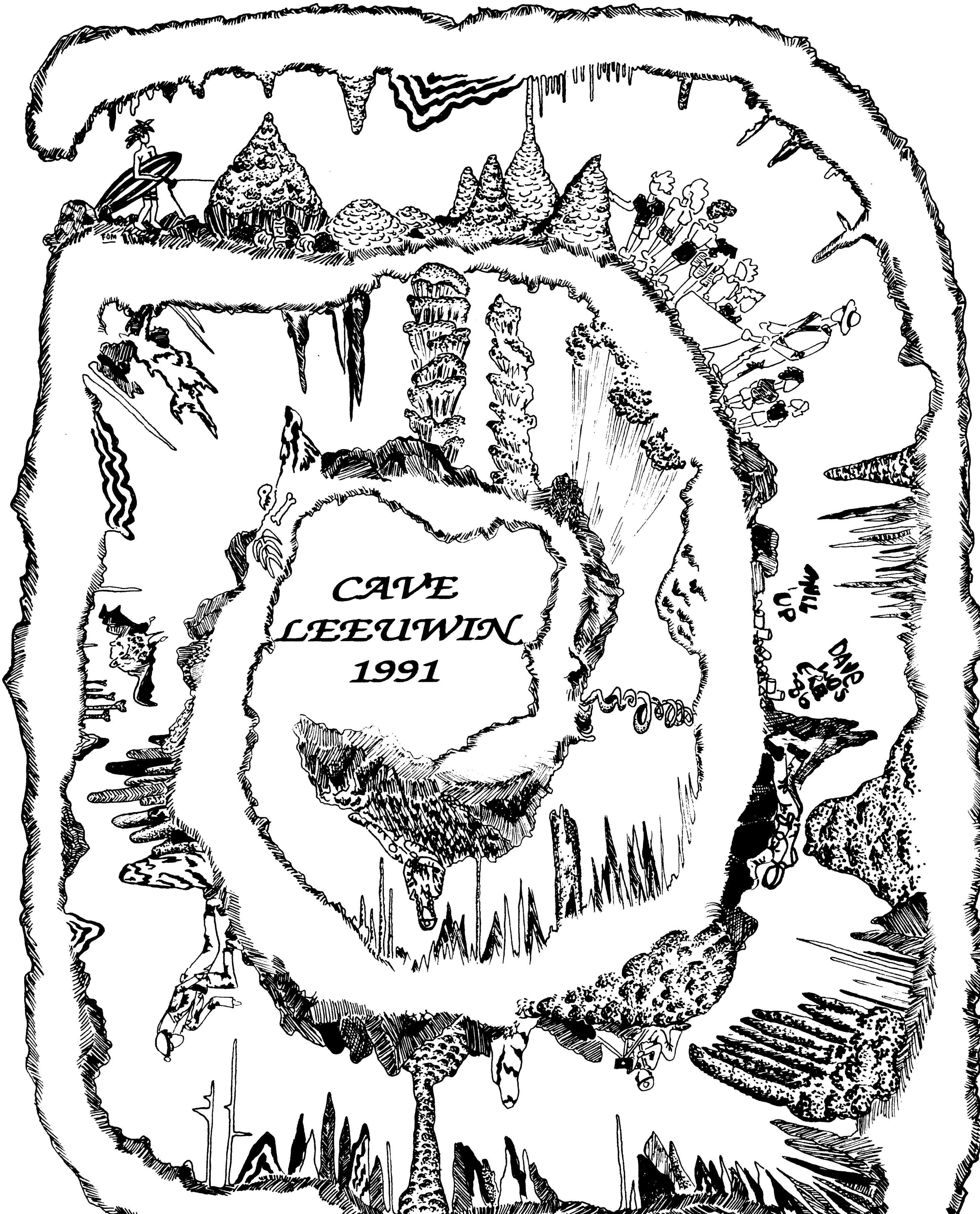

The Preceedings of the 18th Biennial Conference of the Australian Speleological Federation Inc.

AUSTRALIAN SPELEOLOGICAL FEDERATION INC.

Preceedings of the 18th Biennial Speleological Conference

Jointly hosted by:

Western Australian Speleological Group Inc

and

Speleological Research Group of Western Australia

30 December 1990 to 5 January 1991 at Margaret River, W.A.

Published by: Australian Speleological Federation Inc.

Editor: Steven Brooks
The Western Australian Speleological Group
P.O. Box 67, Nedlands.

FORWARD

Producing Preceedings (as opposed to proceedings) for the Biennial conference has become the done thing in recent years. Preceedings require a lot more coordination and organisation than proceedings. The advantage of preceedings is that they are available for the conference, which is not a bad thing for those attending the conference, but it does make things hard on the editors.

Help has been available, of course, in the guise of various other members of the W.A.S.G. Fran O'Meara who drew the cover, Peter Bell, who helped with the photographs (see below), Vanda Longman, who assisted y typing some of the papers, Rauleigh Webb (co-editor of the WACCON proceedings), Paul Drew, who supplied a laser printer for producing the final copy, and various others to numerous to mention individually.

With this calibre of help there was never any doubt that these preceedings would be finished and of the quality expected for the Conference.

The other major contribution to the success of the preceedings are the people who have presented papers for the conference. Without them these preceedings wouldn't exist. In fact, without them the conference wouldn't exist. These people are dedicated to the science and practice of speleology and should be encouraged by the rest of us, and they, in turn, will encourage us to expand our activities and dedication.

Steven Brooks - The Editor

CONTENTS

CHINA KARST TYPES

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ABSTRACT; The diverse karst landscape of China is the result of a number of different factors, forming the largest and most interesting karst areas in the world.

Although exposed carbonatite strata only cover an area of 910,000 Km over one third of China's territory has the distribution of carbonate on which various types of karst developed under the different conditions of geology, topography and climate (Figure 1.) China Karst is the most important and the most widely distributed karst in the world.

The development of China Karst is controlled and affected by the following factors.

1. The lithological character, the thickness and the stratigraphic combination types of carbonatite strata.
2. The geological structure and the feature of neotectonic movement.
3. Climatic conditions.
4. Terrain conditions.

The main types of karst developed in China are controlled by the above-mentioned factors respectively.

There is an obvious regularity of karst distribution from south to north in Eastern China.

(1) Fenglin karst, with a total distribution area of 200,000 Km is widely dispersed over the tropics and the subtropics south of latitude 27^{o} N. (See Area A of Figure 1.) The minimum annual precipitation of 1,000 mm and high temperatures are available for the chemical corrosion of karstification. Topographically constructed by the Peak Cluster - Depression Landform and the Peak Forest - Pain Landform, Fenglin Karst is in fact a sort of Holekarst. Caves are extensively developed, but particularly those modern underground rivers of large scale in the Peak Cluster - Depression Area. Further information about this field could be obtained from the paper of "Fenglin Karst in China".

(2) Karst Low - Hills mainly distributed on the Second - Step Topographic Staircase of China which is located between 27^{o} and 35^{o} of north latitude and on the eastern coastland of North China, namely, the bankland of the Three - Gorges Segment of the Yangtse River, the Qinling Mt., the south edge of the Taihangshan Mt., the Shandong Peninsula and the Liaodong Peninsula. (Area B, Figure 1.) Developed under the climatic conditions of 600 - 1,000 mm annual rainfall and 10^{o} C mean annual temperature, Karst Low - Hills are topographically characterised by the following surfacial karst landforms: gentle low - hills, dolines, dry valleys and stone - teeth. Caves and subterranean streams in Area B are much less than those in the Fenglin Karst area but are still the dominant landscape of underground karst.

(3) Normal Karst Terrains, developed in Area C on Figure 1, are chiefly distributed in the Nuliangshan Mt. Area and the north part of the Taihangshan Mt. of Shanxi Prov. and in the Erduosi District. The karst regions in Area C, with the annual precipitation of less than 500 mm are characterised by the development of normal surface water systems and by the shortage of closed negative relief such as doline and depression. Shallow karrens usually developed instead of stoneteeth on the surface of carbonate rocks. To the formation of the aforementioned changes of karst landscape from south to north in Eastern China, it seems that the variation of climate is much more important than the lithologic factor. For example, Ordovician limestone exposed in Shanxi and Devonian limestone exposed in Guilin are all pure and thick - bedded and have little difference in lithography but have great difference in geomorphologic display - the former displays normal karst terrains and the latter displays Fenglin Karst Landforms. The preliminary conclusion we draw from this point is that, karst landscape is chiefly affected by climatic factor on condition that there is no change in lithology. Surely the great change in morphology among karst landforms developed under the same climatic condition (As we see in the Fenglin Karst Area near Guilin) are due chiefly to the difference in lithology.

When there are thick - bedded interbed or interlayer of carbonatite existed in noncarbonate rocks, independent karst units of anticline, syncline and flaut block may be formed by the folding and developed further into "Tectonic Karst". Tectonic karst is the dominant landscape in the south-bank area of the Three - Gorge Section of the Yangtse River on the east edge of Sichuan Basin and the linear-fold region which is situated within the Sichuan Basin. (Area D, Figure 1.)

The south-bank area of the Three - Gorge Section consists of the western Hubei, the western Hunan and a small piece of the eastern Sichuan. With the interlayers of thick sandshale of Silurian & Devonian, the main carbonatite strata of Cambrian, Permian and Triassic usually formed independent anticlinal karst systems or

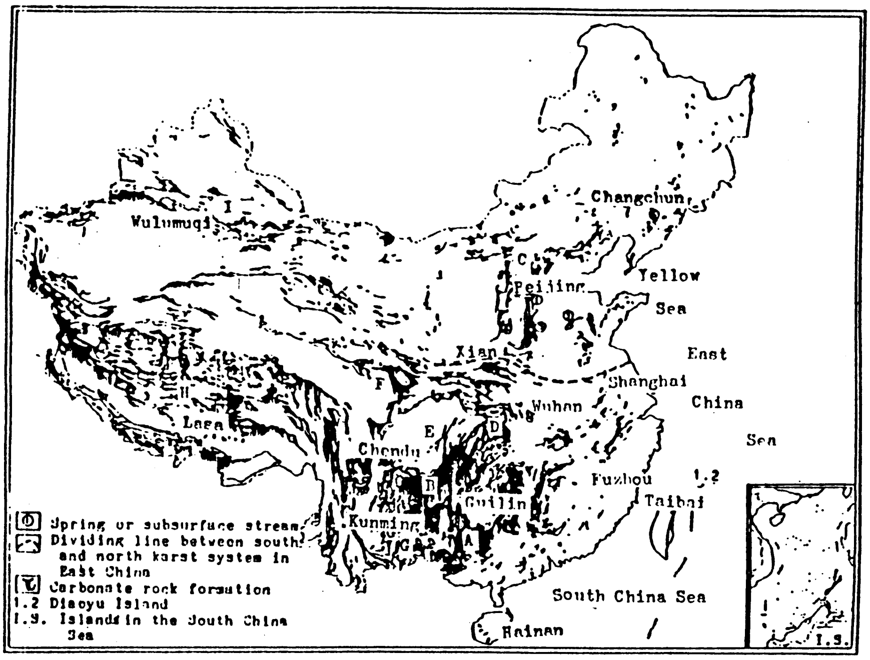

Fig.1 The map showing distribution of carbonate rocks and karst types in China

A--Fenglin Karst(Guilin-Type)

B—Remnant hill with shallow depression Karst(North Guizhou Plateau-Type)

C--Normal landform Karst(Shanxi-Type) D—Tectonic Karst(SanXia-Type)

E--Trough Karst(East Sichuan-Type)

F--High mountain-deep valley karst (Mianshan-Type)

G—Faulted basin Karst(Yunnan-Type)

H--High mountain Karst(Qing-Zang plateau-Type)

I--Arid Karst(East Tianshan-Type)

synclinal karst systems in the area under the structural control of anticline or syncline. (Figure 2.) Karst low - hills and dolines are the main surfacial karst landforms, and sinkholes extensively developed at the bottom of the dolines. Polje sometimes formed in the karst area with anticlinal structure, while karst synclinal mountains formed under the conditions of synclinal structure. The most attractive "Tectonic Karst" is formed in the fold zone which is situated on the east limb of the Sichuan Basin. The anticlines of the area totalled over 40 and each anticline is about 5 - 8 km in width and 40 - 250 km in length. (Figure 3 and Figure 1,E) Stratigraphically the anticlinal limbs are constituted by sand stones of the Upper Triassic with the dip angle changing from 20^{o} - 80^{o}, while the anticlinal axes are taken up by limestones of the Lower Triassic and thus formed karst trough eventually in process of karstification. Topographically the karst trough is constituted by low hills and depressions. There are many sinkholes and deep shafts developed at the bottom of the depression. (Figure 4.) Under some other circumstances polje may develop instead of karst trough. When the drainage system of a polje gets clogged or is not able to drain away the water efficiently, polje will fill with water and form a "Heavenly Lake" such as Qingmuguan Heavenly Lake near Chongqing City and Guangan Heavenly Lake in Huayinshan Mt.

Tectonic Karst developed in Eastern Sichuan also has two important phenomena in hydrogeology and speleology: the emergence of thermal springs and salt springs and the development of longitudinal phreatic caves. The thermal spring is in fact sulphate spring with the water temperature of $35^{o}C$ - $47^{o}C$ and the total dissolved solids of 2 - 2.9 g/l, and the salt spring is sodium-chloride spring with the water temperature of lower than $35^{o}C$ and the total dissolved of 4 - 43 g/l.

Under the structural condition of rake anticline, the longitudinal phreatic caves could form and develop along the buried anticlinal axis - Haidigoudong cave developed in the Longwangdong Anticline Area is the typical example. (Figure 5.) The cave was discovered by a coal mining tunnel on August 27, 1966. The discharge of the cave was 90,000 Cubic Mtrs/Hr at the beginning then declined to 3,400 Cubic Mtrs/Hr after 72 days, and the total discharge of the cave during this period was 16,800,000 Cubic Metres. The recharge source of the cave is in the Hauyinshan Multiple - Fold Area of 20 Km away, and the water quality of the cave is calcium sulfate-type (the content of sulphate ion was 700 - 900 mg/l, the total dissolved solid was 1.1 - 1.3 g/l, the total hardness was 43 - 53 German deg. and the water temperature was 19°C.) With the discharge of the cave water, the previous surfacial springs in the area disappeared gradually and the underground collapse happened.

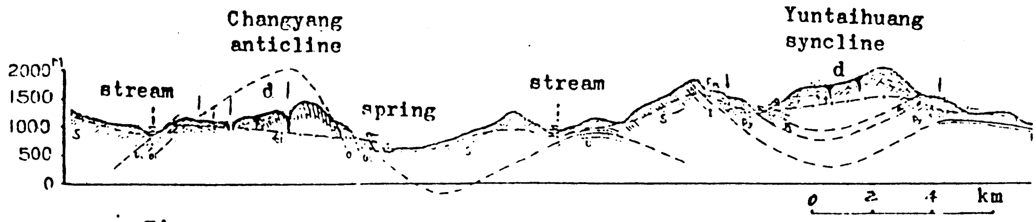

Fig. 2 tectonic control of karst in west Hubei

limestone shale sandstone

Є--Cambrian O--Odovician S--Silurian D--Devonian

P--Permian d--depression and sinkhol

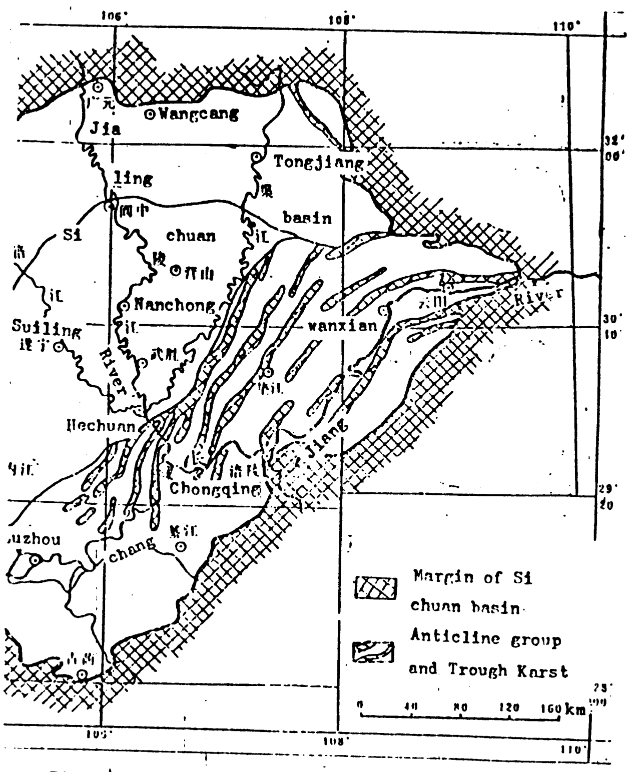

Fig. 3 The anticline group and the Trough Karst (along anticlinal axis) in East Sichuan

The vertical variation of karst landscapes in the same area is evidently affected by the terrain conditions and the most typical example is the "Mianshan Mt. - Type Karst" which is situated on the western edge of the Sichuan Basin. (Area F, Figure 1.) The Mianshan Mt. - Type Karst is constituted by two different subsystems in vertical section: the upper zone of mountain paramos karst and the lower zone of gorge temperate karst. The boundary line of the two subsystems is about 3,700 - 4,000 metres above sea level.

The mountain paramos karst subsystem, developed under the climatic conditions of 800 mm - annual precipitation and 1.0°C - annual temperature in the area whose elevation is higher than 3,700 - 4,000 metres can by subdivided by the altitude of 4,800 metres into two parts: the upper zone and the lower zone. The upper zone is covered by ice & snow all the year round and by the desert vegetation, and is mainly recharged by the summer meltwater. The lower zone is meadow-grass land where the karst landforms formed by corrosional action is not prominent because of the intense physical weathering and the gravitational collapse. There are lots of tooth-peaks, residual stone columns and natural bridges formed by weathering agent in the lower zone. According to the determination, the precipitate water of the lower zone has very strong solvent power of carbonatite. (SIc = -1.61, SId = -3.61,log(pco_2) = -4.21.) Karstic springs of the lower zone has a higher value of the total dissolved solids (0.3 - 0.78g/l) and the temporary hardness (21 - 36.4 German deg) than the karst springs of Northern China because of the severe karstification.

The gorge temperate karst subsystem and the forest zone have the same upper limit. With the mean annual temperature of 3 - 7.3°C and the yearly rainfall of 600 - 800mm, the biology of the gorge temperate karst zone is prosperous and biokarstification exists anywhere at any time. Numbers of karst springs and the relevant tufa deposits on the zone are the most marvellous natural landscapes.

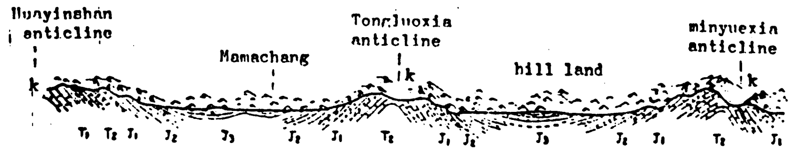

Fig. 4 Topographic and geological profile between anticlines Huayinshan and Minyuexia

k—Trough karst J—Jurassic T—Triassic

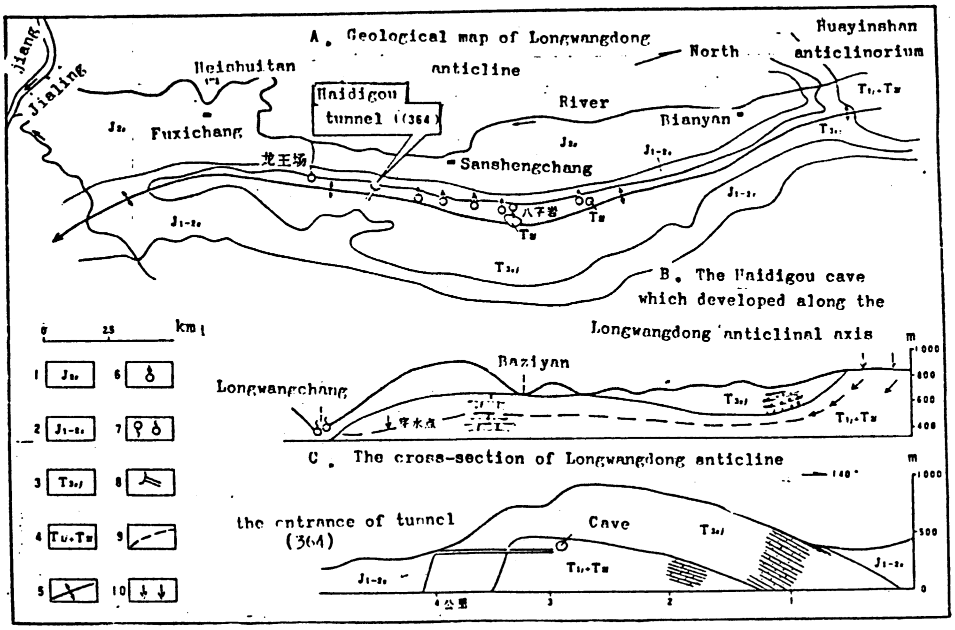

Fig.5 The Haidigou cave which developed along the Longwangdong anticlinal axis

1,2—Jurassic sandstone 3—Triassic sandstone 4—Triassic limestone

5—Anticlinal axis 6— Flowing well 7— Spring 8— Tunnel 9—Caves

10—Water flowing deraction

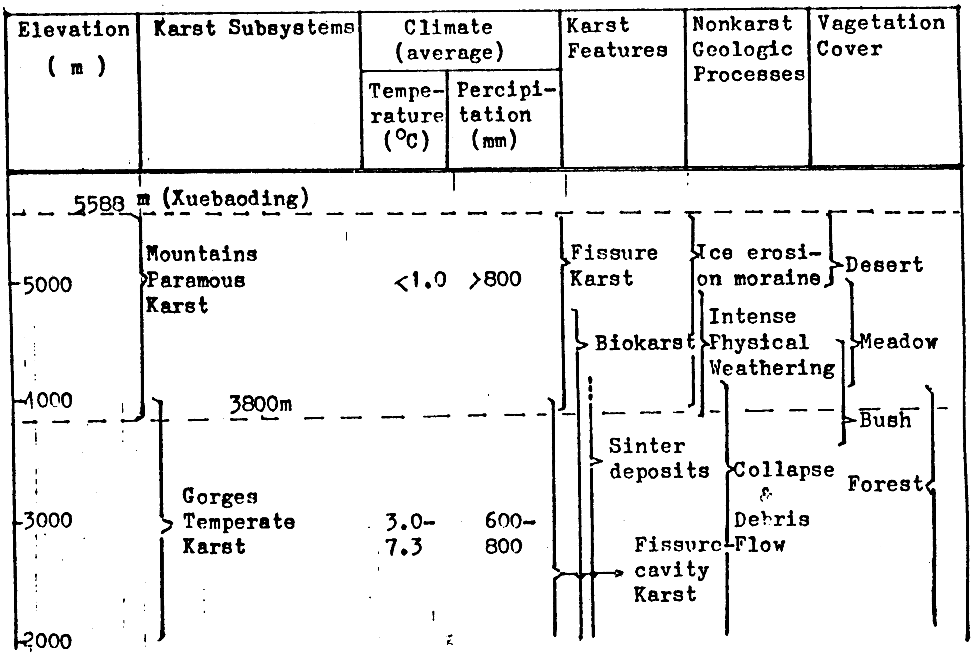

Fig. 6 The basic features of Mianshan Karst systems

REFERENCES

1) Li Datong 1985. Explanation of the Map of Soluble Rock Types in China. Cartographic Publishing House pp38.
2) Zhu Xuewen 1988. Guilin Karst. Shanghai Scientific and Technical Publishers pp188.
3) 朱学稳 1981 川东岩溶及岩溶水特征 四川人民出版社
4) Zhu Xuewen 1989. The Mianshan - Type Karst in West China. Proceedings-Communications of the 10th International Congress of Speleology 1-pp 304-305.

BIOLOGICAL RESEARCH INTO THE CAPE RANGE KARST AREA,

NORTH WEST CAPE PENINSULA, WESTERN AUSTRALIA.

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Abstract; Over the last three years the Cape Range karst area has emerged as one of the more significant troglobitic areas in Australia. A brief history of speleological research in the area is given together with the geographical setting. A synopsis of the fauna is presented as epitomised by C-118. The geographical range of two of the most abundant troglobitic species, a schizomid and a millipede, was increased from 7 to 10 fold between 1988 and 1989 and are now known from 35 and 52 caves respectively. Speciation between the caves appears to be limited but clear genetical discontinuities occur associated with deep gorges. Some detail is presented about the cave environments especially pertaining to the energy source and the association of the fauna with high humidity caves and soil moisture. The caves vary widely in temperature (11^{o}K) and this has profound implications to the drying cycles of the caves. Many caves are dry and/or have high levels of carbon dioxide.

Historical background

Speleological work in Cape Range can be conveniently divided into a number of periods. An Ad Hoc Period (1962 to 1980) when caves were found but often inadequately described or located, the Vine Period (1980 to 1986) when systematic recording of caves commenced, the East Period (1986 -) when intensive exploration began with a number of well equipped and organised workers and the Research Period (1987-), when scientific research started in earnest.

Early expeditions by the Western Australian Museum (1965) and the Western Australian Speleological Group (1968) recorded caves but they were poorly located and not tagged; this is true of many of the early caves. In 1980 Brian Vine, then resident in Exmouth, started to conduct cave exploration in the area, mostly alone, and systematically worked through the old records, authenticated the early records and tagged the caves, in addition he found many new caves in the area and by the time he left Exmouth the index was up to C-119.

Malcolm East inherited the knowledge from Brian Vine in 1986, recruited and trained a number of other local residents, especially Ray Wood and Tom Tomlinson, and set about a major expansion of the knowledge of the caves in Cape Range. By mid-1988 the cave numbers reached C-186.

At this stage two major expeditions undertook a scientific study of the troglobites in the caves. In 1988 funding from the Australian National Parks and Wildlife Service to Bill Humphreys of the Western Australian Museum, permitted Brian Vine and Darren Brooks to spend two months in Cape Range, helping the scientific work and conducting further exploration. By the end of this trip the cave numbers had reached C-210.

In 1989 further funding to Bill Humphreys from the Western Australian Heritage Committee permitted Darren Brooks, Malcolm East, Brian Vine and Ray Wood to spend three months in Cape Range, again helping the scientific work and conducting further exploration. By the end of this trip the cave numbers had reached C-362. As of April 1990 the karst index for Cape Range, Western Australia, included 282 caves, 60 karst features and 11 wells.

During the years a number of publications have dealt with aspects of the cave fauna of the North West Cape peninsula and many more are in preparation (Holthuis 1960; Humphreys 1989, in press a; Humphreys, Adams & Vine 1989; Humphreys, Brooks & Vine 1990; Humphreys & Collis in press; Mees 1962; Knott 1985; Vine, Knott & Humphreys 1988; Whitley 1945).

Regional location and geomorphology.

Cape Range forms the 300 m high spine of North West Cape of Western Australia (Fig. 1) and lies just within the tropics (22^{o} S) in a semi-arid climate. The range is an anticline formed in marine limestones of Miocene age. The caves are formed in Tulki Limestone which overlays Mandu Calcarenite and is overlain by Trealla Limestone (details in Vine, Knott & Humphreys 1988, Humphreys, Adams & Vine 1989).

Cook (1962) believed that caves extending to sea level (300 m deep) could occur on Cape Range, with solution pipes in the hard Tulki Limestone connecting below to caverns in the friable Mandu Calcarenite, none has yet been found. The change with depth in many caves from vertical solution pipes to horizontal development has been interpreted as reflecting this transition (Kendrick & Porter 1973) epitomised by C-163 (Wanderer's Delight), the only cave with considerable lateral extent (*ca* 4 km of passages to date). However, a fossil found there is *Echinolampas westralensis* (Echinoidea: Echinolampadidae) which occurs only in Tulki Limestone. It is a good marker species as different species occur in the Mandu Calcarenite below and the Trealla Limestone above (K. J. McNamara; pers. comm. 1989). Hence it seems that all of the known deep caves are in the Tulki Limestone and do not extend into the Mandu Calcarenite beneath. Similarly some caves which open into a surface geology of Trealla Limestone are, according to the fossils, developed in the Tulki Limestone below (e.g. C-203 and C-246).

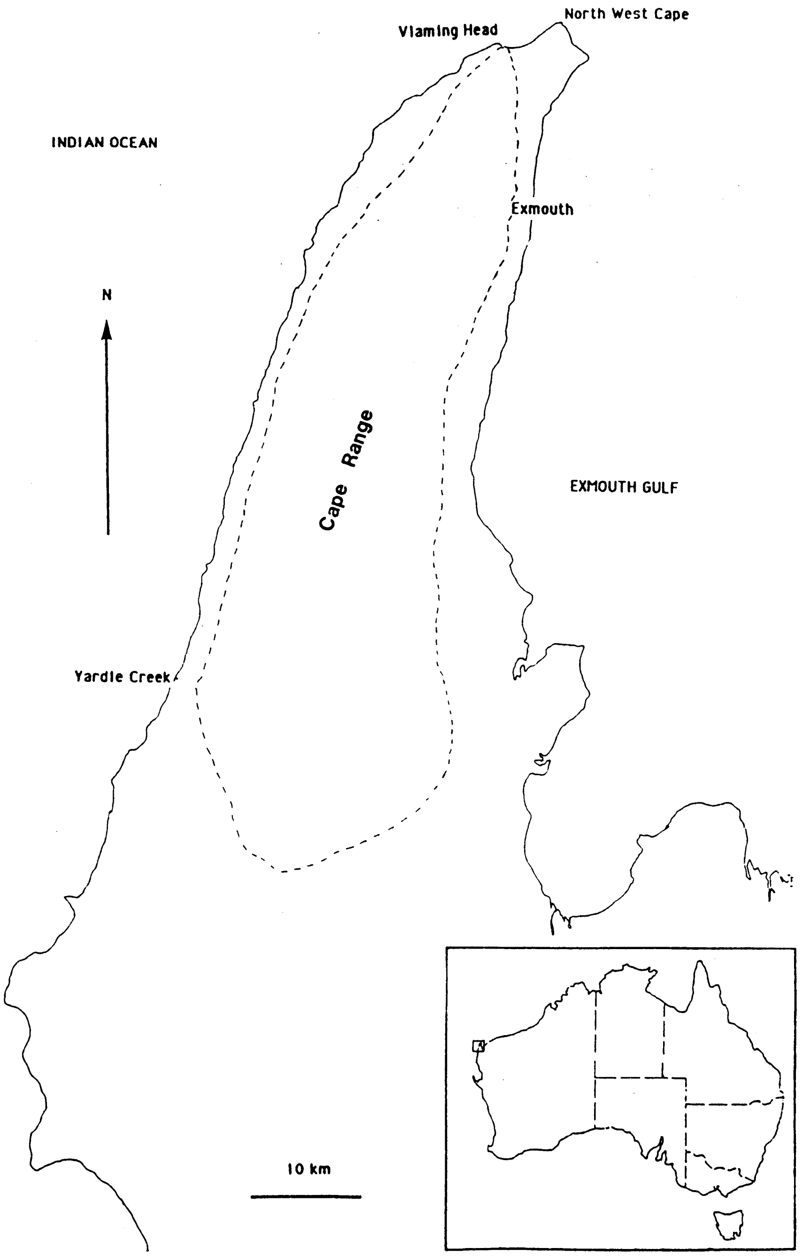

Figure 1: Regional location of Cape Range on North West Cape, Western Australia and the main geomorphological features.

Definitions

The fauna found in caves is traditionally divided amongst:- accidentals (species entering caves by chance); trogloxenes (sporadic cave dwelling species e.g. bats); troglophiles (facultative cave dwelling species, often divided into first level troglophiles, found both in cave and epigean habitats, and second level troglophiles which are found only in caves) and troglobites (obligate cave dwellings species usually with significant eye and pigment reduction and which are of considerable evolutionary interest; Hamilton-Smith 1967; Culver 1982). Various other terms and categories are used by different workers (e.g. Vandel 1965).

The categories are based on the level of dependence on the cave system (Hamilton-Smith 1971) deduced from their distribution within and without caves and the degree of morphological adaptation presumed to be adaptive to cave life. Second level troglophiles may turn out to have clear adaptations to caves in non-morphological characters, e.g. physiological (Barr 1963) or reproductive effort (H. Dalens; Pers. comm. 1989).

As these are, in essence, functional definitions the classification requires assumptions about the nature of the adaptation or detailed knowledge of the species biology for allocation between these categories to be made. As this knowledge is unavailable for the vast majority of Australian cave faunae, especially the newly worked Cape Range area, in this report species are termed troglobites only if the systematist involved considers them to be so or they are eyeless or lack pigment (in taxa normally possessing these characters). Other species are simply recorded as having been found in caves and, through lack of information on their biology and of the epigean community, are not categorised.

Cave fauna

Despite the long standing conviction that troglobites were rare both in Australia (Moore 1964; Hamilton-Smith 1967; Barr 1973) and in tropical caves in general (Vandel 1965; Barr 1968, 1973; Mitchell 1970; Sbordoni 1982), rich troglobitic faunae have been found in many tropical areas (Leleup 1968; Howarth 1983), including both wet tropical (Chillagoe in Queensland; Howarth 1988) and semi-arid tropical (Cape Range) Australia (Vine, Knott & Humphreys 1988; Humphreys 1989, in press; Humphreys, Adams & Vine 1989).

The troglobitic fauna of the North West Cape peninsula of Western Australia was initially mentioned in the context of a subterranean freshwater fauna of the coastal plain (Whitley 1945) and later by Cawthorn (1953). Since then the known range of the fauna has expanded considerably but the species composition has remained unchanged. In addition, a rich troglobite fauna has been found within Cape Range, which forms the spine of the peninsula (Vine *et al*., 1988; Humphreys, 1989, in press a; Humphreys *et al*., 1989). The faunae have no taxa in common at the level of Order.

The coastal plain fringing Cape Range which contains a unique subterranean fauna, comprising two species each of fish and of atyid shrimps. These are the Blind or Cave Gudgeon, *Milyeringa veritas* Whitley (Perciformes: Eleotridae) described from Milyering Well (cave number C-24). It is classified as rare and total protection has been recommended (Michaelis 1985). The Blind Cave Eel, *Anommatophasma candidum* (Mees) (Synbranchiformes: Synbranchidae) described from Tantabiddi Well (C-26). It is classified as vulnerable (Michaelis 1985). The Atydid shrimps *Stygiocaris lancifera* Holthuis and of *S. stylifera* Holthuis (Decapoda: Natantia) were both described from Kudumurra Well (C-25).

The only other aquatic taxa on the peninsula are Amphipoda of marine origin and part of the *Victoriopisa-Eriopisa* complex (Gammaridae; Knott 1985). They occur in each of the four caves known to contain standing water within Cape Range itself, viz. C-18, C-64, C-103 and C-163 (Humphreys 1989, in press; Humphreys, Adams & Vine 1989).

The caves in Cape Range contain a rich, mostly undescribed, troglobitic fauna, in the main representing a relict of a tropical rainforest litter fauna (Humphreys, Adams & Vine 1989; Humphreys 1989, in press), now separated by the Great Sandy Desert and more than 1000 km from the closest possible source area. Much is endemic at the generic level. In addition there are many non-troglobitic species whose association with the caves is unknown due to lack of information on the surface fauna; however, many would probably be unable to survive the present surface climate. This cave fauna has a wide distribution in Cape Range and occurs wherever the Tulki Limestone, in which the caves develop, outcrops.

The fauna includes few as yet described species but the richness of the fauna is evidenced by the known inhabitants of one of the smaller caves. C-118 is small and shallow (23 m; illustrated in Humphreys, Adams & Vine 1989) and is not itself particularly species rich fauna. It includes *Schizomus vinei* Harvey (Chelicerata: Schizomida). A new genus of highly adapted troglobitic millipedes (Diplopoda: Craspedosomida: Paradoxosomatidae). Earthworms (Annelida: Lumbricidae). Mollusca:- n. gen. (Camaeinidae: Sinumeloninae); *Strepsitaurus rugus* (Cotton 1953) (Camaeinidae: Sinumeloninae); *Quistrachia* n. sp. (Pleurodontidae). Crustacea:- *Buddelundia* n. sp. 1 (Isopoda: Armadillidae), not cave adapted; Philosciidae n. sp. A (Isopoda: Philosciidae), troglobite and several other undescribed species and genera. Chilopoda:- *Allothereuea leseurii* (Scutigeromorpha), not cave adapted. Chelicerata:- n. gen. (Araneae: Desidae), depigmented; n. gen. near *Janusia* (Araneae: Ctenidae), troglobite; *Nesticella* n. sp. (Araneae: Nesticidae), depigmented; *Pholcus* sp. (Araneae: Pholcidae), some pigment loss. Collembola:- *Lepidosira* sp. (Entomobryidae). Blattodea:- *Nocticola*

n. sp., highly cave adapted troglobite. Orthoptera:- Nemobiinae: unknown cricket. Hemiptera:- Reduviinae sp. (Heteroptera: Reduviidae); *Stenolemoides* sp. (Emersinae). Coleoptera:- *Clivina* sp. (Carabidae: Clivinini); *Myllocerus* n. sp. (Curculionidae: Polydrosinae); *Mecyclothorax* sp. (Carabidae: Psydritae).

An indication of the early stage of the research in Cape Range can be gained from the fact that between 1988 to 1989 the geographic range extension for the paradoxosomatid millipedes was 7.7 times and for *S. vinei* was 10.6 times and they are now known from 52 and 35 caves respectively.

There are major genetic discontinuities in the fauna associated with the deep gorges which cut through the Tulki Limestone in which the caves have formed, into the Mandu Calcarenite below. Of the species examined in Cape Range the only non-troglobite, an isopod, is panmictic throughout the area, that it interbreeds freely throughout the geographic range examined. The three non- troglobitic species show area of interbreeding separated by geological discontinuities from other areas in which interbreeding occurs. These include the amphipod, the only aquatic species, *S. vinei* and the paradoxosomatid millipedes. While the former two species are considered to represent isolated populations of the same species (Humphreys & Adams, in press), the millipedes show clear genetic and morphological separation and speciation clearly has occurred since isolation.

There is genetical and circumstantial evidence that neighbouring caves, most of which are probably entrance less (Curl 1966), are linked at a level below which cavers can reach (Humphreys 1989, in press). At these levels, relatively devoid of energy, there must occur low populations of the cave animals. When caves are wetted and re-energised by the influx of organic matter, these population move upwards into the newly inhabitable areas and breed (*ibid.*). Until the next influx of water the caves slowly dry and the populations retract and then leave entirely those parts of the cave accessible to cavers.

In Cape Range, long unflooded caves contain troglobites with old age populations (Humphreys, Adams & Vine 1989; Humphreys 1989, in press) which start to breed after flooding and to more widely occupy the cave (*ibid.*). Flooding both wets a cave and deposits organic matter within the cave. In Cape Range the troglobitic fauna is associated with both the organic carbon and water contents of the mud-banks within the caves (Humphreys, Adams & Vine 1989). However, it is not clear whether the reactivation of the fauna results from increases in partial pressure of water in the air, from increased soil water, from increase organic matter or from changes in the structural complexity of the substrate.

The cave environments

Cave faunae are generally considered dependent upon allochthonous organic matter carried into caves by streams, surface run-off or by animals, mainly bats (Harris 1970, 1973) and crickets (Norton, Kane & Poulson 1975; Kane, Norton & Poulson 1975; Kane & Poulson 1976).

The caves of Cape Range are mostly dry and have neither substantial cave cricket populations (of great significance in many North American caves :- Norton, Kane & Poulson 1975; Kane, Norton & Poulson 1975; Kane & Poulson 1976), nor bats to import energy into the caves to support troglobitic populations. As such they are dependent for their energy primarily by the influx of organic matter washed into the cave by intermittent run-off associated with heavy rain.

Cape Range is classified as semi-arid but it is situated in that area of Australia with the least predictable rainfall; both the constancy and contingency (*sensu* Colwell 1974) of the rainfall is low and the probability is low of single rainfalls sufficient to flood deeply caves (see full discussion in Humphreys, Adams & Vine 1989).

Whether a cave floods after a given rainfall depends on the size and nature of its catchment. Some caves flood after little rain (e.g. C-162), while others flood rarely and may not flood for several years and only after >150 mm of rain (e.g. C-118); 25 mm of rain should result in minor inflows into some caves on average every 5.4 months and deep flooding every 56 months (Humphreys, Adams & Vine 1989).

Caves also dry at varying rates according to the characteristics of the cave. Caves with wide openings and/or small size dry rapidly (e.g. C-162), while those with large size and/or narrow openings dry slowly (e.g. C-118). The populations of troglobites are dependent on the influx of organic matter and on the cave humidity and soil water. Hence the presence of fauna in the accessible parts of the caves is a dynamic balance between the probability of inflow into the cave (weather dependent:- low predictability in Cape Range) and the rate of drying of that cave (predictable:- dependent on the physical characteristics of the cave). Hence the caves in Cape Range contain a complex series of troglobite populations expanding and contracting at different rates and on different time scales. The system is quite unlike the classic stable and/or predictable models of caves systems normally encountered in the literature.

In addition the populations of some of the troglobitic species are large. While on the Nullarbor populations are measured in weeks searching per specimen, in Cape Range populations can be measured in number of individuals per hour. In the small caves C-162 and C-118, detailed population work has indicated the presence of thousands of individuals of the species examined (Humphreys, Adams & Vine 1989; Humphreys 1989).

The limited genetic evidence to date suggests that, unlike Chillagoe, there has been little speciation within the karst area, that local caves are connected in areas inaccessible to cavers and that the karst area is separated into genetically distinct population the boundaries of which are related to major geomorphological features. In addition the genetic and geomorphological evidence (bisection of caves by gorges) suggest that the caves were formed and occupied by the troglobites before the major present day landform features (gorges) were formed.

The typical troglobitic fauna (*S. vinei* and millipedes) occurs in about 20% of the 282 caves currently known from Cape Range. The caves containing troglobitic fauna have higher relative humidities (Gadj = 79.47 with 1 d.f; $P < 0.001$) than those without the fauna, have more water in the mud (Gadj = 18.15 with 1 d.f; $P < 0.001$), but do not differ in temperature (Fig. 2: Gadj = 1.22 with 1 d.f; $P = 0.269$). The troglobitic fauna occurs over the entire and very wide temperature range (11°K) found in the caves of Cape Range. However, they are restricted to areas of soil water >12% (Fig. 2) and relative humidity >80% (Fig. 2). Above 80% R.H. there is a strong positive correlation between R.H. and the proportion of caves containing troglobitic fauna ($r=0.981$; $P<0.05$), such that between 95-100% R.H. all caves contain troglobites (Fig. 2).

Caves temperatures generally are close to the mean annual surface temperature (MAST), which at Learmonth is 27.3°C. However, the temperature in winter of different caves is between 17 and 28°C (Fig. 2). Only three of the caves recorded have temperatures within 2°K of MAST (C-159, C-167 and C-169) and the remainder group into warm caves (C-103, C-96, C-64, C-118, C-157 and C-207) ranging between 23.0°C (C-103) and 24.7°C (C-207) and cool caves (C-107, C-18, C-106, C-126, C-163 and C-162) with temperatures between 18.1°C (C-107) and 21.5°C (C-162).

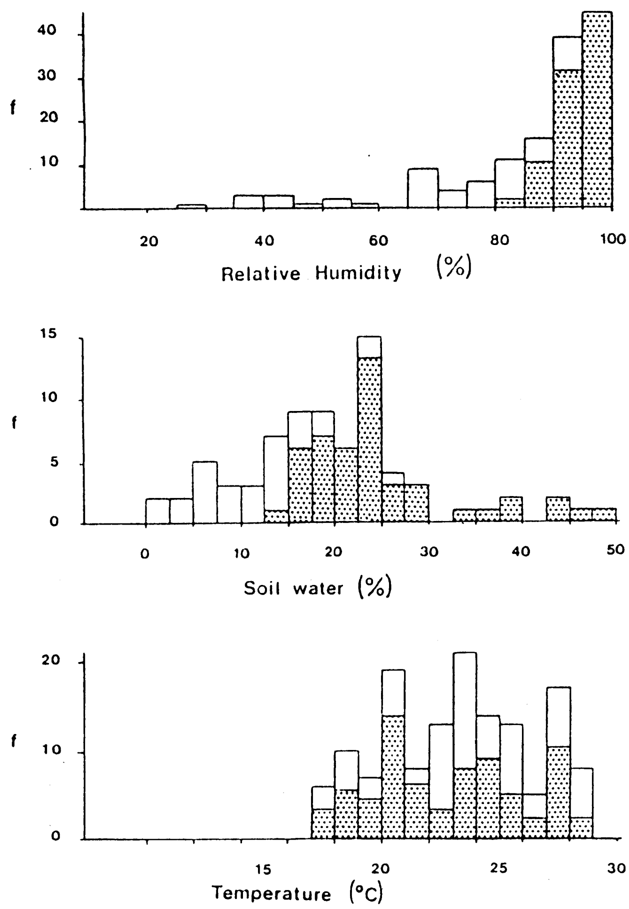

Figure 2: Distribution of relative humidity (upper), soil water content (middle) and dry bulb temperature (lower) in the caves of Cape Range. Shaded area denote the occurrence of troglobites. For relative humidity and temperature (°C) n =141. For soil water (% dry weight) the values are the mean of from two to five samples (299 samples); mean sample number = 3.93, s.d. = 0.98; N=76.

In Cape Range there is no clear reason why cave temperatures differ; caves with similar characteristics vary widely in temperature:- deep, open caves with long leads (C-18, C-207, C-106 and C-163) vary from 18.4°C (C-18) to 24.7°C (C-207); while deep caves with tight entrances cover the range 20.3°C (C-126) to 25.7°C (C-159). The two caves with considerable lateral extension range from 20.7°C (C-163) to 23.3°C (C-64). Conversely the shallow caves often have temperatures clearly related to the relative size of the opening; wide open caves vary in temperature with outside air temperature (C-162 - 21.5°C), while those with tight entrances are closer to MAST (C-118 - 24.5°C). Geographical location also seems unimportant as caves C-167 and C-163 are only 0.9 km apart but differ in temperature by 6.9 °K.

Examining the two caves (C-118 and C-162) in which the population work was conducted shows that the range of temperatures and humidities in C-162, as expected from its low volume to entrance size ratio (VESR), was much greater in C-162 (see plan in Fig. 2) than in C-118 (Table 1) which has a high VESR. The greater range at the back of C-118 is due to this location being a blind collapse close to the surface (survey point 15 Fig. 1 of Humphreys, Adams & Vine 1989); it is an area of dry soil devoid of fauna.

The range of relative humidity is much greater than previously appreciated (Humphreys, Adams & Vine 1989) in the more open caves due to the minima occurring in the early morning (Fig. 3). The humidities are sufficiently low at night to restrict the movement of the cave fauna and one would expect, therefore, to find diurnal changes in the activity patterns of the fauna. It also means that the animals would most likely be driven deeper into the cave at night, rather than potentially moving to the humid surface; this would further restrict the possibility of above ground dispersion (see discussion in Humphreys, Adams & Vine 1989).

Water vapour movement into and from caves.

While temperature *per se* is unimportant to the distribution of the troglobites in Cape Range (Fig. 3), temperature indirectly can have a major influence on the water vapour pressure in the caves and hence the rate of drying of caves.

The net movement of water between caves and the outside is determined by the gradient in partial pressure of water vapour (Edney 1977). Cape Range is just within the world climatic area in which the average daily range in temperature exceeds the average monthly range (Petterssen 1958). Hence in Cape Range, as in many tropical areas (Howarth 1980), the night time temperatures often fall below the cave temperatures; this results in a net movement of water vapour out of the cave at night (tropical caves containing troglobites usually have R.H. close

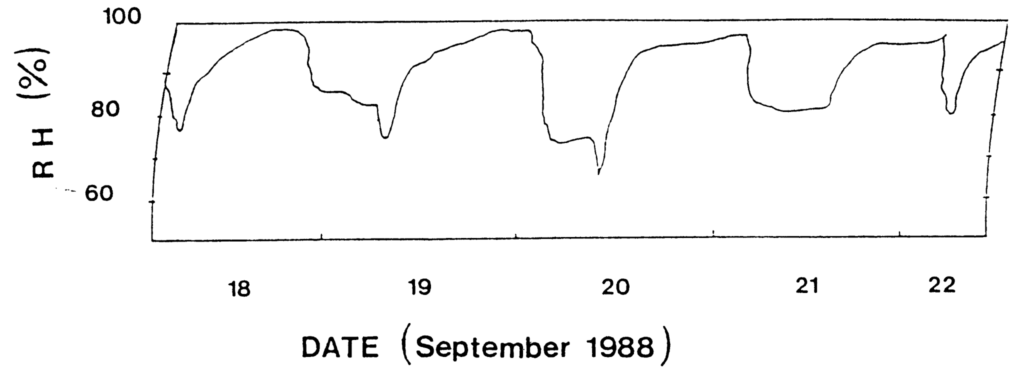

Figure 3: Tracing of the chart from the front thermohydrograph in C-162 for the period 16-20 September 1988. This was the period of most extreme and diurnally synchronised changes in relative humidity. The maximum diurnal change in temperature at this location was ca 3°K.

to 100%). This has been termed the 'tropical winter effect' (Howarth 1980, 1983) by analogy with the excessive drying of caves in colder climates in winter. Hence, all else being equal, warm caves will dry more rapidly and have shorter periods when they are suitable for troglobites. The relevance of this effect will become apparent in the discussion below in relation to the pulses in both the population sizes and the local range of the species in the caves of Cape Range.

Caves in Cape Range have deep temperatures differing by 11°K (17-28°C), mostly being in the range 17-23°C. Hence, because the cave atmospheres are almost saturated with water vapour, there will be about a two fold difference in the water vapour pressure within the faunal caves. Therefore under the same outside conditions some caves will have gradients in water vapour pressure which are the reverse of others. More detailed and long term recording, especially of the climate on the range, would be required to determine these conditions.

The mean minimum temperature is below most cave temperatures from April through September in Cape Range and a net loss of water from the caves would be expected at night during these months. The data for August and September support this conjecture (Table 1 and Fig. 4). No data are available for diurnal changes in cave humidities for Cape Range in summer. However, despite cave temperatures being below outside temperatures throughout the day, the low surface humidities would be expected to prevent an influx of water vapour for much of the summer. The expected vapour pressure gradients, determined from meteorological data from the coastal areas of North West Cape, suggest that only the cooler caves would gain water during the height of summer (Fig. 4). However, these mean monthly values are misleading as there was clearly a diurnal change in the direction of the vapour pressure gradient in the caves in September 1988 (Fig. 4; Table 1).

Figure 4: Annual changes in the partial vapour pressure (mbars) of water on North West Cape and the water vapour pressure of caves at various temperatures and humidities. The surface data are for Learmonth and are calculated for the 0900h (solid line and circles) and 1500h (solid line and squares) meteorological readings of temperature and humidity, as well as for the mean monthly maximum (dotted line and circles) and minimum (dotted line and squares) temperatures (Vine, Knott & Humphreys 1988). The horizontal lines show the partial vapour pressure of caves at the given temperatures and humidities; if the curves lie below a particular horizontal line then, under those conditions of temperature and humidity, water vapour will leave that cave and vice versa. Cave conditions:- 1) 19°C and 100% R.H.; 2) 17°C and 100% R.H.; 3) 17°C and 90% R.H.

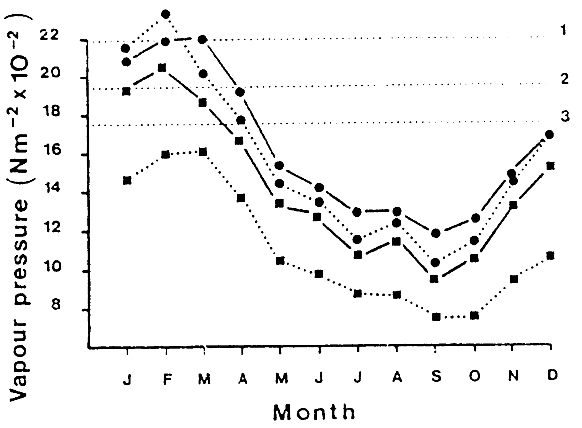

Table 1: The range of temperature and relative humidity recorded in the faunal area closest to the entrance and that in the location furthest from the entrance between 10.8.88 to 22.9.88.

Cave	Sector	Temperature °C	Relative humidity Hygrometer	Hydrograph[1]
C-118	Front	22.5 - 23.5	91 - 97	
C-118	Back	23.5 - 25.7	87 - 100	
C-162	Front	17.8 - 22.8	80 - 100	65 - 100
C-162	Back	17.8 - 22.2	92 - 99	74 - 99

[1]The disparity here is due to the minimum RH reading occurring at about 0600 when no whirling hygrometer readings were taken.

Carbon dioxide

Many caves in Cape Range contain high levels of CO_2 as indicated by human physiological response (e.g. C-66 and C-69). This is particularly the case after rain, even in shallow caves such as C-118 (M. East; pers. comm. 1988). Sections of caves containing troglobites have levels of CO2 ranging from 0.06% (C-126) to 0.5% (C-167) with a mean of 0.18% CO2 (s.d.=0.16, n=7) in cave areas containing troglobites. Because cavers could not sustain entry into some areas of high CO2 levels (>>8% CO2; off scale of indicator tube in a vertical lead in C-207), it is not known whether troglobites inhabited such areas as has been reported for a few caves elsewhere. Troglobites survive high CO2 levels (5.4%; Vandel 1965) and in Bayliss Cave, at Chillagoe in north Queensland, 75% of the 24 species of troglobites occur only in the foul air zone where CO2 concentrations ranged from 0.6 to 6.0% (Howarth 1988).

Other cave contents

The caves contain significant deposits of fossil and sub-fossil material and much of the knowledge of the original fauna of the range has come from these deposits (Kendrick & Porter 1973; Humphreys 1988; A. Baynes and B. Jones, pers. comm. 1989).

The only location in Australia of a Pleistocene habitation site representing a maritime economy is located in rock shelters at the foot of Cape Range (Morse 1988). Evidence of aboriginal occupation of Cape Range is widespread through the range itself in the form of baler shells which are sometimes found in caves. However, owing to the vertical nature of most of the caves few overt signs of cave usage by aboriginal people have been found in Cape Range itself.

Conclusions

Despite the little research conducted into the caves of Cape Range it has emerged as one of the most significant karst areas in Australia in terms of fauna. There is a lack of palaeoclimatic information from this region of Australia and the cave fauna is the only evidence that wet forest has covered the area since the Miocene when the limestones in which the caves have formed were deposited. The high degree of cave adaptation of some of the troglobites suggests that the fauna has been isolated in the caves for a long time but there is no reliable dating for a significantly wetter period. Dates (Th/Ur method) from superficial speleothems range from 12500 to 123000 years BP but with wide errors owing to the very low uranium content (D. Smith, pers. comm. 1990).

ACKNOWLEDGMENTS

This work would not have been possible without the unstinting help of a large number of people in a professional and voluntary capacity. In particular I would like to than the generosity of Dr S. Baseden, Dr A. Baynes, Darren Brooks, Dr H. Dalens, Malcolm East, Dr M. Gray, Dr M. Harvey, Angus Humphreys, Barbara Jones, Ms D. Jones, Dr B. Knott, Dr J. Lawrence, Dr M.B. Malipatil, Dr B. P. Moore, Dr D.C.F. Rentz, Dr L.M. Roth, Dr W.A. Shear, Mrs S.M. Slack-Smith, the late Dr A. Solem, Brian Vine, Julianne Waldock, Ray Wood and Rae Young. Numerous other people have been acknowledged in separate publications.

The Department of Conservation and Land Management permitted work in Cape Range National Park and access to Exmouth Gulf Station is acknowledged from the Lessees. Financial support for various aspects of this work is acknowledged from the Western Australian Museum, the National Heritage Committee and the Australian National Parks and Wildlife Service.

REFERENCES

Barr, T.C. 1963. Ecological classification of cevernicoles. Cave Notes 5: 9-12.

Barr, T.C. (1968). Cave ecology and evolution of troglobites. Evolutionary Biology 2: 35-102.

Barr, T.C. (1973). Refugees of the Ice Age. Natural History, May 1973: 26-35, 72.

Cawthorn, P. 1953. Discovery of subterranean freshwater fauna on the eastern side of North West Cape. Western Australian Naturalist 8: 129-132.

Colwell, R.K. (1974). Predictability, constancy, and contingency of periodic phenomena. Ecology 55: 1148-1153.

Cook, D. 1962. Caves of the Cape Range, North West Cape, Western Australia. J. West. Aust. Speleological Group of the West. Aust. Naturalists Club 1962: 4-11.

Culver, D.C. (1982). Cave life: evolution and ecology. Harvard University Press.

Curl, R. (1966). Caves as a measure of karst. Journal of Geology 74: 798-830.

Edney, E.B. (1977). Water balance in land arthropods. Springer Verlag, Berlin.

Hamilton-Smith, E. (1967). The arthropoda of Australian caves. Journal of the Australian Entomological Society 6:103-118.

Hamilton-Smith, E. 1971. The classification of cavernicoles. National Speleological Society (US) Bull. 33: 63-66. Harris, J.A. (1970). Bat-guano cave environment. Science, New York. 169: 1342-1343.

Harris, J.A. (1973). Structure and dynamics of a cave population of the guano mite *Uroobovella coprophila* (Womersley). Australian Journal of Zoology 21: 239-275.

Holthuis L.B. 1960. Two new species of Atydid shrimps from subterranean waters of N.W. Australia (Decapoda Natantia). Crustaceana 1:47-57.

Howarth, F.G. (1980). The zoogeography of specialized cave animals: a bioclimatic model. Evolution 34: 394-406.

Howarth, F.G. (1983). Bioclimatic and geological factors governing the evolution and distribution of Hawaiian cave insects. Entomololgia Generalis 8: 17-26

Howarth, F.G. (1988). Environmental ecology of north Queensland caves: or why are there so many troglobites in Australia. pp. 76- 84 In Pearson, L (Ed.) 17th biennial conference, Australian Speleological Federation Tropicon Conference, Lake Tinaroo, Far North Queensland. 27-31 Dec. 1988. Australian Speleological Federation, Cairns. 139 pp.

Humphreys, W.F. (1989). The status of relict cave fauna of Cape Range, Western Australia, especially the Schizomida. Report to the Australian National Parks and Wildlife Service, Canberra. 104 pp.

Humphreys, W.F. in press. The biology of a troglobitic schizomid (Chelicerata: Arachnida) from caves in the semi-arid Cape Range, Western Australia. Acta Zoologica Fennica.

Humphreys, W.F., Adams, M. & Vine, B. (1989). The biology of *Schizomus vinei* (Chelicerata: Schizomida) in the caves of Cape Range, Western Australia. Journal of Zoology, London 217:177-201.

Humphreys, W.F., Brooks, R. D. and Vine, B. in press. Rediscovery of the palm *Livistona alfredii* on the North West Cape Peninsula. Records of the Western Australian Museum

Humphreys, W.F. and Collis, G. 1990. Water loss and respiration of cave arthropods from Cape Range, Western Australia. Comparative Biochemistry and Physiology 95A: 101-107.

Kane, T.C., Norton, R.M., & Poulson, T.L. (1975). The ecology of a predaceous troglobitic beetle, *Neaphaenops tellkampfii* (Coleoptera: Carabidae, Trechinae). I. Seasonality of food input and early life history stages. International Journal of Speleology 7: 45-54.

Kane, T.C. & Poulson, T.L. (1976). Foraging by cave beetles: spatial and temporal heterogeneity of prey. Ecology 57: 793-800.

Kendrick, G.W. and Porter, J.K. 1973. Remains of a thylacine (Marsupialia: Dasyuridae) and other fauna from caves in Cape Range, Western Australia. Journal of the Royal Society of Western Australia 56: 116-122.

Knott, B. 1985. Australian aquatic cavernicolous amphipods. Helictite 23: 51-55.

Leleup, N.(1968). Introduction. Mission zoologique belge aux iles Galapagos et en Ecuador(N.et J.Leleup, 1964-1965). Resultats scientifiques. Musee Royal de l'Afrique Centrale. Premier Partie: 9-34. Tervuren, Belgium.

Mees, G.F. 1962. The subterranean fauna of Yardie Creek station, North West Cape, Western Australia. Journal of the Royal Society of Western Australia 45: 24-32.

Michaelis, F. 1985. Threatened fish. A report on the threatened fish of inland waters of Australia. Report Series No. 3. 45 pp. Australian National Parks and Wildlife Service Canberra.

Mitchell, R.W. 1970. Total number and density estimates of some species of cavernicoles inhabiting Fern Cave, Texas. Annales de Speleologie 25: 73-90. Moore, B.P. (1964). Present-day cave beetle fauna in Australia, a pointer to past climatic change. Helictite Oct. 1964, 3-9.

Morse, K. 1988. Mandu Creek rockshelter: Pleistocene human coastal occupation of North West Cape, Western Australia. Archaeol. Oceania 23: 31-88.

Norton, R.M., Kane, T.C. & Poulson, T.L. (1975). The ecology of a predaceous troglobitic beetle, *Neaphaenops tellkampfii* (Coleoptera: Carabidae, Trechinae). II. Adult seasonality, feeding and recruitment. International Journal of Speleology 7: 55-64.

Petterssen, S. (1958). Introduction to meteorology. McGraw-Hill Book Company, New York.

Sbordoni, V. (1982). Advances in speciation of cave animals. pp 219-240. In Barrigozzi, C. (Ed.). Mechanisms of Speciation. Liss, New York.

Vandel, A. (1965). Biospeleology: the biology of cavernicolous animals. Translated by B. E. Freeman. Pergamon Press, Oxford. Vine, B., Knott, B. & Humphreys, W.F. (1988). Observations on the biology of the cave dwelling *Schizomus vinei* (Chelicerata: Schizomida) in Cape Range, Western Australia. Records of the Western Australian Museum 14: 21-34.

Whitley, G. P. 1945. New sharks and fishes from Western Australia. Part 2. Australian Zoologist 11: 35-37.

CAVE RIGHTS FOR TROGLOBITES

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Abstract; Prior to, and during our Bicentennial year it became increasingly popular, even trendy, for the media, politicians and individuals, to recount the continuing struggles of the Australian Aborigine - the original owners of Australia - for land rights. Now, a couple of years after that monumental non-event, it is becoming fashionable to talk land rights again. This time, amongst others, there are those who are calling for land rights for Koalas!

Even though membership of speleological societies has declined in recent years, the pressure on caves and their faunal inhabitants has increased to the point where, in some caves, there is urgent need to raise more than a word or two about land - or more precisely - cave rights for troglobites, the original 'owners' of caves.

Have we mere terrestrials, who are infrequent cave visitors but who often perceive ourselves as the best or logical custodians of caves and all they contain, lost sight of the fact (either through arrogance or ignorance) that troglobites and their troglophile cousins have rights too?

Through aeons of time people have entered caves for a variety of reasons ranging from habitation, art, religious rites, curiosity, impulse, recreation, mining, study or vandalistic intent. All these activities can and do have a detrimental effect on a cave, its environment or fauna either through ignorance or (sometimes callous) indifference.

In recent times some people - especially cavers - have become aware of the <u>physical</u> damage that can and does happen to caves and have moved to protect them, often citing fauna or habitat protection to add plausibility to their argument.

All too often we talk about caves as if they are 'ours' and that we can do just about anything we like in them.
We lock them up to keep everyone but ourselves out.
We talk about being custodians of caves for future generations to enjoy.
Future generations of 'us' - but cave fauna? I think not.

However, talk about preventing or restricting some or all of 'us' from going somewhere in a cave, or perhaps a whole cave, and all hell breaks loose. "You can't prevent 'us' from going caving - we're cavers! We have a 'right' to go caving!" Do we?

We try to regulate our activities in certain areas and sections of caves. We certainly try to regulate the activities of <u>others</u> in caves, but do we really regulate ourselves very well in relation to a particular cave and any fauna it may contain? Do we really care?

How many amongst the general cave and cave diving community have taken the time to question the immediate and cumulative effects of their activities on a cave's fauna or food supply?

How many have given more than a passing thought to bat guano, so often contemptuously trodden underfoot in the haste to explore a cave's confines, excrement that may provide sustenance to a multitude of cave fauna, especially when so few cavers take the time and effort to look for such creatures much less understand their life cycle or needs.

Indeed, who would have thought that even <u>degraded</u> bat guano serves as a food source for cave fauna as has been found recently in some caves of the Nullarbor Plain, and no doubt elsewhere. Have cavers, where there is no option but proceed through guano, established a single file trail, even to the extent of walking in others footsteps?

The point to be emphasized is that even the simple activity of tramping indiscriminately through vulnerable habitats like guano, litter and soil/mud deposits degrades them by breaking down their open structure to form hard compact substrates in which nothing can live. Hence the need for creation of trails which cause minimal disturbance within the cave.

A somewhat different but graphic example of the effects of indiscriminate tramping is to be seen in Roaches Rest Cave, a cave few cavers put much value upon. It once harboured a large community of troglobites (including cockroaches and spiders) which died out, probably with the close of a past moister climatic regime. The evidence for this lay in the accumulation of preserved troglobite carcasses that once littered the cave floor and formed a quite unique historical record of a community now extinct. A couple of decades of visitation and trampling has turned the cave floor into a dust-bowl lacking any evidence of the former inhabitants (Gray. pers.

comm.) Part of the reason for this sort of destructive happening is that invertebrates are relatively invisible to the visitor - better awareness becomes very important here.

Equally importantly, any other source of organic material in a cave should be left undisturbed. Such materials form vital energy 'hot spots' on which the cave biota depends. Even plant root systems, whether alive or decaying and so often found in caves provide food and shelter for cave fauna.

Casual perusal of club literature reveals that there is a higher percentage of recreational rather than 'scientific' caving (SRG is no exception). However, recreational caving is not being criticized as such by this paper. What is being criticized is the indifference towards caves and of the need to take special care of these subterranean environments.

A case in point is the area known as the Dome in Mullamullang Cave, Nullarbor Plain. It has become the 'macho rite' amongst visitors (ASF members or not) to 'do the Dome' (complete the arduous 10km return trip in a day). Indeed, many seem to go to Mullamullang Cave for no other purpose than to prove that they can 'do' the Dome. As Ken Boland of the Victorian Speleological Association so aptly puts it, they come under the influence of the 'Dome Syndrome'. At the moment little has been done to cure people of this detrimental condition. It is now thought that the Dome's fauna, *Tartarus mullamullangensis* (spider) and *Trogloblattella nullarborensis* (cockroach), are either extinct or have suffered a massive population decline due to habitat disturbance as a result of this increased human activity. A high price to pay just to satisfy people's ego. Thirty years ago the Nullarbor Plain was a very remote area and may have been visited by speleologists only once or twice a year. Such trips often took months to prepare. Today numerous expeditions to the Nullarbor are staged each year often with repeated intense activity at certain caves - in keeping with popular practise to areas closer to home. When, at the suggestion of Dr. Mike Gray of the Australian Museum, SRG proposed a 10 year ban on entry to the Dome in an effort to allow any remnant population to re-establish itself, the howls of 'What about us' were very loud indeed.

Between 1982 and 1987 the troglobitic species of Nurina Cave had been lifted from one to seven making it one of the most important biospeleological caves on the Nullarbor Plain. It also has one of the regions highest visitation rates due to its proximity to human habitation and ease of access. Shortly after the discovery of aquatic amphipods in the cave (a *Nullarbor 'first')* and news disseminated around the caving fraternity, a member of one caving party went to the cave with the express purpose of 'photographing the amphipods' *(information extracted from visitor's book Sept. 1985)* This sort of activity should be discouraged due to the risk of habitat disturbance and possible death of the subject/s. An alternative would be availability of studio photographs of (scientifically) collected specimens.

It is important to ensure that an example of our unique Nullarbor cave ecosystems survives as intact as possible. Nurina Cave provides an excellent opportunity for this. It contains a uniquely rich and representative sample of the 'typical' Nullarbor troglobitic fauna and should be a prime candidate for special conservation status and restricted entry.

As a more immediate measure, it has become a practise for societies and individual members of societies to keep some cave locations or section of caves 'secret' from the general caving community *(and their own members)* in an effort to protect the contents. SRG has joined this trend somewhat in relation to Nurina Cave except that we are letting people know about it and why. While recommending to the possible future cave manager Dept. of Conservation and Land Management (CALM) that the cave be gated, SRG is restricting access to the map that shows the location of the Fauna Chamber and Arachnid Alley to scientific perusal only and asks readers to respect this action. The Fauna Chamber and Arachnid Alley are not conducive to exploration caving, aesthetic photography or even the ASF recommended minimum sized party due to the arduous nature of the passageways and the diverse troglobitic fauna that resides there. A sign *(Fig 1)* has been placed at the entrance to these passages asking accidental discoverers of the extensions to respect the rights of the fauna beyond and not to proceed further. The sign also mentions that the spiders webs that would be encountered are virtually invisible to direct lighting. These webs quite often occupy several cubic metres and be destroyed before a person realizes one is there or by small air currents generated by nearby body movement.

CONCLUSION

We are cavers and no doubt wish to continue enjoying being underground for whatever reason. Due to the increasing pressures of population we find ourselves competing with other interest groups for a scarce non-renewable resource. Quite often we have to negotiate with land managers be they government, semi-government or private in order to gain access to caves and adhere to ever restricting rules and regulations. Gone are the days of frontiersville - well almost.

People join a caving club for a variety of reasons in addition to achieving a common goal which is access to caves. The duty of the more experienced members of these clubs is to train the less experienced members how to enter and traverse the confines of any given cave without injury to themselves, their companions or the cave. Perhaps it is time that all club members were made aware that apart from being trained not to injure the cave, they should be trained to take greater care not to injure the cave's natural inhabitants.

HI!
YOU HAVE ENTERED THE AREA KNOWN AS THE "CALCITE CRAWL AND ARE ASKED NOT TO PROCEED ANY FURTHER.

A RICH AND DIVERSE TROGLOBITIC FAUNA COLONY EXISTS NEARBY AND YOUR PRESENCE CAN EASILY DISTURB OR DESTROY THEM OR THEIR HABITAT.

THE FOOD BASE IS THE DEGRADED BAT GUANO FOUND ON THE FLOOR AND SHOULD NOT BE TRODDEN ON UN-NECESSARILY.

VERY RARE AND DELICATE SPIDERS OCCUR. THEY AND THEIR WEBS ARE INVISIBLE TO DIRECT LIGHTING.

THE PASSAGE BEYOND THIS POINT BECOMES QUITE NARROW AND DOES NOT OPEN OUT TO ANYTHING THAT MAY BE PLEASING PHOTOGRAPHICALLY.

IF YOU WANT FURTHER INFORMATION REGARDING THE FAUNA OF THIS CAVE INCLUDING COPIES OF SCIENTIFIC PHOTOGRAPHS YOU ARE URGED TO CONTACT

DR. MIKE GRAY
AUSTRALIAN MUSEUM
COLLEGE ST.
SYDNEY 2000
02 339 8111
OR
NORMAN POULTER SRGWA
PO BOX 120
NEDLANDS 6009
09 276 2495

PLEASE DO NOT PROCEED BEYOND THIS POINT

IF YOU ARE INTERESTED IN CAVING CONTACT THE SECRETARY, AUSTRALIAN SPELEOLOGICAL FEDERATION,
P.O. BOX 388 BROADWAY NSW 2007

IN WESTERN AUSTRALIA, CONTACT:-

SPELEOLOGICAL RESEARCH GROUP WESTERN AUSTRALIA
P.O. BOX 120 NEDLANDS 6009 09 276 2495

WESTERN AUSTRALIAN SPELEOLOGICAL GROUP
P.O. BOX 67 NEDLANDS 6009 09 386 7782

WITCHCLIFFE AREA SPELEOLOGICAL SUB-GROUP
097 555 324

Figure 1

The NSS once adopted a quote reading in part *"leave nothing but footprints"*. That could leave a trail of death and destruction depending on where the foot was placed. It is understood that this quote has now been changed to *"leave nothing but memories."* Does that mean Americans 'float' through caves?

The ASF carries a message on its letterhead saying that *"What we have now is all there ever will be."*

The present author is suggesting that *"what we have now is less than we had yesterday"* would be a more appropriate remark and one that all cavers should bear in mind on entering a cave.

Wherever there is a food source in a cave - it is possible there is also a faunal ecosystem. In times past we have argued the right of a cave to exist. It is about time we acknowledged that the fauna within a cave (no matter how much fear or contempt we may harbour for that fauna), also has a right to exist - and that existence must be protected and respected.

ACKNOWLEDGEMENTS

The assistance of Dr. Brenton Knott, Dept. of Zoology, University of Western Australia and Dr. Mike Gray, Australian Museum in the preparation of this paper is gratefully acknowledged.

THE HYDROGEOLOGY AND SPELEOGENESIS OF YANCHEP

L.V. Bastian

ABSTRACT; Caves at Yanchep are developed in the Tamala Limestone of Pleistocene age. Their distribution falls into a pattern of distinct north-south zones as a consequence of the relationships of this formation to the underlying Bassendean Sand, a total of five zones being recognised.

In the easternmost zone the watertable is in the sand formation below the base of the limestone, which is devoid of caves. The point at which groundwater makes initial contact with the base of the limestone is the Cave Threshold, associated on the surface with a sharp topographic and vegetation change. Water then discharges under pressure down the Groundwater Escarpment Zone, forming abundant cave streams with a typically vigorous flow. These in turn efflux onto the main interdune lake chain, which then drains into a younger dune limestone, to eventually reach the coast as submarine springs. In this zone the groundwater invades the limestone formation, and normal epiphreatic cave development takes over.

The pressure discharge out of the sand formation into the base of the limestone represents a unique form of speleogenesis, for which the term Exophreatic is proposed.

INTRODUCTION

The Yanchep cave area is situated approximately 50 kilometres north of Perth, and a few kilometres inland from the coast. The area is highly cavernous, and several hundred caves are known to exist within a relatively small area, most of which is incorporated within the boundary of the Yanchep National Park. Despite its proximity to Perth, Yanchep has seen very little worthwhile speleological research, and the origin of its cave systems has never been properly understood.

This paper represents the culmination of over 35 years of observations at Yanchep, and especially a recent phase of exploration by the author which commenced in March 1988, and has so far added approximately ninety caves to the Yanchep list.

REGIONAL GEOLOGY AND GROUNDWATER

The surface formation at Yanchep is a dune limestone, the Tamala Limestone (Playford, Cockbain and Low, 1976) of Pleistocene age. This unit, equivalent to the Bridgewater Formation (Boutakoff, 1963) of southeast South Australia, consists of a series of coastal calcareous dune ridges thrown up during successive interglacial high sea levels in the Pleistocene Epoch. The formation lies upon an extensive sand body of older Pleistocene age, the Bassendean Sand (Playford and Low, 1972). This relationship is in marked contrast to the situation in the Naturaliste-Leeuwin area, where Tamala Limestone rests upon impervious Archean gneiss.

The Tamala Limestone dune systems extend inland to around halfway across the Swan Coastal Plain; from thence to the Darling Scarp the Bassendean Sand has no limestone cover. There are two aspects of this relationship which are particularly important to the Yanchep hydrogeology model:

(i) The high carbonate content in the Tamala Limestone has enable lithification to proceed rapidly despite its geological youth, whereas the absence of carbonate from the older Bassendean Sand has left the sand in an entirely unconsolidated state.
(ii) The contact between the two is not horizontal, but slopes westwards from relatively high levels at the eastern extremities of the dune ridges, to be well below sea level at the coast. Neither is this contact an even plane, but undulates according to the topography of the sand formation prior to its burial beneath the dunes.

A large freshwater resource has been identified in the Bassendean Sand, known as the Gnangara Mound. As its name implies, this groundwater resource has an elevated watertable with a mounded shape, which attains its highest levels in an area east and southeast of Yanchep. Radial groundwater flow off the Gnangara Mound results in a flow pattern southwards towards the Swan-Avon river system and westwards towards the coast. The westwards flow sector takes the water into the Tamala Limestone, which then provides the main aquifer for discharge of the groundwater into the Indian Ocean. This process leads to a unique hydrogeology, with several distinctive north-south zones.

Figure 1, showing the regional setting of Yanchep, includes the surface geology in a simplified form.

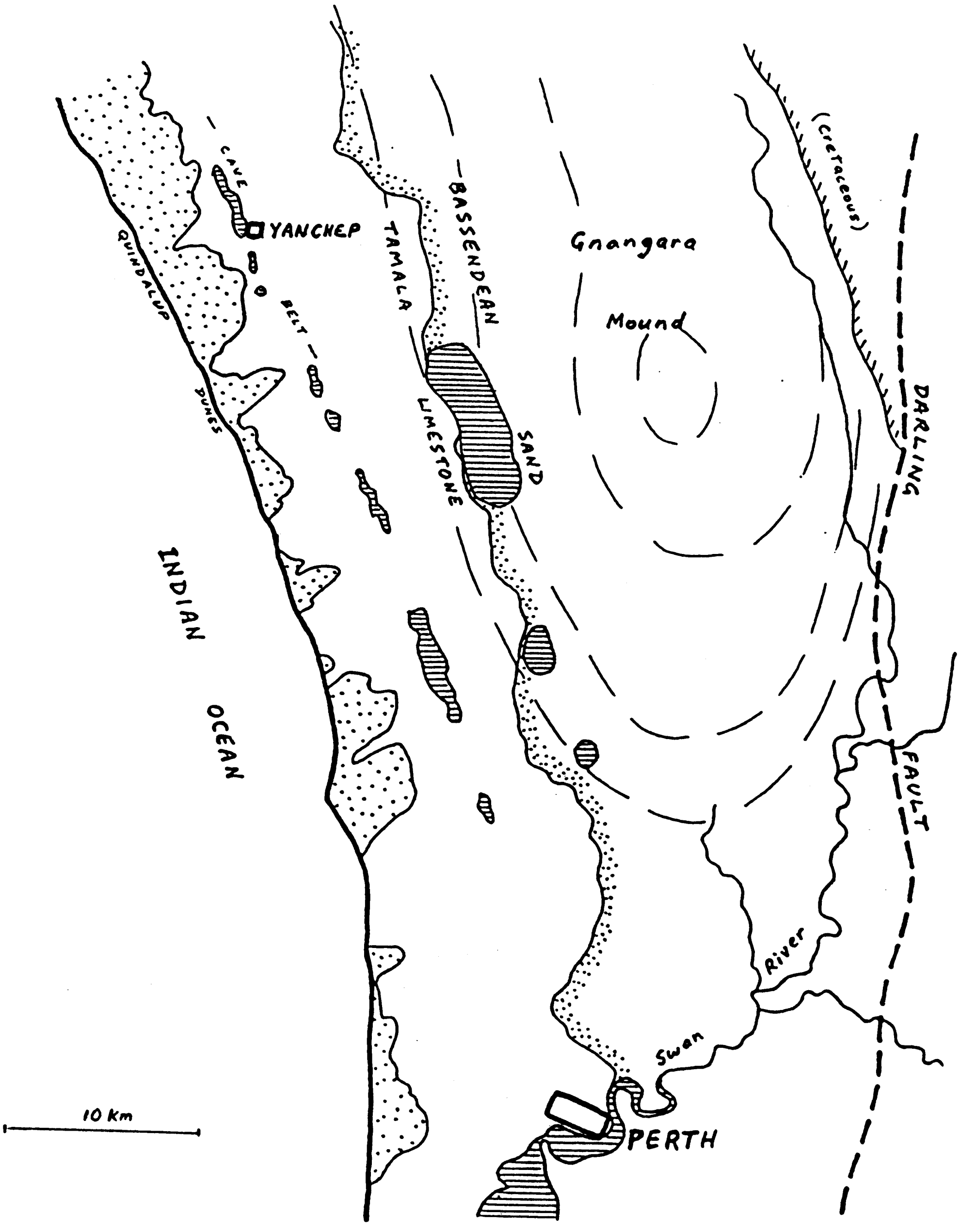


Figure 1. Locality plan.
Watertable contours on the Gnangara Mound
are shown schematically.

HYDROGEOLOGY

The groundwater relationships with respect to the limestone formation fall into five distinct zones aligned roughly parallel to the coastline. From east to west these are:
(i) Subjacent Watertable Zone
(ii) Cave Threshold
(iii) Groundwater Escarpment Zone
(iv) Interdune Lake Chain
(v) Contained Watertable Zone

(i) SUBJACENT WATERTABLE ZONE

In this easternmost zone, extensive tracts of the calcareous dune limestone lie as a veneer over the Bassendean Sand, the watertable being located in the Bassendean Sand, below the base of the limestone.

Fluctuations in the watertable are essentially similar to those occurring in the Gnangara Mound in the main Bassendean Sand area farther to the east, viz. large annual rises and falls. However, even at the springtime maximum the watertable does not rise sufficiently to reach the base of the limestone. Since there is no contact of groundwater with the limestone, solution at the base of the limestone is virtually nil and there is no cave formation.

Karstification is limited to surface phenomena only, such as solution pipes and pinnacles; the pipes characteristically close off with depth. Several limestone quarries sited in this zone about 20 kilometres southeast of Yanchep show these features - in none is there any sign of cave development. Vegetation in the zone lacks tall eucalypts such as tuart, which require good access to the watertable via solution pipes or cave fissures. Instead the vegetation is dominated by shallow rooted species such as the banksias and parrot bush (Dryandra sessilis), with hakeas, small acacias and other shrubs.

(ii) CAVE THRESHOLD

As pointed out above, the base of the Tamala Limestone descends westwards to be well below sea level at the coast. This is steeper than the natural gradient of the watertable, which cannot in any case go below sea level: the latter must therefore intersect the base of the limestone.

The groundwater, being virtually free of dissolved carbonate, has maximum capacity to attack the limestone. The point where groundwater makes initial contact with the limestone is therefore marked by a sharp onset of solutional activity. As a result a semi-continuous belt of caves is developed, corresponding with the line of intersection of groundwater/limestone. On the surface this is manifested by the sudden appearance of collapses, dolines, and fissures. A profound vegetation change is also seen, in the appearance of tuart (Eucalyptus gomphocephala) and a species of melaleuca (Melaleuca huegelii), both of which thrive in broken limestone ground.

The Cave Threshold runs roughly north-south but is far from a straight line, because the undulating topography of the Bassendean Sand surface means there will be marked irregularities in the actual line of intersection of groundwater/limestone. There are even buried hills of Bassendean Sand within the area of intense speleogenesis, represented on the ground by isolated noncavernous pockets surrounded by caves. These are shown conceptually in the idealised cross-section, Figure 2.

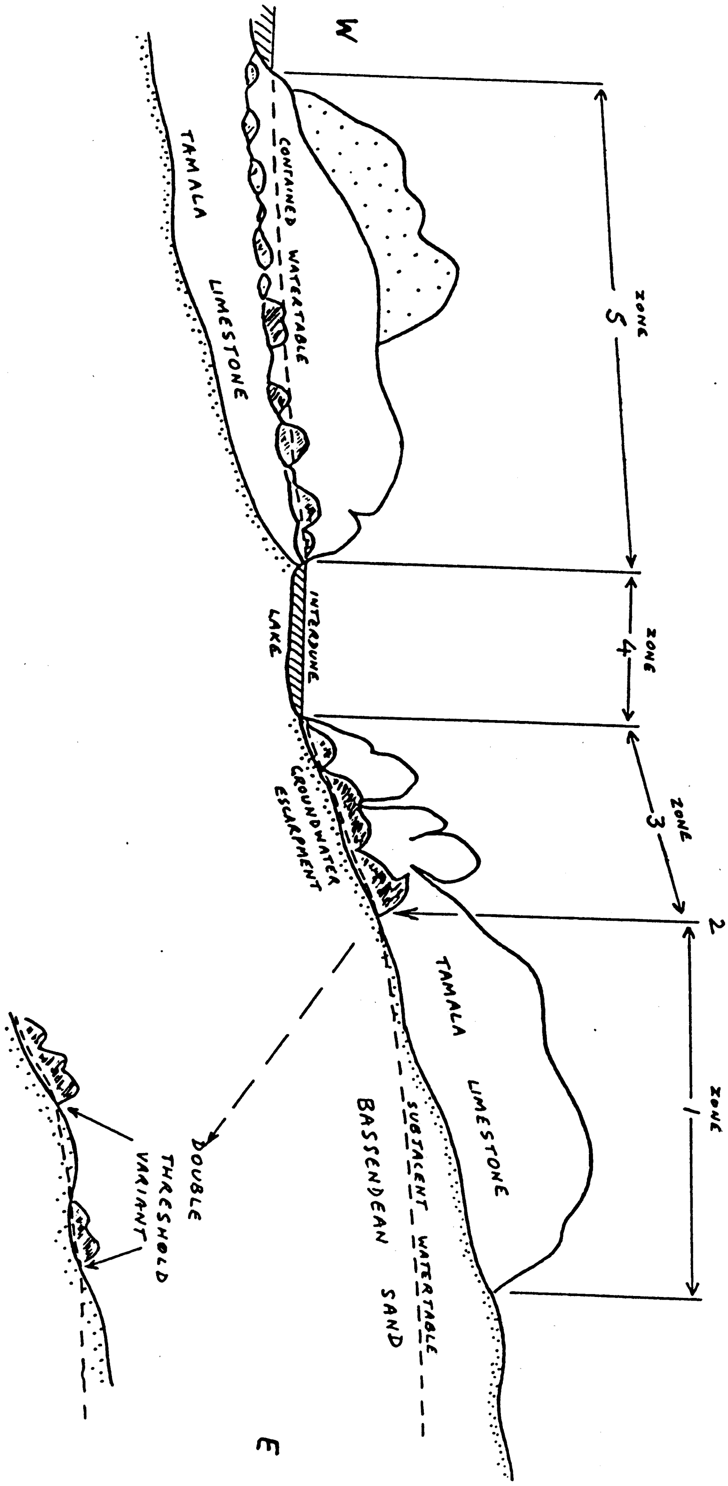
(iii) GROUNDWATER ESCARPMENT ZONE

Westwards from the Cave Threshold the base of the limestone continues to slope more steeply than the natural gradient of the watertable. The strong solutional activity which now occurs at the base of the limestone creates extensive cave systems, into which the groundwater discharges under pressure as a network of subterranean seepages.

The streams fed from these seepages can transport the discharging groundwater away much faster than it can percolate through the sand formation, therefore the watertable becomes oversteepened at the limestone base, and thence follows down the slope of the limestone base until it has descended to a relatively low level, a few metres above sea level. Typically, the watertable will drop from around 15 - 20 metres above sea level at the Threshold point to about 7 metres, within the distance about one kilometre. In colloquial terms, the cave systems extending westwards from the Threshold Zone have "pulled the plug" on the water contained in the Bassendean Sand.

The Groundwater Escarpment Zone can be recognised from water bore data both north and south of Yanchep, as a belt of closely spaced watertable contours. It is important to note that in this zone there is a radical change in the behaviour of the watertable, from the pronounced annual rises and falls characteristic of the Bassendean

Figure 2. Schematic east-west cross-section



Sand, to a virtually constant level. The reason for this is that the open streams in the cave systems can easily accommodate these annual fluctuations - a major rise in watertable simply produces a more vigorous flow in the cave streams, which only rise (and fall) by at most a few centimetres.

(iv) INTERDUNE LAKE CHAIN

On the Indian Ocean coast the Pleistocene dune systems abut each other very closely, with narrow interdune corridors, or in some cases no corridor at all. The broadest of these corridors has in the Yanchep area resulted in a chain of rather narrow lakes, represented within the National Park by the lakes Wilgarup Yonderup - Loch McNess. After a fall in the watertable of about 7 - 8 metres within a kilometre, the cave streams now efflux into this lake chain. With a mean level of around 7 metres above sea level, the lake chain affords a natural boundary between the watertable regime to the east of the lakes and that to the west.

The lakes are not continuous: in some spots paraboloidal dune lobes of the younger western dune system have reached across the gap and partly over the older dune system. In these areas streams from the Groundwater Escarpment Zone change character directly to that of the final Zone, as they cross the lake alignment.

(v) CONTAINED WATERTABLE ZONE

Westwards from the lake chain the watertable flattens off markedly, since it cannot go below sea level. With a distance of about 5 kilometres between the lakes and the coast, the gradient of the watertable becomes little over 1 metre per kilometre, i.e. about one eighth that in the Escarpment Zone. Since the base of the limestone formation is continuing to descend, and will actually go below sea level nearer the coast, the groundwater must rise above the limestone base and thus invade the formation.

This change, in conjunction with the flat gradient, results in a radical change in the type of flow in the cave systems. Instead of the vigorous streams of the Groundwater Escarpment Zone, the water movement changes to the imperceptible flow and ponded lakes characteristic of caves in the phreatic zone. At the western edges of the lakes there are several points where the lakes drain off into cave systems, but exploration has shown that this flow soon disperses into networks of interconnecting tunnels, with epiphreatic solution carved walls. This sluggish dispersed movement then makes its way through to the coast, to emerge eventually as submarine springs.

This regime of a watertable contained within the dune limestone formation has not previously been identified at Yanchep, although well known in the Augusta cave area. The latter, however, does not have the multiple zonation as seen at Yanchep.

CAVE MORPHOLOGY

Cave development at Yanchep falls within the scheme described as syngenetic karst (Jennings 1968), in which the developing karst proceeded contemporaneously with the lithification of the dunes. This process was first recognised by the author (Bastian, 1964), in caves of the west coastal region. A similar type of Pleistocene karst has recently been described from Bats Ridge in Victoria (White, 1989). Yanchep contrasts with the Victorian occurrence in having distinctive cave morphologies for each of the hydrogeological zones.

Caves developed along the Threshold line - the easternmost caves - show a marked north-south alignment, and virtually comprise an integrated cave system, which may be termed the "Threshold Cave System". Continuity along the zone is however interrupted by belts of mass collapsing, represented on the surface as series of deep parallel rifts or groups of collapse dolines. Caves explored within this belt include Minnies Grotto, Tree Cave - Mia Mia Cave, Yanchep Cave, Road Cave to name a few, and also the eastern arm of Boomerang Gorge.

In these Threshold Caves are seen overall the largest chambering of the whole area, because of the powerful solutional attack of the groundwater at the point of first contact with the limestone. Strangely enough however, they are found to be generally devoid of streams. The reason for this is that the cave systems developed down the Groundwater Escarpment Zone have become so effective in draining off groundwater from the Gnangara Mound that they have actually drawn down the watertable permanently. The result of this is that the Threshold Line has gradually shifted westwards from its original position, so that the actual seepages now commence partway downstream from the heads of the cave systems.

In the Groundwater Escarpment Zone are found numerous streams large and small, spilling down the gradient towards the interdune lake chain. It is noteworthy that, unlike the situation in the Naturaliste-Leeuwin belt where the cave streams follow the topography of a buried pre-Pleistocene river pattern (Bastian, op. cit.), the arrangement of these Yanchep streams is much more random. However a crudely dendritic pattern of the cave distribution can be recognised, in which the stream systems concentrate into a series of effluxes along the lake chain, spaced at fairly regular intervals of a hundred metres or so.

Primary solution features are not easy to find, as the major solution activity takes place on collapsed material fallen into the streams. Rotational collapse of fallen roof blocks into the stream beds, as described by Caffyn (1973) can be seen in a number of places at Yanchep. At Cabaret Cave the vigorous activity of a strong stream beneath the cave has caused the stone pillars erected about 60 years ago to part from the ceiling. In Gilgi

Cave (YN27) the author in 1954 noted a large roof fall sometime between two visits, which landed in a permanent running stream. This material disappeared completely within ten years.

In the Contained Watertable Zone west of the lakes, true epiphreatic solution features appear, including complex tunnelling, broad flat ceilings with roof pendants, and concave solution pockets. As a general rule the cave dimensions tend to gradually diminish westwards, as carbonate saturation of the water increases. Likewise the distribution of caves becomes more sparse, as fewer or smaller collapses manage to break through to the surface. In contrast to the dendritic pattern of the cave systems east of the lake chain, a radial pattern can be recognised originating from inflow points along the western shores of the lakes.

There is logically no cessation of cave development all the way to the coast. However, because of the cover of very young dune systems nearer the coast no caves have been found in that area, but it is theoretically possible that a system may be traceable for some distance beneath these cover dunes from its entry point along the eastern fringe of the zone.

UNIQUE SPELEOGENESIS AT YANCHEP

Speleogenesis at Yanchep incorporates a unique phenomenon not paralleled in classic models. The Groundwater Escarpment Zone, although clearly not falling within the phreatic level, does not fit the standard vadose model either. Vadose cave streams are essentially developed without a direct relationship to the watertable, and may occur at any level above the zone of water saturated rock. These Yanchep streams are however necessarily linked to the watertable by virtue of their source under hydrostatic pressure from within the underlying sand formation.

The term Exophreatic is proposed to cover the situation of cave systems developed by pressure discharge from a watertable into the base of a limestone formation.

BIBLIOGRAPHY

Bastian, L.V. 1964 Morphology and development of caves in the southwest of Western Australia. Helictite 2: 105-119.

Boutakoff, N. 1963 The geology and geomorphology of the Portland area. Geological Survey Victoria. Memoir 22.

Caffyn, P. 1973 Rotational collapse of blocks in the caves of the South West. The Western Caver 13(4): 130-132

Jennings, J.N. 1968 Syngenetic Karst in Australia. In: Jennings, J.N. and Williams, P.W. Contributions to the study of karst. Res. Sch. Pac. St. A.N.U. 5: 41-110.

Playford, P.E., Cockbain, A.E. and Low, G.H. 1976. Geology of the Perth Basin. West. Aust. Geol. Surv. Bull. 124.

Playford, P.E. and Low, G.H. 1972 Definitions of some new and revised rock units in the Perth Basin. West. Aust. Geol. Surv. Ann. Rept. 1971: 44-46.

White, S. 1989 Karst features in Pleistocene dunes, Bats Ridges, western Victoria. Helictite 27(2): 53-71.

Postscript: It has not been possible yet to produce a map of the hydrogeological zones at Yanchep, due to the incomplete coverage of the cave distribution mapping. It may be some years yet before the Cave Threshold can be confidently positioned from north to south ends of the Yanchep area. Likewise the patterns of the cave distribution are still very incomplete.

FENGLIN KARST (TOWER AND CONE KARST) IN CHINA

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Fenglin Karst, what is also called "Guilin-Type Karst", is the one type of karst developed most intensely and distributed most widely in China. Topographically constituted by the Peak Cluster Depression Landform and the Peak Forest - Plain Landform, Fenglin Karst mainly distributes in South China, namely, the whole area of Guangxi Zhuang Autonomous Region, Southern Guizhou, Eastern Yunnan, Western Hubei, Western Hunan, and a small area of Southern Sichuan and Guangdong (Figure 1). With a total distribution area of 200,000 square kilometres, China

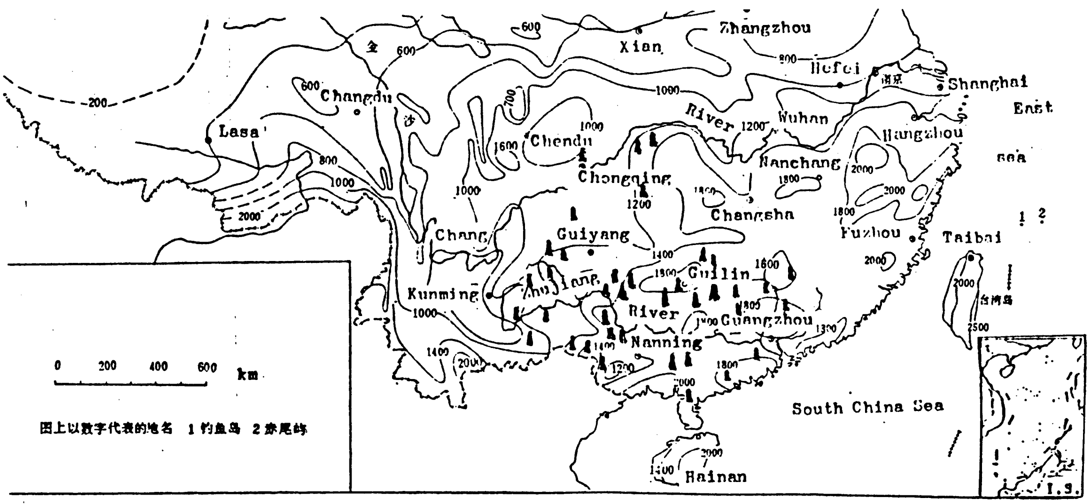


Fig. 1 The distribution of Fenglin karst in south China
(the isoline is annual rainfall)

Fenglin Karst is also the most widely distributed and the most splendid Holekarst in the world. The chief karstification strata are thick-bedded limestones of Devonian, Carboniferous, Permian and Triassic with a total depth over 11,000 metres.

Karst landscapes resemblant to Fenglin Karst in the world almost distribute in the tropics and subtropics such as Viet Nam, Thailand, Laos, Philippines, Papua New Guinea, Cuba, Jamaica, Puerto Rico and Tanzania; and so are commonly considered to be a sort of Tropical Karst by the geomorphologists of today. Quite contrary to typical China Fenglin Karst, the type of karst which we called Cockpit Karst. Cone Karst and Tower Karst actually developed on soft limestones of Cenozonic in some places on earth.

1) Topographical Characteristics of Fenglin Karst.

Having developed for quite a long time under the conditions advantageous to its evolution, Fenglin Karst in China is characterized by a well organized system and is topographically constructed by two different subsystems: the Peak Cluster - Depression subsystem (abbr. Peak Cluster or fengcong) and the Peak Forest - Plain subsystem (abbr. Peak Forest or fenglin) which differ from each other in morphology and display an orderly spatial arrangement.

1. The Peak Cluster - Depression Landform.

Constituted by the base-jointed peaks and the closed depressions among the peaks, the Peak Cluster - Depression Landform is also called Cone Karst as its peaks are mainly in the shape of cone. The depression bottom is commonly rock-bared or covered by a thin layer of soil and usually has sinkhole or shaft developed. In the Peak Cluster areas of China, the difference in height between the peak and the bottom of the depression ranges from tens meters to over 500 meters, and the Peak Cluster - Shallow Depression subform could be distinguished from the Peak Cluster - Deep Depression subform referring to this height difference. The important geomorphological

features of the fengcong districts are that the surficial rivers usually sink down into underground and the subterranean stream systems developed because of the deep-buried water table (Figure 2). Both the huge caves of high level and the longest cave system in China are found in the fengcong regions, some of the underground rivers are more than 200-300 km long.

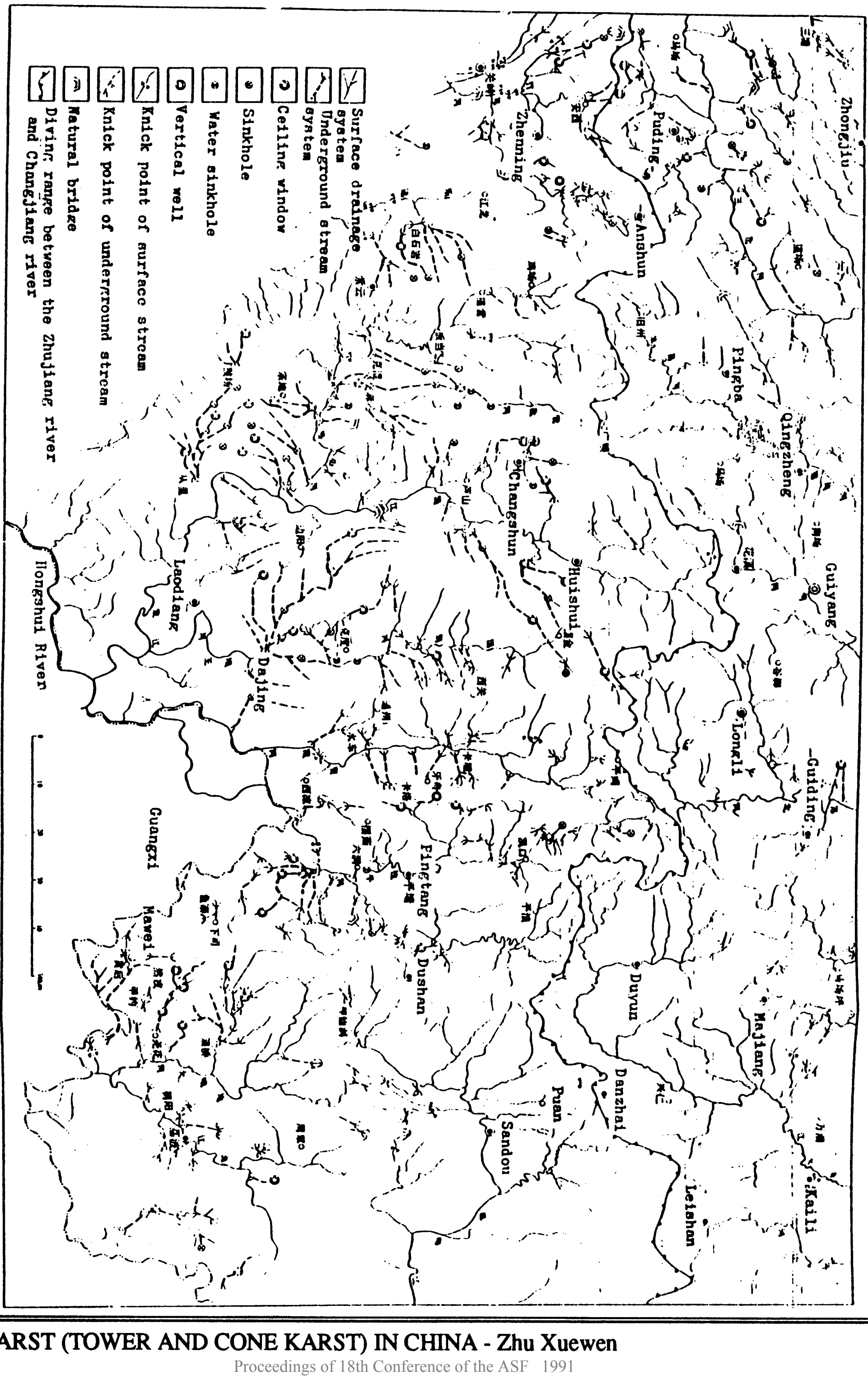


图 2 黔南地区地表水系及地下河系分布图

Fig. 2 Distribution map of the surface river drainage and the underground river system in Southern Guizhou

(after Karst study of S. Guizhou)

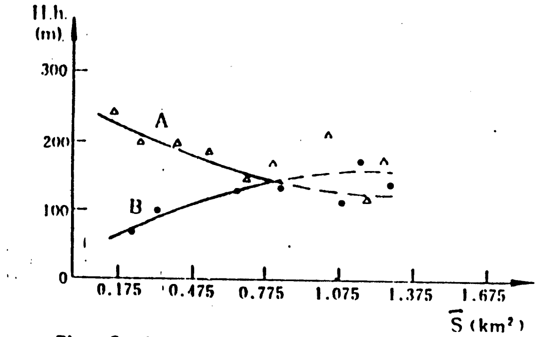


Fig. 3. Relationship between S and H, h in subarea of the study on right bank of the Lijiang River (according to Zhu Dehao)

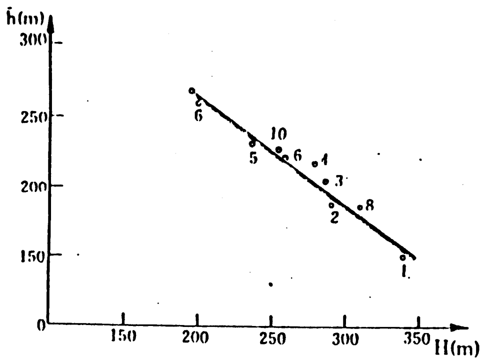


Fig. 4. H-h correlation between individual sets of depression areas (according to Zhu Dehao)

Type	Diameter / Height	Width / height	Relative / height(m)
Single peak n=150	2.66	0.684	59.5
Connected-base peak n=270	3.35	0.588	105.2
Σ_n=220	2.87	0.66	74.3

The Peak Cluster - Depression Landform has many subtypes, and each subtype has its own characteristics in the configuration of underground water system and in the development of subterranean rivers and caves. 1) The margin-type fengcong bounds on nonkarst area. 2) The interfluve-type fengcong is located between two deep-dissected or shallow river valleys. 3) The self-contained watershed-type fengcong is a large area of Cone Karst with an integrated underground water system. 4) The island-type fengcong is dispersed in the Peak Forest-Plain area.

According to the study on fengcong landform in three sample areas in Guangxi made by Zhu Dehao[2,3,5], the morphological features of the depressions in fengcong district are described as below: 1) The depressions are polygonal, and its plane figure is a network constructed by approximate hexagon. (The mean value of the sides of the polygonal depressions of three research areas are 5.3, 5.1, 5.4 respectively.) 2) The plane distribution of the depressions tends to be even. (The spatial analyses of the depressions showed that the characteristic value R are 1.64, 1.67, 1.60 respectively.) 3) the interrelationship among the depression area (S), the depression altitude (H) and the height difference of the

depression (h) can be expressed as follows: the smaller the depression area, the smaller the height difference and the higher the depression altitude; the bigger the depression area, the bigger the height difference and the lower the depression altitude (Figure 3). Figure 4 also shows that the depression elevation is inversely proportional to the height difference of the depression. All these indicate that the depression bottom lowered down more quickly than the peak did in process of the development of fengcong. On Figure 2.3, both slopes of the two curves decline with the increment of the depression area, and it indicates that the evolutionary velocity of the depression would slow down as soon as the depression was enlarged to a certain area -- The extent of the drop of the depression altitude and the extent of the increase of the height difference tend to diminish and to remain approximately stable.

2. The Peak Forest - Plain Landform.

The dominant landscape of the Peak Forest - Plain Landform is the separate stone peaks upstanding over the comparatively flat plain surface. With precipitous cliffs, most stone peaks take the shape of tower and are also called "Tower Karst". According to the density of the peaks, the Peak Forest - Plain Landform can be distinguished into three different forms: the Peak Forest - Plain, the Isolated Peaks - Plain and the Residual Hills - Plain.

The wide and flat plain surface of fenglin is generally covered by a layer of soil or by allogenic alluvial deposit, or even is rock - bared like desert. Water table there is shallowly-buried and always keeps close to the surface. Caves are of small scale and underground stream seldom developed beneath the plain surface.

Besides tower-shaped peaks, there are also saddle-shaped and cone-shaped stone peaks on the plain. According to the study on fenglin landform near Guilin, the average height of the stone peaks is 74.3 meters in a research area of 150 square kilometres. Table 1 lists the main morphological characteristics of the peaks.

One of the most important features of the fenglin landform of "Guilin-Type" is the extensive development of footcaves within the carbonatite peaks. Footcaves are formed by plain surface water flowing through peakfoot into underground during the rain season. Scallops developed widely on the cave walls at the entrance and indicated that almost all footcaves are of "Flow-in Type". Figure 5 shows the morphological construction of the stone peaks of the fenglin landform.

The Peak Forest - Plain Landform can also be subdivided into four different types: the basin-type fenglin, the margin-type fenglin, the valley-type fenglin and the polje-type fenglin. (5,6)

The basin-type fenglin is formed in the confluence basin by the chief geomorphic agent of allogenic water, and generally occupies a large area of dozens km^2 or hundreds km^2. The positive relief of the basin-type fenglin changed from peak forest to isolated peaks then to residual hills with the strengthening of erosion.

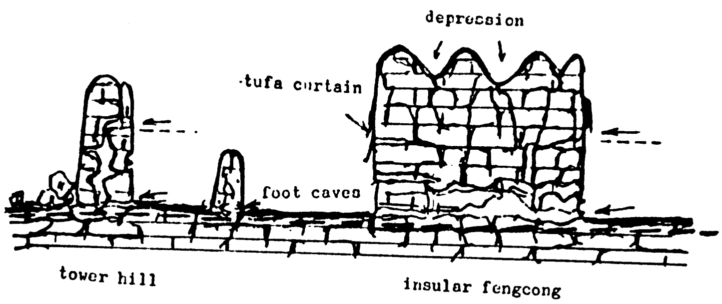


Fig. 5 the form features of karst tower in fenglin plain

The margin-type fenglin is bounded by nonkarst area on one side and by fengcong area on the other side. The formation of this type of fenglin is obviously the result of the corrosion of allogenic water.

The valley-type fenglin is surely formed by valley water and displays a linear distribution. The distribution area of the residual hills in this type of fenglin decrease a lot in comparison with the two subtypes of fenglin mentioned above.

The polje-type fenglin actually exists within the fengcong district of large area and is formed by authigenic water in the relatively watercatching region or in the region of outflow. The formation and the development of the polje-type fenglin is considered to be related to the exposed or shallowly-buried water-resisting underlayer.

2) The distributional regularity of Fenglin Karst.

The distribution of China Fenglin Karst shows some certain regional regularities from the South China Basin to the Yunnan- Guizhou Plateau. Generally speaking, fengcong of big area mainly distributes on the inclined plane of the plateau fringe, while the Peak Forest - Plain Landform dominantly distributes both in the South China Basin and on the Plateau surface. The reason for this distribution regularity is that water table of the plateau slope belt lowered down a lot with the deep dissection of the rivers in process of the uplift of the Yunnan-Guizhou Plateau, while water table of the South China Basin and the plateau surface still keeps close to the surface as showed in Figure 6.

There has long been a misunderstanding of the regional regularity of the distribution of Fenglin Karst. Some geomorphologists believed that the zonality of Fenglin Karst is a very important geomorphic feature in Southern

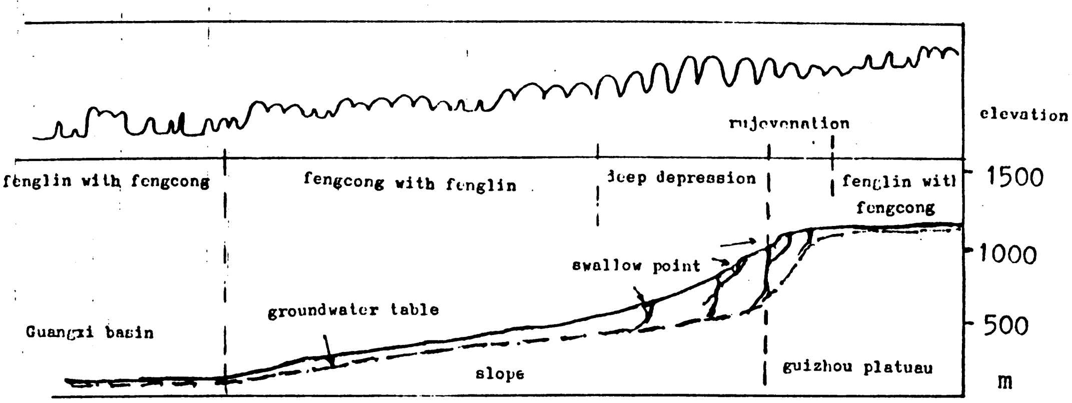


Fig. 6 the relationship between river slope and fenglin landscape

China (8). Figure 7 shows the zones of China Fenglin Karst, namely, Peak Cluster turns orderly into Peak Forest, Isolated Peaks and Residual Hills from the edge of the Yunnan - Guizhou Plateau to the Guangxi Basin. The thought of the zonation ofChina. Fenglin Karst has exerted a tremendous influence in academic circles at home and abroad, and is in fact the theorised distributional regularity derived from the previous theory of Karst Cycle. According to our research works, the actual distribution regularities of Fenglin Karst are as follows:

1) The distributions of the Peak Cluster - Depression Landform and the Peak Forest - Plain Landform are inlaid with each other.

As shown in Figure 8a, there are usually many pieces of fenglin (the margin-type fenglin and the polje-type fenglin) existing in what we called fengcong area defined by Figure 7. On the other hand, the dominant landscape of the "fenglin area" of Figure 7 is actually the fengcong landform as we see in Yishan, Duan, Mashan, Xincheng, Daxin, Longan and Longchuan of Guangxi. The distribution area of fengcong in the Isolated - Peaks area of Figure 7 can compare with or even overpasses that of fenglin. Guilin and Laibin, considered as the most typical geomorphic region of Peak Forest and Residual Hills, have a bigger distribution area of fengcong that that of fenglin (Figure 8b), the percentage of fengcong and fenglin in the natural unit from Guilin to Yangshuo are 52%, 48% respectively. (6)

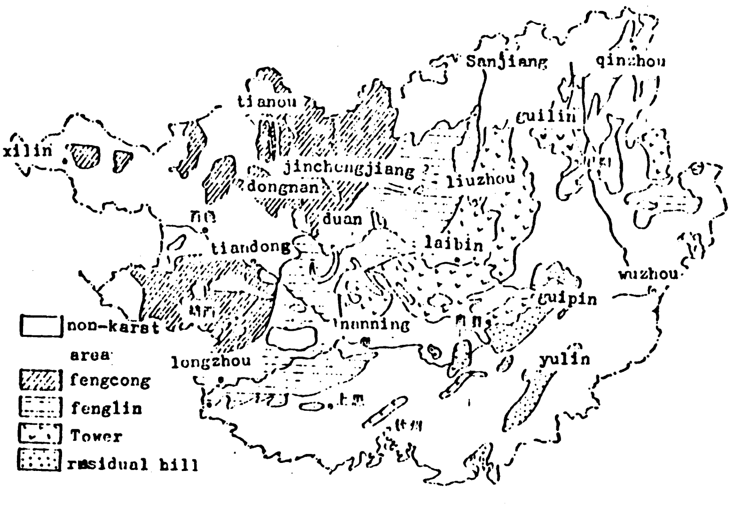


Fig.7 the distribution of types of fenglin karst in Guangxi province (from Introduction of karstology 1983)

There is also a good example to show this disribution regularity of Fenglin Karst in Cuba (7,23): there are about 20 pieces of the polje-type fenglin and the margin-type fenglin inlaid with the fengcong plots within a karst area of about 500 km2 in Sierra de los Organos.

2) The distributions of the Peak Cluster - Depression Landform and the Peak Forest - Plain Landform are in orderly organization.

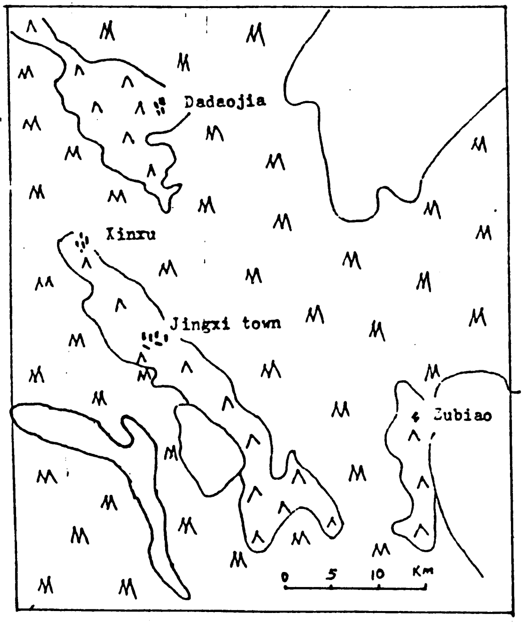


Fig.9a Folji-type Fenglin in Fengcong area. Jing,Guangxi

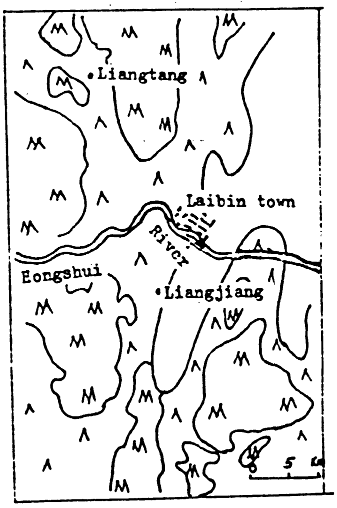
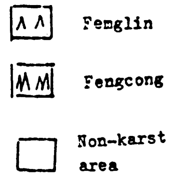


Fig.8b The distribution of Fenglin and Fengcong in Laibin, Guangxi

Fig.8 The distribution regularity of Fenglin landscape



It is common that fengcong and fenglin display an orderly distribution and form a complete functional system in a relatively independent and integrated hydrologic watershed, fenglin landforms developed in Guilin Area is a quite good example (Figure 9). The distribution order of Fenglin Karst System evolved in the center of the Guangxi Basin and on the surface of the Yunnan - Guizhou Plateau. The reason for this phenomenon is thought to be related to the difference in systematicness of the development of Fenglin Karst of different areas which is due chiefly to the features of neotectonic movement and to the difference in dissection of the rivers. (2,5,6)

3) The evolution of Fenglin Karst.

There have been many research papers discussing questions about Fenglin Karst such as the distribution, the spatial relationships and the evolution of the Peak Cluster - Depression Landform and the Peak Forest - Plain Landform. The different viewpoints to these questions can be summarized as below:

1) Based their point of view on the Davis's Theory of Geomorphic Cycle, some karst geomorphologists divided the evolution history of Fenglin Karst into the young stage, the mature stage and the old stage. As they thought that the clear zooning of China Fenglin Karst is the evidence for this evolutional regularity (Figure 2.7), they concluded that China Fenglin Karst has at least three chronologic development stages: the Peak Cluster Stage (the young stage, Cretaceous Period), the Peak Forest Stage (the mature stage, Tertiary Period) and the Isolated Peak Stage (the old stage, Quaternary Period). (8,9,14,16,23)

2) According to the features of neotectonic movements (uplift or subsidence), some karstologists explained the formation and the distribution of assorted Fenglin Karst by using the concept of balance relationship between the rate of uplift and the rate of denudation: Peak Cluster would formed and developed if the rate of denudation were less than that of uplift; on the contrary, Peak Forest would formed and developed if the rate of denudation were over that of uplift. (25,1)

3) From the viewpoint of the System Theory, scientists of the Karst Institute considered the Fenglin Karst as a whole system, and gave their new explanations to the spatial distribution and the development of various Fenglin Karst. That Fenglin Karst developed contemporaneously and systematically is actually the reverse thought to the Davis Theory proposed by them. (2,6)

4) On the basis of the theory of geomorphic cycle, other geomorphologists also combined their viewpoints with the thoughts mentioned above. They put forward that there is a duosystem of the evolution of the Guizhou Karst Landforms, and that the course of karst evolution is defined by the contrast between the rate of uplift and the rate of erosion. (10,11)

In our opinion, the Fenglin Karst is considered to be an organic system which not only constantly adapts itself to the outer circumstances but also evolves uninterruptedly by the law of selforganisation. The various landforms of Fenglin Karst are not the product of the different development stage and thus cannot be separated absolutely; on the contrary, the Peak Cluster - Depression Landform (fengcong) and the Peak Forest - Plain Landform (fenglin) are two contemporaneous subtypes of the Fenglin Karst System. The orderly distribution of assorted karst landforms is the inevitable outcome of the orderly evolution of the System. To a certain open system, there will be two or more possibly evolutionary courses because of the difference in influx and outflux of matter and energy and the difference in spatial allotment of matter and energy within the system -- This is why the system will be able to break into a few subsystems. Such subsystems are closely interrelated, interacted and cooperated in the whole course of the evolution of the syste, and on the whole promote the development of the system. The contemporaneous evolution of the simplest Fenglin Karst System is shown in Figure 10.

In a word, the basic traits of China Fenglin Karst are summarised as follows:

Fenglin Karst is a sort of Holekarst formed by a long term of bare karstification on pure, hard and thick-bedded carbonate rocks under the condition of wet and hot climate. Having developed under the most suitable conditions of lithology and climate for a long history, China Fenglin Karst has a wide distribution, various types and marvellous landscapes. The neotectonic uplift movement occupied a prominent position in the formation of spatial arrangement of Fenglin Karst of South China. As an open organic system, Fenglin Karst has undergone an orderly development by the law of selforganisation in process of adaptation to the surroundings and formed an orderly distribution of assorted karst landforms. The development of the assorted karst terrains is simultaneous. What we want to point out here is that, Fenglin Karst in Southern China formed and developed in any place were there is an exposure of pure and thick-bedded carbonate rocks, especially in pure limestones-exposed districts. Fenglin Karst System usually has fengcong and fenglin two contemporaneous subtypes and is in a high degree of organization as there has been a long history of karstification on exposed carbonatite in Southern China since as early as Tertiary. Only on the edge of the Yunnan-Guizhou Plateau mainly developed the fengcong terrain of large area because the water table there lowered down a lot with the deep dissection of the river valleys in process of neotectonic uplift movement. The Peak Cluster - Depression Landform and the Peak Forest - Plain Landform developed in other karst regions of South China are in both a quite orderly distribution and the good organization. Figure 11 is the conclusion drawn from our systematic research on China Fenglin Karst.

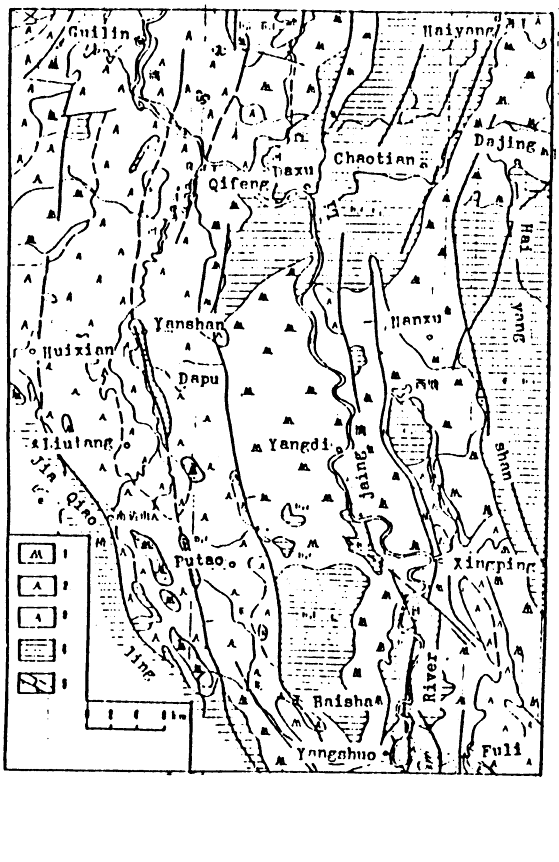


Fig.9 The geomorphological map of Fenglinkarst in Guilin area

1—Fengcong

2—Fenglin

3—Residual hill

4—Non-karst area

5—Fault

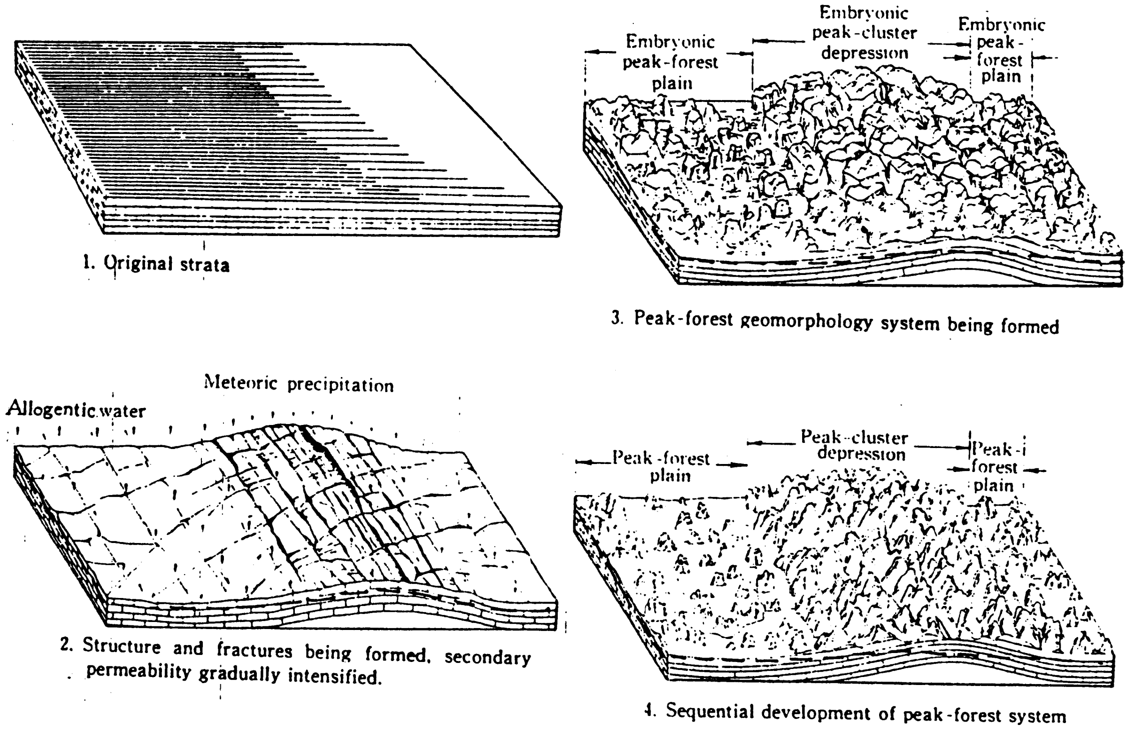


Fig.10 Simple model showing formation and development of peak-forest karst (with a gentle fold and its structural differentiation as an example) Cartographer: Qin Houren

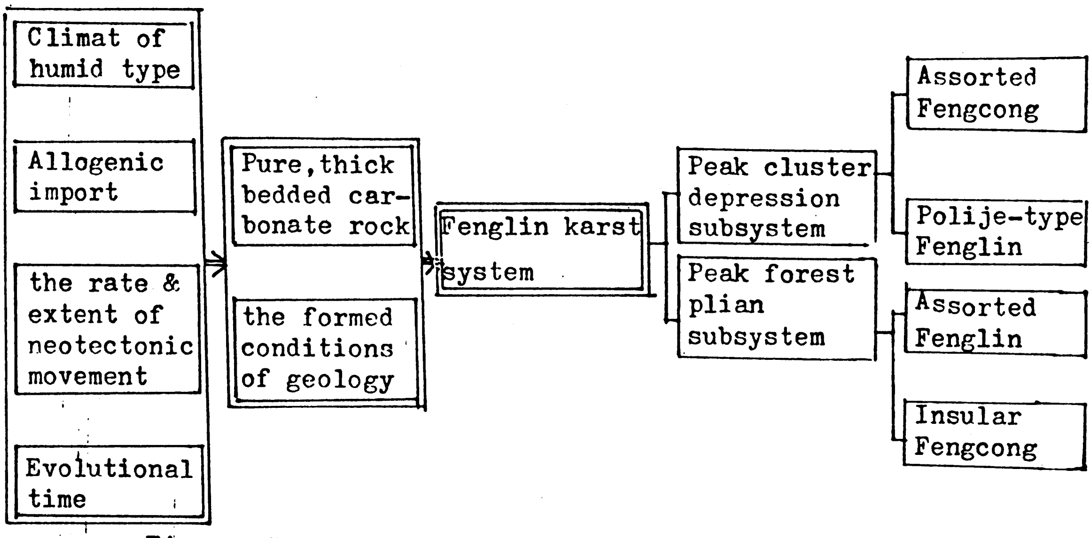


Fig. 11 The system of Fenglin karst landscapes with the conditions of development of Fenglin karst

References

1. Lu Yaoru 1986 Model of karst geomorphological evolution in China. Geographical Research Vol 5 No 4 25-34

2. Zhu Dehau 1984 On substance of different views in studying tropical karst landforms - case of karst features of Peak Forest in Guilin area. Carsollogical Sinica Vol 3 No 2 74-76

3. Zhu Dehau 1985 Some knowledges of morphology and evolution of Fengcong (Peak-Cluster) and depressions - taking some regions in Guangxi as example. Karst Geomorphology and Caves. 57-64

4. Zhu Xuewen, Zhu Dehau and Ru Jinwen 1980 The karst landform of Peak-Forest and its development in Guilin district. 107-119

5. Zhu Xuewen, Wang Xunyi, Zhu Dehau, Gong Zizhen and Qin Houren 1988 Study on karst geomorphology and caves in Guilin. 249 Geological Publishing House

6. Zhu Xuewen 1988 Guilin Karst. 188 Shanghai Scientific and Technical Publishers

7. Zhu Xuewen 1990 Synopsis of Cuba karst. Carsologica Sinica Vol 9 No 2

8. Ren Meie, Liv Zhenzhong 1983 Introduction of Karstology. 330

9. Chen Wenjun 1987 Brief introduction to karst geology of Guilin. 30-39 Selected papers fromthe 2nd All-Chin Symposium on karst sponsored by the Geological Society of China

10. Yang Mingde 1985 Texture and evolution of karst geomorphology in Guizhou Plateau 22-29. Karst Geomorphology and Speleology Scientific Publishers

11. Yang Minde, Zhang Yingjum, P. Smart, T. Waltham 1987 Karst geomorphology of western Guizhou, China. Carsologica Sinica Vol 6 No 4 345-352

12. Yuan Daoxian, Cai Guihong 1988 The science of karst environment 332, Chongqing Publishing House

13. Yuan Daoxian 1984 On Fenglin Topography. Geology of Guangxi, First Issue 79-86

14. Gao Daode, Zhang Shicong Karst in South Guizhou, 205 Guizhou people's Publishing House

15. Zhen Zhaoxuan 1982 The karst morphological characters in south China. Carsologica Sinica Vol 1 No 1 27-32

16. Zhang Shouyue, He Yubin 1979 Study on China karst 333. Scientific House

17. Wei Hongsen 1983. Introduction of methodology of systems science, 174. China People's Publishing House

18. I. Prigogine, I. Stengers 1984 Order out of Chaos, Bantam Books Inc.

19. I. prigogine 1980 From being to becoming: time and complexity in the physical sciences. by W.H. Freeman and Company

20. Cvijic, J 1918 Hydrographic souterraine et evolution morphologizue du karst. Rec. Traw Inst. Geog. Alpine 6(4)

21. Davis W.M 1899. The Geographical Cycle, Geog. Jour. 14, 481- 504

22. Ford,D and Williams, P. 1989 Karst Geomorphology and Hydrology. Unwin Hyman Ltd London 423-545

23. Jakucs, L. 1977 Morphogenetics of karst regions; variants of karst evolution. budapest, Akademiaj Kiado 284

24. Sweeting, M.M 1989 Cone and Tower karst of south China. Geomorphy Rev. Vol 3 No 2 2-6

25. Zhang Zhigan 1980 Karst types in China, Geo. Journal 4,6: 541-570

THE MURONGA LAVA FLOW

M. Godwin and L.M. Pearson.

ABSTRACT; The Muronga Crater, together with a number of closely associated pyroclastic cones, lies in the south central region of the Tertiary McBride volcanic province in North Queensland, Australia.

Muronga's basalt lava sheet is one of the three most recent flows of the McBride Plateau which has a thickness of approximately 600 m.

This paper outlines the three lava tubes, the lava caves already located, some meteorological data and some of the flora and fauna in the locality.

INTRODUCTION

The Muronga Crater is located on Lava Plains Pastoral Holding some 5 km west of the Kennedy Developmental Highway approximately 100 km south of Mt Garnet in North Queensland (Fig 1).

This crater is adjacent to the large flat rimmed scoria cone, Mt Tabletop. It is one of a group of pyroclastic cones apparently associated with the Muronga eruption (Fig 2).

The basaltic lava outflow is generally in a south westerly direction from the crater reaching the southern margin of the McBride Plateau. The main flow is in a southerly direction for 10 km and before turning in a south south westerly direction. The overall length extending for approximately 34 km with a 400 m drop in elevation from the vent to the toe of the flow. The present Spring Creek and Lagoon Creek have been displaced by this flow. A subsidiary flow heads west south west to the north of an older Volcano cone, Mount McMaster, for a distance of 19 km filling a former gentle valley now bounded by Emu and Rocky Creeks.

There are no significant easterly flows from this vent although there have been some minor flows down previous watercourse valleys. Only one of these has crossed the Kennedy Developmental Highway along Wyandotte Creek (Fig 3).

The edge of the flow is marked with thick but narrow width lava tongues. The formation of these is attributed to the high viscosity of the flow. This viscosity may also be responsible for the rough surface of the flow which is still devoid of soil cover in many places and covered with deciduous vine thicket. This thicket has also been noted on aa lava.

Muronga lava flow is one of the three most recent of the eruptions which created the 600 m thick McBride plateau. Isotope dating has established that volcanic activity here commenced approximately 8 million years ago and that the last flow was from Kinrara Crater less than 80,000 years ago (Griffin and McDougall).

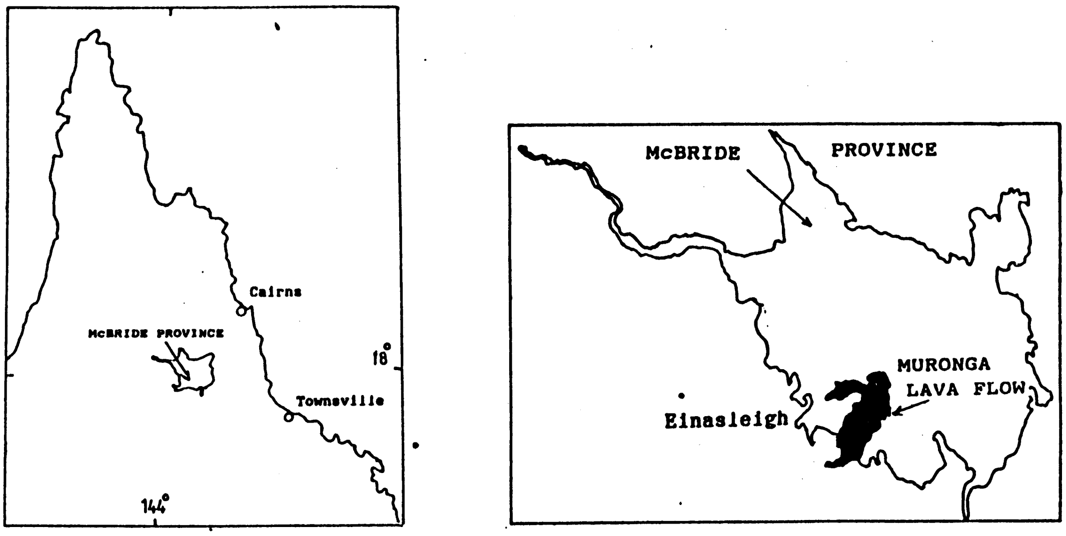


Fig 1 Locations of Muronga lava flow and the McBride Volcanic Province.

Fig 2 Muronga lava vent and the associated pyroclastic cones. Mt Tabletop is the central, flat rimmed cone. The lava vent is between Mt Tabletop and the cone to its right. Dark patches on the foreground are deciduous vine thicket in lava channels. The northern edge of flow is visible as dark line just above ash cones.

Griffin and McDougall[1] obtained an age of about 150,000 years for Muronga basalt so that it is of similar age to the Undara flow which is dated at about 190,000 years.

MURONGA'S ARTERIAL SYSTEM

Some 60 km of lava stream channel or collapsed lava tubes are evident on aerial photographs of the flow, which reached the southern margin of the McBride Plateau.

The Eight Mile Creek lava tube runs almost due south from Muronga Crater on Lava Plains Holding.

No exploration has been done on this tube yet. From images on aerial photographs parts of this tube appear to have been open lava stream channels.

The Spring Creek lava tube runs south south west entering Spring Creek Holding at about the position of Collins No 1 Cave and east of Mt Wheeler, forking around Four Mile Plain.

Seven open and accessible parts of the tube ranging in length from 17 m to 370 m in a 1.5 km segment running south from the original discovery of the obvious collapse. Access to two further sections, one of 80 m and the other of 200 m was given by moving boulders in the entrances. Further details and maps are included in Appendix 1.

The Emu Creek lava tube runs south west from Muronga between Mt McMaster and an unnamed volcano some 4 km north of it. The tube then forks around Emu Hill.

Only 2 km of this tube has been searched. To date two caves have been located in the segment of tube on the northern branch near Emu Hill. One is in the up-flow end of a collapse located by a Rosella Plains Station pilot when mustering cattle and is 30 m long. The other is in the down-flow end of a collapse (Grid Ref St Ronans 7861:460570) and while blocked by a boulder exhausts very warm air and has a strong bat guano odour.

METEOROLOGICAL DATA

Measurements were taken on the 10th and 11th August 1985 using wet and dry thermometers outside the entrance to Collins No 1 Cave and at 4 locations in the tube and are as set out in Appendix 2. Again on 25th August 1985 measurements were obtained in Two Ten Tunnel and Handful Cave.

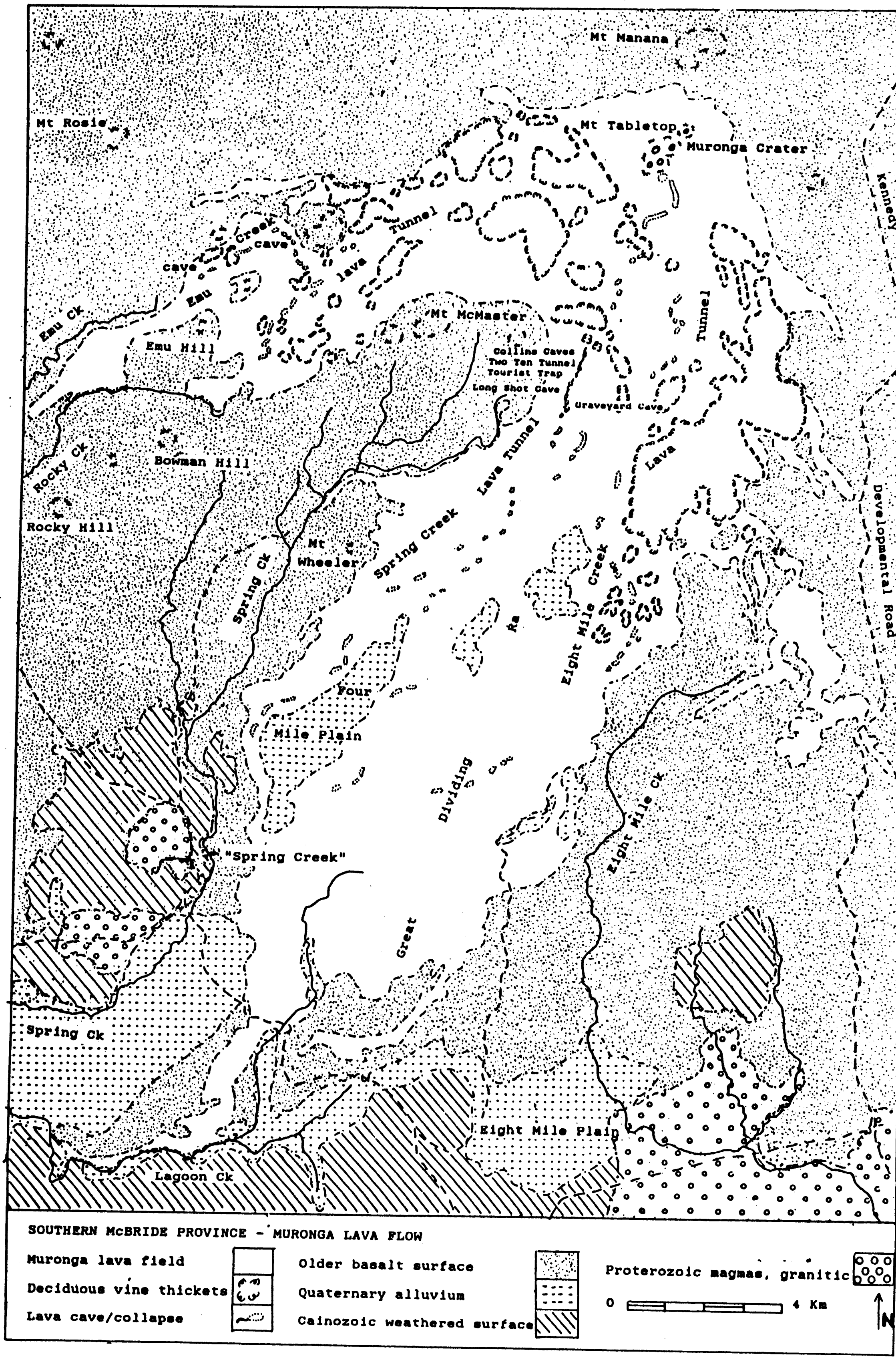


Fig 3 Southern McBride Volcanic Province - Muronga lava flow and surrounding geology.

FLORA

The vegetation of the area has two distinct types.

Eucalypt woodland described as Land Unit Bb 3 of the Boonderoo Land System (Appendix IV) in areas subject to periodic fires

Eeciduous vine thicket described as Land Unit Ca 2 of the Toomba Land System (Appendix IV) on rocky outcrops where fires are absent

The landscape and vegetation are more fully described in Appendix III.

Details of the five land systems which relate landscape with vegetation are given in Appendix IV and the map (Fig 4, Appendix IV) shows the extent of the systems of land units in the area.

FAUNA

Details of fauna sighted are given in Appendix V.

These details are derived from obversations on only several visits and for verterbrates would include only some hundred sightings giving few individuals except for bats which in some cases consist of large colonies.

On 10th August 1985 a population of about 1000 bats (*Miniopteris sp* mainly *M. shreibersii*) were noted but were not present two weeks later, perhaps disturbed by the visit.

Inverterbrates have been sampled in a number of Chillagoe Caving Club Inc. trips to the area or in association with the American Explorers Club Chillagoe Expeditions. Some one thousand specimens have been collected. Many of these specimens are still awaiting identification or indeed classification.

An interesting and possibly troglobitic species of peripatus, which shares features with both the earthworms and arthropods, was found by Howarth and Irvin deep in Two Ten Cave and in the stagnant air zone of Long Shot Cave.

In Hoch and Asche 1988 discussion on Undarana species suggests that the *U. collina* in the Muronga flow is nearly flightless and shows no reaction to light while the *U. rosella* in the 30 km distant Undara flow is capable of short sustained flight and is occasionally attracted to bright light. Thus these species in adjacent lava flows show different levels of cave adaption. They have contrasted this with another cixiid, *Solonaima baylissa*, the most cave adapted species encounteres thus far. Though blind and flightless and thus obligated to the cavernicolous existance it is found in both the Undara and Muronga lava tubes. Further, morphological similarities between the two populations suggest that there is a continuing gene flow between them although there is no obvious connection between the Undara and Muronga lava tube systems.

ACKNOWLEDGEMENTS

Messrs G. & D. Collins and staff of Rosella and Spring Creek cattle stations for reporting the existence of the lava tubes and assistance with aircraft to relocate known entrances.
Messrs D. Irvin, T. Robinson and A. Cummins of Chillagoe Caving Club Inc. for organisation of exploratory expeditions to the flow and for provision of survey details on the caves.

Mrs J. Godwin for typing the land system descriptions which otherwise would never have been completed for this paper. Her patience with us in our efforts to produce this paper are much appreciated.

Mrs A. Atkinson for provision of the aerial photo by HJ Lamont of James Cook University.

APPENDIX I - LAVA TUBES CAVES
(Caves listed from north to south. Maps follow listing)

SPRING CREEK LAVA TUBES

Collins No. 1 Cave

This tunnel was located by Gerry Collins in the northern end of the collapse that he spotted from the air. It is 150 m in length running northwards and contains a blind fork and one which reconnects with the main passage at the extremity of which partial ventilation can be noticed. When visited on 10.08.85 about 1,000 bats (mostly *Miniopteris sp* mainly *M. Shreibersii*) were in residence. These created a spectacle as they departed the cave entrance at twilight to feed. They resembled bees leaving a hive. (This visit may have created a disturbance as they were not present during a visit a fortnight later). The cave is obviously a regular roost as its guano deposits are substantial. The cave interior provided a habitat for several arthropod species one of which (a fly) was parasitic on bats. Arthopods were collected on behalf of the Queensland Museum and the Bishop Museum (Hawaii).

Collins No. 2 Cave

This cave was located in the southern end of the same collapse as Collins No. 1 Cave and about 100 m from the entrance of that cave. It runs southward for about 150 m with a blind branch leading off to the southwest at about 40 m from the entrance. From here on for the next 20 odd metres the tunnel is occupied by a pile of fallen rocks. The narrow end section is reached via a short crawl over a red soil floor. Several species of arthropod were collected from this cave and a substantial difference between this and Collins Cave No 1 is indicated. Of interest was the existence of a myglomorph spider well into the dark section of the cave.

Climatic observation - at 3.45pm (10.08.85) the temperature inside the cave close to the entrance was 20.5°C and the relative humidity 100%.

Two-Ten-Tunnel (located 10.08.85 entrance excavated 25.08.85
P. Cummins, L. Brown, M. Godwin)

The entrance to this cave is 200 m south of the collapse forming the southern end of Collins No. 2 Cave. The tunnel leads a slightly dog-legged course northward for 210 paces from an excavated entrance at the northern end of a 25 m long scrub-filled collapse depression. This depression blocks the northern end of 'Handful Cave'. The cave floor contains only a light covering of two different types of guano. A few bats were in residence at the time of first inspection. Climatic observations - at 10.30am on 25.08.85 the temp and relative. humidity 30 m inside this cave were 22.5°C and 87% respectively while outside the entrance the measurements were 24.0°C and 74% respectively.

(It was noticed that the bleached stems of germinated in-washed seeds reacted by quick movement when a torch was brought close to them). Dr Frank Howarth found the caterpillar-like ancient life form, peripatus here in 1986.

Handful Cave (Excavated by A & W Cummins and D. Brown 25.08.85)

The entrance (excavated) to this section of the tunnel is about 100 m south of the entrance to Two-Ten-Tunnel. It is slightly dog-legged and runs northward toward Two-Ten-Tunnel for 83 m (approx). Drainage rills indicate that drainage is towards the middle of the cave. Climatic measurements in the middle of the tunnel at 10.30am on the 25.08.85 - Temp 23.0°C Relative humidity 91%.

A woodland vegetated collapse southward leads to "Tourist Trap Cave".

Tourist Trap Cave (located by J. Sammarco - an American tourist 11.08.85)

The entrance is in the same collapse depression as 'Handful Cave' and 140 m SSW of it. The tunnel is less than straight and about 100 m in length. It contains two sections of arching 'false floor' A small population of about a dozen orange bodied bats (*Rhinolophus megaphyllus*) as well as two grey bodied bats (*Miniopterus sp.* Juveniles) were in residence 11.08.85. In one section termite galleries extended down the wall from the roof to the red soil floor.

Daylight Cave (located by J. Sammarco 11.08.85)

A small section of collapsed roof gives access to this cave which extends northward about 20 m before being blocked and southward about 40 m where it has another entrance which leads to a collapse at the northern end of 'Long Shot Cave'. An echidna burrow (in use) is located in the mid-section of this cave.

Long Shot Cave (located by J. Sammarco 11.08.85)

This cave is about 370 m in length. The entrance is amongst shrubbery in the southern end of a depression of vine thicket running northwards to "Daylight Cave" 40 m away. The cave has much biological activity no-doubt generated by its high level of detritus in-washed through the roof in places. In fact the roof consists of soil in one place hinting at a very thin roof. Tree roots dangle through the roof in many places and the floor is composed of a deposit of soil and paler material (decomposed basalt?). There are a number of arching 'False Floors' one of which requires a crawl to negotiate. The southern half of the tunnel is noticeably warmer than the northern half and the high CO_2 level (2.8%) generates heavy breathing. A few bats (*Rhinolophus*?) were in residence 11.08.85. A short pool of water with a muddy bottom occurs at the southern end. Dr Frank Howarth and D. Irvin found the caterpillar-like ancient life-form, peripatus here in 1986. It is probably a new species. They also located here troglobitic singing crickets previously known only from South East Asia, blind plant hoppers similar to those from Bayliss and Nasty caves in the Undara system and a large eyeless spider known from Bayliss Cave.

Impatience Cave (located by A. Cummins 24.08.85)

The entrance is about 400 m due south (174^{o} mag) of the entrance to 'Long Shot Cave'. The cave is short (only 17 m) and runs south. The entrance rock scree runs to the end of the cave. It contained three bats (possibly *Eptesicus*) at the time of location.

Graveyard Cave (located by P. Cummins 24.08.85)

This cave is dog-legged, contains an arching false floor, a small daylight through a collapsed roof and an upper and lower level passage way in one section. The remains of a common brushtail possum were found in the upper passage. Tracks and dung of the echidna were found at the dark or southern end of the tunnel. A few bats (possibly *Hipposideros ater*) were in residence at the time of location.

Beyond here there is a marginal increase in slope and lava tongues become more numerous.

EMU CREEK LAVA TUBE

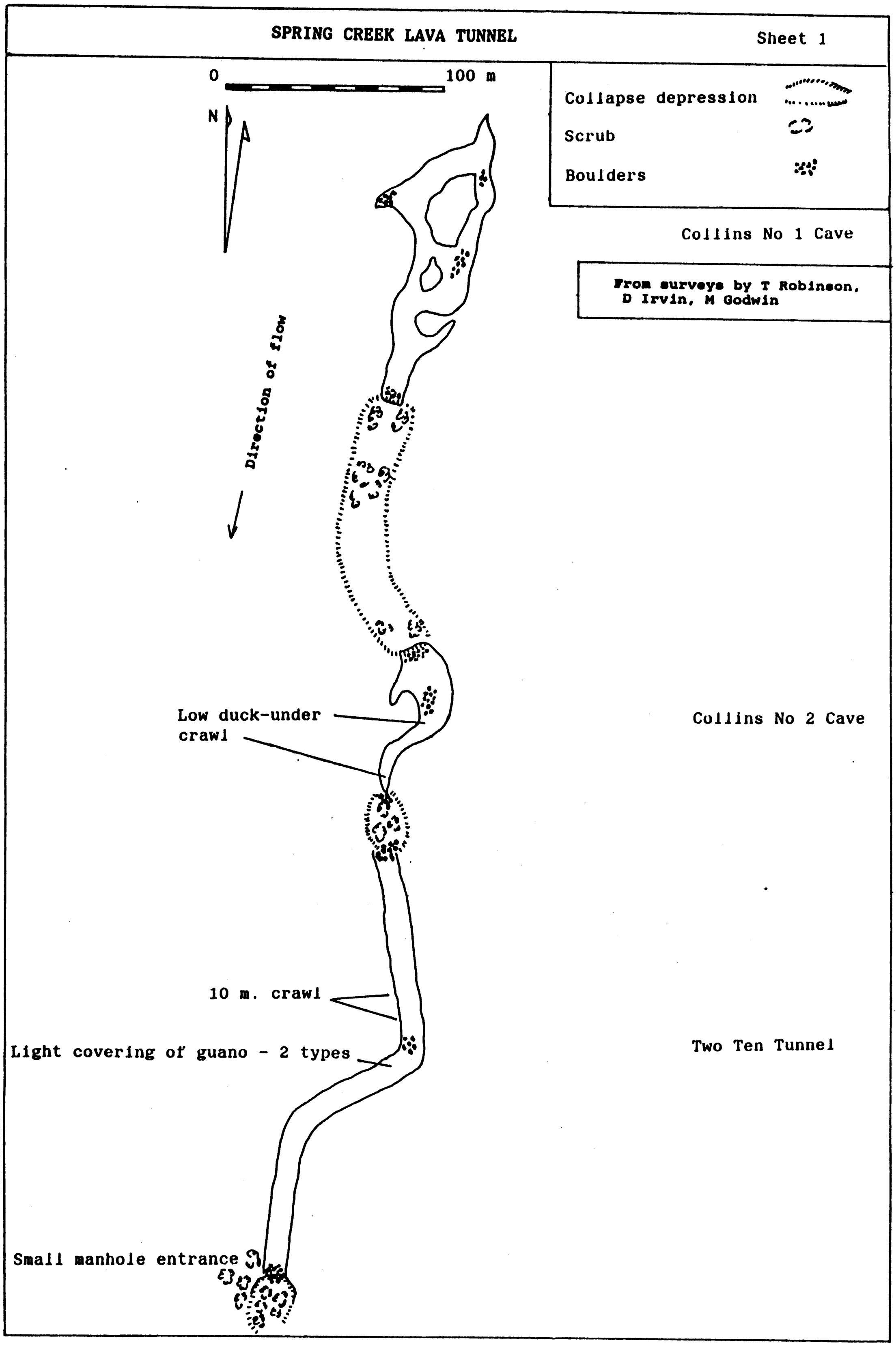
This tunnel system flowed south west from Muronga eventually forking around either side of Emu Hill. Two caves have been located in the north arm of the fork but less than 2 km of this tunnel has been searched.

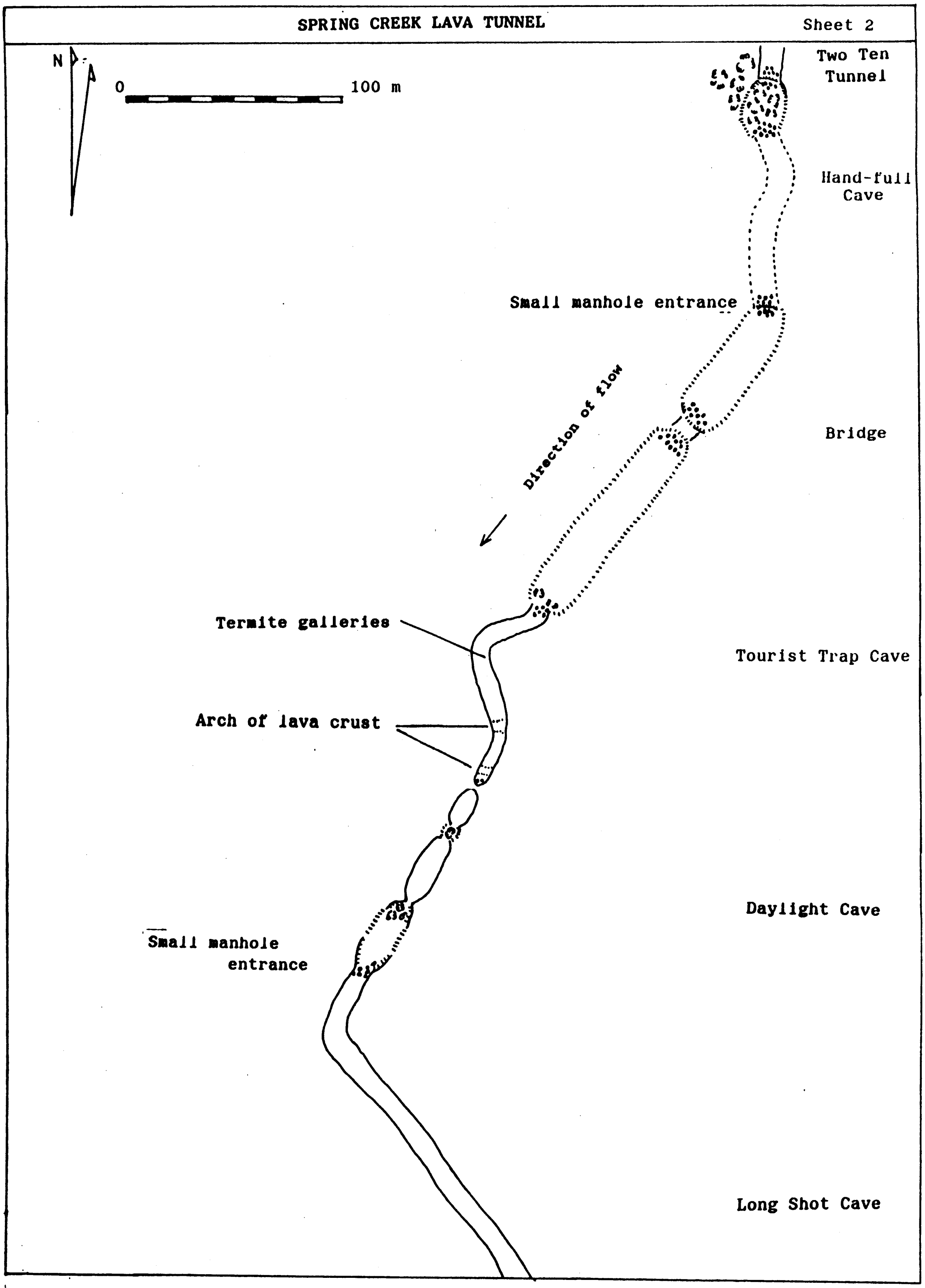
The first is in the down flow end of a collapse at grid ref. St Ronans 7861:460570. A boulder blocks the tight entrance. The cave exhausts very warm air and when visited in Jun 1990 a very strong bat odour could be detected 40 m from the entrance.

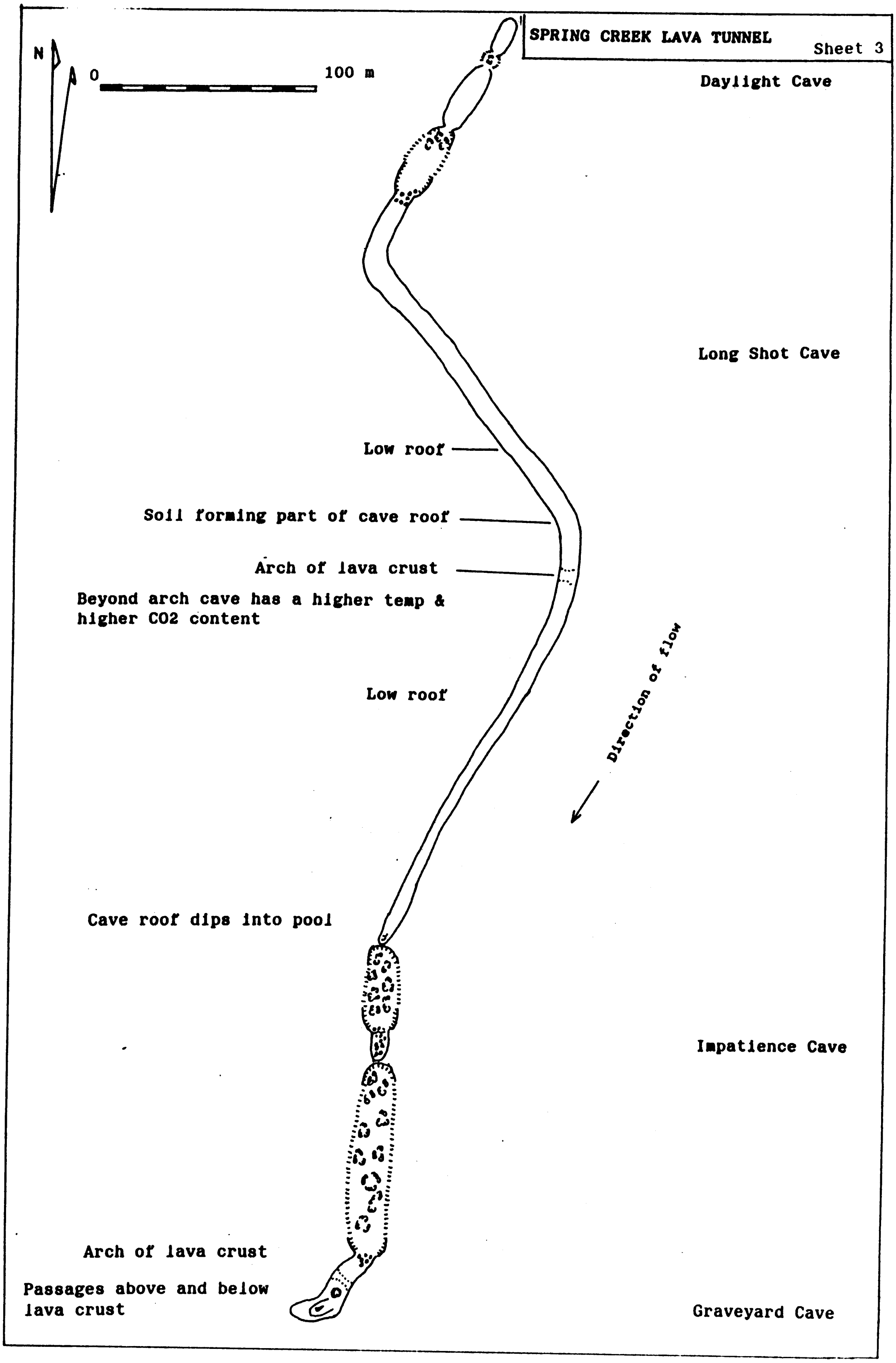
The second was located by the Rosella Plains mustering pilot from the air at grid ref. St Ronans 7861:440563. It is in the up-flow end of a collapse and is about 30 m long.

EIGHT MILE CREEK LAVA TUNNEL

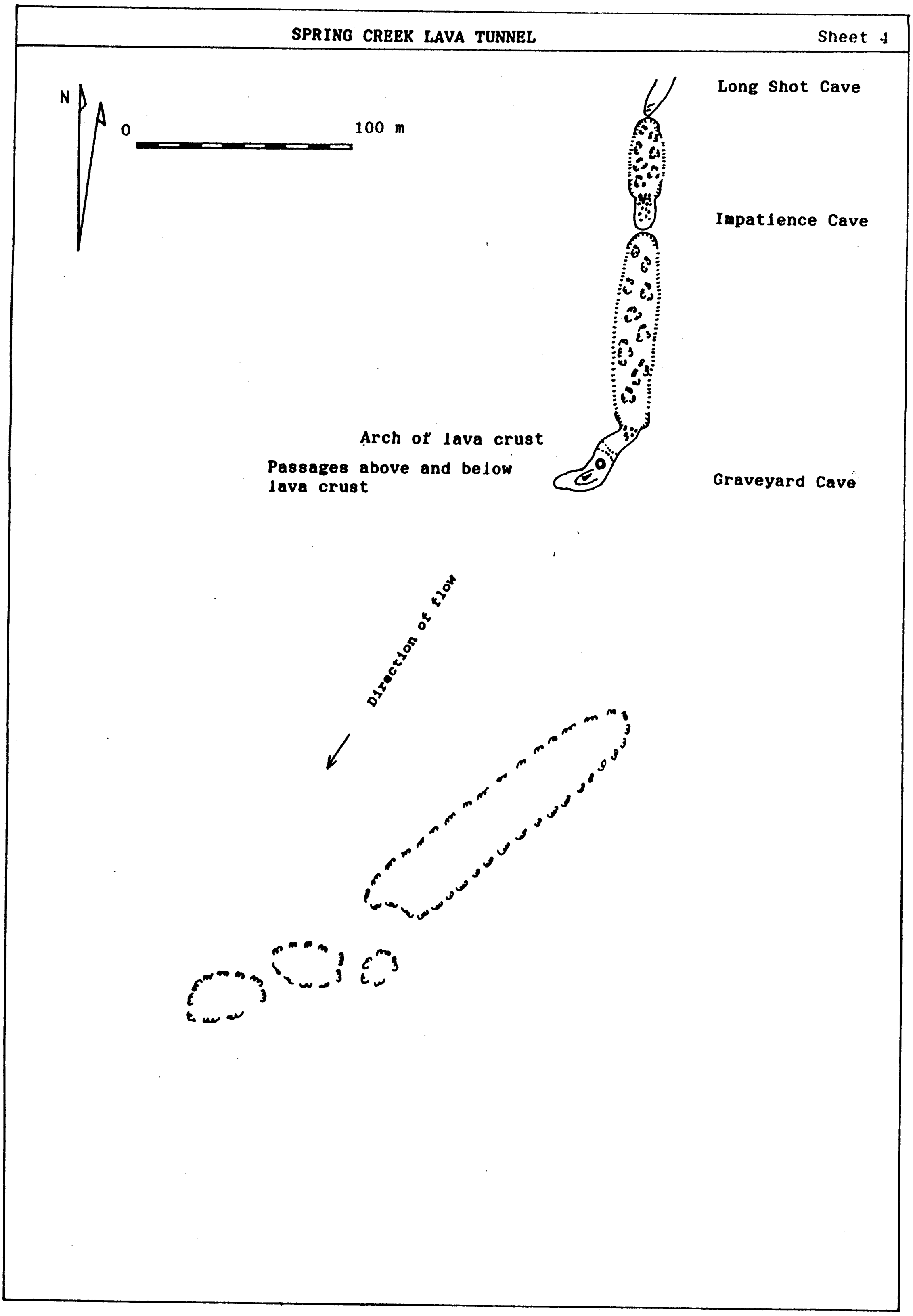
This system has not been searched as yet.


SPRING CREEK LAVA TUNNEL
Sheet 1
0
100 m
N
Collapse depression
Scrub
Boulders
Collins No 1 Cave
From surveys by T Robinson, D Irvin, M Godwin
Direction of flow
Low duck-under crawl
Collins No 2 Cave
10 m. crawl
Light covering of guano - 2 types
Two Ten Tunnel
Small manhole entrance


SPRING CREEK LAVA TUNNEL
Sheet 2
N
0
100 m
Two Ten Tunnel
Hand-full Cave
Small manhole entrance
Direction of flow
Bridge
Termite galleries
Tourist Trap Cave
Arch of lava crust
Daylight Cave
Small manhole entrance
Long Shot Cave



SPRING CREEK LAVA TUNNEL
Sheet 3
N
0
100 m
Daylight Cave
Long Shot Cave
Low roof
Soil forming part of cave roof
Arch of lava crust
Beyond arch cave has a higher temp & higher CO2 content
Low roof
Direction of flow
Cave roof dips into pool
Impatience Cave
Arch of lava crust
Passages above and below lava crust
Graveyard Cave


SPRING CREEK LAVA TUNNEL
Sheet 4
N
0
100 m
Long Shot Cave
Impatience Cave
Arch of lava crust
Passages above and below
lava crust
Graveyard Cave
Direction of flow

APPENDIX II - METEOROLOGICAL DATA

DATE	10-Aug 1985				11-Aug 1985	
TIME	2.00pm		8.30pm		7.00am	
CLIMATIC MEASUREMENT	Temp (C)	Rel. Hum. (%)	Temp (C)	Rel. Hum. (%)	Temp (C)	Rel. Hum. (%)
SITE						
Outside entrance (shade)	29.0	85	18.0	80	14.5	94
Just inside entrance	24.5	85	17.0	95	15.0	94
End of the first eastern (blind) passage	20.0	100	16.5	96	15.0	94
Second fork	19.0	100	16.0	100	15.0	94
Two thirds along eastern (main) passage	19.0	100	16.0	98	15.5	94

Table 1 1985 climatic measurements - Collins No 1 Cave.

DATE	25th Aug 1985	
TIME	10.30am	
CLIMATIC MEASUREMENT	Temp (C)	Rel. Hum. (%)
SITE		
10m inside entrance of Two Ten Tunnel	22.5	87
Entrance depression Two Ten Tunnel	24.0	74
Central part of Handful Cave	23.0	91

Table 2 1985 climatic measurements -Two Ten Tunnel and Handful Cave

APPENDIX III - LANDSCAPE AND VEGETATION (see Perry et. al.)

(a) Eucalypt Woodland on Shallow Rocky Red Soils

The characteristic Land Unit of the tunnel area is the previously mentioned lava plain which is slightly undulating or stepped according to the configuration of various underlying flows. Lava tongues are also evident. Rock covers 50-90% of the surface. The soil is fairly shallow and also occupies the rock joints. It is a red non-cracking clay (Kraznozem - Uf 6.31 (northcote)) whose infiltration and drainage properties are adequate.

The vegetation is a grassy ironbark woodland.

Canopy Species

Narrow leafed ironbark (*Eucalyptus crebra),* variable barked bloodwood (*Euc. erythrophloia),* batwing coral tree (*Erythrina vespertilio*), Silver oak *(Grevillea parallela*).

Understory Species

Variable barked bloodwood, Silver oak, bootlace oak (*Hakea lorea*), (*Grevillea mimosoides*), beefwood (*G. striata*) rare, prickly pine (*bursaria incana*), cocky apple (*Planchonia careya*).

Ground Cover Species

Kangaroo grass (*Themeda triandra*) dominant; black spear grass (*Heteropogon contortus*); giant spear grass (*Heteropogon triticeus*), (*Panicum* possibly *mindanaense*); (*Alysicarpus sp.*), (*Indigofera sp.*), white spear grass (*Aristida sp.*)

The Land Unit is subject to periodic fires.

Perry et al have described this as Land Unit 1 of the Boonderoo Land System. This paper refers to it as L/U Bb 3 (Appendix IV).

(b) Deciduous Vine Ticket on Broken Basalt Lava Where Fires are Absent

On the fresher flows and lava tongues which are little weathered, and in the depressions of the collapsed tunnels, the surface is composed of broken basalt inaccessible to fire. Reddish-brown clay (Kraznozem) soils accumulate deep down between boulders and Deciduous Microphyll Vine Ticket is supported here:

Canopy Species
(*Celtis paniculata*), kurrajong (*Brachychiton australe*), helicopter tree (*Gyrocarpus americanus*), burdekin plum (*Pleiogynium timorense*), fig (*Ficus obliqua*) and (*F. virens*), lacebark (*Brachychiton chillagoensis*), whitewood (*Atalaya hemiglauca*), boonaree (*Heterodendrum oleifolium*).

Understory Species
(*Mallotus philippensis*), grey boxwood (*Drypetes lasiogyna var. australascus*), sandpaper fig (*Ficus opposita*), Shining leaf stinging tree (*Dendrocnide photinphylla*), poison peach (*Trema aspera*), ebony (*diospyros ferrea var. humilis*), (*Alectryon connatus*), wilga (*Geijera salicifolia*), (*Rapania howittiana*), (*Cupaniopsis anacardioides*), (*Antidesma parviflorum*), wallaby apple (*Citriobatus spinescens*), Strychnine bush (*Strychnos axilaris*), currant bush (*Carissa ovata*), *Olea paniculata* (native olive).

Vines
Yam (*Dioscorea transversa*), (*Rhyssopteris timorensis*), grapes (*Cissus oblonga, C. opaca, C. hastata, Tetrastigma sp. (C2848)*), (*Stephania aff. bancroftii*), (*Jasminum racemosum*), (*Eustrephus latifolius*), wonga vine (*Pandorea pandorana*), (*Deeringea amaranthoides*).

Epiphytes
(*Dendrobium liguiforme*), pencil orchid (*Dendrobium teretifolium*), (*Sarcochilus hillii*).

Lithophytes

(*Platycerium veitchii*), (*Cheilanthes vella*).

Ground Cover species

(*Plectranthus sp. aff. parviflorus*), Chaff flower (*Achyranthes aspera*).

Perry et al refers to this as Land Unit 1 of the Toomba Land System. This report refers to it as L/U Ca 2 (Appendix IV).

APPENDIX IV - LAND SYSTEMS OF THE MURONGA LAVA FLOW AREA

The Land Systems were originally described by Perry et al. 1954, based on geological and other data available at the time. Subsequent geological studies together with additional habitat studies of Godwin, 1985 and Godwin and Goosem, 1990 have enabled the production of a more comprehensive description and maps as set out below.

The Toomba and Boonderoo land systems occur on the Muronga flow while the Rosella, Kilbogie and Yanman land systems are in the surrounding adjacent areas or inliers.

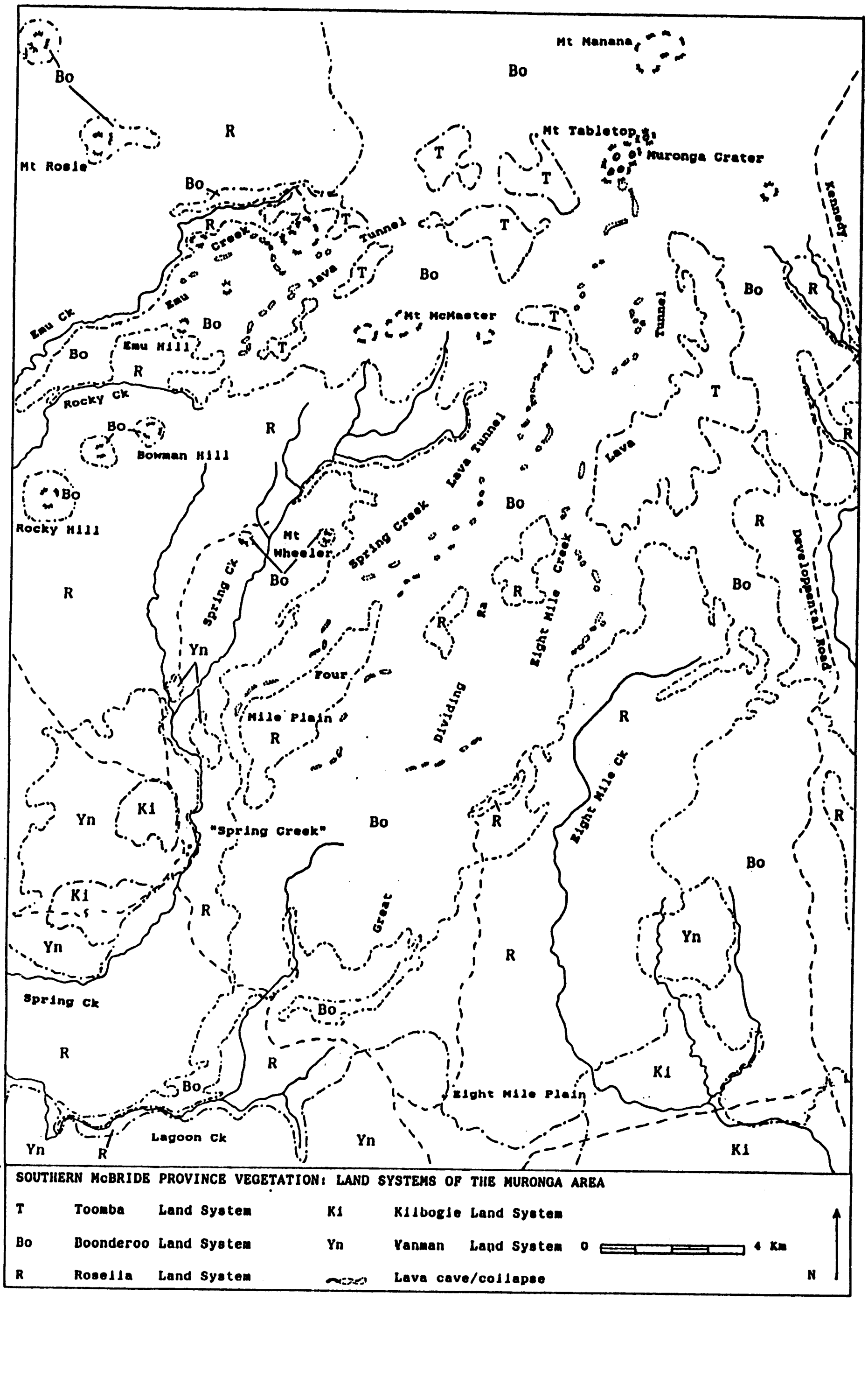
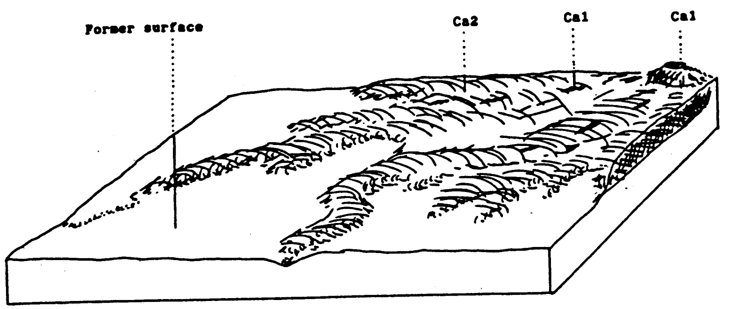


Fig 4 Southern McBride Province - Land Systems of Muronga area.

TOOMBA LAND SYSTEM

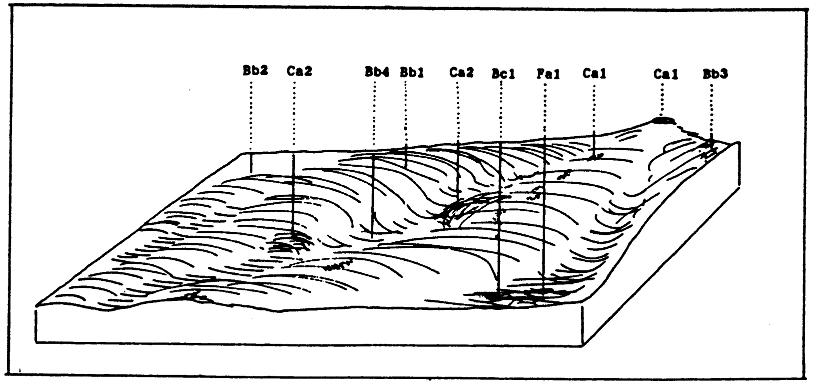
TOPOGRAPHY	Rough lavafield
GEOLOGY	Quaternary basalt.
GEOMORPHOLOGY	Constructional volcanic land surface. Little weathered lava flows.
DRAINAGE	Nil. All Subsurface.
ELEVATION	300 - 800m. Local amplitude < 30m.
CLIMATE	Mean annual rainfall 470 - 590 mm. Mean annual growing season: agricultural 15 - 22 wk., pastoral 20 - 27 wk.



Land Unit	Area	Land Forms	Soils	Vegetation
Ca 2	Large	Very rough, little-weathered basalt plateaux and plains (Fire free)	Rock	Deciduous microphyll vine woodland
Ca 1	Very Small	Central-type vents (Fire free)	Rock	Deciduous microphyll vine woodland

BOONDEROO LAND SYSTEM

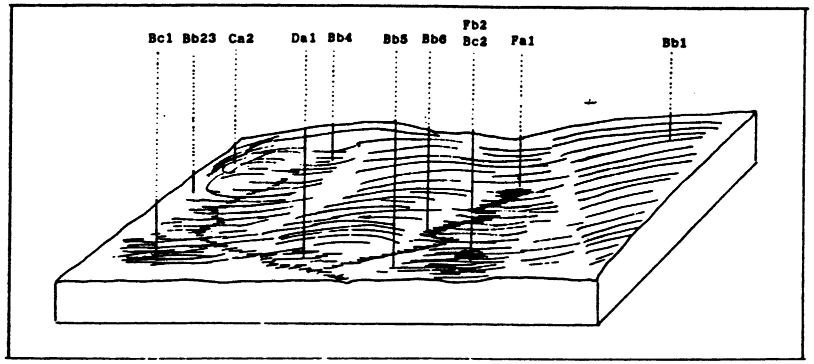
TOPOGRAPHY	Red basalt lava plains
GEOLOGY	Tertiary and Quaternary basalt.
GEOMORPHOLOGY	Constructional volcanic land surface. Basalt plains and plateaux. Pliocene and pleistocene surface.
DRAINAGE	Sparse.
ELEVATION	470 - 1000m. Local amplitude < 70m.
CLIMATE	Mean annual rainfall 500 - 762 mm. Mean annual growing season: agricultural 10 - 25 wk., pastoral 15 - 35 wk.



Land Unit	Area	Land Forms	Soils	Vegetation
Ca 1	V.Small	Vents, Collapses	Basalt rock	Deciduous microphyll vine woodland
Ca 2	Small	Boulder field (fire free)	Basalt rock & soil	Deciduous microphyll vine woodland
Bb 1	Large	Plain	Lang:Kraznozem	Ironbark woodland: E.crebra, E.erythrophloia, E.papuana, Grevillea parallela, Themeda triandia Heteropogon contortus.
Bb 2	Small	Plain	Lang:Kraznozem	Open woodland: E.orgadophila, E.leptophleba
Bb 3	Small	Very low rises	Skeletal: Clay & Rock	Ironbark woodland: E.crebra, E.erythrophloia, E.papuana, Heteropogon contortus, Grevillea parallea, Themeda triandra
Bc 1	Small	Lower areas in the plain	Rosella:Calcareous Cracking Clay	Downs woodland: E.orgadophila, bloodwood (Grassy open woodland)
Bb 4	Small	Lower areas in the plain	Glendhu: Brown Clay	Ironbark woodland with box: E.crebra, E.erythrophloia, E.papuana, Themeda triandra, Heteropogon contortus, Bothriochloa Sp.
Fa 1	Small	Very shallow depressions	Spring & Tobermorey: Calacreous Clay loam	Couch grass, short grass & lagoon vegetation: Cynodon dactylon, Imperata cylindrica, Cyperus Sp., Ophiuros exaltatus

ROSELLA LAND SYSTEM

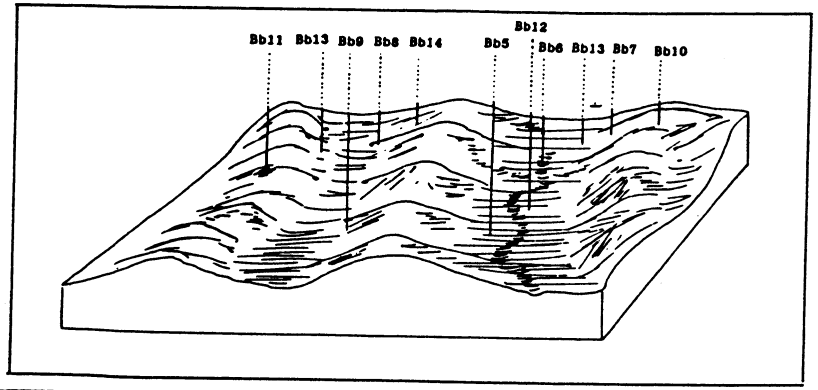
TOPOGRAPHY	Basalt plains and plateaux with black soil
GEOLOGY	Tertiary and Quaternary basalt.
GEOMORPHOLOGY	Constructional volcanic land surface. Pliocene and pleistocene surface.
DRAINAGE	Sparse.
ELEVATION	470 - 1000m. Local amplitude < 70m.
CLIMATE	Mean annual rainfall 500 - 762 mm. Mean annual growing season: agricultural 9 - 25 wk., pastoral 14 - 35 wk.



Land Unit	Area	Land Forms	Soils	Vegetation
Ca 2	Small	Boulder field (fire free)	basalt rock & soil	Deciduous microphyll vine woodland
Bc 1	Large	Plain	Rosella: Calcareous Cracking Clay	Downs woodland (Grassy open woodland) Eucalyptus orgadophila, bloodwood
Bc 2	Moderate	Alluvial plain	Rosella: Calcareous Cracking Clay	Grassy open woodland :E.papuana, E.erythrophloia, Coelorachis Sp.
Fb 2	Moderate	Plain (alluvial)	Rosella: Calcareous Cracking Clay	Grassland (With emersent Eucalypts): Coelorachis rottboelioides
Bb 5	Small	Plain - levee	Rosella: Calcareous Cracking Clay	Medium woodland of box & bloodwood: E.terminalis, E.leptophleba, E.microneura
Bb 1	Small	Plain	Lang: Kraznozom	Ironbark woodland: E.crebra, E.erythrophloia, E.papuana, G.parallela, G.mimosoides, H.contortus, T.triandra
Bb 4	Small	Plain	Glendhu: Brown Clay	Ironbark woodland: E.crebra, E.erythrophloia, E.papuana, G.parallela, G.mimosoides, H.contortus, T.triandra
Bb 6	Small	Stream Channel		Fringing woodland: E.camaldulensis;Casuarina cunninghamiana, Arundinella nepalensis
Da 1	Small	Levee/depression	Rosella: Calcareous Cracking Clay	Ti tree scrub: Melaleuca bracteata
Fa 1	Small	Very shallow depressions	Spring & Tobermorey: Calcareous Clay loam	Couch Grass & Lagoon vegetation: Cynodon dactylon, Imperata cylindrica, Cyperus Sp.
Bb23	Small	Colluvial aprons from adjacent basalt	Gilgae complex - Cracking/ non-cracking Clay	Ironbark/box woodland complex: E.crebra, E.brownii; Coelorachis rottboelioides, blue grass

KILBOGIE LAND SYSTEM

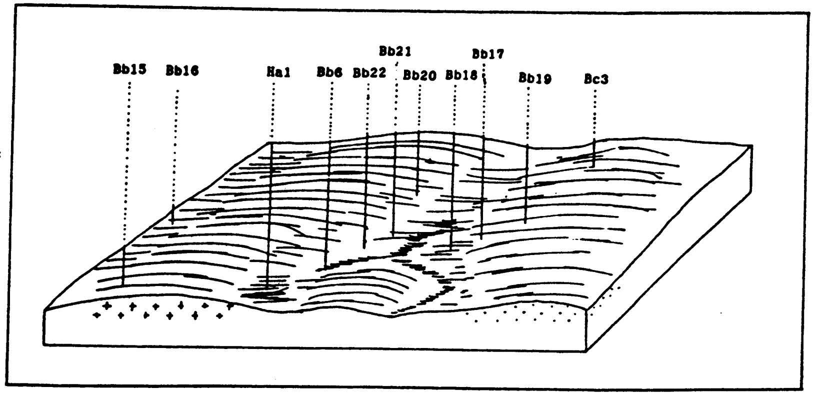
TOPOGRAPHY	Timbered, irregular plains
GEOLOGY	Pre-Cambrian etheridge complex. Metamorphic rocks and granite.
GEOMORPHOLOGY	Destructional land surface. Plains of erosion. Late tertiary to quaternary suface with elements of the pre - mid mesozoic surface.
DRAINAGE	Moderate intensity, subrectangular pattern.
ELEVATION	170 - 800m. Local amplitude < 30m.
CLIMATE	Mean annual rainfall 558 - 812 mm. Mean annual growing season: agricultural 12 - 17 wk.,pastoral 17 - 22 wk.



Land Unit	Area	Land Forms	Soils	Vegetation
Bb 7	Large	Gentle to moderate slopes - metamorphics	Wyandotte:Sand over Clay; Forsayth:Clay loam over clay	Ironbark woodland: E.crebra, E.erythrophloia, E.whitei, E.papuana, Heteropogon contortus, Bothriochloa ewartiana, Themeda triandra
Bb 5	Small	Flatter parts	Rosella:Calcare-ous Cracking Clay	Box woodland: E.microneura
Bb 8	Medium	Lower slopes	Cargoon:Red & Yellow podzolics	Box woodland: E.Brownii
Bb 9	Small	Gentle to moderate slopes on granite	Elliott:Sand over clay Cockatoo / Cullen:Sand	Ironbark woodland:Euc.crebra, E.whitei, E.erythrophloia, E.papuana, Heteropogon contortus, Bothriochloa ewartiana, Themeda
Bb14	Moderate	Gentle to moderate slopes on granite	Red & Yellow podzolics	Ironbark/box woodland: E.crebra, E.microneura
Bb10	Small	Upper slopes	Skeletal sand & Clay	Eucalyptus woodland: E.crebra, E.palycarpa, E.papuana, E.confertiflora, E.brownii, E.shirleyi;Erythrophloeum chlorostachys Acacia Sp., Erythroxylum ellipticum, Terminalia aridicola, Aristida Sp.
Bb11	Small	Upper slopes/Crests	Rock cutcrop	Eucalypt woodland: E.peltata, E.similis, E.shirleyi, Erythroxylum ellipticum, Maytenus cunninghamii, Dodonaea Sp., Acacia Sp.
Bb 6	Small	Stream channels		Fringing woodland: E.camaldulensis;Casuarina cunninghamiana, Arundinella nepalensis
Bb12	Small	Levee	duplex	Box woodland: E.leptophleba, E.papuana, Bothriochloa Sp.
Bb13	Moderate	Gentle slopes	Brown podzolics	Ironbark/Ironwood woodland: E.crebra, Erythrophloeum chlorostachys

YANMAN LAND SYSTEM

TOPOGRAPHY	Timbered plains
GEOLOGY	Etheridge complex and plutonic rocks. Pre-Cambrian and paleozoic. Metamorphic rocks and granite. Minor areas of tertiary terrestrial deposits.
GEOMORPHOLOGY	Destructional land surface. Plains of erosion. Early to mid tertiary surface.
DRAINAGE	Moderately intense, subrectangular pattern.
ELEVATION	250 - 600m. Local amplitude < 50m.
CLIMATE	Mean annual rainfall 584 - 889 mm. Mean annual growing season: agricultural 12 -25 wk.,pastoral 17 - 35 wk.



Land Unit	Area	Land Forms	Soils	Vegetaiton
Bb15	Medium	Gently undulating Granite plains	Zingari & Nangum: Red & yellow earths	Ironbark woodland: E.crebra, E.erythrophoia, E.papuana, E.polycarpa, E.confertiflora, Themeda Sp. Bothriochloa Sp., Aristida Sp., Heteropogon Sp.
Bb16	Large	Laterized parts of gently undulating granite plain	Cargoon, Wallabadah: Red & yellow podzolics	
Bb17		Laterized parts on sandstone	Sturgeon:Red & yellow earths	Poplar gum woodland: E.alba, E.intermedia, E.leptophleba
Bb18		Laterized parts on sandstone	Currajong:Brown sands & loams	
Bb19		Laterized parts on sandstone	Sturgeon:Red & yellow earths	Ironbark/box woodland: E.Crebra, E.leptophleba
Bc 3	Small	Eroding slopes	Shallow duplex soils	Silver - leaf ironbark low open woodland:E.melanophloia E.shirleyi
Bb20	Small	Lower slopes	Bleached podzolics	Box woodland: E.brownii
Bb21	Small	Depressions	Clay soils	Box woodland: E.leptophleba, Bothriochloa Sp., Ophiuros Sp., Dichanthium Sp., Aristida Sp.
Bb22	Small	Flats/Levees		Box woodland: E.microneura; Bothriochloa Sp.
Ha 1	Small	Swamps		Lagoon vegetation: Eleocharis Sp., Pseudoraphis Spinescens.
Bb 6	V.Small	Stream channel		Fringing woodland: E.camaldulensis, Casuarina Cunninghamiana, Melaleuca Sp., Pandanus Sp., Arundinella nepalensis

APPENDIX V - FAUNA OBSERVATIONS

VERTERBRATES
Mammals

Rocky Wallaby	*Petrogale inornata* susp. () - 2 seen (dark tail tips) in broken basalt Deciduous vine thicket and one along Spring Creek in black Ti Tree scrub (status - common)
Grey Kangaroo	*Macropus giganteus* - a few small groups seen in Boonderoo Land System (status - common)
Wallaroo	*Macropus robustus ssp* robustus many small groups encountered in Boonderoo Land System (status - abundant)
Rufous Rat Kangaroo	*Aepyprimnus rufescens* seen in more open areas sometimes on basalt (status - common)
Antilopine	*Macropus antilopinus* groups seen to the west of Emu Creek (status - common)
Dingo	*Cannis familiaris* - mobile - reported to be common in Boonderoo Land System - 2 seen (status - common)
Rabbit	*Oryctolagus cuniculu* - Dung seen around Spring Creek homestead.
Common Brushtail Possum	*Trichosurus vulpecula* - dung seen in DVT particularly under fig trees - 1 dead animal found in 'Graveyard Cave' (status - common)
Echidna	*Tachyglossus aculeatus* - tracks and dung found in caves, in deciduous vine thicket, 1 seen at camp site 25.10.85 Boonderoo L/S (status - common)
Eastern horseshoe bat	*Rhinolophus megaphyllus* -.Population of about 12 in Tourist Trap Cave (August 1985)
Bentwing bat	*Miniopterus sp.* mainly *M.Shreibersii* - Population of 1,000 (est) bats was using Collins No. 1 Cave 10.08.85 - Two weeks after the visit they had left.

(Note: mammals expected here but not yet verified:

Undara eptesicus (*Eptesicus troughtoni*), black striped wallaby *(Macropus dorsalis)*, spectacled hare wallaby (*Largorchestes conspicillatus*). They are known on the Undara System).

Birds

Emu-	*Dromaius novaehollandii* 9 sightings in 4 days Boonderoo Land System (status - common)
Wedgetail Eagle	*Aquila audax* _6 seen in 2 days Boonderoo L/S (status - common)
Whistling Kite	*Haliastur sphenurus* _ A number seen Boonderoo L/S (status - common)
Black Kite	*Milvus migrans* - A number seen Boonderoo Land System (status - common)
Brown Falcon	*Falco berigora* - Boonderoo Land System (status - common)
Boobook Owl	*Ninox novaezeelandiae* - More than one heard 2 nights Boonderoo L/S (status - common)
Crested Pigeon	*Ocyphaps lophates* - Numerous seen Boonderoo L/S (status - common)
Nankeen Kestrel	*Falco cenchroides* - Boonderoo Land System (status - common)
Squatter Pigeon	*Geophaps scripta* - Yanman Land System (status - common)
Northern Jackass	*Dacelo leachii* - Yanman and Boonderoo Land System (status - common)

Reptiles

Death Adder *Acanthophis praelongus* - 1 seen Boonderoo L/S, reported to be common on the basaltic red soils and also on Toomba L/S (status - common)

INVERTERBRATES

This information on cave adapted Arthropods has been compiled from published reports of Howarth, Hoch and Asche, Stone, Irvin.

ONYCHOPORA (ancient form - annelid - arthropod intergrade)
peripatus *(sp. nov.?)* (Howarth and Irvin)
Long Shot Cave, Two Ten Tunnel
ARACHNIDA
Phalangida
- (daddy long legs) (undetermined)
Long Shot Cave
Araneae
pholcidae *Spermophora Sp. nov. (Gray 1973)*
Collins Cave system
family unknown
(eyeless hunting spider) (Howarth and Irvin)
Long Shot Cave
DIPLOPODA
Cambalida (large white eyeless millipede)
Collins Cave system
INSECTA
Dictyoptera (cockroaches)
Nocticolidae
Nocticola sp. nov. (Stone)
Long Shot Cave
Orthoptera
Tettigoniidae (cave crickets)
Singing cave crickets (Howarth and Irvin)
Long Shot Cave
Hemiptera (bugs)
Heteroptera
Emesinae
(thread legged bugs)
Long Shot Cave
Homoptera
Fulgoroidea (plant hoppers)
Cixiidae
Undarana collina
Collins No 2 Cave Two Ten Tunnel
Solonaima baylissa
Long Shot Cave

REFERENCES

ATKINSON, F.A., 1989, The Remarkable Undara Lava Tube System, McBride Volcanic Province, North Queensland, **Tasmanian Cave and Karst Research Group Quarterly Newsletter.**

ATKINSON, F.A., 1990, The Undara Lava Tube System and its Caves, **Helictite 28(1):3.**

ATKINSON, F.A., GRIFFIN, T.J. STEPHENSON, P.J., 1975, A Major Lava Tube System from Undara Volcano, North Queensland, **Bull. Vol**. 39-2, pp. 1-28.

BOTANY BRANCH - DEPT. PRIMARY INDUSTRIES - QLD, 1989, **'Rare and Threatened Plants of Qld'.**

CSIRO, 1964, **'General Report on Lands of the Leichhardt - Gilbert Area, Qld 1953-1954'**

DEPT. NAT. DEVELOPMENT, 1972, **'Burdekin - Townsville Region Resource Series'.**

GRAY, M.R., 1973,Survey of the Spider Fauna of Australian Caves,**Helictite,** 11 (3), 47-75.

GRIFFIN, T.J., AND MCDOUGALL, I., 1975, Geochronolgy of the Cainozoic McBride Volcanic Province Northern Queensland, **J. Geol. Soc. Aust.** 22 (4), pp. 387-96.

GRIMES K. 1980, 'The tertiary Geology of North Queensland' in '**Geology and Geophysics of North Eastern Australia**' Ed Henderson R. and Stephenson P.

HAMILTON-SMITH, E.,1967, The Arthropoda of Australian Caves, **J. Aust. Ent. Soc.** 6, 103-118

HOCH, H. AND ASCHE, M., 1988, Cave-Dwelling Planthoppers of Australia (Insecta: Homoptera: Fulgoriodes)., in Pearson L.M. in (Ed) **Preprints of Tropicon Conference**, Aust. Speleol. Federation.

HOCH, H. AND HOWARTH, F.G., 1989, Six New Cavernicolous Cixiid Planthoppers in the genus Solonaima from Australia, (Homoptera - fulgoroidea), **Systematic Entomology** 14, 377-402

HOWARTH, F.B., 1988, Environmental Ecology of North Queensland Caves: or why there are so many troglobites in Australia, in (Ed) **Preprints of Tropicon Conference**, Aust. Speleol. Federation.

IRVIN D. 1988, ' Spring Creek Lava Tunnels', in Pearson, L.M. (Ed), **Preprints of Tropicon Conference**, Aust. Speleol. Federation.

MATTHEWS, P.G., (Ed.), 1985 **Australian Karst Index Aust.** Speleol. Fed., Melbourne, 481 pp

MOORE, B.P., 1964, Present day Cave Beetle Fauna in Australia - a pointer to the past climatic change, **Helectite,** Oct 1964, 3-9

STEPHENSON, P.J., GRIFFIN, T.J. AND SUTHERLAND, F.L., 1980, Cainozoic Volcanism in Northeastern Australia, in **Geology and Geophysics of Northeastern Australia**, (Eds.) Henderson, R.A. and Stephenson, P.J. pp. 468.

STEVENS, N.C., 1976 Undara Crater and Lava Tubes in de Jersey, N.J. Stevens, N.C. and Willmot, W.F., (Eds.), **Geological Elements of the National Estate in Queensland**, Geol. Soc. Aust., Qld. Div. Brisbane.

STONE, F.D., 1988, The Cockroaches of North Queensland Australia and the Evolution of Tropical Troglobites, in Pearson, L.M. (Ed), **Preprints of Tropicon Conference**, Aust. Speleol. Federation.

THE IMPORTANCE OF CAVES AT YANCHEP, WESTERN AUSTRALIA,
WITH A COMMENT ON CAVE RESEARCH.

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Abstract; Adventurers, explorers, and people with interest in the outdoors - speleologists fit admirably into all these categories - typically find especial excitement in remote places. Equally valid is the adage that many points of interest lie close to home. So it is with our brief story today.

Yanchep National Park is only 50km from Perth, about an hour's drive north of the city centre. Its close proximity to a major urban environment forms part of the reason for our interest in the area. Nevertheless, it is appropriate to begin this account with a description of the caves at Yanchep. The Australian Karst Index (Matthews, 1985) lists 80 caves at Yanchep, although based on current knowledge the list is far from complete. Speleologists acquainted with the area have been forecasting over quite a few years that many more caves remain to be discovered and we gather these predictions are indeed being realized. Clearly, Matthews' excellent compilation is ready to be updated! The Yanchep caves occur in an aeolian calcarenite called Tamala limestone. Playford (1983) suggested that on Rottnest Island the oldest Tamala sediments date from the times of the Riss Glaciation (Pleistocene), and the youngest from the Flandarian (Holocene) transgression. However, the Tamala limestone is strongly diachronous throughout its extent (Wyrwoll and King, 1984) and thus it is not easy to correlate simply the age of Tamala limestone at Yanchep with the age of the Rottnest samples.

Cavern formation in aeolian limestone is of interest because the genesis is concurrent with lithification of the dune fabrics (Bastian, 1964; Jennings, 1968) as opposed to the long hiatus between deposition of limestone underwater with cavern formation occurring a long while later, following emergence. There seems to be general agreement concerning the primary importance of hydrological control over speleogenesis and cave morphology in Tamala limestone (Bastian, 1964; Jennings, 1968; Williamson and Lance, 1979). Bastian (1964) describes two cave morphologies, linear and inclined fissure. Both types occur at Yanchep, and consequently it is a good area for studies of the processes of syngenetic cave formation. Linear caves have domed roofs and are formed along well defined epiphreatic streams that are not easily diverted from their courses. Cave enlargement progresses predominantly through roof collapse; rubble from roof collapse quickly disappears - apparently dissolved by the stream water. A good example of such a cave is Cabaret (YN 5). Inclined fissure caves, which form in more coherent and stronger limestone than do linear caves, have the roof and floor surfaces nearly parallel. A good example at Yanchep is the deeper section of Carpark cave (not listed in Matthews, 1985).

This fairly long preamble highlighting the structural aspects of the Yanchep caves, has brought us now to our focus of interest - the groundwater streams which, according to Allen (1981), coincide with the zone of contact between sand and limestone where changes of transmissivity result in steep gradients of the water table. These epiphreatic streams are in fact the surface of the water table of the Gnangara Mound. More strictly, however, it is the tree rootlets growing along the margins of the cave streams which have captured our attention. Due to the fine branching and compact structure of these tree rootlets we have coined the term 'root mats' for them. The root mats are not found in all the Yanchep caves with water. In Mambibby (YN 12), for example, there are no root mats in any of the three pools, and in Crystal Cave (YN 1) there is but one small root mat. In Cabaret cave (YN 5), on the other hand, the root mats are well developed along both sides of the stream; this is the place where our studies are being conducted.

As has been frequently observed, caves lack a source of primary production, and so the animals which do inhabit caves rely upon sporadic inputs of organic carbon such as: guano, cadavas or plant debris. At Yanchep the caves are sufficiently shallow for tree roots to reach the subterranean conduits of the Gnangara Mound.

The stream in Cabaret Cave lies at 11m AHD and about 8m underground. The cavern is of the linear type and measures 25 m in length. About a quarter of the total length of stream margin is lined with root mats which can only belong to the tuart trees (*Eucalyptus gomphocephala*) growing above. Our studies have developed from two basic questions arising from the idea that the root mats provide a potentially utilizable source of primary production:-

(a) Do animals utilize the root mats as a food source?
(b) If so, how? - by direct feeding upon the root mats, or through a bacterial/fungal intermediate step?

We have cheated a little, because we have long since known that these root mats are home to a number of different animals. In 1980, one of us (B.K.) in collaboration with Chris Austin (then a PhD student), found a new species of janirid isopod and several other kinds of microscopic animals to be abundant in the root mats. Subsequently, Jim Burt undertook an Honours study focussing on the ecology of the Yanchep caves, and the biological adaptations to the stygian realms shown by a couple of the cave amphipods! He (Burt, 1982) lists 15 species of aquatic cavernicoles (which includes four accidentals) from Cabaret Cave. Our species list has been now increased to 25. Culver (1976) cites 3 to 5 species of crustaceans from caves in America as the norm and even then, none are abundant. We will discuss the significance of this fauna when our results are formally published, but there are two species worth special mention here: the amphipod *Austrochiltonia subtenuis* and the gilgie *Cherax quinquecarinatus*. Both species occur in reasonably large numbers in Cabaret Cave and also in nearby surface waters of Loch McNess. Compared with surface water populations, the animals from Cabaret Cave display the classical features of cave adapted animals.e.g. eye-pigment reduction, lower egg number and increased egg size in *A. subtenuis*, (Burt, 1982) and reduced body pigmentation in *C. quinquecarinatus*, (Muir, 1983). Yet Austin (pers. comm.) was not able to detect any genetic separation between surface and subterranean populations of both species using gel electrophoresis techniques. Here, therefore, is an ideal opportunity to investigate the vexatious issue of regression in respect of adaptation to caves, using conspecifics at the surface waters and in the cave. There are few places known where this opportunity occurs; commonly the relationships are at the generic level of similar forms of animals where subterranean and surface populations are close to each other. But, before a useful assault on the issue of regression can be made, it is essential to have conspecific populations in both surface and subterranean environments.

To return to the second question: are the primary consumer animals feeding directly on the root mats, or on bacteria/fungi living on root exudates? We have cheated here, also, in that our studies, which began in January 1990 have concentrated on the structure and function of the root mat. (We plan to begin researching this second question directly next year). At the time of writing this report, the studies are still in progress, and data from our monitoring programme will be provided at the conference upon completion of the first stage of the project.

Having outlined our scientific interest in the Yanchep caves, we will return to a comment made near the beginning of this talk, that part of our interest in the area lies in its close vicinity to Perth. Perth is a rapidly expanding urban centre, and humans require water. The Gnangara Mound is a large reservoir of ground water which can be tapped to help supply some of the increasing demands for water for the expanding population of Perth. The Water Authority of Western Australia (WAWA) has plans to construct three schemes for extracting water from the Gnangara Mound in the near future, and the Yeal scheme is the one likely to have an impact on the Yanchep caves area. The cave streams are very shallow (on average 3cm in depth) and we have no experimental knowledge on how resilient the root mat ecosystems might be to rapidly fluctuating water table levels in the caves. Would one season of no flow be sufficient to sound the death knell of these ecosystems? WAWA plans to restrict changes in the water table at Loch McNess to 0.5m or less (Environmental Protection Authority, 1987), but changes of such magnitude might still translate to unacceptable changes of water levels in the caves. We acknowledge fully that the personnel from WAWA responsible for developing the Yeal and other Gnangara Mound schemes are aware of the scientific value of the Yanchep caves and of the root mat ecosystems, and are taking a responsible attitude to conservation in the area. Nevertheless there is a potential conflict of interest and the situation should be carefully monitored before, during and after the construction of all the Gnangara Mound schemes.

This paper has highlighted the scientific interest in the aquatic ecosystems in the Yanchep caves. The Yanchep caves have also been important for Science in other respects. Archer (1972), Balme *et al.* (1978) and Merrilees (1968, 1979) have highlighted the paleontological value of the cave area with discoveries of skeletal remains of the Giant Kangaroo (*Sthenurus brownei*), wombat (*Vombatus* sp), Tasmanian devil (*Sarcophilus harrisi*), Koala (*Phascolasctos* sp) being notable finds. Indeed, Bettong (YN 51), Thylacine (YN 52) and Sarcophilus (YN 53) caves are listed in the *Australian Karst Index 1985* (Matthews, 1985) as paleontologically important sites. Caves have significance for a number of other scientific reasons - geological, geomorphological and anthropological. The 35 million Chinese who still live in caves can't be wrong! [as pointed out by Paul Theroux (p.65) in his recent travel book "Riding the Iron Rooster]. Theroux continues "There is no government programme to remove these troglodytes, and put them into tenements, but there is a scheme to give them better caves". The Australian Aborigine is not so fortunate, because the caves at Yanchep were home to the dreaded Waugul (Scott in Gentilli, 1963; Bridge, 1963) and this fact probably explains the dearth of aboriginal artefacts in the area, but what veracity lies in the legend of 16 battered female aboriginal skeletons found in Yonderup Cave (YN 2)? If true, this is surely evidence of an atrocity which should be researched.

The point is that caves are important for scientific and cultural reasons. They are recognized as an integral component of the National Estate (Committee of Inquiry into National Estate, 1974). They are being subjected increasingly to change, deliberately by vandalism, or by planned economic development, and also, as Norm Poulter highlights at this Conference, even as an inadvertent byproduct of caving. Study of caves proceeds haphazardly. In part that is as it should be, but it is time to raise the level of research activity concerning cave environments before important cave attributes and biota are irretrievably lost. Good research can proceed efficiently and quickly through well supervised PhD studies, and the speleological fraternity would help itself and also help achieve some of its objectives by working to establish a Commonwealth Government funded postgraduate scholarship. Speleologists should lobby, through their organisations for a scholarship to be awarded each year for postgraduate studies in any aspect of cave science to be administered through the Commonwealth Department of The Arts, Sport, The Environment, Tourism and Territories. Now is an excellent time for mounting such an exercise. The scholarship should be advertised Australia-wide to attract the most outstanding candidate from a wide variety of disciplines in each year. Such a scholarship would increase the pace of scientific research into basic speleological issues. In the late Prof. Jennings, there is an obvious and worthy choice of title for this kind of a scholarship.

ACKNOWLEDGEMENTS
We acknowledge the help given by: the Water Authority of Western Australia, particularly Mr Jeff Kite; the rangers and other personnel from CALM (at Yanchep National Park), especially Mr Ron Shimmon and Mr Jim Smith. We also acknowledge the financial support from: Australian National Parks and Wildlife Service, Murdoch University and University of Western Australia.

REFERENCES

Allen, A.D. (1981). Groundwater resources of the Swan Coastal Plain, near Perth, Western Australia. Pp. 29-74. **In** *Ground Water Resources of the Swan Coastal Plain.* Ed. B. Whelan. CSIRO.

Archer, M. (1972). *Phascolarctos* (Marsupiala, Vombatoidea) and an associated fossil fauna from Koala Cave near Yanchep, Western Australia. **Helictite** (1972): 49-59.

Balme, J., Merrilees, D. and Porter, J.K. (1978). Late Quatenary mammal remains, spanning about 30,000 years, from excavations in Devil's Lair, Western Australia. **Journal of the Royal Society of Western Australia** 61: 33-65.

Bastian, L. (1964). Morphology and development of caves in the southwest of Western Australia. **Helictite** 2: 105-119.

Bridge, P.J. (1963). Yanchep. **The Western Caver** 3: 4-6.

Burt, J.S. (1982). *Aquatic Cavernicoles of the Yanchep Caves.* Honours Thesis (unpublished). Zoology Department, University of Western Australia.

Committee of Inquiry into the National Estate (1974). *Report of the National Estate.* Australian Government Publishing Service. Canberra.

Culver, D.C. (1976). The evolution of cave communities. **American Naturalist** 110: 945 - 957.

Environmental Protection Authority (1987). Report and recommendations of the Gnangara Mound Groundwater Resources. Perth, Western Australia. Bulletin #295.

Gentilli, J. (1963). The Yanchep area. Geography Department, University of Western Australia. Research Report #45.

Jennings, J.N. (1968). Syngenetic karst in Australia. Pp. 41-110 **In** Contributions to the study of karst. Australian National University Department of Geography Publication G/5 (1968).

Lowry, D.C. (1980). Karst styles in Western Australia. Pp. 44-52 **In** WACCON. Proceedings of the Twelfth Biennial Conference, Australian Speleological Foundation.

Matthews, P.G. (1985). Editor of the *Australian Karst Index 1985.* Australian Speleological Federation Incorporated.

Merrilees,D. (1968). Man the destroyer: late Quaternary changes in the Australian marsupial fauna. **Journal of the Royal Society of Western Australia** 51: 1-24

Merrilees, D. (1979). The prehistoric environment in Western Australia. **Journal of the Royal Society of Western Australia 62: 109-128**

Muir, B.G.(1983). Observations on the gilgi (Crustacea, Decapoda *Cherax quinquecarinatus*) in caves at Yanchep. **The Western Caver** 22: 9-17

Playford, P.E. (1983). Geological research on Rottnest Island. **Journal of the Royal Society of Western Australia** 66: 10-15

Williamson, K. (1980). Stream caves in the coastal limestones of moist south-west Western Australia. Pp. 60-67 **In** WACCON Proceedings of the Twelfth Biennial Conference, Australian Speleological Foundation.

Williamson, K. and Lance, K. (1979). The formation of limestone and caves at Yanchep, Western Australia. **The Western Caver** 18: 77-82

Wyrwoll, K.H. and King, P.D. (1984). A criticism of the proposed regional extent of late Cenozoic arid zone advances into south-western Australia. **Catena** 11: 273-288.

PHENOMENAL CAVE CLIMATES.

Neville A. Michie

Abstract: In Australia, as in other parts of the world, there are caves which display unusual and often spectacular physical phenomena. Many of these caves have unusual or extreme climates, often involving massive energy flows or long term storage of huge quantities of heat. In this paper some caves which display interesting climates are described. Theories and observed data which describe the phenomena are presented. Some cave climates can affect cave safety.

Introduction.

Caves are often assumed to have static climates, with the temperature at the annual mean and the humidity as close to 100 percent as may be. This is probably the case for deep, sealed, caves, most of which are unavailable for observation, but most caves that we visit have at least one entrance and few of them have a climate that fits the norm. The operation of a number of physical processes in caves gives each cave a different climate.

On the surface we are familiar with the wind associated with cyclonic and anticyclonic weather systems, and the changes of weather as air masses of differing temperature and humidity pass over us. The daily and annual temperature and humidity cycles complete what we know as weather and climate.

Underground a different set of processes controls the conditions although these may ultimately relate to the surface conditions. In this paper the climates of a number of caves are described as examples of the range and variability of cave climates that are to be found in Australia, and as examples of the physical processes that are involved.

Method

Cave climates were observed by making measurements at a series of positions underground of the temperature, humidity, and velocity of the air, the temperature of water and the temperature and the state of dryness of the walls. Above ground, measurements were made of the air temperature and humidity, wind speed and direction, barometric pressure and rainfall. Additional measurements of surface radiation and vertical atmospheric temperature profile have also been necessary. These measurements had to be made at intervals as short as a couple of minutes over a period as long as several years. It is fortunate in the cases of most caves that only a small number of these measurements were necessary to monitor the cave's climate once the processes that were operating had been identified. A method [4,5] of hourly averaging of measured parameters and subsequent

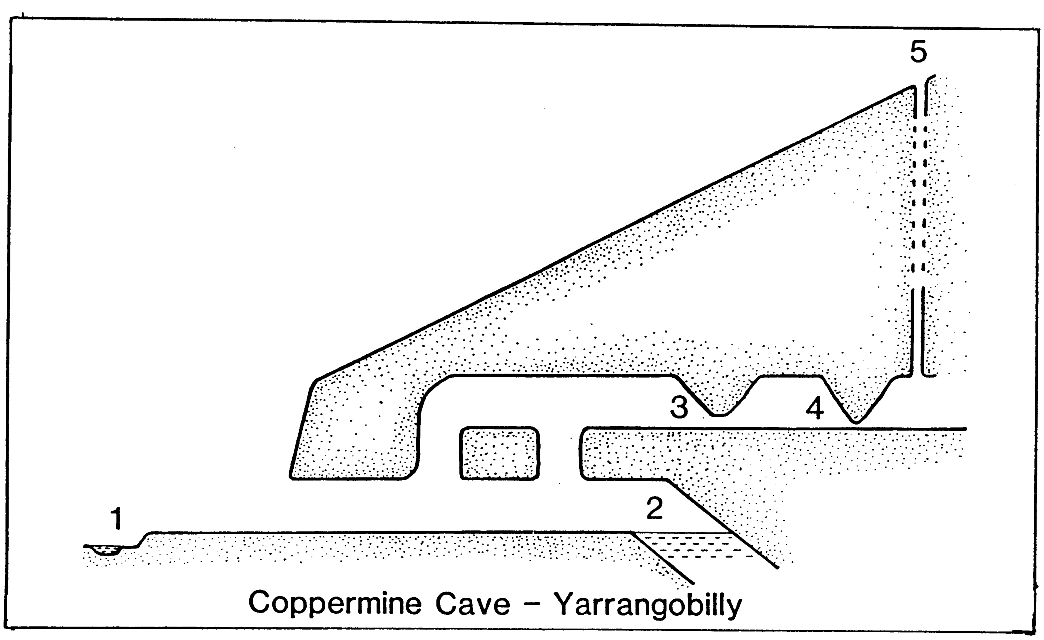

Figure 1. A simplified elevation of Coppermine Cave. 1 the Yarrangobilly River, 2 the stream resurgence, 3 the constriction at the locked bar, 4 the final impasse, 5 the hypothetical upper entrance.

multiple linear regression analysis proved useful in accurately determining the significant influences on the climates of caves that are dominated chimney effects. In such caves there are air flows caused pressure differentials caused by outside winds and by air density changes from air temperature and humidity variations.

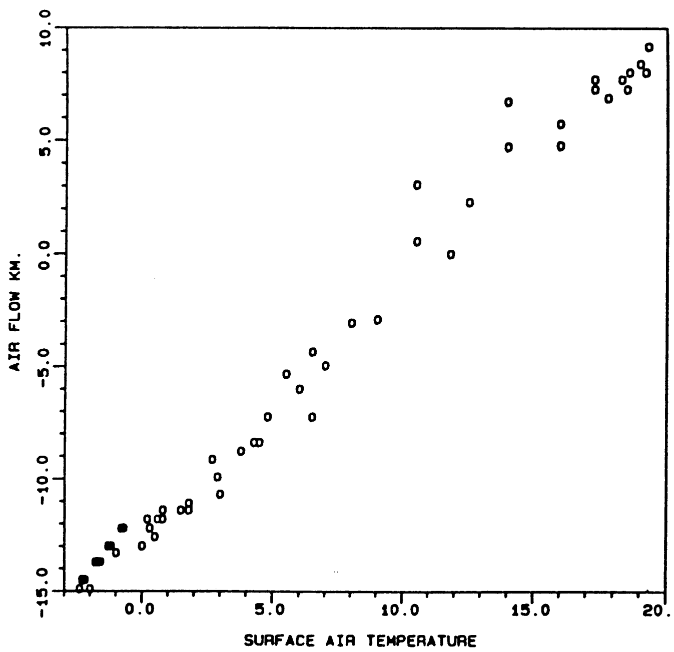

Figure 2. A plot of hourly average temperatures against the air flows for the corresponding hours in Coppermine Cave. 13th - 16th April 1979.

Results

(1) Coppermine Cave at Yarrangobilly (Figure 1), is a long tunnel cave formed by a stream that drains a large catchment. Only the exit which is at river level is accessible and the cave is eventually blocked by a narrow constriction. At this constriction there is a strong air current which is also obvious at a squeeze where there is a locked bar. Measurement and analysis of the air flow and the surface weather conditions [2,3,5] have shown that the air flow in this cave depends on the temperature of the air outside the cave. Figure 2 shows the strong relationship between surface air temperature and air flow in the cave.. The obvious conclusion is that the cave has another entrance much higher than the known entrance, which puts this cave into the category of chimney caves. These caves have a top and bottom entrance and the air flows through the cave in a direction that depends on the difference of density of the air inside and outside the cave. As temperature is the major factor in changing density, and the temperature outside the cave changes with the daily cycle, the airflow changes with time of day and season of the year.

In winter the section of the cave near the entrance becomes very dry and quite cold as the winter air cools the walls by evaporating water from them. In summer the cave gets very humid with water dripping off the roof and walls and the temperature rises. On average the cave, at about 10 degrees Celsius, is warmer than the mean surface temperature (6.8 at Kiandra) perhaps because of the geothermal capture of heat, (the Snowy Mountains area has a greater geothermal flux than most of Australia [1]) and in spite of the expected net evaporation of water caused by the air current.

(2) Mammoth Cave, Jenolan is a large system with several abandoned stream levels and a single known entrance by the ephemeral McKeowns Creek. The northern section of the cave is connected to the known entrance by a small unique constriction known as the Cold Hole (Figure 3). At times air flow of the order of 15 cubic metres per second passes through the Cold Hole to the rest of the cave. Analysis of the variation of the air flow shows that a chimney effect is operating. This has been established by correlating the air flow inside the cave with the temperature outside the cave.

Further north in the cave at a place called the Breeze Hole about one third of the air flows into the nearly vertical Waterfall Passage. Figure 4 shows a record of the airflow at the Cold Hole and the Breeze Hole and the surface air temperature measured on the 4th and 5th of December 1977. As with Coppermine Cave there is no other known entrance. Inside the cave it is apparent that there is more than one other entrance, and that the other two thirds of the air escapes through an upper entrance.

In winter, the sustained airflow dries out the lower sections of the cave making passage along the Central River Level quite pleasant.

If the Breeze Hole is blocked the pressure drop across the blockage can be about 30 Pascals. It is obvious that the air can find no other way past the blockage. The pressure drop corresponds to a chimney of 1000 metre-degrees. That is if the difference between the internal and outside air temperatures is one degree then the chimney must be 1000 metres high. A more probable but equally spectacular case is 10 degrees temperature difference and 100 metres high.

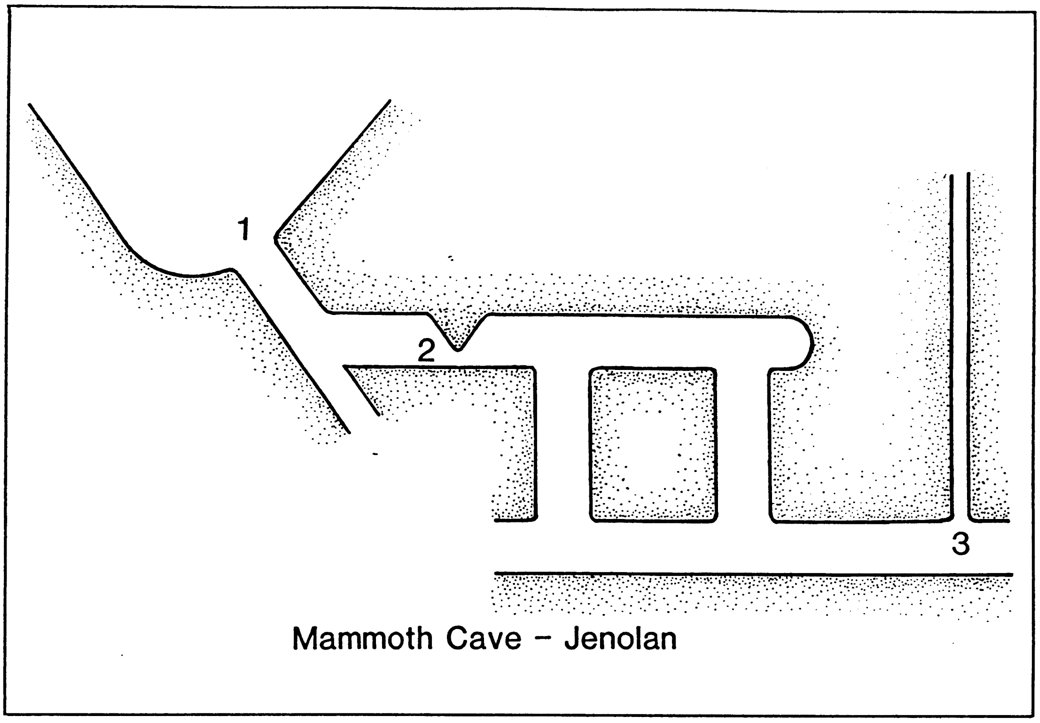

Figure 3. A simplified elevation of Mammoth Cave. 1 the entrance by McKeowns Creek. 2 the constriction known as the Cold Hole. 3 the Breeze Hole which leads to the Waterfall Passage and the hypothetical upper entrance.

Neither of the two postulated upper entrances to Mammoth Cave has been found in spite of the fact that on a cold winter's day below zero Celsius there should be a column of fog rising from each of the entrances as about 20 cubic metres per second of air at 18 degrees Celsius and nearly 100 percent humidity flows out of the unknown entrances. This heating and humidifying of cold air extracts heat from the cave at a rate of over one megawatt.

(3) Cutta Cutta, Katherine. Now this analysis of Cutta Cutta Cave is based on measurements made on 29th July 1981, and the published meteorological summaries from Katherine airport. It would have been better to have measurements from the cave at other times in the year, but in this case the available data is sufficient to identify a probable physical model of the cave.

The Katherine Aero. meteorological station has a mean annual temperature of 27.5 degrees Celsius but the deep cave temperatures are around 32 degrees Celsius.

This is at least partly because the rainfall occurs in the hottest months and the heat is carried into the ground with the water, whereas for most of the year the surface has a very high rate of heat loss by evaporation. The cave temperature is quite impressive, for if the humidity is high it will reduce healthy cavers to lethargic wrecks in minutes.

The amazing thing about Cutta Cutta (see Figure 5) is the temperature. The tourist section of the cave in July had a low temperature of 22 degrees with 68 percent relative humidity. This is quite comfortable in an area where the mid afternoon temperature outside averages 30 degrees. By contrast the nearby Turkish Bath Cave is over 30 degrees and 100 percent humid.

The locals speak of the Turkish Bath Cave as being anomalous but it is Cutta Cutta that is amazing, maintaining a temperature 10 degrees below the earth temperature and a humidity below saturation. One shudders to think of the size of the air conditioning system that would be needed to cool a whole cave by 10 degrees.

Here we will digress to mention a few details of human physiological response to extremes of temperature and humidity.

Basic Human Thermoregulation

Core temperature just less than 40 C. Skin temperature about 32 C. This is maintained at metabolic energy levels ranging from 70 watts asleep up to 800 watts during exceptional levels of physical activity. To transfer this

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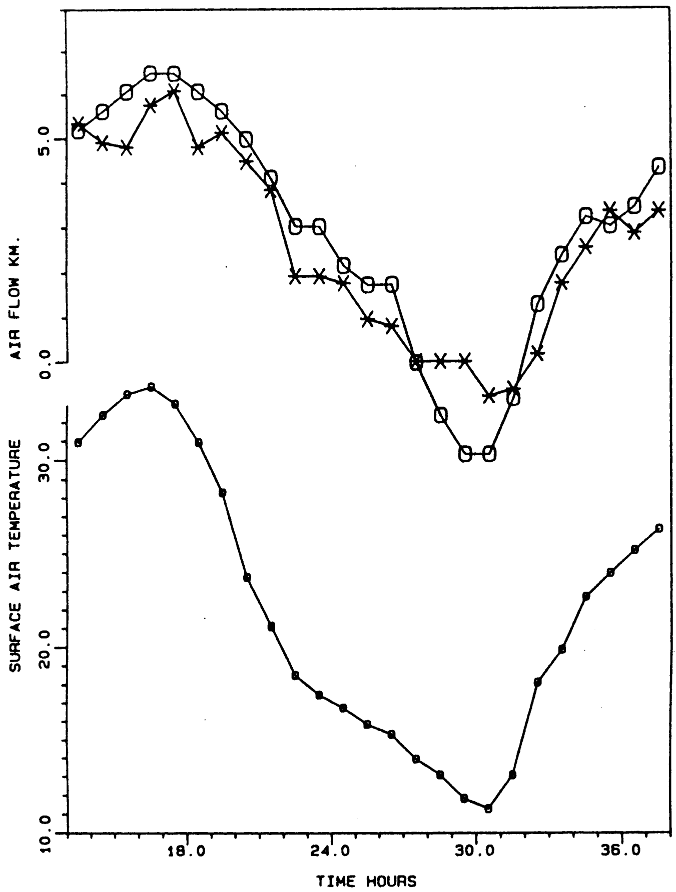


Figure 4. A plot of the measured air flows at the Cold Hole (o), and the Breeze Hole (*), and the surface air temperatures on 4th and 5th December 1977. This illustrates the strong relationships between these variables.

amount of heat to the skin to dissipate it and maintain the all important core temperature may require the constriction of peripheral circulation if heat losses are great, with a consequent drop in skin temperature, or alternately the transport of large volumes of blood if heat losses are not large enough and there is a rise in skin temperature above 32 C. This involves the heart in pumping ever greater quantities of blood through a decreasing temperature gradient.

A moist body loses heat by evaporation and by sensible heat loss (convection). For the human with 32 C skin temperature the skin may be dry or moist depending on the rate of sweating. For a given air velocity over a body the heat loss can have a wide range of values depending on the sweating rate.

What does it all mean? It means that there are limits to human comfort, or in extremes, to human survival. These limits depend on the air temperature, air velocity, air humidity, level of incident radiation (incoming or outgoing) and metabolic rate.

An air temperature of 32 degrees and 100 percent humidity does not allow the skin to dissipate heat without an elevation of its temperature, and is only comfortable at the lowest of metabolic rates. Any exercise will cause distress and extreme levels of exercise can induce collapse, heart failure and death.

So what is amazing about Cutta Cutta Cave? The amazing thing about Cutta Cutta is the cave climate. By means of a chimney circulation that only operates when outside conditions allow cooling, the cave transports heat, from convective transfer and from evaporation so that the cave is very comfortable for humans. The lower reaches of the cave give fair warning to cavers about the nature of the climate in other caves in the area.

The humidity is so high in the lower reaches of Cutta Cutta that the termites do not even build tunnels but just walk down the walls. In the transitional areas one can see termite tunnels that stop as they reach the high humidity area and the termites march on in the open.

For areas such as Katherine or Camooweal there is a danger of abseiling into caves if such action commits cavers to a high effort return. The rate of metabolic heat production when say climbing a ladder may be too high, causing hyperthermal collapse. It is important in such conditions to have facilities for long periods of rest to recover thermal equilibrium during the climb out.

(4) Eagles Nest, Yarrangobilly. From one extreme to another, the Eagles Nest System at Yarrangobilly is a complex system with a closed doline which will encourage the formation of frost hollow events in cold weather. Cold air from the doline feeds, with the circulation assistance of a chimney system, a rockpile heat storage system (Figure 6). The cold weather cools the zone where a large available surface area of rock acts as a rock pile heat storage system. If the outside air temperature rises, cold air flows from the storage zone into the doline until the densities balance. In summer at 35 degrees ambient one can walk into the bottom of the doline and encounter 5 degree temperatures. In winter the cave features ice formations and even in summer in the cave there is a wind tunnel where temperatures of two degrees may be encountered. The other entrance, West Eagles Nest, continually discharges air from the cold rockpile but reheats it to about 9 degrees with collected geothermal heat. Figure 7 shows the strong response of the Y1 chimney to outside air temperature changes and the persistence of outward flow from the Y2 entrance.

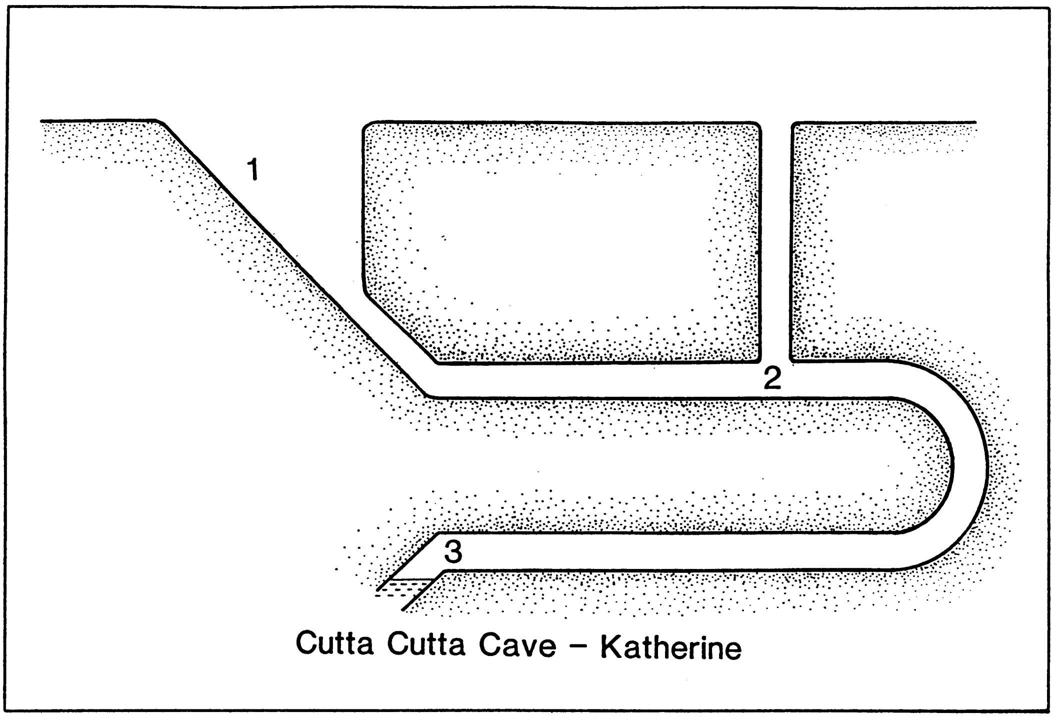


Figure 5. Simple section of Cutta Cutta Cave. 1 entrance doline. 2 chimney to surface at the end of the tourist section. 3 end of lower section featuring high temperature and humidity. When the outside air temperature is low, air enters at 1 and exits through the chimney at 2.

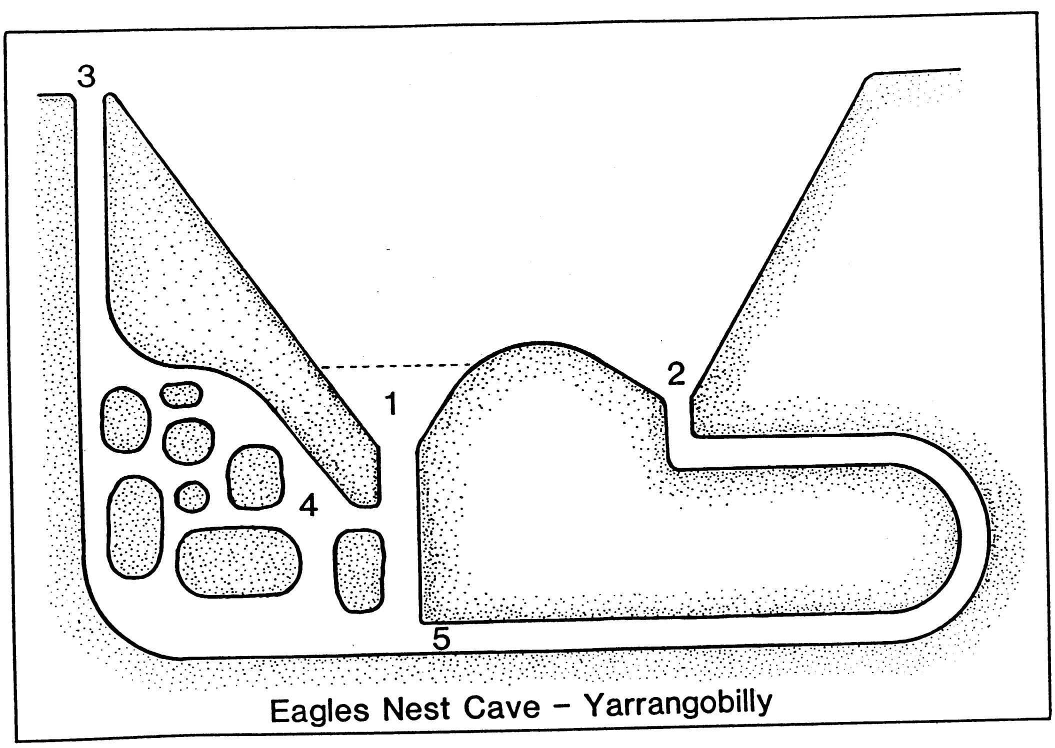


Figure 6. A schematic diagram of Eagles Nest Cave. 1 the Y1 entrance in the doline which is held below 5 degrees. 2 the Y2 entrance where the stream sinks and the air always flows out. 3 The Y3 entrance, the Eyrie, top of the system's chimney. 4 the heat storage area. 5 Hurricane Alley where the temperature is very low.

(5) Mullamullang, Nullarbor Plains (Figure 8) This cave and others in the Nullarbor area are barometric breathers. The volume of the cave is so great and the area of the entrance, by comparison, is so small that changes in the barometric pressure on the surface cause strong winds to blow in and out of the entrance. Figures 9 and 10 show the barometric pressure measured on the surface from the 16th January 1979 for more than two days, and the corresponding air flow in and out of the cave. These data were not gathered without some considerable hardship. The barometer had to be read at frequent intervals at the base camp so that I had to forgo all caving and most of my sleep for over 54 hours to record the readings. In the end everyone else left the area so the observations had to end. Imaging being so close to such a cave and not being able to explore it!

The velocity of the air flow is roughly proportional to the rate of change of the barometric

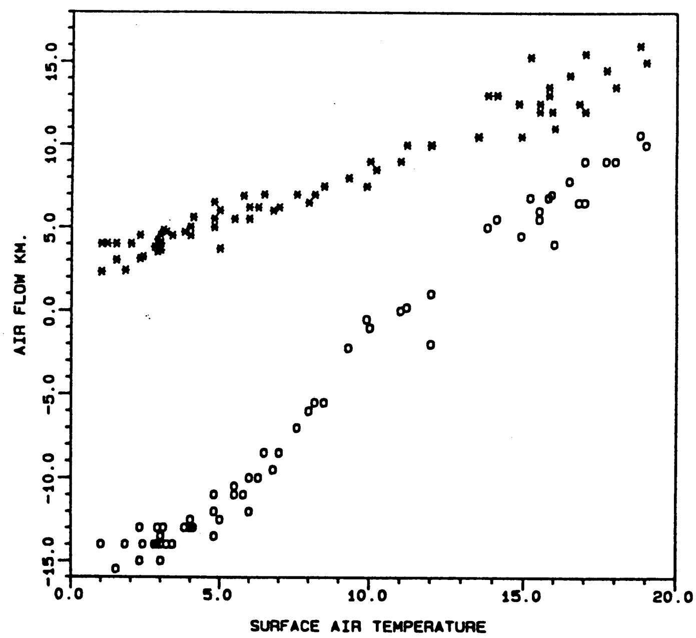


Figure 7. The hourly averages of the surface air temperature plotted against the air flows for the corresponding hours at the Y3 entrance (*) and the Y2 entrance (o).

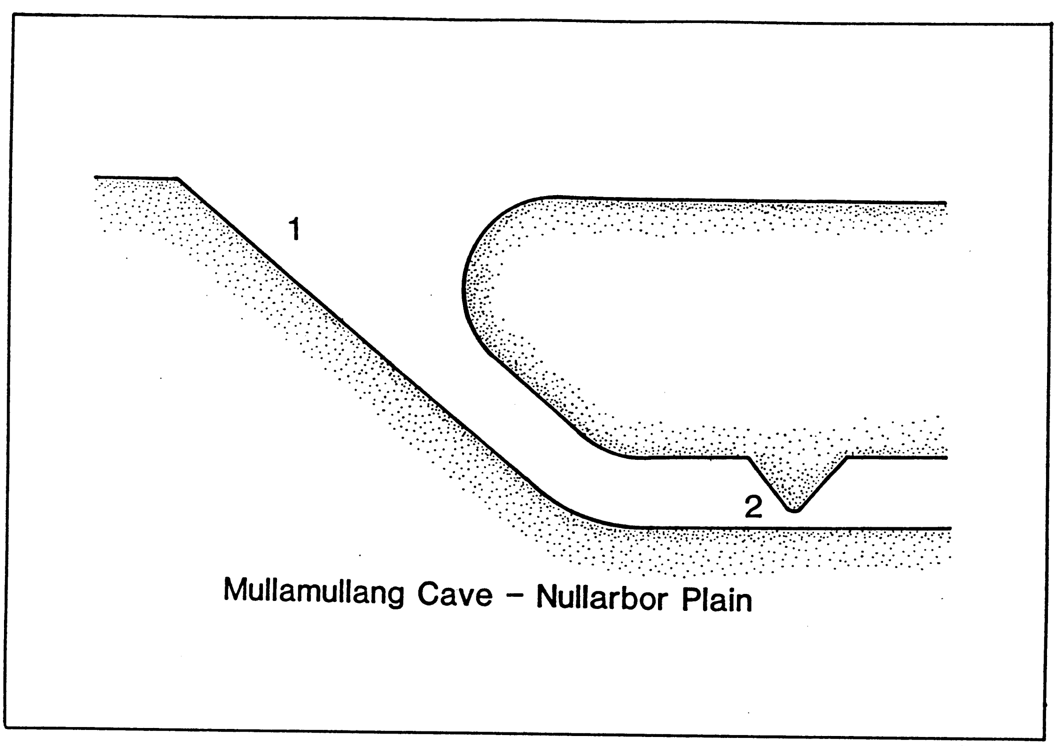


Figure 8. Schematic diagram of Mullamullang showing 1 the entrance doline and 2 the Southerly Buster constriction.

pressure. Thus it follows that the total out flow should be proportional to the barometric pressure as can be seen in Figures 9 and 10. The time delay between these graphs is the subject of great interest because it may reveal details of the structure of the cave. However to observe it needs records that extend over many days. Analysis of the flow in Mullamullang has shown a complex time response with time constants extending beyond two days. From this one may infer that the structure is very long, thin, has very big bits and is complex.

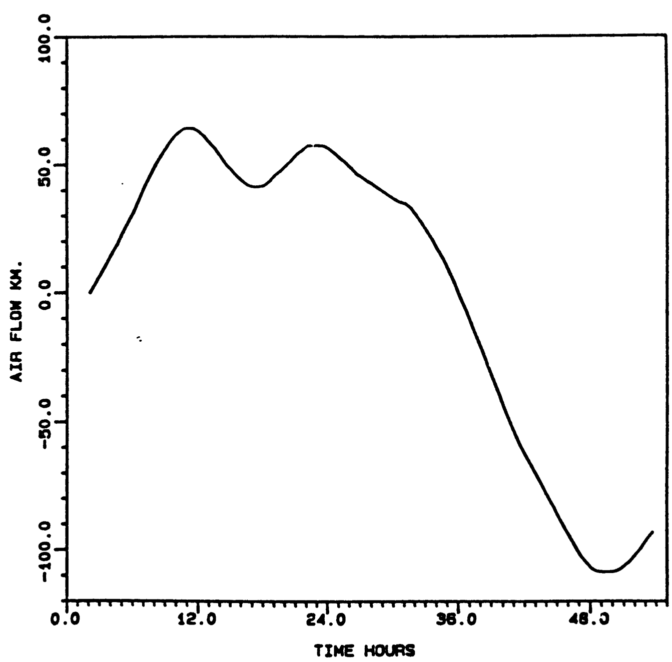
Discussion

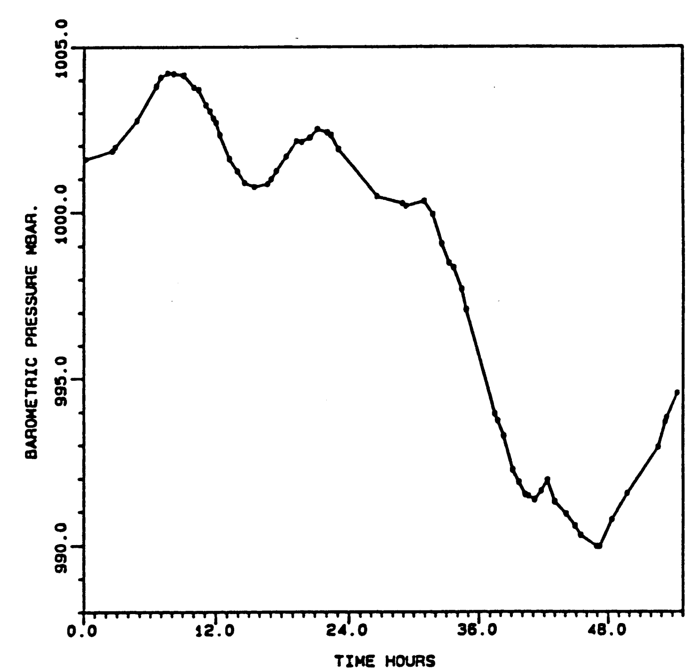
There is a long list of caves with chimney air flows, a lower entrance, but no sign of an upper entrance. It brings up the question of airflow in soils. Water can flow through soils and air is less viscous than water, so what is the place of airflow in soil as a component of cave air circulation? Only more observation and more physical experimentation will tell.

Conclusion

Caves have climates that are determined by the shape of the cave, the outside climate and the presence and distribution of water in the cave. As no two caves have the same shape, it follows that no two caves will have identical climates. Cave climates are important to cave fauna and the formation of speleothems. From climatic observations in caves we can deduce the existence of unknown caves, so that cave climatology can assist cave exploration. We can learn valuable lessons in energy conservation by observing the naturally occurring mechanisms that store heat, modify humidity and circulate air.

The tracing of air currents is still the single greatest physical phenomenon for detecting new caves.





Figures 9 and 10. Plots of the measurements of air flow and barometric pressure at the Southerly Buster in Mullamullang Cave.

References

[1] 1977 Cull,J.P. Geothermal energy prospects in Australia. Search, (8) 4

[2] 1979 Halbert,E.J. and Michie,N.A., Speleo-meteorology at Yarrangobilly. J. Syd. Speleol. Soc. (23) 125-134

[3] 1980 Michie,N.A., and Halbert,E.J., Statistical examination of Coppermine meteorological data. J. Syd. Speleol. Soc. (24) pp. 111-118

[4] 1982 Halbert,E.J. and Michie,N.A., The climate above and below ground. In: Dyson,H.R.,Ellis,R., and James, J.M., (eds), 'Wombeyan Caves'. Syd. Speleol. Soc. Occ. Pap. 8. Pp 224

[5] 1984 Michie,N.A., Determination of the causes of airflow in Coppermine Cave, Yarrangobilly. Helictite 22. (1) pp. 21-30

A Cave Climate Bibliography

Balch,E.S. (1900) Glacieres or Freezing Caverns.

Johnson Reprint Corp. (1970) pp337

Bogli, A. (1980) Karst Hydrology and Physical

Speleology. Springer-Verlag Berlin pp284

Dyson,H.J., Ellis,R. and James,J.M. (Eds.) (1982) Wombeyan

Caves. Occasional Paper No. 8. Sydney Speleological

Society. Sydney. pp.224

Ford,T.D. and Cullingford, C.H.D. (1976) The Science of

Speleology. Academic Press. London. pp593

Geiger,R. (1965) The Climate Near the Ground. Harvard

University Press. Cambridge. USA. pp611

Yoshino,M.M. (1975) Climate in a Small Area. University of

Tokyo Press. pp.549

LITTLE TRIMMER PROJECT:
Instrumented Monitoring of the Underground Environment

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Introduction

This paper describes an experimental set-up to continuously monitor the underground environment in Little Trimmer Cave, Tasmania. Work at Little Trimmer is part of a project being conducted by the Tasmanian Forestry Commission to investigate the effects of logging on karst caves, and was made possible by funding from the Australian National Parks & Wildlife Service.

In its original conception the project involved monitoring hydrological and climatological parameters in a cave before and after logging to permit an assessment of impact to be made. Little Trimmer, a 200m long stream cave at Mole Creek, was selected as an ideal study site. It is situated in relatively undisturbed forest, contains active dripwater flows, and is accessibile and securable. In view of the probability of at least some damage to the cave in the course of the study, it was important that the site not be one of high conservation value.

Despite uncertainty as to the viability of logging the area, it was decided to proceed as planned on the basis that obtaining basic data on the relationship between external and underground environments was the principal aim of the project. A better understanding of karst processes in the Tasmanian context is seen as essential from a forest management perspective (Kiernan, 1984). Moreover, baseline information from Little Trimmer will provide a necessary control with which to compare data from caves in areas that have already been logged.

Instrumentation

The project relies heavily on commercially available data loggers with various monitoring attachments. Unidata Starlog 6003 and Wesdata 390 models have been employed. The Unidata loggers are able to record a large number of variables, though memory space and battery life put constraints on this in practice. Two Unidata loggers monitor three variables each, receiving inputs from tipping bucket rainfall gauges, temperature probes, and a humidity sensor. An additional four single-channel Wesdata loggers record temperatures and stream stage.

Initial performance of data loggers in the field has been encouraging. However, limitations in the use of some equipment in an underground context have become apparent. This has included the effect of very high humidities on the humidity probe, and the precipitation of calcite on the tipping mechanism of rainfall gauges used to record drip rates. It is expected that recalibration of the rainfall gauges will become necessary as a result. A slightly different problem emerged with the discovery that rats had chewed through a cable leading to the rainfall gauge. Fortunately, this appears to have been an isolated incident of sabotage.

Downloading of data loggers is accomplished in the field with a Toshiba portable computer. However, more frequent visits to the site are necessary to monitor other variables that are not being continuously recorded (see Table 1), and to collect water samples. The possibility of using an automatic water sampler to sample the cave stream at selected flow rates is being investigated.

Hydrology

The process of logging can have a considerable impact on local hydrology, thereby modifying karst processes occuring on the surface and below the ground (Kiernan, 1988). This may take the form of changing flow regimes and stream sediment loads, while deforestation and soil compaction are likely to affect biological processes in the soil that determine the chemical characteristics of percolation water. Thus obtaining an understanding of the behaviour and chemistry of water flows in the cave is a priority.

To facilitate accurate recording of stream flow, a V-notch weir and depth probe sensor were installed at a narrow point within the cave. A continuous record of dripwater flows at two points is obtained from tipping bucket rainfall gauges located beneath stalactite clusters. A large funnel directs drips into the tipping bucket at one site, while a plastic sheet suspended above the floor collects more dispersed drips at another site. The rapid deposition of carbonate on the collection apparatus is a factor that will need to be taken into consideration when interpreting the results of water analyses. Several other drips that are too slow for the tipping buckets are collected over week-long periods in small plastic bags attached to the tips of stalactites. The flow rate of one very active stalactite - up to 47 l/hour at times - is noted at the time of each visit using a funnel and measuring cylinder. Dripwater and stream samples are collected regularly and analysed for major ions.

Parameter	Method of Recording	Type of Record
Stream flow	Weir and depth probe.	Continuous
Dripwater flows	Tipping bucket rainfall gauges.	Continuous
Slow drips	Collected in plastic bags attached to stalactites.	Average over the period of collection
Fast drips	On-the-spot measurement.	Instantaneous value
Water chemistry	Manual collection of samples for lab analysis. Conductivity and pH recorded on site.	Instantaneous value
Water temperature	Temperature probe.	Continuous
Air temperatures	Temperature probes.	Continuous
Relative humidity	Humidity sensor.	Continuous
Air flows	Data from temperature probes and manual record with digital anemometer.	Mixed
Air CO_2	Draeger gas analyzer.	Instantaneous value
Soil CO_2	Miotke probe and Draeger unit.	Instantaneous value
Precipitation	Tipping bucket rainfall gauge.	Continuous

Table 1: Summary of data collection techniques at Little Trimmer. samples are collected regularly and analysed for major stations.

The stream that emerges from Little Trimmer appears to be fed primarily by percolation water. A mean value of 252ppm for total hardness is evident from weekly samples collected between July and October 1990. This approximates the mean total hardness of dripwater flows in the cave, which range in hardness from 146 to 320ppm over the same period. However, the Little Trimmer stream is too volatile to consist entirely of autogenic water. There are abrupt flood peaks in the order of 0.5 cumecs that contrast with more typical flows below 0.01 cumecs. This lends support to speculation by Kiernan (1984) that in times of flood the stream is boosted by overflow from a vadose stream system that bypasses the cave during moderate flows. If this is the case then Little Trimmer further illustrates the complexity of hydrological relationships that need to be taken into consideration in land management planning in karst areas. Analysis of water samples and water tracing during peak flows may contribute to a better understanding of how the system operates.

The two dripwater sites that are being continuously monitored with rainfall gauges have mean flow rates that are quite different. One drip site is located close to the entrance, only 7m below the surface, and is subject to large fluctuations in flow rate. The other drip is beneath some 35m of rock towards the end of the cave, and has a far more muted range of flows. Despite their differences, corresponding peaks in response to rainfall events are evident in the hydrographs of both drips.

With data on flow rates, water chemistry and surface climate, it is hoped to draw some conclusions regarding the nature of the factors influencing dripwater chemistry. These are by no means well understood. The seminal study by Pitty (1966) in the UK suggested a correlation between drip hardness, antecedent surface temperature and hence microbial activity in the soil. However, the results of related studies in this country by Jennings (1979) and Goede (1981) have been less easy to interpret.

Climatology

Variables such as temperature, the velocity and direction of air movements, humidity and CO_2 levels influence speleothem development and are decisive to the well-being of subterranean ecosystems. Cave morphology is an important determinant of rates of air exchange with the external environment and the location of microclimatic zones within caves (De Freitas et al, 1982). However, it is likely that cave climates are susceptible to activities above ground that alter the vegetation cover, soil characteristics, and water flows.

At Little Trimmer the existence of a small upper entrance is responsible for relatively vigorous air flows resulting from the "chimney effect" (Wigley & Brown, 1978). Continuous recording of air flows with conventional anemometers has not been viable due to the limitations of available instruments, logger memory capacity, and budget restrictions. Instead, monitoring this parameter has relied on temperature probes installed a short distance inside both upper and lower entrances. These record on a half-hourly basis, as does an additional temperature probe located on the surface.

Comparison of data from the three probes shows distinctive patterns that are consistent with chimney effect winds. Peaks on a plot of temperature at the upper entrance correspond to warm external temperatures, while at such times the lower entrance temperature remains unchanged. It is concluded that the temperature inside the upper entrance is responding to a warm inward draught. Conversely, decreases in temperature at the lower entrance correspond to cold external conditions, and presumably indicate a reversal of air flow direction. Some empirical support for these predictions is available from notes on the direction of air flow made during visits to the cave. A draught is particularly prominent at a constriction near the top entrance, and wind velocities of several metres per second have been measured at this point using a small digital anemometer. Observations indicate that external winds also affect air movement at times.

Contrasting the well-ventilated section of passage between the two entances, is an area of greater climatic stability deeper into the cave. Temperatures here remain essentially constant at 9.5^{o}C, though with slightly higher temperatures apparent at ceiling level. The period of record is as yet too short to detect possible seasonal variations. As might be expected, relative humidity in the more remote sections of the cave approaches 100%. This has presented problems for a Vaisala brand humidity probe being used at Little Trimmer. At such high humidities, small temperature or pressure changes are sufficient to induce condensation on the sensor, with resultant erroneous readings. The probe has now been located closer to one of the entrances where slightly less humid conditions prevail.

Biological Monitoring

One of the original selection criteria for the study site was that the cave should be relatively expendable. However, the results of biological surveying indicate that Little Trimmer contains a rich assemblage of invertebrate fauna. A total of 25 species have been recorded, including 5 troglobites and several species awaiting description. To take advantage of regular visits to the site, a simple biological monitoring program has been designed (Eberhard, 1990). This involves periodic censuses of the most common species in a variety of substrate types. Basic life history data of this sort will be useful in predicting the effects on cave ecosystems of changes to the hydrological and climatological parameters described above.

Human Impacts

The likely impact on the cave and its biological inhabitants by the researchers themselves caused concern from the outset. To reduce widespread trampling, string has been used to define paths along necessary routes and to delineate zones for the protection of important habitats. While the intention is to minimise damage, the study is an opportunity to assess the effects of intensive visitation on a cave. This involves a record of activity in the cave together with observations on the spread of dirt on flowstone floors, compaction of sediments on paths, and physical modification of calcite deposits. In addition to documenting the effect of research, this information is of interest in planning related to the recreational use of caves. The fact that the accessibility of many caves is greatly enhanced with the advent of logging roads makes this a relevant concern from a forest management viewpoint.

Summary

The use of data loggers has greatly facilitated research on the underground environment at Little Trimmer. These allow comprehensive gathering of data with relatively little effort. Problems of equipment malfunction that have hampered previous studies of this kind are likely to be reduced.

The project has focused on hydrology and climatology, both of which are crucial to karst processes and cave ecosystems. By characterising the interaction of surface and underground environments, it is envisaged that the study will contribute to a better understanding of the likely impact of forestry and other land uses on karst landscapes.

Acknowledgements

The project has been made possible by a grant to Kevin Kiernan from the Australian National Parks & Wildlife Service under the States Assistance Scheme. Andrew Causon and Terry Leary of the Rivers & Water Supply Commission, Hobart, have provided essential expertise. The assistance of Chester Shaw and Vic Fahey of the Department of Parks, Wildlife & Heritage at Mole Creek has been much appreciated. Andy Spate (N.S.W. National Parks & Wildlife Service), Stefan Eberhard (University of Tasmania), Harry Cox (Government Analyst & Chemist, Hobart), and Frank Brown (Department of Environment & Planning, Hobart) have all made valuable contributions. Rex Tuson has generously allowed free access to the study site via his Loatta property. For help in other ways we are grateful to our Forestry Commission colleagues, Mick Brown, Humphrey Elliot, Sheryl Wolfe and Mark Burrows.

References

De Freitas, C.R., Littlejohn, R.N., Clarkson, T.S. & Kristament, I.S., (1982), "Cave Climate: Assessment of Airflow and Ventilation", J. Climatol. 2: 383-397.

Eberhard, S., (1990), Little Trimmer Cave Project: Biological Monitoring Programme, Unpublished Report to the Forestry Commission, Tasmania.

Goede, A., (1981), "Variation in Hardness of Cave Drips at Two Tasmanian Sites", Helictite 19(2): 57-67.

Jennings, J.N., (1979), "Hardness Controls of Cave Drips, Murray Cave, Cooleman Plain, Kosciusko National Park", Helictite 17(1): 30-38.

Kiernan, K.K., (1984), Land Use in Karst Areas: Forestry Operations and the Mole Creek Caves, Unpublished report to the Forestry Commission and National Parks and Wildlife Service, Tasmania.

Kiernan, K.K., (1988), The Management of Soluble Rock Landscapes: An Australian Perspective, Speleo. Res. Council, Sydney.

Pitty, A.F., (1966), An Approach to the Study of Karst Water: Illustrated by Results from Pooles Cavern, Buxton, Univ. Hull Occ. Pap. Geogr. No.5.

Wigley, T.M.L., & M.C. Brown, (1976), "The Physics of Caves", pp.329-358 (in) T.D. Ford & C.H.D. Cullingford (eds), The Science of Speleology, Academic Press, London.

LEEUWIN-NATURALIST NATIONAL PARK
Cave Permits
Draft Issue Plan

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WHAT DO YOU THINK?

We want to know what you think of the proposals in this draft issue paper; have you thought of writing a submission?

WHY WRITE A SUBMISSION?

It is an opportunity to provide information, express your opinion, suggest alternatives and have a say on how we are proposing to manage access to caves within the Leeuwin Naturaliste National Park.

If you prefer not to write your own submission you could make a joint submission with others.

WHAT HAPPENS TO YOUR SUBMISSION?

All submissions are analysed and the draft will be reviewed in the light of the submissions. A summary of the submissions will be published, including an indication of how the Permit System was amended in response to the submissions. If a submission is marked CONFIDENTIAL it will not be quoted in the summary.

WHAT MAKES AN EFFECTIVE SUBMISSION?

To ensure your submission is as effective as possible:

* make it concise and clear
* list your points according to the sections and page numbers.
* describe briefly each subject or issue you wish to discuss.
* say whether you agree or disagree with any or all of the recommendations. Clearly state your reasons (particularly if you disagree) and give sources of information where possible.
* suggest alternatives to deal with any issue with which you may disagree.

NB. It is as important to indicate those recommendations you agree with as it is those with which you disagree.

Proceedings of 18th Conference of the ASF 1991

Each submission is important in its own right but those that give reasons for concerns, give support where appropriate and offer useful information and suggestions are most useful.

DEADLINE

Submissions are welcome for six weeks until 28 December 1990.

WHERE TO SEND YOUR SUBMISSION

Written submissions should be sent to Neil Taylor at the above address.

1. INTRODUCTION:

CALM welcomes comment on the proposal to introduce a Permit System for cave access within caves of the Leeuwin Naturaliste National Park (L.N.N.P.). Although not a statutory requirement, this proposal will affect a large number of cave users, and thus public views are being sought.

The introduction of a permit system is a recommendation of the L.N.N.P. Management Plan. The numbers of people using caves appears to be increasing sharply. The permit system will enable managers to retain a balance between recreational use and conservation.

The Cave Management Advisory Committee for the L.N.N.P. (comprising CALM and outside bodies) have been regularly meeting over the past 18 months to draft the proposal. They have prepared this proposal on behalf of the Executive Director of CALM.

Trends in other States of Australia and overseas seem to be restricting public access into caves. This is a result of recent deaths in caves, and a growing realization among managing authorities that a presence is necessary for the long term survival of cave systems.

The Advisory Committee feels it is important that people commenting on the proposal (Section 7) understand the background information from which the committee has drawn its proposal (Sections 2 - 6).

The Advisory Committee would like to thank those people and organisations that have already made comments which have been incorporated into the draft.

2. SIGNIFICANCE OF CAVES IN THE L.N.N.P.

Caves and karst features are a unique non-renewable resource. The L.N.N.P. has some of the most highly decorated caves in Australia. They occur in a narrow limestone belt from Augusta to Yallingup extending underground to approximately 50 metres. Their popularity with people seeking an adventure experience is increasing.

Caves have significant conservation scientific, scenic and recreational values. This is perhaps not as well understood in the community as it might be. A consequence is that caves are not given the same protection as other non-renewable natural resources.

Conservation Value

Caves are virtually an irreplaceable resource and so must be conserved for the sake of conservation itself.

Scientific Value

The L.N.N.P. Caves continue to have scientific value. Some of the early reservations of caves were vested in the W A Museum to enable them to have control and undertake scientific work. Fossil remains, including human, have been frequently found in South West caves and have contributed significantly to the knowledge of the past.

Scenic Value

Caves provide opportunities for aesthetic appreciation of the natural features nature creates such as straws, shawls, stalagmites, stalactites, flowstone, and many others. With increasing numbers of our community living in cities, an increasingly important function of caves is to provide opportunities for people to "emotionally recharge".

Recreational Value

Caves also provide unique recreational opportunities. For example, caves provide "character building" opportunities to overcome physical challenges such as crawls, squeezes, shafts and stream crossings. Meeting these challenges as a team is an important component in working together; for example developing trust.

The significance of karst features in the L.N.N.P. cannot be over emphasised; they are a non-renewable resource with potential benefits to the whole community. Some uses result in conflict between users; and between users and the resource. CALM is endeavouring to strike a balance between types of users to ensure that the resource is available for future generations. This balance is likely to be a delicate one which may change with time as community attitudes and management capabilities change. The proposed Permit System is designed to provide opportunities for everyone, while protecting the resource.

3. HISTORY OF CAVE MANAGEMENT ON THE LEEUWIN-NATURALISTE RIDGE

Discovery and Development Phase.

From the early 1890s caves were discovered by the pioneers of the south-west. The government of the day was aware of the tourist potential of caves and hence appointed Marmaduke Terry in 1900 to locate all the karst features of the Leeuwin-Naturaliste Ridge. Terry's survey located the major cave sites known today and led to a number of caves being developed for tourism in the 1920s.

Although tourist use of caves was low, damage to these caves was considerable. It was during the period from 1920s to the 1950s that significant vandalism occurred in Calgardup Cave and other commercial and non-commercial caves.

Speleological Groups

In the late 1950s Jewel Cave was explored by Lloyd Robinson, Cliff Spackman and Lex Bastian. It was this exploration and subsequent discoveries that led to the formation of the Western Australian Speleological Group in 1958. With Lex Bastian as its first president the group began to document speleological activities and resources for the first time in Western Australia.

In the 1970s a further Speleological Group the Speleological Research Group of WA (SRGWA) was formed. These two groups are the only groups affiliated with the National Group: the Australian Speleological Federation. They are also the only groups documenting their activities through the publication of club magazines.

Management Controls

There is more known about Caves currently than was the case in the 1970's, although many areas were set aside as reserves and marked on Forest Department maps as containing caves.

The West Australian Museum (WAM) had made significant paleontological discoveries in a number of the caves in the south-west and had special reserves created surrounding Devil's Lair and others. The control of these reserves eventually became CALM's responsibility at the request of the WAM.

Until the late 1970's, access to some caves was restricted by means of locked gates. The mid 1980s saw the Department of Conservation and Land Management (CALM) appointed a Caves Ranger and take control of the locked caves within the Leeuwin-Naturaliste Ridge. Access to these caves continues to be controlled via the Caves Access Committee (CAC), which advises CALM of all activities that take place.

Each speleological group and CALM is represented on the Committee (Appendix I).

4. MANAGEMENT CONCERNS

4.1 Conservation of Caves

CALM has the responsibility in National Parks to attain a balance between Recreation and Conservation matters. It is of concern that visitation levels are rapidly escalating, without any upper limits of use being in place. Because karst systems are a non-renewable resource, they must be used cautiously while impacts are monitored.

4.2 Visitation Levels

The numbers of recreational and commercial cave users is rapidly increasing. This is based on the wear around cave entrances, the log book at Giants Cave, the Cave Rangers observations of numbers of cars and the requests to the Cave Ranger for cave access by groups. Other techniques such as the proposed permit system, photographic surveys and pedestrian counters will enable CALM to gain more accurate assessments of current use patterns and predict future trends.

The limited data currently available on caving numbers is shown in Appendix II. Note the extremely heavy use of Giants Cave. Currently there has been no survey of users to get impressions of (among other things) whether the high levels of use impinged on their enjoyment or not.

Currently, knowledge of visitor use such as numbers, frequency of use, and group sizes is sketchy. It is important that CALM gains this information in the future. Once numbers are accurately known and impacts assessed it will be possible to propose more accurate limits on the numbers of users. The proposed permit system an important source of this information.

4.3 Safety

CALM has a 'duty of care' (defined by statute law in W.A.) to take all 'reasonable' actions to see that any 'person will not suffer injury or damage by reason of any danger'. Caving is dangerous, given the wide variety of hazards, and it is not desirable or practical to signpost every potential problem.

There has been a need to rescue several people from caves in the Park over the last few years. They required medical treatment on site and their injuries could have resulted in a fatality. It is likely that a large number of minor abrasions and 'near misses' go unreported.

The proposed Permit System proposes to educate and direct potential cavers to minimize the likelihood of serious injury.

The proposed permit system will encourage and educate cavers to:

-be guided by experienced people;

-attempt the easiest/least hazardous caves first and;

-plan caving trips rather than undertaking them on an ad hoc 'spur of the moment' basis.

CALM has the difficult task of trying to achieve a balance between fulfilling its 'duty of care' to the public and maintaining an attractive environment to enjoy. If safety standards are not set high and followed by cavers, the probable outcome will be (if people are seriously hurt) more stringent controls.

5. TRENDS IN OTHER STATES AND OVERSEAS

Other Australian States

The management of caves on public lands vary greatly throughout Australia depending on the Government departments involved. For example in Tasmania one of Australia's most popular caves Kubla Khan has recently been "closed" to all caving activities while the Management Plan for the cave is formulated. At the other extreme a mining company is encroaching upon Exit Cave (until recently Australia's longest cave) at Ida Bay in Tasmania and it appears that the mining company will obtain approval to extend their quarry into the catchment of Exit Cave.

In New South Wales permit systems have been applied to many caving areas such as Jenolan, Yarrangabilly, Wombeyan and Wyanbene for many years. In some of these only one permit is issued for a weekend. The maximum party size is 12. At present Management Plans are in preparation for Wellington and Jenolan and there has been lengthy debate over the use of cave classification as a management tool.

South Australia has just released a draft policy to manage public access to caves within National Parks and Wildlife Service Reserves. This document is currently available for public comment. It outlines a system of cave classification to control access to caves with a heavy emphasis on cave conservation and ensuring leader qualification through a system of accreditation.

In a similar manner to Tasmania, South Australia has "closed" all caves in the new section of the Nullarbor National Park while the Management Plan is prepared.

USA Experience

Following an extensive survey of the major cave systems in the USA the single common factor in all systems was that a permit was required to visit wild caves. These Permit Systems varied greatly depending on who was issuing the permits however the most comprehensive system was that used by the Bureau of Land Management in Carlsbad, New Mexico. Here, the issue of a permit depended upon the purpose of the trip, the qualification of the leader, the 'resource value' of the cave or section of cave, the visitation rate, etc. Access is very tightly controlled.

The USA is also unusual in that it enacted Federal Cave Protection legislation in 1989.

New Zealand Experience

Commercial adventure caves are strictly controlled by the Department of Conservation with one or possibly two concessioners permitted to conduct adventure tours in each caving area. Speleologists require permits to enter caves and the general public is discouraged from visiting "wild" caves because of the potentially dangerous nature of a number of these as they are prone to flash flooding.

British Experience

Many caves in Britain are locked and access is generally controlled by the local speleological society. Owing to the large number of cavers many of the more popular caves can be booked for over a year in advance.

Severe "overcrowding" occurs in many British caves with up to five parties in the same cave on the same day. These problems are particularly bad at Pitch Heads where four or five ladders or ropes may be rigged at once.

Sarawak Experience

The Gunong Mulu National Park in Sarawak contains the cave with the largest known chamber of any cave in the world. If a speleologist wishes to visit this or other caves within the park then Ministerial Approval is required.

This brief outline of trends indicates that cave access is generally undergoing tighter controls. The Advisory Committee has borrowed from these trends but has been careful to design a proposal similar to the existing system so that it is accepted and adhered to once implemented.

6. THE EXISTING SYSTEM

The current 'system' evolved over the years, with control and management being largely in the hands of the two speological clubs. Since the establishment of CALM, there has been co-operation between CALM and the clubs. The clubs are now keen for CALM to take a much more active role. The current 'system' allows the general public access to all caves they can find which are not locked or controlled. Access to locked caves is via approval from the Caves Access Committee (CAC). Currently fees are only payable to gain access to locked caves.

People are encouraged to register at Giants Cave before entering. The Cave Ranger has encouraged all groups visiting caves to advise him before the visit to ensure there is not a clash with another large group. The Cave Ranger reports that about 70 percent of groups now routinely contact him prior to a visit. Currently there are no restriction on the numbers of users that can go caving or roping in the one cave system.

7. THE PROPOSED PERMIT SYSTEM

In general terms the caves in the Leeuwin Naturaliste National Park will be classified into five broad categories which give varying levels of public access (Appendix III summarizes conditions at a glance).

1. Tourist Caves
2. Adventure Caves Class I
3. Adventure Caves Class II
4. Restricted Access Class I
5. Restricted Access Class II

1. Tourist Caves

These are managed by the Tourist Bureau as a commercial enterprise. Guides conduct the public through the various caves at selected times for a fee. The caves are modified with steps and lighting to accomodate easy access. They are not under CALM control.

2. Adventure Caves: Class I

There are currently only three caves within this category (Giants, Calgardup and Tunnel). More could be added if deemed necessary in the future. These caves have been selected because:-

a) they are already popular and frequently visited.
b) they are relatively safe (CALM has replaced old stairways and provided safe carparking).
c) they offer a diversity of experience.
d) they provide adventure experience and have very attractive formations.

No fees will apply to caves in this category, although donations will be encouraged. All users will be asked to register on site before entering and a donation box will encourage people to contribute to the maintenance costs of the site.

The only restriction will be that total group sizes must be no more than 20 people (16 people plus 4 guides). Detailed information will provided to guide cavers on safety equipment and the hazards to be aware of. If groups of more than 20 arrive (e.g. typically school tours) they will need to break up into small groups of less than 20 and enter consecutively with half hour intervals between groups.

3. Adventure Caves: Class II

There are currently 18 caves in this category. (See Appendix IV). As the system develops, caves may be added or deleted from this list. Changes will depend upon use and further inventories of the caves being undertaken.

The permit for entry into these caves will cost $1 per head. There will need to be an approved trip leader. It is likely that the permit will be arranged by the trip leader or one responsible person within the group, rather than each individual applying.

A Draft Application Form for a Permit is shown in Appendix V. It must be lodged at the CALM Busselton District Office at least 10 working days before the proposed trip, and requires details of the trip leader plus all members within the party. Each application can apply for entry into four different caves, over a three month period. The application is also used by CALM to obtain basic statistics on users. Trip leaders for Adventure Class II excursions will need to complete a form (Appendix VI) to indicate to us their experience. Details will be entered onto a register so that they need only complete the form once. People will need to apply for trip leader status for all caves in the category.

Once an Application Form is approved the actual Permit will be issued to the trip leader. He/She must carry it when undertaking the caving trip. The trip leader will be required to complete the bottom section and leave it visible on his/her dash so that the Cave Ranger can see at a glance who are authorized. The back of the permit will detail general safety regulations and list any specific hazards/requirements to the caves proposed to be entered.

4. Restricted Access: Class I

All these caves are locked. Access to these caves is restricted because of the significance of each cave (e.g. hazards, scientific research, quality of decorations, etc). The Cave Advisory Committee for the L.N.N.P. will be writing recommendations to CALM listing criteria upon which caves should be locked. If accepted additional caves may be locked and/or current locked caves opened. The criteria will be circulated in caving clubs' newsletters.

Current access is by groups with authorized trip leaders. Authorized trip leaders are those approved by the existing clubs based on their knowledge, experience and skills. Numbers of trips per year and persons per trips are strictly controlled.

It is proposed that to gain access into this category a person has to be an authorized trip leader or be in a party approved by the CAC A fee of $5 a trip, is payable to the CAC to cover their administration fees. Once the CAC approves a trip, CALM may issue a permit to authorize the trip (no fee).

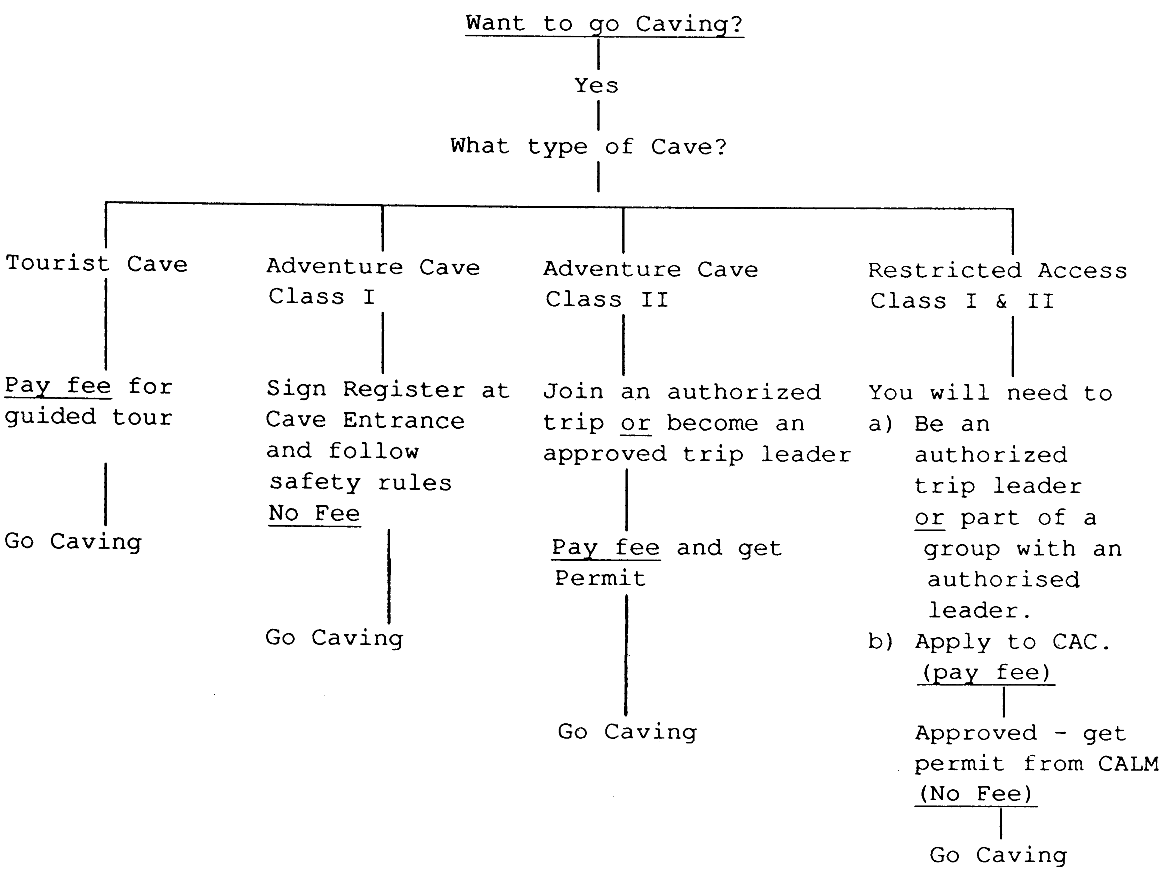
5. **Restricted Access: Class II**

These are the remaining caves within the Park. Any new caves discovered/opened will automatically be placed into this category until fully inventoried. The Committee acknowledge that this group may need further discussion in the future once further inventory work is done. For example, dangerous caves, reference caves, culturally significant sites, new caves, etc.

Access to these is the same as Restricted Access Class I sites. No trip fees are payable but clubs pay an annual fee to CALM.

The numbers of approved trips within this category is extremely low.

Following is a summary of the above important points suggested in this plan:-



Proposed Permit System

The proposed permit system may inconvenience responsible cave users who will now have to book in advance for caves that currently have no restrictions. This disadvantage is negliable when compared to the advantages of the permit system. These being;

1. Cave Conservation is significantly improved by encouraging responsible leadership, restricting group size to a number that the leader can control (and the cave can accept) and in the long term by establishing visitor numbers that the caves have a capacity to cater for.

2. Cave Safety is improved by grading caves, with respect to the degree of difficulty, insisting on competent leadership, by providing information about general and particular cave hazards and by discouraging spur of the moment decisions to go caving.

3. Cave users will be able to book caves and avoid the disappointment of finding a cave already in use or overcrowded.

4. Ongoing research and monitoring will be improved and encouraged contributing to the conservation of the cave resource.

The current cave classification system was prepared by the State working group on cave protection and management. This system was modified by the Cave Management Advisory Committee into the five broad classes of caves outlined. It is envisaged that these classes could be modified as future research and monitoring provides further information to derive classes such as Reference Caves, Dangerous Caves or Caves of Special Significance. These additional classes of caves are likely to be sub-classes within the five broad classes.

Classification of caves into the five broad classes was based upon:

Cave Lengths

The lengths of all the caves were inventoried to ensure both long and short caves were represented in each category as far as possible. No Long Cave Systems were placed into the Adventure Cave Class II category because of the safety considerations (see top half of Appendix II).

Vertical Entrances

The number of caves with vertical entrances were examined and the length and "quality" of the descent was identified. It was determined that the Adventure Caves Class I and II contained the majority of the vertical caving experiences available in the LNNP.

Resource Value

Finally a system of assigning a "Resource Value" to each cave/karst feature was examined. This system was devised for use in Carlsbad, New Mexico by the United States Bureau of Land Management. The "Resource Value" is assigned to each cave/karst feature after determining the contents of the cave or feature. The extensive cave inventories required to ensure that caves are afforded the appropriate "Resource Value" could not be undertaken, rather speleological literature and local knowledge was used to determine these assignments.

Base inventory studies will be necessary in all Adventure Caves (Class I and II) in the future and this process will be continued on an ongoing basis. Such cave inventories and ongoing monitoring was specified in the L.N.N.P. Management Plan and will provide CALM with a more concise method of resource evaluation in future re-evaluations.

CONCLUSION

This paper on the proposed Permit System has been written so that members of the community interested in caving have an opportunity to comment on the proposal. The proposal is a result of concerns CALM has for the conservation of Caves, public safety and other factors previously discussed.

CALM welcomes any comments whether positive or negative. When commenting on a sector of the proposal please clearly write why you agree or disagree and suggest alternatives if possible with supporting data. It helps analysis of comments if you reference your comments to a page and/or a section number.

All submissions are analysed and the draft reviewed in light of the submissions. A summary of the submissions including an indication of how the Permit System was amended will be posted to all persons/organisations making a submission. If a submission is marked Confidential it will not be quoted in the summary.

DEADLINE

Submissions are welcome until Friday, 15 February 1991.

Where to send your Submission

Neil Taylor
Sec/Chairman Cave Management Advisory Committee L.N.N.P.
C/- Dept of Conservation and Land Management
North Boyanup Road
BUNBURY WA 6230

APPENDIX I

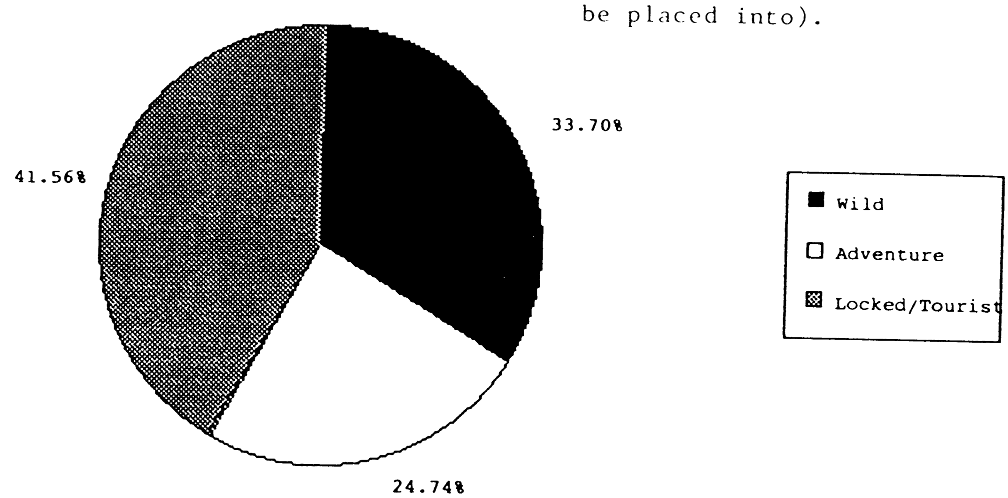
MEMBERSHIP CAVE MANAGEMENT COMMITTEE

MEMBERSHIP CAVE MANAGEMENT COMMITTEE

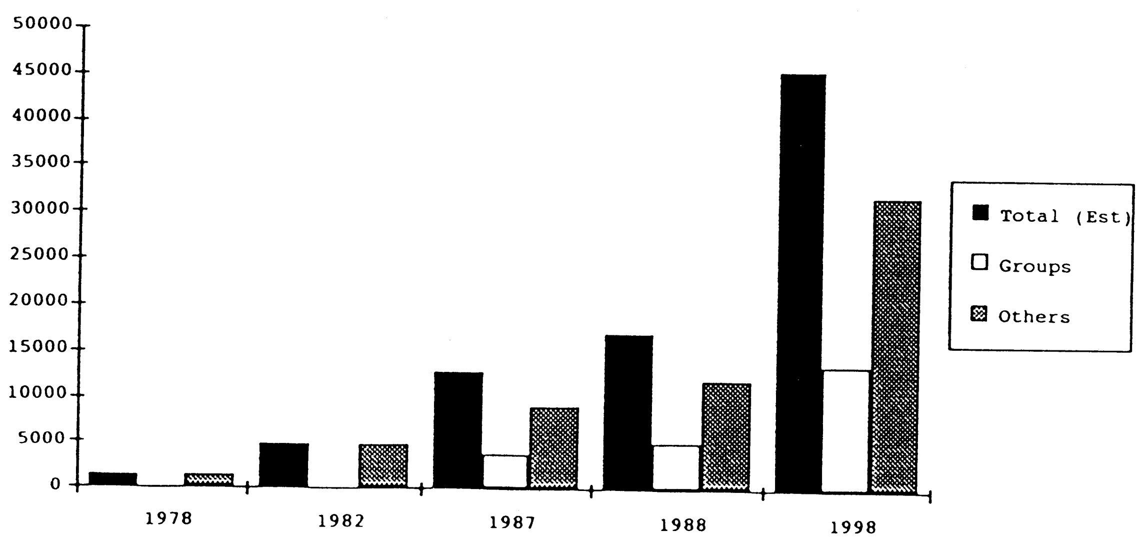
Mr Neil Taylor North Boyanup Road BUNBURY WA 6230 Work Phone No. 097 254 300 Home Phone No. 097 552 189 Fax No. 097 254 351	Recreation Officer CALM SEC/CHAIRMAN
Mr Rob Klok C/- C.A.L.M. MARGARET RIVER WA 6285 Work Phone No. 097 555 324 Home Phone No. 097 555 324 Fax No. 097 521 135	Cave Ranger L.N.N.P. CALM
Mr Ian Rotheram Queens Street BUSSELTON WA 6280 Work Phone No. 097 521 677 Home Phone No. 097 521 135 Fax No. 521 432	Busselton District Manager CALM
Mr Norm Poulter PO Box 120 NEDLANDS WA 6009 Work Phone No. 09 380 2766 Home Phone No. 09 276 2495 Fax Electron Microscopy Centre 09 380 1014	Member of SRG W.A.
Mr Rauleigh Webb 16 Loftus Street NEDLANDS WA 6009 Home Phone No. 09 386 7782 Fax No. 09 221 3865 Work No. 09 221 1116	Member of W.A.S.G.
Mr Peter Bell 69 Mason Road SOUTH LAKES WA 6164 Home Phone No. 09 417 3843 Fax No. 09 328 8434 Work No. 09 328 9811	Member of W.A.S.G.
Mr Keith Tritton Manager, Tourist Bureau Margaret River PO Box 171 MARGARET RIVER WA 6285 Home Phone No. 097 572 338 Work Phone No. 097 572 911 and Fax also	Manager, Margaret River Tourist Bureau

APPENDIX II

Cave Lengths for the South-West Area (one criteria looked at when assessing which category caves should be placed into).



Giants Cave Calculated Visitation Figures



APPENDIX III

CAVE CLASSIFICATION WITHIN THE LEEUWIN-NATURALISTE NATIONAL PARK

CLASSIFICATION OF CAVES	CALM PERMIT REQUIRED	RECORDS	NUMBERS	ENTRY FEES $	ACCESS BY COMMERCIAL OPERATORS
Tourist Caves	No	Exact Numbers known from tickets sold	public demand	Set by Tourist Bureau	Yes
Adventure Caves Class I	Yes Self Registration Permit completed by user at Cave entrance.	Self-Registration and by using people counters to check % of users registering.	Maximum group size of 20 **	Donation box on Site suggesting 50c/head	Yes CALM charges commercial operators an annual fee.
Adventure Caves Class II	Yes Permit by Application to Busselton Office. *	Permits to be pre-numbered up to set limits. People counters to check (the % of) unauthorized access.	Each cave has max. no.s/week determined. (See Appendix IV	$1.00/head/cave	Yes Providing group sizes are abided by and permits obtained
Restricted Access Class 1 (locked)	Yes Permit issued by CALM if approved by CAC.	Cave Ranger has Record of all approved trips; CALM issues Permit.	Speological clubs have Max No.s written down in Club by Laws	Annual Speleogical Club Registration fee set by CALM. ***	No
Restricted Access Class II	Yes Permit issued by CALM Busselton	Numbers of Permits issued from Busselton Office	Advisory Committee to advise CALM on Max. No.s/Year	Annual Speleogical Club registration fee set by CALM. ***	No.

* Persons applying for a permit into these caves must apply two weeks in advance of the trip.
Applications can be in person or in writing with the Permit being sent out by mail only if payment has been made in advance.
All correspondence must be through the Busselton Office during normal working hours.

** Effects of this group size restriction will be monitored and other proposals implemented as required to reduce numbers.
20 is an overall total number of 16 cavers plus 4 leaders.

*** It is proposed that access into the Restricted Access Caves class I and II would need at least one member of a Speological Club; likely to be the approved trip leader.

APPENDIX IV

ADVENTURE CAVES CLASS II (ATTACHMENT I)

NAME OF CAVE	MAX. NO. PEOPLE/TRIP	MAX. NO. TRIPS/WEEK	MAX. NO. TRIPS/YEAR	TOTAL MAX. PEOPLE/YEAR
WI16	20	10	520	10,400
Brides	10	10	520	5,200
Golgotha *	10	2	104	1,040
Museum	10	2	104	1,040
Mill	10	2	104	1,040
Nannup	6	2	104	1,040
Terrible	10	2	104	1,040
Northcote Grotto	10	2	104	1,040
M.R. 10	6	2	104	624
Witchcliffe	6	1	52	312
Dingo	6	2	104	624
Block	6	1	52	312
Mordang Dar	6	2	104	624
Ruddicks	6	1	52	312
Arumvale Pipe	6	1	52	312
Blackboy Hollow *	6	1	52	312
Deepdene	6	1	52	312
Quinninup Lake	6	1	52	312
TOTALS			1,820	25,896

* Locked Caves not under CAC control - key available once permit approved.

Adventure Caves Class I

Tunnel	20	Maximum number of trips to be decided when better Statistics available.
Giants	20	
Calgardup	20	

APPENDIX V

Busselton CALM
Office: Tel (097) 521677
Fax (097) 521432

APPLICATION FOR A CAVE PERMIT

This form applies only to the Leeuwin Naturaliste National Park.

A. General Information:

1. Beginners to Caving may venture into Giants, Tunnel and Calgardup free of charge by registering at the entrance of each cave. These have been selected because they are relatively safe, but still provide interesting viewing. Revenue collected from the donation boxes will be spent on improving caves in the L.N.N.P.

2. People/groups who have experienced the above caves may apply to go into additional caves (examples on Reverse Side) after the set fee is paid.

3. Limited access with approved trip leaders is permitted into Restricted Access Caves Class I and II. Applications will need to be through a speleological club.

4. Applications should be at the Busselton Office at least 10 working days prior to the proposed trip date.

B. Applicant Details:

Trip Leader (Please include Name and address. Must be 18 years or older, Telephone No., affiliation, commercial operator and D.O.B.).

....

....

Names of other Party Members (Asterisk Co-leaders) Experience level Rating (See Over)

....

....

....

....

....

....

Person to Contact in Emergency (Name, address and telephone)

....

....

C. Destination

Cave Name(s)	Use Date: Time am/pm
....	....
....	....
....	....
....	....

D. Statistics

1. How did you find out about the Permit System?

....

2. Briefly describe the purpose of your visit?

....

3. Any other Comments:

....

Examples of Caves Available to the Public under Permit

Name of Cave	Max. No. People/Trip
Brides	20
WI16	20
Museum	10
Mill	10
Nannup	6
Terrible	10
Northcote Grotto	10
M.R. 10	6

Experience Level Rating

0	First Caving Trip
1	Been on previous local trip
2	Some local experience
3	Extensive local experience
4	Extensive W.A. experience
5	Experience in States other than W.A.
6	International and extensive W.A. experience
7	Only International experience

APPENDIX V

CAVE PERMIT

LEEUWIN NATURALISTE NATIONAL PARK

IMPORTANT
Notes:

1. This permit should be carried by the trip leader after the bottom section is torn off and displayed on the dash of the trip leaders vehicle. (Please fill in vehicles in party just prior to going caving).
2. This form becomes valid as permission to conduct the activity when signed by a CALM officer on behalf of the Executive Director, Conservation and Land Management.
3. Please read the permit conditions carefully before signing this permit.

Permit Details:	1	2	3	4
Permitted Cave(s):	....	....	....	....
Date Entry:	....	....	....	....
Number in Party:	....	....	....	....
AM/PM	....	....	....	....

Trip Leader: (Name and Address) ....

....

Fee: $.................

Permit Number: | | | | | |

Signed for Executive Director Date / /

===

Permit Number: ALL VEHICLES IN THE PARTY

MAKE	COLOUR	REGISTRATION
....	....	....
....	....	....
....	....	....
....	....	....
....	....	....

CONDITIONS OF ENTRY

1. Maximum and minimum numbers to be observed.
   Maximum and minimun numbers vary but minimum is three.
2. A minimum of one light source per person.
3. Clothing and footwear should be robust.
4. Cave formations must not be handled.
5. Any damage in the cave should be reported to the Busselton Office.
6. Follow obvious or marked trails.

APPENDIX VI

APPLICATION TO BECOME A TRIP LEADER FOR ADVENTURE CAVES CLASS II

List Adventure Caves Class II you wish to be approved of as a trip leader:

....

....

....

....

....

Are you competent in all skills required to lead the cave trip? YES/NO

Please list your skills and qualifications.

....

....

....

....

Note: The above form is a vital one in the success of the proposed permit system. Please give thought to the content of such a form and suggest improvements.

A DISCUSSION OF THE SOLUTION OF LIMESTONE BY SULFURIC ACID AND ITS IMPORTANCE IN AUSTRALIAN CAVES

By Julia M. James
School of Chemistry,
University of Sydney,
NSW 2006

INTRODUCTION

In most karst systems the excavation of limestone by the action of sulfuric acid has been neglected because it is the minor corrosive agent. The major cavity excavator is the acid produced by the solution of carbon dioxide in water ("carbonic acid"). During the two last decades a number of caves have been identified where sulfuric acid is making the major contribution to their present solutional enlargement. Cavern development by sulfuric acid can be divided into three general categories:

Type 1-solution Waters containing sulfuric acid dissolve the limestone and the products are removed as carbon dioxide into the cave atmosphere and as ions in the cave water.

This type of sulfuric acid action is usually associated with acid mine drainage and was first discussed (Howard, 1960 and Morehouse, 1968) in papers on the speleogenesis of the Dubuque Caves, Iowa, USA. The caves were discovered during intensive mining of the district for lead and zinc sulfides. Type 1 sulfuric acid dissolution of limestone is also taking place at the Ok Tedi Gold mine in Papua New Guinea. Waters seeping from mineralised skarns of pyrite and chalcopyrite are extremely acid (average pH of 2.3) and flow directly onto the Darai limestone, eroding it. Drilling has produced large cavities in the limestone adjacent to the skarns. There are numerous examples of this type of sulfuric acid attack on limestone recorded in the international speleological literature.

Type 2-replacement-solution This is the action of sulfuric acid on the limestone replacing it with gypsum and then subsequently the gypsum is dissolved to form a cavity.

The first record of *in situ* replacement of limestone by gypsum was made by White and Pohl, 1965 where in order to explain the morphology of the gypsum deposits encountered in Mammoth Cave, Kentucky, USA they postulated gypsum replacement of limestone in the cave walls by attack of acidic sulfate solutions. These authors did not extend their discussion to the implications of the above observation on the solution of limestone and the development of caves.

Egemeier, 1973 first introduced the concept of the replacement of calcium carbonate by gypsum and then the subsequent solution of the gypsum to create caverns. Egemeier developed his theory from a detailed examination of the Kane Caves, Big Horn Basin, Wyoming, USA. The chemical analytical data in Egemeier's thesis (Egemeier, 1973) and the resulting paper (Egemeier, 1981) are still the most detailed and comprehensive of any study of any cave where replacement-solution is taking place. In his discussion he produces convincing morphological evidence for cavern development by replacement-solution. We (James and White in preparation) have carried out additional experiments and our results confirm that replacement-solution is currently occurring in Lower Kane Cave and Hellespont Cave.

The cave in the Cave and Basin Hot Springs, National Park on Sulphur Mountain, Banff, Canada has been made by a thermal spring which first produced an enormous tufa deposit. Then as the dominant chemical characteristics of the spring changed from carbonate to sulfate and hydrogen sulfide, erosion of the tufa commenced. The sulfuric acid produced by oxidation of hydrogen sulfide is replacing the calcium carbonate of the tufa with gypsum. The gypsum is dissolving and a cave is growing in the tufa. Cesspool cave, Virginia, USA (Hubbard *et al.*, 1986) is of similar origin.

Cueva del Azufre in Tabasco, Mexico (Azufre is Spanish for sulfur) (Pisarowicz, 1988) is certainly the most active and thus the most unpleasant sulfuric acid cave yet recorded. The water flowing out of the cave is milky white with colloidal sulfur. Inside the cave the white gypsum covered cave walls are mottled bright yellow from sulfur crystals. The water dripping from the walls has a pH of 1 resulting in the disintegration of caving overalls and acid burnt cavers. To add further to the discomfort of the cavers the temperature of the cave water is 30°C.

The above examples are active caves where replacement-solution is currently taking place and when discovered were regarded as rare, however, already other examples have been recorded in Italy and the USSR. Once the active replacement-solution had been observed to be occurring in these caves, numerous investigators began to find evidence that many other caves could have had an episode of enlargement by sulfuric acid erosion.

The most studied examples are the caves of the Guadalupe Mountains, New Mexico, USA. The best known cave is Carlsbad Caverns and the evidence for an episode of sulfuric acid attack is extensive - a review can be found in Hill, 1987. I will only quote one piece of the morphological evidence for limestone replacement by gypsum as presented by Queen *et al.*, 1977.

"Gypsum blocks in Carlsbad Caverns and Cottonwood Cave may be found to display all petrographic textures found in the surrounding carbonates, travertine, pisolites, fossils, breccias, bedding and primary pores. Where no displacement or recrystallisation of the gypsum has occurred these textures in the gypsum may be correlated bed for bed with the carbonate. The contact of this type of gypsum with the carbonate is knife sharp."

I consider this to be conclusive evidence for replacement solution.

Salt wedging...Gypsum in its own right will enlarge caves when it crystalises in porous rock and in joints and cracks, the crystals first grow in the larger voids and then force their way into the smaller ones. The forces exerted by the growing gypsum crystals are great and can exceed the mechanical strength of the rock causing it to fracture.

This process is occurring in many caves; if the rock is competent little wedging takes place, the gypsum forms as a crust which periodically falls to the floor as a gypsum snow. An example of such a deposit can be found in Mamo Kananda, Muller Range, PNG these cave passages tend to be small and cavern enlargement is minimal. However, if the limestone is porous then sands consisting of limestone and gypsum and fallen boulders are the result of wall rock breakdown. Such breakdown deposits are frequently encountered in the higher dry levels of the Zongolica Caves, Chilchotla, Oaxaca, Mexico where the resulting caverns are frequently very large.

AUSTRALIAN EXAMPLES

Type 1 solution There are as yet no recorded Australian examples of this type of sulfuric acid attack. However, there is potential for Type 1 caves to form. There are a number of areas where sulfide mineralisation is associated with limestone, for example Cooleman, Wombeyan and Cleifden in NSW. Caves known to be close to such mineralisation should be examined for evidence of sulfuric acid weathering.

Type 2. replacement-solution Again there are no recorded Australian examples of replacement-solution either currently active caves or of caves that may have formed by sulfuric acid action in the past.

Type 3 salt wedging Enlargement of caves by gypsum crystal wedging definitely occurs in many Australian Caves. Australia is the second driest continent and has many arid and semi-arid karst areas. There have been periods of gypsum wedging in the caves of the Nullarbor although at present any action due to gypsum is eclipsed by halite wedging.

It is clear from this brief survey that it is unlikely that there are going to be Australian caves where sulfuric acid corrosion is greater than "carbonic acid" corrosion. However there is often subtle corrosion from sulfuric acid taking place in caves and if there is adequate analytical data available for the cave waters then it is possible to calculate its contribution to the total erosion.

INDICATORS OF SULFURIC ACID CORROSION

There are two main indicators that sulfuric acid has been or is active in caves. Sulfate speleothems in the cave and sulfate in the cave waters.

Sulfate minerals in the caves

The presence calcium sulfate-2-water as gypsum or selenite in the cave may indicate that there has been sulfuric acid attack on limestone.

* In Australian caves gypsum is the second most common secondary mineral; calcite being the first.

* Gypsum can be found in caves at all latitudes and has been recorded as being present in caves from Far North Queensland to Tasmania.

* In caves of all altitudes; the highest Australian gypsum is to be found Yarrangobilly Caves in the Snowy Mountains and Anna Kananda in Tasmania, the lowest a few metres above sea level in Pannikin Plain cave on the Nullarbor Plain.

* In caves from areas with a wide range of precipitation; gypsum is found in very wet caves such as Herberts' Pot, Tasmania to extremely dry caves below the desert. However, it is in the caves below the desert that gypsum is most frequently found.

Forms of gypsum. There are almost as many varieties of gypsum speleothems are there are of calcite. The various morphologies of gypsum and selenite deposits found in caves are classified and described in Hill and Forti, 1986.

The following general observations can be made about gypsum speleothems

* Gypsum speleothems in most caves do not occur with calcite; gypsum flowers the classical example of evaporite speleothems are usually pure gypsum although they may contain occluded detrital materials.

* Massive gypsum crystals and selenite grow from muds in places where there is no observable calcium carbonate or sulfate source.

* Gypsum speleothems are fast growing and ephemeral.

Conditions for gypsum growth The most important conditions for gypsum growth are reduced humidity either by the cave atmosphere being dry or by the gypsum carrying solutions being evaporated by strong draughts.

Sulfate in the cave waters

The other indicator of sulfuric acid attack on limestone is sulfate in the cave waters. All cave waters contain some sulfate, unfortunately until recently it has been difficult to analyse for sulfate and thus has often been omitted from karst water analyses.

SOURCES OF SULFATE

If there is gypsum in the cave or sulfate in the karst waters then it can have come from one or more of the following sources.

Solution of sulfate deposits In the arid and semi-arid regions of Australia the gypsum in the caves may be derived from the mineral being present on the surface or in rock strata and dissolving in seepage water and reprecipitating on entry to the caves. Limestones may contain deposits of both anhydrite and gypsum if these are directly in the path of descending meteoric waters, solution of the sulfate will take place and cause a cavity to form.

Sea-water and sulfate thermal and connate waters The caves of the Nullarbor have been invaded by Sea-water and the sulfate levels are very high. Many Australian groundwaters have a high sulfate content.

The oxidation of sulfides Sulfides are sources of reduced sulfur and can thus be oxidised to sulfuric acid.

e.g. $4FeS_2(s) + 15O_2(aq) + 14H_2O(l) \rightarrow Fe(OH)_3(s) + 16H^+(aq) + 8SO_4^{2-}(aq)$

Pyrite and chalcopyrite are the only commonly occurring sulfides that can generate acid. Other sulfides can relocate acid (relocation implies separation of the two reactions either by space or time: that is the overall reaction has no net generation of acid. Most Australian limestones contain some pyrite and this reaction will be occurring to some extent in any cave that is in a limestone that contains pyrite.

Hydrogen sulfide is produced by acid attack on sulfides and by the decomposition of organic materials containing sulfur and by bacterial sulfate reduction. When organics or bacteria are implicated in the production of hydrogen sulfide in acidic conditions carbon dioxide will also be produced. Most of the H_2S formation on earth to the bacteria of the genera *Desulfovibrio, Desulfotomaculum* and *Desulfomonas*. These bacteria are widely distributed in caves and in the soil above caves, thus a component of the erosion will be due to sulfuric acid in all caves where the carbon dioxide comes from organic sources. During the oxidation of hydrogen sulfide there is no net acid production however a weak acid is converted to a strong acid.

Elemental sulfur oxidation Oxidation of sulfur produces sulfuric acid however native sulfur is rare in caves and will not be discussed here.

Acid rain A major component of acid rain is sulfuric acid, this when it falls on karst can caused considerable dissolution of the limestone.

In many parts of Europe and North America cavers are claiming to be able to observe the effects of acid rain in caves. A number of studies are in progress in order to quantify its contribution to the development of caverns and the solution of speleothems. Acid rain is unlikely to become a problem in Australian karst areas.

CALCULATIONS ON THE AMOUNT OF SULFURIC ACID CORROSION OF KARST

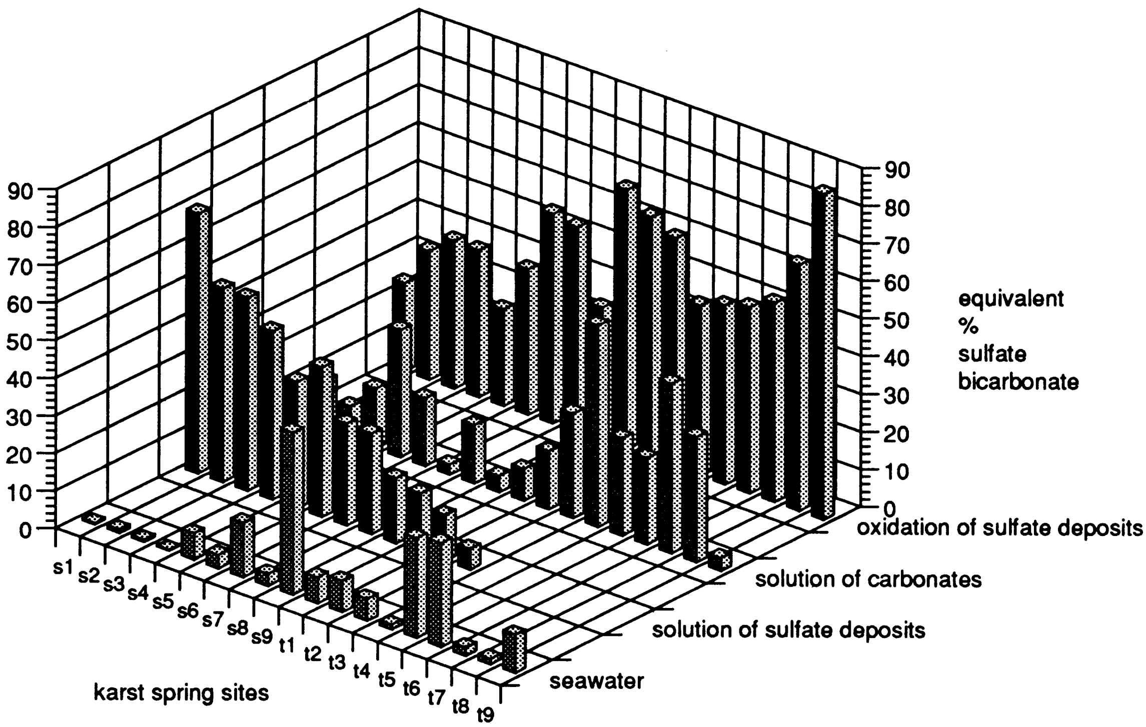


Figure 1....The origins of sulfate in various USSR karst waters (Durov, 1956).

The first literature contribution quantifying the contribution from various sulfate sources was a paper by Durov, 1956. This paper fortunately has been translated from Russian and reprinted in the Cave Geology series of the National Speleological Society. It has suffered in translation and unfortunately the original chemical data has been omitted. The conclusions presented in Durov, 1956 are shown in Figure 1;
of the 19 examined cases.

* 11 of them have a predominance of the products of the oxidation of sulfides

* In 7 cases dissolving gypsum does not merit any attention as a source of dissolved salts.

* In 6 out of the twelve cases where a component can be attributed to dissolving of gypsum the products of the zone of oxidation exceed that due to dissolving gypsum.

* In 17 cases, the overwhelming majority the action of sulfuric acid is significantly greater than that of carbonic acid.

Since the Durov 1956 paper no one had considered the sulfate content of karst waters as an indicator of the sulfuric acid reaction. Durov's calculations were complex and involved the use of other ions present in karst waters. If the chemistry of the input and spring waters is known and provided the chemical analysis does not show any influence of sea-water, other saline waters or solution of calcium sulfate deposits. A simple calculation can be carried out to estimate the extent of sulfuric attack on the limestone.

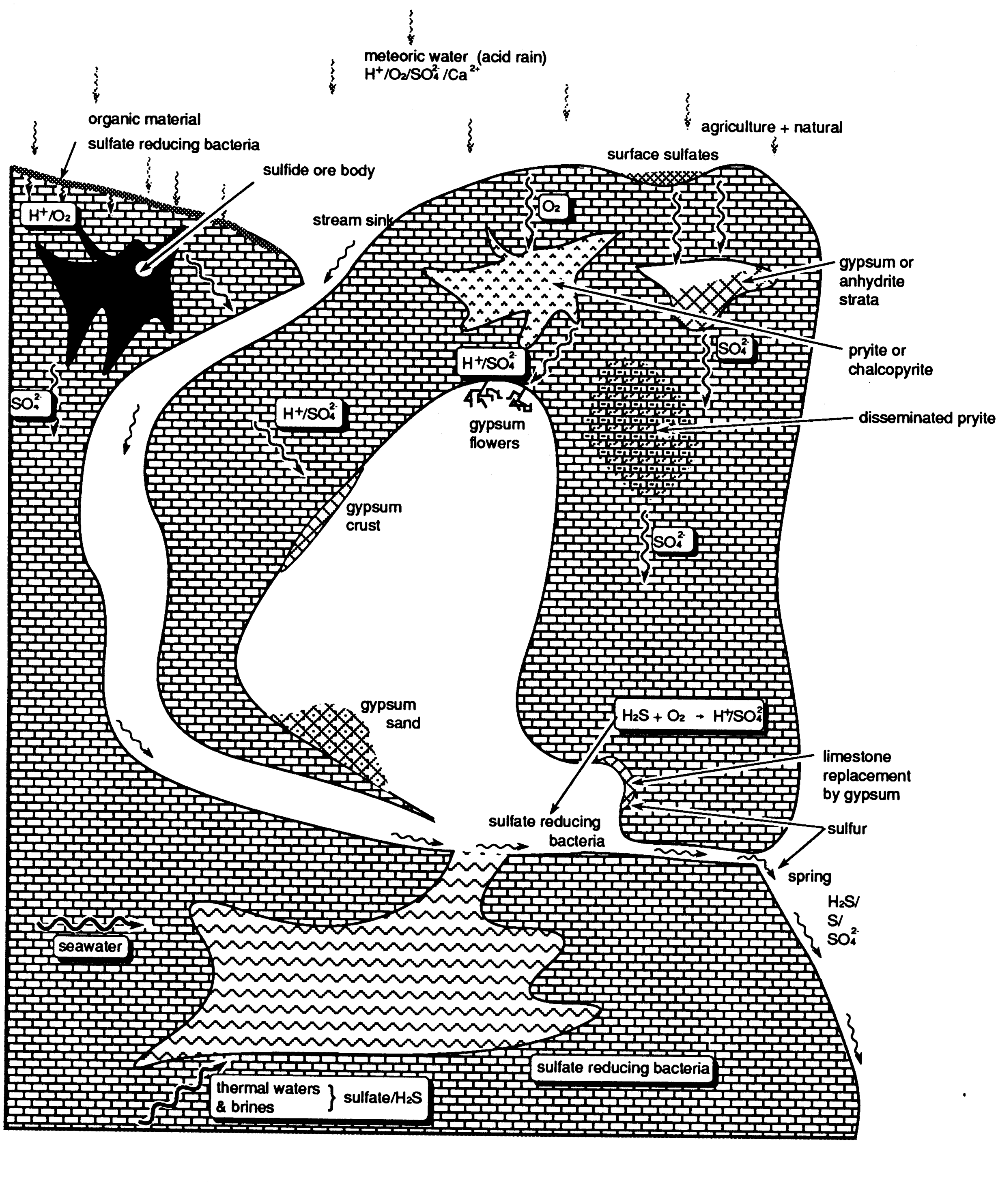


Figure 2...Sulfates and sulfuric acid in caves

There are two reactions of sulfuric acid with limestone.

(1) EXCESS SULFURIC ACID

$$CaCO_3(s) + 2H^+(aq) + SO_4^{2-}(aq) \rightleftharpoons Ca^{2+}(aq) + SO_4^{2-}(aq) + H_2O(l) + CO_2(g)$$

(2) EXCESS CALCIUM CARBONATE

$$2CaCO_3(s) + 2H^+(aq) + SO_4^{2-}(aq) \rightleftharpoons 2Ca^{2+}(aq) + SO_4^{2-}(aq) + 2HCO_3^-(aq)$$

When calcium carbonate is treated with excess sulfuric acid the first reaction takes place. From this equation it can be observed that one 1 mole of $H_2SO_4(aq)$ will dissolve 1 mole of $CaCO_3(s)$.

When calcium carbonate is in excess...the situation in the cave....the reaction is represented by the second equation. It should be noted that one mole of sulfuric acid will now dissolve two moles of calcium carbonate. This reaction can be used to calculate the extent of sulfuric acid corrosion.
For example Harvey Creek Cave Spring (Ok Tedi, PNG) waters contain 112 mg L^{-1} of calcium carbonate and 20 mg L^{-1} of SO_4^{2-}. Using the relationship in equation (2), calculations show that some 30-40% of the solution has taken place by oxidation of sulfides. This is not surprising as the cave waters are known to collect in and drain through pyrite skarns, a small component of this will be derived from the oxidation of reduced organic sulfur. Definitely no gypsum solution as the average annual rainfall is 8.3 m. and definitely no sea-water the spring is at an altitude of 1800 m.

Doing similar calculations for the Bungonia Efflux waters I get an 8% contribution from sulfuric acid corrosion. In all areas where there is decaying organic material there will be always be a small proportion of sulfuric acid weathering. This should be considered a normal contribution and to be present in all karst waters generated by organically produced carbon dioxide.

Preliminary calculations on the Nullarbor cave waters indicate that most of the sulfate comes from sea-water or connate waters and there will be a small component from calcium sulfate-2-water from the surface of the plain and within the limestone. At present there is no sulfate component that can be identified as coming from the oxidation of sulfides either mineral or organic.

CONCLUDING REMARKS

Figure 2 summarises the discussion in this paper on sulfuric acid and sulfates in caves. It is clear that there is cavern development due to sulfuric acid in Australia but in the cases where it can be identified its effect is small when compared with that due to carbonic acid.

There is a need to examine Australian caving areas for corrosion by sulfuric acid, both present and past. Wherever karst waters are analysed it should be routine to measure the following; calcium, magnesium, sodium, potassium, hydrogencarbonate, chloride and sulfate. The pH should be measured on a calibrated pH meter to 2 decimal places. These are the essential parameters needed to calculate the relative importance of corrosion by sulfuric acid to that by carbonic acid.

REFERENCES

DUROV S.A., 1956. On the question about the origin of the salt composition of karst water. *Ukrainian Chemical Journal* **22** pages 106-111.
English translation Cave Geology 1 pages 185-190.

EGEMEIER S.J., 1973. Cavern development by thermal waters with possible bearing on ore deposition. PhD. Thesis, Geology, Stanford University.

EGEMEIER S.J., 1981. Cavern development by thermal waters. National Speleological Society Bulletin **43** pages 31-51.

HILL C.A., 1987. Geology of Carlsbad Caverns and other caves in the Guadalupe Mountains, New Mexico and Texas. *New Mexico Bureau of Mines and Mineral Resources* Bulletin 117, 149 pages.

HILL C.A. and FORTI P., 1986. Cave minerals of the world. National Speleological Society, Huntsville, Alabama, 238 pages.

HOWARD A.D., 1960. Geology and origin of the crevice caves of the Iowa, Ilinois and Wisconsin lead-zinc district. *Journal of the Yale Speleological Society.* **2**(4) pages 61-95.

HUBBARD D.A., HERMAN J.S. and BELL P.A., 1986. The role of sulfide oxidation in the genesis of Cesspool Cave, Virginia, USA. *The proceedings of the 9th International Congress of Speleology,* International Speleology, Barcelona, pages 255-257.

MOREHOUSE D.F., 1968. Cave development via the sulfuric acid reaction. *National Speleological Society Bulletin* **30** pages 1-10.

QUEEN, J.M. PALMER A.N. and PALMER M.V, 1977 Speleogenesis of the Guadalupe Mountains, New Mexico: gypsum replacement of carbonate by brine mixing. Proceedings of Seventh International Congress of Speleology, Sheffield, U.K. pp 333-336.

PISAROWICZ J., 1988. The Revenge of Chac, 1988 in Tabasco. *Association for Mexican Cave Studies Activities Newsletter* No.17, pages 129-138.

POHL E.R. and WHITE W.B., 1965. Sulfate minerals: their origin in the Central Kentucky Karst. *Amer. Mineral.* **50** pages 1461-1465.

HOW OLD ARE AUSTRALIA'S CAVES ?
Evidence from Buchan, eastern Victoria, and Chillagoe, north Queensland

John Webb
Department of Geology,
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Bundoora,
Victoria 3083

During recent years evidence has begun to accumulate that the karst landscapes in Australia may be considerably older than previously imagined. At Buchan in eastern Victoria, there are high level caves that formed as phreatic systems along vertical joints. The water table associated with these caves lay along the bed of a large ancestral river, which was at least 180 m above the present-day rivers in the area. This ancestral river was partially filled by basalt lava flows around 40 million years ago, and the caves were drained by downcutting of the river soon afterwards. Thus the high level caves at Buchan formed more than 40 million years ago.

There are also low level caves in the Buchan area. These are horizontal epiphreatic systems, characterized by very flat roofs that developed along the water table when it was stable for some period of time. The lowest level passages, which are only 2-3 m above the present water table, were filled with sediment after they had formed. Palaeomagnetic studies of this sediment indicate that is was probably deposited when the Earth's magnetic field was reversed. The last major period of reversal finished about 730,000 years ago, so the caves must be at least this old. Previously these cave systems were believed to be less than 100,000 years old.

At Chillagoe in north Queensland, these is evidence of mush older karst development. The limestone landscape here is characterized by spectacular towerkarst development, and the individual towers can rise as much as 100 m above the surrounding plains. Around the bases of the towers, and very rarely close to their summits, are small outcrops of ferruginous and quartose sandstone, all apparently in situ.

The elevations of these sandstone outcrops range from 340 m to over 400 m. This sandstone has been correlated with other outcrops further north, which contain Early Cretaceous fossils. This shows that in the Early Cretaceous, about 130 million years ago, the limestone towers were at least 60 m high, i.e. the Chillagoe towerkarst was already in existence. In the Early Cretaceous the limestone was partially or completely covered by the sandstone, which has since been largely eroded away.

The age of the caves within the towers at Chillagoe is more difficult to determine. No standstone outcrops have been found in any of the caves, so they may have formed after the sandstone covering the towers had been removed by erosion.

The current thinking on the origin of limestone caves mainly comes from the Northern Hemisphere, where most caves were formed as a result of the major climatic and sea level fluctuations during the last two million years. However, these variations had much less effect in Australia, and as a result our landscapes are considerably older, and have developed over much longer time periods than the Northern Hemisphere examples. Thus Australian caves have much to offer in the refinement of current theories of karst formation, because they show that effect of time, a factor lacking in the younger landscapes of the world.

STEGAMITES - A FORM OF CAVE SHIELD?

By Rauleigh Webb
Western Australian Speleological Group (Inc)

Abstract: The description of an unusual speleothem from two caves on the Nullarbor Plain. The name of Stegamite is proposed for the formation as it appears like the ridges on the back of a Stegasourous.

The dissolution of a broken section of one of the Stegamites in Hydrochloric Acid indicated that the black material was probably organic in origin.

Theory's for the formation of Stegamites are postulated.

INTRODUCTION

During the first trip to take Ultra-Light aircraft (Trykes) to the Nullarbor Plain to locate caves, the entrance to a new cave was located by the aircraft. This cave was named Matilda (N-370) by the pilot making the discovery. The exploration of Matilda was unusual in that it had not been previously explored except cursorily by Wayne Tyson and "Stubbie" on the day it was found.

Then on the subsequent trip to survey the cave track marking occurred as the cave was explored. Great care was taken to restrict damage to the tracks that were being marked.

It was on this second trip to explore, track mark and survey Matilda and Gorange Cave (N-360) that the unusual ridges in the floors of both caves were noticed. The formations were named Stegamites as they appear as ridges in black calcite floors similar to the ridges on the back of a Stegasaurous.

Description

Stegamites always occurs on the floor of caves in areas where calcite flows covers the floor. To date the speleothems only occur in calcite that is black in colour. An X-ray diffraction examination of a sample of a stegamite indicated 99%+ pure calcite with what appeared to be minute quantities of black organic material.

The stegamites in Plate 1 indicate the average size of the stegamites discovered. The formations range in size from 5cm wide x 5cm high x 30cm long to 1m wide x 1.3m high x 1.6 m long. They appear as a "ridge" in the calcite floor generally with a crack along the top of the "ridge". They do not appear to be aligned within a single sheet of calcite but rather appear at angles random to each other.

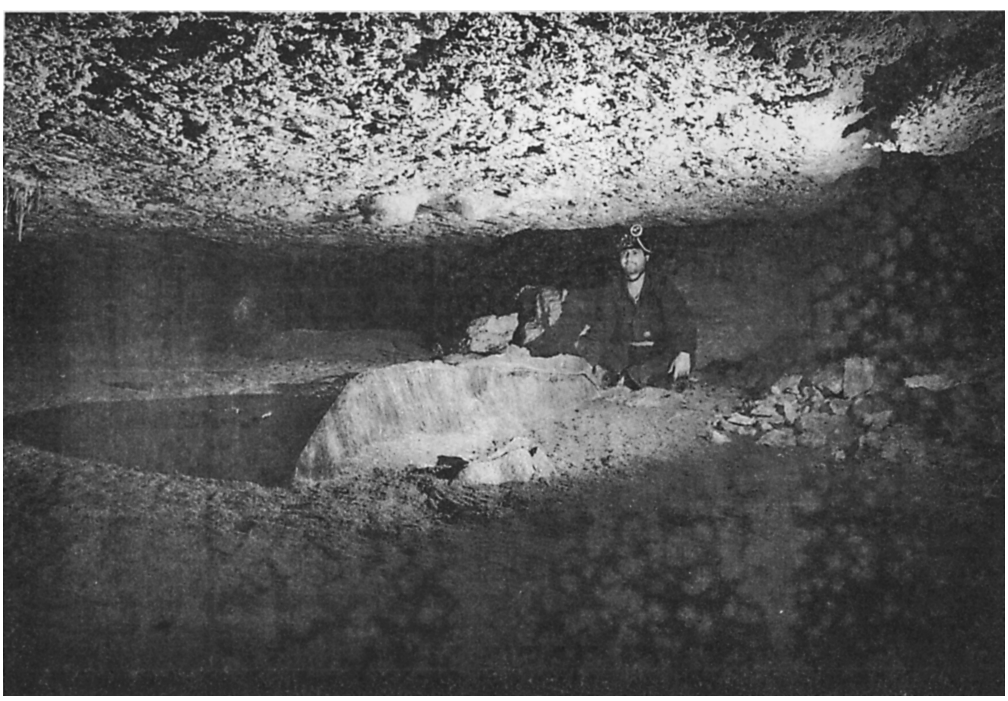


Plate 1 - Stegamites in Gorange Cave, Derek Hobbs for scale.

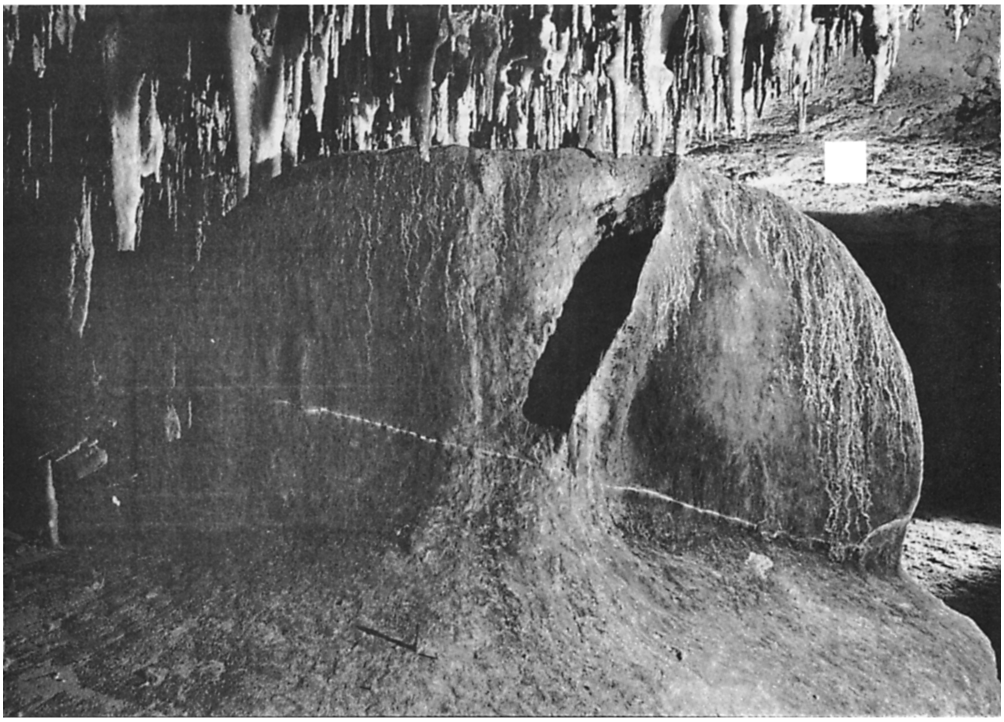


Plate 2 - Front view of large Stegamite.

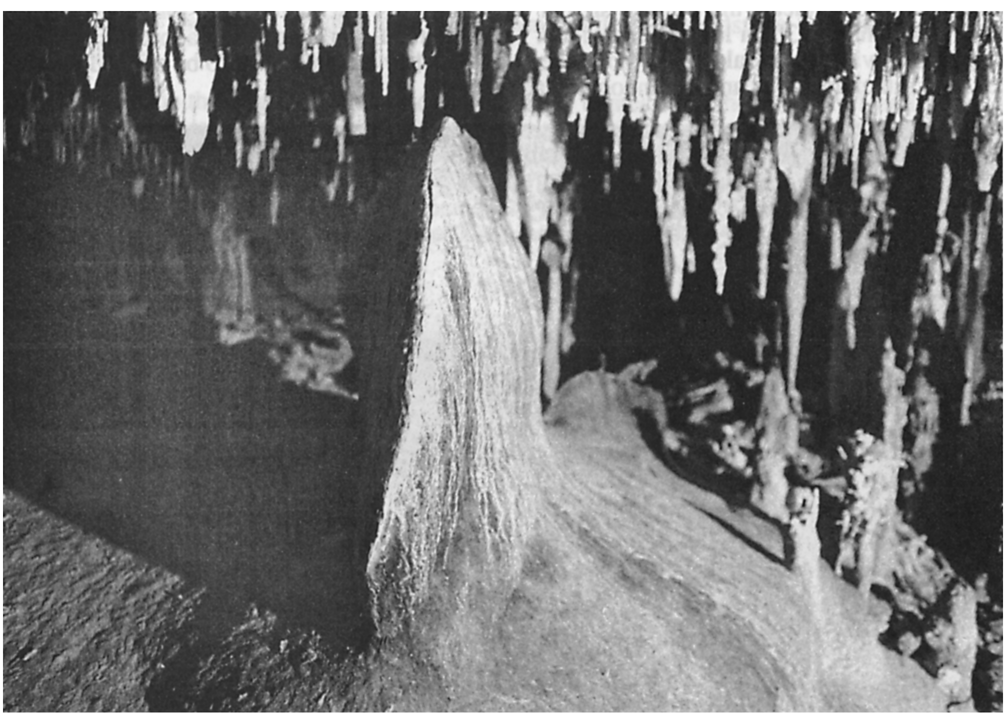


Plate 3 - Side view of Stegamite in Plate 2.

Some stegamites appear to have shattered during their formation. In some cases just the top "ridge" of the stegamite has fractured. Examination of this fractured top of the stegamite indicates that it consists of tens of layers of calcite varying in thickness from 1 micron to 2 millimetres. These layers are angled at approximately 45 degrees to the horizontal. They also appear to be horizontally bedded along the length of the formation.

The colour of these layers also varies from white to black. The white layers are generally much smaller in thickness than the much thicker black layers which dominate the formation. A preliminary examination under a scanning electron microscope indicates that the very fine white layers may be gypsum.

A great deal of work has been done on the colour of speleothems. In particular White (1981) used reflectance spectra to postulate that the commonly held theory that the yellow to brown colouration of speleothems is not due to iron oxides but rather the colouration is probably due to humic substances from the overlying soils.

Furthermore Hill (1982) has examined the origin of a number of the black deposits found in caves. These were broadly grouped into:-

Manganese Deposits
Soot
Guano
and Humate and other carbonaceous matter.

In the case of stegamites and other black speleothems in Matilda and Gorange caves the black colouration is thought to organic in nature as the colour is taken up in chloroform once the bulk of a sample has been dissolved in acid. Further tests will be preformed to determine the exact nature of the black material.

One unusual stegamite shown front on (Plate 2) and side on (Plate 3) appears to resemble a large shell. It is approximately 1.2 metres high x 1.5 metres long x 0.25 metres thick.

Cave Shields

The only other formation that may be related to stegamites are cave shields. Shields consist of two oval or circular parallel plates (this may resemble the stegamite shown in Plate 2) which are separated by a medial crack. The shield is formed by solutions being forced from the medial capillary crack at the rim of the shield. Shields can occur on floors, cave walls or ceilings with the calcite deposited in concentrically arranged crystalline zones (Hill 1986).

A very interesting theory for how the shield keeps its medial crack open was postulated by Moore (1958) and later Schmidt (1963). This theory proposes that action of the earth's tides effect the water flows in the medial crack and ensures that it remains open.

Proposed Theory for the Formation of Stegamites

It is proposed that stegamites are formed in a manner similar to cave shields in that solutions are forced through a crack or joint in the floor. However they differ from cave shields in that concentric plates are not formed.

Instead the solution is thought to be forced through the crack and flow across the floor forming the calcite sheet. During this process the "ridge" is forming in the floor much like a volcano with the lava (solution) pouring over the rim of the cone ("ridge").

However in the case of stegamites, as the flow is from a crack in the floor, the flow forms ridges instead of a volcano shape.

In two cases, secondary stegamites appear to have formed on the original speleothem. In Plate 2 a small secondary stegamite appears on the side of the larger formation. This is probably the result of the medial crack closing but the solution finding its way through the weakest section of the formation, forcing a new crack in the side of the original stegamite. It should be noted that these secondary stegamites were only observed on the two largest stegamites, the one shown in Plate 2 and another in Matilda.

The major differentiation between stegamites and shields is the lack of concentrically arranged plates in stegamites. They appear to comprise of horizontal layers of calcite and hence are clearly not formed in the same manner as shields.

The complete absence of black material in the thin white layers (which preliminary examination indicates may be gypsum) in stegamites clearly indicate variations in the climatic conditions during the deposition of calcite layers. The large number of gypsum stalactites, formed over calcite stalactites, occurring in Gorange Cave also adds credence to the possibility of gypsum layers forming on calcite during periods of low rainfall.

Acknowledgements

I would like to thank Lex Bastian and David Honey for their assistance with the chemical analysis of the Stegamite sample. Many thanks also to Lucinda Coates for the photographs.

References

Hill C.A. (1982) Origin of Black Deposits in Caves, NSS Bulletin, 44:15-19.

Hill C.A. and Forti P. (1986) Cave Minerals of the World, NSS, Huntsville, ALABAMA. pp 57-59.

Moore G. W. (1958) Role of earth tides in the formation of disc-shaped cave deposits, NSS News, V16:11, p113-114.

Schmidt V. (1963) Schields, joints and earth tides, Netherworld News, V6:1, p115-120.

White (1981) Reflectance Spectra and Colour in Speleothems, NSS Bulletin, 43: 20-26.

A NEW TOPOFIL

Alan Warild

Topofils have been used in Europe for many years in cave and to a lesser extent, surface surveying. Their main advantages over other survey instruments are their lightness, compactness, speed of use and their lack of restriction over survey leg length. Some topofils have been further streamlined to produce a single unit which measures distance, bearing and inclination. This topofil solves some of the problems of earlier models by using the same 360° protractor to measure both bearing and inclination.

COMPASS SIGHTING MECHANISM

The sighting mechanism consists the compass capsule from a Silva 7NL compass (a needle rather than a moving card compass) set into a hole in the topofil box lid and held down by a brass bridge. At the centre of this bridge is mounted a 1.5 mm diameter sighting pin surrounded by a brass washer "bullseye". Around this is a sighting mirror surrounded by a 360° twin scale protractor mounted on a 3 mm white perspex backing sheet to improve rigidity.

The assembly is calibrated in two steps. Firstly, the sighting pin is locked as close a possible over the centre of the compass. The protractor is then adjusted so that the sighting pin is at its exact centre by laying a complete protractor over the top of the first and moving them until the pin is under the crosshairs of the top protractor. The bridge and protractor are screwed into oversized holes in the topofil lid to allow for this. The second calibration is done by tying a thread between two stations and reading its bearing with a sighting compass or other topofil. The topofil is set up so that the thread is wrapped around the sighting pin, then runs across the correct bearing on the protractor to the other station. The compass is then rotated until its needle lines up with the arrow on the compass base and locked in position with a lock screw. Note that the diameter of the sighting pin induces a centring error into all readings but this is "calibrated out', provided the thread is always wrapped the same way - I use clockwise. By taking the magnetic declination of an area into account, the topofil can also be set to read true or grid north.

COUNTER AND LEVEL MECHANISM

The plastic five digit counter must first be dis-assembled and the steel spindle replaced by a brass or stainless steel one to avoid magnetic effects on the compass. The centimetre digit at the right end and the 100's of metres digit at the left end are superfluous, so to make note taking easier and more accurate, they are masked. This has the effect of the counter always displaying a rounded down figure. Note however that this does not mean each survey leg is rounded to the nearest 10 cm. The counter still counts in single centimetres, but it displays in decimetres from the starting point.

The counter wheel is a ten centimetre circumference rubber coated wheel which can be turned down from nylon or polyester or built from a suitable sized plastic cotton
reel. The wheel should be as light as possible so that it's inertia is minimal. Heavy wheels tend to skid when started quickly and keep spinning after a sudden stop, introducing errors and possibly "derailing" the thread. Rubber coating (bicycle tube) helps reduce skidding and the friction arm dampens over-running.

The counter mechanism is mounted on the back of the level window from a builder's level which in turn fits neatly into a hole cut into the lid of the topofil box.

The counter is calibrated by reeling out a metre of thread against a tape or ruler and seeing how close it is to correct. Changes are made by adjusting the size of the counter wheel. Turned wheels can be cut marginally oversize and the wheel carefully filed to the precise size. A wheel which is too small is built up using a strip of plastic adhesive tape, the length of which is adjusted until the correct size is obtained. Once the counter is good over a metre it must be fine tuned over a greater distance of say ten metres.

The level is calibrated by hanging a weight from a thread wound clockwise around the sighting pin and the body of the topofil resting on a table. The topofil is then tilted until the thread coincides with the 90° mark and the level window rotated until the bubble is in the correct position. Once again, oversized holes are used to make this minor movement possible.

USING THE TOPOFIL

DISTANCE is taken by noting the initial topofil reading at the first station, then running a straight line of thread and touching the thread outlet hole to the next station. The new reading (cumulative distance) can then be read off.

BEARING is taken by wrapping the thread coming from the station clockwise around the sighting pin and pulling it taut. The topofil is held horizontal and in line with the station while it is rotated until the north arrow lines up with the arrow on the compass base. The bearing is the degree mark over which the thread passes. This is fine when sights are close to horizontal. When taking upward sights the thread passes over the protractor some distance above it, making parallax errors possible. To reduce such errors a mirror can be inserted around the compass. When the reflection of the thread is obscured by the thread itself, the eye is directly above and the reading is parallax free. Should the mirror be unusable, it is necessary keep one's eye directly above the sighting pin - not too difficult with the aid of the 'bullseye' while looking end-on at the pin. Downward sights are more difficult and potentially less accurate. The topofil is oriented as above but then the thread drops off over the side of the topofil. The thread must therefore be lifted with one finger a few centimetres out from the side of the box and moved from side to side until it makes a straight line in the horizontal plane from the topofil to the station.

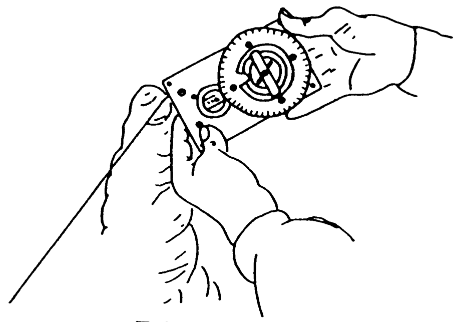
INCLINATION is taken by turning the topofil so that the protractor is vertical with the thread just off its face. The instrument is then leveled using the level bubble and the reading taken.

TOPOTACTICS

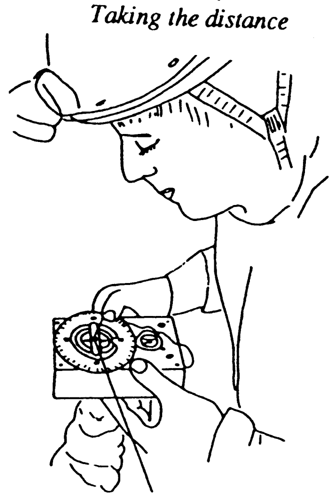
A topofil survey is most efficient with two surveyors: One to read the topofil and the other to take notes. When a team is short-handed a topofil survey can be done alone with no loss of accuracy although it will be considerably slower.

Topofil surveys are best as a series of backsights. The instrument man begins by pulling out enough thread to tie off to the first station, then calls out a "first topo" to the note-taker, who repeats it. He then runs out a straight line of thread to the next station. This is preferably a small projection he can later wrap the thread around, which also has a view forward. After calling out the distance, he holds the topofil above the station or in line between the stations and takes a compass reading which he calls to the note-taker. He next holds the instrument beside or in line with the station and takes the inclination. All readings are repeated by the note-taker. Care must be taken to ensure that the thread is not snagged between stations and that it is not allowed to sag while taking compass and clinometer readings.

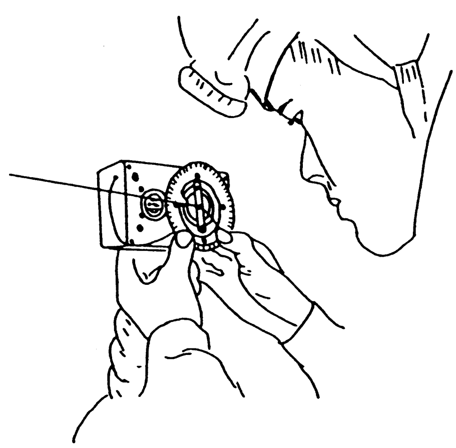
After the readings are taken, the thread is wrapped around the station two or three times by pulling sufficient thread as stretch from the leg just measured. Finding the exact point on the thread can be facilitated by making a mud mark on it at the correct point when the distance is taken or by running the topofil past the station until the thread begins to run and taking the point on it where it passes the station. If there are no suitable projections to tie the thread to it can be anchored by a rock or held by the note-taker.



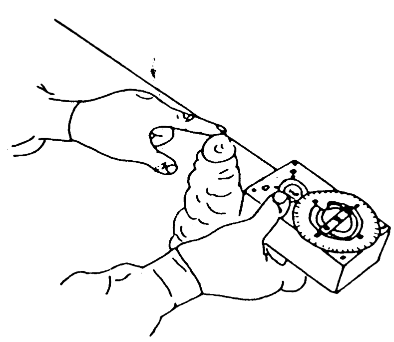
Taking the distance



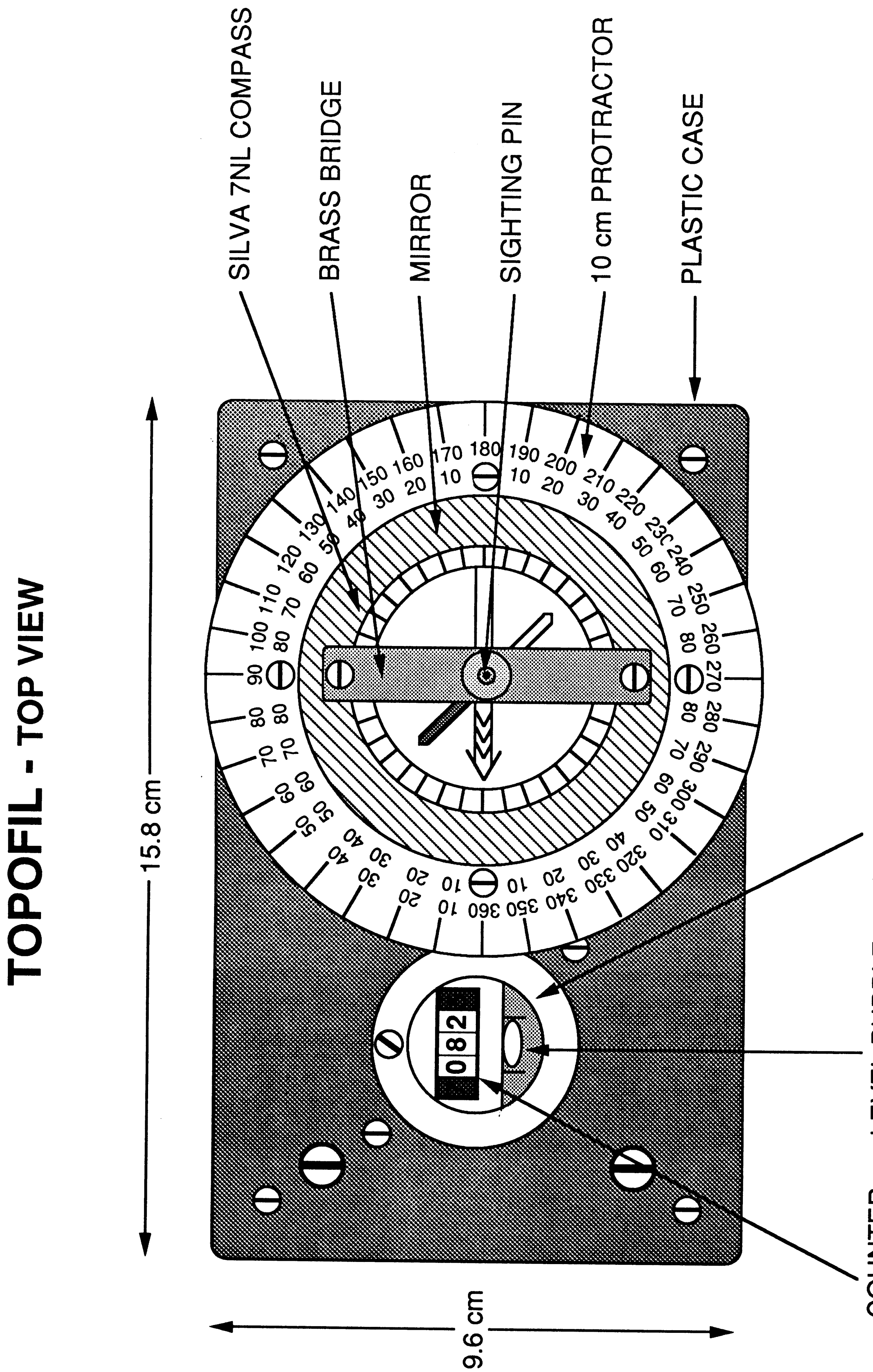
Compass bearing



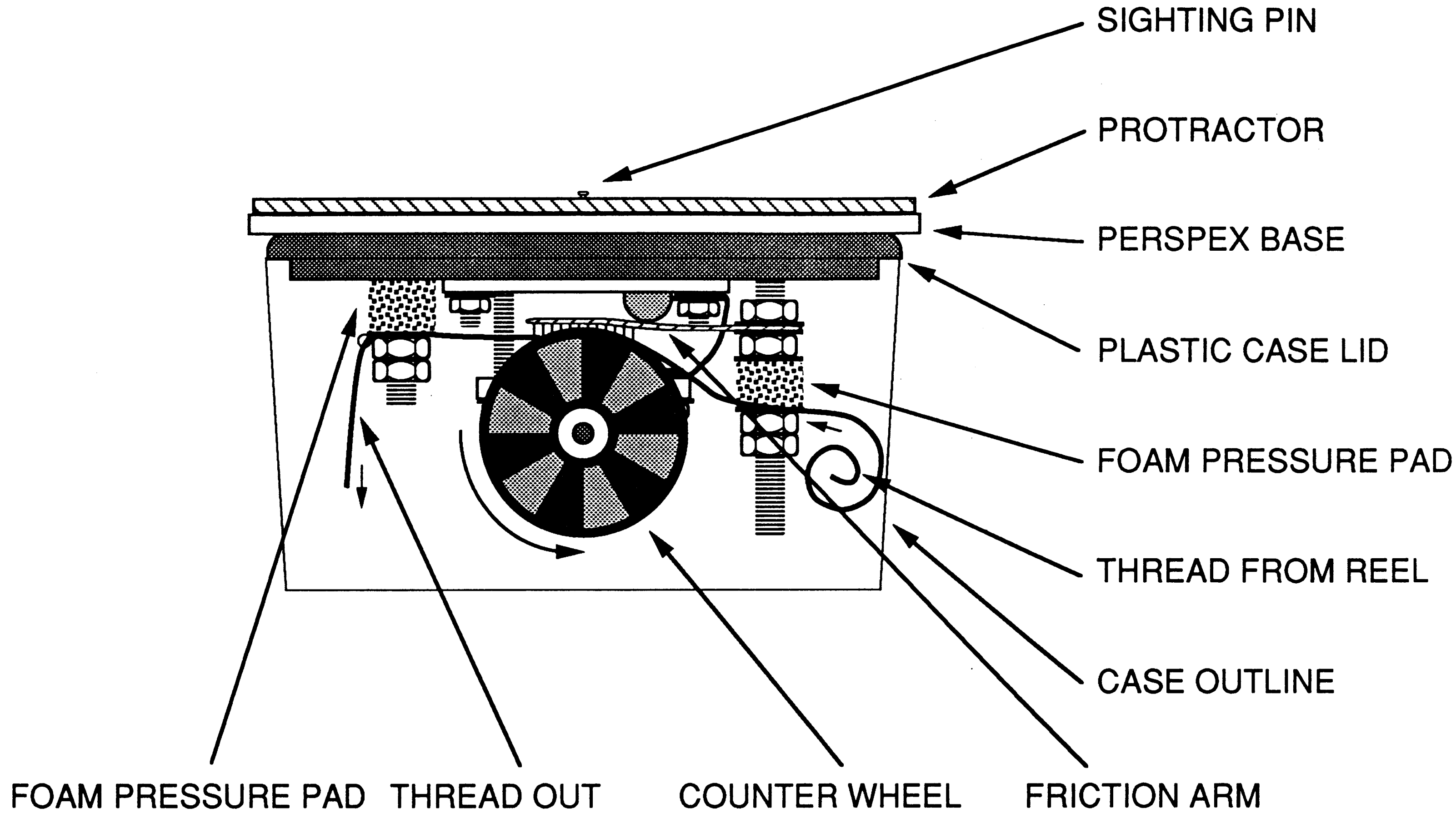
Clinometer reading



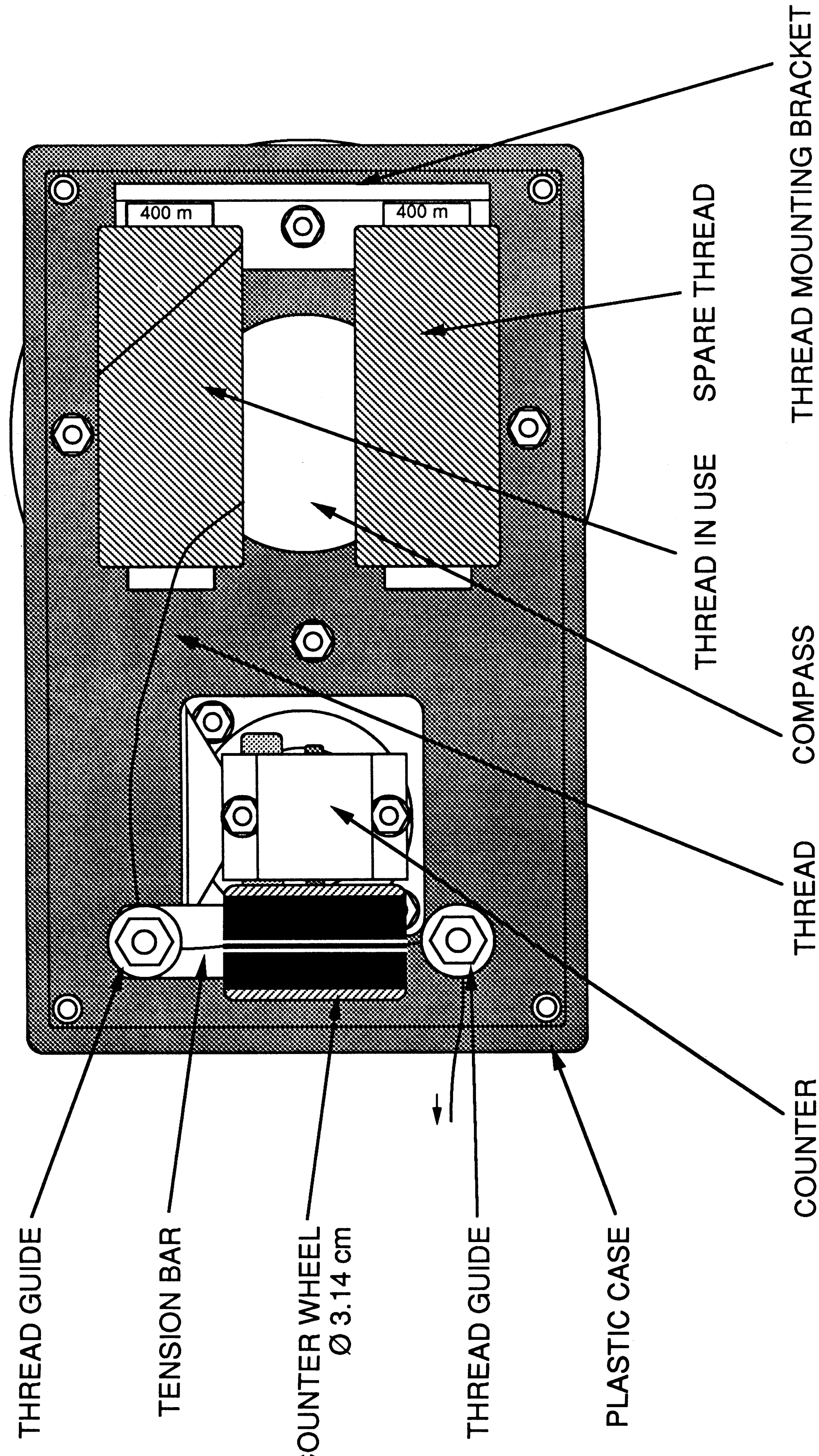
Finding the correct point on the thread


TOPOFIL - TOP VIEW
SILVA 7NL COMPASS
BRASS BRIDGE
MIRROR
SIGHTING PIN
10 cm PROTRACTOR
PLASTIC CASE
WINDOW
LEVEL BUBBLE
COUNTER
15.8 cm
9.6 cm

TOPOFIL - END VIEW



TOPOFIL - INSIDE VIEW



DETERMINING CAVE VISITATION LEVELS:
A PRESSURE ACTIVATED COUNTER

by Rauleigh Webb
Western Australian Speleological Group (Inc)

Abstract: The description of a counter that can be used to determine cave visitor levels is given.

The preliminary results of visitor numbers determined using the pressure counters are presented for Giants Cave (WI-21) and Calgardup Cave (WI-49).

INTRODUCTION

Cave visitation rates are a very important factor in making informed management decisions relating to caves. A previous visitor book study combined with on-site visitor counting produced crude, though valuable, estimates of cave visitor levels to Giants Cave (WI-21) in the South-West of Western Australia (Webb 1989).

These estimates were used to convince the management authority, the Department of Conservation and Land Management (CALM), that the visitation rates to this and other caves in the region were unacceptably high. However the visitation rates to other caves were unknown and very poorly studied.

In an attempt to monitor the rates and levels of cave visitation to Adventure and Wild caves in the Leeuwin-Naturaliste National Park (LNNP) the Cave Management Advisory Committee (CMAC) proposed the use of foot counters. These pressure counters were being trialed on tracks in the National Park in an attempt to determine Park visitor numbers.

The Counter

The counter, shown in Figure 1, was constructed as follows. A marine plywood board (A) was used to back the pressure contact device (B,C,D). This contact device (B,C,D) was purchased commercially as a roll of plastic (B) containing a horizontal matrix of metal contacts (C) held apart with a thin layer of foam. These metal contacts are connected by a thin vertical strip of metal (C).

The plastic was attached to the marine ply with Sylastic and tacks. Wires (E) were soldered to the ends of the vertical metal strips and then soldered to the leads from the electronic counter (F). This completed the circuit so that every foot placed on the contact device (B) incremented the electronic counter (F). If the contact device was held closed the counter would not be incremented multiple times unless the contacts were opened and closed multiple times. This is likely to occur if cavers jump up and down on the counter!

The electronic counter contains a 9V battery which the vendors claim has a life of up to three years. In the cave the counter was housed in an air-tight tin with the wires entering the tin through a hole in the top that was filled with Sylastic.

A small amount of Silica Gel was placed in the containers to reduce water vapour. The entire board and plastic pressure device was covered with canvas to protect it.

The major problem with the counters was corrosion at soldering points. In all cases if the joint was open to the atmosphere then corrosion occurred. In several cases this caused the counter to stop registering.

Placing the Counters

Giants Cave (WI-21) is known to have high visitation and previous results to compare the results of the counter and hence this was chosen as the first site. The counter was placed some 200m into the cave at the base of the first upward staircase. This location was chosen as a point where all visitors were likely to traverse as the staircase is the easiest route onwards.

Due to the large number of visitors passing this point the soil was so heavily compacted that after digging it up with a shovel it lifted in slabs and had to be cut and broken up with the shovel. At first the counter was placed some 8 cm below the surface as it appeared to work perfectly at this depth. However after 1 to 2 months the counter became erratic as the soil had become compacted and was acting as a large plate.

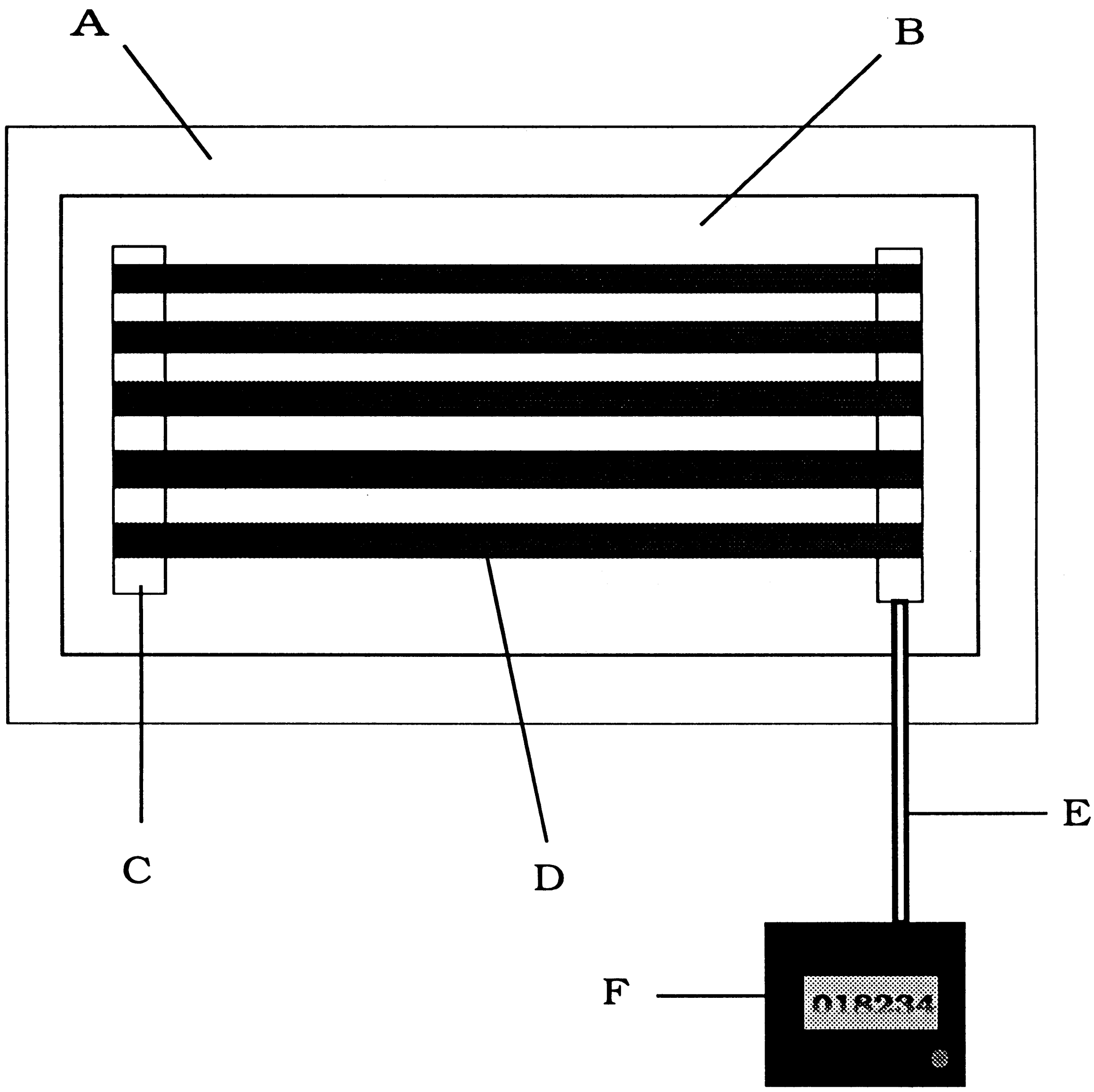


Figure 1
(The Pressure Pad Counter)

Digging up the counter required breaking up the "slab" of compacted soil, loosening the soil, and then raising the level of the counter to only a few centimeters below the surface. At this depth the counter was more obvious as the "ground" sounded hollow at that point. It did in fact draw attention and on one occasion was found uncovered on a reading trip.

Similar experiences occurred in Calgardup Cave (WI-49) where two counters were placed in the cave. The cave has two major extensions from the entrance and one counter was placed in each extension. One location was more likely to count all visitors as it was in a passage constriction that visitors were likely to traverse (Counter 2 in Table 1). However in the second case visitors were likely to bypass the counter by traversing it on the other side of the passage (Counter 1 in Table 1). Counter 1 was in fact uncovered by visitors and found in pieces by the Ranger. After repair the counter was returned to the cave but the electronic counter was stolen within one month.

The Results

The counter in Giants Cave was installed just prior to Easter 1990 and the very large figure of 2710 (Table 1) after only 14 days clearly indicates the high level of visitation that occurs over the Easter holidays.

The figures shown in Table 1 clearly indicate the steady increase in visitor numbers when the counters are read on a regular basis. Over the period from September to early December the counters were read almost every seven days by Rob Klok (CALM - Caves Ranger). These figures indicate a consistent count on a weekly basis.

Actual and Estimate Counts

The actual counts from the counter are labelled Actual Count while an Estimate Count of 70% of the Actual has been used to reduce errors noted in the counters when multiple counts are made by one person. This effect is somewhat counteracted by the counter failing to count some people at all. Controls are yet to be performed. Once a period of actuals versus counted have been observed then the Estimate Count will be more accurate.

Daily and Annual Estimates

The daily estimates are a calculation based on the Estimate Count divided by the number of days of recording. The Annual Estimates are the Daily Estimate multiplied by 365. In general the Annual Estimates appear consistent throughout the period of regular recordings.

The Average Daily Estimates for Giants Cave over the period of Nov-Dev 1990 provides an estimated annual visitation rate of approximately 15000. This figure is believed to be on the low side given the use of the conservative 70% estimate. If this is true then the figure corresponds well with the annual estimates of 17000 to 18000 proposed by Webb (1989) as a result of visitor book and on-site studies.

It should be noted that these estimates are certainly low as they DO NOT take into consideration the peaks such as that observed Easter. Furthermore the busiest two months of the year, January and February, are yet to be counted!

Hence annual estimates of 25000 plus are very likely.

Giants Cave (WI-21)
Counter Figures
Percentage Estimate 70%

Date Read	No of Days	Actual Count	Estimate Count	Daily Estimate	Annual Estimate
10/03/1990	0				
24/03/1990	14	2710	1897	135	49457
01/04/1990	22	3113	2179	99	36153
21/04/1990	42	6078	4255	101	36974
02/09/1990	176	10171	7120	40.5	14765
08/09/1990	182	10447	7313	40.2	14666
14/09/1990	188	10700	7490	39.8	14542
22/09/1990	196	11087	7761	39.6	14453
29/09/1990	203	11640	8148	40.1	14650
06/10/1990	210	12232	8562	40.8	14882
13/10/1990	217	12918	9043	41.7	15210
20/10/1990	224	13451	9416	42.0	15343
28/10/1990	232	13908	9736	42.0	15317
01/11/1990	236	13931	9752	41.3	15082
11/11/1990	246	14314	10020	40.7	14867
18/11/1990	253	14690	10283	40.6	14835
23/11/1990	258	15082	10557	40.9	14936
24/11/1990	259	15143	10600	40.9	14938
30/11/1990	265	15643	10950	41.3	15082
08/12/1990	273	16116	11281	41.3	15083
10/03/1991	365	21547	15083	41.3	15083
Average Daily for Sept-Nov 1990 =>				41	14926

Table 1

Calgardup Cave (WI-49) Counter No 1
Counter Figures
Percentage Estimate 70%

Date Read	No of Days	Actual Count	Estimate Count	Daily Estimate	Annual Estimate
24/03/1990	0				
31/03/1990	7	162	113	16	5913
21/04/1990	28	536	375	13	4891
18/08/1990	147	6391	4474	30	11108
02/09/1990	162	6554	4588	28	10337
24/03/1991	365	14767	10337	22	8062
Average Daily for Sept-Nov 1990 =>				29	10722

Calgardup Cave (WI-49) Counter No 2
Counter Figures
Percentage Estimate 70%

Date Read	No of Days	Actual Count	Estimate Count	Daily Estimate	Annual Estimate
24/03/1990	0				
31/03/1990	7	254	178	25	9271
21/04/1990	28	1705	1194	43	15558
02/09/1990	162	6716	4701	29.0	10592
28/10/1990	218	10628	7440	34.1	12456
01/11/1990	222	10717	7502	33.8	12334
11/11/1990	232	11245	7871	33.9	12384
18/11/1990	239	11544	8081	33.8	12341
25/11/1990	246	11828	8280	33.7	12285
30/11/1990	251	12220	8554	34.1	12439
09/12/1990	260	12979	9085	34.9	12754
24/03/1991	365	17795	12456	32.8	11969
Average Daily for Sept-Nov 1990 =>				33	12173

Table 1 (Continued)

Future Counters

These counters are not perfect and certainly not the best method of counting cave visitors. However at approximately $120 per counter they are relatively cheap compared to other electronic means.

Having said they are cheap it is proposed to trial a more reliable and expensive counter, an infrared beam counter, which can be incorporated into a set of stairways in the near future.

Using the Results

It is the authors sincere hope that the CMAC is able to use these and future estimates to propose management initiatives that result in a reduction of this level of visitation. If conference delegates visit Giants and Calgardup caves they should be appalled by the severe vandalism and degradation that has occurred in both caves. It is now in the hands of the management authority to put in place management policies that ensure further severe degradation of these and other caves does not occur.

References

Webb, R. (1989) Proceedings of the Australasian Cave Management Association, Punaukaiki, New Zealand.

WHAT HAPPENED AT YESSABAH.

Keir Vaughn-Taylor

History recalls that the formative years at Kempsey were pioneered by a logging industry based on giant cedar trees. The wood from these trees was exported to England where forests had already been depleted for construction of ships to support colonial interests. Victorian governments had some regard to resource protection and logging bans to preserve Kempsey Cedar were applied from distant Sydney. Cedar smuggling provided employment opportunities to sawyers of the incredible wage of 5 pounds per week and as a result by 1845 Kempsey cedar no longer existed.

During these same years the Yessabah Hill 15 kilometres west of Kempsey was designated a reserve because of its outstanding caves, rainforests and fossils. Over the years the national heritage values of the hill were gradually forgotten and a mine, started in the 1930s grew to a size where by 1980 a number of caves had been destroyed. Mining plans drawn in the 1960s reveal an intent to remove Yessabah Hill completely. Except for a series of major errors on the part of the mining company and a gathering environmental awareness by the public, those plans would have demolished the Hill.

In 1982 David Mitchell Melcann purchased the Yessabah mine from Australian Portland Cement. This would be of passing interest in the farcical play that follows, except that this event was to become of key importance to the bearing of the Yessabah Court proceedings. When the new owners of the mine assumed control their first action was to replace the four local workers on the mine with men of their own. The manager of the mine occupied a house near the mine site and he was given two weeks prior to Christmas to move to another premises. A tragic story in the true Hinch tradition but also catastrophic for David Mitchell Melcann, in terms of local public support. Other significance of the ownership transfer was only realised much later.

In 1983 DMM failed to renew their lease before the old lease lapsed and this meant that they would have to reapply. This was no doubt regarded by their management as an annoying technicality that would be dealt with in the fullness of time. However, an unexpected problem arose. National Parks and Wildlife lodged an objection to the new lease preventing the granting of a new lease. This objection was to stand for six years before it was realised by the speleological community that there was no lease, and that mining at Yessabah could be legally challenged.

The operation of the mine over the intervening six years had been given a certain legitimacy when the Department of Minerals and Energy issued a mining licence. This licence permitted for the removal of material from stockpiles, loose rocks and boulders that had been mined prior to the expiry of the valid mining licence.

It was the removal of these "stray boulders" that led the Kempsey Speleological Society to believe that more caves were facing destruction. KSS wrote to the ASF with underwhelming response. SUSS members were advised of the situation and exploratory visits to Yessabah revealed an area of rare beauty of exceptional value. We learned of the inadequate legal documents supporting the operation and intended to explore Court proceedings but we also approached the problem by developing a publicity campaign which was successful in unexpected ways.

Derryn Hinch is a tabloid TV journalist with a sympathy towards environmental issues and an audience of more than a million people. We escorted a Hinch news crew to the site and provided them with a preresearched story and some excellent footage of sweet furry bats. When the 10 second promotional clips for the story went to air, the Hinch office was immediately contacted by David Mitchell Melcann and warned that DMM was <u>not mining</u> at Yessabah but instead were removing loose tailings under the perfectly legal mining licence that had been issued by the Department of Minerals and Energy. They warned that if the segment went to air they would take legal action. Hinch used the Unisearch service at the University of New South Wales to locate and hire a mining engineer, Dr Gour Sen. He was flown to Yessabah to perform scientific tests and confirm whether DMM were mining or not. On camera Dr Sen was shown applying a chemical analysis to date the age of exposed rock. He was asked "Are you absolutely sure that they have been mining here recently ?" and he answered yes.

Bob Carr leader of the opposition asked questions in the Parliament about whether the mine at Yessabah was operating illegally. At the same time Hinch went to air charging the mining company with "raping, pillaging and plundering".

Shortly afterwards the Chief of Staff of the Department of Minerals and Energy, Mr Ken Hollands telephoned Dr Gour Sen. What was said we shall never know except that the conversation severely frightened Mr Sen. When questioned later by the Hinch reporter Chris Smith, Dr Sen changed his earlier claims and denied he had made any assertions about whether there was mining at Yessabah and also claimed that the Hinch Program had misquoted him. Dr Sen was to say later, to the Environmental Defenders Office that "he must extricate himself from this matter at all costs". In response to the Parliamentary questions the Department of Minerals and Energy representatives payed a "surprise" visit to the mine site. After thoroughly examining the site these representatives declared that there was no evidence of mining and the allegations were groundless.

Mr Andy Spate had been attempting to negotiate for National Parks and Wildlife Service over the issues relating to the mine. At the January ASF conference, Mr Spate encouraged SUSS committee members to proceed with legal action in an attempt to promote a "meaningful dialogue".

I applied for legal aid through the government agency, the Environmental Defender Office and with the support of their solicitors this application was successful. The case could be heard in the Land and Environment Court where we would claim that David Mitchell Melcann were contravening zoning regulations. Yessabah is not zoned for mining and the mine could not normally operate in that area. If however a company has worked the area for many years, then that company has a right of "previous use" and they are permitted to continue business as long as there is no expansion greater than 10 percent. David Mitchell Melcann has that right at Yessabah but ......they were claiming that they had not been mining at all for the last six years .... in which case their "previous use" rights would have lapsed.

If however, they were to admit that they have been mining, an action could be brought in the Mining Court. For an individual to appear in the Mining Court special dispensation called a fiat must be authorised by the Attorney General that gives the applicant Standing. The fiat makes provision that a case of significant public interest may be heard in front of the Mining Court. If the fiat is granted , this only allows the case to be heard in the Court and has no influence upon the outcome of the trial.

In Australia, history records very little success obtaining fiats for environmental cases. In Tasmania when standing was sought regarding the Dams issue, the Attorney General felt that there was a case to be tried of significant public interest and gave the fiat. He was subsequently sacked by the then Premier, Robin Grey who made himself Attorney General and cancelled the fiat. When the Attorney General of Queensland was asked to grant standing for Central Queensland Speleological Society in the Mt Etna issue, he remained silent. This inequity in law, is one reason why mining companies are able to flagrantly breach laws and not worry about the consequences of legal proceedings.

In addition to obtaining the permission of the Attorney General, we would need a further application to legal aid to run the case in the Mining Court. We launched both these applications with perhaps a naive faith in the justice of our case. At this time we were criticised as being fringe group greenies without the support of the overall environmental movement. Fortunately the Mt Etna experience had shown that support from as many environmental groups as possible can be invaluable and so as a matter of course we had been sending major conservation groups with bulletin sheets to keep them informed of the state of our case. We managed to orchestrate letters of support for our fiat application from these groups to the Attorney General, Mr Dowd.

While waiting for a response from Mr Dowd, we were advised that great progress was being made with a compromise plan negotiated between the National Parks and Wildlife Service, and the mining company. We were urged by all concerned to "lay off" and now we were faced with the prospect of placing our faith in the compromise plan and dropping the Standing application (probably forever), or continuing our action.

Mr Andy Spate, of National Parks and Wildlife advised us that the compromise plan limited the new lease to 5 years, extraction was going to be limited to 15,000 tons a year and the mine operation would remain in the present area of development. National Parks had applied for the Yessabah Hill to be declared a Nature Reserve but this application had been blocked by an objection by the Mining Company. National Parks were anxious to see a settlement reached so the company would lift this objection. Our actions were "rocking the boat".

Kempsey Speleological Society was reluctant to support us since it was being assured by the National Parks and Wildlife Service that their negotiations were being threatened by our disruptive influence. KSS had been shown a "restrained" mining plan (which was probably genuine) but the full implications of that plan are not clear to a casual observer.

We did not know it then, but the Attorney General, Mr Dowd was in the process of turning our application down and our fight in the Mining Court was to never take place. In retrospect, we now know our case was in serious trouble.

Around about this time Greenpeace was involved in a somewhat radical media action, blocking a covert industrial waste pipe under the ocean. Greenpeace was going to be the first group to apply a newly legislated act, Section 25 of the Environmental Offences and Penalties Act, in an action against Caltex for its undersea pollution. For reasons we may never know, that case never came to Court.

Section 25 provides Standing for an individual or group at the discretion of a government body such as the State Pollution Control Commission. Since we believed the Attorney General would be reticent about granting our fiat we thought that with an application to the SPCC for a Section 25 there might be extra pressure on the SPCC to grant the fiat by the Attorney General to relieve him of the the problem of public outcry. At worst it gave us two bites at the cherry.

By now the significance of the transfer of ownership from Australian Portland Cement to David Mitchell Melcann was realised. The mining licence which permitted tailings and loose boulder recovery did not transfer with the ownership of the lease. Not only was there no mining lease, there was no legitimate mining licence.

It was a major worry that if National Parks dropped its objection (which was likely if a negotiated settlement had been reached) then the Minister of Mines would grant a new lease and our Court case would be academic. Certainly we thought that the Minister could not legally grant a lease and the Environmental Defenders Office faxed numerous letters pointing this out. Other environmental groups also wrote to the Minister of their concern about furry bats and finally he cleared his mail box of this junk mail by declaring that no lease would be granted until after the issue was resolved in Court.

Our resolve to apply for the Section 25 was strengthened when in a meeting with representatives of David Mitchell Melcann and the Department of Minerals and Energy, we were able to view the mining plan that National Parks had endorsed in their settlement offer. This plan showed the construction of a waste disposal area ten times greater in the size of the present dump, a three - four times increase in the extraction rates rising to an annual extraction of 50,000 metric tonnes and a lowering of the quarry benches to approximately 30 - 40 meters below their present level. The plan showed the boundary of the mining lease was close to the existing damaged area but wandered, and on average lay approximately 10 meters from the present quarry wall towards the rainforest and Karst area. The top of the hill was to be removed. Even assuming that DMM had a mining lease, this plan was not permissible by law without an environmental impact statement since it represented an increase in extraction that was greater than 10 percent. This did not seem to have occurred to them. In the meetin it was indicated that the mining would be away from the western quarry walls and the caves. The waste disposal area they said, was "a miscalculation" and there was to be increased disposal area. They said there would be a re-generation plan under the advice and management of National Parks.

Bungonia is a tragic example of the value of mining lease conditions. Mining companies may clearly breach whatever conditions that their convenience dictates and without fear of legal consequences. In the meeting our group indicated that we were not satisfied with lease conditions as any a guarantee of protection. We agreed to formulate a settlement plan and the means of enforcing the plan would be determined by our lawyers. This in effect means that David Mitchell Melcann will be required to give an undertaking to the Land and Environment Court. Unlike mining lease requirements, a fiat from the Attorney General is not required to enforce them. Failure by a company to comply with the undertakings is Contempt of Court punishable by penalties including winding up the company and jail sentences for the Board of Directors.

The same morning that we were due to appear in Court, the news arrived that the SPCC had granted us a Section 25. It was unfortunate timing. David Mitchell Melcann's lawyers went to Court with the belief that "it was all over" and my barrister went with, a "Big Stick". It was a revelation that we were suddenly in a position to take out an injunction and close the mine. Perhaps they knew about the fiat application to the Attorney General and perhaps they knew that we were "fixed" in that department, but certainly the Section 25 caught them unawares. The word "treachery" was doubtlessly in the vocabulary of David Mitchell's lawyers that afternoon and the immediate response of the company was to deny all access by our experts to the mine site.

This made the development of a mining settlement much more difficult since it was necessary for our experts to examine the site. A hurried letter of apology was dispatched, explaining the sudden arrival of the Section 25 on the morning of the Court hearing. The letter reassured them that we still very much wanted a meaningful dialogue. Settlement could not be reached without access to the mine site. Naturally, until a settlement was consumated it would be naive to terminate legal proceedings. We certainly were sincere about designing a solution by which a mine might be tolerated on the site and it was with reserved suspicion that permission was granted to inspect and we took the opportunity to gather as much information as we could.

It should be possible, we thought, to remove limestone from sections of the hill such that there is minimal visual impact and no further intrusions on cavities and meso-caverns. Les Hall, bat expert flew from Brisbane to see the main Bat Cave. He was apparently highly impressed and commented that the site was of much more importance than had been realised. Armstrong Osborne noted that the caves were likely to form an interconnected system and that intrusions from the mine could alter the climates of the caves and this might change the temperatures within the caves and result in serious disturbances to the habitat of the bats. There was also a danger of breaching the water table.

SUSS trips to Yessabah were organised to explore and survey the significant caves in the area. We began documenting the trend, development and interrelationships of the caves and surveyed as many of the major caves on the pinnacle karst as the time permitted. We then linked these surveys together with an overland traverse which included a line of karst features crossing farming property on the hillside opposite to the western side of Yessabah hill. These features included a number of small cave entrances that had been blocked and one significant doline previously used as a garbage dump. The doline was found to contain two 5000 gallon water tanks, the remains of an FJ Holden, and an assortment of refuse from the 60's and 70's.

The Kempsey Speleological Society have already mapped 92 caves on Yessabah Hill and our efforts raised the entrance tag numbers up to the century. Our survey efforts show that their work has been accurately and thoroughly executed and with some squeezing added some extensions to the previous maps. Although our survey efforts are duplicating much of their work, our efforts are not wasted since the raw data we obtain is to be stored on the Geodesy database, capable of three dimensional graphics presentation and data manipulation by computer.

As Armstrong suggested, interconnection of the caves is a strong characteristic at Yessabah, with different formation characteristics in close proximity to one another. In some cases several caves may form within metres of one another under completely different influences and developing characteristics attributable to those influences.

Joints within the limestone of the Pinnacles area contribute to the vertical shafts and impressive pinnacle development. The walls of these deep fissures are sculpted and dissolved by cascading rain water and descend 25 meters to the large phreatic chambers of Daylight Cave. The vertical shafts are created along joints which interconnect with horizontal vadose passages.

The abseil into Daylight cave reveals unexpected systems of skylights and connections leading to the surface sometimes even below the abseil. Daylight was found to contain millions of small fossil bones calcified into the floor of the upper levels and more significantly, the daylight areas of the cave are crowned with formations on the floor bearing many of the stromatalitic features of the craybacks seen at Jenolan and Wombeyan. These were photographed and forwarded to a group at Sydney University studying the crayback formations.

East of these shafts into Daylight, a canyon like doline marks the ancient collapse of a cave that was once the extension of Y27. Its' entrance is now nestled in the southern end of the canyon with the northern end at the top of a cliff overlooking bench RL53. The cliff end of the canyon is largely filled with rectangular boulders which are possibly the remains of the collapsed roof. While there are only small caves and fissures to be found within the boulder pile, the sides of the canyon contain joint features that extend at right angles, some 20m, and merge into the vertical shafts of Daylight Cave.

On the western side of the Pinnacles area, the large surface area of the limestone cliffs collects sheets of rainwater that spill down into the pinnacled landscape of the western face, eroding the gullies, ravines and erosion pools. The major caves such as Y30 (Deep Slide Cave) dip in the opposite direction to the surface drainage on the hill and along the bedding plane in the direction of the mine. The bottom of Y30 was found to contain a small intermittent stream draining southward along the strike of the bedding plane.

A number of vertical drainage caves evidently carry large quantities of water in times of rain. In rain periods, Downpipe Cave accepts surface spillage water from several entrances in the rillenkaren pinnacles and transports water along short stream passages bedded with rounded river gravels. Solution tubes and waterfalls drop some 30m to a doline on a lower level surrounded by as yet undocumented caves and very close to the Bat Cave. In the Pinnacles area I found two downpipes containing vertical passage perfectly smoothed by downpouring water. The entrance to one of these caves starts high in the Pinnacles area and boasts a fine display of cave coral. The coral is unusually formed because of the competing influences of precipitation by strong upward airflows from the lower tube and dissolution of the coral by the capture of rainwater at the cave entrance. Both these down pipes required SRT for further investigation.

On the western cliff side, caves dip down into the hill towards the east. Their entrances have formed along the terraces that run south along the Yessabah Hill. Y27, 26, 25 with a descending trend to the exposed entrances. Terraces above and below show the same laminar layout and it appears that in general while the caves formed on each terrace are very interconnected, the interplay between their upstairs and downstairs neighbours is sparse. Downpipe caves seem to perform this during high run off periods only.

In addition to the obvious connections, examination of our surveys reveals a close proximity of False Floor Cave and Daylight Cave and also a strong possibility of connection between Downpipe and Bat Cave. One of the down pipe caves is highly likely to connect with Daylight Cave but the other is likely to drain west.

A creek bed runs south to north on the western side of Yessabah Hill. Beneath the drainpipes and Pinnacles, the western drainage is evidenced by a spring and boggy ground at the bottom of this escarpment. Many years ago a water collection lake was dug near this location and locals report that the collection lake filled as soon as it was dug, and that it has always been full. The lake expels a considerable water flow into the ponds that abut the weighstation office of the mine. Immediately above the lake is one of the more significant caves, False Floor cave and below its entrance there is a rockpile easily capable of harbouring more cavities.

Drainage can also be observed a kilometre to the south with two effluxes of considerable water volume draining into Dungay Creek. One of these springs emerges beneath the roots of a tree growing out of a doline in a limestone outcrop. The boggy plateau above Dungay Creek level is fed by springs. Southern water drainage is perhaps also indicated by the attributes of the southern most cave Y50 (Water Cave). Water Cave is home to a number of bats and has a copious bat guano collected on the floor and walls. The Water Cave entrance is approximately 4m across, with a short phreatic tunnel disappearing into rock collapse to the right of the entrance. Here the evidence of terraces melds with the ground since the sharp relief of the hill is here, nearly gone. There are cracks, solution tubes and small caverns on the limestone outcrop either side of Water Cave, but there is no obvious way of gaining access to more caves in the immediate area.

The main entrance to Water Cave rapidly descends to a short squeeze, after which descent continues along a keyhole passage finally to a small lake. The keyhole passage has a slot in the floor and the roof is scalloped. It is the only cave at Yessabah so far found that contains a sump. I dived this sump using cave diving equipment and found that it descends to 6m where a 4m long passage on the right hand side dips to a maximum depth of 8m into an unnegotiable silt filled passage. The walls of the passage under the water are caked and ribbed with formations similar to limestone formations of flowstone and stalactites, however they are made of bat guano and decompose when touched. The passage continues but is unnegotiable by a diver.

The most striking area at Yessabah is the pinnacle karst and it is sobering to see the towering pinnacles of grey scarred by mining action and partly lost forever in empty box canyons. One minor cave descends 40 meters just inside the wall of the one of the mine benches. The internal wall of this cave on the side of the mine is cracked and and fractured with a main passage that drops to join the main Daylight Cave. In one place a newly exposed entrance stands as a balcony to a 15 meter drop to a mining bench. In the distant field, cedar might once have grown but now their mighty forms are only ghosts, it is all dead and gone.

Our feelings of dismay over the presence of the mine were emphasised by the opinions of environmental groups now also involved in the issues. These were the groups that peppered the SPCC and the Attorney General with letters of support on our behalf. Their attitude to the mining is one of "zero tolerance". They perceive our negotiations as an attempt to rationalise the existence of a mine with no legal or moral right to occupy the area, and our attitude seems far too conciliatory. We have legal aid, the legal advantage, the insult of unfair cover up practices and small furry bats to care for..... the environmentalists believe we should, "lower the blade and push". If the case goes to Court, then the practices of the Department of Minerals and Energy would be layed bare to public scrutiny. This factor acts in favour of obtaining more favourable conditions in any settlement since there are many embarrassing indiscretions which some people would prefer were not explored in the gaze of the public arena.

The way we conduct business on this issue reflects on our credibility in the future. As part of an enticement to compromise, David Mitchell Melcann offered the speleological community a position on the "Interdepartmental Committee" which may represent a communication channel from ASF to the limestone mining industry. The position might be toothless however it might also discourage certain mining practices and encourage more expenditure on studies by academics grossly under utilised by industry and government. Such liaison may prevent new developments in valuable karst areas from ever beginning and perhaps with backup from ASF help to end undesirable mining works.

While it is clear that the mining industry only moves in the interests of the community when the "blade" is poised, it should be seen by the industry that we are negotiators capable of recognising the needs, interests and importance of the mining industry. There are many other important karst areas under threat from mismanagement. These will no doubt soon receive more attention from speleologists but there may not be the same series of fortuitous mistakes by our adversaries.

Perhaps for some this bribe is not worth the price of a mine on Yessabah. There is one other major factor that encourages the evil of "negotiation". My ever confident barrister frequently reminds me "litigation is never certain". At Mt Etna the mining company showed that it was prepared to expend large sums of money fighting off greenies, and in the end the money they paid for good lawyers, won their case. At Yessabah they could pay for the best legal advice and with support from a sympathetic government and local council eventually development consent might be obtained. What is won today may later be lost........ as was the case at Bungonia. There are no guarantees but a negotiated settlement more firmly fixes the protection of the area for as long as an organisation such as ASF is capable of monitoring them.

These last weeks we have prepared both for settlement and a possible Court case. The various experts that visited the site have made affidavids quanitifying the importance of values relating to heritage, flora, fauna and karst. We need to prove that mining is inconsistant with these values and that there has been mining contrary to regulations. To this end the reluctant Goure Sen will be subpoenaed and his evidence under oath could become public. Tonnages removed from the mine may be deduced from the royalties paid to the Department of Minerals and Energy and from a photogramatrist's examination of aerial photographs. Since 1983 approximately 100,000 metric tonnes of material have been removed and this is confirmed by the royalty payments.

Ian cooper drafted a new mining plan designating all mining to take place only on the lower bences of the mine. It seemed that the area most likely to intersect caves was in the upper benches since here already a number of caves have been destroyed. On the existing lower benches there is no sign of more caves but there is a risk of intersecting the water table if the level of the benches goes too low. Further removal of material on the upper benches would cause such a high cliff line that the edge stability will be further degraded. In fairness, the mine planned to mine along the dip line away from the cliff face and cavernous area. It should be noted that this was not done previously and the present cliffs are about 25 metres high and unstable. They will inevitably slide into the mine benches under the influences of normal erosion with the loss of some rainforest and caves.

The main considerations of our mine plan include immediate regeneration of the top benches although there will be removal of unstable rock and an upper limit on the total extraction permitted from the mine and then only from within designated areas on the mine. At first we were unimpressed at the 21 year lease. This seemed important to the mine manager and he emphasised that this was the normal period at which mining leases are granted. After some consideration we felt that the real factor of importance was the total limestone extracted, rather than the time over which it was taken. Once an acceptable quantity of extraction has been determined, slow extraction is less damaging since smaller blasts are used and accompanied by a smaller less frenetic mining operation.

DMM claimed that at least 700,000 metric tonnes of limestone were required to be economically feasible. Ian's new plan which confined removal to the lower benches only, provides 600,000 tonnes of limestone. This is a quantity above what they are permitted to take without performing a new Environmental Impact Statement. Over the lifetime of the lease period an EIS will be done and then the full amount will be extracted.

Crushed limestone is presently selling for $30 a tonne which means this plan provides reserves of limestone worth 18 million dollars. Only time will show whether they will accept this plan or whether we shall run the Gauntlet.