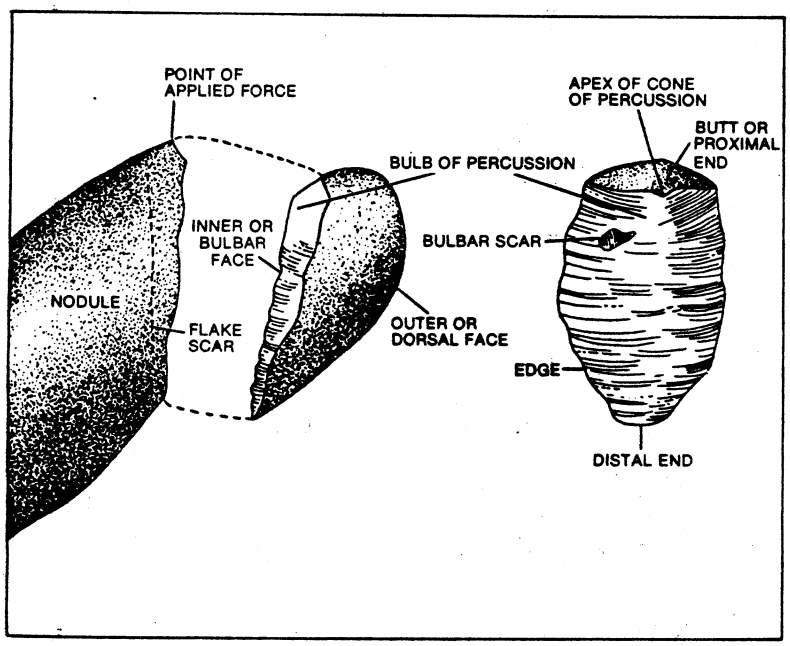

Figure 5. Features of a stone flake made by percussion typical of many waste flakes found in stone working, quarry and occupation sites (after J. Bordaz, *Tools of the Old and New Stone Age*).

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Occupation sites tend to be found in caves or shelters that under most circumstances would make pleasant and protected camp sites. They seem to be restricted to the light or twilight zone.

The recognition of an occupation site may at times be quite difficult and requires the identification of one or more of the features described above being out of their natural context. This may involve much tedious and careful searching, for example, the finding of a stone pebble or flake in a shelter with no obvious gravel deposits associated with it, or a piece of freshwater mussel in a cave above any flood level or perhaps adjacent to a now dry or saline lake or watercourse, would be a positive indicator that an occupation site may be at hand. Often occupation deposits may be buried under more recent debris and soil. In such cases close inspection of any disturbances could yield a clue. Rabbit and other animal burrows can bring underlying material to the surface. The walls of burrows may also be revealing. Any erosion gullies may have material exposed in the walls. Heavier material such as stone waste flakes may remain at the base of the gully as a lag. Frequently careful scrutiny of any slope approaching a cave may yield things of interest, especially around the dripline where erosion pools with lags of coarser materials occur.

Under no circumstances should any artefacts or any other materials be collected or removed from their original position on a site nor should any digging, augering or scratching about the surface be indulged in. Obviously if every party visiting a site made their own collection and dug their own little hole a large amount of disturbance would occur eventually rendering the site archaeologically valueless. Detailed site assessment is best left to someone working for or with the local archaeological agency.

Details worth noting about a site would include a sketch map or plan of the site showing any features such as artefacts, hearths, any disturbances, the apparent extent of the deposit, a detailed list of any archaeological materials that derive from the site, and any other details that appear to be useful.

FLINT MINING

Flint is a homogeneous fine-grained siliceous material which is well-known for its workability for making stone tools and as such was sought after by prehistoric aborigines. It is deposited as a concretion in limestone often within a particular layer. To date the only known flint-mining sites are from the Nullarbor where bands of flint nodules outcrop in the walls of several caves. These nodules were dug out and/or broken off leaving hollows with digging scars in the limestone, often the innermost pieces of the nodule staying behind (Plate 3). A relative age, modern versus ancient, of this quarrying can be given by surface weathering on the hollows and mineral growth on the remaining flint. Any suspected flint encountered should be closely inspected to see if any pieces were broken by natural weathering or by deliberate human percussion, in which case they would have features as shown in Figure 5. However, some confusion can occur where modern rock-hounds or specimen-seekers have been collecting flint, in which case characteristic marks of the geological pick and steel chisel may be present.

Where flint was quarried in complete darkness or in a dull twilight zone, burnt-out torch stubs and hearths may be found. Such items can be used for radio-carbon dating of quarrying activities provided they are not disturbed or contaminated.

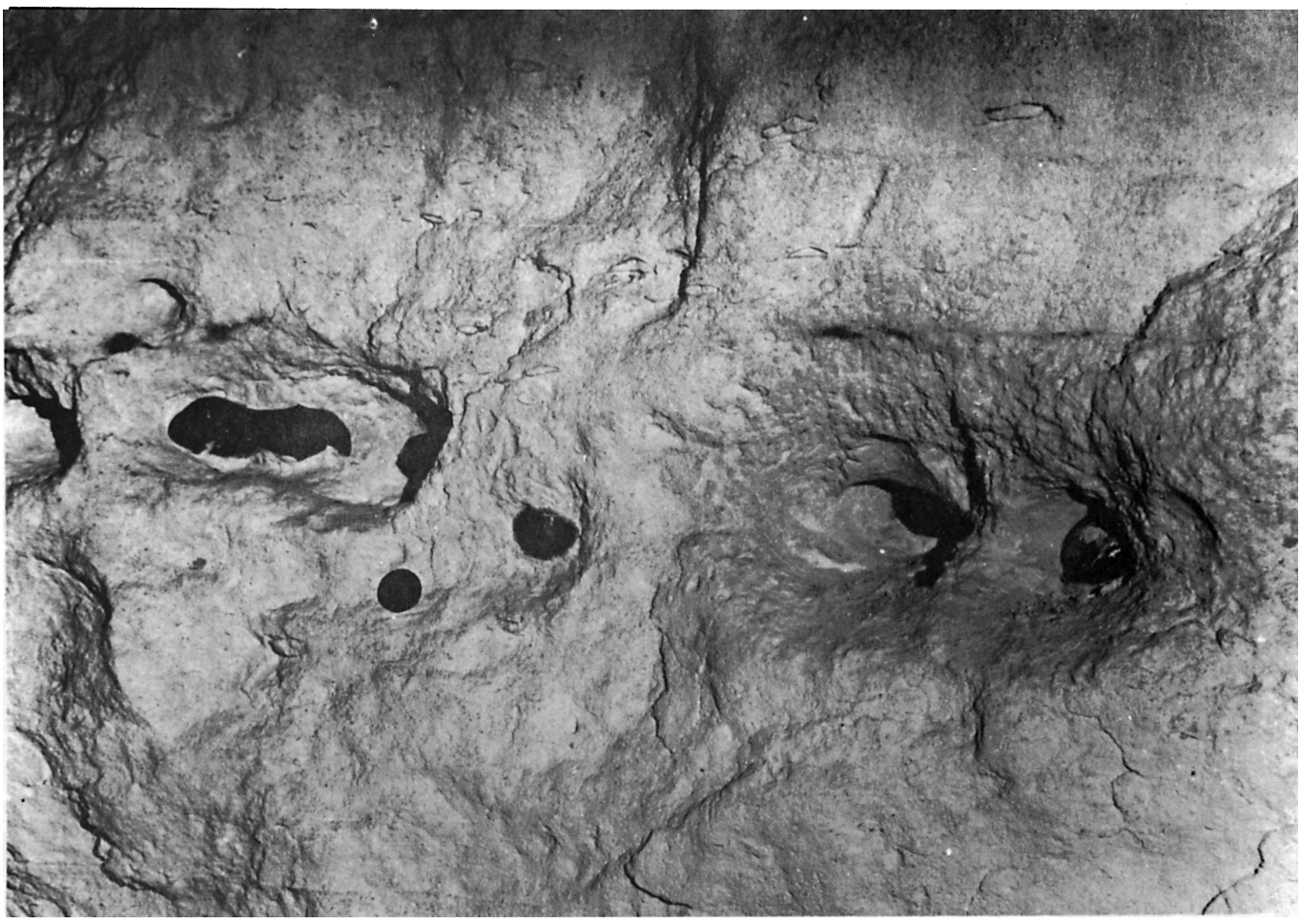

Plate 3. Flint quarrying, showing remnants of flint nodules at base of excavated holes in wall. Note: 5 cm diameter lens cap and original flint/limestone contact surface in second hole from right. Weebubbie Cave, W.A.

SKELETAL SITES

Some caves from north-west Australia have been used by aborigines as burial sites or repositories for skeletal material. If discovered they should be left undisturbed.

STONE AND OTHER ARRANGEMENTS

Stone and bone arrangements and placements have been found in caves. These may consist of singly-placed boulders or a number of boulders to form a design or cairn. In Koonalda Cave a series of placed boulders bearing engravings appear to mark paths leading to varous features including bone placements. Once again the key to identification is whether the rocks, bones, etc., could have got into their position or orientation by any natural process other than human. If not one must take care not to overlook modern activities like survey cairn building. The presence of engravings, artefacts, etc., may help to weight one's conclusion.

SACRED SITES

Caves, painted shelters, burial caves and other features may still be sacred to Australian aborigines and the people of Papua New Guinea. If such a situation is thought to exist any visitation, recording, photography and publication should only be undertaken with prior discussion and permission of the people concerned.

MISCELLANEOUS SITES

It seems likely that in drier areas suitable caves would have been used as water sources. Certainly on the Nullarbor "gnamma holes", small solutional rock-holes in limestone pans, were periodically used for water.

Although unrecorded to date, cave-dwelling bats could have been used as a food resource. Often scatters of odd stone waste flakes and implements occur near such features of interest.

Dessicated human palaeofaeces from some American caves have yielded valuable insight into the diet and diseases of prehistoric people. Although apparently unrecorded in Australia they could occur in a very dry environment.

Even prehistoric footprints have been reported from quite inaccessible places in some French caves.

SITE MANAGEMENT AND PROTECTION

A variety of threats and causes of damage to sites exist. These may be either wilful or inadvertent. The latter is largely caused by ignorance of a site in a particular cave or by ignorance and/or non-recognition of the features associated with the site concerned.

Wall or boulder engravings can easily be modified or obliterated by leaning on, brushing against, bumping one's head into, dragging one's tripod across or even just by kicking up some dust. Walking over unobserved stone or bone arrangements, surface scatters of artefacts, debris from flint-quarrying sites, hearths, torch stubs, etc., can destroy or bury such features. The uninformed digger on a quest for new caves could easily disturb or bury an unrecognised site. Over-crowding, lack of time and organisation whilst inspecting or photographing sites, especially engravings and paintings, greatly increases the chance for damage to occur as these conditions can contribute to unnecessary haste and clumsiness. In the often delicate environment outside a cave or in its doline heavy use of access tracks along a poor route can lead to excessive erosion. This may disturb or bury sites both archaeological and palaeontoligical. Grazing stock, rabbits and other animals can cause similar problems. Some obvious causes of wilful damage include the graffitist and art imitator, the collector rummaging through sites for artefacts and the rockhound after flint.

Once a site has been recognised, its management is the responsibility of the local state archaeological agency. This may involve some access restrictions but ought not of necessity lead to total closure. In most cases a suitable access policy should be able to be sorted out between speleos and the agency concerned. This would be very much dependant on the type of cave and site and may involve using guides, either official or honorary that are fully aware of the cave and site concerned. Restrictions may be placed on party size or visitor/guide ratios and minimum lighting and other equipment might be specified. This along with perhaps track-marking and the provision of simple aesthetic guiding rails where appropriate (for example, around

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excavations or especially in front of engravings) in constricted areas, should give adequate protection to sites during visitation. For remoter areas with little or no onsite management personnel where a site is well known, the provision of some "in cave" interpretation in the parts of the cave concerned, so as not to attract undue attention except to those who have stumbled across the feature, may present a suitable alternative. This could be something along the lines of the "self-guided" tourist cave. The removal of any graffiti and rubbish from a site is always desirable as their presence only attracts more. Where a cave has been gated to protect a site it is important that a suitable explanatory sign be included. This should state the reasons for gating, give some basic information about the site and say where further information and possible access could be obtained.

CONCLUSION

Caves and rock shelters are known to contain some valuable relics of prehistoric aboriginal activities and doubtless more will be found especially with the current increase amongst speleos of concern and interest in the caves they visit and what is happening to them. A greater awareness of archaeological features by speleos should both enrich their experience and the general knowledge of this unique heritage.

FURTHER READING

As this paper was mainly concerned with promoting a greater awareness of archaeological features of caves it has not been referenced. However, much of the information is derived from the following selected list of references which gives a general coverage of archaeology and archaeological cave sites in Australia. Additional references can be obtained from the various editions of *Australian Speleo Abstracts*.

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APPENDIX: ARCHAEOLOGICAL AGENCIES

Queensland:	Department of Aboriginal and Islanders Advancement, 418-424 Ann Street, BRISBANE, Qld. 4000
South Australia:	Aboriginal and Historic Relics Preservation, 43 Fullarton Road, KENT TOWN, S.A. 5067
New South Wales:	National Parks and Wildlife Service, A.D.C. Building, 189-193 Kent Street, SYDNEY, N.S.W. 2000
Tasmania:	National Parks and Wildlife Service, P.O. Box 210, SANDY BAY, Tas. 7005
Northern Territory:	Museum and Art Galleries of the Northern Territory, P.O. Box 4646, DARWIN, N.T. 5794
Victoria:	Victoria Archaeological Survey, 29-31 Victoria Avenue, ALBERT PARK, Vic. 3206
Western Australia:	Western Australian Museum, Francis Street, PERTH, W.A. 6000
Papua-New Guinea:	Niugini Archaeological Survey, Department of Anthropology and Sociology, University of P.N.G., Box 4820 P.O. University.

PALAEOCLIMATIC INFORMATION FROM CAVES

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Abstract

Palaeoclimatic information can be obtained from caves by analysing the oxygen isotope composition of calcite and aragonite deposited as stalagmites.

A palaeotemperature record is useful only if it can be dated. In the last decade considerable progress has been made in the radiometric dating of speleothems by means of the uranium-thorium method. Material from 2 000 to 300 000 years old can be dated by this method.

Two oxygen isotopes ^{16}O and ^{18}O are used in palaeotemperature work. In nature there are small natural variations in the ratio between the two ($^{18}O/^{16}O$) and the value of the ratio is temperature dependent. The values can be measured by means of a stable isotope mass spectrometer and are expressed as parts per thousand ($^{o}/_{oo}$), and designated as $\delta^{18}O$. Measurements are made on sealed samples of carbon dioxide gas prepared from calcium carbonate.

If closely spaced samples are taken from a longitudinal section of a stalagmite and the value of $\delta^{18}O$ determined for each sample a curve of temperature change against time can be plotted if the age of different layers within the stalagmites can also be determined.

Tasmania, the south-east of Australia and the south-west of Western Australia offer considerable scope for this field of research.

INTRODUCTION

Palaeoclimatic information is of interest because of Man's increasing concern about the possibility of rapid climatic change in the perhaps not too distant future. Either a swing to significantly warmer conditions or to significantly cooler conditions could spell disaster for our present day civilization.

Warmer conditions would cause melting of the Greenland and Antarctic icecaps resulting in wholesale inundation of coastal plains. Colder conditions would severely restrict agriculture and would cover large areas of land with glacial ice.

The climate is changing at present and a major concern is to assess the relative extent to which man-made and natural factors are responsible. Natural factors tend to be cyclic in nature and if we have available to us an accurately dated record of past temperature change we can start to predict future changes due to natural factors. Then, by comparing them with actual changes we may ultimately assess the influence of Man on our changing climate (Calder, 1974).

Such records can be obtained from oxygen isotope analysis of the ice sheets of Greenland and Antarctica, from deep sea cores and from speleothems in caves.

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GOEDE – PALAEOCLIMATIC INFORMATION FROM CAVES

The most suitable for palaeotemperature work are stalagmites because they are characterised by slow vertical growth and show distinct growth layers which can be sampled when the stalagmite is cut lengthwise (Plate 1).

RADIOMETRIC DATING

No palaeotemperature record is useful unless it can be dated. During the last ten years reliable Uranium/Thorium dating has become available (Harmon, Thompson, Schwarcz & Ford, 1975; Gascoyne, Schwarcz & Ford, 1978). Most stalagmites contain minute amounts of uranium including ^{234}U which decays to ^{230}Th with a half-life of 247 000 years. The development of α particle spectrometry has made possible analytical measurements of very small quantities of radio-active isotopes. The U/Th method of dating can be used over a time period of 2 000 to 300 000 years BP - a time range which is covered by very few other dating methods.

For a stalagmite to be dated it must have:

(1) A U content of not less than 0.1 ppm. Uranium content can be determined quickly and cheaply by delayed neutron analysis by the Australian Atomic Energy Commission in Sydney.

(2) An absence of clays and a very low content of other detrital minerals (< 0.5%), otherwise the specimen must be rejected. The ratio $^{230}Th/^{232}Th$ is determined during the dating procedure. It gives an indication of the degree of detrital contamination. If the ratio is < 20 the sample is once again rejected.

(3) Absence of any evidence of post-depositional recrystallisation.

OXYGEN ISOTOPES

The element oxygen has three stable isotopes, ^{16}O, ^{17}O and ^{18}O. The two that concern us in palaeotemperature work are ^{16}O and ^{18}O. Oxygen 16 is by far the most abundant being approximately 500 times more common than ^{18}O. However, in nature there are small variations in the ratio ($^{18}O/^{16}O$) and these can be used to gain information on palaeotemperatures (Bowen, 1966; Hendy & Wilson, 1968; Hendy, 1969; Harmon, Thompson, Schwarcz & Ford, 1978).

METHOD OF MEASUREMENT

Measurement of the ratio is by means of a stable isotope mass spectrometer. It is made on CO_2 gas and is calculated as follows:

$$\delta\ ^{18}O\ ^{o}/_{oo} = \left[\frac{(^{18}O/^{16}O)SAMPLE - (^{18}O/^{16}O)STANDARD}{(^{18}O/^{16}O)STANDARD}\right] \times 1000$$

Measurements are made in this way because the mass spectrometer can measure differences between two samples much more accurately than the actual value for one sample. The procedure eliminates any systematic measurement errors. The ratio is multiplied by 1000 to avoid dealing with small fractions of numbers. The standard most often used is SMOW and is approximately equal to the mean isotopic composition of ocean water.

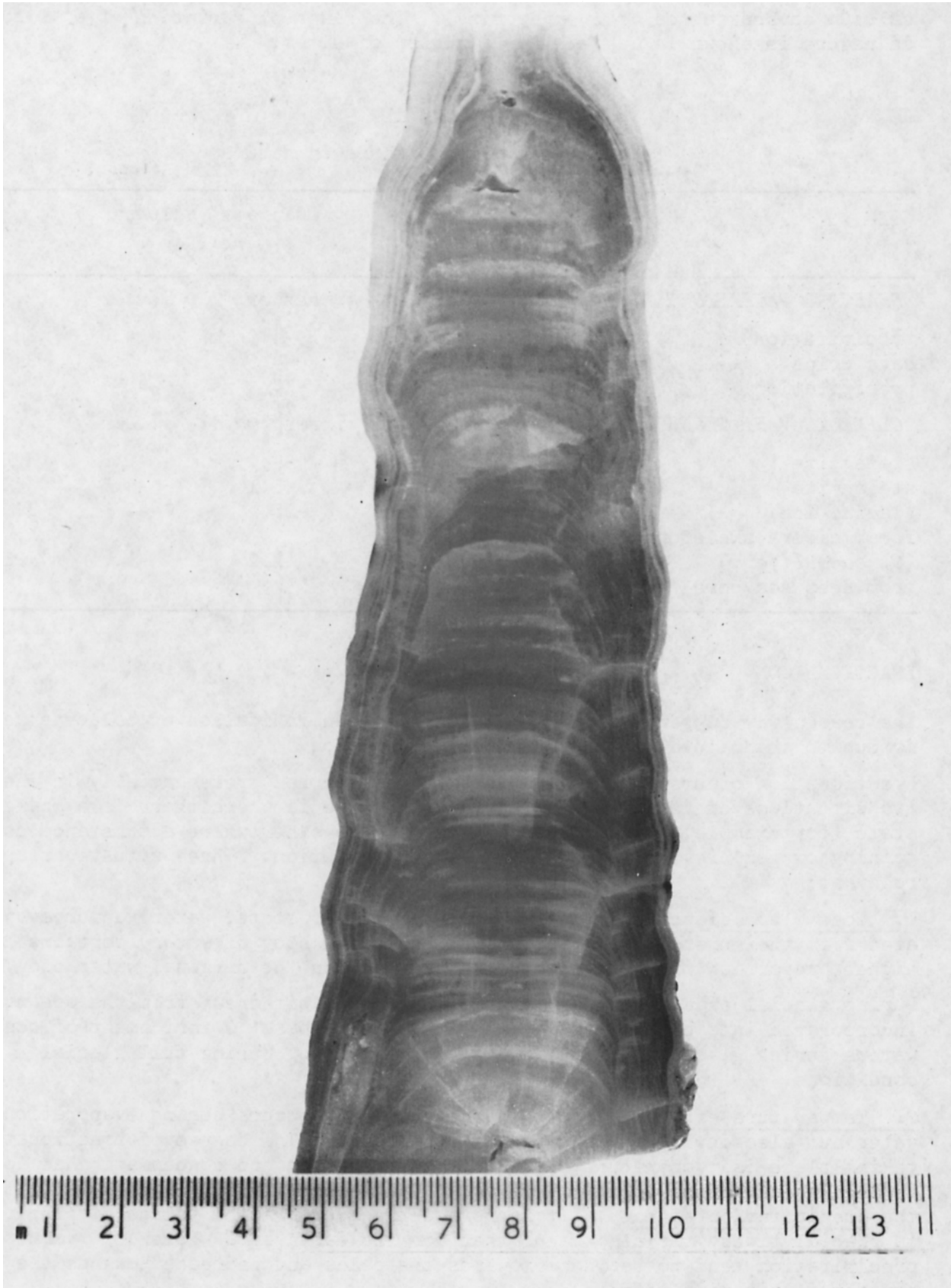

Plate 1. A small stalagmite showing internal structure, from King George V Cave, Hastings, Tasmania.

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The substances on which $\delta^{18}O$ is usually determined are H_2O (water, ice) and calcium carbonate (calcite, aragonite). The range of variation of $\delta^{18}O$ found in nature is shown in Table 1 for a number of sites.

Table 1

Variations of $\delta^{18}O$ found in nature

Material analysed	Location	Range of values ($\delta^{18}O$)		Standard
SEASONAL VARIATIONS		*summer*	*winter*	
precipitation	Virginia, U.S.A.	-1.0	-14.0	SMOW
cave drips	Virginia, U.S.A.	-4.5	-7.9	SMOW
precipitation	Thule, NW Greenland	-17	-40	SMOW
CLIMATIC VARIATIONS		*interglacial*	*glacial*	
stalagmite	North Island, N.Z.	-4.0	-2.5	PDB
stalagmite	Virginia, U.S.A.	-6.1	-4.6	PDB
glacial ice	Thule, NW Greenland	-25	-43	SMOW
foraminifera skeletons (*G. sacculifera*) from deep sea core	Equatorial Pacific Core V28-238	-2.2	-1.0	Bl

FRACTIONATION

The reason why oxygen isotope ratios can give an indication of palaeotemperature is due to the natural occurrence of fractionation.

Fractionation occurs when one isotope is transferred preferentially in one of two situations of interest to us. One such case is where there is a change of state (for example, from liquid to gas) and the other where a substance containing oxygen crystallises from an aqueous solution. Three situations are relevant:

1. Ice volume effect. When there is a change of state, water vapour evaporated from the surface of the ocean (or any other body of water) contains a higher proportion of the lighter isotope ^{16}O than the original water body.

During glacial phases large amounts of water are withdrawn from the oceans and incorporated into continental ice sheets. It causes ^{18}O enrichment of ocean waters during glacial times of the order of $1.1^{o}/_{oo}$ during full glacial conditions.

2. Temperature effects. Fractionation not only occurs during evaporation of water but also during condensation and freezing. The degree of fractionation taking place is temperature dependent. Evaporation and condensation at lower temperatures produce lower values of $\delta^{18}O$ in precipitation (sometimes called the precipitation effect). It means a depression of $\delta^{18}O$ values of precipitation in glacial times. It also means that for the earth as a whole $\delta^{18}O$ values in precipitation tend to decrease towards the poles and increase towards the equator (latitudinal effect).

Outside the equatorial zone there is also a marked seasonal variation with higher values of $\delta^{18}O$ in summer precipitation and lower values in winter precipitation (seasonal effect). Seasonal temperature effects are variable in time and space (Dansgaard, 1964). For six continental sites in the U.S.A. they were found to vary from + 0.17 to + 0.39 $\delta^{18}O$ $^{o}/_{oo}$ $^{o}C^{-1}$ (Harmon, Schwarcz & Ford, 1978).

These variations cannot be used to estimate the temperature effects during a glacial-interglacial cycle because the seasonal effect would be affected by the temperature of evaporation at the source area as well as at the site of condensation and precipitation.

In addition both latitudinal and seasonal effects differ from the glacial-interglacial temperature effect because the latter is also influenced by the ice volume effect which tends to reduce the magnitude of the temperature effect. For West Virginia, U.S.A. Harmon, Schwarcz & Ford (1978) estimate the glacial-interglacial temperature effect to be + 0.14 $^{o}/_{oo}$ $^{o}C^{-1}$.

3. Crystallisation effect. When a substance containing oxygen crystallises from a saturated solution of water or where calcite or aragonite is extracted from water by biochemical means, fractionation also occurs. The calcite or aragonite is slightly enriched in ^{18}O in relation to the water from which it crystallises and the degree of enrichment is temperature dependent. Bowen (1966) states:

Temperature	Ratio in parent solution	Ratio in $CaCO_3$
0°C	1:500	1.026:500
25°C	1:500	1.022:500

This means that for water of constant isotopic composition, $\delta^{18}O_c$ (the $\delta^{18}O$ value of calcium carbonate) will be inversely related to the temperature at which it formed. We can call this the crystallisation effect and its magnitude is -0.24 $^{o}/_{oo}$ $^{o}C^{-1}$ (Harmon, Schwarcz & Ford, 1978). This value does not always apply to biochemically deposited calcium carbonate (Shackleton, Wiseman & Buckley, 1973).

PALAEOTEMPERATURE SOURCES

So far three sources of palaeotemperature information using oxygen isotopes have been utilized.

1. Continental ice sheets. Profiles have been sampled from cores drilled through the Greenland ice sheet at Camp Century and the Antarctic ice sheet at Byrd Station. Variations in the isotopic ratio appear to be controlled primarily by temperature change, low values coinciding with glacial periods and high values with interglacial periods (Langway, Dansgaard, Johnson & Clausen, 1973).

2. Calcareous deep sea sediments. (Mainly in tropical oceans.) Deep sea cores are sampled at regular intervals for shells of particular species of foraminifera and samples analysed for $\delta^{18}O$. Isotopic variations appear to be controlled mainly by the ice volume effect with the crystallisation effect playing only a minor role. Variations are much smaller than in ice cores. Low values coincide with interglacial periods and high values with glacial periods (Shackleton & Opdyke, 1973).

3. Stalagmites. They can be used to provide palaeoclimatic information provided they have formed under conditions of isotopic equilibrium with the

cave seepage waters from which they have been deposited. Isotopic equilibrium means that evaporation of water should play no part in carbonate deposition – deposition must occur in an atmosphere saturated with water vapour. This excludes the use of stalagmites close to cave entrances and probably also from caves in more arid regions.

It is possible to test for equilibrium conditions by carrying out a number of oxygen isotope analyses on a single growth layer which should all yield similar values under equilibrium conditions. It can also be done by carrying out both oxygen and carbon isotope analyses for a number of samples on a single growth layer. In the latter case, if there is a correlation between the $^{18}O/^{16}O$ ratio and the $^{13}C/^{12}C$ ratio the stalagmite was not formed under equilibrium conditions (Thompson, Schwarcz & Ford, 1974).

Caves have the advantage that with rare exceptions they have an almost constant temperature environment (annual temperature variation < 1°C) and the temperature is approximately equal to the mean annual surface temperature above the cave.

If stalagmites formed from seepage water with a constant isotopic composition, then determination of palaeotemperature values would be simple because we would be dealing only with the crystallisation effect, where

$$T = \sqrt{\frac{2780}{\ln K_{c-w} + .00289}}$$

where T is absolute temperature (K)
and K_{c-w} equals $(^{18}O/^{16}O)_c$ / $(^{18}O/^{16}O)_w$
(from Harmon, Schwarcz & Ford, 1978).

Unfortunately the isotopic composition of seepage water varies. Variation is caused by temperature effects - both short term due to seasonal change and long term due to climatic change.

Fortunately, when calcium carbonate is deposited small amounts of seepage water are trapped in cavities and this water is then sealed in by further deposition to form inclusions. When sealed in, the oxygen isotope composition of the water is representative of the water from which the particular layer crystallised.

If the oxygen isotope composition of the water remained unchanged after sealing, we could determine the isotopic composition and hence the temperature at which the particular layer of calcite formed. However, this is not the case - the oxygen isotope composition may change after inclusion because of exchange with the surrounding calcite (Schwarcz & Harmon, 1976).

By a fortunate circumstance we can reconstruct original oxygen isotope composition of the fluid by measuring its D/H ratio - the ratio of deuterium to hydrogen. Since the surrounding calcite does not contain hydrogen this can be expected to have retained its original value. In all meteoric waters (and seepage waters derived from them) there is a close statistical relationship between the D/H ratio and the $^{18}O/^{16}O$ ratio. The line of best fit is known as the meteoric water line and is represented by the regression equation
$\delta D = 8\ \delta^{18}O + 10.$

Hence it is possible to calculate the temperature of formation for those layers for which inclusion waters have been analysed. These values can then be used to calibrate the curve $\delta^{18}O$ against time in terms of temperature change. This must be done for every locality if an estimate of palaeotemperature change is to be obtained.

CONCLUSION

The techniques outlined in this paper enable the reconstruction of a dated temperature record from stalagmites for the last 300 000 years of the earth's history. Past mean annual temperatures of karst areas, where suitable speleothems are available, can be estimated with a total error of ± 2°C (Harmon, Schwarcz & Ford, 1978). However, relative temperature changes of as little as 0.1°C may be detected.

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A.S.F. MEMBERSHIP DEMOGRAPHY

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Abstract

Historical membership data based on Australian Speleological Federation (A.S.F.) Capitation numbers has been collected and analysed. Predictions for growth of member society numbers and total A.S.F. membership are made according to computed linear regessions. Increases are related to growth and popularity of caving and general societal changes. Recommendations are made for changes in A.S.F. Capitation and membership policies to improve the A.S.F's representativeness. An individual A.S.F. member number is proposed to allow analysis of membership dropout rates.

INTRODUCTION

This paper represents the first detailed study of the membership of the Australian Speleological Federation (A.S.F.). Whilst some membership data has been previously published, no attempt has hitherto been made to analyse membership trends and to predict what will happen in the future. We have, therefore, taken an historical overview upon which predictions have been made of membership of the A.S.F.

DATA SOURCE

The raw data on A.S.F. membership is the total membership covered by A.S.F. capitation payments (Annual levy per member per society).

Whilst the A.S.F. capitation fee does not represent the total membership of the A.S.F. societies, it does reflect society and therefore A.S.F. growth in real terms, as A.S.F. capitation payments are generally regarded as being representative of the "full" membership component which in turn is indicative of the more stable segment of society membership.

In addition, a comparision was undertaken between the Australian data and the United States of America (U.S.A.) data (Wefer, 1971). Unlike the A.S.F., the National Speleological Society (N.S.S.) in the U.S.A. is based on individual membership and some of these individuals club together to form grottos.

MEMBERSHIP PREDICTIONS

The primary raw data is given in Table 1, upon which a number of linear regressions were computed to enable predctions to be made as to when A.S.F. membership will reach 1000 members and what the membership will be in 1990.

Although the correlations are quite satisfactory, the membership oscillates past the line of best fit sufficiently for us to be wary in using the equations 1-4 (see Appendix A).

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Table 1

A.S.F. membership analysis and comparisons

(based upon A.S.F. capitation payments)

STATE	1978	1977	1976	1975	1974	1973	1972	1971	1970	1969
Queensland										
Clubs	1	2	2	2	2	2	2	2	1	1
Membership	49	71	69	64	75	40	66	75	70	54
3 year av.	63	68	69	60	60	60	70	66	-	-
Trend index	95	103	105	91	91	91	106	100	-	-
% natl memb.	8.2	9.7	10.0	10.1	11.2	6.5	11.2	12.8	13.2	11.7
N.S.W. & A.C.T.										
Clubs	12	14	14	13	12	12	10	10	11	11
Membership	298	416	394	354	358	376	300	319	281	298
3 year av.	369	388	369	363	345	331	300	299	-	-
Trend index	123	130	123	121	115	111	100	100	-	-
% natl memb.	20.7	56.7	56.9	55.7	53.3	61.3	51.0	54.3	52.9	64.8
Victoria										
Clubs	1	1	1	1	1	1	1	1	1	1
Membership	75	67	55	42	59	77	75	51	48	36
3 year av.	66	55	52	59	70	68	58	45	-	-
Trend index	146	122	116	131	156	151	129	100	-	-
% natl memb.	12.6	9.2	7.4	6.6	8.8	12.6	12.8	8.7	9.0	7.8
Tasmania										
Clubs	2	2	3	3	3	2	2	2	1	1
Membership	48	45	68	60	62	30	53	55	25	25
3 year av.	54	58	63	51	48	46	44	35	-	-
Trend index	154	166	180	146	137	131	126	100	-	-
% natl memb.	8.1	6.2	9.8	9.4	9.2	4.9	9.0	9.4	4.7	5.4
South Aust.										
Clubs	1	1	1	1	1	1	1	1	1	1
Membership	58	56	52	58	54	47	51	45	45	47
3 year av.	55	55	55	63	51	48	47	46	-	-
Trend index	120	120	120	115	111	104	102	100	-	-
% natl memb.	9.8	7.7	7.5	9.1	8.0	7.7	8.7	7.7	8.5	10.2
Western Aust.										
Clubs	1	2	1	1	1	1	1	1	1	1
Membership	68	77	55	58	64	43	43	43	62	n.a.
3 year av.	67	63	59	55	50	43	49	-	-	-
Trend index	137	129	120	112	102	88	100	-	-	-
% natl memb.	11.4	10.5	7.9	9.1	9.5	7.0	7.3	7.3	11.7	-
National A.S.F.										
Clubs	18	22	22	21	20	19	17	17	16	15
Membership	596	732	693	636	672	613	588	543	531	460
3 year av.	674	687	667	640	624	581	554	511	-	-
Trend index	132	134	131	125	122	114	108	100	-	-

Using equation No. 2 (best correlation) and equation No. 4 (most data) membership projections were computed and these are shown in Table 2. Perusal of Table 2 indicates that the fit is fairly good in the mid 70's in both cases, but in basing forward projections on the derived equations note should be made of just how much divergence is built-in back to 1961. With these limitations in mind, the two projections were made, the results being:

Equation No.	1000 Members	Membership 1990	Correlation Coefficient
1	1987	1109	0.81
2	1982	1451	0.96
3	1987	1098	0.93
4	1990	996	0.90

As shown, there is a spread of 8 years between the optimistic and pessimistic growth estimates to 1000 members, and a spread of about 50% in the 1990 estimates.

In comparison with the American data, we have a large "intercept" meaning we started with relatively more members in the formative years of the A.S.F. but have not had the groth at anywhere near the U.S.A. rate. It is suspected that this refelects the difference between joining the N.S.S. as an individual member, and the difficulty in getting into a society, and that society then being admitted as a "Full" member of the A.S.F., and the practice of paying A.S.F. capitation for "full" members only. If the total membership of each society were covered by capitation payments, the membership would probably show a higher growth rate.

A preliminary sampling of the relationship between the membership covered by capitation payments and the total society membership indicates that approximately 60% of the total society membership is covered by the capitation payments. However the sample is not sufficiently large enough to be conclusive. Capitation based on all fee paying members of each society would increase A.S.F. funds and give the A.S.F. a larger and more representative membership total.

SOCIETY MEMBERSHIP STRENGTH

Over the analysis period, the average membership per society has been remarkably stable at around 33 members. However, the number of societies in the A.S.F. versus time varies more slowly, about one society every two years, and on this basis we would expect some 31 societies as members of the A.S.F. by 1990.

It is worthwhile to note that this situation is not the same as Wefer found in the N.S.S. He found that the number of members per grotto (society) was predicted to rise from 32.1 in 1970 to 44.3 in 2000 and that the number of grottos per state would grow rapidly from 2.2 per state to 19.5 per state by 2000. Thus in the N.S.S. the number of members in a grotto is expected to grow slowly while the number of grottos grows rapidly.

In contrast, if the A.S.F. continues its historic attitudes regarding membership, excluding associate status, then A.S.F. membership is predicted to rise by just less than 50% from the current 22 societies to 31 societies in 1990.

Table 2

A.S.F. Members vs Year

YEAR	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79
Raw Data	455	-	400	450	-	-	-	-	460	531	543	588	613	672	636	693	732	596	-
Predicted Equation 2	323	340	358	377	397	418	440	463	488	514	542	571	601	633	667	702	740	779	820
Predicted Equation 4	408	421	434	448	462	477	492	508	524	540	558	575	593	612	632	651	672	693	715

Notes: Raw data represents the total number of cavers covered by A.S.F. Capitation payments.

BOGG & PAVEY – A.S.F. MEMBERSHIP DEMOGRAPHY

IS THE A.S.F. REPRESENTATIVE?

What is really happening in the Australian caving community, is that more and more groups are being formed but, they are not being admitted into the A.S.F. as "Full" members. The number of societies known to the N.S.W. Speleological Council which is 33 in 1978, will testify to this (N.S.W. Speleological Council Annual Report, 1977). We expect this situation would apply in other States but at this juncture, adequate data are not available regarding the number of non-A.S.F. groups nor the membership that they would represent, on a State by State basis. If we assume that the average membership strength is 33 members per society, then it is obvious that the A.S.F. cannot lay claim to being a truly representative national body. Using the N.S.W. situation as a basis, we estimate total potential membership to be around 1000 in 1978 of which 416 are currently full members of A.S.F. societies.

Clearly it is the A.S.F's challenge to get these groups under the wing in the first instance and eventually encourage them into becoming "Full" members, of the A.S.F. A result of such a policy would be that the A.S.F. could expect a greater drop out rate as it would no longer be selecting for membership on a sole basis of established "stability" as is currently required of an applicant society.

MEMBERSHIP DISTRIBUTION

In all states, except N.S.W., membership of the A.S.F. (cavers per State) has been fairly stable (see Table 1) with some growth being evidenced recently. Each State, except N.S.W., has had a reasonably constant 7-10% of total membership of the A.S.F. N.S.W. is the "high flier" in A.S.F. membership and its high percentage of total A.S.F. membership is remarkably stable.

On a per capita basis (see Table 3) both Queensland and Victoria are the "odd ones out" which is due possibly to cave area remoteness relative to centres of major population and the difficulties of "access".

It is obvious that there is a greater awareness of caves as a recreational resource and of caving as a sport, as shown by the steady increase in the per capita ratios. In 1970 there was one A.S.F. member for each 23 700 persons and in 1977 one for each 19 100 persons. In the same period there was a national population increase of 11%.

DROPOUTS

The N.S.S. in the U.S.A. assigns a membership number to each member. This number is not re-issued if the member leaves the N.S.S. but is re-assigned if the member rejoins. Thus Wefer (1971) was able from yearly membership data and the highest assigned N.S.S. number to calculate membership dropout rates. This we have not been able to do for the A.S.F. as it would require access to complete membership lists for each society since it joined the A.S.F. and considerable work to sort the long term members from the short term members.

Thus we are not able to determine average caving "lifetimes" for the A.S.F. population and hence confirm or deny the popularly held belief that most cavers belong to a club for only two years on average.

We recommend that the A.S.F. consider adopting a unique identification number for each member and suggest that only a small modification to the current A.S.F. Newsletter address list system would be sufficient. Namely the number currently

Table 3

Cavers per capita comparisons

(ratio of cavers to population)

STATE	DATA	1977	1976	1975	1974	1973	1972	1971	1970
Queensland	Population (000)	2136.8	2111.7	2084.0	2046.1	1987.3	1943.5	1852.3	1812.8
	Cavers	71	69	64	75	40	66	75	70
	Ratio 1:(000)	30.1	45.1	32.6	27.3	49.9	29.3	24.7	25.9
New South Wales & A.C.T.	Population (000)	5164.9	5117.6	5075.4	5015.1	4961.5	4904.9	4802.3	4711.3
	Cavers	416	394	354	358	376	300	319	281
	Ratio 1:(000)	12.4	23.0	14.3	14.0	13.2	16.4	15.1	16.8
Victoria	Population (000)	3782.3	3746.0	3719.1	3676.8	3628.4	3577.4	3537.5	3842.0
	Cavers	67	55	42	59	77	75	51	48
	Ratio 1:(000)	56.5	68.1	88.6	62.3	47.1	47.7	69.4	72.5
Tasmania	Population (000)	410.6	407.4	404.7	399.3	395.7	392.2	392.8	390.3
	Cavers	45	68	60	62	30	53	55	25
	Ratio 1:(000)	9.1	6.0	6.8	6.4	13.2	7.4	7.1	15.6
South Australia	Population (000)	1276.8	1261.6	1252.1	1236.2	1217.9	1202.4	1185.5	1170.2
	Cavers	56	52	58	54	47	51	45	45
	Ratio 1:(000)	22.8	24.3	21.6	22.9	25.9	23.6	26.3	26.0
Western Australia	Population (000)	1197.1	1169.8	1146.7	1117.4	1089.3	1070.9	1048.9	1014.1
	Cavers	77	55	58	64	43	43	62	62
	Ratio 1:(000)	15.6	21.3	19.8	17.5	25.3	24.9	16.9	16.4
National A.S.F.	Population (000)	13968.6	13814.1	13682.0	13494.7	13280.7	13080.4	12819.3	12580.9
	Cavers	732	693	636	672	613	588	543	531
	Ratio 1;(000)	19.1	19.9	21.5	20.1	21.7	22.2	23.6	23.7

Notes: Population figures are as at 30 June except for 1970 and 1971 which are as at 30 December for each year.
National cavers and population figures exclude the Northern Territory.

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used should not be re-assigned if the member drops out.

Society drop out rates have not been carefully examined due to a lack of data but at least seven societies which were once members have gone defunct, several others have been quiescent for several years and then recovered and two have resigned and later rejoined. Despite the A.S.F. striving for stability it is clear that the current policy does not eliminate the problem of a fair proportion of societies "dying".

GROWTH FACTORS

We identify the following as significant factors in the growth of the number of cavers in the population in contrast to the slow growth of A.S.F. membership.

Education system. The encouragement of much greater outdoor recreational activity through schools, including geology excursions, wider definitions of "school sports", and formation of outdoor clubs and in the wider community government campaigns such as "Life, Be in it.", Outward Bound Schools, etc.

Publicity and Promotions. Greater public awareness of caves has occurred through television programmes and newspaper coverage of caving activities, feature articles in magazines and even our own conservation campaigns.

Scouts and Caving. The Scout Association has various objectives including encouragement of leadership, initiative, responsibility and adventure. Caves are seen as providing a resource for the development of these objectives without the necessity for a large capital expenditure to provide the facilities. Caving is seen by the Scouting hierachy as having sufficient sustainable resources for the majority to enjoy. This activity has had a multiplier effect with migration of scouts and former scouts into the established societies and/or into the formation of their own group.

Documentation. A.S.F. member societies have contributed to an explosion in the "commercial" documentation of our caves. With such publications as "Speleo Handbook", "Caves of the Nullarbor", "Australian Caves and Caving", "Mammoth Cave Jenolan", "S.A. Cave Reference Book", "Mt Etna Caves" and in particular "Bungonia Caves". These books have made it much easier for people to find out about caves and their locations than ever before with little significant contribution to the societies' long term capital funds.

Leisure and mobility. The population has gained increased leisure time through reduced working hours and innovations like flexitime. In addition greater unemployment and an increasing population distribution relative to caving areas have given greater opportunities for people to go caving. In real dollar terms transport has become relatively cheaper over the last ten years and levels of mobility within the society have increased substantially making both the access to caves and the means of getting there easier to come by. Improved road systems and surfaces have decreased travelling times to closer areas and encouraged people to travel further to reach caving areas.

THE A.S.F'S COURSE OF ACTION

Unfortunately, we have probably progressed beyond the point of no return so far as attempting to depress the growth in numbers and awareness of caving. Clearly our aim must be to espouse the real advantages and benifits of joining the established societies and participating in our form of organised speleology

through public education. There is an inherent drawback with this policy and that is that the members of the A.S.F. must practise what they preach. "If we endorse it - we enforce it". In particular we should practise our own code of ethics. This will require the A.S.F. societies to tighten up their standard of practice and to develop a carefully planned and excuted policy of training, guidance, exposure, and supervision of prospective members. Our aim should be to quality and not quantity. Recruitment should be directed towards the genuinely interested individual rather than encouraging once only thrill seekers. The A.S.F. must continue to provide leadership for groups in formative stages and encourage them to join. Hence we should strive for a steady but stronger A.S.F. membership growth coupled with a much stronger society membership growth. An early step should be a change in the A.S.F. capitation policy to include all fee paying society members rather than just "full" members.

We believe that the A.S.F. must stop being exclusivist about membership and aim at involving every genuine and reasonably responsible group of cavers. The A.S.F. organisational arrangements must be capable of absorbing the growing and projected membership whilst fostering improvements in communications and co-operation. From the above must rise a strong sense of unity and direction to enable concise objectives and strategies to be formulated not only nationally but on a State basis also (Hamilton-Smith, 1978; Bunton, 1978).

CONCLUSION

The number of A.S.F. member societies is growing at about one every two years and on average each society maintains about 33 "full" members. A.S.F. membership is not keeping pace with the growth of cavers in the community either on a society or national basis. The A.S.F. must alter its membership policies to include the growing number of new societies under its wing, unless it wishes to lose any claim to represent speleology in Australia which it may now have. The A.S.F. needs also to improve its behavioural image with regard to its code of ethics and safety. The A.S.F. should consider adoption of a membership number for each individual in A.S.F. societies and should base its funding upon all fee paying members of member societies rather than on "full" members.

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APPENDIX A

COMPUTATIONS

U.S.A. DATA

The number of U.S.A. members follows the function

$$N = 10.99_e^{0.0828t}$$

where t is the number of years since 1900.

AUSTRALIAN DATA

Linear regressions computed on Log_eNvsT.

1969-78 period inclusive (least squares line of best fit).

$$N = 39.25_e^{0.037t} \quad \ldots . \text{ Equation 1}$$

with a correlation coefficient of +0.81.
Note: 1978 figures are inconclusive as not all members financial.

1969-77 period inclusive.

$$N = 13.7_e^{0.0518t} \quad \ldots . \text{ Equation 2}$$

with a correlation coefficient of +0.964 (very good).

Additional membership data from A.S.F. Newsletter sampling:
1961, N = 455; 1963, N = 400; 1964, N = 450.

1961-77, all data.

$$N = 47.55_e^{0.035t} \quad \ldots . \text{ Equation 3}$$

with a correlation coefficient of +0.93.

1961-78, most data.

$$N = 61.2_e^{0.031t} \quad \ldots . \text{ Equation 4}$$

with a correlation coefficient of +0.90.

CHANGES IN EDUCATION: SOME IMPLICATIONS FOR CAVE USAGE AND MANAGEMENT

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Abstract

This paper will highlight some significant changes in the direction and philosophy of education in Australia in recent years, notably the growth of recreation, environmental and outdoor education and of field studies in the school curriculum. The growth in caving activity and the demands this is likely to place on cave and karst resources will be examined. Possible matters of policy for A.S.F. and club administrations will be raised for discussion.

In other papers and discussion this week we have learnt of the growth of caving as a recreational activity in Australia. Some quantitative data has been presented and analysed, and predictions made which have great impact on our own activities and policies as individuals, clubs and the Federation.

What I would like to do now is to point out where some of this growth is occurring, try to explain why, and then raise some policy issues for the Federation, for individual clubs and for management authorities. I have chosen to concentrate on just one source of growth but the implications and policy issues raised are much the same. Let me start with some background.

Most of us here have probably been educated in a system, derived philosophically from English grammar and comprehensive schools with an overlay of American egalitarianism. You queued for a measured and pre-determined allotment of English, Mathematics, Science, Geography or whatever, studied the subjects for a prescribed period, passed the prescribed examinations, and perhaps proceeded to college or university to follow the same procedure for another three, four or five years. Competitive sport was important, at least for the talented few, but quite divorced from the academic curriculum.

In this system, physical education was something you did on Wednesday afternoon, bushwalking or camping was something you did with the Scouts and the environment was a trendy area which you and some like-minded friends dabbled with in your spare time, if you had ever heard of it, of course. Rock climbing, caving and trekking in Nepal were weekend or vacation pursuits for the unsociable or eccentric.

The one thing which all these pursuits had in common was that they were separate from "real" education. They were extra-curricular, extra-mural. So there was a limited range of academically oriented subjects, each studied with a single textbook, each separate from one another from the world outside.

Well, things have changed. What I want to do now is to draw your attention to what the economists and financiers would call the growth stocks in the

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education industry. The two most significant changes, and they are closely related, are the trend towards an integration of education, leisure and work, and a boom in what could loosely be termed education for personal development.

The practical effects of these trends have been a large increase in the variety of subjects offered in schools, a greatly increased range of materials used in learning, more and more work being done outside school walls and school time of a kind not traditionally regarded as school work, and a greater involvement of people other than teachers in the education of students

At this stage, instead of continuing to ramble incoherently as educational practitioners are liable to, I want to pause to paint a few vignettes. I am sure you will forgive me if many of them are from Canberra. Not only are these the ones with which I am most familiar, but for several reasons Canberra's school system is now probably the most progressive, flexible and innovative in Australia. Just how progressive, flexible and innovative you might be able to gather from the fact that one school - a government school in fact - offers, for credit, such delights as Body Massage and Sexual Awareness 1, 2, 3, 4, 5 and 6!

1. Many schools, in Canberra at least, offer courses or activities related to caving which carry credit for school certificates or even tertiary matriculation. For example, St Edmunds College offers Caving I, implying there is more to come. This course is registered with the A.C.T. Schools Authority and appears on students' school certificates.

Phillip and Dickson Colleges have karst geomorphology as a half term unit in their geography courses. Hawker College offers majors in Recreation and in Wilderness Activities, including canoeing, cross-country skiing and outdoor survival. All these courses are justified in terms of their potential for personal development, their effect on self-confidence, team cooperation and so on. It is instructive to note that in a recent schools cartography competition, the prize-winning entry was a map of Dog Leg Cave at Wee Jasper.

2. All state education systems operate field centres which combine studies of the environment, geography and science as well as recreational activities. For example, near Yallingup in this state, Fracture Cave, Solution Cave and Maxwell House Cave are used by school groups as part of a fieldwork programme. The Queensland Department of Education's Outdoor Education Centre at Boonah operates a highly successful wilderness experience programme which combines environmental education, camping and adventure in a wilderness setting.

3. Case studies of environmental issues and management conflicts involving cave and karst resources are creeping into the educational literature, especially in geography, social studies and politics as well as environmental studies. The Colong and Bungonia issues have been used not only as studies of environmental conflict but as examples of the workings of pressure groups, grass roots democracy and political decision-making, even of personal and organisational ethics. One of the best documented examples, of course, is that of Mt Etna and I know of at least two publications applying this issue as a case study in the context of geography and environmental studies.

4. Schools are becoming more involved in issues of social controversy and conflict, ethics and values. These know no subject discipline boundaries and are learnt, not from text-books but from diverse sources including field work and observation, guest speakers and case study materials. In this context, I suggest there is great scope for an enterprising Queensland speleo to develop a role play exercise based on Mt Etna, similar to one done

commercially on Western Port Bay in Victoria. I would be glad to assist in any such venture.

5. School expeditions are replacing traditional organised tours as major contributions to learning, and there is already an Australian Schools Expeditionary Society. Significant research and exploratory work has been carried out by British senior school students on the caves of Ireland, Iceland and north Norway. There is no reason to doubt that remote areas of Australia, Niugini and South-east Asia could receive the attention of similar expeditions.

PROGNOSIS

1. Clearly we can expect a continuation of the trends I have outlined. There is going to be a continued increase in usage of caves and karst regions, and much of this increase will come from a younger age group.

2. I question whether this need necessarily result in degradation either of the caves themselves or of the cave experience as a learning experience. For one thing, demand can be channelled by wise management classification into a relatively limited number of wild caves. For another, for most youngsters caving will be as ephemeral an interest as yo-yos, but the experience is much more likely to enrich their lives and create positive attitudes to conservation and sound management.

3. Remoteness or physical difficulty of access will not be a protection for caves, indeed it may act as an attraction. There is obviously a huge latent demand for adventure activities, wilderness experience and holidays in outlandish places, and caving has joined these. I doubt that I shall be the last speleo featured in the *A.S.F. Newsletter* 'contemplating the sink of the Harpan River Cave in Nepal.' To illustrate, there are now glossy brochures pushing commercial trekking expeditions to remote parts of Nepal, Kashmir, the Yemen Arab Republic, even diving expeditions to the Red Sea off Port Sudan. There are semi-commercially operated caving instruction courses in several places here and overseas, for example, the Whernside Centre in Yorkshire. Roy Skinner has written of his wilderness tours of Exit Cave. Who is to doubt the appeal of commercial tours to the Nullarbor Caves, or to the karst country of Niugini and South-east Asia?

4. I have a feeling that some of this increased demand stems from a lack of opportunity in younger days, and that to some extent the present boom in caving therefore represents a telescoping effect of current demand with deferred demand. If this is true, we may expect a slackening of the rate of growth in five to ten years.

A number of institutional factors operates to make the trends described likely to continue.

Education in Australia is becoming increasingly decentralised, meaning that the locus of decision-making about what students study and what is undertaken is decided by the school and not by a centralised bureaucracy. The curriculum is much broader, encompassing disciplines and experiences never previously considered part of the schools' responsibilities. It follows that if the demand and opportunity for caving activities arises in a school, there are few bureaucratic barriers to prevent it.

If as a group of speleologists we take our responsibilities seriously, we should be seeking to influence decision-makers in the educational sphere,

as well as in management authorities, in areas of concern to us. These decision-makers would include directors of outdoor education and field studies centres, principals' associations and individual school principals and/or school boards. Practical assistance could take the form of simplified codes of safety, ethics and conservation (I believe our present codes are too detailed for juniors), suggesting the need for minimum standards of leadership training, experience and maturity, and providing occasional guest speakers to schools. The public relations role should incorporate more case study materials suitable for school use in geography, environmental studies, politics and so on. Just a small example to illustrate. Earlier on I mentioned a field study course at Yallingup. One of the instructions reads 'Do not remove material from caves.' This is fine. But it goes on to say 'We can arrange for specimens to go back to your schools from "dead" caves'!!

DISCUSSION

[Following presentation of the paper, spirited discussion took place on the following propositions which do not necessarily reflect Federation policy.]

1. Without neglecting scientific and conservational aims, we must examine our policies and devote more of our energies and resources to the recreational, managerial and educational facets.

2. In turn, without neglecting to influence policy-makers in management authorities, we must pay more attention to serving the educational function, both in the public relations arena and in schools. This could be looked on as a policy of sound investment in the future.

3. We must encourage and support management initiatives towards classification of caves.

4. We must press the case for a "representative" rather than an "outstanding" approach to the determination of significance of cave and karst resources. This case is strengthened by recognition of the value of caves for educational experiences. In this connection, several recent papers on conservation and management of caves have completely omitted reference to their significance for educational experiences.

5. We must remove any perceptions of exclusivism which others may have about our membership and our policies, by involving a more representative range of cave users.

6. We must ask ourselves whether our policies on access to controlled areas should be based on purpose of the speleological visit rather than on organisational affiliation.