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Helictite

JOURNAL OF AUSTRALASIAN CAVE RESEARCH

River passage of Giant's Cave, Witchcliff, in the south-west of Western Australia.
Diprotodon poulter in operation.

HELICTITE

Helictite was founded by Edward A. Lane and Aola M. Richards in 1962.

This Journal was (and is) intended to be wide ranging in scope from the scientific study of caves and their contents, to the history of caves and cave areas and the technical aspects of cave study and exploration. The territory covered is Australasia in the truest sence – Australia, New Zealand, the near Pacific Islands, New Guinea and surrounding areas, Indonesia and Borneo.

In 1974 the Speleological Research Council Limited agreed to support the Journal with financial assistance and in 1976 took over full responsibility for its production.

Speleological Research Council Limited

The Speleological Research Council Limited, the publisher and owner of Helictite, is a non-profit limited liability company incorporated in May 1964. The aims of the Speleological Research Council Limited are:-

To explore and chart and organize and promote the exploration and charting of caves and cave systems.

To promote, support and asist in the scientific evaluation and investigation of caves and to foster speleology as a science and a sport.

To promote and to asist in the promotion of speleology and speleological Societies and to asist such Societies with grants of money and otherwise.

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CONTENTS

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REVIEWS

WORLD OF CAVES, A.C. Waltham, 1976. Orbis Publishing Ltd., London. 128 pp (31x23 cm). 145 full colour plates, 8 maps and glossary (73 terms). Bibliography (25 items), list of 20 longest and deepest caves and index. Review copy $11.00, supplied by Caverbooks, 11 Arkana Street, Telopea, N.S.W. 2117

At last an international book on the "world of caves" that actually gives Australia a little bit more recognition than that we have some big caves on the Nullarbor. This book is claimed by some to be the most beautiful coffee table book on caves published to date. The photographs alone make it well worth every cent, and just a brief glance through it should convince anyone with the slightest interest in caves to purchase it unhesitatingly.

There are 15 full page illustrations and 7 others which are spread over a couple of pages and whilst being rather impressive, this is a layout which I find, most times, spoils the photograph rather than enhances it. All but the larger blow-ups have reproduced with exceptional clarity and good colour balance.

This is a truly international book as the illustrations come from 35 countries. However, England and France take precedence over Jamaica, Yugoslavia, Australia, the United States of America and Canada.

The colour plates are keyed to the text reasonably well although the Australian examples used to illustrate types of cave decoration in the first chapter are not mentioned in the text. Generally the text is aimed at the more scientific aspects of caving. It describes different types of caves from areas around the world, how they form and develop and the life to be found in them. Information is also given on equipment and techniques and the way cavers find, explore, survey and study the caves.

Australian caves come under discussion in the chapters on prehistoric cave art (Koonalda Cave and the shelter caves of Ayers Rock), and again in the chapter on 'Caves around the World' under the subtitle 'Australia and New Zealand'. Australian caving areas and individual caves which rate a brief mention are: Jenolan, Nullarbor, Mullamullang, Weebubbie, The Tunnel (Kimberleys), Augusta Jewel, Strongs and Khazad-dum. Not a particularly good coverage of Australian caves but considerably better than has been given in other books claiming to cover caves and caving on a world-wide basis.

Three prominent Australian cavers contributed the photographs which show our caves off to advantage. Caves from Jenolan, Wombeyan, Buchan are featured along with the perennial photographers' favourites Croesus, Kubla Khan and Augusta Jewel Caves. There is also a photograph of aboriginal paintings in a rock shelter in northern Queensland.

A book that will delight and spread some light about caves, cavers and caving, to all those who have an interest in caves, be they tourists, novices or veteran speleologists.

Ross Ellis

INDEX TO THE CENERA AND SPECIES OF FOSSIL MAMMALIA DESCRIBED FROM AUSTRALIA AND NEW GUINEA BETWEEN 1838 AND 1968, J.A. Mahoney and W.D.L. Ride. Western Australian Museum Special Publication No. 6, 1975 : 250pp.

Any person especially if he or she is not a palaeontologist or a zoologist, who has had to deal with literature about Australian mammalian fossils, will have encountered great difficulty in pursuing a reliable course through a veritable jungle. This book, the result of many years of prodigious industry and critical scholarship by two of Australia's best known mammalian palaeontologists, provides one of the essential tools for navigation through this jungle. It expressly declines taxonomic revision and is a bibliographic tool, a nomenclator or checklist, organised on a taxonomic basis only at the higher levels. As such it will be invaluable to all concerned with this field of study. Type localities and type specimens are documented and a meticulous bibliography provided. Since so many of the fossils in question come from caves, much of this book has relevance for cavers. It is not meant to be read consecutively, though unpurposeful perusal of its pages is not without reward. Most scholars as investigators or as editors leave ample clues to prove their membership of common imperfect humanity right down to the present day. In the bibliography, many articles relating to these fossils from early Australian newspapers and many personal letters of like content are republished and they make fascinating reading.

J.N. Jennings

A NEW DEVELOPMENT IN SOLVING PROBLEMS OF LARGE SCALE SPELEOPHOTOGRAPHY

"DIPROTODON POULTER"

Norman Poulter

Abstract

A discussion of the special requirements of photography in large caverns is followed by a history of the "Diprotodon" magnesium flare as a lighting source. A new model, Diprotodon poulter is described in detail.

INTRODUCTION

Illumination of large caverns for the purpose of speleophotography has always been difficult. Many methods and techniques have been devised throughout the years, ranging from the simple burning of magnesium ribbon or flares, painting the scene with short-range flash (bulb or electronic), use of large press bulbs (PF60 and PF100) and finally, the magnesium burning Diprotodons. Diprotodons have an effective single source range of 200 m, depending on the burn time. This light source, believed to be unique to the Australian speleological scene, is named after Australia's largest known marsupial, the extinct *Diprotodon*.

BACKGROUND

Magnesium ribbon and flares have been used intermittently in various parts of Australia with results of dubious quality. Other chemicals, emitting light when mixed and burnt (e.g. magnesium and potassium chlorate; thermite and aluminium), have also been tried with similar results. They also fell into disfavour due to difficulty in calculating exposure values, unacceptable reciprocity failure, colour shift and the usual by-products of burning - dense smoke and fallout of oxides. Another reason for rejection is that some chemicals become highly explosive when mixed (Anderson 1969).

Flash painting, using bulb or electronic flash, is a technique used widely throughout Australia in all types of caves. This open flash method involves mounting the camera on a tripod (as with all other methods mentioned) and walking around the area to be illuminated, firing the flash-gun every few metres. This method, although time consuming, is highly effective. The main advantages of flash painting are natural colouration, controlled exposure and greater sense of depth due to effective shadowing.

However, in large caverns, flash painting has numerous disadvantages. Consider a scene requiring 100 flashes. Bulb flash-guns are excluded by high bulb cost (15¢ to 30¢ each) and their bulk. The modern dry cell battery electronic flash-gun is therefore used because of its small size, fast recycling time and long flash life (approximately 10 000 flashes per tube). Other factors that can cause trouble with flash painting are:

i. maintaining correct flash to subject distance,

ii. moving over unstable terrain with little or no light,

iii. getting disoriented and illuminating areas not covered by the camera's field of view,

iv. ghosting - caused when a person, already silhouetted against a rock moves and re-illuminates the rock. This results in either body or limbs disappearing to be replaced by rock, or rock showing through parts of the body.

v. omitting illumination of foregrounds and ceilings through lack of foresight, navigational errors during the exposure or insufficient range of the flash used, depending on the angle of acceptance of the camera's lens.

Press flashbulbs (PF60 and PF100) have not been used to a large extent in caves, no doubt due to their high unit cost, their bulk and fragility and the size of the gun necessary to discharge them. In the case of the flash painting described above, press flashbulbs could have done the same job with fewer bulbs, either singly or in combination with small flash sources, as well as sufficiently illuminating the ceiling and foreground.

An innovation with the use of press flashbulbs was described in a paper by E.G. Anderson (S.U.S.S.) at the 7th ASF Biennial Conference. He had developed the Macroflash Mk. 1. This device used a large aluminium bowl (approximately 45 cm diameter) with six bulb mountings around its periphery. The bulbs could be fired singly or simultaneously. The main advantages of the Macroflash, which had a variable range of up to 130 m, were accurate exposure calculation and ease of operation minus the characteristic and disadvantageous smoke, the fallout effect of burning magnesium and other chemicals. The bulk of the Macroflash, coupled with the high cost of bulbs, no doubt precluded the device from general acceptance.

THE DIPROTODONS

The first Diprotodon was built by H.G. Watson of Ceduna S.A. in 1932 (Lewis pers. comm.). The device utilised an old fire extinguisher which released pressurised air, blowing magnesium powder from another container across a lighted wick to create a continuous flare. In 1955 a similar model (Figure 1A) was built by Captain M.T. Thomson (C.E.G.S.A.) and it was this unit that became known as the Diprotodon Mk. 1. The name has been applied to all successive improvements to this device (Hill 1966).

Prior to the 1956-57 Nullarbor Expedition, Fairlie-Cunningham (n.d.) created the Mk. 2. The fire extinguisher was replaced by a balloon as air source, thus greatly reducing bulk and weight. However, fuel consumption and flame size were still a problem. The Mk. 2 consumed 30 g of magnesium a second and the flame size was 1.2 m x 0.9 m x 0.3 m. Both H. Fairlie-Cunningham and T. Draper used Mk. 2 Diprotodons on this expedition.

The 1965-66 Nullarbor Expedition used the Diprotodon Mk. 3 devised by R.C. Crowle (S.U.S.S.) which again reduced size and weight and replaced the igniter wick with a wire element of nickel-chromium (ni-chrome) composition, making the flame self-sustaining once ignition has taken place by means of a candle. Disadvantages of the unit were the uneven powder feed and candle igniter. A typical exposure with the Mk. 3 to illuminate a subject 30 m away was 10 to 15 seconds at f5.6 and using 50 ASA film. The 1965 Crowle model was the last Mark as it then became popular to name the new breeds of Diprotodon after the people who created them.

A major advance in Diprotodon technology came early in 1966 when A.L. Hill (C.E.G.S.A.) built the tripod-mounted Diprotodon hillii (Figure 1B). Although based on the Mk. 3, design was further simplified and method of ignition improved by incorporating a match holder under the ni-chrome element. Other changes were to use a brass polish tin for a magnesium magazine, a car headlight reflector and several parts from a kerosene pressure lamp. D. hillii is the most used design in Australia and, in recent years, has had several near accidents attributed to it, mainly due to experimentation (Bosler and Perkins 1974; Lewis 1974). The reflectors could be hazardous on occasions when partially burnt and unburnt magnesium collected on the reflector and ignited during a burn. These 'spotfires' could burn through the brass reflector and cause serious burns if they landed on parts of the operator's body.

Of great significance with D. hillii, however, was the replacement of the chip form of magnesium by free flowing High Density Magnesium (HDMg) which virtually eliminated blockages. These factors made D. hillii the first compact, economical and efficient bulk light source to be developed. High Density Magnesium, an early rocket fuel, is manufactured by melting magnesium in an atmosphere of inert gas (usually nitrogen), then pouring it through a fine colander into a bath of liquefied gas, usually liquid nitrogen. The only known source of HDMg in Australia is the Cave Exploration Group South Australia.

A problem that arises with the use of any Diprotodon is that of exposure calculation, especially when there are a multitude of cameras 'riding' on the flash using an equal multitude of ASA ratings. It therefore became necessary to devise some sort of calculator which gave quick, accurate aperture settings and exposure times, while taking into account the variables of distance, film speed, light output, rock reflectivity and reciprocity failure. Such a calculator was devised by Hill (see below) which gave the light output of D. hillii as 'E'.

Prior to the 1968 A.S.F. Conference, the Diprotodon crowle hand-held model came into existence and could be used without the ni-chrome element. Using HDMg, D. crowle featured a pressurised magnesium magazine and did not use a reflector. D. crowle did not gain acceptance, the prototype being the only one built.

I became interested in Diprotodons at the 1968 A.S.F. Conference and during 1969 constructed a D hillii dispensing with the balloon propellant in favour of a disposable butane 'gas-pak' (Poulter 1974). As a propellant, flammable gas would be superior to air for the following reasons:

- i. wick type igniters would be eliminated,
- ii. ignited gas would preheat the element,
- iii. ignited gas would pre-ignite the HDMg, (however, not enough heat is generated to maintain ignition so the element is still necessary),
- iv. with 'unlimited' propellant at a constant pressure, longer burns could be undertaken with less flame flickering,
- v. less HDMg would be wasted due to instantaneous ignition,
- vi. magnesium blockages would be easier to clear by momentarily increasing gas pressure.

Although the prototype showed promise and the advantages of a flammable gas propellant were realised, the 1969 model was a failure due to control valve difficulties with the 'gas-pak'.

Persistent problems with the use of Diprotodons are heat, smoke and magnesium oxide fallout. During 1969, E.H. Sangster (C.E.G.S.A.) experimented with the attachment of an electrostatic smoke precipitator charged by a high voltage TV transformer. Tests in Cathedral Cave, Naracoorte, S.A., were inconclusive, as were experiments of adding oxidants to the HDMg (Lewis pers. comm.).

The desirability of an efficient Diprotodon was again highlighted during the 1971-72 C.E.G.S.A. Nullarbor Expedition. The D. hillii taken on the trip rarely worked reliably, always needing two people to operate it, mainly due to lack of tripods (Poulter 1972). The balloon pressure source gave continuous trouble and the ni-chrome element failed to maintain ignition, most likely due to poor location in relation to the nozzle. A 'field-repair' of a flexible hose connected to a carbide light helped by directing acetylene gas to the ignition area, thus assisting the work of the element. Unfortunately, it also meant that one operator had to try and look at the flame with unprotected eyes in an attempt to keep the hose in the correct position. Despite working in such a primitive and hazardous way, some of the most successful Nullarbor Diprotodon photographs were achieved.

With experience gained from Diprotodon photography under Nullarbor conditions, I attempted during 1972 to build a reliable unit using LP gas as a propellant supplied from a Primus 2000 gas bottle. Although increasing construction cost and weight, the LP gas offered superior gas control. The ignition nozzle followed the design of a Primus pinpoint 'A' flame torch and was prone to magnesium blockages. Although early trials were successful in Giants Cave (W.A.), subsequent usage in Tasmania proved that magnesium blockages were too frequent to be acceptable. Gas flow was also at an unacceptable level through using a jet that was too small for the flow rate required.

NEW MODEL

During 1973 I worked again towards a reliable Diprotodon trying several nozzle designs and finally settling on one that results in a new species - the Diprotodon poulter (Figure 2). The design is the most elaborate to date and also the most expensive due to the many Primus components in its construction. Unlike the D. hillii, a headlight reflector is not used and the ni-chrome element is replaced by stainless steel wire. The design makes use of a Primus control valve, 'H' jet and burner; the nozzle is a modified 'H' type full flame burner. The use of LP gas virtually eliminates magnesium blockages. Watching the burn through oxy-acetylene welding goggles, if a magnesium blockage seems to be occurring, one can overcome it by adjusting the magnesium flow rate or increasing the gas flow momentarily. Although giving a more even distribution of illumination, the decision to remove the headlight reflector from the design has meant that light output has dropped making slightly longer burns necessary. On the exposure guide, D. poulter has a light output of 'D' (see below).

The main advantages of D. poulter are its reliability and efficiency, allowing rapid site movement; therefore more ambitious photographs can be attempted as against the single position technique frequently used with other types. The most elaborate photographs taken with D. poulter to date have been a four-place Diprotodon shot of Abakurrie Cave (Nullarbor, W.A.), range 330 m, and a three-place Diprotodon, 40 place electronic flash near the Sail-Dropoff area of Mullamullang Cave (Madura, W.A.), range 170 m.

CONSTRUCTION

As mentioned above, D. poulter is both elaborate and expensive in its construction. The main body of the unit is similar in basic design to its predecessor, with the exception of gas inlet and ignition areas (Figures 2A and 2B). The body is made from 1"AF brass hexagon with a ¼" Whitworth tripod socket tapped into its base. A ¼" hole is drilled part the way down the stem with a thread to suit a modified laboratory gas valve at the top. A horizontal hole to accept the gas flow tube is then drilled and a stainless steel (or brass) tube of 3/16" ID silver-soldered into position. The stem hole is then drilled deeper to break through the wall of the stainless steel tube. All burrs must be removed from the wall of the tube after this operation.

A laboratory gas valve is then locked into the open position and the capacity of the valve enlarged by drilling a 3/16" hole through the entire unit. A ¼" hole is then drilled up from the bottom of the valve to, but not into, the valve barrel. Both ends of the valve are then threaded. To prevent the valve being mounted upside down (thus causing blockages), one thread should be larger than the other.

The magnesium magazine depends on availability of manufacturing equipment. D. hillii used a brass polish tin, the screw cap of which was soldered to a tube that was then screwed into the magnesium control valve and a hole drilled through it. Not being one who polishes brass very often, I used a steel soft drink can, removing the ends and manufacturing new ones. The brass base has a short stem with an internal thread matching that of the top of the magnesium control valve and the top section that forms the internal base of the magazine is tapered to direct the HDMg towards a central hole of 3/16" diameter. The top, also of brass, has a large threaded hole in it. A polyvinyl chloride cap is then made to suit the thread. The ends are soft soldered into position. In this way, the magazine can be used to carry the small components of the Diprotodon during transit, thus preventing their loss. The cap also prevents the unused magnesium becoming contaminated by magnesium oxide, fallout immediately after cessation of a burn or by spillage while changing sites during a multiple Diprotodon exposure.

Construction of the gas system is the most complicated part of the procedure. A Primus 'H' jet and 'H' full flame burner are incorporated. The burner is cut through at the cross-section of the secondary air inlet holes (Figure 2B). The threaded section (c) is machined to become the mounting adaptor for the gas inlet system. The small primary air inlet holes are closed by solder, taking care that the solder does not flow into the internal thread.

The remaining tube part of the burner (e) can now be used in the manufacture of the nozzle. A new centre boss must be made and is then silver-soldered onto the stainless steel tube as shown in Figure 2B. The front of the nozzle is cut back at an angle on the lower side to allow burnt magnesium to fall down and not congeal around the nozzle. Four small holes are drilled around the circumference of the front of the nozzle for mounting the ignition element.

The unit is now ready for 'setting' the gas flame. A 1/16" primary air inlet hole is drilled in front of the gas inlet jet and 8 equispaced 1/16" secondary holes are drilled around the nozzle as shown in Figures 2A and 2B. The procedure to determine the final size of these holes is as follows. Making sure that the magnesium control valve is fitted and shut, the LP gas is connected via the gas control valve. Gas is allowed to come through slowly and is ignited. Flow rate is increased until a flameout occurs. The secondary air inlet holes should be opened by small increments until a flame of about 0.3 m length occurs without flameout. The secondary air inlet holes generally do not exceed 1/8" in diameter.

The ignition element is made from 2 lengths of 0.03" stainless steel wire. As shown in the diagram, the main section passes from top to bottom of the nozzle, along the centreline. The second section comes in from one side, acting as a stabiliser, and the two are then welded together. It is possible to dispense with the stabilising section by flattening the end of the wire to produce a strip and filing slots in the nozzle, thus eliminating lateral movement of the element.

OPERATION

To fire a Diprotodon after assembly, close all valves. Open the gas control valve and ignite the gas, adjusting the valve until a flame length of approximately 11 cm is achieved. The magnesium control valve is then slowly opened, allowing the magnesium to fall under gravity where it is mixed with the gas and carried through to the nozzle, complete ignition occurring when the metal hits the hot element. A piece of stainless steel wire is generally required to prevent periodic build-up of burnt magnesium on the element.

EXPOSURE CALCULATION

The next problem is to calculate its light output and accurately apply the results to a photographic exposure. Factors governing exposure calculation are: light output, Diprotodon to subject distance, reflectivity of subject surface, film speed (ASA), reciprocity failure and filters to correct colour shift.

When Hill developed D. hillii early in 1966, a simple exposure guide (Figure 3) based on a 'Johnson' exposure meter was developed along with it, giving direct reading of aperture settings and related exposure times while simultaneously correcting for reciprocity failure (Gartrell pers. comm.). Once the output of a Diprotodon has been measured and related to the alphabetical output scale of the guide, exposure calculations become relatively fast and accurate. As the light from a Diprotodon is of a continuous nature, output can be determined from a direct reading meter.

An 'Avo' light meter was used to measure the output of the D. poulter and gave a reading of 40 footcandles (fc) when located 3 m and 30° from the light source. This reading is then converted to candlepower (C) by the formula $C = I \times D^2$ where I = illumination in fc, and D = distance from light source in feet.

$$C = I \times D^2$$
$$= 40 \times 10^2$$
$$= 4000 \text{ candlepower (approximately equivalent to a 1000 watt light)}$$

The determined output of the light source can be related to the guide by trial and error.

First determine the amount of light falling on a subject to be illuminated. This is calculated by substituting known values in the previous formula.

Example

C = 4000 D = 50 ft. $I = \frac{C}{D^2}$

$= \frac{4000}{50^2}$

$= 1.6$ fc

exposure time can now be obtained by the formula $T = \frac{K \times N^2}{I \times S}$, where T = exposure time in seconds, K = constant, N = lens aperture (f stop), I = illumination falling on scene in fc and S = ASA exposure index.

Example

K = 20 N = 1.4 I = 1.6 (above) S = 100 ASA

$T = \frac{K \times N^2}{I \times S}$

$= \frac{20 \times 1.4^2}{1.6 \times 100}$

= ¼ second

As the above formula does not allow for reciprocity failure it can only be related to the exposure guide when 'T' is less than 1 second, and correction for reciprocity failure is insignificant. *'Reciprocity failure is the failure of the exposure to depend only on the product of the factors intensity (which is controlled by camera aperture) and exposure time. Failure usually occurs at very low or very high intensities or very long or very short exposure times and has the effect of a speed loss by the film and an increase in contrast for very long exposure times.'* (Hill 1966).

Another factor that the formula does not take into consideration is the light absorption or reflectivity of the subject. The above calculation of f1.4 x ¼ s at 50 ft was worked out for the highly reflective, cream-coloured limestone caves of the Nullarbor Plain. The same aperture setting using the same film and distance, when used on the dark limestone of Tasmanian caves, would require an exposure time approximately four times longer, i.e. 1 second.

Exposure guide advantages are that it:

i. does away with mathematical calculations,

ii. allows for light reflectivity/absorption by the subject,

iii. gives multiple aperture (f stop) settings,

with related reciprocity failure corrected exposure times.

D. hillii has an output rating of 'E' on the exposure guide and has a 6" headlight reflector as part of its construction. The reflector was omitted from the design of D. poulter, primarily to give a more even distribution of light. Therefore the light of D. poulter was called upon to do more work, i.e. a similar amount of light illuminates a larger area than D. hillii, resulting in a lower overall light output than D. hillii. Bearing in mind the above, the user can now relate the results of the formula to the exposure guide. As the output of D. poulter is less than that of D. hillii, output 'D' is chosen.

Example

Distance = 50 ft, output = 'D' = 100 ASA, reflectivity = average (Nullarbor), light angle = 0-45° (usually constant).

Answer

f1.4 x ¼ second.

Reliable exposure calculations that are automatically corrected for reciprocity failure can now be made by using the guide.

COLOUR SHIFT

The correction of colour shift one way or the other when using Diprotodons has never received much attention from speleophotographers as sometimes the colour shift enhances the resulting photograph. Colour shift can be overcome by the use of correcting filters and will be discussed below.

LIGHT QUALITY

Having found the quantity of light put out by a Diprotodon, the final step is to determine the quality of the light and make the necessary allowances. In black and white photography, the colour or quality of light is only of limited importance for the practical photographer. In colour photography, however, light quality is of the utmost practical importance and the most commonly employed method of defining the light quality is by means of its colour temperature. Colour temperatures are measured on the

Absolute (or Kelvin) Scale, a scale of temperature which has degrees (Kelvin's K) of the same magnitude as the Celsius scale, with zero at -273°C. By definition, colour temperature is concerned with the visual appearance of a source; it does not necessarily describe photographic effect.

High Density Magnesium burns with a colour temperature of 4200 K which is comparable with the 4000 K of clear flash bulbs. The colour temperature of 'photographic' daylight (sunlight + skylight) is 5500 K. Daylight type film, most commonly used in speleophotography (as it can be used outside the cave), usually has a temperature of 5600 K. To balance the discrepancy between the colour temperature of the light source (4200 K) and 'daylight' (5500 K), colour correcting filters should be used. This is done by first finding the mired value of the colour temperature. For every colour temperature an associated 'mired' value (micro-reciprocal degree), can be obtained from the formula:

$$\text{mired value} = \frac{10^6}{T} \text{ where t = colour temperature in Kelvins.}$$

$$\text{Daylight MV} = \frac{1\ 000\ 000}{5500} = 181 \qquad \text{Diprotodon MV} = \frac{1\ 000\ 000}{4200} = 238$$

The Diprotodon MV is then subtracted from the Daylight MV giving a mired shift value of -57. By consulting the table of Kodak mired shift values of 'Wratten' filters, we find that an 80D filter is needed to regain true colour rendition when using a Diprotodon as a light source, with an appropriate increase in exposure, usually about one stop. With the use of supplementary light sources, e.g. electronic flash, the filter must, of course, be removed before flashing commences.

CONCLUSION

No attempt shall be made to describe the best methods of using Diprotodons except to point out that most users regard the device as a fixed light source and not as a mobile source. This is basically wrong. The Diprotodons were originally developed to illuminate large and long chambers. This can be done more economically and with more photographically pleasing effects if the Diprotodon is moved around the area to be illuminated, similar to electronic flash but on a much larger scale. Although multiple Diprotodon shots consume more time and energy in the execution, the saving in the lower consumption of HDMg and the superior photographic results more than outweigh these disadvantages.

ACKNOWLEDGEMENTS

The evolution of Diprotodons has been spread spasmodically over many years with little information on the various species being recorded. For the preparation of this paper I am grateful for the technical assistance provided by Mr. S. Blackburn and Mr. G. Husca of the Electron Microscope Centre, University of Western Australia. Special thanks must go to Mr. I. Lewis and Dr. G. Gartrell of C.E.G.S.A. for providing previously unpublished information and diagrams and for the assistance of Mr. Lewis in the final compilation of this paper. My thanks also to the Cave Exploration Group South Australia for permission to republish Figures 1B and 3 from 'Mullamullang Cave Expeditions 1966' and to Mr. A. Saar of Western Australian Speleological Group for his grammatical corrections of the final draft. Photographic reductions were done by Mr. S. Blackburn and Mr. E.G. Rhodes.

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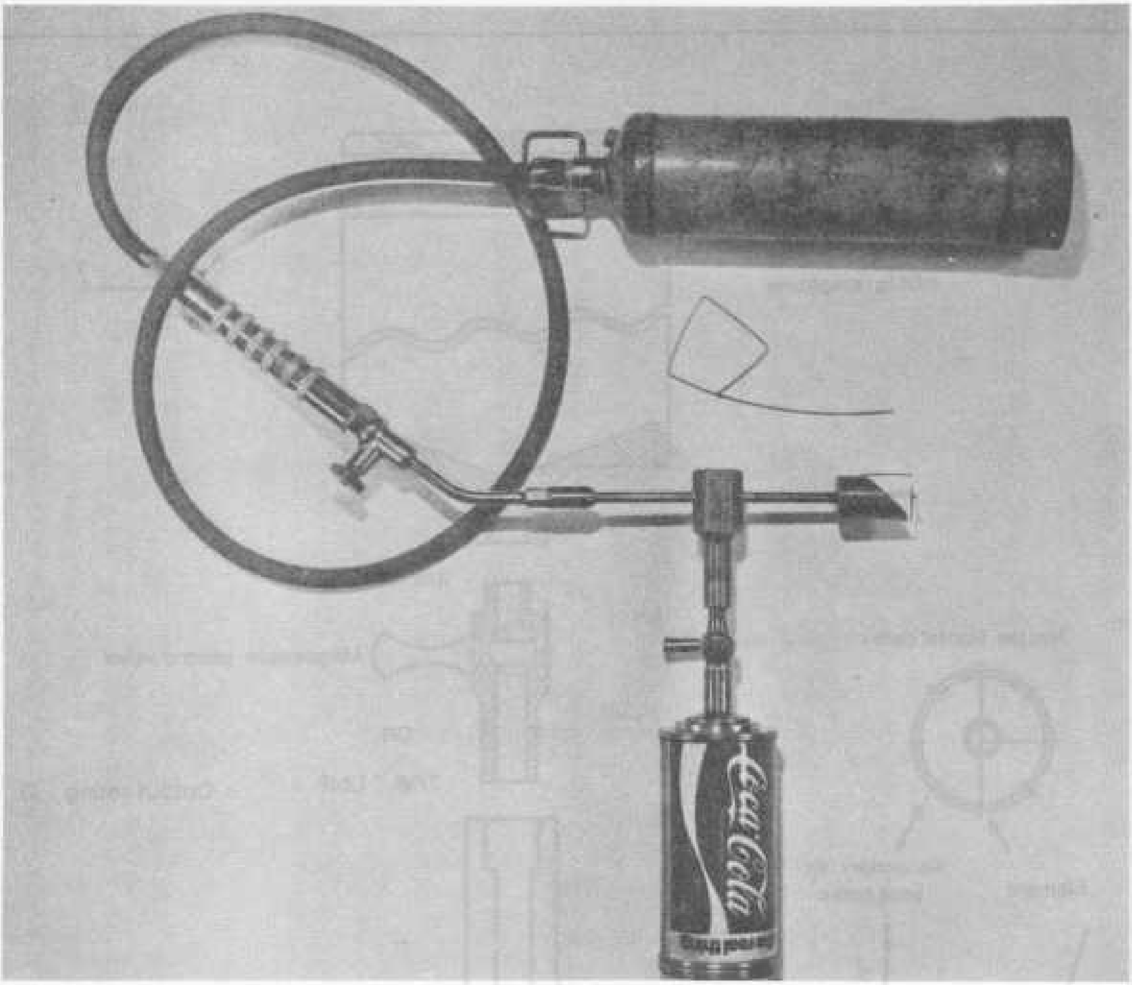


Plate 1 Diprotodon poulter.

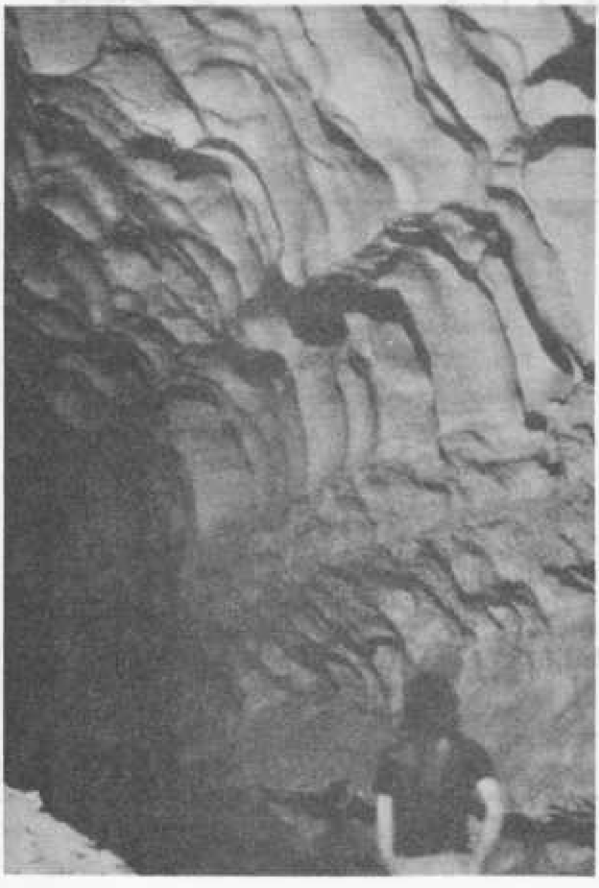
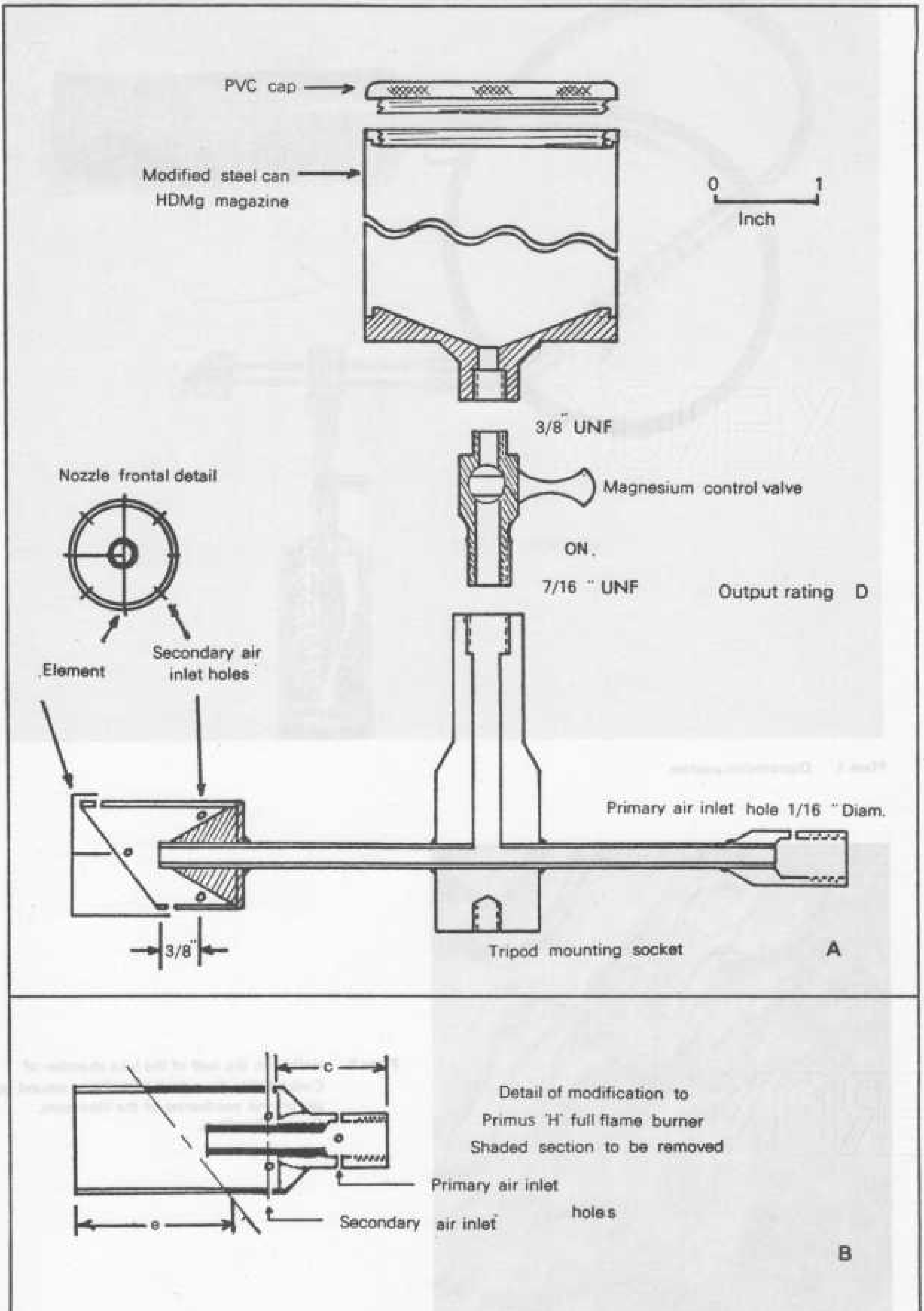
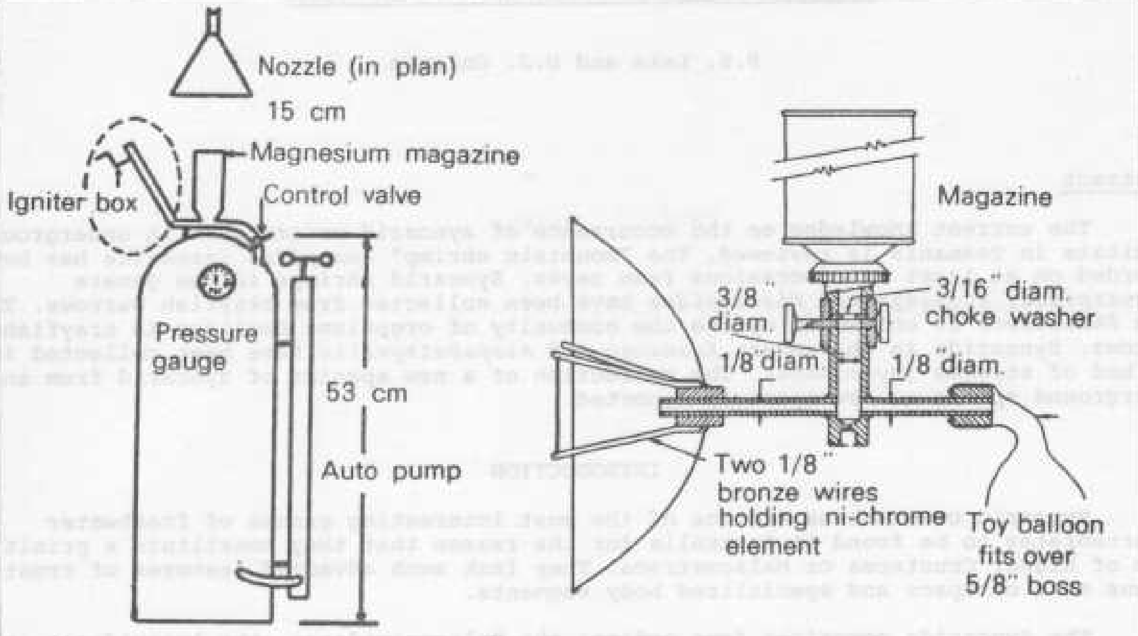


Plate 2 Hollow in the wall of the lake chamber of Cocklebiddy Cave, Nullarbor Plain, caused by salt crystal weathering of the limestone. Range 25 metres.



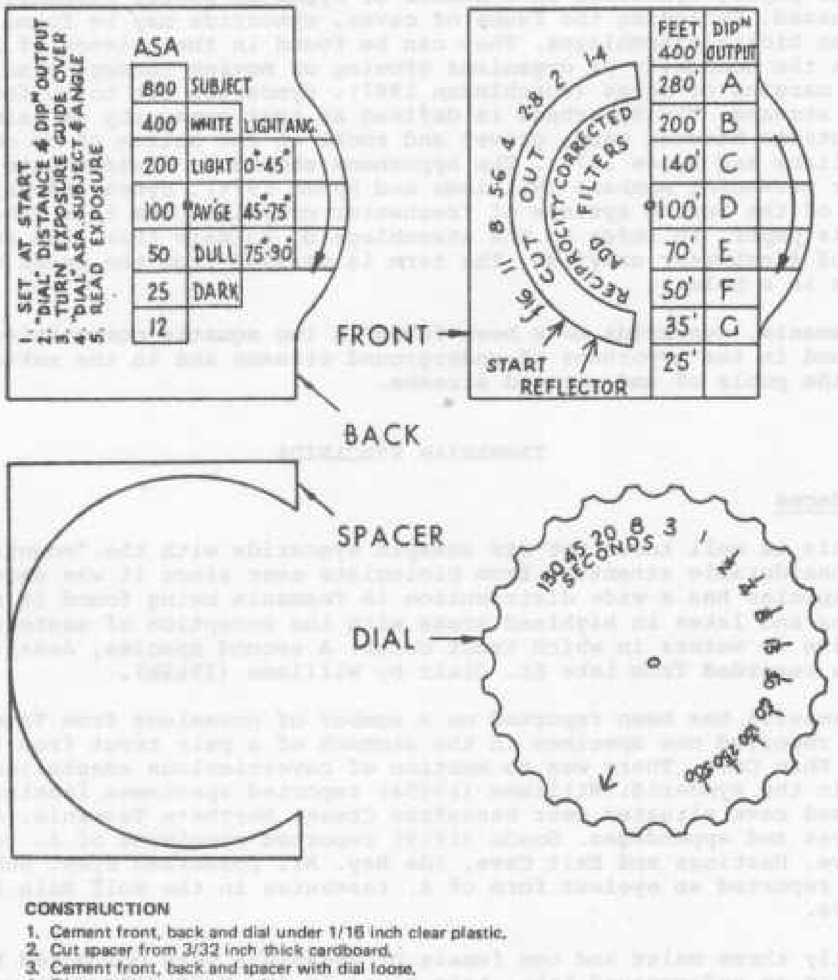
DIPROTODON POULTER FIG 2



A DIPROTODON MARK 1 Output rating F

B DIPROTODON HILLII Output rating E

FIG. 1



CONSTRUCTION

1. Cement front, back and dial under 1/16 inch clear plastic.
2. Cut spacer from 3/32 inch thick cardboard.
3. Cement front, back and spacer with dial loose.
4. Rivet dial in centre to run free.

EXPOSURE EXAMPLE

Say 'Lake Cigalere from Camp One', Set start and dial 70 feet distance; Diprotodon hillii has an output E, 50ASA, average wall lighting, and angle 0° to 45°, Exposure is 8 seconds at f4.

DIPROTODON EXPOSURE GUIDE FIG. 3

ON THE SUBTERRANEAN SYNCARIDS OF TASMANIA

P.S. Lake and D.J. Coleman

Abstract

The current knowledge on the occurrence of syncarid crustaceans in underground habitats in Tasmania is reviewed. The "mountain shrimp" *Anaspides tasmaniae* has been recorded on at least five occasions from caves. Syncarid shrimps in the genera *Allanaspides*, *Koonunga* and *Micraspides* have been collected from crayfish burrows. The term *Pholeteros* is coined to define the community of organisms dwelling in crayfish burrows. Syncarids in the genera *Koonunga* and *Atopobathynella* have been collected in the bed of streams (Hyporheos). The collection of a new species of syncarid from an underground spring at Devonport is reported.

INTRODUCTION

Syncarid crustaceans are one of the most interesting groups of freshwater invertebrates to be found in Australia for the reason that they constitute a primitive form of higher Crustacea or Malacostraca. They lack such advanced features of crustaceans as a carapace and specialized body segments.

The Syncarida comprises four orders: the Palaeocaridacea, the Anaspidacea, the Stygocaridacea and the Bathynellacea (Kaestner 1970). The Palaeocaridacea is extinct. Both the Stygocaridacea and the Bathynellacea are found in aquatic interstitial habitats only and in adapting to such habitats they possess small but elongated body forms. The Anaspidacea are macroscopic crustaceans with several species living in surface waters including the famous *Anaspides tasmaniae* (Thomson) the first extant syncarid discovered and described.

In this paper, syncarids in a number of hypogean biotic assemblages or communities are discussed. Excluding the fauna of caves, syncarids may be found in Tasmania in three hypogean biotic assemblages. They can be found in the *psammon* of lakes. Psammon is defined as the community of organisms growing or moving through sand on the bottom of or on the margins of lakes (Hutchinson 1967). Syncarids are to be found in the *hyporheos* of streams. The hyporheos is defined as that community of animals which live in the interstices between sand, gravel and rocks on the bottom of or on the margin of streams (Williams and Hynes 1974). The hyporheos should be divided into two groups - occasional or permanent members (Williams and Hynes 1974). Syncarids may also be found in the water of the burrow systems of freshwater crayfish. The term *"pholeteros"* is coined in this paper, to refer to the assemblage of animals that live in the water of the burrows of freshwater crayfish. The term is derived from the Greek word; *pholeter-os:* one who lurks in a hole.

In Tasmania, syncarids have been found in two aquatic communities of caves. They have been found in the hyporheos of underground streams and in the nekton (free-swimming animals) of the pools of underground streams.

TASMANIAN SYNCARIDA

Order Anaspidacea

Tasmania is well known for its anaspid syncarids with the "mountain shrimp" attracting considerable attention from biologists ever since it was described by Thomson (1893). The species has a wide distribution in Tasmania being found in small runnels, streams, tarns and lakes in highland areas with the exception of eastern Tasmania. It does not thrive in waters in which trout occur. A second species, *Anaspides spinulae* Williams, was recorded from Lake St. Clair by Williams (1965b).

A. tasmaniae has been reported on a number of occasions from Tasmanian caves. Scott (1960) reported one specimen in the stomach of a pale trout from the River Alph inside Kubla Khan Cave. There was no mention of cavernicolous adaptations such as pale colouration in the syncarid. Williams (1965a) reported specimens lacking body pigment from an unnamed cave situated near Sassafras Creek, Northern Tasmania. All the specimens had normal eyes and appendages. Goede (1969) reported specimens of *A. tasmaniae* from Newdegate Cave, Hastings and Exit Cave, Ida Bay. All possessed eyes. Subsequently he (Goede 1972) reported an eyeless form of *A. tasmaniae* in the Wolf Hole System near Newdegate Cave.

Recently three males and one female of *Anaspides* were collected by Dr. P. Murray on 22.6.75 from an underground Lake, Lake Pluto in the Wolf Hole System. The lengths of the animals from rostrum tip to telson tip were 24.0, 25.3, 25.7 mm (males) and 26.8 mm (female). As noted by Goede (1972), the animals from this locality are different from other hypogean forms of *Anaspides* in their lack of eyes (anopthalmia). While eyestalks are present, there are no signs of eye pigmentation or ommatidial facets. The animals lack body pigment, both when alive and when preserved.

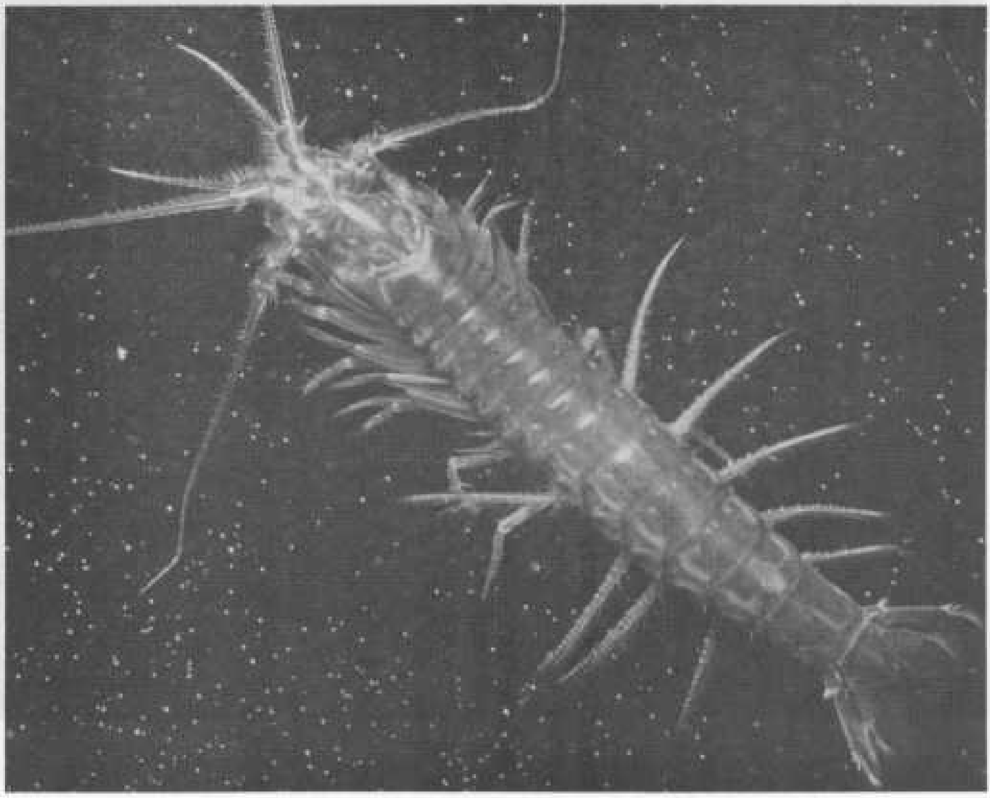


Plate 1 A normal, mature "mountain shrimp" *Anaspides tasmaniae* (Thomson). About twice natural size.

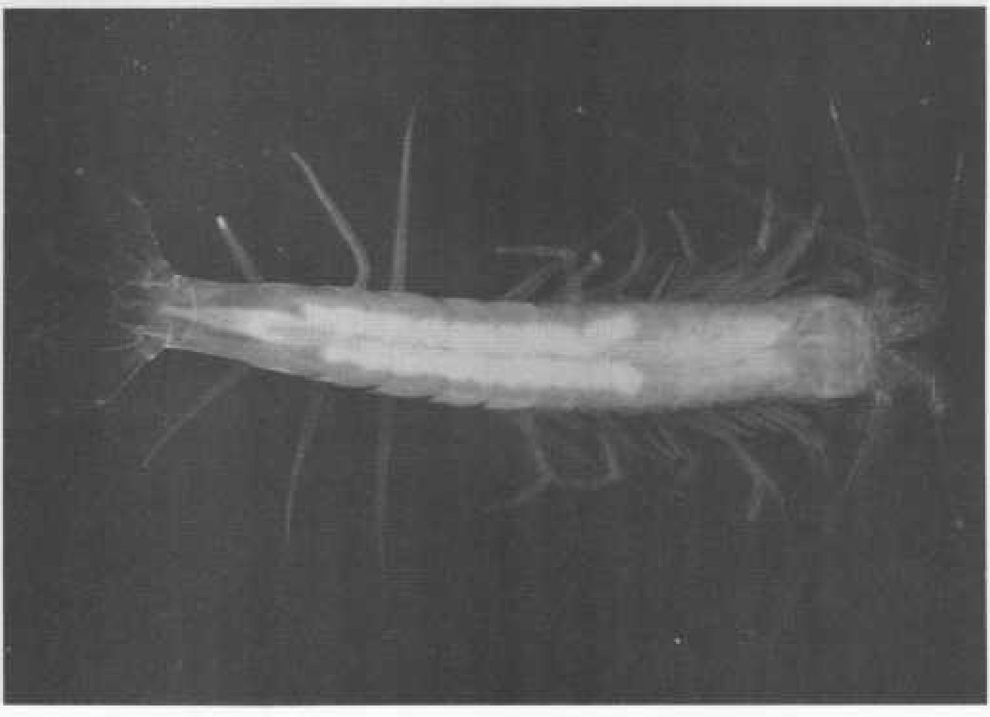


Plate 2 A blind and unpigmented *Anaspides tasmaniae* (male) from Lake Pluto in the Wolf Hole Cave System near Hastings, Tasmania. Collected 22/6/75 by Dr. P. Murray. About twice natural size.

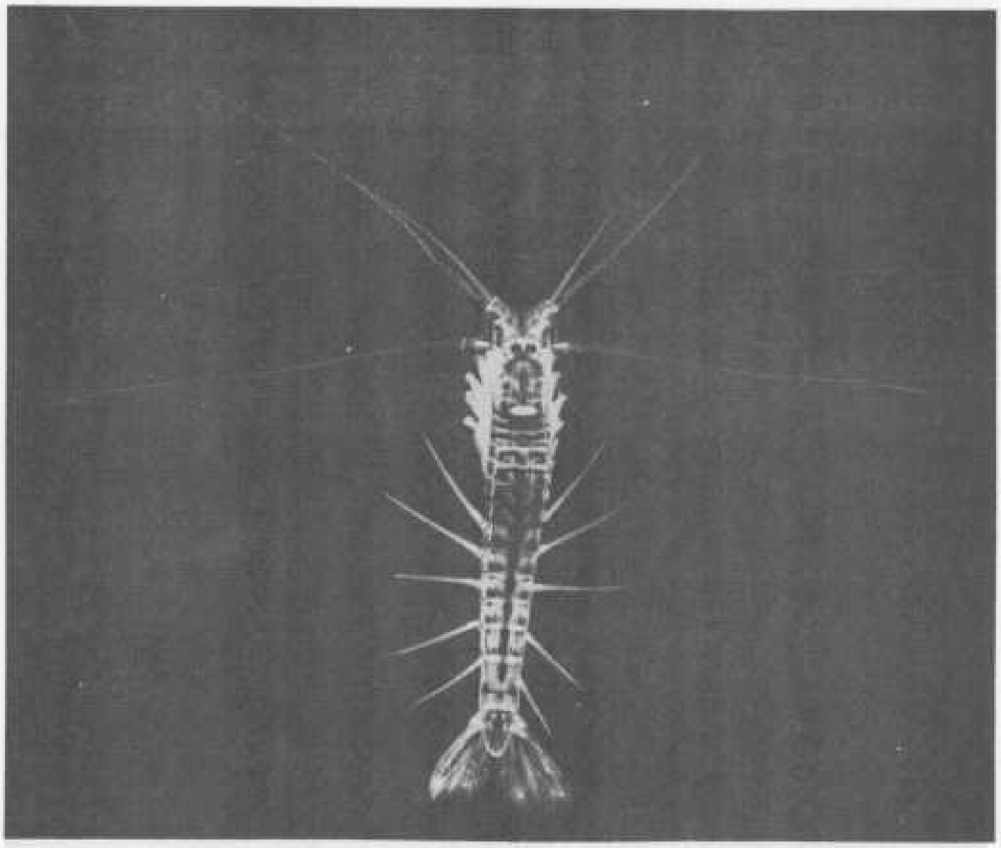


Plate 3 A mature male of *Allanaspides helonomus* Swain, Wilson, Hickman and Ong. Note the fenestra dorsalis on the cephalothoracic tergite. About seven times natural size. (Photograph, courtesy of Dr. R. Swain.)

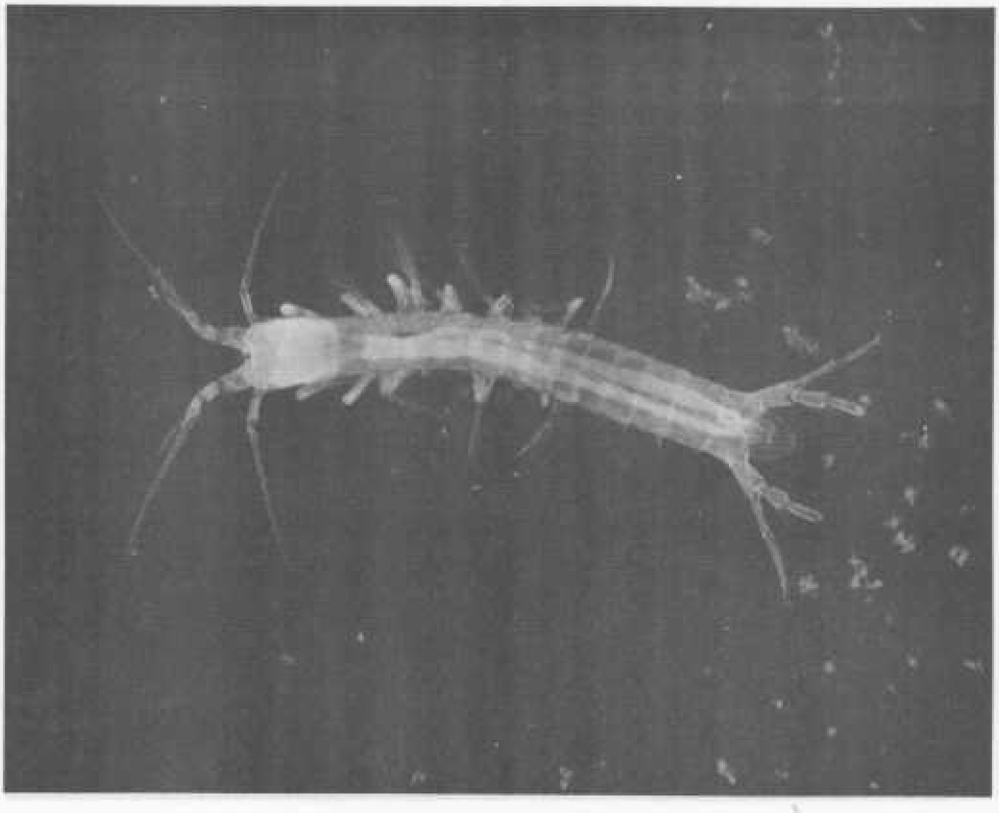


Plate 4 *Psammaspides* n.sp. from a spring at Davenport. About fifty times natural size. (Photograph, courtesy of Dr. R. Gaymey.)

These specimens were examined for the characters used by Williams (1965a,b) to distinguish *A. tasmaniae* from *A. spinulae*, namely the spinulation of the posterior margins of the third, fourth and fifth epimera, the dorsal and dorso-lateral margins of the fifth and sixth abdominal segments, the outer distal angle of the uropod peduncle and the posterior margin of the telson. The specimens from Wolf Hole do not differ from *A. tasmaniae* in the first three characters, but they are distinct from both other species in telson spination. In surface-dwelling *A. tasmaniae* the posterior margin of the telson has many stout spines "constituting a somewhat irregular spine row" (Williams 1965b). In the specimens from Wolf Hole the posterior margin of the male telson has six spines symmetrically positioned while in the female the posterior margin of the telson has four stout spines.

Goede (1972) lists the eyeless form of *Anaspides* as an example of a "species" occurring in only one cave or system of related caves within a limestone area. It certainly appears that the Wolf Hole population of *Anaspides* is isolated with distinctive morphological characters.

The population of *A. tasmaniae* from other cave systems appear to be troglophiles which may occasionally interbreed with epigean populations. In contrast the Wolf Hole form of *Anaspides* appears to be an obligate cavernicole or troglobite, completely isolated from epigean relatives. It is doubtful whether epigean populations of *Anaspides* now exist close to this cave. We will not assign any form of taxonomic status to the eyeless form of *Anaspides* for a thorough taxonomic revision of the genus *Anaspides* is being carried out by Dr. R. Swain (pers comm.).

Also in the family Anaspididae are two recently discovered species - *Allanaspides helonomus* Swain, Wilson, Hi-kman and Ong and *Alanaspides hickmani* Swain, Wilson and Ong. Both species possess a distinctive organ on their dorsal surface called the "fenestra dorsalis". They occur in discrete localities in button grass swamps in south-west Tasmania; both have been found in the hypogean environment of the burrow systems of the crayfish *Parastacoides tasmanicus* (Erichson) or the pholeteros (Swain, Wilson, Hickman and Ong 1970, Swain, Wilson and Ong 1971, Lake and Newcombe 1975).

The family Koonungidae is represented in Tasmania by two genera *Koonunga* Sayce and *Micraspides* G.E. Nicholls. *Koonunga* has been collected in the north-west of Tasmania and King Island (Williams 1974). It has also been found on Hunter Island. It is uncertain whether this species is *K. cursor* Sayce. *K. cursor* Sayce was originally collected from weed-filled pools in "a tiny rivulet" at Ringwood, Victoria, which "almost dried up for a few months each summer" (Sayce 1902). Drummond (1959) states that koonungids can be collected in "pits two to three feet deep in the beds of dried-out streams". Thus koonungids form a temporary component of the hyporheos in such streams. Drummond (1959) also notes that koonungids live in crayfish burrows. The crayfish are most likely to be of the genus *Engaeus* Erichson. In times of heavy rain the koonungids are often flushed from the burrows into nearby surface waters and they have been collected in this situation in north-west Tasmania.

Micraspides calmani Nicholls was originally collected from muddy water draining out of sphagnum moss and from water inside the burrows of *"Engaeus"* near Queenstown and Mt. Heemskirk near the west coast of Tasmania (Nicholls 1931). While *Engaeus* is known to occur in this area, it is mainly found in scrub and pockets of rain forest along streams, rivers and creeks, and it is most likely that the burrows in which *M. calmani* Nicholls was collected belonged to *Parastacoides* Clark. At Crotty in western Tasmania *Micraspides* has been collected from the burrows of *P. tasmanicus* (Lake and Newcombe 1975). Nicholls (1931) recognised that Koonunga may live for part of its life in surface waters, but regarded *Micraspides* as "leading a wholly cryptozoic life in the muddy floor of shallow swamps beneath sphagnum or in the water or liquid mud which fills the burrows of the "land-crab" *"Engaeus"*. All known specimens of *Micraspides* are eyeless and unpigmented. It is uncertain whether all the specimens of *Micraspides* collected by members of the Department of Zoology, University of Tasmania, belong to *M. calmani*; the Koonungidae require taxonomic revision.

In Tasmania there are at least three genera of syncarids, *Allanaspides* Swain, Wilson, Hickman and Ong, *Micraspides* and *Koonunga* which live in the free, not interstitial water of the burrows of parastacid crayfish. Other animals to be found in the pholeteros include amphipods, phreatoicid isopods, janirid isopods, cyclopoid copepods (Nichols 1931, Lake and Newcombe 1975). Occupation of the water of crayfish burrows is not unique to Australia for in North America there have been reports of ostracods, copepods, amphipods, oligochaetes, nematodes, collembolans and chironomid larvae all occurring in crayfish burrows (Creaser 1931, Williams, Williams and Hynes 1974). Creaser (1931) and Williams, Williams and Hynes (1974) suggested that the burrow fauna (pholeteros) may be involved in the reestablishment of the fauna of temporary ponds as well as possibly evolving into a "subterranean crustacean fauna". Williams, Williams and Hynes (1974) regard the burrow system of *Cambarus fodiens* (Cottle) as refuges for part of "the temporary stream fauna until the streams start flowing again". Animals may be either permanent or temporary members of the pholeteros.

Recently Schminke (1974b) described a new syncarid *Psammaspides williamsi* Schminke from the interstitial water of gravel alongside a creek near Halls Creek, northern New South Wales. Schminke (1974b) regards the species as being a member of the "mesopsammon" but in a strict sense it is a member of the hyporheos.

He placed the species in a new family, the Psammaspididae which he considers to bridge a gap between the Stygocaridacea and the Anaspidacea. The animal lacks eyes and is unpigmented. In the winters of 1974 and 1975 a new species of syncarid related to *Psammaspides* was collected from an underground spring at Devonport. The spring emerges from a well-weathered tertiary basalt outcrop on the edge of what was once a tea-tree swamp, but which is now suburbia. The Tasmanian species is not, in our opinion a member of the mesopsammon or hyporheos, but is an inhabitant of the free water of underground springs.

Order Stygocaridacea

Members of the Order Stygocaridacea are all hypogean animals. They have been found in psammon and hyporheos in Australia, New Zealand and South America (Schminke and Noodt 1968, Schminke 1975). In Australia they have been collected in the hyporheos alongside the Tambo River in Victoria (Schminke 1971). Possibly, collecting in suitable places will lead to their discovery in Tasmania.

Order Bathynellacea

The Bathynellacea consists of two families, the Bathynellidae and the Parabathynellidae (Schminke 1973). The order appears to have lived in the sea in Carboniferous times and to have migrated into surface fresh water during this period (Schminke 1974a). Subsequently they became restricted to living in subterranean waters in the interstitial spaces between sand grains and gravel (Schminke 1972, 1974a). They have been collected as part of the hyporheos and of the psammon. Their dispersive capacity is poor and consequently the zoogeography of the bathynellaceans may provide useful information on past intercontinental connections and relationships (Schminke 1974a, 1975, Schminke and Wells 1974).

On the Australian mainland four genera of Parabathynellidae occur - *Hexabathynella* Schminke, *Notabathynella* Schminke, *Chilibathynella* Noodt and *Atopobathynella* Schminke (Schminke 1972, 1973). *Hexabathynella* is unusual in that its species are euryhaline and occur in the interstitial environment of marine beaches. One species, *H. halophila* Schminke was collected at Coledale Beach, Stanwell Park, N.S.W. (Schminke 1972). *Notobathynella* is found on the Australian mainland and in New Zealand, while *Chilibathynella* occurs on the Australian mainland and in South America. *Atopobathynella* contains four species (Schminke 1971, 1973); *A. valdiviana* (Noodt) in South America, *A. compagna* Schminke on the Australian mainland and in New Zealand, *A. chelifera* Schminke on the Australian mainland and *A. hospitalis* Schminke in Tasmania in the interstitial water of gravel on the banks of St. Patrick's River (Schminke 1971, 1973). While most of the Australian freshwater bathynellaceans have formed part of the hyporheos of surface streams, a possibly new species of *Atopobathynella* has recently been collected in the hyporheos of an underground stream in Western Grand Fissure, Exit Cave, Tasmania, by Dr. Y. Morimoto (Goede 1975).

The Bathynellidae appear to have a distribution paralleling that of the Parabathynellidae (Schminke 1974a) with east Asia being the original centre of dispersal (Schminke 1975). The systematic relationships within the family are not well understood, and undescribed species have been discovered in Australia and New Zealand (Schminke and Wells 1974, Schminke 1974a). About 12 new species have been collected by Dr. H.K. Schminke from Australian mainland, Tasmania and New Zealand (Schminke and Wells 1974). In Tasmania, undescribed species were collected in hyporheos from the North Esk River, St. Patrick's River, Stirling River near Rosebery and the Nelson River near Queenstown. These species have been described in Schminke's (1971) thesis but the descriptions have not been published. Schminke (pers. comm. 29.12.1975) considers that it is difficult to determine the exact status of these species and the family needs to be thoroughly and carefully revised.

As Williams (1974) suggested, further collecting with the proper equipment in Tasmania is likely to produce additional species of bathynellaceans. The faunal sampling of freshwater interstitial environments in Tasmania, indeed of Australia, has been greatly neglected, even though Nicholls (1946) suggested that the freshwater "subterranean environments of Australia may well yield new subterranean forms."

ACKNOWLEDGEMENTS

We are indebted to Mr. A. Goede, Department of Geography, University of Tasmania, and Dr. R. Swain, Department of Zoology, University of Tasmania, for information and for criticism of this paper. One of us (D. Coleman) is supported by a grant from the Australian Biological Resources Council.

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APPENDIX

Definition of some terms

Epimera - plural of epimeron. Epimeron: posterior lateral portion of pleuron (small lateral plate on either side of typical body segment) in crustaceans and many other anthropods.

Hyporheos - the assemblage of animals that live in the water-filled interstices between the sand, gravel and rocks on the bottom of or on the margins of streams.

Pholeteros - the assemblage of animals that live in the water of the burrows of freshwater crayfish. The term is derived from the Greek *pholster-os:* one who lurks in a hole.

Psammon - the community of organisms (plants and animals) that grow in or move through sand on the bottom of, or on the margin of lakes and seas.

Telson - median posterior projection of the last body segment in many crustaceans.

Uropods - the paired appendages of the posterior abdominal segment in syncaid shrimps.

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FRUSTRATION AND NEW YEAR CAVES AND THEIR NEIGHBOURHOOD, COOLEMAN PLAIN, N.S.W.

L.G. Rieder, J.N. Jennings and G. Francis

Abstract

Frustration and New Year Caves are active between-caves, paralleling in plan and profile the ephemeral stream bed of the V-shaped valley in which their entrances are found. The main streamsink in this valley system feeds their stream, which in turn supplies Zed Cave, a short outflow cave just outside the mouth of this valley. This modest derangement of surface drainage pattern is in keeping with the caves which show slight vadose modification of epiphreatic cave development. Although these active caves are young, they probably formed prior to a Late Pleistocene cold period (30,000 to 10,000 B.P.) on the basis of soils evidence. Clown Cave on the brow of the valley, a dry cave with indications of sluggish phreatic development, is related to a planation phase of Middle or Lower Tertiary age before valley incision. Bow and Keyslot Caves are abandoned in-and-out and outflow caves respectively, formed when the surface stream channel was a few metres above the present valley bottom so they antedate the active river caves a little. This hydrologically independent part of Cooleman Plain mirrors in most respects the major part draining to the Blue Waterholes, differing chiefly in the greater proportion of between-caves discovered so far.

INTRODUCTION

Above the outlet gorge of Cooleman Plain, there are only two valleys that do not supply water to the Blue Waterholes, which are otherwise the springs for the remainder of this small, impounded karst (Jennings 1967). Frustration and New Year Caves are neighbours in the larger and more downstream of these two valleys, therefore an independent geomorphic and hydrologic unit worthy of separate description for comparison with the major part of Cooleman Plain. Frustration Cave (CP 10, grid reference 706007 Currango 1/50,000 Sheet 8626-IV) was discovered by J. Paix of Nowra shortly prior to December 31, 1965 (Anon, 1966). In the period of 1 to 3 January, 1966, members of Highland Caving Group (Anderson, 1966) dug their way into New Year Cave (CP 9, 707003). This was extended upstream by Canberra Speleological Society in an unsuccessful effort to link it with Frustration Cave (Anon. 1967). Sydney University Speleological Society members led by L.G. Rieder, have concentrated on this area, especially since 1971, making surveys of these caves.

GEOLOGY

Geologically Cooleman Plain is a synclinal basin of Silurian sedimentary rocks surrounded and to a limited extent overlain by Devonian igneous rocks (Owen and others 1974).

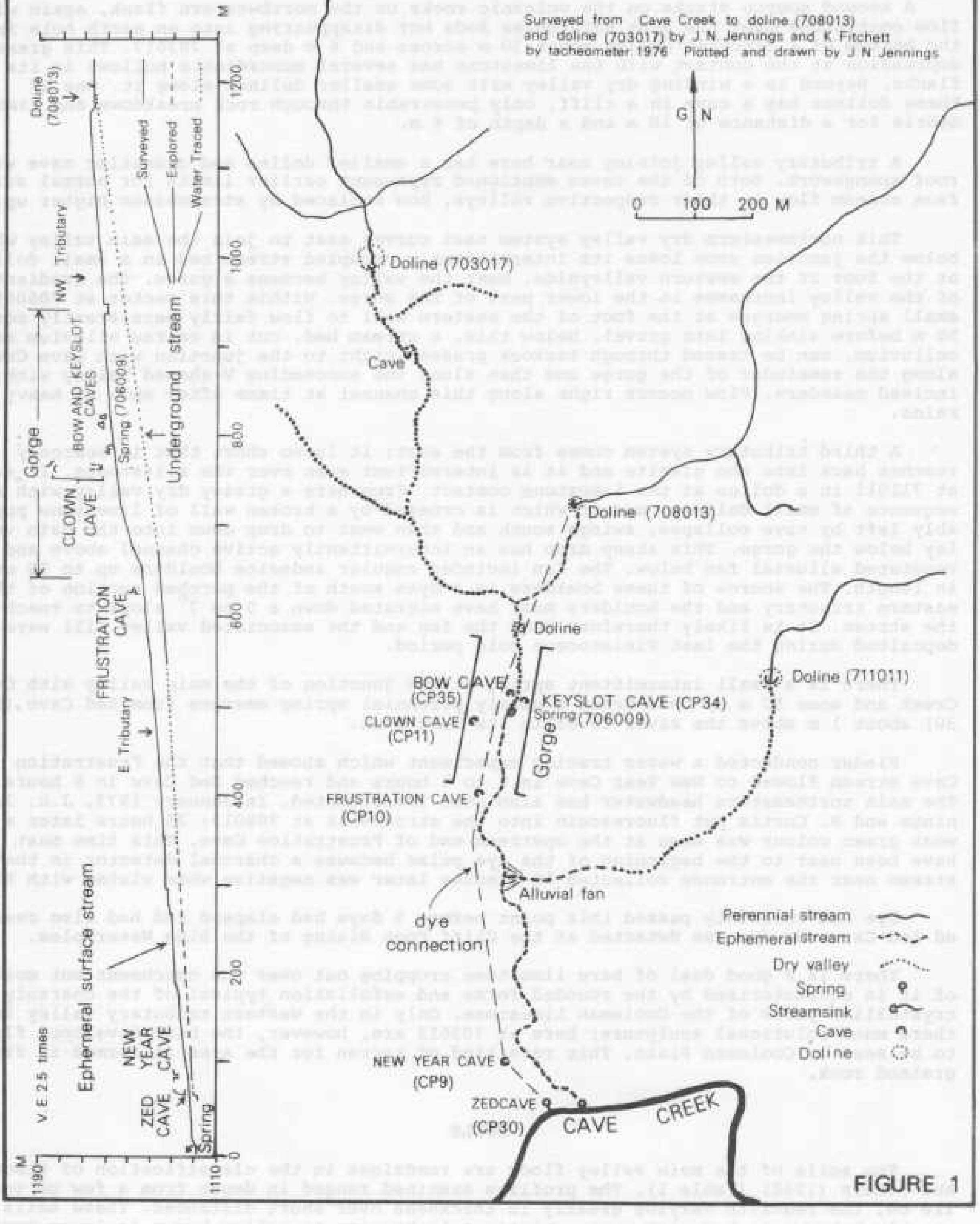
The middle of the eastern side, with which we are concerned here, is representative of the whole. The lower part of the Frustration-New Year Caves valley is developed in Late Silurian Cooleman Limestone. Much of it is strongly recrystallised to a sugary texture with coarse calcite crystals commonly 2 to 4 mm across but reaching 10mm. On the western side of the valley unmetamorphosed, thick bedded, fossiliferous limestone is found. Lenses of siliceous material, sometimes containing iron oxides, are present in the limestone as quartzite and ironstone. To the east and northwest the Cooleman Limestone is overlain by the Late Silurian Blue Waterholes Beds, here dominantly micaceous siltstones. Beyond these beds to the east across the Black Mountain Fault is Jackson Granite, intruded in Middle Devonian time, whilst to the north rhyolite of the Mountain Creek Volcanics and the Rolling Ground Latite, both Early Devonian extrusives of acid to intermediate composition, overlie the Silurian sediments. To the north and east the divide of the catchment under consideration lies within these various igneous outcrops.

Folding along roughly N-S axes took place in Late Devonian times, accompanied by faulting.

SURFACE MORPHOLOGY AND HYDROLOGY (Figure 1)

Because of this geological variety, the drainage of this small area also matches that of the whole plain, with more or less perennial headwater streams on the impervious non-carbonate rocks and with the lower parts of the system deranged hydrologically to varying degrees through water going underground.

The longest stream rises to the northeast on the granite of Mt Jackson and becomes very swampy as it crosses the siltstones. Almost as soon as it passes onto the limestone, this stream, now of second order with a normal flow of about 1 litre/second, sinks underground at 708013 in a doline with only a low downvalley lip of about 3 m height (Jennings 1967). In 1967 the water flowed into an earth and rock hole in its flat floor but now it enters joints in bedrock at two points at the foot of the western slope.


Surveyed from Cave Creek to doline (708013) and doline (703017) by J.N.Jennings and K.Fitchett by tacheometer 1976 Plotted and drawn by J.N.Jennings
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Doline
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BOW CAVE (CP35)
KEYSLOT CAVE (CP34)
Spring (706009)
CLOWN CAVE (CP11)
Gorge
FRUSTRATION CAVE (CP10)
Alluvial fan
dye connection
NEW YEAR CAVE (CP9)
ZEDCAVE (CP30)
CAVE CREEK
Perennial stream
Ephemeral stream
Dry valley
Spring
Streamsink
Cave
Doline
Doline (708013)
Surveyed
Explored
Water Traced
NW Tributary
BOW AND KEYSLOT CAVES
Spring (706009)
Gorge
CLOWN CAVE
Underground stream
FRUSTRATION CAVE
E Tributary
Ephemeral surface stream
NEW YEAR CAVE
ZED CAVE
Spring
V.E. 2.5 times
M
1190
1110
0
200
400
600
800
1000
1200
FIGURE 1

This is a semi-blind valley because the doline fills to overflowing for the stream to flow further down the valley on infrequent occasions when saturated soil is subject to melting snow and heavy rain.

A second source starts on the volcanic rocks on the northwestern flank, again with flow continuing over the Blue Waterholes Beds but disappearing into an earth hole in the bottom of a circular doline about 30 m across and 6 m deep at 703017. This grassy depression at the contact with the limestone has several subordinate hollows in its flanks. Beyond is a winding dry valley with some smaller dolines along it. One of these dolines has a cave in a cliff, only penetrable through rock breakdown and timber debris for a distance of 10 m and a depth of 6 m.

A tributary valley joining near here has a smaller doline and a smaller cave with roof spongework. Both of the caves mentioned represent earlier limits for normal surface stream flow in their respective valleys, now replaced by streamsinks higher up.

This northwestern dry valley system next curves east to join the main valley which below the junction soon loses its intermittently occupied stream bed in a small doline at the foot of the western valleyside. Next the valley becomes a gorge. The gradient of the valley increases in the lower part of the gorge. Within this sector at 706009 a small spring emerges at the foot of the eastern wall to flow fairly persistently some 50 m before sinking into gravel. Below this, a stream bed, cut in coarse alluvium and colluvium, can be traced through tussock grasses right to the junction with Cave Creek along the remainder of the gorge and then along the succeeding V-shaped valley with incised meanders. Flow occurs right along this channel at times after snow or heavy rains.

A third tributary system comes from the east; it is so short that it scarcely reaches back into the granite and it is intermittent even over the siltstones. It sinks at 711011 in a doline at the limestone contact. From here a grassy dry valley with a sequence of small dolines, one of which is crossed by a broken wall of limestone probably left by cave collapse, swings south and then west to drop down into the main valley below the gorge. This steep drop has an intermittently active channel above and a vegetated alluvial fan below. The fan includes angular andesite boulders up to 50 cm in length. The source of these boulders is a dyke south of the perched section of this eastern tributary and the boulders must have migrated down a 5 to 7° slope to reach the stream. It is likely therefore that the fan and the associated valley fill were deposited during the last Pleistocene cold period.

There is a small intermittent spring at the junction of the main valley with Cave Creek and some 50 m up Cave Creek a nearly perennial spring emerges from Zed Cave (CP 30) about 1 m above the river level in its left bank.

Rieder conducted a water tracing experiment which showed that the Frustration Cave stream flowed to New Year Cave in 7 to 8 hours and reached Zed Cave in 9 hours. The main northeastern headwater has also been investigated. In January 1973, J.N. Jennings and R. Curtis put fluorescein into the streamsink at 708013; 25 hours later a weak green colour was seen at the upstream end of Frustration Cave. This time must have been near to the beginning of the dye pulse because a charcoal detector in the stream near the entrance collected 10 minutes later was negative when eluted with KOH.

Dye had certainly passed this point before 5 days had elapsed and had also reached Zed Cave. No dye was detected at the Cliff Foot Rising of the Blue Waterholes.

There is a good deal of bare limestone cropping out over the catchment but most of it is characterised by the rounded forms and exfoliation typical of the coarsely crystalline parts of the Cooleman Limestone. Only in the western tributary valley is there much solutional sculpture; here at 703013 are, however, the best developed flutes to be seen on Cooleman Plain. This rare kind of karren for the area is formed in finer grained rock.

SOILS

The soils of the main valley floor are rendzinas in the classification of Stace and others (1968) (Table 1). The profiles examined ranged in depth from a few cm to 110 cm, the regolith varying greatly in thickness over short distances. These soils are black-brown to brownish grey, sometimes lightening to yellow brown in lower horizons. Texture ranges from sandy and silty clays to clay loams, becoming finer with depth but without well differentiated horizons (Table 1). Soil reaction is strongly alkaline. Absence of the mottling characteristic of groundwater rendzinas suggests that soil development took place above the watertable in a period after subsurface drainage had been established in the valley.

The soils of the valleysides in the limestone are mostly skeletal, but on the less steep slopes there has been some profile development. These soils correspond most closely with the Brown Earth of Stace and others (1968), (cf. Brown Limestone Soil of Costin 1964). They are brown to grey brown, lightening to yellow or reddish brown at depth. Textures range from sandy to silty clay with an alkaline reaction.

The amount of soil cover varies with joint spacing. Where the joints are more closely spaced, there is a greater proportion of soil cover. Where joints are widely spaced there are prominent benches in bare limestone, with very restricted areas of thin gravelly soil along incipient grikes.

TABLE 1. SOIL PROFILE DATA

Depth	Gravel % whole soil	% soil less gravel			pH	Munsell Colour	Description
		Sand	Silt	Clay			
Rendzina from Valley Floor							
0-10	10.1	48.1	17.5	37.2	8.0	10YR2/2 (moist)	Medium crumb, friable, fairly sharp to gradational boundary
10-25	21.3	40.3	18.1	43.1	8.5	10YR2/1 (moist)	Medium crumb, friable
25-100	43.5	29.6	37.0	44.4	8.5	10YR2/2 (moist)	Numerous calcite grains up to 6mm, abrupt to limestone
Brown Earth from Midslope							
0-10	6	24.5	33.4	43.6	7.5	10YR3/3 (moist)	Fine crumb, gradational to sharp boundary
25-90	21	14.8	28.4	59.0	8.0	7.5YR4/6	Medium crumb; shiny peds; abrupt to limestone

The soils contain much larger amounts of calcite sand and fine gravel then is usual in residual limestone soils; this is a result of the coarse crystallinity with weathering along grain boundaries.

The rendzinas here (but not generally over Cooleman Plain) contain abundant calcite both as skeletal grains and as secondary carbonate in the fine earth fraction. However the upper horizon of the brown earths on the slopes contained little or no calcite in the skeletal grains and no carbonate in the fine earth. Thus greater leaching takes place on the slopes despite less soil moisture there. Trudgill (1976) has shown that more calcite removal takes place from the better drained soils over limestone in Ireland. Jennings (in press) measured more solutional loss from limestone tablets in rendzina soil from a flat interfluve site than from a doline nearby in the neighbourhood of Murray Cave and in this case also the better drained site is giving the greater solution. So this relationship may apply generally at Cooleman Plain.

The absence of gleying in the fine grained matrix of the valley fill or rendzina developed on it suggests that the valley was already well drained when the fill was laid down.

UNDERGROUND GEOMORPHOLOGY

Frustration Cave (Figure 2A)

A between-cave, Frustration Cave, is entered from the right bank (western) slope about 5 m above the floor of the main valley just below its gorge reach. Its small entrance had to be cleared of loose rock; colluvial earth and boulders extend about 2 m downslope outside as well as down the entrance passage. Inside a small solution tube winds steeply down into the roof of a stream passage where it has been enlarged by collapse. About 4.5 m below the entrance a horizontal solution tube, with roof bell-holes and with one wall in blocky fill, runs upvalley some 10 m till blocked by earth fill. It is approximately at the valley floor level and represents an earlier phreatic development in the history of the cave. There are two blind shafts which join the steeply inclined entrance passage about 5 m down; they are almost vertical, about 6 m tall and 0.6 m in diameter, with gently domed tops. The total descent to the stream is 13.5 m.

The cave extends rather less upvalley then downvalley. Upvalley it begins in a pool in a low crawl along a SE joint. This flood passage rises a little into a high chamber, with talus, mud and calcite decorations, along the same joint. Upwards this chamber contracts and then expands to end in a small solution slot connecting with the surface about 22 m above.

Nearly as far as the entrance chamber, the passage, now descending, is narrow but increases in height. In the roof there are remnants of pressure tube (e.g. cross-section 5) but there is plentiful evidence of vadose deepening in the form of channel incurves and meander niches in the walls and small meandering canyons in the floor (e.g. cross-section 9). The rock surfaces are solutionally smoothed. The floor is irregular but has some gravel; small breaches reveal a low stream passage close below, which in part consists of an elliptical tube. In plan this section winds angularly along SE, SW and W vertical joints with a short oxbow with rimstone pools.

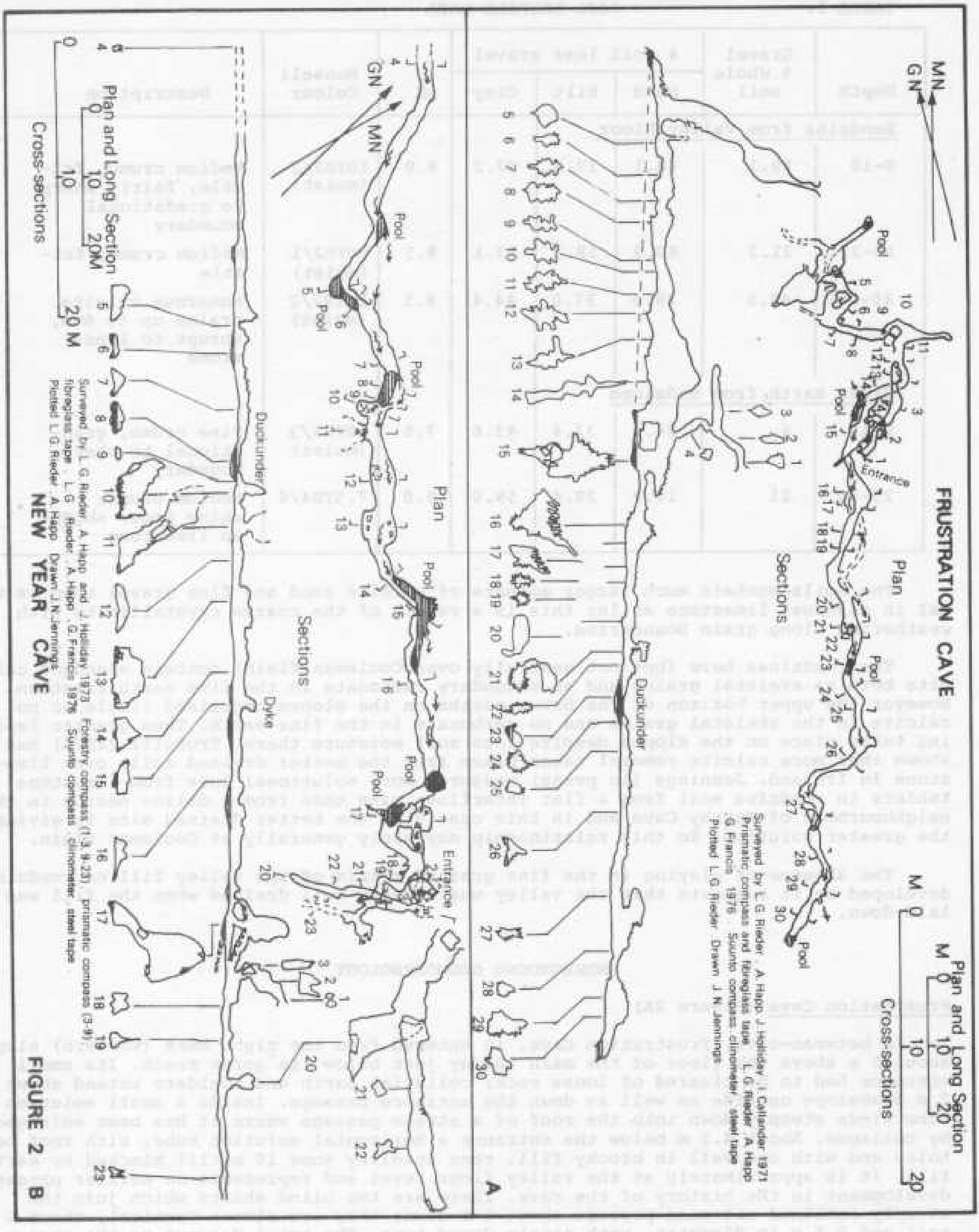

FRUSTRATION CAVE
Plan
Sections
Entrance
Pool
Duckunder
Plan and Long Section
Cross-sections
Surveyed by L.G. Rieder, A. Happ, J. Holliday, J. Callander 1971
Prismatic compass and fibreglass tape L.G. Rieder, A. Happ
G. Francis 1976 Suunto compass, clinometer, steel tape
Plotted L.G. Rieder Drawn J.N. Jennings
NEW YEAR CAVE
Dyke
Surveyed by L.G. Rieder, A. Happ and J. Holliday 1973 Forestry compass (1-3, 9-23), prismatic compass (3-9)
fibreglass tape L.G. Rieder, A. Happ, G. Francis 1976 Suunto compass, clinometer, steel tape
Plotted L.G. Rieder A. Happ Drawn J.N. Jennings

FIGURE 2 B

Though enlarged by collapse, the entrance chamber, which is the roomiest part of the whole cave, has rock pendants of moderate size in the roof and channel grooves in the walls (cross-section 15). There are fill remnants of gravel with a clay and silt matrix on the walls also. The stream enters the chamber from the left bank, having followed an impenetrably small passage from the upstream pool. A smaller room follows with roof pendants again and vadose floor channels (cross-sections 16, 17).

Downstream the passage is narrow and generally low, including a constriction with only 17 cm of air space above a pool (cross-section 29). Before this point, the stream has abandoned the main passage to follow a slightly lower, impenetrable anabranch behind the right wall for some 15 m. Thereafter the passage is an active stream cave to the end. Roof, walls and parts of the floor are intricately sculptured, with many angular projections covered in scallops. There are allogenic gravels and sand in active transport along the stream bed. At the end there is a small pool too tight for penetration but in low flow the stream escapes a few metres above this into a joint cleft in the right wall. Hereabouts the roof is higher (cross-section 29) but retains the prevailing character. A few metres upstream of this, there is a small, straw-decorated grotto above. Though trending S as a whole, the downstream section varies from SW to SE under joint influence.

Along the active streamway there is a fall in the cave floor to the final pool with an average gradient of 1 in 16, particularly uniform towards the bottom end.

New Year Cave (Figure 2B)

Angular rock debris was excavated to open up two small entrances and there has been recent rockfall partially blocking the lower entrance afresh. The entrances lead tightly and tortuously with angular bends down some 8 m to the horizontally developed stream cave at a point close to its downvalley limit of exploration. There is a small, solution tube in this descending section too tight to be used.

J. Mendum (pers. comm. 1971) and M. Listing (pers. comm. 1973) have described the stream passage upstream of a tight squeeze which has so far been the limit of survey. An estimated length of 180 m of stream cave prolongs the NW trend of the surveyed cave. It consists of low wet passage, with a few larger dry chambers. Tight V-tubes and horizontal fissures prevent further progress upstream.

The surveyed part generally consists of narrow, low passage with a gravel floor over which the low stage stream meanders. Parts retain a pressure flow elliptical form. Walls are commonly etched by solution in flood conditions and there are also incurves and recesses which have been fashioned by solution with the help of mechanical attack also. Scalloping is prevalent. Vertical joints guide the legs of the cave in plan, with bedding planes occasionally forming the roof. There are a number of shallow pools at bends in the passage, one of them (cross-section 8) almost reaching the roof in an elliptical pressure tube guided by a horizontal joint. There are also three anabranches in the left wall, too small to follow and, in order downstream, 10, 5 and 12 m in length. Only one cuts off a corner.

At cross-sections 14 and 15 the cave first runs alongside a felsite dyke in the left wall running ENE and then breaches it in a low-roofed constriction which is a major obstacle to flood flow. Waterworn block gravel up to 5 cm in diameter derived from the dyke becomes prevalent downstream.

At cross-section 10 the passage widens along a cross-joint and the roof domes up to nearly 5 m; there is some breakdown but the feature may be due originally to phreatic solution. There is some flowstone here. Close by at cross-section 11, there is a similar but larger feature rising 9 m; it is unsurveyed. Close to the entrance there is a further dome chamber (cross-section 17) located on a short passage cutting across a bend. Detached blocks plug its roof. At this bend the low stage stream escapes by an impenetrable cleft. Beyond here the absence of fines amongst the gravel suggests that the stream only flows further in flood and has winnowed its bedload.

Downvalley from the entrance, the passage is low and narrow, making sharp, joint-controlled bends one after the other. It ends in an inverted-V squeeze along a SW joint, too tight for penetration, and in a rockpile extending SE. A major cross-joint (cross-section 20) has allowed an upper level passage to develop which at one end leads to a second entrance blocked by collapse. This downvalley end of the cave is complex under the influence of criss-crossing vertical joints normal to the valley-side which is close.

The longitudinal profile of the cave has a uniform but low gradient of 1 in 18.

Other Caves

In the two walls of the gorge near the spring at 706009, there are two small, inactive caves opposite one another. In the right wall, Bow Cave (CP 35) is a very short, curving in- and out- cave about 6 m above the valley bottom and only slightly modified by rockfall and seepage solution (Figure 3B). It has the capacity easily to take discharges of a surface stream comparable with flood flows of today in the gorge. In the left wall, Keyslot Cave (CP 34) (Figure 3C), 4 m above the valley bottom, is more problematic in origin. It has a straight, smaller, joint-controlled passage running in 20 m to a T-junction, where there are impenetrably narrow fissures, one running back to the gorge at an acute angle and one penetrating into the hill. Scalloping in the main passage indicates a former outward flow. It may be another in-and-out passage of the gorge stream but the discrepancy in size between the large outflow passage and the small supposed inflow passage is against this interpretation. An alternative view is that it is simply a former outflow cave which had two outlets, possibly successive. This is supported by the presence of the spring below this cave, though a larger spring than this would appear to have been necessary for its formation. There is also a discrepancy between the size of the fissure issuing from the hill and the large size of the main outlet.

Clown Cave (CP 11) (Figure 3A) is located near the top of the right wall of the gorge at 705008. Its small entrance leads steeply down into the wall of a single chamber that comprises the bulk of this cave. The chamber is 29 m long, 6 to 9 m wide except for a short constriction, and 15 m in overall height. A tall, narrow fissure passage runs off at right angles through a tight connection. This cave has been much modified by breakdown and speleothems, but very large rock pendants up to 6 m long remain to point to a phreatic origin. Even the bottom of this cave is above the valley floor outside.

Zed Cave (CP 30) has been surveyed for 10 m only along the roomy fissure passage behind the entrance (Figure 3D). Beyond a low, wet squeeze, another passage, estimated at 36 m long, has been explored to tighter but draughty squeezes (Anderson 1966).

SPELEOGENESIS

The most significant speleogenetic features of this part of Cooleman Plain are the parallelisms in plan and profile between Frustration and New Year Caves and the adjacent valley (Figure 1). This underground waterway follows the right wall of the valley below its floor level, some 8 m at Frustration and only 2 to 3 m at New Year Cave since the valley is falling more steeply than the caves do. The fill in the downstream section of the valley has largely been removed. A 2 m section is exposed with bedrock 0.5 m below the base so that it is likely the cave is actually running below the bedrock valley for some distance above the junction. At the junction Cave Creek is running practically on bedrock. When the cave stream eventually emerges in Zed Cave, it is slightly above the level of the junction of the tributary talweg and Cave Creek. In plan Frustration Cave runs N-S where the valley does and New Year Cave runs NW-SE, again in concordance with the valley. However there is departure from the surface valley at its mouth, since the stream escapes through the right bank divide to Zed Cave but the deflection is only about 50 m.

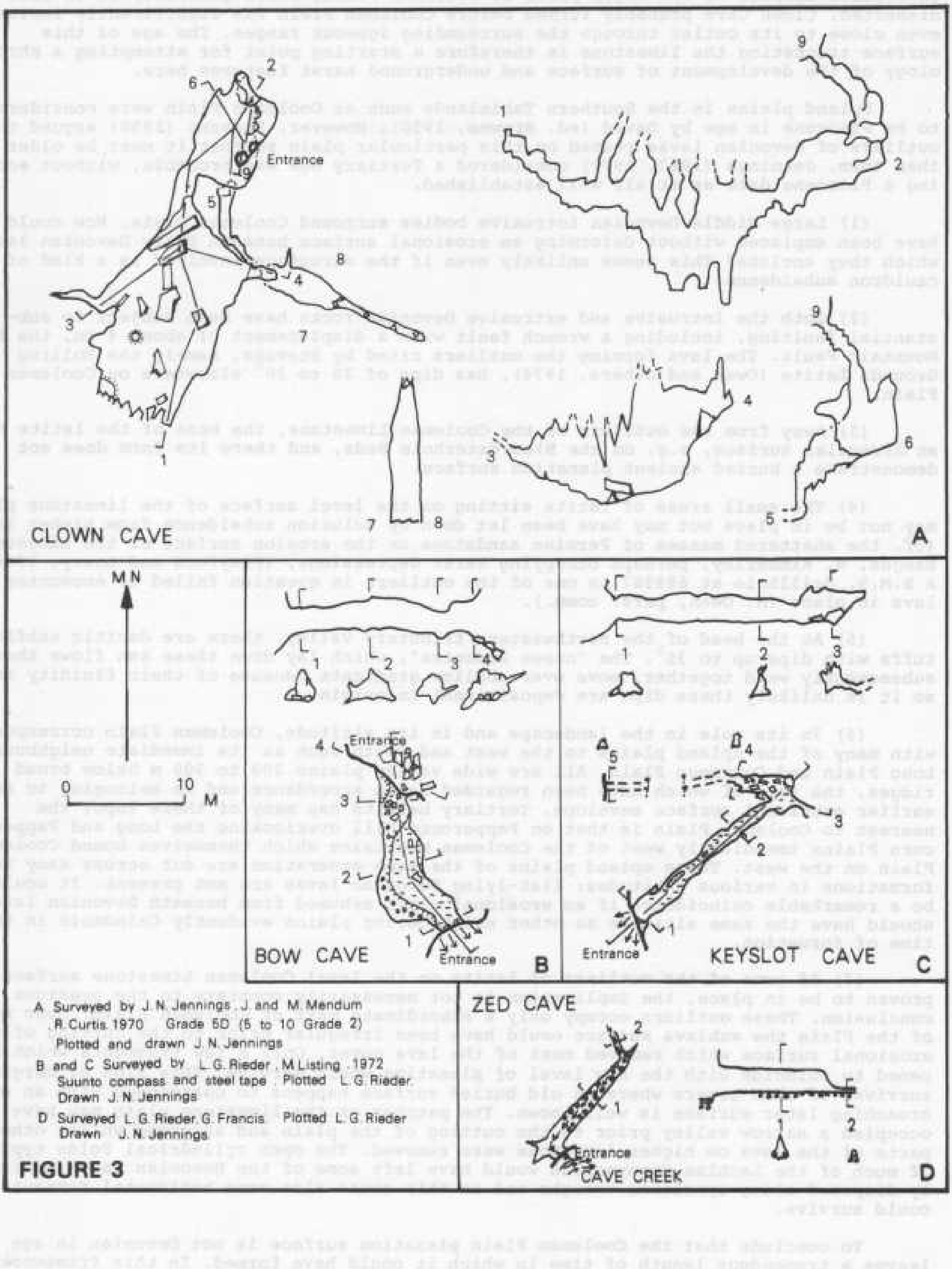
The phreatic characters found in Frustration and New Year Caves - the slightly undulatory roofs and the roof and wall pockets - belong more to a shallow, epiphreatic cave with pressure flow than to Davis-Bretz phreatic conditions with slowly moving water. Subsequent vadose modification, indicated by meandering canyons and channel incuts in the walls, has widened and graded the floors.

Less straightforward is the interpretation of the entrances and other upward projections from the stream passages. Angular rock was removed to open up the entrances of the caves, and in Frustration Cave entrance this is of coarser-grained limestone than that which forms the entrance but is to be matched higher up the slope. This fill may have been the product of freeze-thaw action in the cold period that the Snowy Mountains suffered 30,000 to 15,000 B.P. (Jennings 1976). Upward stoping by cave breakdown from the horizontal cave passage has contributed to the formation of these entrances. Nevertheless in both there is sufficient solutional sculpturing left to demonstrate that flowing water has contributed to their formation. The choice lies between percolation water or stream inflow working downwards and spring outflow working upwards under pressure. The parallelism in longitudinal profile of the underground stream and the surface talweg demands that even the epiphreatic stage of the cave formation must have taken place after the valley was cut down to its present level to all intents and purposes. This precludes a stream inflow origin for the entrances because flood levels in the valley would have failed to rise above the valley floor enough for inflow into them even in the case of New Year Cave. Whether the valleyside would have been sufficiently watertight to permit and the hydrostatic head in the cave systems great enough to cause upwards outflow through the entrances also seems doubtful.

The high chambers and domes which do not reach the surface raise similar issues. Variation in resistance to erosion seems unlikely as a cause. Some of them lie close to places where changes of pressure may formerly have occurred, e.g. near the passage constriction of cross-section 10 in New Year Cave or near an entrance (cross-section 17). Mixing corrosion in the epiphreatic phase is another possible mechanism and this could be combined with subsequent percolation water solution from above to explain the cave entrances also. The blind shafts near Frustration Cave entrance are suggestive of mixing corrosion. However the argument presented above against a spring outflow origin applies in this connection also with almost equal force. On the other hand no special factor to gather together considerable amounts of seepage water to fashion these features is apparent. Past phases of greater effective precipitation and so of runoff from neighbouring impervious rocks would make this explanation more feasible and there is some evidence for this having happened (Jennings 1976).

DATING

Attempts to date most cave systems in the Eastern Uplands of Australia are perforce at least as speculative as much of the preceding discussion of speleogenesis.



A. Surveyed by J.N. Jennings, J. and M. Mendum, R. Curtis. 1970 Grade 5D (5 to 10 Grade 2) Plotted and drawn J.N. Jennings

B and C Surveyed by L.G. Rieder, M. Listing. 1972 Suunto compass and steel tape. Plotted L.G. Rieder. Drawn J.N. Jennings

D Surveyed L.G. Rieder, G. Francis. Plotted L.G. Rieder Drawn J.N. Jennings

FIGURE 3

Practically at the brow of the gorge, Clown Cave must have developed before the valley had been cut. Close to this cave the interfluves are mainly rounded but east of the main valley there is a marked shelf on the limestone which clearly belongs to the interfluve surface of the major parts of Cooleman Plain, where generally it is less dissected. Clown Cave probably formed before Cooleman Plain was significantly incised even close to its outlet through the surrounding igneous ranges. The age of this surface truncating the limestone is therefore a starting point for attempting a chronology of the development of surface and underground karst features here.

Upland plains in the Southern Tablelands such as Cooleman Plain were considered to be Pliocene in age by David (ed. Browne, 1950). However, Stevens (1958) argued that outliers of Devonian lavas rested on this particular plain so that it must be older than them. Jennings (1967, 1972) considered a Tertiary age was probable, without accepting a Pliocene date as at all well established.

(1) Large Middle Devonian intrusive bodies surround Cooleman Plain. How could they have been emplaced without deforming an erosional surface beneath Early Devonian lavas which they enclose? This seems unlikely even if the structure involved is a kind of cauldron subsidence.

(2) Both the intrusive and extrusive Devonian rocks have been subject to substantial faulting, including a wrench fault with a displacement of about 4 km, the Black Mountain Fault. The lava forming the outliers cited by Stevens, namely the Rolling Grounds Latite (Owen and others, 1974), has dips of 20 to 30° elsewhere on Cooleman Plain.

(3) Away from the outliers of the Cooleman Limestone, the base of the latite has an irregular surface, e.g. on the Blue Waterhole Beds, and there its form does not demonstrate a buried ancient planation surface.

(4) The small areas of latite sitting on the level surface of the limestone plain may not be in place but may have been let down by solution subsidence from higher levels (cf. the shattered masses of Permian sandstone on the erosion surface of the Limestone Ranges, W. Kimberley, perhaps occupying karst depressions, (Playford and Lowry, 1966). A B.M.R. drillhole at 698987 in one of the outliers in question failed to encounter lava in place (M. Owen, pers. comm.).

(5) At the head of the northwestern tributary valley, there are dacitic ashflow tuffs with dips up to 35°. The "nuees ardentes", which lay down these ash flows that subsequently weld together, move over shallow gradients because of their fluidity and so it is unlikely these dips are depositional in origin.

(6) In its role in the landscape and in its altitude, Cooleman Plain corresponds with many of the upland plains to the west and south such as its immediate neighbours, Long Plain and Currango Plain. All are wide valley plains 200 to 300 m below broad ridges, the tops of which have been regarded as in accordance and as belonging to an earlier erosional surface envelope. Tertiary basalts cap many of these tops; the nearest to Cooleman Plain is that on Peppercorn Hill overlooking the Long and Peppercorn Plains immediately west of the Cooleman Mountains which themselves bound Cooleman Plain on the west. These upland plains of the same generation are cut across many rock formations in various attitudes; flat-lying Devonian lavas are not present. It would be a remarkable coincidence if an erosional plain exhumed from beneath Devonian lavas should have the same altitude as other neighbouring plains evidently Cainozoic in their time of formation.

(7) If some of the outliers of latite on the level Cooleman Limestone surface are proven to be in place, the implication is not necessarily contrary to the previous conclusion. These outliers occupy only a subordinate part of Cooleman Plain. Over much of the Plain the sublava surface could have been irregular prior to the cutting of the erosional surface which removed most of the lava cover. Only a few fragments which happened to coincide with the new level of planation would survive. This kind of marginal survival of thin covers where an old buried surface happens to correspond with an encroaching later surface is well known. The patches on the limestone plain may have occupied a narrow valley prior to the cutting of the plain and survived whilst other parts of the lava on higher limestone were removed. The open cylindrical folds typical of much of the Lachlan Geosyncline would have left some of the Devonian lavas horizontally disposed along synclinal troughs and on this count also some horizontal remnants could survive.

To conclude that the Cooleman Plain planation surface is not Devonian in age still leaves a tremendous length of time in which it could have formed. In this framework the Tertiary basalts have not yet been employed to narrow down the timing as much as they may. The nearest patch to Cooleman Plain is on Peppercorn Hill; though it has not been dated itself, it is very likely to belong to the surrounding Snowy Province basalts of 22 to 18 m.y. age (Wellman and McDougall, 1974). Even accepting this correlation, difficulties remain.

Although some of these basalts occupy the highest parts of the landscape around them like the Peppercorn Hill fragment, e.g. Round Mountain, Tabletop Mountain, others lie lower down in the relief. Near Kiandra, the basalts of the New Chum gold diggings cap flat-topped hills but are underlain by substantial Tertiary sediments, the base of which is in parts only 20 to 30 m above the floor of the Kiandra Plain. Moreover basalts of the same age lie on the limestone strath along the Yarrangobilly River valley. Many of these occurrences have been lowered by solution subsidence but some of the higher ones are in their original place at 1160 m compared with the 1270 m of Cooleman Plain. Again on the western side of the Fifteen Mile Plateau near Kiandra the basalts descend 330 m into the Tumut River valley (Hall and Lloyd, 1954). Therefore the Peppercorn Hill basalt may be a remnant of a more extensive flow which possibly extended down onto the Little Peppercorn Plain and the Long Plain on each side. Thus these plains may be older than the Lower Miocene basalts, not younger as Jennings (1972) has argued. More detailed studies of the denudation chronology of the whole area are needed to determine which interpretation is correct.

The iron-cemented sandstones and ironstone detritus of Cooleman Plain are relevant to the issue. The detritus is widely scattered as a result of some lowering of the interfluve surface and valleys cutting into it. However some areas of iron-rich sandstone are intact in marginal and slightly higher positions. In the Southern and Central Tablelands, similar materials in association with Tertiary basalts can be shown to be older than Lower Miocene. However it is not possible to correlate these occurrences on their lithology alone and to extrapolate this date on present knowledge.

Caves such as Clown Cave, which have developed in slow phreatic hydrodynamic conditions beneath the planation surface, may therefore be Middle or Lower Tertiary in age rather than Upper Tertiary as was suggested before. This older dating makes even worse the problems of the absence of any old sediments in the cave and of insufficient loss of material to match modern denudation rates (Jennings 1972). Extrapolation of present-day process rates backwards in time is, however, a hazardous step.

The Tertiary planation surface was dissected markedly prior to the formation of the other caves discussed in this paper. A wave of erosion had retreated headwards up the Goodradigbee River and Cave Creek before the caves formed in relation to the incised tributary valley. The most significant time marker for this development is the Lower Miocene basalt in the Wee Jasper Creek valley, tributary to the Goodradigbee River some 50 km to the north. This basalt reaches to within 40 m of the present valley floor and overlies river terrace deposits. Slow downcutting of Wee Jasper Creek since then may be due to the resistance to mechanical erosion of the Goodradigbee by the granite in Burrinjuck Gorge. Again the implication is that rejuvenation may have reached Cooleman Plain much earlier than was conceived prior to the dating of the basalts (Jennings 1972), though headwater retreat may have proceeded more slowly up tributaries like Cave Creek than up the main valley.

Bow and Keyslot Caves in the gorge formed when the valley bottom was several metres higher than at present. Their relative position within the relief points to broad correspondence with the upper level of Barber Cave, with Cooleman-Right Cooleman Cave and with the earlier phases of the development of Murray Cave, all of which preceded a final deepening of Cave Creek and its North Branch valley by amounts varying between 2 to 3 and 13 m. From relationships to deposits regarded as periglacial and periglacial-fluvial it has been argued that Murray and Barber Caves must antedate a Pleistocene cold period in their beginnings (Jennings 1966, 1968).

Frustration and New Year Caves exhibit many geomorphic criteria for caves in a youthful stage of development; active passages close to the surface, scarcity of abandoned passages, simple drainage system and simple passage forms. Equally indicative is the parallelism of the caves to the valley of which they have captured the drainage with a minimum of displacement. Scarcity of speleothems matches this attribution of youth without demanding it.

To translate this geomorphic "stage" of youthfulness into time, radiometric dating of speleothems could in the future prove valuable because these caves can be expected to fall within the range of the uranium-thorium decay series. Meanwhile we must depend on inferences like those already employed above. These two caves and Zed Cave are closely related to the present profile of the associated valley. It is likely that they relate more to the bedrock profile which is concealed somewhat by aggradation than to the surface talweg. Some interval of time passed between their formation and that of Bow and Keyslot Caves. The 1 m drop from Zed Cave into Cave Creek relates this active system to the lower active passage of Barber Cave which drops 2 m to the creek. This small amount of incision may have substituted vadose flow for epiphreatic flow as the normal regime for much of Barber Cave and perhaps all of the Frustration-New Year Caves system. This wave of erosion does not yet seem to have affected the Blue Waterholes only 200 m upstream from the latter. This again supports the idea of a young age for these caves. Nevertheless the absence of gleying in the valley fill outside Frustration and New Year Caves may imply that underground drainage had developed prior to the deposition of the fill. Thus even these youngest caves may antedate the last Pleistocene cold period. This argument conflicts with the Murray Cave evidence where the active outflow (nevertheless now a flood overflow only) has developed subsequently to an earlier outflow level correlated with an aggradation terrace thought to belong to this same cold period.

CONCLUSION

It is useful to conclude with a comparison between the Frustration-New Year Caves area with the major part of Cooleman Plain from which it functions separately. In both, inflow cave development is slight. Only one of two factors which can be thought to cause this over the Plain applies here, namely the annular relief pattern consequent on the geological structure which ensures that the input of aggressive water from the non-carbonate surround is divided amongst many small streamsinks from the gorges of rejuvenation.

Outflow cave development in the shape of Zed Cave is small in comparison with Cooleman-Right Cooleman and Murray Caves; the obvious explanation of the difference in magnitude is sheer lack of discharge.

On the other hand, between-caves comprise most of the known cave development here whereas for the Plain as a whole the portion is much less with only River Cave and Keith's Faint Cave so far known. These latter two belong to a much larger underground stream, that of the South Branch of Cave Creek, which however detours far more from the former surface watercourse it has replaced, and lies much father from the surface than Frustration and New Year Caves. The likelihood of surface connections to create between-caves is much less therefore. For similar reasons it is not surprising that no discovery along the underground course of the North Branch of Cave Creek has yet been made between its main streamsinks in its left bank about half a kilometre upstream of Murray Cave and the Blue Waterholes. Despite much effort, Cooleman-Right Cooleman Cave has not yielded a connection with it.

Overall this small segment of Cooleman Plain exhibits just as strongly as its major extent a tight, if not complete relationship between cave development and rejuvenation.

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A CHEMICAL INVESTIGATION OF SOME GROUNDWATERS OF THE NORTHERN LIMESTONE AT JENOLAN CAVES

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Abstract

A brief description of the geology and drainage of the Northern Limestone at Jenolan Caves is introduced. Approaches to karst geochemistry are given. The reasons are given for the choice of complete chemical analyses followed by calculations of the thermochemical parameters (saturation indices with respect to calcite and dolomite, SIc and SId, and the partial pressure of carbon dioxide P_{CO_2}) for the Jenolan groundwaters. The methods of chemical analysis and thermochemical calculations are reported. The results of the ground water survey are presented both as the raw chemical data and the derived thermochemical data. The raw data give more useful information than the calculated parameters. The results obtained by this survey are consistent with observations and the previous knowledge of the underground drainage of the Northern Limestone. The water chemistry reflected the rock type and the residence time of the water in bedrock and gravels. It is concluded that the Jenolan Underground River and Central River have different types of source and that Central River is not a braid of the Jenolan Underground River.

INTRODUCTION

The Northern Limestone

Jenolan Caves lie in a belt of steeply dipping Silurian limestone which forms the western limb of a partially overturned syncline (Pratt, 1965; Chalker, 1970). The strike of the limestone ranges from north to north-west and the dip inclines to both east and west. The limestone overlies the Ordovician Oberon Hill Chert and Jaunter Tuff, and is overlain on the eastern side by the Silurian Jenolan Beds which are mainly argillites. At the northern end of McKeowns Valley these argillites are in turn overlain by the Terrace Creek Rhyolite. The Silurian strata are intruded by Bindook Porphyry, thought to be of Devonian age. Several intrusive phases have been recognised, including rhyolite-porphyry and quartz porphyrite (Pratt, 1965).

The Jenolan Caves Limestone is largely an algal - stromatoporal biomicrite and biomicrudite, with fossils of varying sizes in a lime mud matrix. In some areas it has been recrystallised to coarser sparry calcite. The limestone is compact and pure (96 to 99% $CaCO_3$) (Chalker, 1970) and magnesium carbonate ($MgCO_3$) is usually about 1% (Carne and Jones, 1919).

The limestone at Jenolan Caves can be divided into northern and southern sections, which are independent. The drainage of the Northern Limestone drains to Blue Lake.

The main surface feature of the Northern Limestone is the dry valley of the Jenolan River (McKeowns Valley). This river has a substantial flow of water upstream from the limestone and on reaching the carbonate rock it sinks into the gravel of the streambed. Upstream from the river's normal sinking point are a number of karst features; however the limestone supporting these is present as isolated small outcrops (Dunkley, 1972). The water now travels underground until it reappears in Blue Lake 3 km away. After heavy rain the water continues to flow down the dry bed of the Jenolan River and sinks in many other places in it, to join the underground drainage (Shannon, 1976). In floods the water flows the full length of the limestone valley through the Devils Coachhouse (a large natural arch) to Blue Lake.

A number of small tributaries flow onto the Northern Limestone between the main sink of the Jenolan River and Blue Lake. Normally these streams sink into the gravel just before they reach the dry bed of the Jenolan River. The underground drainage channels in the Northern Limestone are visible in a number of caves; in some places the water appears as fast flowing streams and elsewhere as underground lakes.

There appear to be two major streams in the Northern Limestone. The Jenolan Underground River is seen in the Imperial Cave and resurges into Blue Lake. The same river 1.5 km upstream in Mammoth Cave is called Lower River (and for the purpose of this paper will be referred to as the Jenolan Underground River) and carries most of the water seen in the cave. Also in Mammoth Cave is Central River which contains much less water, is on a higher level and is observed to flow at four places in the cave. The water levels and flow in Central River are very susceptible to surface weather changes whereas the Jenolan Underground River has more regular flow. Central River probably joins the Jenolan Underground River between Mammoth Cave and Imperial Cave.

Approaches to Karst Geochemistry

The study of the Northern Limestone waters involved a full chemical analysis. This analysis for all major ionic species permitted inferences about the origins of the waters. In addition, thermochemical parameters were calculated from these analytical data by the method of Langmuir (Langmuir, 1971). The chemical theory involved and

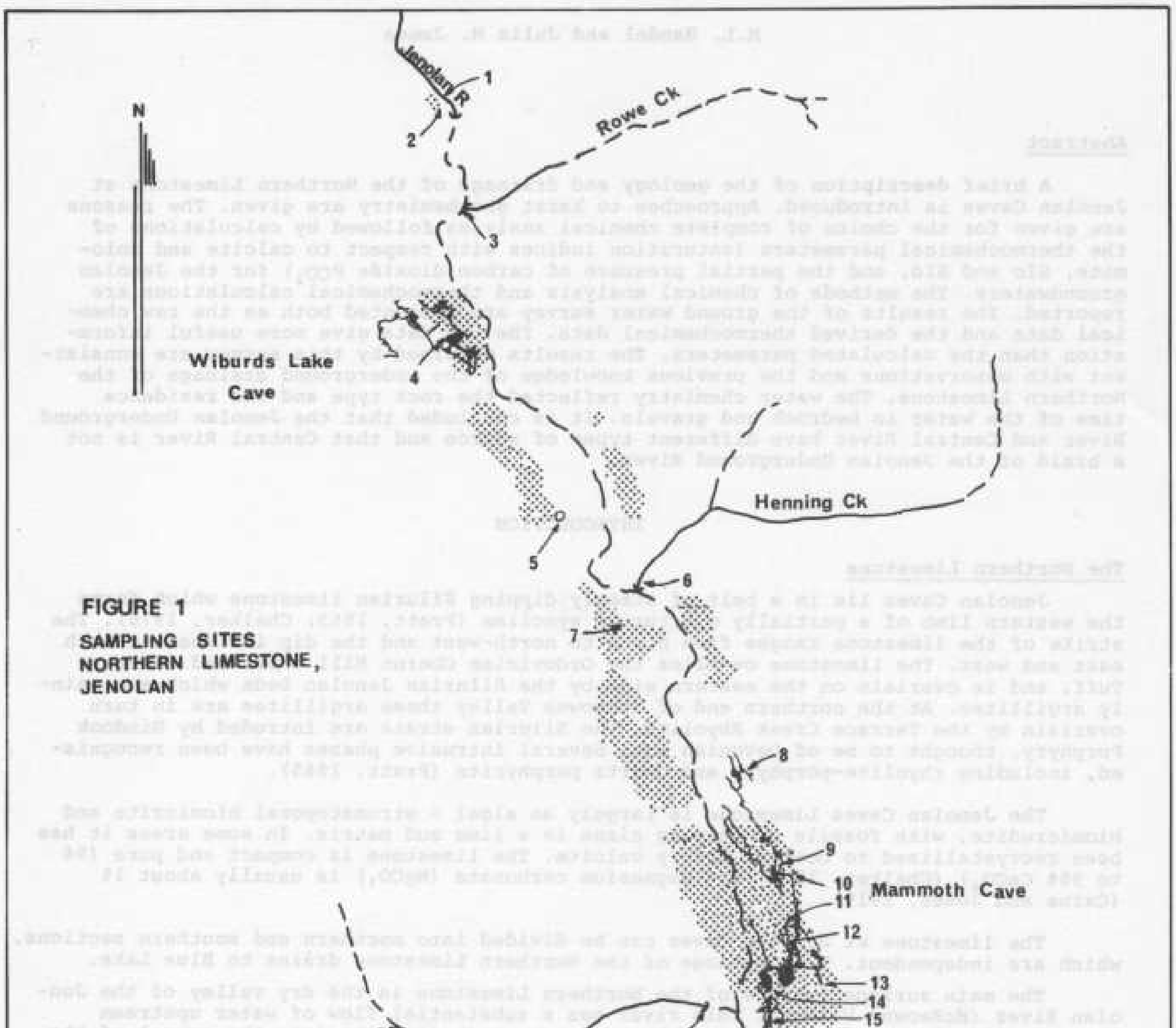

FIGURE 1
SAMPLING SITES
NORTHERN LIMESTONE,
JENOLAN

the method of calculation are shown in Appendix I. A Fortran IV programme was written by M. Handel for these calculations.

One of the derived parameters is P_{CO_2} (partial pressure of carbon dioxide); this is related to the proportions of free surface and phreatic flow, the presence and character of pollutants and soil cover. SIc and SId are the degree of saturation of the groundwater with respect to calcite and dolomite and these parameters relate to the type of source rock, source area and the residence time of the underground water in the karst rock. The reliability of these derived thermochemical parameters is often questioned. The major problem is that the derived parameters are very sensitive to fluctuations in pH and so a highly accurate and precise pH is required for field measurements.

Another method for obtaining one of these parameters, the saturation of the waters with respect to calcite, is an experimental one (Stenner, 1969, Stenner, 1970 and Picknett, 1972). In this method two samples are taken from each site, one of which has added to it a small quantity of Analar calcium carbonate. The added calcium carbonate is brought into equilibrium, keeping the sample at the temperature of the cave water, and then both samples are analysed for their calcium and magnesium content. Practical difficulties in the cave make the latter method very difficult. The water chemical survey at Jenolan involved much sampling at difficult-to-reach cave sites. For example, the difference between duplicate samples is often ±2 ppm of Ca^{2+}, enough to invalidate results by this method. The safer and more informative method of complete chemical analysis checked by computing total ionic strength, with careful pH measurement in the field was chosen for the study of the Jenolan groundwaters.

TABLE 1. FIELD pH AND TEMPERATURE DATA FOR WATER SAMPLING SITES.

Site	Location	pH	T(°C)
1.	Jenolan River: at point where the water sinks	7.05	11.8
2.	Watersend Cave: small pool just inside entrance (10m from site 1).	7.08	11.4
3.	Rowe Creek: water sinks on reaching the dry Jenolan River.	7.09	11.5
4.	Wiburds Lake Cave: at point where the stream enters the full lake.	7.10	12.8
5.	J67 Doline: full of water and algae at time of sampling, usually dry.	7.10	13.3
6.	Hennings Creek: point at which water sinks on reaching dry Jenolan River.	7.02	11.9
7.	Maiden Cave: lake inside cave.	7.09	13.0
8.	Twiddley-Om-Pom: most northern point of Central River inside Mammoth Cave.	6.7	12.2
9.	The Bypass: a flood passage of Central River which was flowing at the time.	7.01	12.3
10.	Waterfall Passage: a small stream in this passage, is a tributary of Central River.	6.9	13.2
11.	First Crossing: the first crossing of Central River.	6.7	12.5
12.	Central Lake: Downstream of first crossing and connected to it.	7.2	12.8
13.	Ice Pick Lake: this sample was not from the lake itself but from turbid waterfilled U-tube before it is reached.	6.92	12.3
14.	Grinning Monster Lake: a deep lake; part of the Lower River system.	6.98	13.2
15.	Lower River: upstream part of the Jenolan Underground River.	7.00	14.0
16.	Slug Lake: sample taken from a flooded passage before the true lake.	6.99	13.2
17.	Dillon's Creek: at sink just before dry Jenolan River.	7.02	10.7
18.	Playing Fields Creek: at sink just before dry Jenolan River.	7.08	12.0
19.	Imperial Cave: from the Jenolan Underground River.	7.01	13.0
20.	Resurgence: of Jenolan Underground River into Blue Lake.	7.00	13.5
21.	Blue Lake: influence of water from Northern and Southern Limestone as well as Surveyors Creek from the west.	7.62	13.0
22.	Drip: collected from the drip in 'dripping aven' in Mammoth Cave.	7.00	13.0

Methods

The twenty-two groundwater samples were collected from the sites shown in Table 1 and the diagram, on the weekend of the 10th April, 1976. The water levels in the caves at Jenolan were slightly higher than normal due to recent rain. However, no rain fell on the four previous days to or during the sampling programme. Temperature and pH, specific conductance and dissolved oxygen were measured at the sites (for instruments used see Appendix II). In the laboratory analyses were carried out for the follow-

Table II. Chemical analyses for Jenolan Groundwaters.

	Site	Concentrations in m molar (i.e. epm)														Ion Charge Balance	
		Ca^{2+}	Mg^{2+}	HCO_3^-	K^+	Na^+	SO_4^{2-}	SiO_2	Cl^-	NO_3^-	PO_4^{3-}	Fe^{3+}	Cu^{2+}	Zn^{2+}	Mn^{2+}	Anionic	Cationic
1.	Jenolan R.	0.12	0.09	0.54	0.18	.11	0.02	0.09	0.15	0.02	nd	5.8	1.2	.38	nd	.71	.71
2.	Watersend C.	0.18	0.09	0.69	0.17	.11	0.01	0.08	0.15	0.02	nd	5.8	2.0	1.91	nd	.84	.82
3.	Rowe Ck.	0.14	0.08	0.56	0.10	.14	0.01	0.11	0.15	0.02	nd	6.3	2.4	.96	nd	.71	.68
4.	Wiburds L.C.	0.27	0.09	0.88	0.15	.11	0.03	0.08	0.15	0.02	nd	7.1	1.6	.96	nd	1.07	.98
5.	J67 Doline	0.57	0.10	1.42	0.18	.14	0.03	0.08	0.15	0.23	nd	6.3	6.3	1.41	3.19	1.84	1.66
6.	Hennings Ck.	0.19	0.11	0.84	0.12	.18	0.01	0.13	0.15	0.02	nd	4.5	2.0	1.41	nd	.99	.90
7.	Maiden C.	1.12	0.09	2.42	0.12	.09	0.03	0.06	0.15	0.02	nd	5.1	4.3	2.79	nd	2.63	2.63
8.	T-O-P	0.74	0.14	1.80	0.12	.17	0.01	0.10	0.15	0.02	nd	2.7	2.8	1.83	nd	1.97	2.06
9.	The Bypass	0.71	0.13	1.76	0.15	.17	0.03	0.09	0.15	0.02	.008	5.4	3.9	3.06	nd	1.98	2.00
10.	The Waterfall P.	0.35	0.24	1.32	0.14	.24	0.03	0.11	0.15	0.02	.006	3.1	1.6	1.83	nd	1.60	1.56
11.	Central R.	0.68	0.12	1.67	0.20	.15	0.03	0.09	0.15	0.02	nd	6.5	2.8	2.37	nd	1.86	1.94
12.	Central L.	0.68	0.12	1.66	0.13	.15	0.04	0.08	0.15	0.02	nd	5.8	2.8	1.22	nd	1.93	1.88
13.	Ice Pick L.	0.66	0.13	1.65	0.17	.17	0.01	0.08	0.15	0.02	nd	4.0	2.0	1.41	nd	1.86	1.92
14.	Grin.Mon.L.	0.87	0.15	2.04	0.17	.17	0.04	0.08	0.15	0.02	nd	6.3	2.0	1.03	nd	2.31	2.38
15.	Lower R.	0.87	0.15	2.04	0.18	.15	0.04	0.08	0.15	0.02	nd	4.5	1.6	0.88	nd	2.31	2.37
16.	Slug L.	0.96	0.15	2.17	0.18	.14	0.04	0.08	0.15	0.02	.008	1.8	1.2	2.87	nd	2.46	2.54
17.	Dillons Ck.	0.49	0.27	1.10	0.15	.12	0.27	0.09	0.15	0.02	nd	3.6	1.2	2.41	nd	1.83	1.78
18.	Playing F.Ck.	0.67	0.41	1.75	0.15	.23	0.28	0.09	0.15	0.02	nd	5.1	1.2	0.88	nd	2.53	2.54
19.	Imperial C.	0.88	0.15	2.03	0.18	.15	0.04	0.08	0.15	0.02	nd	4.0	1.6	3.75	nd	2.28	2.39
20.	Resurgence	0.85	0.15	2.00	0.10	.14	0.04	0.08	0.15	0.02	nd	5.4	1.6	1.91	nd	2.25	2.24
21.	Blue L.	0.82	0.17	1.93	0.17	.14	0.06	0.06	0.15	0.02	nd	3.1	1.6	0.88	nd	2.24	2.29
22.	Drip	0.82	0.13	1.84	0.09	.09	0.02	0.04	0.15	0.02	nd	3.1	1.6	0.88	nd	2.07	2.08

nd = not detected

Fe^{3+}, Cu^{2+}, Zn^{2+}, Mn^{2+}: $\times 10^{-4}$

ing species: Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}, Cu^{2+}, Fe^{3+}, Zn^{2+}, Mn^{2+}, Ni^{2+}, Pb^{2+}, HCO_3^-, Cl^-, NO_3^-, PO_4^{3-}, SO_4^{2-}, and dissolved SiO_2. (The methods of chemical analysis are shown in Appendix III.)

TABLE III. DERIVED THERMOCHEMICAL DATA FOR JENOLAN GROUNDWATERS.

Site		$\frac{2(Ca^{2+} + Mg^{2+})}{(HCO_3^-)}$	$\frac{(Ca^{2+})}{(Mg^{2+})}$	$\log_{10} P_{CO_2}$	SI_c	SI_d
1.	Jenolan R.	0.78	1.3	-2.67	-2.55	-5.21
2.	Watersend C.	0.77	2.0	-2.60	-2.25	-4.80
3.	Rowe Ck.	0.79	1.8	-2.70	-2.44	-5.10
4.	Wiburds L.C.	0.82	3.0	-2.52	-1.97	-4.39
5.	J67 Doline	0.94	5.7	-2.34	-1.50	-3.71
6.	Hennings Ck.	0.71	1.7	-2.46	-2.21	-4.64
7.	Maiden C.	1.00	12.4	-2.12	-1.02	-3.11
8.	T-O-P	0.98	5.3	-1.84	-1.68	-4.07
9.	The Bypass	0.95	5.5	-2.16	-1.41	-3.53
10.	Waterfall P.	0.89	1.5	-2.16	-1.91	-3.95
11.	Central R.	0.95	5.7	-1.87	-1.75	-4.23
12.	Central L.	0.96	5.7	-2.37	-1.25	-3.23
13.	Ice Pick L.	0.95	5.1	-2.10	-1.54	-3.77
14.	Grin. Mon. L.	1.00	5.8	-2.07	-1.30	-3.32
15.	Lower R.	1.00	5.8	-2.09	-1.27	-3.26
16.	Slug L.	1.02	6.4	-2.06	-1.22	-3.21
17.	Dillons Ck.	1.38	1.8	-2.38	-1.76	-3.77
18.	Playing F. Ck.	1.23	1.6	-2.26	-1.40	-2.98
19.	Imperial C.	1.01	5.9	-2.11	-1.26	-3.26
20.	Resurgence	1.00	5.7	-2.10	-1.29	-3.30
21.	Blue L.	1.02	4.8	-2.73	-0.70	-2.05
22.	Drip	1.03	6.3	-2.13	-1.33	-3.43

RESULTS AND DISCUSSION

The chemical analyses for the groundwaters are shown in Table II and the derived thermochemical data in Table III. Some striking trends are observed in the raw data which appear to give more information than the derived parameters.

In general the thermochemical data show the following. There is only a slight increase in the P_{CO_2} of the cave waters, compared with surface flow. A greater increase was expected (Langmuir, 1971). These values indicate that the waters have had ample opportunity to degas in the free surface streams found in the caves. The low values of SIc indicate that the cave waters are well below saturation and are consistent with the lack of deposited carbonates in the underground streamways of the Northern Limestone and with the absence of tufa deposits at the resurgence. Saturation indices with respect to dolomite (i.e. SId) are also low; again this would be expected as the limestone of the Jenolan area is low in magnesium (Chalker, 1970).

INPUT WATER TO THE JENOLAN UNDERGROUND RIVER

The Sinking Streams

There are two groups of sinking streams and they are quite distinct in their chemical characteristics. These are the creeks of the upper and eastern McKeowns Valley and the creeks that flow from the western side of the valley. The first group includes the Jenolan River and Rowe and Hennings Creeks and the second Playing Fields and Dillons Creek. All the input streams have low (Ca^{2+}/Mg^{2+}) ratios between 1.3 and 1.8 but the concentrations of Ca^{2+} and Mg^{2+} are much lower, by a factor of four, in the first group of creeks than the second. This is because the streams reflect the mineralogy of the rocks which they flow across before sinking into the limestone.

The Jenolan River and the eastern tributary creeks Rowe and Hennings Creeks have catchments on the Jenolan Beds, Bindook Porphyry and Terrace Creek Rhyolite. These rocks weather to produce potassium ions in solution. Playing Fields and Dillons Creek catchments are mainly on the Oberon Hill Chert, Jaunter Tuff and Kowmung Lutite. These latter rocks contain unstable silicate minerals which weather to produce magnesium ions in solution; also they contain significant quantities of pyrite and other iron sulphides. These weather to produce sulphuric acid which can react with the 1% calcite contained in the Jaunter Tuff, so maintaining the same Ca^{2+}/Mg^{2+} ratios as the other creeks but causing the higher concentrations. Playing Fields and Dillons Creeks are, as expected, high in Mg^{2+} and sulphate.

Groundwater from the Alluvial Flats

Groundwater from the alluvial flats could only be sampled at two sites. The first site is Watersend Cave which has water that has travelled a distance of only 10 m through the gravel from the sinking Jenolan River, and yet a significant increase in calcium and bicarbonate concentrations is observed. The second site is the J67 doline which is located away from the Jenolan River.

This doline was half full of water at the time of sampling indicating the high rest level of the water in the alluvial flats. The concentrations of calcium and bicarbonate are again higher than those for the sinking streams. It is evident that the storage water in the alluvial flats can accumulate calcium and bicarbonate, because of its long residence time and the extra limestone available as clasts in the alluvium for solution, while percolating on its route to the cave streams. The J67 doline also contains unusually high concentrations of nitrate, copper and manganese. The nitrate source is probably the bacteria and algae in the pool. Olive green algae can be seen suspended in the stagnant waters. The copper may be a weathering product of the boulders of Bindook Porphyry found in the flat around the doline. This rock contains small quantities of chalcopyrite (CuFeS) which breaks down to produce copper ions.

The Stream in Waterfall Passage

The stream in Waterfall Passage is considered to be an underground counterpart of the lateral surface creeks. The chemical features that distinguish it from the surface creeks are its slightly higher concentrations of calcium, magnesium and bicarbonate; this would be expected of an underground stream which has been in contact with the limestone for a greater length of time than its surface counterpart. The water that feeds the stream does not appear from a single source but is derived from a multiple of tiny waterfalls discharging from cracks in the limestone/argillite contact. No active fluvial features have been noticed on the surface above this section of Mammoth Cave. This example of subsurface drainage is probably not unique.

Cave Lakes

Other sources of input water into the Jenolan Underground River are the lakes in Wiburds Lake Cave and Maiden Cave. The water sample taken from Wiburds Lake Cave is relatively low in calcium and bicarbonate for underground water. The route of the water from it to the Jenolan Underground River must be very restricted because the water that the cave receives in wet periods from J56 and J58 caves remains in the lake for months. So this water has ample time and limestone for its calcium and bicarbonate concentrations to increase before it reaches the Jenolan Underground River.

The lake in Maiden Cave is perched 5 m above the dry Jenolan River bed only 40 m away (Campbell, 1976). This lake at the time of sampling had the highest calcium and bicarbonate values recorded. Unlike Wiburds Lake the floor of the cave is bedrock, not silt, hence the limestone is readily available for solution. There are no features in Maiden Cave to suggest that water flows into the lake, it appears to well up from the lake's bottom. If the water has to percolate through alluvium then high ionic concentrations and slow drainage times are to be expected. It is believed that Wiburds Lake and Maiden Cave drain to the Jenolan Underground River.

Drips

The drip sample obtained was not from a speleothem as there are few calcite deposits in Mammoth Cave. It was obtained from an unseen source high in the roof of a cavern. It has a chemistry that was similar to that of the Jenolan Underground River.

CENTRAL RIVER

Central River (sites 8, 9, 11, 12 and 13) has bicarbonate concentrations decreasing from 1.80 epm at Twiddley-Om-Pom to 1.65 epm at Ice Pick Lake. This dilution effect is also evident in the calcium and magnesium values and has previously been noted by Halbert and Michie (1973). Since Central River is neither saturated with respect to calcite or dolomite (Table IV) precipitation cannot be taking place. An alternative explanation for the dilution effect is that Central River is fed by many small streams similar to the one found in Waterfall Passage. The limestone/argillite contact (the eastern boundary) is visible in Twiddley-Om-Pom and Waterfall Passage indicating that Central River may derive some of its water from this contact.

In addition some of the water in Central River comes from the Hennings Creek sink in the gravel deposits at the south east of Rowe Flat.

THE JENOLAN UNDERGROUND RIVER

Although the Jenolan Underground River flows for several kilometres, changes in the chemical nature are minimal (see Table II). The distinguishing features of the Jenolan Underground River are its relatively high concentrations of calcite and bicarbonate for groundwater at the date of sampling in the Jenolan area and hence a relatively high SIc value for its entire observable length. The river is large in volume, fast flowing and has a non-calcareous gravel bed, thus reducing interaction with the limestone after the water has reached it. The closer a cave river becomes to saturation the slower it will take up limestone and the flow through time is sufficiently fast to overcome this kinetic effect. The relatively high calcium and bicarbonate contents must have been acquired under different conditions to those found in the free surface underground stream. When the Jenolan Underground River reappears on the surface at Blue Lake its chemistry changes, Blue Lake has high saturation indices. It is unlikely that the water from the Southern Limestone which also flows into Blue Lake causes this.

THE DRAINAGE PATTERN

The chemistry of the Jenolan Underground River may throw some light on its source. The steady flow of the river, even through dry periods is convincing evidence that it is fed largely by storage water from the alluvial flats primarily in Rowe flat in the absence of large limestone areas above the upstream site on this river (Shannon, 1976). The high calcium and bicarbonate values are in agreement with this postulation. There is reason to believe that there is some underground water coming from further upstream than the main sink of the Jenolan River. A model for the source of the Jenolan Underground River is one where a small flow of water originates from the Far Northern Limestone and to this conduit is added the water of Wiburds Lake Cave and Maiden Cave.

TABLE IV. THE CAVE RIVERS AND ASSOCIATED LAKES.

Site	(HCO_3^-)	$\frac{(Ca^{2+})}{(HCO_3^-)}$	$\frac{2(Ca^{2+} + Mg^{2+})}{(HCO_3^-)}$
Central River			
8. T-O-P	1.80	.41	0.98
9. The Bypass	1.76	.40	0.95
11. Central R.	1.67	.41	0.95
12. Central L.	1.66	.41	0.96
13. Ice Pick L.	1.65	.40	0.95
Mean	1.71 (S.D. 0.07)	.41 (S.D. 0.01)	
Jenolan Underground River			
14. Grin. Mon. L.	2.04	0.43	1.00
15. Lower R.	2.04	0.43	1.00
16. Slug L.	2.17	0.44	1.02
19. Imperial C.	2.03	0.43	1.01
20. Resurgence	2.00	0.43	1.00
Mean	2.06 (S.D. 0.07)	0.43 (S.D. 0.00)	

The popular hypothesis that Central River is a braid of the Jenolan Underground River seems unlikely because the two rivers have a distinctly different chemical composition (Table IV). Using the Wilcoxson's sum of ranks test for each of the three groups of data, there is at least 99% assurance that the Central River values are of a different population to those of the Jenolan Underground River. Thus the alternate hypothesis that Central River is a tributary of the Jenolan Underground River and joins it somewhere between Mammoth Cave and Imperial Cave seems to be the correct one.

CONCLUSION

The chemistry of the groundwater of the Northern Limestone is surprisingly consistent with observation and previous knowledge of its route before sampling. This investigation has endorsed some of the hydrology postulates and left others in greater doubt. To obtain a complete picture of the underground drainage further chemical investigations of the same magnitude and at different stages of flow are required.

ACKNOWLEDGEMENTS

Permission to collect water samples from Jenolan Caves was kindly granted by the Department of Tourism and the Jenolan Caves Management. The cavers of Sydney University Speleological Society and Sydney Speleological Society are to be thanked for their hard work in difficult conditions transporting samples and instruments to and from the sampling sites. Ms Helen Phillp is sincerely thanked for the silica and trace metal analyses. Prof. H.C. Freeman and the staff of the Inorganic Chemistry Department for allowing this project to be presented as part of M. Handel's third year practical assessment. Finally Geoff Franciz who has made the geological contributions to the text and together with Joe Jennings has read it critically and commented constructively.

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APPENDIX I

CHEMICAL THEORY AND METHOD OF CALCULATION

The following equilibria must be considered in the solution chemistry of calcium and magnesium carbonates and in calculations of SIc, SId and P_{CO_2}.

$$H_2O = H^+ + OH^-$$
$$CO_2 \text{ (solution)} + H_2O = H_2CO_3$$
$$H_2CO_3 = H^+ + HCO_3^-$$
$$HCO_3 = H^+ + CO_3^{2-}$$
$$CaCO_3 = Ca^{2+} + CO_3^{2-}$$
$$MgCO_3 = Mg^{2+} + CO_3^{2-}$$

Saturation Index with respect to calcite = SIc = $\log((Ca^{2+})(CO_3^{2-})/Kc)$. Saturation Index with respect to dolomite = SId = $\log((Ca^{2+})(Mg^{2+})(CO_3^{2-})^2/Kd)$. When SIc or SId equal zero then the ground water is saturated with respect to the carbonate in question.

Partial pressure of $CO_2 = (H_2CO_3)/K_{CO_2} = P_{CO_2}$.

The equilibrium constants used in the calculations are expressed as negative logarithms. The data are derived from Langmuir 1971 p.120 and are valid in the temperature range 10-15°C.

$$pK_{CO_2} = -\log_{10}((H_2CO_3)/P_{CO_2}) = 1.13 + 0.014T$$

$$pK_1 = -\log_{10}((H^+)(HCO_3^-)/(H_2CO_3)) = 6.54 - 0.008T$$

$$pK_2 = -\log_{10}((H^+)(CO_3^{2-})/(HCO_3^-)) = 10.61 - 0.012T$$

$$pKc = -\log_{10}((Ca^{2+})(CO_3^{2-})) = 8.34 - 0.002T$$

$$pKd = -\log_{10}((Ca^{2+})(Mg^{2+})(CO_3^{2-})^2) = 16.55 + 0.016T$$

The brackets denote activities of the ions.

Ion activities are calculated from the definition $\alpha_i = \gamma_i m_i$ where α_i, γ_i and m_i are the activity, the activity coefficient and molarity of the species i respectively.

The ion activity coefficients are computed from ionic strength (I) using the Debye-Huckel equation (Garrels and Christ, 1965).

The calculations for each water sampling site are as follows:

(1) Ionic strength = $I = \frac{1}{2}\Sigma m_i z_i^2$,
where m_i is molarity and z_i is valence of ionic species i.

(2) Calculate activity coefficient, γ_i, for Ca^{2+}, Mg^{2+}, HCO_3^-

$$\log_{10}\gamma_i = \frac{-0.4970 \times z_i^2\sqrt{I}}{1 + 0.3259 \times 10^8 \times d_i\sqrt{I}}$$

where $d(Ca^{2+}) = 6 \times 10^{-8}$ cm
$d(Mg^{2+}) = 8 \times 10^{-8}$ cm
$d(HCO_3^{2-}) = 4.25 \times 10^{-8}$ cm

(3) Calculate activities for Ca^+, Mg^+ and HCO^- where $\alpha_i = \gamma_i m_i$.

(4) Determine values of K_{CO_2}, K_1, K_2, Kc and Kd as defined above for the temperature (T) of the water sampled.

(5) Calculate P_{CO_2}, SIc, SId.

$$P_{CO_2} = (H_2CO_3)/K_{CO_2}$$

$$= \frac{(10^{-pH})(HCO_3^-)}{K_1 K_{CO_2}}$$

$$SIc = \log_{10}((Ca^{2+})(CO_3^{2-})/Kc)$$

$$= \log_{10}((Ca^{2+})(HCO_3^-)K_2.10^{+pH}/Kc)$$

$$SId = \log_{10}((Ca^{2+})(Mg^{2+})(CO_3^{2-})^2/Kd)$$

$$= \log_{10}((Ca^{2+})(Mg^{2+})(HCO_3^-)^2 K_2^2 10^2 \times {}^{pH}/Kd)$$

APPENDIX II

pH was measured after electrodes and meter were calibrated in nominal pH 4 to 6.8 using buffers brought to within ± 1°C of ground water temperature. Measurements were made with a Pye Unicam 293 battery powered millivolt pH meter and combined Philips field pH electrode no. C21D.

Temperature was measured using a mercury in glass thermometer.

APPENDIX III

Calcium and Magnesium were determined as follows:-

Total calcium + magnesium was titrated with 0.01M EDTA using Erichrome Black T as indicator (Vogel 1968, p.436-7).

Calcium determined by titrating with 0.01M EDTA using Erichrome Blue-Black R as indicator. Magnesium was determined by subtracting calcium from the total calcium + magnesium (Vogel 1968, p.439-441).

Copper, Iron, Zinc, Manganese, Nickel and Lead were determined by Atomic Absorption Spectroscopy using a Varian Techtron AA6 Spectrophotometer. All samples were firstly concentrated 40 times by use of a Buchi rotary evaporator, and acidified to 0.25M HCl.

Sodium was determined by Emmision Spectroscopy using a Varian Techtron AA6 Spectrophotometer.

Potassium was determined by Atomic Absorption Spectroscopy using a Varian Techtron AA6 Spectrophotometer.

Bicarbonate was determined within 24 hours of sampling, by titration against standard 0.01M HCl to the inflexion point (between pH 4.1 and 4.5) using a Radiometer pH meter 28 and a Philips combined pH electrode no. C21D (Barnes, 1964).

pH was determined by use of a Radiometer pH meter model 28 using a Philips combined ph electrode no. C21D.

Chloride was determined by direct titration with 0.01M $AgNO_3$ (silver nitrate) using K_2CrO_4 (potassium chromate) as indicator. The AgCl (silver chloride) is quantitatively precipitated before red silver chromate is formed (Taras et al 1971, p.96-97).

Nitrate was determined by reduction with hydrazine allowing colorimetric determination with Griess reagent (Kodama 1963, p.464).

Sulphate was determined by turbidermetric method using a Unicam SP600 Spectrophotometer (Taras et al 1971, p.334-5).

Silica was converted to molylibdosilisic acid followed by colorimetric analysis using a Unicam SP600 (Taras et al, p.303-5).

PROTECTION OF TASMANIAN CAVE FAUNA

On the 27th of April 1976, several Tasmanian cave species were proclaimed as protected. A wildlife ammendment regulation under the National Parks and Wildlife Act 1970 (Statutary Rule No. 88 of 1976) added the species to the totally protected list. The species involved were:

Beetles Idacarabus, Goedetrechus mendumae, Goedetrechus parallelus, Tasmanotrechus cockerilli;

Cave Crickets Micropathus, Cavernotettix, Parvotettix;

Glow-worms Arachnocampa tasmaniensis;

Harvestmen Monoxyomma, Lomanella;

Pseudoscorpions Pseudotyrannochthonius typhus, Pseudotyrannochthonius tasmanicus.

There are several implications:

(i) to collect cave fauna from State Reserves, the collector requires authority from the Minister administering the National Parks and Wildlife Act (this was also needed before the ammendment),

(ii) to collect cave fauna from Conservation Areas, the collector requires permission of the managing authority, usually the National Parks and Wildlife Service. (Again, this was needed before the ammendment),

(iii) to collect the fauna specified in the ammendment from areas outside reserved land authority is needed from the Director of the National Parks and Wildlife Service. This is the main change and will allow control over unwise or unnecessary collecting.

Application for written permits should be directed to:

The Director,
National Parks and Wildlife Service,
P.O. Box 210,
Sandy Bay,
Tasmania. 7005

Andrew Skinner

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