TROPICON

IN AUSTRALIA'S BICENTENARY YEAR

PRE PRINTS OF PAPERS

TO BE PRESENTED AT
TINAROO FALLS
FAR NORTH QUEENSLAND

27th to 31st December 1988.

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LAKE TINAROO

FAR NORTH QUEENSLAND.

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Les Pearson,
Publisher.

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SPEECHES

APPROXIMATE TRANSCRIPT OF THE OPENING ADDRESS TO TROPICON

Paul Wilson.

When Les Pearson telephoned me asking me to be the opening speaker at the 1988 Caving Conference I was both flattered and honoured. The invitation was quite unexpected. It has given me the opportunity to return to the north, albeit briefly, and to renew very dear friendships.

In opening the conference let me, as a certified Queenslander, extend a warm Australian welcome to our overseas guests and an enthusiastic welcome to Queensland to our interstate visitors. To those, like myself, from elsewhere in the State, "glad you could make it - isn't it a relief to get away from Expo City", and to the locals, "it's great to be back in your lovely part of the world".

As I wasn't sure what the theme of my talk should be Les suggested that the early days of the Chillagoe Caving Club would be an appropriate topic, and so it is. If my account is a personal view I hope I shall be forgiven, as there are many stories other than mine. In a sense the club was in existence before I ever arrived in Chillagoe as there has been regular local caving activity since 1890. For me, arriving in Chillagoe in December 1972 to begin work as a labourer for the Forestry Department was the end of an overland trek from England. I never thought that I would stay for nearly four years.

Pat Kinnear used to talk about "the cavers from Cairns" and I met many of them when Alan Cummins, Tom Robinson and Les Pearson, arrived in town with a mob of Venturer Scouts. I was only the catalyst, as I had been on caving club committees in the U.K. and knew what needed to be done. We quickly started talking about the possibilities, with the younger local cavers supplying enthusiasm, and the Kinnears adding wisdom and respectability.

The original philosophy, which appears to have endured, was to keep the bureaucracy to a minimum, make the paperwork as efficient as possible, keep the annual subscription low and get on with the caving. We organized a public meeting in the Chillagoe Hall, formed the club, chose a nice simple name, elected Vince Kinnear as President, myself as Secretary/Treasurer and went caving.

The years 1973 and 1974 were the most formative. We bought some ladders and nylon rope and taught most of the members the basics of tackling pitches and proper belaying. We taught ourselves surveying and mapping and embarked on a programme of identifying and tagging all the known caves. This project, which was to take a further two years, was a legacy of the 1968 visit to Chillagoe of the Sydney Speleological Society. The SSS had left behind a map, with all the "known" caves on it, and a large bunch of orphan aluminium cave tags.

The tagging project developed into the current register of caves at Chillagoe and the Mitchell-Palmer, which has been so magnificently prepared by the club under the umbrella of the Queensland National Parks and Wildlife Service.

In those early days we enjoyed very many amusing incidents of which one of the most funny was the day we learnt the art of digging. Having mapped much of the Queenslander we knew that there was more to be found in the area, and we were starting to map Cathedral Cave. Having done much digging in Yorkshire and South Wales, silted up phreatic tubes were just my thing and I started to dig into a likely one. Ralph Page thought this was highly amusing, and sat and passed appropriate cynical comment - until I got a strong draught - in fact a wind. Then Ralph and a few others joined in - until Ralph became stuck in the hole.

Came a distant muffled voice, "What do I do now?"

"Take off your helmet", was the reply. This was accompanied by gestures to the others and to Ralph's ankles. "Now dig the helmet into the soil in front of your face". "Grip the helmet tightly", and with that, we pulled Ralph's ankles bringing him and half the tunnel with him. When we saw Ralph's face and the state of his helmet everyone collapsed in a heap. Within half an hour we were standing in the Queenslander.

One of the most interesting systems at Chillagoe is Christmas Pot, and an exchange through trip on SRT is thoroughly recommended. The cave is unusual for Chillagoe because all entrances are vertical and it had an undived sump at the end.

One September day Vince stopped the Forestry Landrover next to what is now called Suicide (after Suicide Bend in the Mungana road - now removed). Graeme Hawkins and I groveled around in a four layer wedding cake type of a thing at the west side of the bluff until Vince headed off for the top of the bluff, and we followed. Vince sat down on the peak of the bluff while we wandered around until we found a large black rift with a cold wind coming out of it. "Jeepers, Vince, come and look at this!", but the smile on Vince's face indicated he knew the cave was there all the time.

The Christmas visit of The Cavers generated much interest and so we set off with our new ladders, ropes and the borrowed Forestry ladders. By the rift there was considerable debate as to the depth of the hole, and eventually we clipped on 3 25 foot sections and I elected to go down first. The rift opened into a roomy vertical cavern that just swallowed my light, and the ladder had an ominous swing to it. At about 40 feet down it was clear that the ladder was nowhere near the bottom. Back to the top and on went our last section. This time Ricky Hipworth had a turn and made it to the ledge at about 100 feet down. The bottom of the rift turned out to be another ladder length down but we climbed it on a hand line. That was probably the best day's caving any of us had in the early days, but it was another year before Suicide had yielded most of its secrets.

If there was a point at which The Chillagoe Caving Club became respectable it was at the 1974 ASF conference at The University of Queensland. There were two Chillagoe delegates, Tom Robinson and myself, and we managed to persuade many other delegates to pay us a visit. The club benefited enormously from the contacts we made, and has gone from strength to strength.

I should like to finish with a change of mood, by paying my respects to two people who ought to be here, and are sadly missed. Pat Kinnear was a fount of wisdom in Chillagoe and was popular with all the visiting cavers. A visitor in January 1975 on his first trip to Chillagoe was Joe Jennings, and the visit altered his perception of tropical karst, but not so much as it altered mine. Joe quickly became known in the top pub as 'The Professor', and he was accompanied by one of his students, Joyce Lundberg. We spent a week exploring and in animated discussion about the formation of the caves, a discussion which continued through correspondence and papers.

Caving in the far north is different, exciting, and great fun. I am sure that this conference and the subsequent field trips will live up to the expectations of all the visitors. Welcome to everybody, and good caving.

Paul Wilson,
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THE JENOLAN CAVE SYSTEM SURVEYING PROJECT.

PART 2 - TECHNIQUES AND COMPUTING.

Mark H. Bonwick, Russell Q. Bridge, Chris D. Dunne, Julia M. James, David J. Martin and Greg M. Tunnock.

ABSTRACT

The range of techniques used to survey The Jenolan Cave System are presented. The methods of data reduction, plotting and graphics are included. The way in which the plans and sections are going to be produced for publication and used is announced. The methods used for checking accuracy are described.

INTRODUCTION

The Jenolan Cave System Surveying Project - Part 1 (James et al., 1988) contained the history, organisation and an assessment of The Jenolan Cave System Surveying Project. This paper discusses the technical aspects of the survey and presents the methods and instruments used and the computer techniques used to reduce the field data and produce a traverse plot.

INSTRUMENTS AND METHODS

Survey datum

The survey datum point is a surveyors drill hole and wings on top of Camp Rock in the Grand Arch. This station (G0001) was given arbitrary coordinates of E 3000.0, N 7000.0 and Ht 800.0. At a later stage it is planned to tie this point into the National Grid. Both the surface and underground surveys have this datum. A magnetic bearing of 75 degrees between surface survey points G0001 and D0001 (bolthead in roof of pumphouse) provides the baseline for the bearings of the theodolite surveys.

Instruments

A wide range of surveying instruments have been used as different sections of the caves have been surveyed to appropriate standards. The main tourist paths and the surface have been surveyed at the highest possible standard. At the other end of the scale the survey of areas which it has not been possible to enter because of delicate decoration can only be estimated.

Theodolites

Most of the main tourist paths have been surveyed by theodolite with electronic distance measuring (EDM). Included angle techniques are necessary in these areas due to magnetic interference from metallic handrails, wire mesh and power cables.

Sokkisha Set 3 - Most of the underground theodolite work was carried out with a Sokkisha Set 3 (School of Civil and Mining Engineering, University of Sydney) with an SDR2 Electronic Field Book, essentially a data logger/computer. This instrument has infra-red electronic distance measurement (EDM) and a resolution of 1 mm for distance and 1 second for angles. In terms of accuracy, the standard deviation is +/- (5 mm+3 ppm) for distance measurement and +/- 4 seconds for angles.

Nikon NTD-3 - This did not have the data logger/ computer and therefore was not as convenient for the sketcher. This instrument was used for the Jubilee-Imperial main traverse and for the surface survey. It has the same precision and accuracy as the above Sokkisha Set 3. Angles were manually reduced.

Civil Eng. 'ancient theodolite' (Cooke, Troughton & Simms V 208) - This instrument was used for the wire sections of the Righthand branch of the Jubilee cave. This instrument has a resolution of 1 minute. However, in restricted passages the lighter, more mobile forestry compasses are much easier to use. Angles were manually reduced.

Underground theodolite survey team - A party would comprise;

- theodolite operator
- forward tripod operator
- rear tripod operator
- data recorder
- passage detail and station cross section sketcher

Advantage of instant XYZ coordinates - The Sokkisha Set 3 computer calculates rectangular station coordinates as each leg is surveyed. These are recorded in the data logger's memory and also on booking sheets by the data recorder as a backup and for the sketcher who may be several stations behind the instruments. High grade sketches can then be made immediately to scale. Having rectangular coordinates available in the cave for plotting improves both the rate and quality of passage sketching. The other instruments can only produce angle and distance and the sketcher is required to mentally reduce this in order to scale the sketch.

Tripod placement - The rate determining step both in this and other theodolite surveying is usually the tripod placement. The function of the forward tripod operator is to set up the tripod at each new station, mark the survey station and measure the height of the prism above the station. Both tripod operators must light the prisms to allow instrument readings to be taken. When a set of readings at a station are complete the rear tripod operator passes his tripod to the forward tripod operator in a leap frogging system. Where party numbers were limited the rear tripod and data recording functions were combined. The data recorder also records passage left, right, up and down data at each station.

Occasional problems were encountered with the tripods in narrow or low passages. These were usually solved by innovative tripod placements. In at least one instance a low section was surveyed by placing a tribrach directly on the passage floor. In narrow cave passages it was not unusual for a tripod to block access and passages where this was likely to occur were surveyed at times when there were no tours. Tourists occasionally had to climb around tripods.

Theodolite stations - All theodolite stations were permanantly marked. This was necessary to allow a survey to be continued at a later date and so that tripods could be reset if accidently bumped. In the cave on the northern side of the system these were usually drill holes in the concrete paths. In the Southern caves masonry nails were driven into the concrete or rock. The nails were found to be much easier to relocate as some drill holes tended to fill up with dirt or muddy water and disappear, whilst others proved virtually indistinguishable from drip holes in the path.

Markers from old surveys, particularly the survey through Lucas, Orient and Baal for the Binoomea Cut, were used when convenient. Even if the old survey marks were not convenient for a main traverse station they were usually surveyed in by a radiation for reference.

Surface Survey - An important difference of the surface survey from the underground survey was the use of triangulation (and trilateration - measuring distances). In contrast, the underground survey, including the underground theodolite survey was almost entirely traversing, i.e. progression from station to station one leg at a time.

Because of the relatively long survey legs involved in the surface survey (up to 850m), it was desirable to establish a network of stations where the connecting legs form a series of braced figures. To illustrate: a rectangular figure where the diagonals have also been measured, is a stronger figure, mathematically, than one where only the sides have been measured. Thus, from a given station readings might be made to two or three or even four other stations.

Again because of the longer length of most of the surface survey legs, the placement of tripods often involved a circuitous walk between stations (up to three times the line of sight distance) and, in general, readings could not be taken till all tripods were in place. Rather than leave the booker and reader idle and then, in turn, tripod operators for long periods, it was common to use a survey team of only two or three people.

Surface survey stations, where they are on rock, have been marked with a drill hole and wings; otherwise a surveyor's peg has been placed. Two-way radios were an advantage when working on some of the longer survey legs.

The present northern and southern extremes of the surface survey are, respectively: the Spider Cave entrance tag and station S0005 opposite the entrance to Binoomea Cut. Station S0006, on top of Lucas Rocks is 150m above Camp Rock (the survey datum point) and is the second highest station. Another, slightly higher station is nearly a kilometre away to the north beside the Six Foot Track on the edge of Binoomea Ridge.

Surface theodolite survey team - A party would comprise;

- instrument operator
- data recorder (booker)
- tripod operator

Depending upon the placement of some surface survey stations, a tripod "minder" was more often necessary than an operator. For example, station S0014 on the roadway on de Burgh's Bridge near the Grand Arch needed a "minder" to keep vehicles from demolishing the tripod.

Forestry Compass

Ushikata forestry compasses were used in many of the narrow tourist sections where magnetic interference was a problem. These instruments were made available to the Project by Keith Oliver and Hills Speleological Society. They are a tripod mounted instrument with a compass, inclinometer and a telescopic sight and are used to conduct included angle surveys. These were usually read to a precision of 0.5 degree. Distance measurement was by fibreglass tape read to the nearest 0.05 m. Forward and backward sights were taken to specific levels on wooden sticks with tape measures glued to them (a staff in surveyors parlance). Stadia techniques were not used. Survey stations were marked with drill holes.

Forestry compass survey team - A party would comprise;

- compass operator
- forward staff and tape operator
- rear staff operator
- data recorder
- passage floor detail and station cross section sketcher

Where party numbers were limited the data recording function was combined with either the sketching or rear staff operation. Passage detail was normally sketched by neglecting the magnetic anomalies and using forward bearings as true bearings. This obviated the need to calculate included angles in the cave but resulted in some less than correct sketches.

Calibration - These instruments were not calibrated. Calibration of the inclinometer is not warranted as the reading at each station is dependent upon the accuracy to which the instrument is levelled (usually achieved by a spirit level attached to the instrument).

Tape, Compass and Clinometer

Most side passages were surveyed using conventional tape, compass and clinometer surveys. Suunto instruments, KB-14 compass and PM-5 clinometer, and fibreglass tape were almost invariably used. These were read to the nearest 0.5 degree and 0.05 m respectively.

Suunto survey team - A party would comprise;
- instrument reader
- tape operator
- data recorder and passage floor detail and cross section sketcher

Surveys were usually conducted as a series of forward sights. Where a survey started in an area where magnetic interference was possible backsights were often taken to the tie in point to keep the compass as far from the interference as possible. On several occasions these instruments were used for included angle surveys.

Survey stations were not usually marked unless a junction or point to be continued from at a later date required marking. Plastic track marking tape held in place with a rock or tied to a suitable feature was the most commonly used method. Marking pens were used to write the station label on the tape.

Calibration - Compasses were calibrated by having two people sight each compass between two points in the upper car park at Jenolan. This data was used to determine a mean bearing, deviation from mean for each compass and standard deviation. Two compasses out of eleven had a deviation from the mean in excess of the standard deviation. A new mean was calculated with these two compasses excluded from the data set. The resulting standard deviation was 0.5 degrees. Calibration constants for each compass were determined using this mean. The compass with the worst error (-2 degrees) was withdrawn from service. Clinometers were calibrated by setting each one on a flat plate and having two people take a sight. The clinometer was then turned through 180 degrees and the sights repeated. Calibration constants for each instrument were determined from this data.

Thread Measurement Devices

Most of the Imperial Riverway and some side passages were surveyed using topofils built by Al Warild. These instruments comprise a thread length counter, compass and clinometer mounted together as a single unit. A counter reading is recorded at each survey station as cotton thread is spooled out between the stations. The length of the survey leg is calculated by taking the difference in counter readings.

Topofil Survey Team - A party would comprise;
- topofil operator
- data recorder and passage floor detail and cross section sketcher

Surveys were typically conducted as a series of backsights and all thread was removed. Survey stations were not normally marked.

Range Finders

In passages that could not be entered a 'Ranging 120' optical range finder was used to measure distance.

Underwater Surveying

Underwater surveys were carried out using a calibrated diving line, divers compasses and depth gauges.

Data Sheets

Tape, compass and topofil data was recorded on a standard form originally developed for the Muller '82 expedition. Special data sheets were designed for recording data from other instruments. A data header page was used to record the section of cave, date, surveyors and instruments.

COMPUTER DATA REDUCTION

Mainframe Computing - During 1987 the survey data was processed on a Unisys 1100 series mainframe computer. A Fortran program written by David Martin in 1982 to handle the Atea Kananda data was modified to accept Topofil and included angle survey data. Some traverse plots were produced on a 750 mm wide Calcomp drum plotter.

PC computing - At the start of the project consideration was given to using SMAPS Version 3 (Dotson, 1985). Whilst this integrated program provides a user friendly data entry and least squares loop closure facility it had several major disadvantages for this project: it did not support thread measurement or included angle data; it did not calculate coordinates for left, right up and down data; and did not support plotters. Whilst the data file structure used by this project is unique the coordinate calculation program could easily be modified to create

SMAPS compatible files. The data file structure was designed with this possibility in mind.

In December 1987 the survey data and Fortran data reduction program were transferred from the mainframe to an IBM AT personal computer. The program was extensively enhanced during the early part of 1988. Large plots are handled by transferring ASCII MS-DOS format plotting files to a Hewlett Packard CAD system (Figure 1). Checking plots at A4 and A3 may be generated on a HP7475A plotter using the Autocad computer aided drafting (CAD) package. A text editor (SPFPC) is used for entering and editing data.

Data from the Sokkisha SDR2 was initially processed using the 'SURVIS' survey information system (Foresight Systems and Datacom Group) consisting of seven modules. A Fortran program was written to convert files generated by this system to the format used on the IBM AT.

Traverse plotting - A plotting program was developed by Greg Tunnock on a Hewlett Packard CAD system comprising a HP9000 model 350 and HP7580 plotter capable of handling A1 sheets. Time on this computer system was provided by J.N. Almgren. Plots are normally generated at a scale of 1:200. Solid lines are used to represent the traverse lines and dotted lines represent the left and right or up and down data. The station label and a symbol may be drawn at each survey station.

On-site data entry - Data entry at Jenolan became possible in March 1988 with a Hewlett Packard HP75D micro computer which stores data in battery backed memory or on magnetic strips. It is later transferred to an MS-DOS format floppy disk for processing by the IBM AT. The software, developed by Mark Bonwick for the Chilchotla 87 Mexico expedition, features user friendly data entry and co-ordinate calculation modules for both tape, compass and topofil data. A Think Jet printer provides hard copy output to facilitate proof reading and field plotting.

Contour plots - Contour plots of the major chambers Grand Arch, Devils Coach House, Carlotta Arch and the Exhibition Chamber will be produced using the SURVIS system.

Computer graphics - When the data gathering and reduction is complete it is proposed to produce three dimensional graphic models of the system using software developed by Keir Vaughan-Taylor.

Traverse Closure

Where a loop contains both high accuracy theodolite data and lower accuracy magnetic data the closure is usually on the basis that the adjustment is restricted to the magnetic survey legs. This is justified as closure errors in loops surveyed entirely with the Sokkisha equipment are typically less than 50 mm. The high grade theodolite survey effectively constrains the coordinates of many junctions in what is quite a complex network. The closure problem is then reduced to a number of fairly small simple networks. Closed junction coordinates for these networks are determined using methods similar to those given by Irwin and Stenner (1975). More sophisticated treatment of the misclosures, such as least squares adjustment, is unlikely to improve the final product as most misclosures are small.

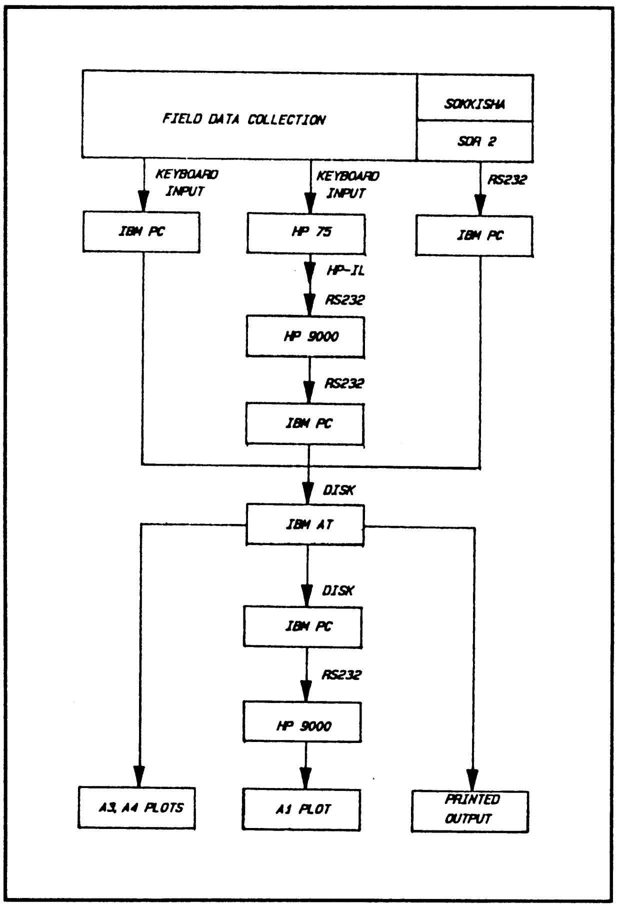

Figure 1 - Flow Chart for Computer Applications.

CHECKING SURVEYS

Radio Direction Finding

RDF is being used by Mark Bonwick and Ron Allum to locate on the surface the extremities of passages which have not been surveyed by theodolite traverse; surface points are then located by surface theodolite traverse.

Cave to surface RDF has been attempted for the following locations; Red Cave, Alabaster Hall, Water Cavern sump, Victoria Bower and Imperial Riverway Sump 7. The initial attempt at locating Victoria Bower resulted in a 43 m horizontal discrepancy. The surveys indicated that the vertical separation between the surface and underground points was about 1 m. With this small separation the point located was in fact a false null. This exercise was repeated and the results are still being evaluated.

Cave to cave RDF has been used for the following; Water Cavern to Sump 4 and Imperial Riverway to Spider. The misclose between the Sump 4 RDF fix and the surveyed coordinates is 3.1 m. The accuracy of the Spider - Imperial RDF fix cannot be established until the connection is surveyed.

Loop Closure

Other checks on survey accuracy are provided by loop misclures. All loops surveyed entirely with theodolites have closure errors less than 100 mm. Some sections of survey with other instruments have been resurveyed where an unacceptable misclose has been encountered. Unacceptable misclures have resulted from; tie-in station labels incorrectly booked, forestry compass bearing booking errors, and magnetic interference.

Sketch checking

Sketches are drawn to scale and then taken into the cave for checking and improving.

PRESENTATION OF RESULTS

From the computer data it will be possible to generate the depth of the cave, the traverse length of the cave system, the plan length for the cave system, an approximate volume; a new figure for an Australian cave.

The plan of the known system will fit on a sheet 800 mm x 600 mm at a scale of 1:2000. This will be published as a line drawing which also shows surface features. The plan will be drawn at 1:500 for development, tourist and exploration information and published as two sheets. Plans with passage cross sections at 1:200, detailed contour maps of all the major chambers and their features at 1:200 and a 1:500 projected section (North - South) are planned for scientific studies.

The survey data is sufficiently complete for it to be used for three dimensional computer graphics representation and possibly for the preparation of a model.

It is hoped to publish the survey as a book complete with descriptions of the cave, photographs and artists sketches.

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THE FAUNA CONSERVATION ACT AND SWIFLET PROTECTION IN QUEENSLAND.

David R. Flett and Michael Godwin.

ABSTRACT

Northern white-rumped swifltets are birds native to Australia, South East Asia and Western Pacific which roost and breed in caves. Classified as protected fauna under the Queensland Governments Fauna Act, all birds are protected both on and off National parks. Disturbance of birds by the casual visitor, mostly cavers, and by researchers has the potential to permanently disrupt colonies. Research into the birds biology is essential for management of colonies. Chillagoe National Parks and Wildlife field staff are monitoring all visits to Swiftlet colonies to determine the degree of disturbance.

The authors are devising guidelines for future visitors to follow when visiting a Swiftlet colony.

SWIFTLETS

The Northern white-rumped swiftlet, previously called the Grey swiftlet, occurs in a coastal belt extending from the tip of Cape York Peninsula to the Tropic of Capricorn. (Readers Digest 1983). The birds are fast flying, insect eaters which breed only in dark caves. They have an echo-location system - a system of "clicks" - which have only been recorded from birds in caves. The Australian birds occur solely in Queensland. The birds breed in caves and lay eggs in shallow scallop shaped nets made of sticks and saliva. The presence of a "narrow pale grey band on the rump appears dirty white in flight," gives the bird its name (Readers Digest 1983). Breeding is centered on the summer months and may extend over an eight month period.

OCCURRENCE

National Parks where the bird breeds includes Dunk Island, Mt Spec, Chillagoe - Mungana, Finch Hatton Gorge, Barron Gorge, Mt Bartle Frere, Cape Tribulation, Palmerston National Park, Grey Peaks National Park and Mossman Gorge.

Other areas where the Swiftlet breeds include Tully River Gorge, Malbon Thompson Range, Bedarra Island, and Mitchell - Palmer caves. Broken River caves, Russell River Gorge, Downey Creek area, other Chillagoe caves. Swiftlet colonies at Chillagoe are the largest known in Queensland.

FAUNA CONSERVATION ACT

The Fauna Conservation Act of 1985 provides varying levels of protection for most species native to Queensland. It classes Northern white rumped swiftlets as "protected fauna". Regulation and monitoring of activities affecting these animals or their habitat is achieved by a permit system. Permits are issued by the QNPWS Directorate of Field Operations in Brisbane after careful evaluation.

General speleo and related activities, especially during the lengthy breeding season, have the potential to inadvertantly disrupt swiftlet populations.

In an effort to avoid such foreign disruption, a list of the known swiftlet colonies in the Chillagoe - Mungana area has been compiled so that speleological trips can be planned to bypass them. (Table I).

DISTURBANCE OF BREEDING COLONIES

Disturbance to individual swiftlets or to their colony includes both natural and human factors. Potential factors affecting the birds survival both in and outside the cave includes those listed in Tables 2 and 3 on the following pages.

CONCLUSION

The swiftlet in Queensland is protected by the Fauna Conservation Act both on and off National Parks. Prosecution of any visitor, be it a caver, researcher or member of the public can occur if "undue disturbance" is caused to the birds. Legitimate scientific study or observation of these birds can be carried out under a relevant permit issued by the Queensland National Parks and Wildlife Service. Techniques for visiting bird colonies are being scientifically devised.

These will ultimately be determined by the findings of observations made during every cave visit and by follow up inspections to disturbed colonies.

At the moment there are too many unknowns concerning the degree of disturbance colonies will tolerate. There is some indication the birds can partly adapt to limited disturbance.

Avoidance of nesting chambers, especially during the breeding, season is essential.

TABLE 1 -
CHILLAGOE - MUNGANA CAVES WITH SWIFTLETS COLONIES

Cave Number	Name of Cave	Tower	On N.P.	Off N.P.
CH 5	Tower of London Cave	Tower of London	x	
CH 9	Royal Arch Cave	Royal Arch	x	
CH 26	Clam Cavern	Walkunders		x
CH 30	Stop Press Cave	Piano	x	
CH 46	Snakey Cavern	Royal Arch	x	
CH 52	Swiftlet Cave	Royal Arch	x	
CH 81	New Southlander Cave	Queenslander	x	
CH 124	Flow Cavern	Royal Arch	x	
CH 132	Pharoah's Tomb Cave	Royal Arch	x	
CH 133	But Good Cave	Royal Arch	x	
CH 138	Chinese Cavern	Con Tower		x
CH 144	Christmas Pot	Suicide		x
CH 146	Guano Pot	Suicide		x
CH 167	Crack Pot	Suicide		x
CH 169	Squeeze Pot	Suicide		x
CH 176	Capricorn Cave	Queenslander	x	
CH 187	Gordale Scar Pot	Spring	x	
CH 221	September Cave	Walkunder South		x
CH 227	Pope John Paul 1 Cave	Spring	x	
CH 306	Mudlark	Spring	x	
CH 312	Project 31	Moffat		x
CH 322	Swiftlet Scallops	Markham		x
CH 338*	Epiglotis Pot	Markham		x
CH 359	Pretty Small Cave	Royal Arch	x	
CH 361	Atlas Cave	Markham		x
CH 362	Hercules	Markham		x
CH 374	Swiftlet Scallops 2nd Entrance	Markham		x
CH 375*	Faces in the Sky	Markham		x
CH 379	Tarby's Swiftlet Pot	Spring	x	
CH 380	Golgotha	Tower of London	x	
CH 381	Swiftrimelt	Royal Arch	x	
CH 382	Otobeaswiftlet	Royal Arch	x	
CH 397	Shirls Triple Twirl	Royal Arch	x	
CH 398	Swiftlet Swallet	Markham		x

*Possible swiftlet cave

TABLE 2.
NATURAL FACTORS AFFECTING BIRDS

(a) Internal Cave Environment

Factor	Effect on bird/s	Reason for Effect
Snakes/Rats	Fear	Potential Predator
Climate (in cave)	Determines suitability for nesting/breeding	Special conditions needed

(b) External Cave Environment

Factor	Effect on bird/s	Reason for Effect
Climate (including rainfall)	Determines numbers in cave	Numbers determined by food availability
Thunder	Panic	Disrupts the cave environment
Lightning	Nil	Lightning unlikely to penetrate dark caves

TABLE 3
UN-NATURAL FACTORS AFFECTING BIRDS

(a) Internal Cave Environment

Factor	Effect on bird/s	Reason for Effect
Visitor Lights	Panic	Intrusion, disrupts darkness
Noise (talking)	Panic	Intrusion, disrupts darkness
Visitor presence	Panic	Intrusion, potential predator
Bird handling	Stress	Potential injury, predator
Nest handling	Stress	Damage to nest
Egg removal	Stress	Intrusion, effort need for replacement
Bird removal (permanent)	Stress	Loss of mate and parent
Bird removal (temporary)	Stress	Confusion to mate and young
Mist netting	Stress	Potential injury
Photography	Stress	Intrusion, birds startled
Mining (outside cave)	Scattering or removal of birds	Loss of feeding and other roosting and breeding areas
Blasting (outside)	Scattering or depletion of birds, panic	Disturbance to home (noise), interfering with breeding
Confinement in a narrow area by visitors	Panic	Feel trapped, potential predator

(b) External Cave Environment

Factor	Effect on bird/s	Reason for Effect
Mining/Blasting (of caves)	Scattering, depletion of birds	Loss of home

ACKNOWLEDGMENTS

Keith McDonnald and Buzz Symonds, Fauna Rangers from Townsville and Cairns, greatly assisted with information on the Fauna Act. The Chillagoe Caving Club assisted by offering criticism and by giving access to their many years of trip sheets. Jeanette Mombelli from Queensland National Parks and Wildlife Service, Cairns office greatly assisted with the typing.

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BROKEN RIVER KARST: A SPELEOLOGICAL FIELD GUIDE, NORTH QUEENSLAND, AUSTRALIA.

Chillagoe Caving Club Inc. and Queensland National Parks and Wildlife Service. Editor - M. Godwin.

ABSTRACT

Limestone bearing formations of the South Western Broken River Province are reviewed and mapped showing known outcrops and caves. Habitats of the area and caves located are also described.

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MANAGEMENT OF NON-TOURIST CAVES BY QUEENSLAND NATIONAL PARKS AND WILDLIFE SERVICE AT CHILLAGOE, NORTH QUEENSLAND.

David R. Flett.

ABSTRACT

Hundreds of cave entrances occur in the Chillagoe - Mungana-Rookwood Cave complex. Only "major"or "significant" entrances are tagged, and about 1/3 occur inside Queensland National Parks and Wildlife Service Reserves. The caves outside National Park occur in grazing, mining and forestry areas. Access to all non-tourist caves is possible through the Chillagoe Caving Club, although the Queensland National Parks and Wildlife Service has the right of determining entry into any of its caves. Applicants wishing to enter any National Park cave must apply beforehand at the Chillagoe Queensland National Parks and Wildlife Service office and lodge a trip sheet immediately after their visit.

INTRODUCTION

Remnants of Silurian - Devonian coral reefs have formed a broken belt of metamorphosed limestone sediments about 35 km long and 2-5 km wide (Chillagoe Karst 1982). The belt runs north west to south east with Chillagoe town positioned in the lower one third of the belt. The limestone is very weathered and is described as a "Tower Karst in Decay" (Ford, 1978). Within most limestone outcrops there are caves.

CAVES

At the time of writing the Chillagoe Caving Club advises that four hundred cave entrances have been tagged. Significant entrances are tagged so in some cases a cave will have several marked and several unmarked entrances. As a different number is allocated to each entrance, so too are names. For example the Queenslander Cave on National Park, which technically is one cave as all entrances and passages join up, has entrances including CH 51 (Queenslander Cave), CH 55 (Little Italy), CH 15 (Cathedral Cave) and CH 84 (Epi Phrenetic) etc.

Of the four hundred or so tagged entrances so far approximately 140 are on 9 National Park Reserves (see appendix). The areas of National Park in Chillagoe - Mungana include the Royal Arch National Park (1514 ha), Donna National Park (178 ha), Spring National Park (125 ha), Piano-Jubilee (125 ha), Cathedral National Park also called Queenslander (35 ha) and various other Reserves ranging from 0.65 ha to 20 ha.

CAVE FEATURES

The caves are generally shallow and extend upward from the plains level outside, to the top of the outcropping limestone. Some caves do however go below plains level, but all would probably be confined to about 20 metres above and below ground level.

As the limestone is greatly weathered many caves have collapsed roofs. The entry of light and circulating air into the caves allows moss, fern, stinging trees small herbs and fig trees to grow on the walls and floors of these chambers, and a dying out and dulling of the formations. The predominant formations in the cave include massive amounts of all types of cave coral. Stalactites and stalagmites occur less frequently and are irregular in shape due to irregular growth. Flowstone is very common as are rimstones and rimstone pools. However visible calcite crystal is patchy, occurring in isolated areas. Floors of both silt and mud and calcite deposit also occur. Virtually every cave has massive amounts of iron oxide staining, fig tree roots and intact or remnant false floors.

CAVE MANAGEMENT

The first permanent (documented) European settlement in Chillagoe began when William Atherton applied for grazing leases on 20 April 1888. Mining began in 1988, and Tea Tree Cave, next to one of the earliest copper mines has graffiti back to 1888 (Flett 1987). Discovery of caves and visitation of them involved mostly locals until 1964, when local resident Vince Kinnear, present Chillagoe post master, was appointed honorary guide of the Queensland Department of Forestry. Vince's position became permanent with Forestry in 1966 and led to the development of the two main tourist caves, the Donna and Royal Arch. Prior to 1964, locals acted as volunteer guides although in the 1920's and 1930's the Mungana Caves Trust was set up by the Council of the day (Woothakata, now Mareeba Shire). Train loads of visitors from Cairns would be shown around several Mungana caves including Piano, Spring and Cathedral Caves.

From 1964 to 1975 the Department of Forestry were cave managers. The Queensland National Parks and Wildlife Service was a small branch within the Department. Since 1975, Queensland National Parks and Wildlife Service has been the autonomous manager.

From 1976 - 1977, Queensland National Parks and Wildlife Service employee, Mr Paul Wilson, documented and explored all known caves in the area. He devised a classification system under which all caves both on and off National Parks should be managed (Wilson, 1977).

Caves were classified on accessibility, fragility, potential usage and scientific value. Recommendations have followed seeking extension of existing National Park areas gazetted in 1940. For example diprotodon bones have been discovered in one cave, and fragile formations and swiftlet colonies discovered in others outside the park reserves.

VISITATION TO "NON-TOURIST" CAVES

Only two caves at Chillagoe are currently being used by the Queensland National Parks and Wildlife Service for guided tours. A third, the Trezkinn Cave has progressively been developed since work began on a walkway about 1979. It has been used on an intermittent basis, especially during peak periods of visitation and with large community groups (for example schools). Fees for guided tours have been levied since 1 November 1988, although no visitors have been taken into the Trezkinn since then. Several self guided caves on National Parks are advertised for visitation and include the Bauhinia and Pompey caves on the Donna National Park, and the Fairy No 1 and No 2 Caves on the Royal Arch National Park. The Royal Archway Cave at Mungana, partly on National Park, has also been developed for inexperienced visitors. The self guided caves show a different dimension on cave size, length and appearance to the guided tours. They reflect the different stages of cave evaluation (for example build up and breakdown cycle). The Donna Cave is "old" in that it is only seasonally wet and speleothem growth is almost finished, yet its intact roof means it is "young" for a Chillagoe cave. It is a dark cave contrasting with the guided Royal Arch which shows a progression to a middle age cave, with roofs beginning to collapse. The collapsed roof of the Royal Archway indicates an older cave again.

No commercial operators are permitted to visit non-tourist "wild" caves on National Parks, although "Caving Capers" is a group which visits undeveloped caves off National Parks at Mungana on a weekly basis.

Caves off National Parks are either under the management and/or ownership/lease of the surrounding Chillagoe and Rookwood Cattle Stations, Lands Departments, and Departments of Forestry and Mines.

SPELEOLOGISTS AND CAVES

There are two types of cavers anywhere. The first are those sensitive cavers who "go caving" to appreciate cave formations, its structure and biology. These cavers are sensitive to what they walk over, and will spend time removing footwear to avoid crushing bones or fragile formations etc. The other is the caver who is interested in "adventure", and becomes less sensitive to the needs of the cave, and more interested in being able to negotiate difficult areas etc. This type of caver is one who is more likely to cause damage in the enthusiasm to "explore", and needs to be held in check.

For all caving trips on National Parks, a trip sheet must be lodged immediately following the visit. This helps monitor cave use, identifies potential user problems, acts as a data collection system concerning, bats, swiftlets, fossil, damage, litter etc. The system to date for visiting non-tourist Queensland National Parks and Wildlife Service caves has been very casual, but due to increasing visitation and a tightening up to prevent damage, permits will probably soon be needed beforehand to visit certain sensitive caves. Guidelines for these caves are currently under review.

PROBLEMS MANAGING NON-TOURIST CAVES

Probably the most difficult problem in managing non-tourist caves is the prevention of damage to speleothems by insensitive cavers. However in many Chillagoe caves even the most careful caver can cause visible destruction, inadvertently touching or walking over brittle cave coral. Because there is so much cave coral in caves, cavers often become complacent and damage to cave coral is not considered "too important". However broken cave coral visually down grades a cave very quickly.

Most cavers are sensitive enough to realise that touching formations causes discoloration, however from my experience at Chillagoe not all cavers are sensitive to the damage caused from footprints. As many caves have mud floors, muddy footwear can, and has been, responsible for discoloration of rimstones, flowstone and crystal caves.

Biological management of all caves over the last few years has received a much greater priority than previously. Cavers visiting bat and swiftlet colonies must be extremely sensitive not to disturb the animals. Finding these animals in the past and observing them streaming off ceilings, flying in chambers, observing nests and eggs and photographing them has been done with various degrees of sensitivity, based more on individual personalities than a set approach. Management of swiftlet and bat colonies is one of avoidance as much as possible and totally during breeding, unless the Queensland National Parks and Wildlife Service has issued permits to do so. This applies to caves both on and off National Parks. From a Queensland National Parks and Wildlife Service point of view, managing its non-tourist caves on National Parks has been difficult due to its commitment to daily guided tours. With the pressure of increased usage and accessibility of caves, through opening up of areas by marble and gold mining, greater monitoring of caves and cave visits is necessary. For Queensland National Parks and Wildlife Service to be a responsible manager it has to tighten up control of visitation to non-tourist caves. This initially may result in inconvenience to past, long-term cave users, but surely as all cave managers and users are working towards the same goal (that is, preservation of caves in as near undamaged state for as long as possible) then this inconvenience should be accepted. By cavers having to "apply" to visit sensitive caves on National Park, previously visited without any restrictions, then surely this must be of benefit to the cave.

CONCLUSION

Problems of managing "non-tourist" caves are essentially one of people. To prevent caves on National Parks from being unnecessarily damaged, visitation to some sensitive caves will have to be monitored through prior approval from Queensland National Parks and Wildlife Service. Visitation to all caves will also necessitate completing a trip sheet. Queensland National Parks and Wildlife Service management of caves is first and foremost one of protecting biology (bats and swiftlets) and cave formations, and secondly one of managing visitors.

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Note -
As many National Park boundaries cross through towers, it is often difficult to determine whether all or part of a cave is in a National Park. These lists are good approximations only. For example, no attempt was made to work out which caves in Queensland Tower are outside National Park. Much of the tower is on National Park but the western and south-eastern portions are not.

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APPENDIX

CHILLAGOE - MUNGANA - ROOKWOOD CAVERNOUS TOWERS

Wholly on National Park

Donna
Piano
Royal Arch
Tower of London

Partly on National Park

Carpentaria
Eclipse
Spring
Queenslander
Ryan Imperial
Markham

Off National Park

Already
Bedding Plane
Cathedral Rock
Con Tower
Conference
Corkscrew
Critic
Currajong
Dumpy
Ellis Rowan
Haunted
Heffernan
Hippies
Horseshoe
Jack
Katie Breen
Moffat
Needle Eye
One Mile
Pinnacle Ridge
Pollard
Pteropus
Racecourse
Ramparts
Redcap
Ryans Creek
Shaggy Dog
Suicide
Tall Tree
Trehenan
Twin
Wallaroo
Weetbix

Chillagoe - Mungana - Rookwood Caves. Location of Tagged Entrances up to 400

Wholly on National Park
CH 2, 5, 6, 9, 10, 12-17, 21-23, 28-29, 30, 39, 44-49, 50-53, 55-59, 60, 79, 80-91, 95-97, 100, 102-107, 110, 111-113, 116, 118, 124-129, 130-133, 136-137, 145, 148, 157, 162, 164, 168, 171-172, 176-182, 187, 203, 207, 227, 230, 232-233, 251-259, 264-266, 279, 280, 284, 288-289, 291-292, 293-298, 301, 304-306, 308-309, 343-344, 359-360, 379, 380--382, 397 (Total - 138).

Partly on National Park
CH 203, 204 (Total - 2)

Off National Park
(Total - 259)

Indeterminate/Unknown
CH 396 (Total - 1)

THE BARKLY KARST REGION, NORTH-WEST QUEENSLAND.

Ken G. Grimes.

ABSTRACT

Although underlain by thick and widespread carbonate rocks, the Barkly Karst Region has a fully developed surface drainage and karst features are poorly developed. On the main tableland only isolated collapse dolines and associated caves occur, with the greatest density being near Camooweal. Underground drainage does occur but movement is slow. In the dissected northern margin there are several large grike fields and well developed karren, as well as dolines, caves, and karst springs. However, the dense surface drainage system is still fully functional in the wet season.

The main cave passage development might date back to wetter climates and higher water tables of the Tertiary. More recent karst development in the region has been retarded and the area is in an extremely youthful stage. The retardation is the result of the arid climate, the lack of relief, and the extensive black soil cover on the tableland which has restricted infiltration. None-the-less, individual caves can be quite large, with Kalkadoon Cave having 5400 m of surveyed passage, and many unexplored leads.

Biological interest lies in the crabs and rare bats which are found in the caves.

INTRODUCTION

The Barkly Karst Region extends from Queensland into the Northern Territory, and corresponds to the carbonate rocks of the Early Paleozoic Georgina Basin (de Keyser, 1974) and also to the geographical feature known as the Barkly Tableland (Stewart, 1954). This paper presents a survey of the karst features of that part of the Barkly Karst Region lying within Queensland, and between latitude 18°35'S and 21°00'S (see Fig 1). Karst feature are rare further to the south, but have been recorded as far as the Boulia area. The present paper is a revision of a previous unpublished assignment (Grimes, 1977a). It is based on air photo interpretation at the regional scale (Grimes 1974a), on several visits to the Camooweal and Lawn Hill cave areas with University of Queensland Speleological Society (UQSS) parties between 1974 and 1980, and on observations made during geological mapping in the region in 1983-84.

The regional geology and climate of the region will be summarized first to provide a background to the following detailed description of both the surface karst features and the caves. Finally some suggestions are made concerning the climatic and geological controls on karst development in the area. Discussion is limited mainly to the areas visited by the UQSS: the Camooweal area within the tableland, and the Lawn Hill area at the northeastern margin. These represent two styles of karst development in the area.

The earliest reports I have found on the caves are those of Keys (1900) and Danes (1911). More recent karst studies in the area have been restricted to a brief description of the surface karst and spring deposits at Riversleigh, south of Lawn Hill, by Williams (1978); and to various reports on cave exploration by the UQSS and other Speleological Groups (e.g. Bourke, 1970; Shannon, 1970; Halbert and Ellis, 1970; Pavey, 1972, 1974; Grimes 1975, 1977b, 1980; Jolly and Grimes, 1978; Canty, 1979; Little, 1986). Shannon, 1969 and 1970 summarizes exploration up to that time and lists earlier publications, including descriptions by Lamond (1968) of a number of outlying caves in Queensland and the adjoining parts of the Northern Territory, most of which have never been visited by speleologists. Dolines have been shown on some, but not all, of the 1:250 000 geological maps of the region; and caves and sink holes are described in several of the accompanying geological reports.

The region as a whole is referred to as the Barkly Karst Region (BK) in the Australian Karst Index (Matthews, 1985), but the Camooweal area (C), and the Colless Creek area (CK), which fall within the region, have been given separate listings and codes.

Most of the region is held under grazing leases, but there are National Parks in the Camooweal and Lawn Hill Gorge areas, which cover some of the caves and karst features.

The region has an arid (BWhw)[1] to semi-arid (BShw) climate with conditions becoming drier and more continental to the south. The effectiveness of the rainfall is limited by its summer incidence and by the fact that much of it falls in thunder storms followed by hot sunny conditions. During the Pleistocene the climate would have fluctuated, with the changes being most likely towards greater aridity during the glacial stages (when the Gulf of Carpentaria would have been largely dry), and conditions similar to or slightly wetter than the present during the inter-glacial stages. However, during most of the Tertiary, conditions would have been wetter and the country much more densely forested. Drier conditions similar to the present would only have appeared towards the end of the Tertiary, about 5 - 10 million years ago (Galloway and Kemp, 1984).

[1] *Koppen's climatic classes.*

Vegetation in the area varies from treeless grasslands on the black soils of the tablelands to open low woodlands on the limestones and other rock types. In the north, gallery forest follows the margins of the permanent spring-fed streams.

The regional geology is summarized in Fig. 1 and is presented in more detail in de Keyser 1974. The karst features are developed on the dolomite and limestone[1] lithosomes of the early Paleozoic Georgina Basin. The carbonates are generally flat lying, well bedded, and moderately to well jointed. Some folding has occurred in the Undilla area and near the basin margins. Through much of the region the carbonates are mantled by a thick heavy clay soil (black soil). East and southeast of Camooweal they are overlain by thin Mesozoic sediments and lateritic soils (Grimes, 1985). The laterite is developed on a mid-Tertiary surface (correlated with the Tennant Creek Surface by Grimes, 1974b) which existed over much of the area. This surface is characterized by both ferricretes and silcretes. Much of the siliceous lag gravel found on the surface in the Camooweal area probably is derived from these silcretes as chert is rare in the carbonate rocks exposed in the caves. This mid Tertiary surface was uplifted later in the Tertiary and dissection followed in the northern margins of the tableland, and is continuing at present with the dissected area slowly advancing southwards. The remainder of the tableland has suffered little erosion since the uplift. In the dissected Lawn Hill area the Tertiary surface is recognizable as a planar summit level surface. The meandering and bifurcating pattern of Lawn Hill Gorge is a superimposed drainage inherited from this surface.

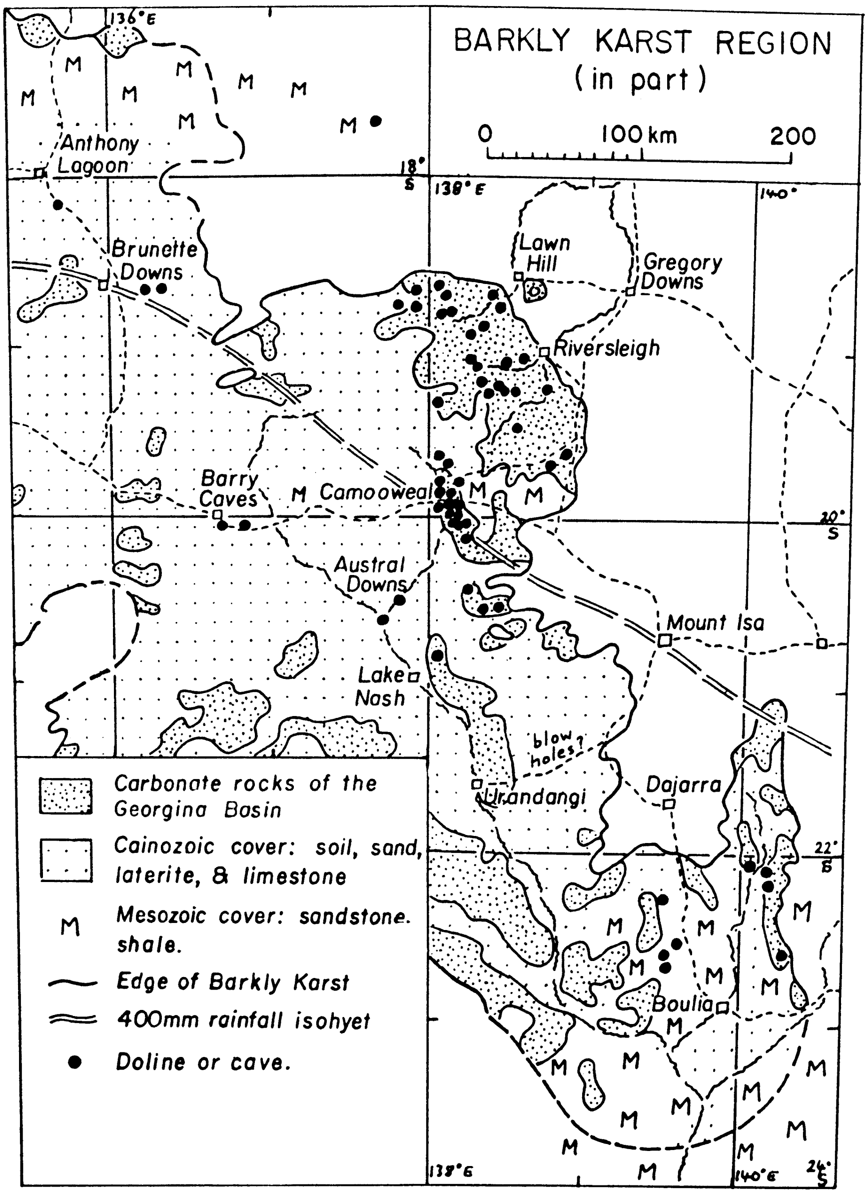

Figure 1: Barkly Karst region : Locality map.

[1] The dolomites and limestones of the area can only be readily distinguished by laboratory tests, the term "carbonate" will be used here in a general sense for both lithologies.

PALEOKARST

During a recent geological mapping operation (Grimes 1985) I found float and a number of small isolated deposits of silicified quartz sandstone and laminated shale within the carbonate areas near Camooweal. These were in small areas less than 50 m across and surrounded by Cambrian carbonate rocks. The exposures were very poor and no contacts were seen, but the most likely explanation is that these could be paleokarst deposits in old dolines or caves. Their age is uncertain, and as both the Tertiary and Mesozoic land surfaces were very close to the present surface in this area, the features could relate to either. No fossils were found, but the induration suggests that they must predate the formation of the mid Tertiary duricrusts. Some soft laminated shale also occurs as rubble on the floor of the final big chamber of Spinifex Cave, well below the surface.

A Miocene deposit at Riversleigh, on the northeast margin of the region, fills an old valley incised into the Paleozoic carbonates. This contains an abundant vertebrate fauna (Archer, 1988), and although no definite cave sediments have been recognised, the presence of numerous bat bones seems to indicate the existence of some caves in the area at that time.

Opik, Carter & Randal (1973, page 4) reported isolated "Mesozoic" deposits within the carbonate rocks in the Camooweal 1:250 000 sheet area. These might be surface stream deposits, or might be filling karst depressions. The age control is poor in most cases.

THE KARST LANDFORMS

Surface Karst Features

Drainage:
In spite of the large area of carbonate rocks underlying the region, the surface drainage is almost completely integrated. In the northern, dissected, area there is an incised, closely spaced dendritic drainage system with channel densities of 3 - 5 per km (Grimes 1974b). Only a few blind valleys occur where streams sink into dolines. The largest of these valleys is only 700 m long. Underground drainage is evidenced by the springs near the edge of the region, but seems to be subordinate to the surface drainage.

On the undissected part of the tableland to the south the surface drainage is much less dense, averaging 0.7 channels per km, but is still fully integrated and again only a few blind valleys occur. The longest of these is an exceptional 3 km. Much of this area is covered by black soil. In this soil the rainfall pools locally in small gilgai, which reduces the run-off onto streams. The heavy clay also limits seepage downwards into the underlying rocks.

Small scale solutional sculpturing, karren:
Karren are best developed in the northern dissected area, probably because of the greater rainfall and the more extensive areas of bare limestone. They are most common in beds of strongly jointed carbonate rocks. In these the joints have been enlarged to form large grike fields with fissures up to 4 m wide and 10 m deep. The rocky pinnacles between the grikes have been serrated by solution flutes and other karren forms also occur. These grike fields probably have the best cave potential, as indicated by the preliminary exploration of the Colless Creek Grikefield (see below).

In the southern area karren are rare. Small grikes occur near some dolines. Solutional etching of fine structures in the rock is the main feature seen.

Dolines:
The distribution of large dolines in the area is shown in Fig 1. In all, more than 80 dolines greater than 50 m have been located in the region using high altitude air photos. Many of these have been checked for caves, and they are documented in the Australian Karst Index (Matthews, 1985). About half of the dolines checked in the Camooweal area contained caves, and some known caves are in small depressions not visible on the air photos. Some dolines in more remote areas still have not been checked.

The main concentration of dolines is in the Camooweal area (Fig 1), but even there the doline density of 0.47 per km^2 is less than the densities of between 0.57 and 2400 per km^2 reported in a world wide survey by Cramer (1941). In the northern area smaller solutional dolines occur in the grike fields, but their density has not been estimated. Isolated dolines and stream sinks occur as far south as the Boulia area (see Fig 1, and listing in Matthews, 1985).

The large dolines appear to be nearly all derived from the collapse of cave roofs. Smaller dolines are rare. Some intermediate size dolines with rubble walls have a central mud mound (e.g. 4C-1040). These may be the result of mud blocking the central (less well drained) area, while water is still entering the better drained rubble around the margins and keeping those areas clear.

Springs and tufa deposits:
Along the northern margins of the region permanent large springs feed the major streams which flow out of the dissected plateau. In these streams and in the adjoining flood plains calcareous tufa deposits have been built up by precipitation from the saturated waters (Williams, 1978). In Lawn Hill Gorge one such deposit has formed a narrow dam right across the gorge, with a 1 m waterfall.

Subsurface Karst Features

Caves of the Colless Creek area (Lawn Hill Gorge National Park):

The Colless Creek grike field, west of Lawn Hill Gorge, seems to have good potential for extensive maze caves, but has not yet been properly explored. A number of short visits have found several small caves and one extensive one: Colonel Light Cave, (Grimes, 1978, 1979, Canty, 1979).

Fig 2 illustrates Colonel Light Cave (4CK-2). This is a horizontal joint-controlled maze system with 1350 m of surveyed passages. It comprises an irregular network of intersecting tall narrow passages, many of which connect via slots with the grikes on the surface. These connections are typically at passage junctions. The floor level is roughly horizontal, and covered with rubble except in the western passages where a sandy to silty floor shows signs of having been deposited by strong (wet season) currents. Solution undercuts are common

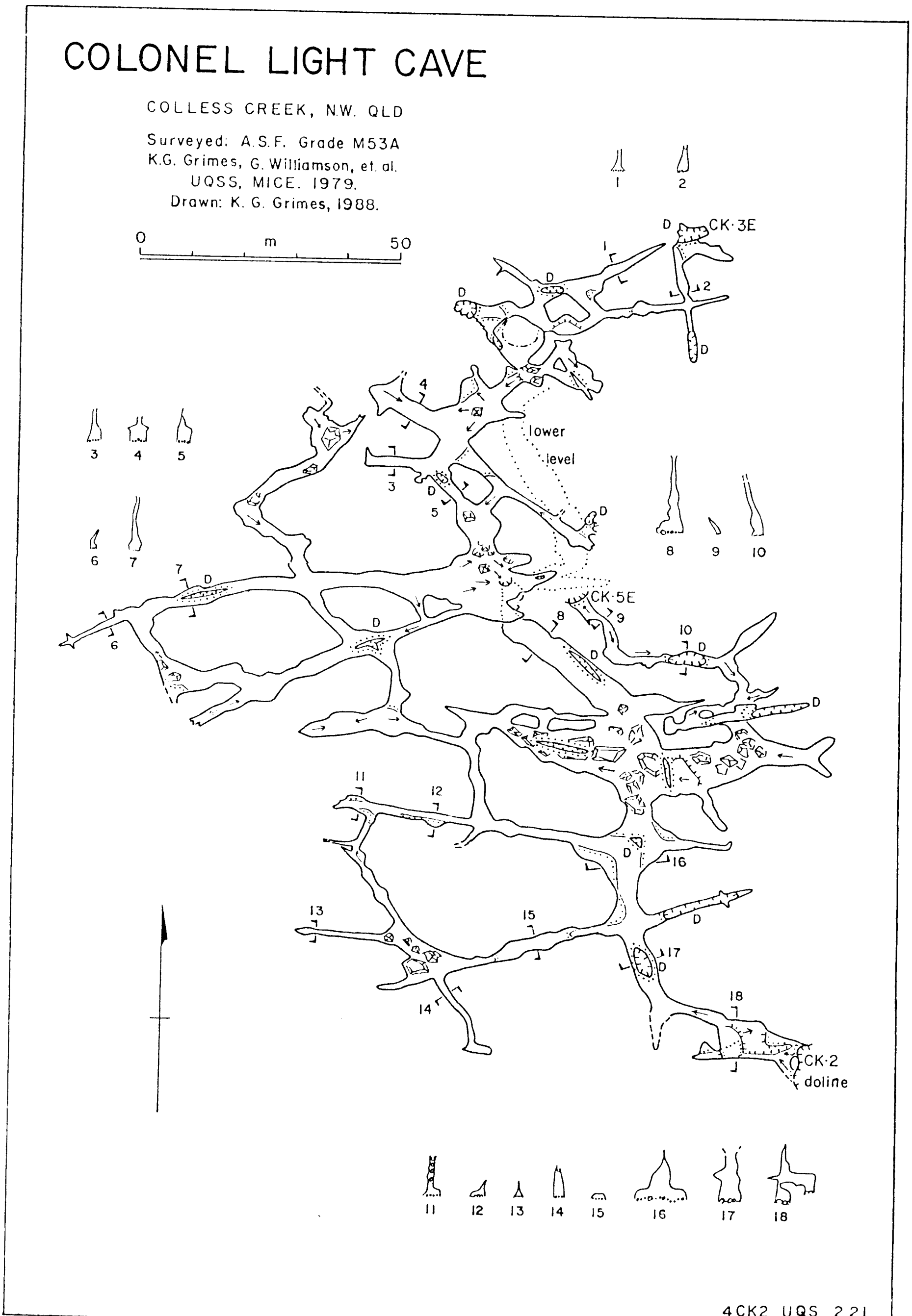

Figure 2: Colonel Light Cave (4CK-2), Colless Creek area.

at the base of the passage walls, indicating an old standing water level, about 15-20 m below the surface, and some distance above the present creek level. There is an incompletely explored horizontal lower level which, at about 45-50 m below the surface, is close to the present creek level. Speleothems are more common than in the Camooweal area to the south, but are still far from abundant when compared with those in humid karst areas.

The formation of the upper level cave passages must predate, or be contemporary with, the early stages of incision of the gorge; and the undercuts might indicate a still-stand in the incision. The Miocene fossil-rich deposits of the Carl Creek Limestone, near Riversleigh (Archer, 1988), occur in a valley which has been cut into the Tennant Creek Surface to a similar depth to that of the passages in this cave, and might well be contemporary. The fossils indicate that the Miocene climate was much wetter than the present, which would have aided karst development. The lower level is close to the present floor of the gorge, and may therefore be younger than the late Tertiary uplift and incision of the area.

Caves of the Camooweal area:
This is the area in which most exploration has been done. Of the 56 dolines and stream sinks listed for this area in the Australian Karst Index, 26 contain known

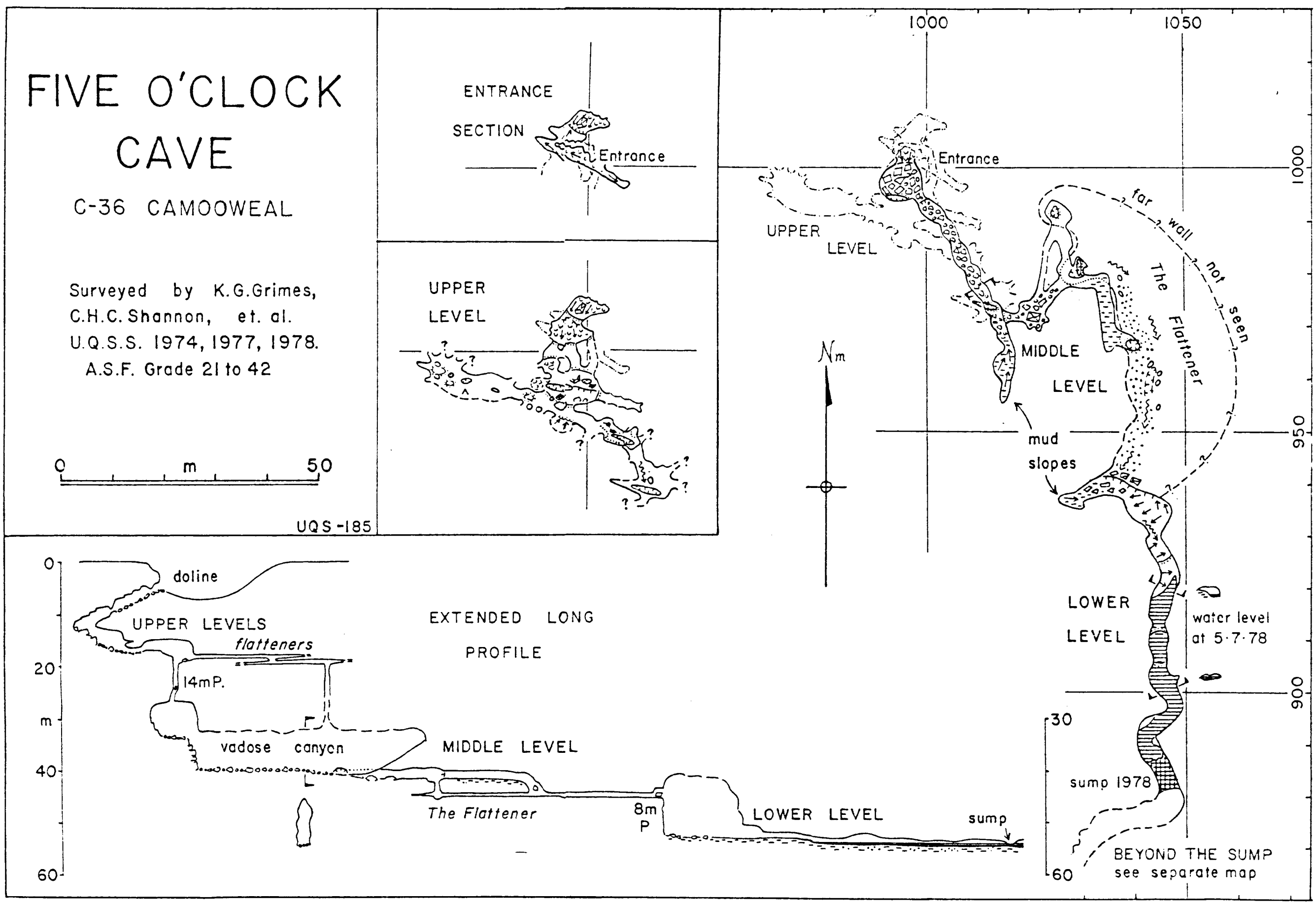

Figure 3: Five O'Clock Cave (4C-36), plan and long profile of main section.

caves (Matthews, 1985). For a bibliography of cave descriptions up to about 1980 see the listings in Matthews; I will cite only more recent publications here.

The caves vary from short cavities in rock pile to large systems having up to 5.4 km of mapped passage. Figs 3 and 4 illustrate a typical large cave found in the area.

In general the caves comprise alternating vertical shafts and long horizontal sections. The major passages are up to 10 m or more in diameter. The systems appear to have developed in the phreatic zone with control by either bedding or successive levels of the water table, or both. The bedding is sub-horizontal, which makes it difficult to distinguish the effects of bedding from water table effects. Nothephreatic conditions are indicated by mazes and in the smaller scale by sponge-works of small centimetre-sized tubes. Some of the more soluble beds have been almost completely removed to leave extensive "flatteners". Since draining there has been modification and enlargement of the major passages by vadose flow. Vadose seepage seems to have had only a minor effect, and speleothems are rare.

In many of the larger caves in the area, the entrance chamber and initial passages are large, but these lead to a series of smaller bifurcating low level distributary tunnels which radiate away from the entrance area.

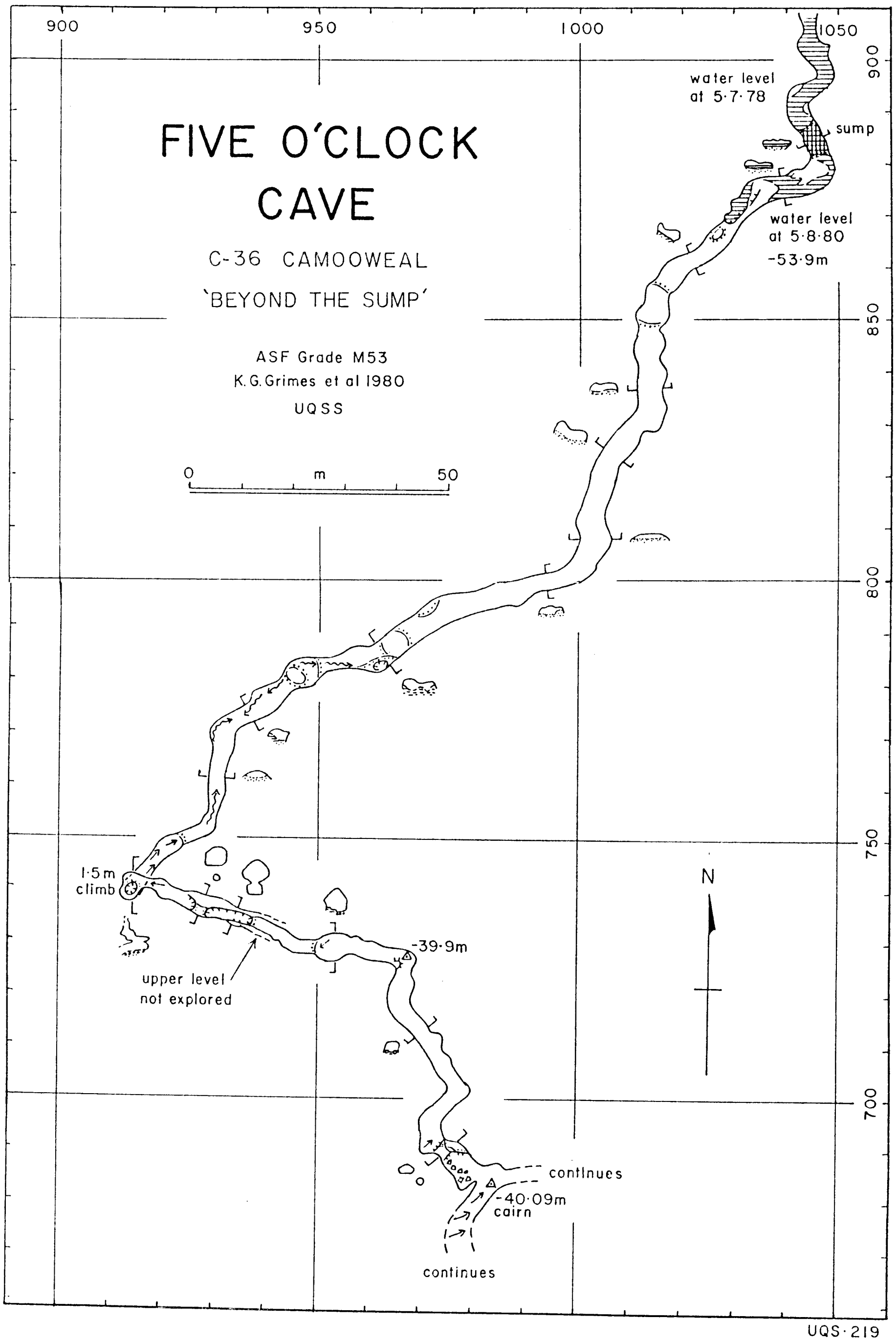

Figure 4: Five O'Clock Cave, plan of the section beyond the sump.

These are typically long, low (0.5 to 1.5 m), muddy, hot and humid tunnels which either terminate in a mud sump, or continue beyond the present limits of exploration (The "Sod It, Let's Go Home" point - Pavey, pers. comm.). It seems that aggressive surface water is entering the system at a single point: now the doline, but initially probably an area of outcrop which was not sealed by black soil, or which was adjacent to a rise from which surface water was being channelled. From this entrance point the water is distributed downwards and outwards in a radial pattern through the underground passages, which are largest near the source and smaller further out. However, the final small low-level passages maintain consistent diameters over long distances, even when bifurcating.

The different styles of passage development and their genesis are illustrated by **Five O'clock Cave (4C-36)** which shows the greatest diversity of forms (Figs 3 and 4). This cave has several levels, probably related to major still-stands of the water table, but bedding control is also obvious in mazes and flatteners.

The entrance passage and initial chamber are dominated by breakdown at the margin of the doline which overlies the cave. The upper level Maze (largely unsurveyed) and the Flattener in the middle level are low horizontal sections developed nothephreatically along soluble beds. The upper level Maze has two levels, only one metre apart vertically - indicating two soluble beds. The Flattener is a single horizontal slot less than 1 m high, and about 50 m long, with only occasional pillars remaining to support the roof.

The vertical fissure connecting the upper and middle levels, and the chamber beneath it, may have been initiated phreatically, following a joint, but they have been enlarged by vertical vadose flow (this would be a waterfall in the wet season).

The large meandering canyons of the middle and lower sections may have commenced as dynamic phreatic tubes near the water table of the time, as indicated by their horizontal meandering ceilings, but have cut down to the present floor by vadose flow as they were drained. The two sections are separated by a mud plug, presumably beneath an old entrance. The "Sump", about 54 m below the surface plain, is higher than general for the present regional water table. In 1977 and 1979 this was terminal, though the water was lower in 1979. However, following a series of dry years, by 1980 it had lowered sufficiently to allow penetration into the start of a long tunnel that continued beyond the limits of exploration (only the first 350 m were surveyed (Fig 4), but exploration by MICE[1] penetrated well beyond that point). By 1986 the water level had risen again so that a short duck under was required (Little, 1986). The length of this sump would be very sensitive to water levels, and it should be approached with care. Beyond the sump, the final phreatic tunnel, varying from 1-4 m high, runs more or less horizontal for the first 250 m, but then rises steeply to a level about 40 m below the surface and continues as a larger passage on that level to a junction at the present limit of the survey.

THE KARST HYDROLOGY

Some of the dolines have short surface streams flowing into them and two (4C-1008 and 1042) take flood waters from the Georgina River and Nowranie Creek respectively. There is evidence from flood debris that the caves sometimes fill almost completely during the wet season. However, the preservation of footprints in low level passages indicates that this has not happened over the last ten years. Some flooding seems to have occurred in Kalkadoon Cave at least since the early 1960s when groups of cavers from MISS[2] are known to have entered it (Calder, 1961) as we saw no footprints on our first visit in 1974.

In the Camooweal area the regional water table is between 70 and 75 m below the plain, and terminal lakes occur at this level in many of the deeper caves.

At first sight it would seem that the springs in the northern dissected margin of the area might be the outflow points for water which entered the ground at Camooweal. However, Randal (pers. comm.) says that the regional water table is below the level of these springs which must therefore be fed by local rainfall seepage. The regional slope of the water table, as shown by water bores, is to the south and water movement must be in this direction (Randal, 1967, 1978; and pers. comm.). No springs have been reported from the southern part of the Georgina Basin and the water may eventually leak vertically into the overlying aquifers of the Great Artesian Basin.

CAVE BIOLOGY

There has been little in the way of systematic biological studies. However, the trip reports of parties visiting the area contain numerous brief reports on insects, crabs, bats, owls, and snakes; such as the report on a light trap in Kaiser Creek (4C-12) by Wellings in Halbert and Ellis, 1970.

The main biological interest in the caves of the region lies in the bats and the crabs.

Hamilton-Smith (1978) has listed bat sightings in the region. In the Lawn Hill area he reports *Taphozous georgianus*, and *Hipposideros ater* in the caves, and a species of Nicticeius in the palm trees of the Gorge. From the Camooweal area he reported *Macroderma gigas*, (the pale phase of which has been sighted in a number of the caves) and *Rhinonycteris aurantius* in

[1] *Mount Isa Cave Explorers (1975 - c.1985).*

[2] *Mt Isa Speleological Society (c.1954 - c.1966).*

Kalkadoon Cave. This last was identified from bones, but live specimens have since been caught (Little, 1986). Canty (1979) photographed a dark phase of *M. gigas* in Ridgepole cave, west of Colless Creek, and there are unconfirmed reports of it at Colless Creek.

The crabs are less interesting than one would suppose, as they are a species of freshwater crab *(Parathelphusa transversa)* which is common in the surface water holes in the region. They are washed into the caves during the wet season, but seem to survive quite successfully within those caves which have permanent pools - if the number of sightings, and the presence of numerous burrows in Niggle and Barwidgee Caves are any indication. It is not known whether they are breeding in the caves.

CAVE CLIMATE

Halbert (1970) has made the only detailed study of the cave climates at Camooweal; in which he made a theoretical division of the caves into four meteorological types. Generally speaking the deeper parts of the caves have a non-varying hot and humid climate, while nearer the entrance/s they are cooler and dryer, and show more variation with time. Halbert reported a maximum of 100% humidity and 28.3°C (in Tods passage, Niggle Cave). I have since recorded higher temperatures in Kalkadoon of 29.5°C and 100% RH at the CASA-BSG junction (Grimes, 1980) and 30.5°C in UNSWSS passage (Grimes, 1979); and I once came down with a mild case of hyperthermia at the far end of CASA. On a couple of occasions, when cavers entered a new chamber or passage, the (presumably supersaturated) air condensed suddenly on their breath and fogged the whole area up in a few minutes.

DISCUSSION

Given that the area is underlain by an extensive layer of carbonate rocks, one is struck by the relative paucity of karst features and the dominance of surface drainage.

An explanation is that the karst cycle in the area has been retarded and is still in a youthful stage of development: extremely youthful in the south and only a little more advanced in the north.

The area is an uplifted mid Tertiary peneplain and the present drainage is inherited from this plain. Some excellent examples of superimposed drainage occur in the Lawn Hill Gorge area. Most of the higher levels of the caves may have developed during the wetter climates of the early and mid Tertiary, and would have been drained during the late Tertiary uplift. Some lowering of the water table may also have been due to the onset of the drier climates at the end of the Tertiary.

Karst development since the late Tertiary uplift of the peneplain has been retarded by several factors. The most obvious factor is the arid climate, which has restricted the development both because of the lack of water and because of the paucity of vegetation which could provide a source of carbon dioxide in the water. The slightly greater development in the north results from a combination of: the more active subsurface drainage because of the greater relief at the margin of the uplifted tableland; the more humid climate; and the lack of black soil cover, which has been stripped off. The impermeable black soils of the tableland would have inhibited the penetration of rainwater into the underlying rocks. It is notable that the area of densest doline distribution, near Camooweal, is one in which there is outcropping limestone, and in which more porous lateritic soils occur instead of the black soils.

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CAVES (Karst, survey and management)

THE JENOLAN CAVE SYSTEM SURVEYING PROJECT.

PART 1 - HISTORY, ORGANISATION AND ASSESSMENT.

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ABSTRACT

The Jenolan Cave System Surveying Project is introduced and reasons are given for resurveying the cave system to a higher standard. A brief history of surveying in the Jenolan Cave System is presented and the use indicated of previous surveys in the current project. The cavers and clubs involved in the project are recorded. The survey commenced in 1987 and is now at the end of its second year, many changes in general organisation occurred between the two years and these are discussed. Some conclusions are drawn and plans for the future are presented.

INTRODUCTION

The brief - In 1986 the Jenolan Scientific Advisory Committee (Convener, Ernst Holland) established that a complete high grade survey of the Jenolan Show Caves was required. The survey was needed to allow scientific studies, notably of the geology and hydrology, to be adequately interpreted. The committee felt that the survey should be of a standard that would assist any future deliberations pertaining to the development of the caves. The proposal to survey the system was endorsed and supported (without financial commitment) by the Jenolan Caves management and staff. The authors of this paper agreed to co-ordinate the survey and negotiated special conditions that allowed the survey to be carried out at weekends while cave inspections were in progress.

A name for the game - When the surveying project commenced in 1987 a name was needed for the cave system that was to be surveyed. The accepted title of "Jenolan Show Caves" was regarded as being inelegant and restrictive. Of the cave being surveyed over half of it is not shown and is unlikely ever to be shown to the public. Equally unacceptable was a title containing the combined names of the various "caves" of the system. These are of historical origin and are associated with the necessity to limit the length of, and increase the number of tours available to the public. Thus it was proposed that the cave be called The Jenolan Cave System; its correct geomorphic name.

The name "Jenolan Cave System" is not presumptive even though there are some 300 other Jenolan Caves (Australian Karst Index, Mathews, 1985). At the time of naming, The Jenolan Cave System was conservatively estimated to be some four times longer than Mammoth Cave; the second longest cave at Jenolan at 3150 m. Further, Mammoth Cave is known to be hydrologically connected to The Jenolan Cave System through Spider Cave.

HISTORY

Trickett map and model - The first surveying in The Jenolan Cave System was by Oliver Trickett in 1897 and 1898 (Dunkley, 1986). The published result (Trickett, 1899) was a simplified plan and section of the main passages, which adequately represented the caves for the visitors and showed the relationship between the caves and the surface topography. From these surveys Trickett constructed an excellent three dimensional model of the caves which can be viewed in the Resource Centre at Jenolan Caves. Both the model and the "compass" surveys were incomplete and inadequate for scientific studies and cave development planning.

Post Trickett surveys - in the intervening 88 years considerable lengths of new cave passage had been discovered, only some of which had been surveyed. At the commencement of the project the Jenolan Caves Scientific Advisory Committee requested from speleological societies photocopies of all Jenolan maps held in their libraries; the photocopies would be paid for. Only one society responded and produced maps of some of the minor caves. Individuals were more cooperative; John Dunkley, Guy Cox, Keith Oliver and Ian Wood were especially helpful in supplying both surveys and original data. Other sources of existing surveys were the somewhat incomplete set of maps held at Jenolan Caves and the Department of Public Works archives. Where an existing survey met the required standard and its data was available, then that section of the cave system would not be resurveyed. Table 1 lists the use made of existing surveys.

ORGANISATION

The surveyors - It was believed that the project would benefit from being a truly inter-club effort. Although the clubs were not solicited for surveying teams, it was made clear that any interested club could approach the organisers or the Jenolan Caves management, supply a surveying team and be given a section of cave to survey and instructions on how to survey if necessary. The open house policy did not really work. It was obvious that teams of experienced surveyors were the most efficient and training new teams was impractical and led to a decrease in standards. At present, teams tend to be from the same club and new participants to the project are trained by their club.

The major clubs participating in the project are Highland Caving Group, Hills Speleological Society, Sydney Speleological Society and Sydney University Speleological Society. Many other cavers, both national and inter-

TABLE 1
USES MADE OF EXISTING SURVEYS

Trickett's Map	This map together with additions made by Keith Oliver of recently explored sections has provided a base for planning the resurvey.
Lucas, Orient and Baal Dept. Public Works.	This highly accurate survey had been carried out in order to position the Binoomea Cut which enables tourist parties to access easily the Temple of Baal and the Orient Caves. It was intended to use this survey for the main traverse but the data attached to the plan could not be computed. It has been used for comparison with the resurvey.
Nettle and Arch Caves	Keith Oliver's original data and sketch of the caves were used. Survey stations could be easily relocated and left, right, up and down data added.
Ribbon Cave Ribbon	Cave was resurveyed before it was realised that Keith Oliver's original data and sketch were available. In excellent agreement with the resurvey.
Flitch of Bacon SUSS	This area was surveyed as part of the main theodolite traverse (Bonwick et al., 1988) and discrepancies were noted. The original forestry compass survey was incorrect.
Jubilee Cave SUSS	These maps were supplied by John Dunkley and again discrepancies were noticed. This time the latter survey was incorrect due to booking and proof reading errors in the forestry compass resurvey.
Barralong SUSS	John Dunkley supplied the original data and the final Barralong survey, this is being used as a base for the resurvey. It is suspected that there is a mistake in the previous plot of the data (G. Kates, pers.comm.).
Pool of Cerberus UNWSS	Data and sketch supplied by Ian Wood. Agreement with resurvey was excellent.
Imperial Riverway SAGCDG	The Imperial Riverway to the boulder pile past sump 4 and to sump 7. Agree ment was excellent with the resurvey of the airfilled sections. Data for the underwater and inaccessible air filled sections were used and adjusted by Radio Direction Finding.
Wilson's Last Cavern UNWSS	Sketch by Andrew Pavey used to check resurvey.
Imperial Cave SSS	This high accuracy survey had been carried out to position a "possible" tunnel either into the Diamond Cave passage or into Fairy Bower. It has been used for comparison with the resurvey.
Spider Cave SUSS	The survey of this cave has been published (Cox and Welch, 1984). Original data and master map were supplied by Guy Cox and have been used.

national, have also participated in the project. Appendix 1 is a list of all who have assisted in 1987 and 1988 and the names of those who are known to have contributed to the existing surveys that have been used in this project. Those who have played principal roles in the project have been singled out for special acknowledgement in the text.

Invaluable assistance has been given to the project by The Jenolan Caves management and the guiding staff, who have aided the project in many ways; directing the surveyors to little known and unrecorded parts of the system, helping with surveying and checking surveys, loaning equipment and office space and providing interest and enthusiasm for the encouragement of project members. The names of the Jenolan Caves Guides are also recorded in Appendix 1.

The survey - It was intended that, wherever possible, the underground survey should be carried out using conventional magnetic cave exploration surveying techniques for which there were a number of data reduction computer programs available. Included angle surveying techniques (theodolites) would only be used where magnetic interference was present. A high grade surface survey would be used to link all the entrances and underground passages located by Radio Direction Finding (RDF). A detailed discussion of the surveying and computing techniques appears in The Jenolan Cave System Surveying Project - Part 2 (Bonwick et al., 1988)

Computing and drafting - When the computer data for a section of the cave was properly adjusted with loops closing, plans and projections were produced at appropriate scales. The field sketches are transferred to the master survey and then are taken into the cave to be checked and improved. The final stage is to fair draft the maps in a suitable form for publication. This demanding task is to be undertaken by Graeme Kates and Rick Pinnock.

General organisation -It was realised at the commencement of the project that the Jenolan Show Caves formed part of a very long and complex system. The length of 7200 m for the Jenolan Show Caves quoted in the Australian Karst Index (Mathews, 1985) was known to be a vast underestimate. However, even seven kilometres of cave requires considerable organisation of survey data and sketches. The organisation increases significantly with multiple parties surveying. These parties have to be coordinated so that surveys and survey station numbers would not be duplicated and be supplied with tie-in points to the master survey. In 1987 the organistion of the survey was planned; by the end of the year it was clear that a reassessment of procedures was necessary. At the beginning of 1988 a meeting of most of the regular surveyors was held to discuss and agree upon ways to improve the organisation before that year's surveying started.

Survey station labelling - Five character alphanumeric survey station labels were used. Typically the first character in the label is an alphabet character which indicates the section of the cave system. The remaining four characters are numerics. A unique series was usually allocated to each group each weekend. During 1988 clubs were allocated a numeric sequence in the Southern Caves. Table 2 shows the characters that have been allocated for the various sections of the cave; the locations are somewhat arbitrary and have been made to assist data handling and plotting.

Areas allocated - In order to simplify the organisation and to complete one section at a time it was decided to divide the system into two main sections; the caves north of the Grand Arch (the Northern caves) and the caves south of the Grand Arch (the Southern caves). The Northern caves were to be surveyed first. The initial survey of the Northern caves was finished early in 1988, it is still being checked.

During the survey of the Northern caves, surveying teams were allocated passages one at a time with a view to finishing areas of the cave systematically. This was inefficient, time consuming for the organisers and lead to some duplication of surveying. As a result, teams in the Southern caves were given all the side passages in an area to survey.

TABLE 2
CAVE SECTION CHARACTER ALLOCATIONS

B	Binoomea Caves; includes Binoomea Cut, Baal, Orient and Ribbon
C	Chifley
D	Devils Coach House; includes Nettle and Arch
G	Grand Arch; including minor passages off the Grand Arch
H	Spider Cave
J	Jubilee; including Imperial Riverway
L	Lucas
M	Imperial; including Elder and Jersey
R	River; including Pool of Cerberus
S	Surface
W	Barralong; including Red and White Temples
Z	Lightswitch boxes

Familiarisation - At the commencement of the survey none of the organisers were familiar with the cave to be surveyed. Over the first year they were introduced to the cave a section at a time. This meant that they and a few others spent considerable amounts of time escorting the surveyors to their starting points. At the suggestion of Ernst Holland, before commencing the survey of the Southern caves, a familiarisation tour was carried out for all regular surveyors. During the tour, areas requiring special treatment either because they were fragile or needed exploration were pointed out. The result of the familiarisation tour meant that the organisers have been freed from their escort duties.

Tie-in points - In the Northern caves side passages were often surveyed before the main traverse and this lead to numerous problems in establishing tie-in points. The only permanent survey stations placed in the Northern caves during this project were drill holes in the concrete paths. Relocation of these holes has proved difficult as they become filled with dirt and are virtually indistinguishable from drip holes in the concrete.

The Southern caves main traverse was marked with surveyors nails. In case side passages were surveyed before the main traverse on the Southern caves survey, all lightswitch boxes were given a Dymo tag number and the red light on the box was taken as a station. The lightswitch boxes were then surveyed in during the theodolite traverse. However, it must be realised that lightswitch boxes are semi-permanent stations as one has already been moved due to upgrading of the electrical wiring.

The surface traverse has been marked with surveyors drill holes with wings or wooden pegs.

Sketches - Many of the early sketches for the Northern caves are not drawn to scale. The sketchers tended to use map symbols that they were familiar with despite being issued with a set of ASF map symbols (Mathews, 1985). Transcribing these sketches to a master map was extremely time consuming and the assistance of Vicki Bonwick in this task is gratefully acknowledged. During the survey of the Southern caves the field sketches were requested at a scale of either 1:100 or 1:200 with ASF map symbols.

In organising data and sketches, filing them by date was a mistake for rapid retrieval. Files by area are more effective.

Table 3 summarizes the changes in organisation that occurred between the Northern and Southern caves surveys.

Length of the project - With four or five survey teams working one weekend per month the project had been estimated to take a year. The project is about to enter its 17th month and is likely to take some 24 months. The organisational problems have slowed all aspects of producing the final maps but they cannot be entirely blamed for the slow progress. Maintaining the quality of the main underground and surface traverses and the quality control on the magnetic underground survey have all been time consuming. At no stage have standards been compromised in order to finish the project rapidly.

Exploration - in order for this survey to be as complete as possible all squeezes, grovels and climbs were investigated. During these investigations only a short length of new cave has been entered for the first time. The ends of "promising" passages are almost always decorated with the graffiti of previous explorers and date from the 1890's to the 1960's. Many of these passages remained concealed from the surveying teams until shown to them by Ernst Holland and other guides at Jenolan. During these investigations some myths have been destroyed and others confirmed.

The most successful exploration during the time of the project has been the connection of the Imperial Riverway with Spider Cave by SUSS. This has added an additional 2 km plus passage to The Jenolan Cave System. The assistance of Jill Rowling, Guy Cox and Mike Lake in supplying and transferring the original

TABLE 3

CHANGES IN ORGANISATION NORTHERN - SOUTHERN CAVES

	1987 Northern caves	1988 Southern caves
1.	No familiarisation tour	Familiarisation tour conducted
2.	Several groups surveying side passages in the one section	Group allocated a section and surveyed all side passages
3.	Theodolite traverse generally behind side passage surveying	Theodolite traverse generally ahead of side passage surveying
4.	Coordinates for main traverse not available until computed.	Coordinates for main traverse available in cave
5.	Main traverse stations marked with drill holes.	Main traverse stations marked with nails
6.	Light switch boxes not surveyed in	Light switch boxes surveyed in
7.	Sketches at random scales	Sketches at 1:100 or 1:200
8.	ASF survey symbols not always used	ASF survey symbols used
9.	Data and sketches filed by date	Data and sketches filed by area
10.	Sketches often needed to be redrawn photocopied reduced or enlarged before inclusion on final map.	Sketches drawn to correct scale by surveyor before inclusion on the final map.

data for Spider Cave to the projects data base is acknowledged.

The survey has enabled exploration to become focused on areas where further connections with very close caves may be made such as Aladdin, Glass and False Frenchmans. Because of its considerable length a connection with Mammoth Cave is the most desirable, the distance between the southern end of Mammoth Cave and the northern end of Spider Cave is 500 m. Slowly the Jenolan master cave system is yielding its secrets and Henry Shannon's Hairy Diprotodon is being exposed.

Conservation - during exploration and surveying, special care has had to be taken of the particularly fragile nature of The Jenolan Cave System. Without due caution it would have been possible to destroy irreplaceable decorations and sediments and to further mark the cave with graffiti. In the early stages of the survey, teams were reluctant to investigate and survey in delicate areas and thus missed many extensions. Later a combination of specific instruction from the Jenolan Caves senior guide, taking in clean clothes, taking off clothes and padding exploration equipment, meant that all but the most fragile areas could be explored and surveyed. However, a climb to a promising lead at the top of the Temple of Baal Chamber had to be abandoned because of the risk of falling mud and calcite hitting a splendid decoration known as the Angels' Wing.

ASSESSMENT AND THE FUTURE

During the first two years of the Jenolan Cave System Surveying project much has been learnt by all participants. Two of the organisers were completely confident in their ability to survey caves in general and long caves in particular. They had surveyed and prepared maps of caves all over the World and the two most notable are the Atea Kananda at 35 km and Mamo Kananda at 55 km (James et al., 1983). The main difference in this survey is the standard at which it is being carried out and the checking that is going into the final production. There have been smaller caves and sections of cave surveyed at similiar standards but nowhere has a cave as large and as complex as The Jenolan Cave System been surveyed in this manner. The way in which the results of the project are to be published are presented in The Jenolan Cave System Surveying Project - Part 2, Techniques and Computing (Bonwick et al., 1988).

The length and depth of The Jenolan Cave System - The published length for The Jenolan Cave System must be acceptable both nationally and internationally. The cave system after its connection with Spider Cave is a contender for the honour of being the longest cave in Australia. The present longest cave is Exit Cave, Tasmania at 17 km (Mathews, 1985).

The first contentious point is whether caves on two sides of an arch are part of the same system. The consensus is that they are and there are only a few dissenting voices. The second is what length to use for the large features such as the Grand Arch and connections to the passages off it. In order to obtain a contour survey of the Grand Arch over 8 km of traverse was measured. To establish a length for this feature there are two possibilities. One is to survey from passage to passage around the circumference of the feature. The length of a feature such as the Grand Arch is the traverse line from dripline to dripline with projections to the passages leading from it. This was the method used after discussions with an international group of speleologists attending the Man's Impact on Karst conference at Jenolan, August 1988.

At the time of writing the length of The Jenolan Cave System derived from the main computer traverse (after the data has been reduced) is 14.4 km; this includes 1.8 km for Spider Cave. There is still a considerable amount of data from recent surveying to transfer to the data reduction program. The present depth of The Jenolan Cave System is 104 m but this figure will increase as the main computer traverse does not as yet include the highest point of the cave system.

What is there left to survey? - There are many extensive sections of the cave yet to be surveyed; they are:- the Spider-Imperial connection and Spider Cave extensions, part of the Lucas main traverse, Exhibition Chamber and side passages and the Barralong side passages together with the Red and White Temples.

There is only one known existing survey of the dives in the Southern caves where significant lengths of underwater passages have been explored.

These will be surveyed by the cave divers.

The future - In the future it is expected that the Jenolan Cave System Surveying Project will extend and become The Jenolan Caves Surveying Project. Hence the complete network of cave and surface traverses for Jenolan will be available on one data base.

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APPENDIX 1
ACKNOWLEDGEMENTS

The organisers of The Jenolan Caves Survey Project gratefully acknowledge the help and encouragement of the cavers listed in the table below. This list will continue to grow as more cavers participate and other contributions are brought to the attention of the organisers.

ALLAN, TONY
ALLUM, ROBYN
ALLUM, RON
ANDERSON, TED
BARLOW, CAREY
BARLOW, DAVID
BONWICK, MARK
BONWICK, VICKI
BOWMAN, GLEN
BRANAGAN, DAVID
BRIDGE, DONNA
BRIDGE, RUSSELL
BRIDGE, SUZANNE
BRISTER, K
BROWN, CHRIS
BROWN, PETER
BYE, JULIE
CALLAGHAN, JOHN
CARRICK, STEPHEN
CHALKER, LEONE
CHALLIS, BRYN
CHAMBERS, MATTHEW
CLEVER, BRYAN
COCHRANE, JANE
COLE, PHIL
CONNOLLY, DEBBIE
COX, GUY
CRAWLEY, STEVE
CULLY, PETER
DEVINE, LOUISE
DOUGHTY, DAVE
DUFFIN, A.
DUGGAN, JAMES
DUNKLEY, JEANETTE
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DUNNE, CHRIS
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FURBY, JUDITH
GIANNOTIS, NICK
GIBIAN, MIKE
GIBSON, FERGUS
GIBSON, MARGARET
GIBSON, REG
GREY, MIKE
WOOD, IAN
GRUNDY, ALAN
GUY, RICHARD
HAMPTON, FRAN
HARDY, ANTHONY
HAWKES, NICK
HAWKINS, ROBERT
HAY, A.
HEARN, DAVID
HINE, LIONEL
HOBBS, DEREK
HOLLAND, ERNST
HOOLITHAN, KELLY
HUGHES, KEVIN
INNES, GEOFF
JAMES, JULIA
KATES, GRAEME
KEIR, BELINDA
KING, RANDALL
LAKE, MIKE
LARKIN, PATRICK
LAURENDET, CRAIG
LAURENDET, HELEN
LAURENDET, MARK
LEWIS, IAN
LINDSAY, ROBERT
LUKEY, CHRIS
LUTHERBURROW, IAN
MACKENZIE, W.
MATTS, DON
MARTIN, DAVE
MATHER, C.
McCARTNEY, JUDY
McCARTNEY SIMON
McLAREN, ANNE
McLAREN, SONNY
McNEAL, JUDY
McNEAL, RICHARD
MELHUISH, NICK
MICHIE, JANE
MICHIE, KATE
MICHIE, NEVILLE
MITCHELL, CAROL
MORRIS PETER
MUENZENRIEDER,LUDWIG
MURRAY, SIMON
NEWBOULD, RON
NIEUWENDYK, PETER
NURSE, BEN
OLIVER, JENNY
OLIVER, KEITH
OLIVER, PETER
OSBORN, JOHN
OSBORNE, ARMSTRONG
O'DRISCOLL, STEVE
PEMBLE, HARRY
PASLEY, KEITH
PAVEY, ANDREW
PINNOCK, KIM
PINNOCK, RICK
PROBST, CHRIS
PRUST, PHIL
RAWLINSON, NOEL
RIDEOUT, JOHN
RIDGLEY, ADRIAN
RITCHIE, BILL
ROGERS, PETER
ROSS, CHRIS
ROWLING, JILL
RUBIN, JEFF
RUDMAN, TIM
RUXTON, PETER
RYAN, GREG
SCANLAN, NIGEL
SCOTT, MARTIN
SEABROOK, JIM
SHANNON, HENRY
SIMINGTON, ALISTER
SPATE, ANDY
SPENCE, PAUL
SPENCE, R.
STARAJ, MARK
STARCY, M.
STOFFELS, DIRK
TOOMER, PHIL
TRICKETT, OLIVER
TUNNOCK, GREG
TUNNOCK, LYN
VAUGHAN-TAYLOR, KIER
WARILD, ALAN
WASMUND, MICHAEL
WELCH, BRUCE
WELLINGS, PETER
WHEATLEY, ADRIAN
WHITE, TONY
WILCOX, LIANE
WILCOX, SHANE
WILKINSON, G.
WILSON, MARK

ADDITIONAL

FRANKLIN, ROSS
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MOSS, PAUL
SMITH, MARTIN
STEENWICK, KEITH
WINGLEE, PETER

AERIAL PHOTOGRAPHY - AN IMPORTANT TOOL USED IN EXPLORATION AND RECORDING OF LIMESTONE KARST AREAS IN FAR NORTH QUEENSLAND, AUSTRALIA.

Tom W. L. Robinson.

ABSTRACT

The existence of caves at Chillagoe has been known for over a century. In those days, however, knowledge came from individual experience or by word of mouth from someone with that experience. Only in the last twenty years has an organised attempt been made, to document features as an aid to conservation of this and other, limestone areas.

This documentation involved the naming or numbering of the limestone outcrops and tagging of the individual entrances to caves with a numbered metal plate identifying the cave to which it led. Having tagged an entrance it became extremely important to record exactly where it could be found by persons who had never been there before. In North Queensland, relocation can be hampered by the complex and rugged tower karst terrain and the vegetation, which seasonally camouflages or exposes, the bedrock slopes and collapse dolines. Add to this insufficient information as to the whereabouts of the entrance, and you have the recipe for a lost cave.

INTRODUCTION

Most cavers in North Queensland have experienced difficulties in the relocation of a cave. Often, in looking for an elusive entrance, they find others. Recognizing the correct entrance can be difficult unless it is accompanied by an accurate description or a photograph, if the latter is possible. The position of the actual tag should be noted in the original entrance description, as a guide to just where to look. Chillagoe Caving Club have adopted a convention of placing tags on the left hand side of entrances at about chest height and visible from the most practical approach to the entrance. Where entrances are large dolines, lengthy grikes or shafts this convention breaks down so the description is vital.

Ideally, external surveys from the cave tag to a base datum point should be the responsibility of the tagger. This should be provided together with an entrance description, and if possible, bearings to other salient features visible from the entrance, not forgetting the relevant tower numbers.

Where there are no other established base datum points, the job of recording an entrance becomes more difficult. In areas where time and access problems are not great, it is possible to spend time establishing survey datum points on, or at the foot of, the cavernous towers. These can be used as reference points for later cave entrance location surveys. Care must be taken in the choice of reference points. Blazed trees are not successful. Numbered plates attached to trees by nails were attacked by sap chemicals, expelled or overgrown within two years of application. Large rocks at the foot of bed-rock slopes are far more easily recognized as reference points, and may be photographed for record purposes. Should they be identified with numbered triangular shaped perimeter survey tags, these should be fixed in a way that expansion or contraction will not loosen them. (One such survey tag was removed by a Bower bird, and was later recovered from its bower.)

AERIAL PHOTOGRAPHY

In remote wilderness areas, such activity may be considered a waste of precious time, especially when exploration is considered to be of prime importance. In such areas aerial photography has much to offer. Firstly by obtaining the relevant photographs of the area in stereo pairs, larger scale detail maps can be prepared of the area to be of assistance to the ground party. It is advisable to purchase those flown at the lowest altitude, and if possible have them enlarged to 1:5000 scale for mapping purposes. Maps drawn to scales larger than this will be too small to record entrances clearly, should the density of cave entrances be great.

Such aerial photography will also indicate drainage patterns, the breakdown of the tower into tower groups, and other landmarks useful for survey purposes. Sometimes resolution on the photo allows cave entrances to be suggested.

OBLIQUE AERIAL PHOTOGRAPHY

Having produced a map of the area, other forms of aerial photography complement the system. Actually an extension of "photo tagging", this method involves the taking of a number of low level, oblique aerial photographs, while circumnavigating the tower or towers concerned. It is essential that these obliques should contain the whole "face" of the tower including the top and the base and to avoid confusion, should the aircraft be on an extensive photographic mission, detailed records should be kept of the position of the aircraft relative to the towers for each photograph in the sequence. Copies of these photos can be used in the field by parties to more readily identify the actual position of entrances which can be marked on the photograph. An entrance location and description is all that is required to supplement the oblique photos and accurately place the entrance position on the map.

CONCLUSIONS

Though initially expensive this method of recording cave entrances is very effective and is really the only form of "photo tagging" suitable to North Queensland tower karst areas. It also provides a "bird's eye" view and often gives the cave explorer clues of where to look for new caves.

COMPARISON OF NORTH QUEENSLAND TROPICAL KARST AREAS

Tom W.L.Robinson

ABSTRACT

Comparisons between the Chillagoe, Mitchell-Palmer, Wallace Creek and Mt. Consider areas. Factors contributing to the evolution of the present day landscape.

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CAVES (Karst, survey and management)

"IS ASF RELEVANT?" TWO PERSPECTIVES.

Andy Spate and John Dunkley.

ABSTRACT

Lack of understanding of the respective roles and aspirations of managers and cavers by each party often leads to adversarial positions and potential conflict. These two papers address questions relating to communication between cavers, cave managers and cave scientists.

1. MANAGERIAL INTERACTION WITH CAVERS

Andy Spate

ABSTRACT

This paper addresses the needs, expectations and obligations of cave and karst managers and of users. It is primarily concerned with the interaction between managers and users of wild caves.

Examples of conflict are briefly discussed and some suggestions for non-adversarial interaction are given. It is emphasized that interactions between managers and users must be two way and that both sides must understand the responsibilities, aspirations and obligations of the user.

2. ASF: HOW RESPONSIVE AND HOW RESPONSIBLE

John Dunkley

ABSTRACT

This paper develops some of Andy Spate's themes and asks whether ASF (or cavers generally) are capable of an intelligent response. Central to the success of ASF policies and image of organized speleology generally has been the close relationship between members interested in scientific research, conservation/management and recreational caving. However several developments in recent years call into question the continued effectiveness of ASF in addressing all of its stated aims.

Some suggestions are offered for discussion and debate.

INTRODUCTION

This paper is concerned with the needs, inter-relationships and roles of managers and users of non-tourist ("wild") caves. Some managers will be private landholders, tourist cave operators, other park rangers or similar. Obviously there will be different responsibilities but reactions are often similar. Users will extend in a broad spectrum from highly motivated and skilled cavers and scientists to out and out "ratbags". Hamilton-Smith (1981) has a useful discussion of the user spectrum; perhaps the manager spectrum should also be examined in a similar way.

First of all I feel that I must make a personal statement about my job and my involvement with cave users. This paper is in many ways a personal credo and perhaps plea for both cavers and managers to become more aware of each others needs and hopes. I have written elsewhere (Spate 1973, 1984) of my views that use of caves (by cavers and tourists) is more damaging to the cave resource than is sporadic quarrying, rubbish dumps and perhaps forestry operations. Davey (1976) presents a useful discussion of these problems. That is not to say that there are not very considerable dangers from such activities especially at places like Mount Etna, Yessabah and in Tasmania.

My position is unusual in that I manage directly no karst resources. I tender advice to Service staff (at district, regional and head office levels) and to some organizations outside the Service which request assistance from the Service. Examples of these latter include shire councils, NSW Government agencies and in a few cases Government agencies outside NSW. I have also had a long amateur caving career and have conducted research into various aspects of karst in various parts of Australia. Because of this personal involvement with caves I am often called upon to act as a "prisoners friend" to cavers and research workers. The resultant wearing of two hats I find quite difficult and debilitating - I thought I was becoming paranoid but recently found out that this paranoia takes only 4-6 weeks to develop in cavers becoming managers/guides.

To some extent the cave management in NSW has entered a new era with a more open and professional approach to the management of caves and karst. The reasons for this are many; the increasing professionalism of bureaucracies and cavers, increasing public pressure and avenues for public involvement, reduction in management by regulations displayed on quaint antique boards (all saying penalty "Five Pounds"). The recognition, by managers, of the legitimacy of recreational caving as an "appropriate use" has certainly helped here as the whole approach has become more honest. In the past caving clubs have invented scientific looking excuses for obtaining access to controlled areas; these appear to have fooled managers. Perhaps they were just looking the other way? Hopefully these times are past and both cave users and managers recognize that there must be a spectrum of recreational, scientific and management opportunities.

When communications between manager and user break down, or have never been established, there often tends to be a runaway or snowballing effect and the parties become more and more distant. A recent example of this are the events surrounding the imbroglio around Kubla Khan Cave at Mole Creek in Tasmania. I believe that the "Mexican standoff" which has eventuated was utterly predictable and should never have happened.

Positive management, possibly involving physical works, is apparently required. A caving club started a hardening project which was ultimately halted by the management authority. It is unlikely that the managerial authority has the means or perhaps the expertise to carry out within-cave works and there seems to have been some double standards in relation to the control of visitors to the cave. Here, it appears to me, managers have lost access to labour and expertise and "face" in front of part of the caving community. Cavers, on their part, have lost contact with the managers and perhaps were behaving not very sensibly, or even perhaps irresponsibly, toward the cave. I believe there is "egg" on both faces.

The sudden advent of the Jenolan Environment Protection Committee and resulting multi-media controversy in my view is a similar case but perhaps with a reversal of the "silliness" role. However, more good is likely to emerge from the Jenolan happening than the Tasmanian affray.

On a smaller scale, we recently have had a cave dig encounter a very interesting looking sub-fossil deposit at Bungonia. The management body called a halt to this dig for around six weeks whilst some relatively cursory investigations took place. Interesting rumours began to circulate around the Sydney caving scene about the heavy hand of bureaucracy and about deliberate attempts to destroy the site completely.

Such digs should be closely monitored by both the diggers and managers to ensure that stratified sediments and/or bones are not destroyed, cave microclimates changed and that opening of new entrances does not lead to aggravation of management problems. The Punchbowl-Signature tunnel at Wee Jasper, dug and blocked in the 1960s, is a good example of this latter. History is now in danger of repeating itself at Bungonia with a similar dig. I believe that the ASF Code of Ethics adequately covers the situation for digging, but enthusiasm is often a distorter of ethics.

ROLE OF THE MANAGER.

The manager of publicly owned karst resources will have a variety of roles; some of these roles will be statutory, others will be traditional and thus perhaps of dubious value to either manager or user. An example of this latter might be the artificial minimum party sizes that seem to appear spontaneously in tourist cave areas. Often the one or two person party is the one most interested in the resource, they may well have a great deal to offer the guide also.

Obviously the management direction will vary with the responsibilities and directions of the management body. But, as with other non-renewable resources, a conservative direction is indicated even if primary functions include revenue raising or tourist demand servicing. Clearly such conservative directions are hard to justify to accountants and similar professions - and hard-line government adoption of user-pays principles do not necessarily help either.

A further complicating factor often raised is that of public safety. The NSW NPWS is often under pressure to open or reopen vehicular tracks to caves so that people can be rescued more easily. This is usually by people not aligned with formal caving groups who in NSW at least seem relatively happy to walk. Davey has pointed out that life is basically dangerous but this sort of statement is unlikely to impress the legal fraternity and the rising tide of "American" style litigation can only make the public safety red-herring more complex.

A third complicating factor is that of lack of resources and of priorities directed toward active on- and in-the-ground management. Whilst the human and money resource situation is unlikely to improve dramatically across the board there seems to be an increasing recognition of karst values amongst our management authorities and thus overall karst management is improving. Whether this increase has anywhere near the same slope as the gradient of increasing use pressures is another question.

The manager is thus the "meat in the sandwich" between the many conflicting expectations of the public and the statutes. For example the public would, I think, expect a cave tour to be completely safe (like cars, roads, cigarettes, etc.). However, the attraction of adventure tours must, in part at least, be the presence of real or perceived dangers such as darkness, vertical drops and so on.

All of this forces us into the spectrum approach where we provide opportunities for different sorts of use (e.g. the so-called OROS - the outdoor recreational opportunity spectrum of Stankey and others). In many ways wild cave areas managed by cave tourism authorities have traditionally been utilized this way but as a bi-modal, rather than as a continuous, distribution. Adventure tours start to introduce the continuity but are probably not enough to satisfy the full range of demands. In addition we certainly don't cope well with the apportioning the spectrum of cave and karst resources to match the user demands. This, of course, is the realm of cave classification which requires both a detailed knowledge of the local resource and the state and national perspective. We need more scientists looking at basic documentation of caves and their contents, at how their ecosystems work and what, if any, buffering capacity they have to cope with surface and underground disturbance. Unfortunately this sort of information is difficult to obtain and indeed difficult to relate to effective management strategies and tactics.

Very soon we must face up, nationally, to the fact that we have not enough of the resources to continue the way we (cavers and managers) have been going over the last few decades. One of the biggest tasks facing the manager will be to convince users of these limitations. Users like myself must realize that the "golden age" of caving is now past in Australia. This is demonstrated by the Australian leadership and involvement internationally in cave exploration in Papua New Guinea, Thailand and Mexico.

ROLE AND EXPECTATIONS OF CAVERS

I believe that the roles and expectations of cavers are not well understood by managers. This lack of understanding has in my opinion been partially engendered by the caving fraternity and some of the frustrations that both parties are now experiencing indicate that past practices and attitudes need change. Amongst these changes are the need for managers to recognize the validity of recreational caving as a pastime and users must also realize the limited nature of the resource and accept that some restriction will increasingly become the norm.

The question "Why does one go caving?" is frequently asked and is as frequently poorly answered as are most of these sorts of questions. One can respond with Sir John Hunt's immortal reply but the reasons are obviously far more complex. Much of the reason is clearly to do with the social networks that are established - managers reading trip reports that deal mainly with the Saturday night around the campfire may understand some of this. These sorts of reports may well arise from the difficulty most people have verbalizing or writing about emotive experiences. They rarely reflect the professional standards that many caving groups profess and certainly don't often provide the sorts of information managers must have in order to understand the resources they are entrusted with on behalf of the community.

The experience that cavers are attempting to satisfy include elements of the following inter-related needs:

* The need for "wilderness" experience over a broad range of expectations.
* The need to discover unknown places and new caves. This latter rarely happens but a degree of "unknownness" is probably there in most caves.
* The need for building social awareness and contacts - getting away from it all with some friends.
* The need to do something different without the obvious controls of modern society.
* The need to contribute to society in order to justify the relatively privileged access that has been made available in the past. As the "newness" of the experience dies away to be replaced by genuine inquisitiveness this need becomes more dominant.

Those interested in the motivation of cavers are urged to read Leakey (1978) who argued that the primary motive is one of fear coupled with being born to lead or to follow. He also points out that writing about caving is the supreme way of achieving fame and status in speleology - and avoids the inconvenience of actually going underground.

ROLE AND EXPECTATIONS OF RESEARCH WORKERS

There is clearly a continuum of researchers from the cave mapper through to dedicated and full-time institutionally supported workers. However there are a number of needs in common of which the most basic is access. This often needs to be relatively unfettered and sometimes extremely short notice - for example hydrological research needs access at times of extreme events which are unpredictable.

Sampling may be required and this may be destructive and sometimes on a wide scale. Sampling needs often sit uneasily on the shoulders of the managers of natural resources.

- resource documentation
- management actions based on sound advice
- sampling needs including destructive sampling
- sites of significance
- unfettered access
- lack of other visitor interference
- access needs conflicting with resource needs (bats in winter)

RESEARCH NEEDS OF MANAGERS OF NON-TOURIST CAVES

- resource documentation
- effect of use
- carrying capacity
- reactive capacity of the resource
- how to handle wild cave users
- what knowledge means to the manager

WORKING WITH USERS

- flexibility
- firmness
- cave access committees
- permits / contact / keys
- Jenolan Sci. C'ttee
- Wyanbene example
- rationing

USER RESPONSIBILITIES

- privileged positions
- rationality
- continuation of the integrity of the resource
- flexibility
- freedom
- mutual respect and understanding

CONCLUSIONS

It may be enough in this forum to finish with a quotation from Leakey (1978)

> "Finally mention must be made of the tiny minority who are the salt of the earth in caving. The only people of this century's cavers who future generations will revere in hatred and condemnation of the rest will be those few - the Show Cave Owners. Caves are continually being eroded away by cavers - albeit usually unintentionally floors are damaged and formations smashed. It is only with the protection of a Show Cave and the elements of access control that go with it, that some of our caves are likely to be conserved for future generations. Thus those who will achieve ultimate fame will be the Show Cave owners and/or proprietors."

ACKNOWLEDGEMENTS

Ian Household for explaining I am not alone in my paranoia.

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NOTES

LAVA TUBES

THE REMARKABLE UNDARA LAVA TUBE SYSTEM - A GEOLOGIST'S VIEW.

Anne Atkinson.

DEDICATION

To the memory of our dear son TOM
who built the first stairs into Barkers Cave
- and never lost his interest.

ABSTRACT

More than 20 arches and caves up to 13.5 m high and 1350 m long (but most less than 200 m) have been discovered in the remarkable Undara Lava Tube System. A total of over 6 km of tubes have now been surveyed and the first profile ever to depict a source volcano in addition to representative caves and arches is presented. Despite an age of 190,000 years, protection from weathering has allowed preservation of features usually seen only in younger or Recent lavas.

An estimated 23 km^3 of lava were erupted from the Undara Volcano to form a lava field 1550 km^2 in area. One of the flows extended over 160 km to become the longest flow in Australia and one of the longest flows in the world. This great length is attributed to very high effusion rate, favourable topography and lava tube efficiency. Temperature of eruption is estimated at approximately 1200°C, with no unusual viscosity.

The lava tube system, marked by caves, arches and long level ridges, extends for more than 100 km. The WALL SECTION is the first Earth feature considered analogous to sinuous ridges on the MOON. Other features are comparable with those described in lava tube systems elsewhere.

Oval to elongate depressions are adjacent to, or aligned with, the caves and arches. These are conspicuous on air photos as their "rain forest" vegetation contrasts sharply with the open forest of the surrounding country. The relationship of surface collapses to uncollapsed segments of the tube system is of particular interest.

Lava tubes are common in highly fluid volcanic eruptions but few have been recognised in older lava fields and their mode of formation has long been controversial (Atkinson, 1988, this volume).

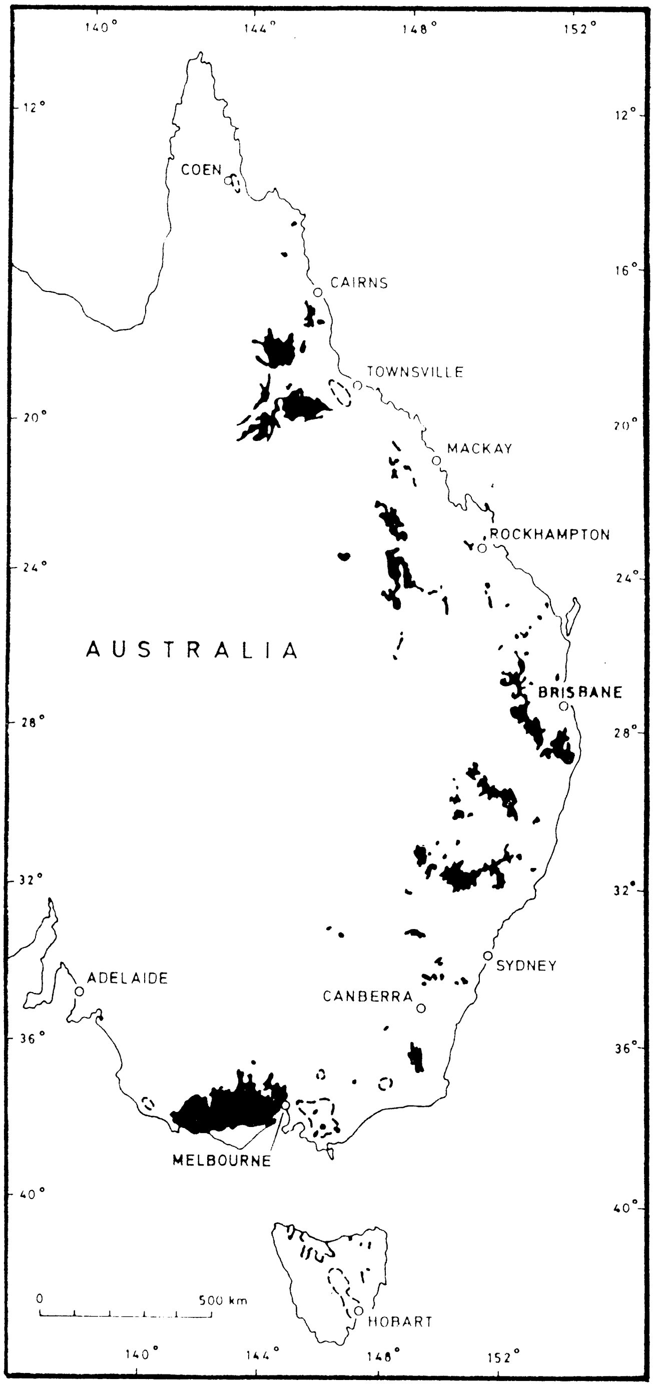


Figure 1: Cainozoic basalt outcrops of eastern and southeastern Australia, occur within 400 km of the coast and extend for over 4000 km. (Stephenson et al., 1980)

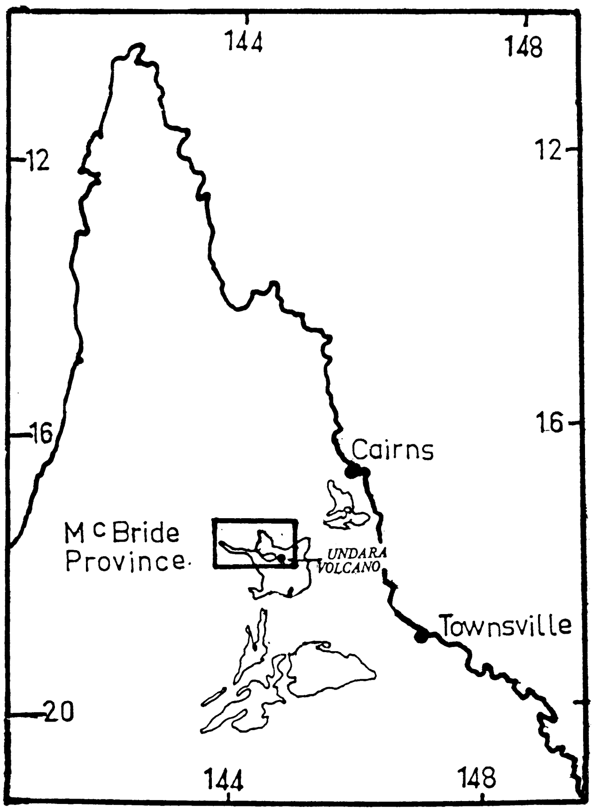


Figure 2: The main areas (provinces) of Cainozoic basalt outcropping in northeastern Australia. The boxed area is shown in Figure 6.

INTRODUCTION

Victorian lava tubes were the first described in Australia by Ollier and Brown (1965) and others. In North Queensland tubes are known in at least six localities (P.J. Stephenson, pers. comm., 1988) including Blackbraes and Spring Creek Stations and Barkers Crater area. Air photo interpretation indicates further tubes in the Toomba Flow (Nulla Province), and Kinrara Flow (McBride Province), in addition to those of Undara Volcano.

FIELD OBSERVATIONS - OVERSEAS

It has been the author's incredible good fortune on overseas visits, (1972, 1974 and 1980) to make brief observations, some in the company of noted geologists and speleologists, in the states of Washington, Hawaii, Oregon, Idaho, U.S.A., and in France, Sicily, Iceland, the Eolian Islands. As these observations are the basis for conclusions reached in this and the preceding paper they merit mention:

On the Island of Hawaii, in 1972, lava was flowing through a tube into the lava lake at Mauna Ulu and, in 1974, there was an eruption in the caldera of Kilauea Volcano. During a visit in 1980 no eruption was in progress but this and the previous visits afforded opportunity to study very recent flow features. Details of some are given in this paper.

LOCATION AND GEOLOGICAL SETTING

In eastern Australia, Cainozoic volcanism extended more than 4,000 km (Fig. 1), Stephenson, Griffin and Sutherland. In North Queensland, within 200 km of the east coast, there are five major areas, or provinces (Fig. 2) and the Undara Volcano is situated near the centre of the McBride Province (Fig. 2). The province covers approximately 5000 km^2 and topographically forms a broad dome. Of over 160 vents, the majority are in the central region and only one volcano, Kinrara, is younger than the Undara Volcano (Fig. 3).

The Yaramulla Section, in the western branch of the Undara System, contains most of the caves and arches and is in proximity to the largest granite inlier.

Figure 3: Aerial view of Undara Crater, 340 m across, looking West. The tube system commences in the line of depression running away from the crater towards the right. Photo: Tom Atkinson.

PREVIOUS INVESTIGATIONS

Unlike the American Indians whose pictographs and ancient fires give evidence of the use of lava caves from prehistoric times, local aborigines state that their people would have avoided such places. No drawings or evidence of fires have been found in the caves - only a few artifacts at one cave entrance. Two caves, Barkers (Figs. 4a and 4b) and Road Cave (Fig. 17), have been known for more than eighty years. The former was mapped by Shannon in 1969 but most of the caves were discovered, entered and mapped only in the course of the author's work, 1972-74.

TWIDALE (1956) in discussing the distribution of volcanic centres in the McBride Province noted that there were only two lineaments. Apparently through inadequate field investigation he incorrectly interpreted the aligned collapse depressions as "a clear arcuate fissure .... with a centre of eruption at its southeast end".

BEST (1960) and WHITE (1962) were the first to recognize the lava tube system. Without opportunity for detailed investigation, they interpreted the pattern of collapse features (Figure 5) as a collapsed lava tunnel, with north and west branches. SHANNON made the first lava tube survey in the system (Barkers Cave) in 1969.

Following the UQSS visit to the area in 1977, GRIMES (1977) made a very useful compilation of data from previous studies of the major known caves and these were published by MATHEWS (1988) who entered the cave names and brief descriptions in the ASF's Karst Index. IRWIN and GODWIN surveyed The Wind Tunnel and Inner Dome Cave this year.

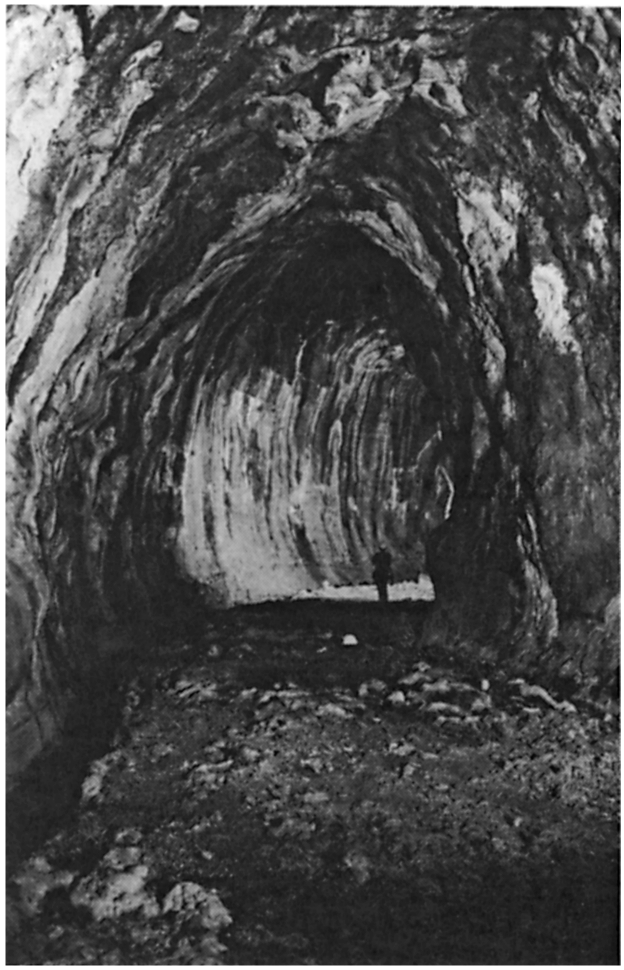


Figure 4a: Barkers Cave, 50 m from its entrance. Note gutter on left and lava level lines evident almost to the roof on distant wall. The lava tube height is 13.5 m at this point - the highest measured in the System. Granite hills are in closer proximity here than at any other location along the tube System. The relationship is interpreted between this and the height of the lava tube. Photo: H.J. Lamont, J.C.U.N.Q.

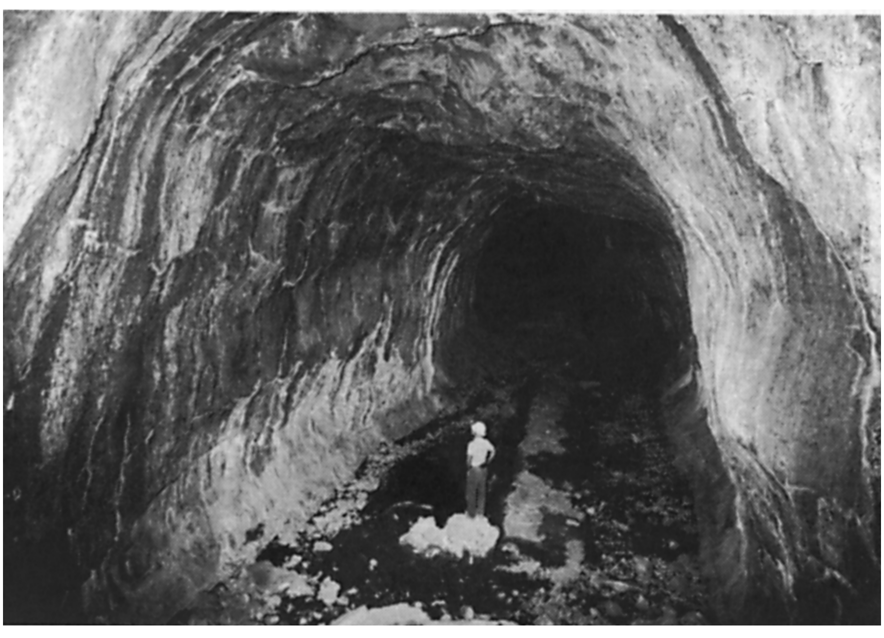


Figure 4b: Barkers Cave, viewed from the entrance collapse. Some of the original arched floor is exposed and has a distinctive "rope" structure. The distant cross section is almost circular. It is noted with interest that a distinctive pattern of vesicles on the large block in the centre foreground can be matched to one in the cave "roof" immediately above it. Photo: H.J. Lamont, J.C.U.N.Q.

Figure 5: Aerial view of aligned collapse depressions near Yaramulla, looking East. Kalkani, a pyroclastic cone not connected with Undara, is on the left. Photo: H.J. Lamont, J.C.U.N.Q.

AIMS OF 1972 - 1974 INVESTIGATION

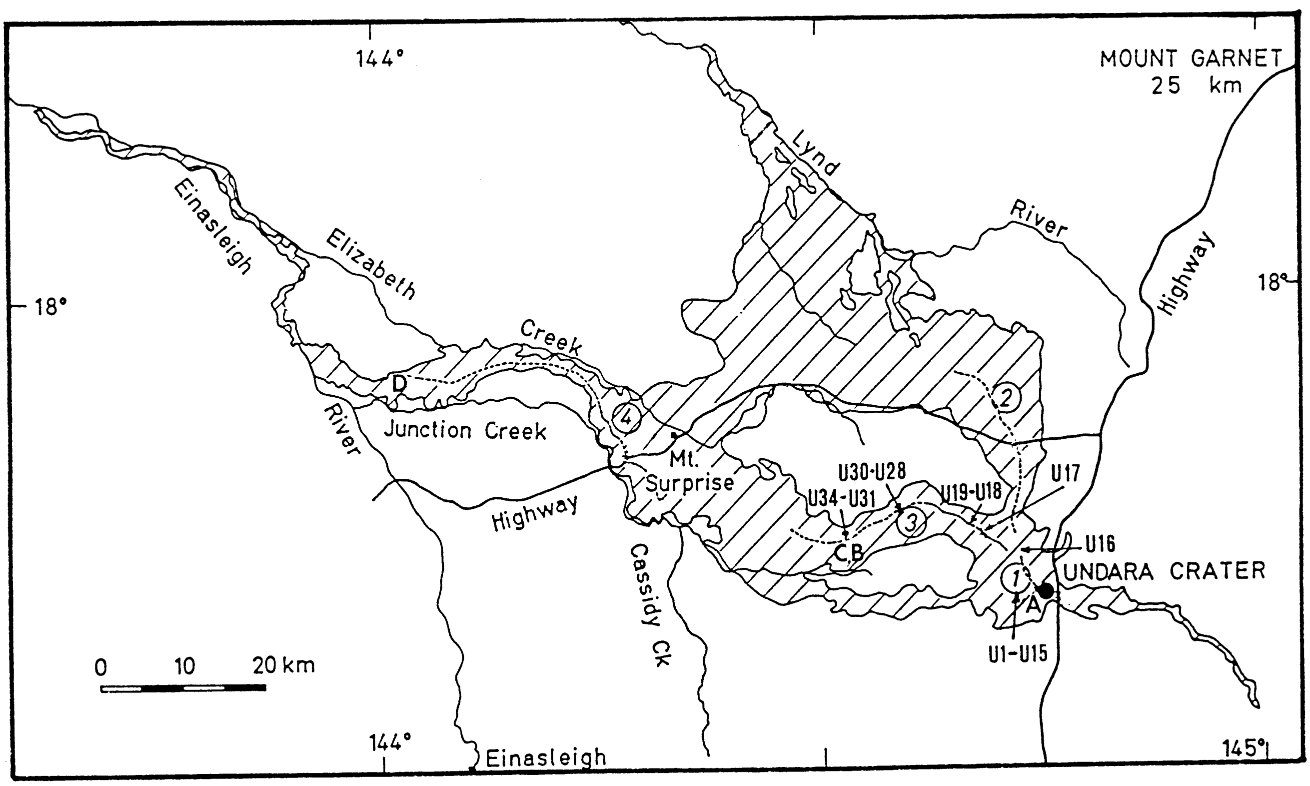
The aims of the 1972 - 1974 investigation were twofold:

1. At three locations (Figure 6), namely:
   a). close to the crater;
   b). maximum distance from it;
   c). at an intermediate location -

- to measure and map (Fig. 7) representative caves in order to establish any relationships between shape, size and distance from the source volcano. This would provide the data required to draft a longitudinal profile (Fig. 8) through a source crater as well as representative caves. No similar project had previously been attempted anywhere in the world (R. Greeley, pers. comm., 1974).

2. To discover evidence which would confirm or refute the mode of formation postulated by Ollier and Brown (1965) for lava caves in Victoria, by Hatheway (1971) for caves in New Mexico and by Greeley and Hyde (1972) for caves on Mt St Helens, U.S.A.

Figure 6: The Undara lava field. Circled numbers denote sections of the lava tube system referred to in the text: 1, Crater Section; 2, North Section; 3, Yaramulla Section; 4, Wall Section. Other numbers are locations of cave entrances as shown in Figure 8. Letters "A" to "D" denote locations of specimens chemically analysed (Table 2)



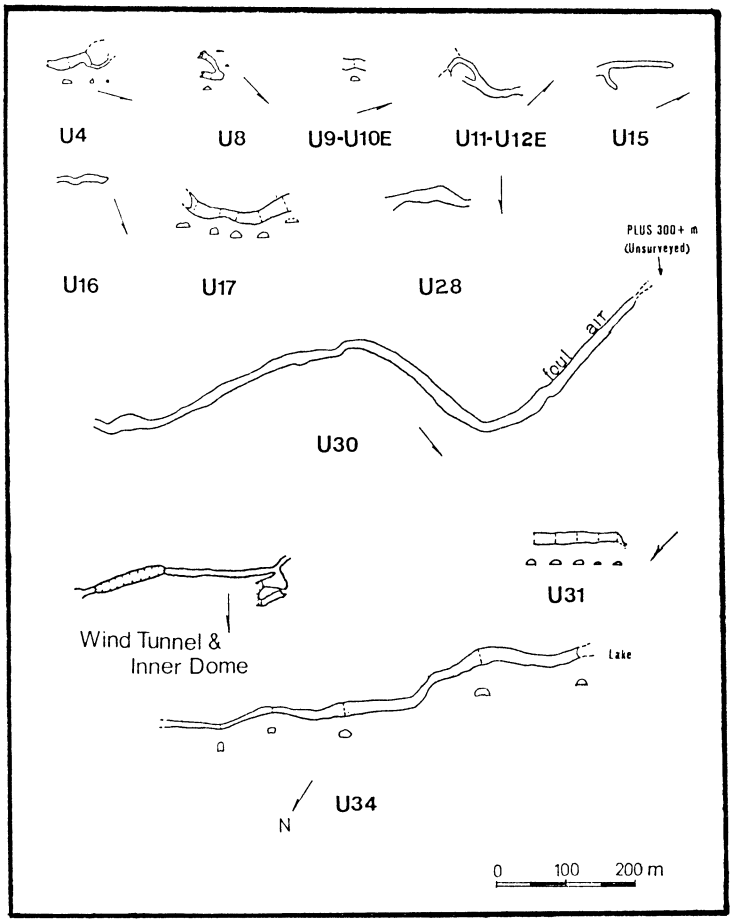
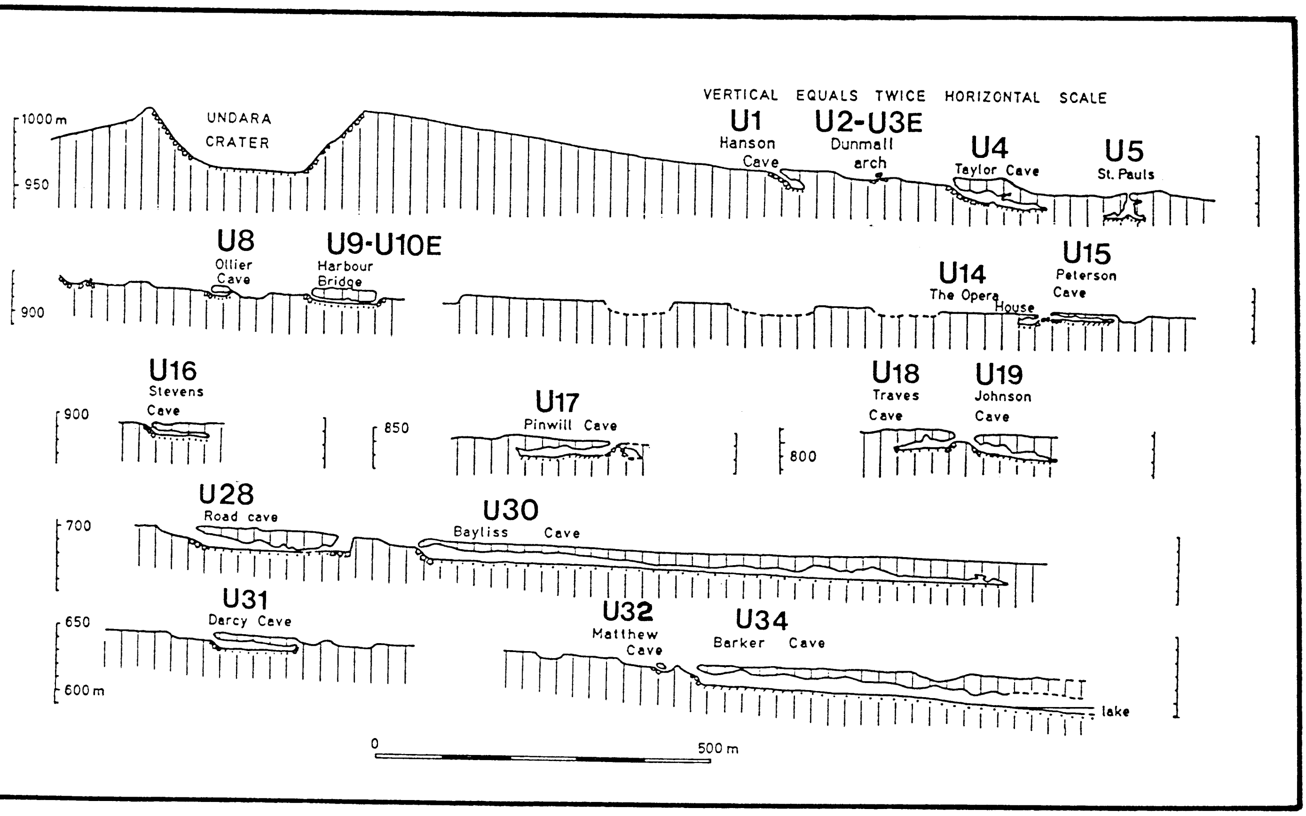


Figure 7: Maps of selected caves, with some cross sections. In all cases, lava moved from left to right. Localities - see Figure 6; cave names, Figure 8. Cave U11-12E is Greeley Cave; The Wind Tunnel and Inner Dome plans are shown. The extension (1987) of over 350 m of Bayliss Cave, now measured to over 1350 m, makes it the longest lava tube recorded in Australia. The extension is not shown as it has not yet been surveyed.

METHODS OF STUDY

Caves (locations, Fig. 6) and some collapse depressions (Fig. 5) were measured by tape, prismatic compass and Abney level from a datum approximately 10 cm square, painted on a conspicuous block at the base of each entrance collapse. At the suggestion of NASA geologist Greeley, helium balloons were used to measure cave heights. A narrow ribbon was marked and rolled on to a fishing reel and just prior to use a strong balloon was filled with helium and attached to the ribbon. Balloon gas was inadvertently supplied on one trip and found unsatisfactory. The length and inclination/s of entrance collapses were measured. Finally, a surface datum was painted to correspond as closely as possible with the cave datum. To ascertain roof thicknesses a surface traverse was then made from this point on the same bearings as the cave traverse, steel fence posts being left at most stations for easy future reference.

Figure 8: Longitudinal profiles of various caves down flow from Undara Crater. The A.S.F. Cave Register numbers are shown. Floor symbols: sediment (dotted), ropy lava (lined) and collapse blocks.



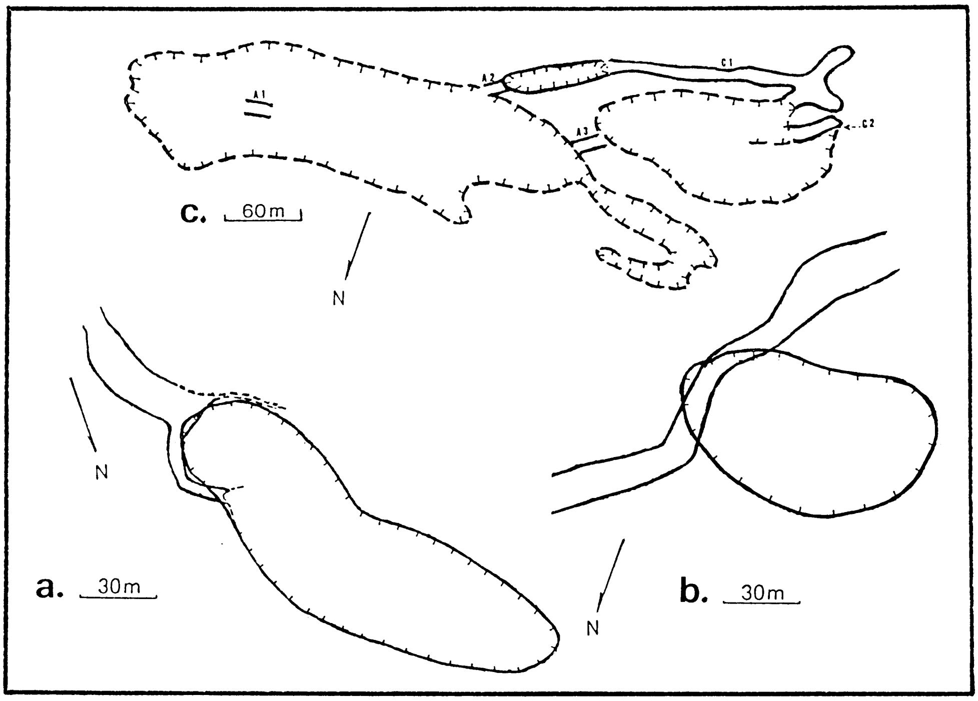


Figure 9. Relationship between surface depressions and caves: (a) Taylor Cave; (b) Barkers Cave; (c) The Wind Tunnel and Inner Dome Caves.

When no clear picture emerged re mode of formation of the tubes and because of their close proximity to some caves, two wide depressions (Figs. 9a and 9b) were investigated in 1973 by Atkinson and assistants. Similar depressions were mapped at Wind Tunnel by Irvin and Godwin in 1988 (Fig. 9c).

The method of study most significant to this investigation was, however, OBSERVATION OF FLOWING AND YOUNG LAVA. On the Island of Hawaii, in addition to traversing young lava fields (some still hot!), in the company of G.A. Macdonald and D.W. Peterson, Scientist-in-charge and staff of U.S.G.S. Volcano Observatory, the author was able to observe the following during eruption (Mauna Ulu, 1972; Kilauea Caldera, 1974):

- lava flowing in a channel;

- channel "roofing"; rafting of "roof" segments; jamming and accumulation of "roof" segments;

- lava flowing in a tube with lavicicles forming and dripping from "roof";

- temporary flow stoppage with cooling and darkening of flow front, followed by inflation and continued flow;

- degassing of flow and inflation of bubbles (less than 25 cm) of volcanic gas on the surface of channels;

- formation of spatter cone;

- formation of tree moulds;

- and other wonders.

UNDARA VOLCANO AND ITS LAVA FIELD

The Undara lava field covers 1,550 km² in the NW quadrant of the McBride Basalt Province (Fig.2). Its impressive crater (Fig. 3) is 340 m across and 49 m deep with inner slopes of up to 40°. The low rim rises only 20 m above the surrounding lava field. Outward slopes from the rim vary from 30° to 5° on the NW side. Although the major outflows occurred to the North and NW no evidence of a lava tube has been found there, despite prolonged search.

The crater walls are mainly covered by angular blocks (up to several meters across) of **highly vesicular to massive basalt.** Several indistinct terraces may mark former levels of a lava lake. Part of the crater floor is covered with fine red soil containing fragments of scoriaceous material and a small area of smooth pahoehoe basalt.

Undara Volcano, 1020 m, is the highest point in the McBride province. It erupted **190,000** years ago (Griffin and MacDougall 1975) and lavas flowed from it in all directions but mainly to the NW (Fig. 6). The major flow there reached and followed a precursor of Junction Creek and Einasleigh River for a total length of 160 km to become the longest lava flow in Australia and one of the longest flows in the world (Walker, pers. comm., 1974). Another flow, approximately 90 km long, entered the Lynd River (Fig. 6).

General thickness of the Undara lava field is estimated from 5 m near the edges up to 20 m or more in the thickest parts. Along "The Wall", West of Mt. Surprise (Figs. 10a and 10b), the flow could be up to 40 m thick but this is restricted to the width of "The Wall". Exploratory drilling on the north side of "The Wall" showed basalt depth of 25 m. Thus, if an average thickness of 15

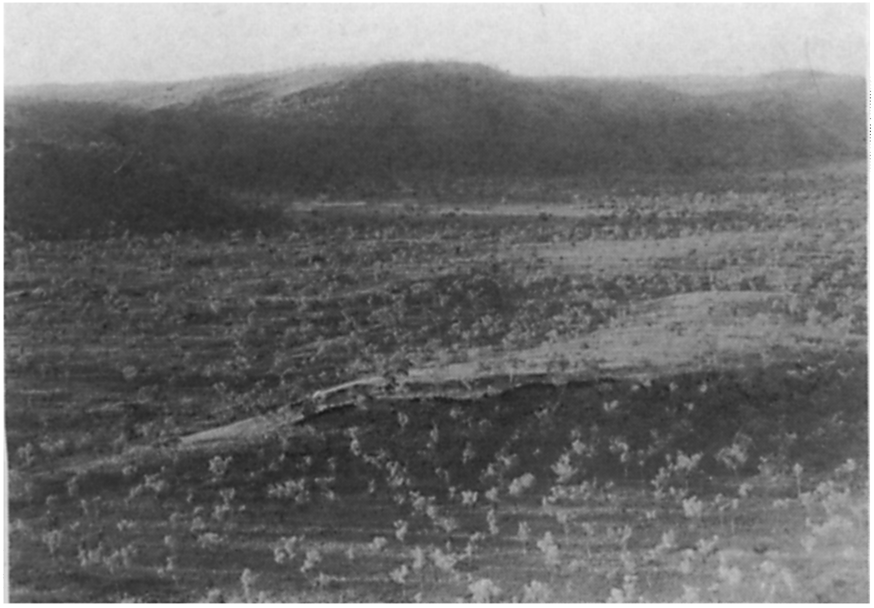


Figure 10a. Oblique aerial view of "The Wall", from the South. Note mega-columns flanking central collapsed area at the termination. Photo: Jon Edmonds

m is estimated for the whole flow, the total volume of lava erupted from the Undara Volcano is approximately **23 km³**.

It is of interest to note that where rock is exposed near the axis of the flow, polygonal mega-**jointing** (Spry, 1962) up to 1.75 m, is evident from the crater to the termination of "The Wall". The author has not examined the flow beyond this point but the constant size of jointing over a distance of 90 km would seem to be significant.

The Undara lavas were erupted at **temperatures ranging from 1175° C to 1220° C.** They do not appear have had unusual viscosities (Atkinson et. al., 1975) which accords with the conclusions of Walker (1973) that very long lava flows reflect continued high effusion rates rather than unusually low viscosity. Stephenson and Griffin (1976a) reached a similar conclusion in a study of eight long basaltic flows in Queensland.

The main lava tube system extends North and then NW from the Volcano. For convenience four sections (Fig. 6) are named:

1. **Crater Section** - extending North from Undara crater for 4 km; average slope 1.0°.

2. **North Section** - continuing a further 16 km possibly more than 28 km; average slope 0.5°.

3. **Yaramulla Section** - extending West from the Crater Section for over 35 km; average slope 0.7°.

4. **Wall Section** - approximately 35 km in length; an almost continuous narrow ridge, known locally as "The Wall", characterizes the western end of the system; average slope 0.09°.

The caves and arches occur in the Crater and Yaramulla Sections. In the North Section no caves have yet been

Figure 10b. Termination of "The Wall" viewed from the North. Note the mega-columns on horizon. Photo: Tom Atkinson.

discovered but a line of collapse depressions suggests the presence of a lava tube.

CAVES, ARCHES AND COLLAPSE DEPRESSIONS

The lava caves and arches in the Undara system are very well preserved in spite of their age (190,000 years). Most of the known caves, with total length exceeding 6 km, were mapped in detail by Atkinson and assistants (1972-1974). Examples are given in Fig. 7 and basic measurements are listed in Table 1. (Detailed maps are available on request).

Most of the caves are elongate in the direction of the main flow. Except for short distances, the original floors of caves with up-flow entrances are covered by later silty sediment. The maps and cross-sections (Fig. 7) and longitudinal profiles (Fig. 8) indicate the variation in shape, size and "roof" thickness.

Although **most caves terminate down-flow** with collapses or a gentle downward curve of ceiling to silt floor, there are exceptions described in a later section. Barkers Cave has been explored only as far as a lake, the cave ceiling steadily declining to water level (Figs. 8 and 11). Several caves have down flow entrances and have little or no silt on their floors. Apart from collapse terminations found in some of these up-tube caves, two caves, Pinwill and The Opera House (Figure 12) have abrupt walls across the cave.

Cave floors represent the final flow in the tube. Some floors are almost flat, others are arched, as near the entrance to Barkers Cave, (Fig. 4b) and in some caves there are pronounced marginal gutters (Fig. 4a).

Where exposed some floors show interesting variations: the best examples of ropy lava being in Pinwill Cave and the almost inaccessible east Chapel of St. Paul's. In a central position near the entrance to Barkers Cave, crust fragments, approximately 8 cm thick, have been rafted at varying oblique angles (Figure 13) in a manner similar to ice slabs on a frozen river. In Peterson Cave there is a small but unique floor surface: lava drops from "roof" re-melt appear to have pitted the floor as rain drops pit a muddy surface.

TABLE 1 - UNDARA LAVA TUBE SYSTEM - CAVE DIMENSIONS
* Atkinson, Griffin and Stephenson 1975. # Estimate only.

Cave	Register Number (ASF)	Length (m)	Maximum Height (m)	Maximum Width (m)
* Hanson	U-1	40	3	12
* Dunmall Arch	U-2, U-3E	-	2	6
* Taylor	U-4	108	10.8	16.3
* Peter	U-	13.8	3.8	9.9
* St. Paul's	U-5	8	-	-
* Sarah	U-6	-	-	-
* Ollier	U-8	49.4	3	10.4
* Harbour Bridge	U-9, U-10E	35	5	14.3
* Greeley	U-11, U12E	103	3.8	12.4
* Frances	U-13	-	-	-
* Opera House	U-14	30	-	-
* Peterson	U-15	102	3.7	17.1
* Stevens	U-16	70.4	3.0	8.8
* Pinwill	U-17	150	8.9	21.0
* Traves	U-18	67	10.6	14.0
* Atkinson (formerly Johnson)	U-19	101.2	7.8	28.0
Wind Tunnel and Inner Dome	U-	467	-	20.0
Arch 1	U-21	160	5+	25.0
Arch 2	U-22	-	10	25.0
Arch 3 (SW)	U-23	50	-	-
Arch 3 (SE)	U-	100	-	-
Picnic 1	U-24	420	-	-
Picnic 2 (NE)	U-25	45	-	-
Dave 1	U-26	50	-	-
Dave 2	U-27	27	-	-
* Road	U-28	220	9.4	21.2
* Bayliss	U-30	1350+ (1988)	11.5	18.9
Nasty	U-25	100 #	6.0 #	15.0 #
* Darcy	U-31	99	6.3	16.3
* Matthew	U-32	40	-	-
* Barkers	U-34	905 (1968)	13.5	19.8

Figure 11: Terminal lake, Barkers Cave. Photo: R. Dutton.

On the walls and roof of most caves there is a lava lining, typically a single layer up to 20 cm. In some places linings approach one metre in thickness. At various locations the tube lining has fallen off the wall to expose the host lava behind it. The lining is sometimes multi-layered, the best example being in Pinwill Cave, where fifteen layers, 2-4cm thick, are revealed at one location (Fig. 14b). At the entrance to the same cave a thin slab of lining, "The Table", (? showing slight plastic deformation) has become dislodged and now rests in a near-horizontal position (Fig. 14a). Most walls feature a glazed surface, with drip and dribble structures resembling cake icing (Fig. 15). In places there are lavicicles (lava stalactites), commonly 2-4 cm, rarely up to 8 cm, suspended from the roof and wall cavities (Fig. 16). Lava stalagmites are rare.

In most caves, **lava level lines and ledges** are present, representing fluctuating lava levels. The highest levels are usually evident very close to the full height of the roof, the best examples being in Taylor, Road and Barkers Caves (Figs 4a, 17 and 18). Within caves, these lines and ledges had been observed by torch light and with single flash but never with the clarity revealed in the Lamont photographs, particularly Figure 4a. The lava level lines usually slope down-tube at low angles, presumably equivalent to the original tube slope.

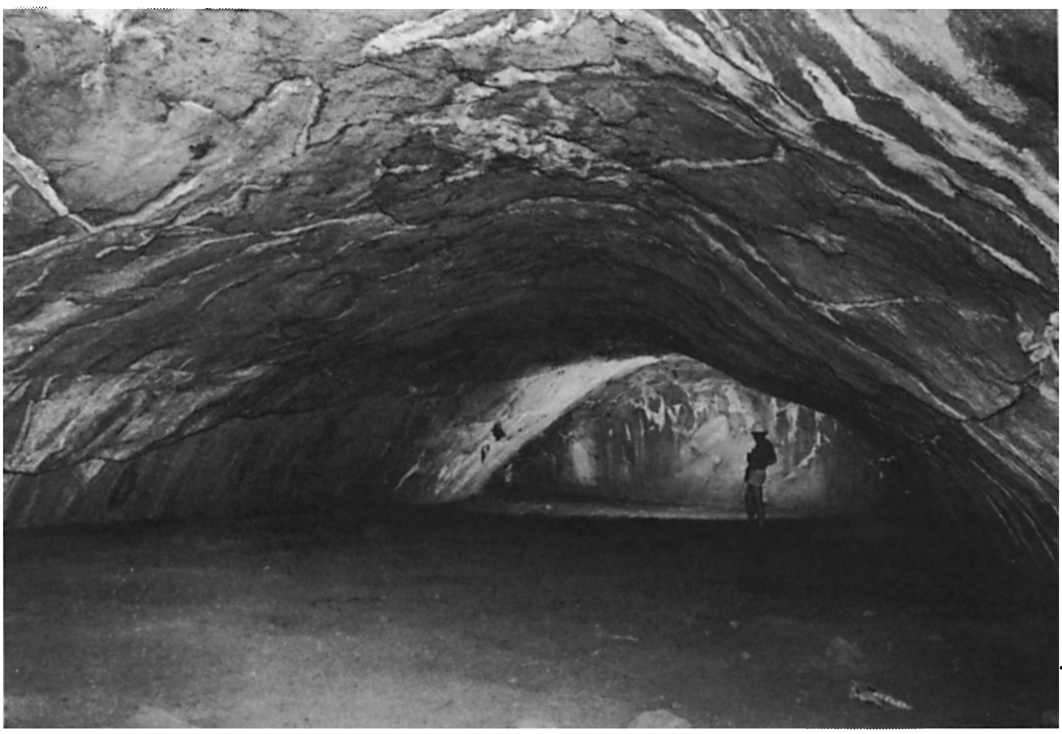


Figure 12: Termination of The Opera House, (note "wings"). Entrance is downflow. Photo: H.J. Lamont, J.C.U.N.Q.

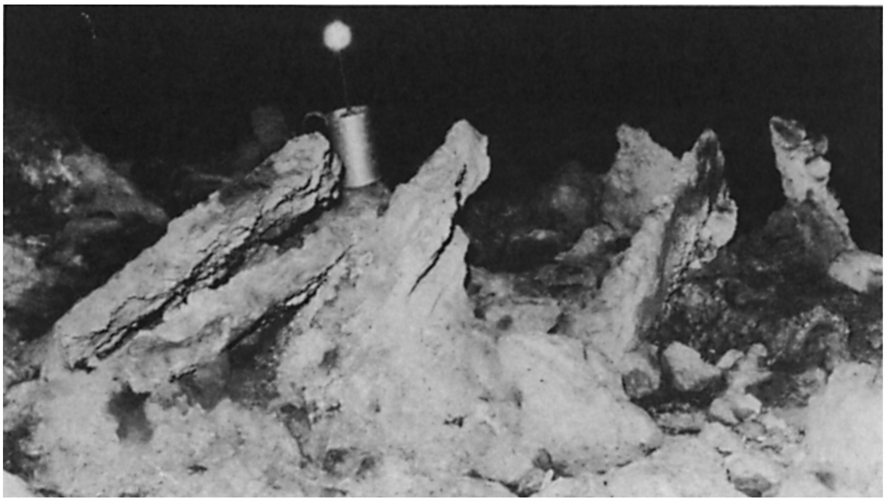


Figure 13: "Rafted" blocks of crust of the final flow have jammed at various angles. Location: Barkers Cave. Photo: V.G.Atkinson.

Figure 14a: Thin sheet of lining near the entrance to Pinwill-Cave. ? shows a degree of plastic deformation. Photo: V.G. Atkinson.

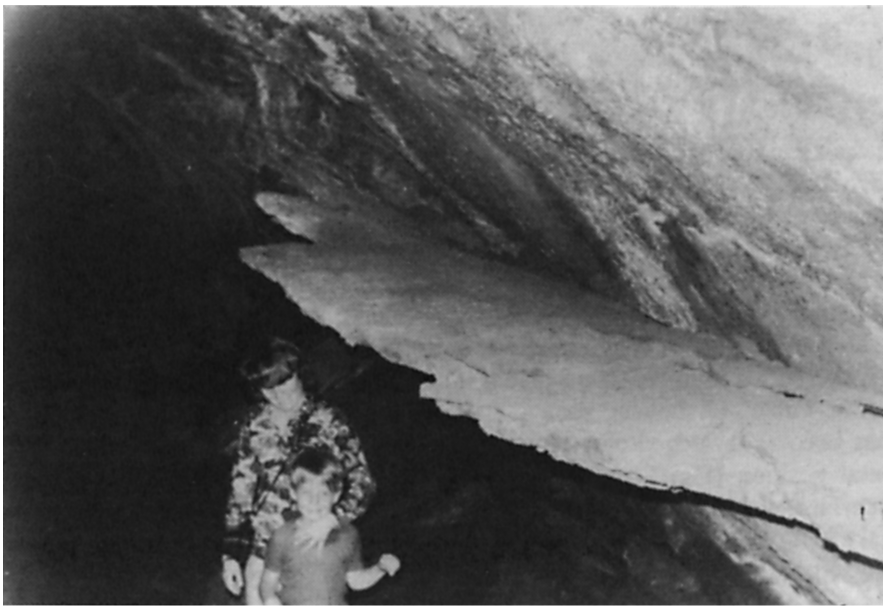


Figure 14b: Multi-layered lining in Pinwill Cave. Up to fifteen layers are exposed at this location. Photo: V.G. Atkinson

Figure 15: Lava dribbles in Barkers Cave. Photo: H.J. Lamont, J.C.U.N.Q.

The "**pavements**" (here-named) in Taylor Cave (Figure 18) are evidence of prolonged flow at a constant level. In the same way as deposition occurs on the convex bank of a fluvial river, lava consolidates where rate of flow is less against the convex bank. This is well illustrated in the Hawaii Volcanoes National Park film: Anthology of Hawaiian Volcanoes, where flow rates can be observed to vary laterally across the flow from the fountaining at Kiluea Iki (1969).

To date no caves have been discovered in the Wall Section of the Undara Lava Tube System but it merits mention here as the first Earth volcanic feature considered analogous to extra-terrestrial sinuous ridges (Greeley, pers. comm., 1972). This section of the system consists of a very long narrow ridge (Figs. 10a and 10b) that rises up to nearly 20 m above the general level of the flow and can be traced for 37 km. The upper surface of the ridge is relatively flat and varies in width from 70 m to 300 m. Its down-flow slope averages only 1.72 m per km, with occasional undulations. The side slopes of the ridge are up to 29°. There are several depressions, within 2 km of the termination of "The Wall". One of these may represent a collapsed lava pond which breached the wall. Another, Edmonds Lake, is a narrower, axial oval depression which is interpreted as a collapsed segment of the tube.

The significance of "The Wall" is uncertain. The tongue of lava surmounted by the ridge, certainly flowed down a precursor of Junction and Elizabeth Creeks. That the narrow ridge is localized above a former stream bed has been proved by very successful water bores in its vicinity. The nearly level course of "The Wall" and the fact that it delivered sufficient lava to flow a further 70 km beyond its termination (without further "Wall" features), suggests it had special features - it probably operated as an extensive lava tube.

COLLAPSE DEPRESSIONS AND THEIR RELATIONSHIPS TO CAVES

The following measurements emphasize a clear distinction between the collapse depressions associated with the Undara caves:

caves - up to 20 m wide;
narrower depressions - 30-60 m;
wider depressions - 50-100 m.

The **narrower depressions** commonly give entry to caves. This relationship allows the deduction that they formed by the collapse of segments of the tube. One or two "rain forest" trees almost conceal entrances to some caves but other vegetation within these depressions differs little from that of adjacent open forest. They are therefore difficult to see on air photos.

Wider depressions form a strong linear pattern, made conspicuous by dark green "rain forest" vegetation (Fig. 5). (See also Fig. 1c, Atkinson 1988, this volume). These depressions seldom give access to caves and they have

Figure 16: Lavicicles up to six cm long in Bayliss Cave. Photo: V. G. Atkinson.

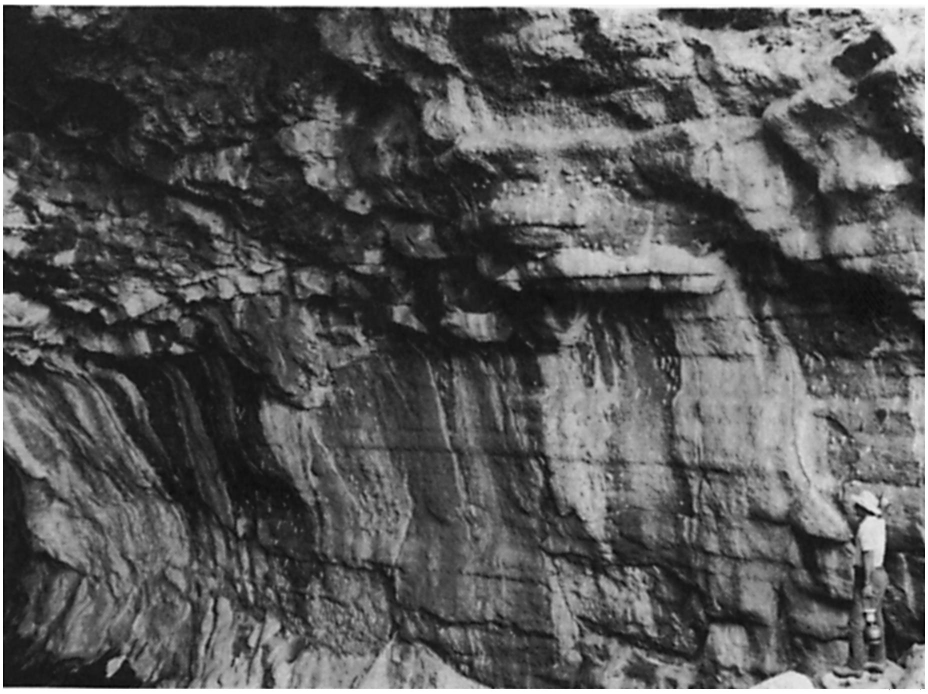


Figure 17: Road Cave. Lava level lines extend from floor to "roof" of this cave. They are the most distinctive yet discovered in the System and are more easily studied than at other locations as they are in daylight at the eastern entrance. Photo: H.J. Lamont.

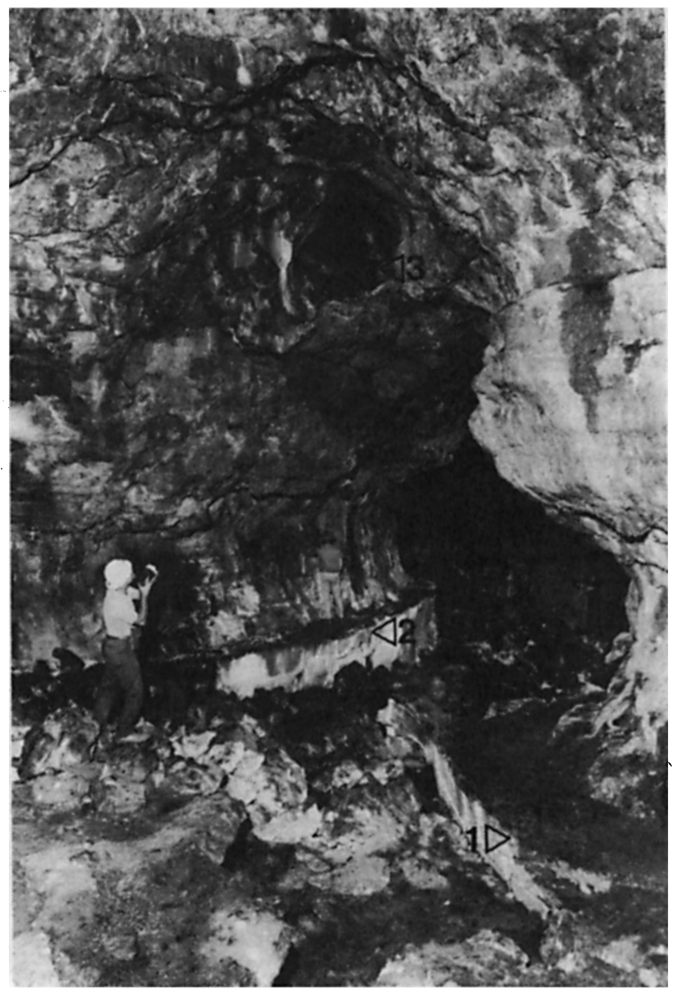
have features which distinguish them from the generally narrower depressions formed by lava tube collapse. The large depressions vary in shape from circular or oval, for example Barkers Depression (Fig 19), to elongate (up to 900 m) in the direction of flow, except West of Barker's Knob, where their erratic shapes may indicate that the flow traversed marshy ground.

Rims of the wider depressions are characteristically elevated, suggesting that they represent former lava ponds. Rims and slopes of the depressions are made up of a jumble of blocks of various shapes and sizes (Fig 19b). Local areas of blocks (Fig. 19c) are interpreted as segments of lava pond crust, because they have flat upper surfaces with low vesicularity (Fig. 19d). This conclusion was drawn after discussion with R. Greeley and D. W. Peterson (1972 and 1974) from similarity to those depicted in the collapsed lava pond, Oregon, U.S.A. (Figures 21a and 21b, supplied by R. Greeley). Near the base of some depressions lower surfaces of some blocks are moulded and occasionally have fragments embedded. Rare blocks retain an original ropy lava surface.

During the 1972-1974 investigation two caves with adjacent wide depressions were mapped in detail (Figs. 9a and 9b).

Figure 18: Taylor Cave. The prominent "pavements" (1 and 2) are evidence of an extended period of constant rate of flow. Solidification has been greatest at the apex of convexity, as in a fluvial river. There is a cylindrical opening (3) in the "roof" above the figure. The location of this opening suggests that some lava, ponded in Death Adder Depression, (in alignment to the North), may have drained back into the tube through this conduit. Photo: H.J. Lamont, J.C.U.N.Q.

In Taylor Cave, 60 m North of the entrance there is a long, deep depression directly in line with the initial cave trend. The cave might well have been expected to terminate in a collapsed closure beneath the depression, but this is not the case. Close to the edge of the depression the cave branches and the two passages roughly



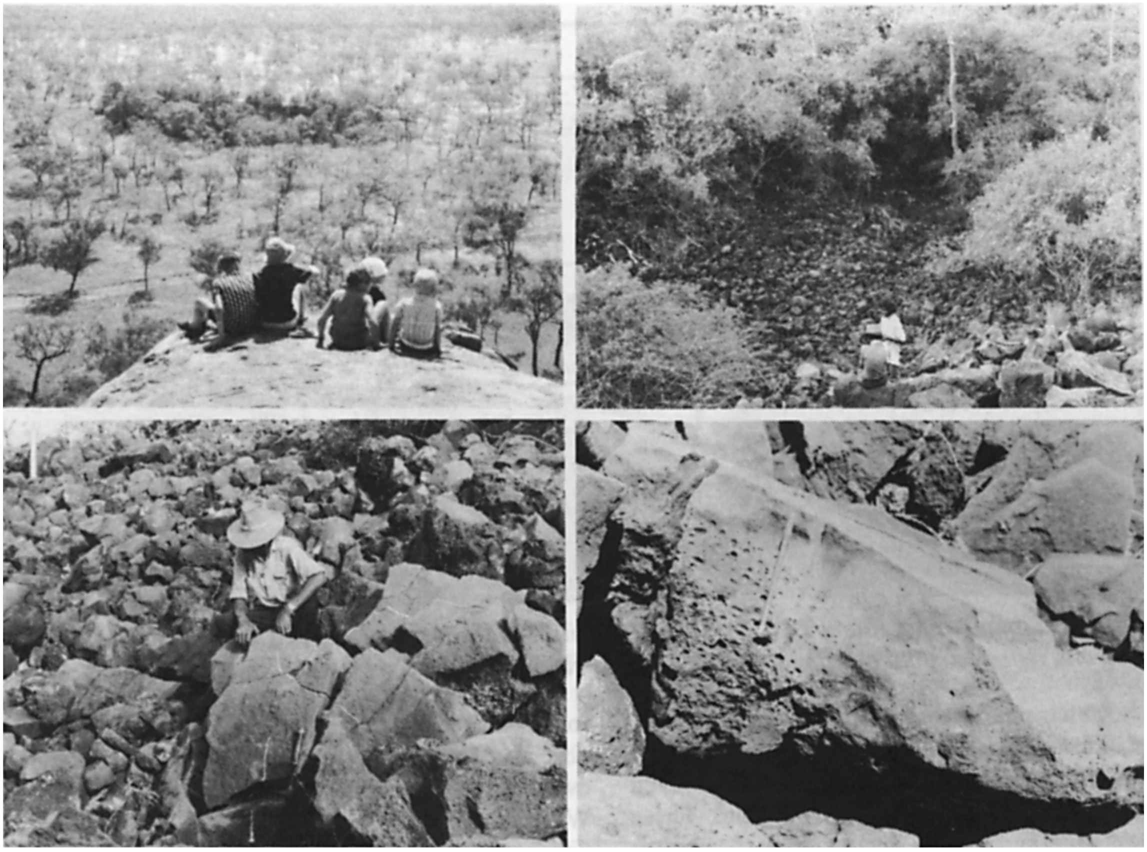


Figure 19: Barkers Depression, a drained lava pond adjacent to Barkers Cave. (a) Viewed from Barkers Knob, a granite approx 500 m to the South; (b) View from inside looking South-West; (c) "Mosaic" of crustal blocks at steep angles on inner western wall. Some corresponding cracks in adjacent blocks have been marked with chalk for clarity; (d) Crustal block showing variation in vesicularity. In the degassed upper surface vesicles are microscopic to small, contrasting sharply with those of the lower surface.

follow its outer margins. Each branch closes to an inaccessibly small tunnel, and near its termination the east branch bifurcates again. The lava level lines in the east branch are nearly horizontal and follow along both sides of the cave and across the wide pillar at the end.

The relation of the Taylor Cave passages to the depression suggests the collapse interfered with the functioning tube. The location of the cylindrical vent above the person in Figure 18 suggests that some of the ponded lava drained back into the main tube through it. It seems likely that "roof" collapse took place into a wide running tube, which bifurcated around the constriction but was constricted and finally dammed. At a late stage, the dam of lava inside the tube was drained through minor outlets.

Barkers Cave changes its course to go around the major depression 220 m West of the cave entrance (Fig. 9b). A small cavity occurs in the cave roof close under the eastern end and there are circular depressions up to 1.5 m across on the inner slope of the depression. These may be evidence that the depression drained and collapsed into a flowing tube, which adjusted its course around the collapse obstruction.

Wind Tunnel (192 m) was discovered in 1988 by Irvin and Godwin. An interesting relationship between the cave and associated collapse depressions is depicted in Fig. 9c. At the eastern side of an aligned depression, entry was gained to an arch 20 m long. At the western end the cave branched in three directions and the northern branch opened into a wide depression. No exit was found in the northwest and southwest branches of the cave.

Figure 20, from Macdonald and Abbott (1972), shows Halemaumau in Kilauea Caldera, Island of Hawaii, as an active lava lake in 1894. Similarity in appearance of its raised rim and those of wider depressions in the Undara flow, particularly Barkers depression, gave the author the first clue as to their origin.

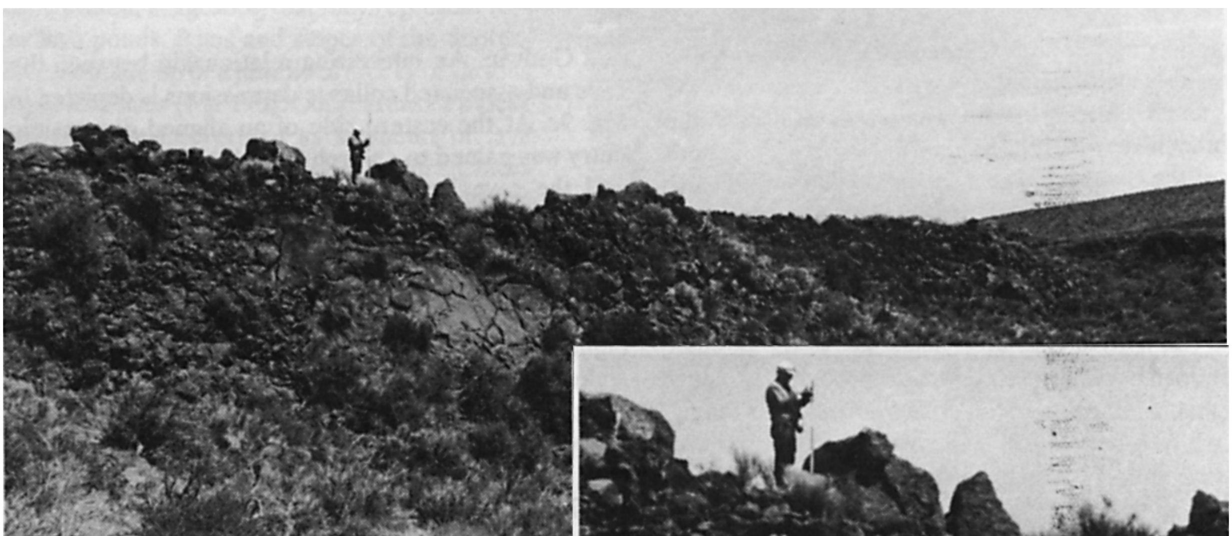
Figure 21, supplied by NASA geologist, R. Greeley, shows a "mosaic" of blocks, which he interpreted as former crust of a drained lava lake in Recent lava in Oregon, USA.

Figures 20 and 21 and discussion with D.W. Peterson were thus of great interest and significance in aiding interpretation of the wider depressions in the Undara Flow. They are interpreted as collapsed lava ponds. D.W. Peterson et al. (op. cit.) have observed in Hawaii

Figure 20: Halemaumau, within Kilauea Caldera, Is. of Hawaii, 1894. The lava lake is held in a ring shaped levee built by spattering and repeated small overflows. (an anonymous etching reproduced by Macdonald and Abbott, 1972).

that lava becomes ponded in specific areas, particularly where the slope is small. Once formed, the ponds tend to perpetuate themselves during the life of the flow, even when the flow front has advanced far beyond. These ponds crust over, and molten lava beneath the crust is interconnected with lava tubes that had been developing in the flow both upstream and downstream from the pond.

In Hawaii, the crusted surfaces of these ponds have been observed to subside, as the rate of flow the system dwindles and ponded lava drains back into the tube. When he visited Undara in 1976, D.W. Peterson was delighted to find that all features that he observed in the wide collapses confirmed the origin he had suggested.



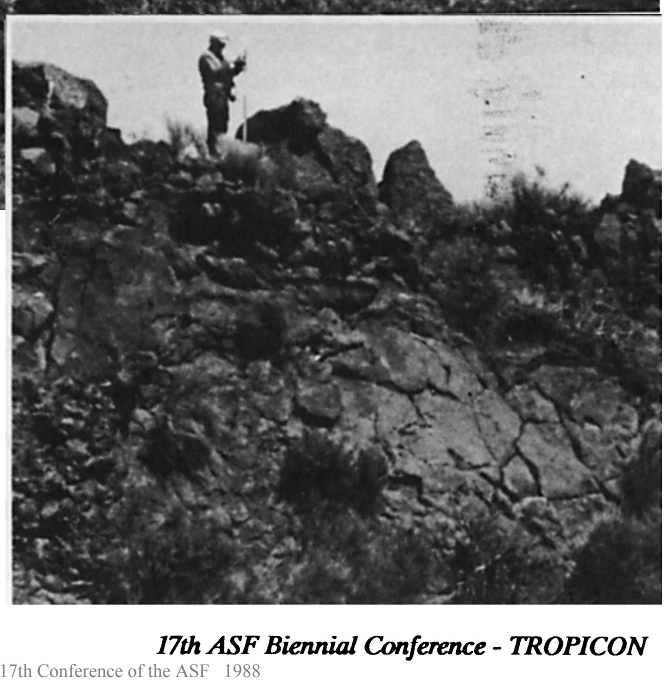


Figure 21: (a) Drained lava pond, Oregon, U.S.A., viewed from inside. Note the "mosaic" of crustal blocks forming part of the wall below the figure. (b) Detail of "mosaic". Photo: R. Greeley, NASA, U.S.A.

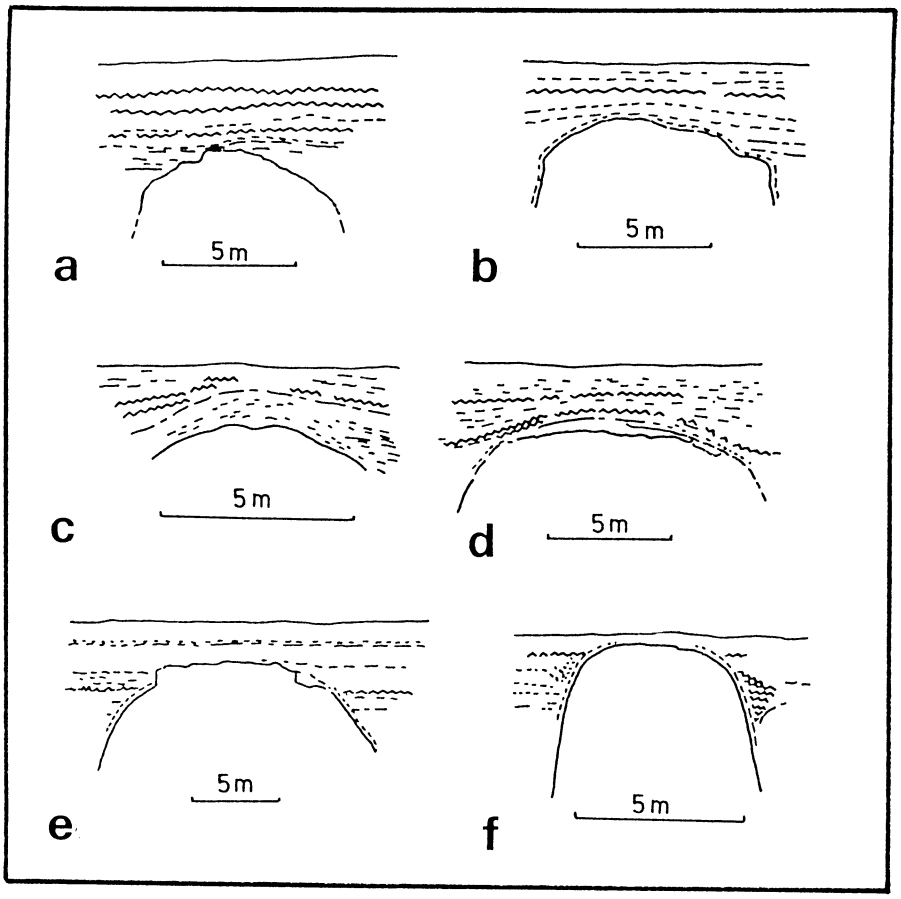


Figure 22: Cave entrance structures showing thickening of "roofs" by successive surface flow units; (a) Taylor; (b) Harbour Bridge; (c) Peterson; (d) Pinwill; (e) Road; (f) Barker. Flow units are indicated by wavy lines for recognised flow surfaces. Other near-horizontal lines are major vesicle zones. Diagram: P.J. Stephenson.

MODE OF FORMATION OF THE UNDARA LAVA TUBE SYSTEM

All observations to date confirm formation by "roofing" over a major lava channel and the thickening of "roofs" by subsequent flow units (Figs. 22 and 23), some of which flowed over ropy surfaces and bear rope imprints on their lower surfaces. That the ropy surfaces and imprints are not common is of little significance when it is remembered that Macdonald and Abbott record (1972) that ropy structure is often evident only over a small proportion of any flow.

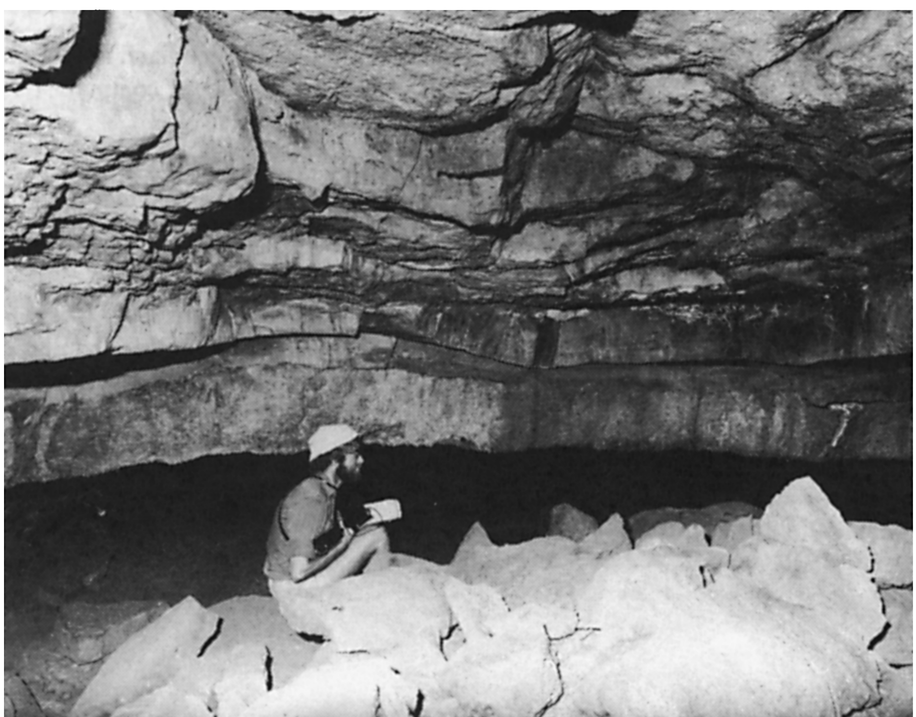


Figure 23: Roof structure inside Peterson Cave, (east branch). A ropy flow unit interface. The prominent arched flow unit just above the observers head, has a ropy interface. Higher ropy interfaces also occur. Photo: H.J. Lamont, J.C.U.N.Q..

Final drainage of much of the lava from the System provided segments that can be entered today. Further details and discussion of hypotheses concerning the formation of lava tubes in general and of the Undara Lava Tube System in particular, are given in Atkinson 1988, this volume.

SUMMARY AND CONCLUSIONS

1. 190,000 years ago the Undara Volcano erupted approximately 23 km^3 of lava. Its lava field covers 1,550 km^2.

2. The Undara lavas are thought to have had normal viscosities and no unusual properties.

3. The Undara flow extended 160 km on very low gradients (average 0.3°). This length resulted from a very high rate of effusion, coupled with channelling and an efficient lava tube system.

4. Evidence of a major lava tube system is preserved as various collapse depressions and in drained and partly drained caves. The caves are up to 1.35 km long, and a narrow ridge, "The Wall", 37 km long, is believed to have contained a lava tube.

5. The lava tubes of the Undara System developed by the "roofing" over of major lava channels.

6. Within the caves, protection from weathering has allowed preservation of ropy surfaces and other characteristics of active and recent lava flows. Other than long lavicicles (lava stalactites), cave features are comparable with those in other parts of the world.

7. Two distinct types of depression are associated with a line of narrower lava caves. The wide depressions probably represent collapsed lava ponds, whereas the narrower depressions were formed by lava tube collapse.

8. Most caves with obvious entrances have probably been discovered.

9. Many future discoveries may result from the movement of some appropriate blocks in wider collapse depressions.

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The wide speleological knowledge of Dr. W.R. Halliday, then of Seattle, U.S.A., prompted him to request the paper by Stevens and Atkinson (1976) for the International Symposium 1972: Vulcanospeleology and its Extraterrestrial Applications. The continued interest and enthusiasm of Associate Professor Stephenson, J.C.U.N.Q, who supervised the 1972-74 field work and Drs. Halliday and Stevens U.Q., are acknowledged with gratitude.

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APPENDIX I

TABLE 2
UNDARA LAVA TUBE SYSTEM - MAJOR ELEMENT CHEMICAL ANALYSES
Specimen locations are shown on Figure 6.

* These analyses on samples dried at 110° C
n.d.: not determined

	A	B	C	D
SiO_2	48.85	49.30	49.50	48.20
TiO_2	1.82	1.70	1.67	1.75
Al_2O_3	15.23	15.40	15.90	15.80
FeO_3	2.52	11.0	10.53	4.46
FeO	7.46	trace	0.06	6.38
MnO	0.16	0.15	0.15	0.17
MgO	8.55	8.10	7.10	7.85
CaO	9.16	8.02	8.39	8.02
Na_2O	3.90	4.20	3.87	3.57
K_2O	1.75	1.77	1.53	1.71
H_2O+	0.35	n.d.	n.d.	n.d.
H_2O-	0.17	*	*	*
P_2O_5	0.64	0.50	0.34	0.72
CO_2	0.13	n.d.	n.d.	n.d.
Total	100.69	100.14	99.04	98.63
Locality (Fig. 6)	A	B & C	B & C	D

Analyses
"A": Host rock, Barkers Cave entrance,
"B": Cave lining,Barkers Cave entrance;

Analyses:
"A". T.J. Griffin, using XRF; Na, flame photometric; Fe^2, by titration.
"B"-"D". P.J. Stephenson and T.J. Griffin, using Atomic Absorption (HF-Boric Acid digestion); P, spectrophotometric; Fe^2, by titration.

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VULCANOSPELEOLOGY - EXTRA TERRESTRIAL APPLICATIONS AND THE CONTROVERSY: MODE OF FORMATION OF LAVA TUBES.

Anne Atkinson.

ABSTRACT

Basaltic composition of rock samples from the MOON stimulated great interest in terrestrial volcanic features, particularly lava tubes, as analogues to lunar and planetary surface features (Figures 1a to 1e). With this stimulus, their mode of formation was re-examined.

Features of active and Recent lavas and stages in the development of actively forming lava tubes have been studied in Hawaii (Fig. 2). It was noted that, in some lava channels that had crusted over, tubes formed when flow diminished. These observations provide an explanation, the "Hawaiian" theory, of many features of older tubes and also their mode of formation in general and, in particular, that of the Undara Lava Tube System, North Queensland.

Alternative hypotheses for the formation of tubes are examined. One worker claims that the "Hawaiian" theory is applicable only to tubes less than 1 km long, but the length of the Undara System refutes such a distinction. To explain the formation of some more complex lava tubes, alternative hypotheses may be necessary.

Figure 1a: A meandering channel which may represent a collapsed lava tube in a lunar mare area near Apollo 15 landing site. (National Geographic Magazine, U.S.A.) Photo: Astronaut A.M. Worden, NASA Apollo 15 Mission.

Figure 1b: ?Partially collapsed lava tube, lunar mare area. (National Geographic Magazine, U.S.A.). Photo: Astronaut A.M. Worden, NASA Apollo 15 Mission.

INTRODUCTION

Pictographs in some American lava tubes evidence their pre- historic use and in Europe they have been visited since at least as early as the eighteenth century. However, they do not contain decorations to compare with those of limestone caves so it was not until the first LUNAR SAMPLES proved to be basaltic, megascopically (Fig. 3, at end) and microscopically (MacKenzie, 1982) similar to terrestrial basalts, with only minor geochemical differences, that a real interest was awakened in their nature and mode of formation. (The minor geochemical differences of lunar basalts are believed by some to be due to their age of 3.6 billion years.)

The shape of channels on the lunar surface (Fig. 1a) had suggested fluvial origin but such an hypothesis could not be supported in the absence of atmosphere. It was therefore proposed (Kuiper, Strom and LePoole, 1966; Oberbeck, Quaide and Greeley, 1969; Greeley, 1970, 1971a) that sinuous lunar rills (Fig. 1a) may be collapsed lava tubes (Fig. 1c). From Mariner 9 photographs Greeley (1972b) identified similar features in three regions on Mars.

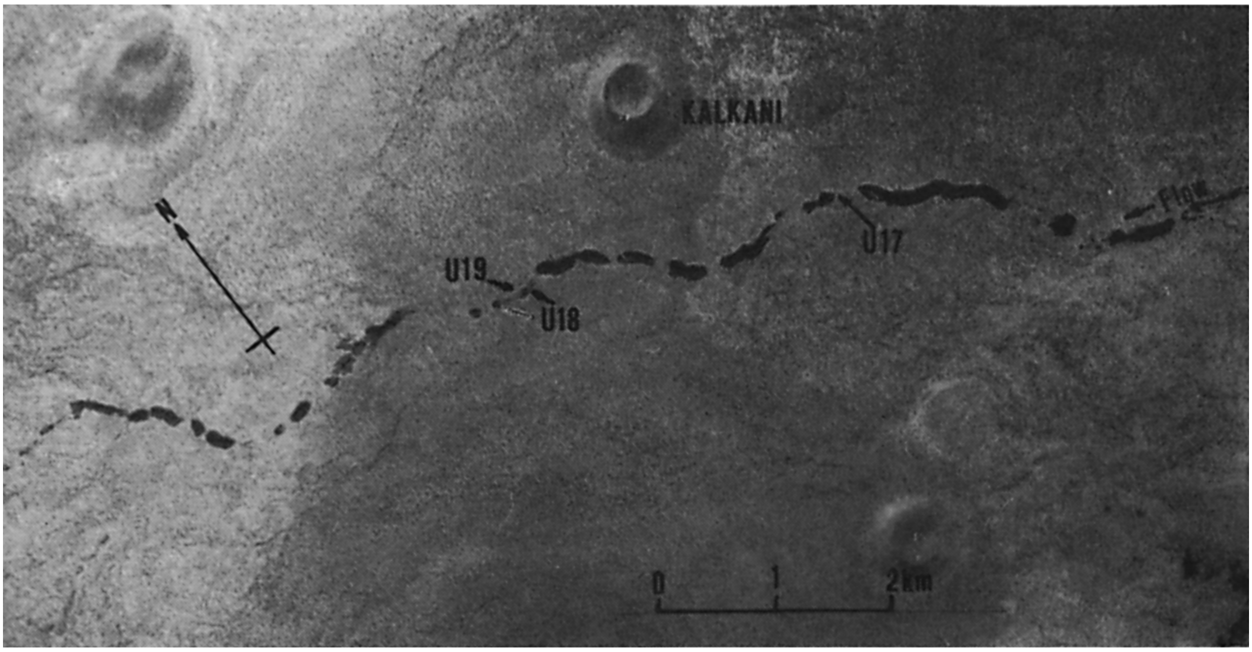


Figure 1c: Wide collapse depressions aligned with and/or adjacent to the Yaramulla Section of the Undara Lava Tube System, North Queensland. Air photograph: Department of National Mapping, Australia.

Great interest was aroused at NASA Headquarters, San Francisco,USA, when the author proposed in 1972 that the WALL SECTION of the Undara Lava Tube System might represent a terrestrial analogue to the sinuous ridges (Fig. 1d) on mare regions of the Moon. A request from NASA that an immediate detailed study of "The Wall" be made by a student of JCUNQ had to be ignored as neither party was willing to fund the project.

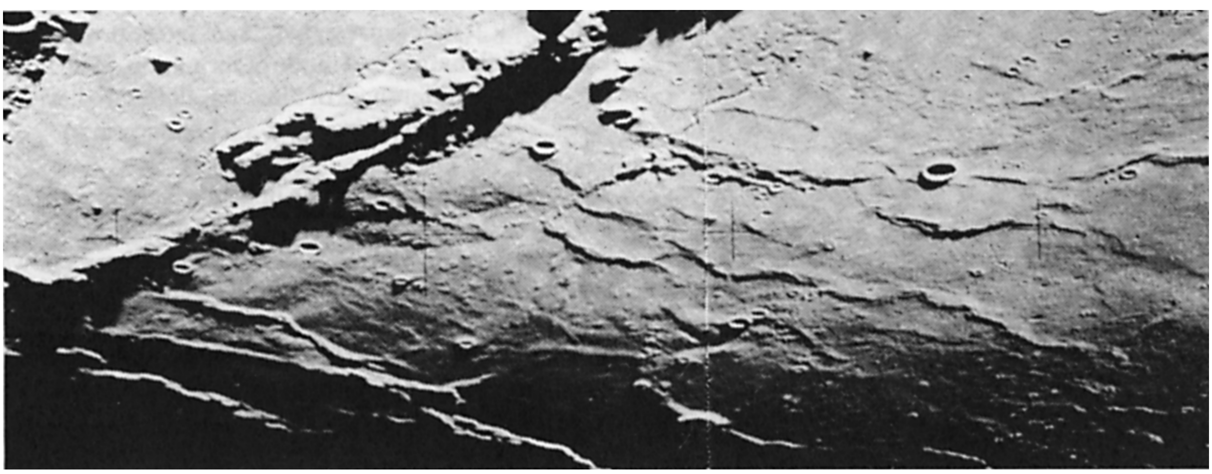
In the strictest sense, the words "lava" and "basalt" are not interchangeable, "lava" referring to rock in its molten state, "basalt" to a solidified volcanic rock within a restricted compositional range. Commonly, however, the word "lava" is used in either sense, and is used thus, in this paper. Similarly the words "cave", "tube" and "tunnel" are used here synonymously.

FIELD OBSERVATIONS

Data for mapping and details of geomorphology of the Undara System were collected during extended field trips over a period of two years. The author considers, however, that the opportunity to make the following observations overseas were of inestimable value and profoundly influenced conclusions reached in this and the preceding paper.

Eruptions and active lava flow were witnessed on the Island of Hawaii in 1972 and 1974. Some details are given in Atkinson 1988. During those visits and in 1980, young volcanic features were also studied there and in the states of Washington, Oregon and Idaho, U.S.A., and in Iceland, France, Sicily and the Eolian Islands.

Figure 1d: Flat basaltic areas surround a long jagged spine of mountains on the lunar surface near Aristarchus Plateau. Beyond the mountains, note the "ranks" of little ridges. (National Geographic Magazine, U.S.A.). Photo: Astronaut A.M. Worden, NASA Apollo 15 Mission.



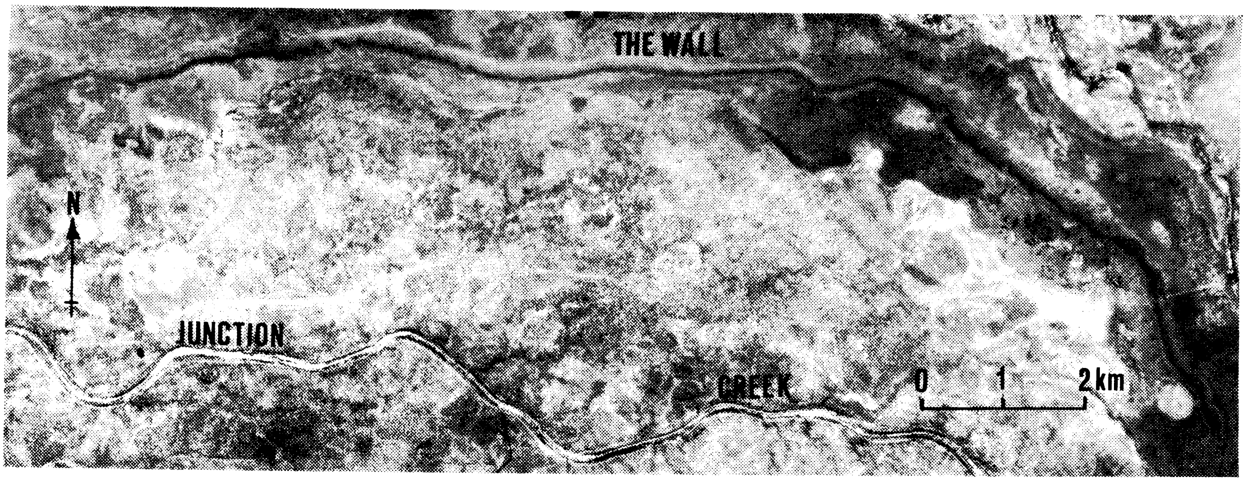


Figure 1e: Vertical aerial photograph of the western end of the Wall Section of the Undara Lava Tube System. This low basalt ridge is 37 km long and may be analogous to sinuous ridges on lunar basaltic areas. (See also Figures 10a and 10b, Atkinson 1988, this volume). Air photograph: Department of National Mapping, Australia.

TYPES OF LAVA THAT HOST LAVA TUBES

Macdonald and Abbott (1972) state that, in Hawaii, lava tubes are common only in fluid pahoehoe* lava, that they are very rare in the viscous aa* type. S. Thorarisson (pers. comm., 1974) agreed that this was the case in Iceland also. A keen speleologist all his life, Thorarisson was, therefore, very interested in the discovery by the author and V.G. Atkinson in 1974, of a short tube, still warm, in the 1973 aa flow that threatened the township on the Island of Heimaey, Iceland.

OBSERVATIONS OF ACTIVE LAVA TUBE MECHANISMS

Wentworth and Macdonald (1953), Greeley (1971b, 1972a), Macdonald and Abbott (1972) and Peterson and Swanson (1974) have made observations of lava tube formation in active and Recent flows in Hawaii. Their work shows that the following are the stages in the development of major lava tubes. Figures 2a to 2d, from Macdonald and Abbott (1972), illustrate these stages. Figure 2e has been added for reasons explained below.

1. A river of pahoehoe lava, confined in a valley, quickly crusts over and develops a "roof". The flow also begins to solidify against valley walls and floor (Fig. 2a). The "roofing" occurs in several different ways, including growth of semi-solid surface crusts by cooling, crusts floating down the channel jamming and accumulating at obstructions, and by the growth of levees from the channel sides through repeated overflows, splashing and spattering. "Roofs" formed by any of these processes may be thickened and strengthened by new surface flow units.

2. As solidification of the "roof", walls and base continue, the flow becomes concentrated within a cylinder (Fig. 2b). If eruption ceases and the tube drains completely, its cross section is circular. (The author saw one such perfectly cylindrical straight section, 1.7 m diameter, over 6 m long and with an inclination of about 5°, in a cave in the Cascade Mountains, Oregon, U.S.A.)

3. When the supply of lava diminishes during an eruption it no longer fills the whole tube. Volcanic gases, escaping from the flow into this cavity, may ignite producing a temperature considerably higher than that of molten lava. This may cause some re-melting of the roof with drips of lava forming lava stalagtites (lavicicles) up to 30 cm (Fig. 2c). Occasionally lava stalagmites form. Lavicicles are commonly vertical. Deflection is rare and apparently caused by a current of very hot gas or air passing through the tube. In the Undara System, deflection has been noted only near the entrance to Barkers Cave.

4. Effusion rates fluctuate but whenever a constant rate is maintained, near-horizontal ledges of lava solidify on the tube walls - **lava level lines** (Atkinson, Griffin and Stephenson, 1975; Stephenson and Griffin, 1976b and Atkinson, 1988, text and figures 4a this volume). Further diminution of the flow lowers the level in the tube. Finally the flow congeals to form the floor of the tube (Fig.2d).

Note re Figure 2e

The author has taken the liberty of adding this to Macdonald and Abbott's Figures 2a to 2d (1972) in order to illustrate one mode of formation proposed for major ridges associated with a lava tube system, such as the WALL SECTION of the Undara System.

* *Aa and pahoehoe are Polynesian terms referring to physical state, not chemical composition.*

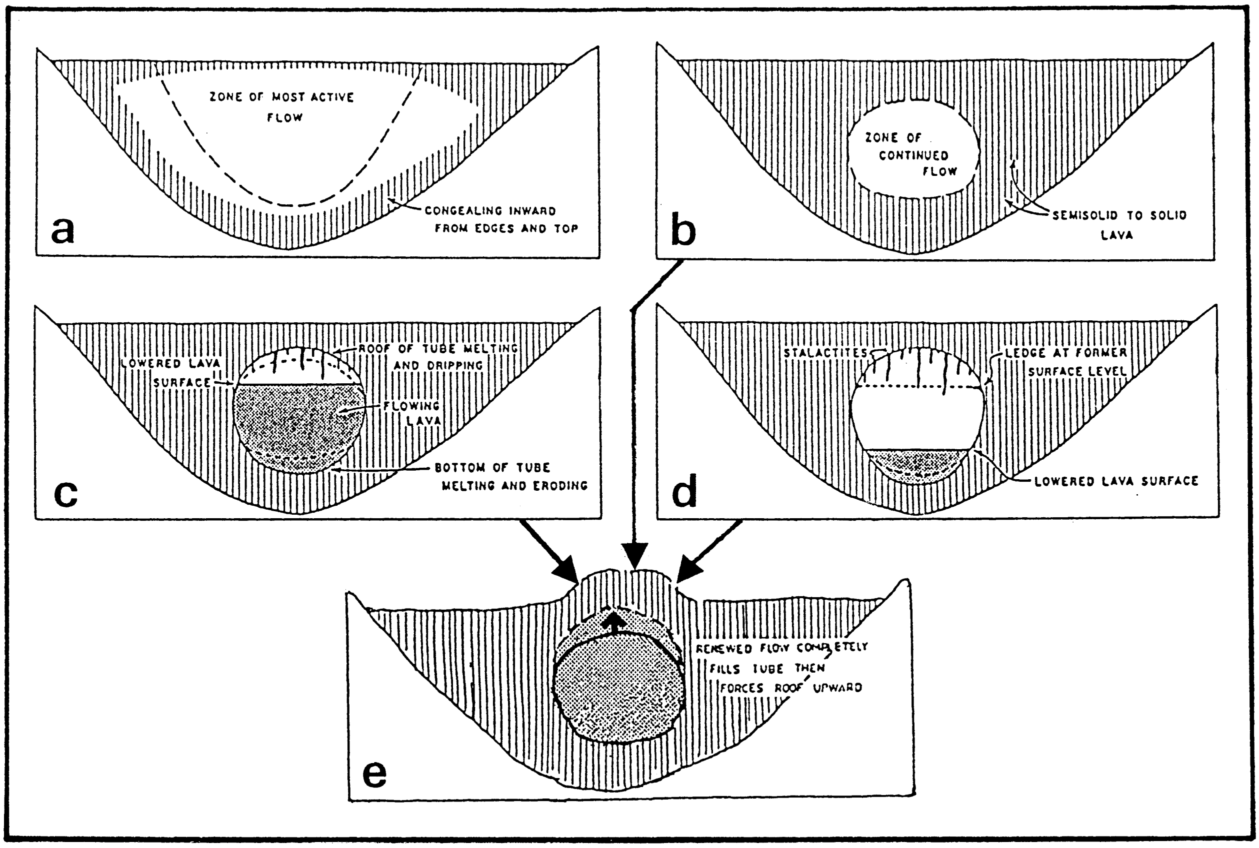


Figure 2a - 2d: Diagrams to illustrate stages observed in thedevelopment of lava tubes in Hawaii. (from Macdonald and Abbott, 1972)
a: The lava flow, confined in a valley, develops a thin crust and starts to solidify inward from the edges, but the centre continues to flow;
b: The active movement of liquid becomes restricted to a more or less cylindrical, pipelike zone near the axis;
c: The supply of lava diminishes and the liquid no longer fills the pipe. Burning gases above the liquid heat the roof of the pipe and cause it to melt and drip.
d: Further diminuition of the supply lowers the level of the surface of the liquid, which eventually congeals to form a flat floor in the tube.
e: Diagram to illustrate possible mode of formation of a basaltic ridge such as the Wall Section of the System near Mt. Surprise, North Queensland. (See also Figures 10a and 10b, Atkinson 1988).

To support this hypothesis it is noted that:

- the axis of a flow is commonly inflated above its surrounding lava field (Greely, 1971b, Greeley, 1972a and Greeley and Hyde, 1972)

- small drain tubes (up to 0.75 m wide and 6 m long on the flanks of Mauna Loa, Island of Hawaii, have semi-circular "roofs", no more than 3 cm thick (pers obs.).

As small tubes sometimes exhibit such convexity, it is proposed that the impetus of renewed, late stage activity from a source volcano could force a semi-solid roof of a large tube to arch upward.

The ballooning of 37 km of tube to an almost uniform level is difficult to envisage and L.M. Pearson suggests (Pers. comm. 1988.) an alternative hypothesis which fits more closely with observed features on the terminal section of "The Wall".

1. The location of "The Wall" section marks a watercourse in the paleo-drainage (the precursor of Elizabeth and Junction Creeks) down which the Undara lava flowed. The minimal slope would lessen the lava velocity, allow a longer time for cooling to take place and increase viscosity of the lava.

2. The lava field extended laterally by overflow from the channel. Levees formed, as observed by Greeley (1971b and 1972a) on the Island of Hawaii and depicted at Halemaumau (Fig. 19 Atkinson 1988), elevating the channel above the surrounding lava field.

3. A temporary halt in eruption allowed solidification of the "toe" at the termination, damming the flow. Cooling and contraction led to some mega-jointing.

4. Renewed activity caused minimal inflation of the "toe" before the lava continued to flow down to the Einasleigh River beyond the termination of "The Wall".

5. Flow ceased and the tube drained, partially or totally. For most of its length the roof was self-supporting, or not drained, but near the termination, Edmonds Lake (here named) formed by axial collapse of a drained section. This collapse also left mega-columns flanking the slumped central area and the slope to the West.

For the formation of "The Wall" it is possible that both mechanisms operated but in the terminal section and possibly for most of the length of "The Wall", the second hypothesis is favoured.

MECHANISMS PROPOSED FOR SOME OLDER LAVA TUBES

It is difficult to understand that some would propose hypotheses so different from the mechanisms of tube formation actually observed in active lavas. Such hypotheses, however, have been proposed and are, perhaps necessary to explain some complex tubes.

In complex lava caves in Victoria, OLLIER AND BROWN (1965) observed that "layered" lava was a consistent feature and proposed that tubes developed as discordant late-stage structures by some process of residual lava segregation. Cylinders of flowing lava developed and eroded some of the virtually solid lava to form the final tubes. Drained tubes were left as caves with a congealed lining.

GREELEY and HYDE (1972) concluded that most of the tubes of the Cave Basalt, Mt. St. Helens, Washington, U.S.A., had formed by the mechanism proposed by Ollier and Brown (1965).

HATHEWAY (1971) extended the hypothesis of Ollier and Brown (1965) to explain the development of an extensive tube system. He proposed that tubes originated at the toes of individual flow units and began in the form of evacuating bodies which he termed mobile cylinders. Lava was freed in an up-slope process as the cylinder continually searched out a position of maximum gradient within the flow unit. In most cases, Hatheway supposed growth of the cylinder continued until the source area or vent was reached.

In 1976 Hatheway argued that his theory of tube formation was compatible with that based on observations of actively forming tubes in Hawaii, his theory being applicable to tubes more than 1 km long, the "Hawaiian" theory to tubes less than 1 km. Evidence in the Undara System supports formation by the "roofing" of a running channel. There, the hypotheses of Ollier and Brown (1965) and Hatheway (1971 and 1976) do not seem applicable.

WOOD (1974) maintains, as PETERSON and SWANSON (1974) also believe, that the "layered" lava, on which Ollier and Brown (1974) based their hypothesis, simply corresponds to a flow composed of successive flow units.

In discussing the size of lava tubes BULLARD (1977) claims that their size "is influenced by the the thickness of the flow, the viscosity, the rate of cooling, and the slope of the surface on which it flows". Bullard appears to support the mechanism of formation proposed by Ollier & Brown (1965).

OLLIER (1988) still does not seem to agree that the layers in a flow represent successive units of flow, as observers in Hawaii claim (see above). He appears to accept Nichols' (1936) explanation of the formation of flow units in preference to observations of active flow recorded by Greeley (1971b and 1972a and Peterson and Swanson (1974) and others. He points out that the term "layered lava" is still useful as a less specific term than "flow unit".

Presumably later additional Hawaiian observations, noted above, have persuaded Ollier (1988) to abandon the "layered lava" hypothesis, proposed by himself and Brown, (op. cit., 1965) as the main mode of formation of lava tubes. For tube formation, Ollier (1988) now considers that "three mechanisms appear to be dominant", the following two producing major tubes:

1. Channel "roofing" by accretion of spatter from levees - a process observed in Hawaii by Wentworth and Macdonald (1953), Waters (1960) Greeley (1971b and 1972a), Peterson and Swanson (1974) and in Iceland by Kjartansson (1940).

2. - and, quoting Hatheway and Herring (1970), "by the development of mobile cylinders of lava in a cooler, more viscous host rock. These cylinders transport fluid lava to the "toe" of the flow as long as the source provided a continuous supply. When this ceased the tube probably drained rapidly".

Ollier (1988) does not comment on the difference between the hypothesis of Hatheway and Herring (1970), quoted in the preceding paragraph, and Hatheway's 1971 hypothesis, viz. that "mobile cylinders" originated at the "toes" of flows and extended up-flow toward the source.

POSSIBLE DEVELOPMENT OF THE UNDARA LAVA TUBE SYSTEM

WALKER (1973) discussed the development of very long lava flows and concluded their formation is characterized by a high rate of effusion. At Undara, this was probably responsible for the rapid development of the main length of the flow which attained 160 km,with an average gradient of only 0.3° (0.12° over the last 100 km). Extrapolating Walker's relationships (op cit.), Undara's average effusion rate must have exceeded 1000 m^3/s. Walker (pers. comm., 1974) considered that to have reached a length in excess of 160 km to become the longest flow in Australia and one of the longest in the world, eruption must have been concluded in less than three weeks, possibly in less than one week.

The elongated ridge, the Wall Section of the Undara System, was probably part of a lava tube which acted as the main feeding channel for the long flow down the Einasleigh River (Atkinson 1988, Fig. 3). Lateral parts of the flow no doubt extended by breakouts and flooding away from the main lava channel. It is concluded that once formed, this main lava tube must have been continuously maintained. Accepting this, it is conceivable that a continuous lava tube system functioned between the Undara crater and the termination of "The Wall" - over a distance of 90 km (Atkinson et al., 1975).

Sand was found under the basalt (some apparently fused) in successful water bores in and adjacent to the Yaramulla and Wall Sections of the Undara Lava Tube System. This is interpreted as evidence that, at least in those areas, the flow was channelled by one or more former water courses.

The lava front was presumably fed by major channel flow along which tube formation was progressively occurring. Once initiated, the lava tube was maintained as an effectively heat-insulated channel, as PETERSON and SWANSON (1974) stressed. SHAW, (1969) claimed that lava flowing in the relatively confined tube / channel probably also partly maintained its temperature and fluidity through viscous frictional effects.

SUMMARY AND CONCLUSIONS

1. Interest in lava tubes and other terrestrial features was stimulated when some lunar rock samples proved basaltic.

2. In addition to recorded work, personal observation of younger volcanic features are of inestimable value to any who try to interpret features in older lava fields.

3. In Hawaii, more or less continuous crusts are observed forming on channels in active lava flows. When flow diminishes, its level drops, leaving a space or lava cave/tube/tunnel between the "roof" and the final flow.

4. Observation of the above mechanism, and of features of active and Recent lavas, provide a very satisfactory basis for hypotheses concerning the formation of lava tubes in general and of the Undara Lava Tube System in particular, though some authors still propose more complicated mechanisms based on their observations in older lava tubes.

ACKNOWLEDGEMENTS

Associate Professor P.J. Stephenson and Dr T.J. Griffin kindly gave permission to use material from our joint paper (1975);

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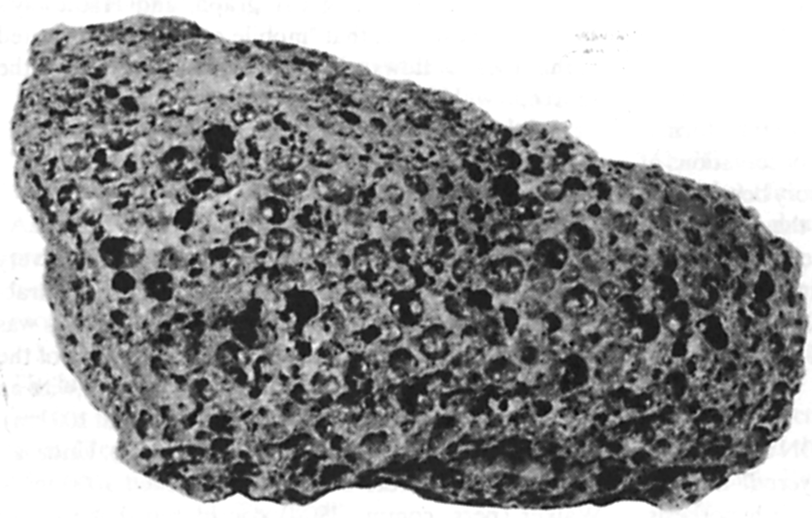

Figure 3. Lunar vesicular basalt. More than half this specimen is "pore" space. The "pores" or vesicles, are formed by frothing and bubbling during volcanism and indicate high gas activity at one time on the Moon. The appearance in hand specimen and under the microscope show no marked difference from terrestrial basalts but there are slight chemical differences. (National Geographic Magazine, U.S.A. & MacKenzie et al. 1982). Photo: NASA, U.S.A.

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THE COLLINS SYSTEM - A RECENT LAVA TUBE DISCOVERY.

Douglas Irvin.

ABSTRACT.

In May 1985 Gerry Collins of Rosella Plains Station led us to a tunnel he had seen about 10 years previously. It proved to be part of a series of 9 tunnels with a total passage length of approximately 1100 m. The caves are briefly described. Some of the biological findings are given.

INTRODUCTION.

> "'The entrance is straight ahead', a voice boomed out of the sky. And sure enough, there it was. This was a highlight of Brother Nicholas Sullivan's 1985 Explorer's Club Expedition. One might think, from this, that it had divine guidance.
>
> Gerry Collins had led us to the area where about ten years previously he had seen a tunnel entrance. We had driven around for an hour in rough country and not found it. He told us to wait while he went back for the plane. The entrance was quickly spotted from the air and he came and guided us to it. The Piper Cub is used for mustering and has a loud hailer in it. Hence the guiding voice from the sky."

This is the opening description in the report of our first trip to the Collins system. On the first trip we were able to take the biologists Frank Howarth and Fred Stone.

We were there for less than 24 hours and a survey of Collins No. 1 Cave was made and Collins No. 2 was explored. No. 1 is about 150 m long and ends in a rubble pile that is venting. The cave may be extended with digging. For part of its length it has two parallel interconnected passages that are about 7 m wide and 5 m high. This is quite unlike the tunnels at Undara. There are two piles of guano each over a metre high under bat roosting sites. A large number of bats (1000+) were present. No. 2 is about 100 m long and is a simpler tunnel. It has a low section and also ends in a venting rock pile.

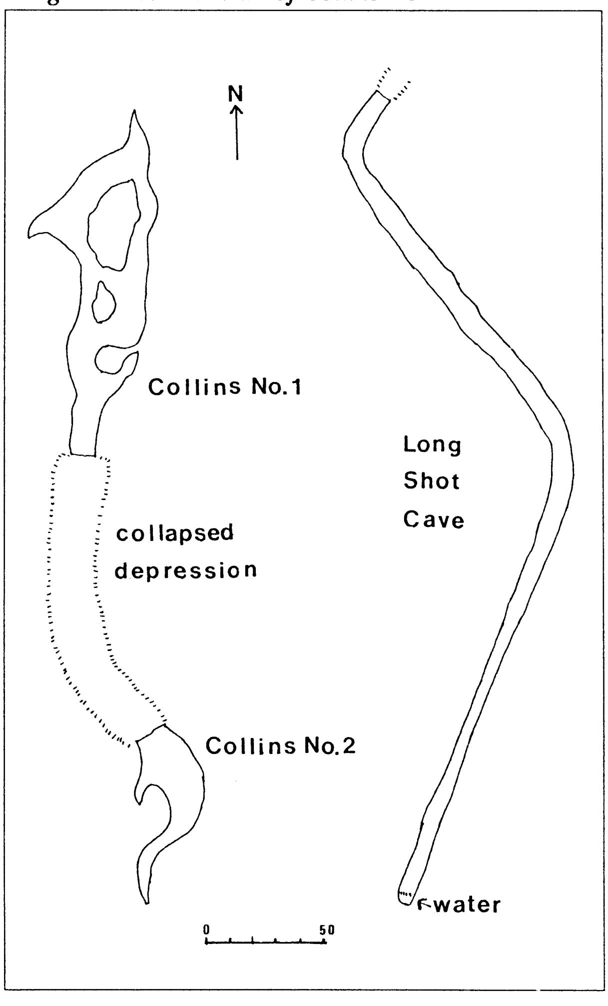
Frank Howarth and Fred Stone did some hasty collecting. From the lavicicles on the wall it could be seen that the lava flow was from north to south. The tubes were aligned at about 5°.

On return to Cairns the aerial photos for the area were studied and the caves tentatively located. A source for the lava flow was sought. The next craters to the north on a 5° bearing are a group of steep cones which are probably pyroclastic. These do not produce lava tunnels. Further north is Mount Tabletop which about 9 km from Collins No. 1. This is a layman's guess as to the source of the Collins lava flow.

The next trips were not made until August 1985. The area to the north of Collins No. 1 was checked but only deciduous vine thicket on large areas of aa lava was found. This is not the type that forms lava tubes. It appears that this could be later flow that covered the area. Checking down-flow from Collins No. 2 about 500 m, the next cave found was Tourist Trap, which is about 100 m long.

The next cave is Daylight Cave with about 50 m of passage. It has an interesting entrance with a roof about

Figure 1. Three of the major tubes of the Collins System. Longshot is 650 m south of Collins No. 2.



2 m thick and 8 m wide. The ceiling is quite flat. There is a horizontal crack across the arch and a brick like pattern of vertical cracks. It is not a place to shelter in an earthquake.

A collapse leads south from Daylight Cave and Long Shot Cave is in the end of this. The opening had to be enlarged to get in. This is the major cave of the Collins system and is about 370 m long. It contains bats, humidity, CO_2, tree and grass roots and has a small pool of water at the end. By now the tunnels were getting smaller in cross section, being only a couple of metres wide in places.

The next trip was a fortnight later and two more caves down flow from Long Shot were found. The first was Impatience Cave, only about 17 m long, with rock scree going the whole length. A few bats were present. The last cave was Graveyard Cave about 110 m south. It is about 50 m long and has a two level structure. It also had some bats in it. Beyond this last cave there is a marginal increase in slope and there are numerous lava tongues. This is probably the southern end of the lava flow.

The depressions between Collins No. 2 and Tourist Trap were checked and entrances were "expanded by lithological rearrangement to accommodate a human torso" to quote Mick Godwin's report. Never let it be said that we do any digging. The northern one is Two-Ten-Tunnel and is about 210 m long. It ends at the collapse that is at the southern end of Collins No. 2. The floor has some guano on it and a few bats were present. The stems of germinated seeds reacted by quick movement when a torch was brought close to them.

Handful Cave is about 80 m long and starts in the depression that contains Tourist Trap and ends at the depression of Two-Ten-Tunnel.

BIOLOGY

The following year (1986) Frank Howarth and I spent three days there collecting. Most of the time was spent in Long Shot and Two-Ten-Tunnel as these held the most potential for cave life. In the Undara system it was found that the caves with foul air had the most cave adapted life. Long Shot Cave confirmed this theory. It had CO_2 levels as high as 2.8% at the terminal.

These are some of the highlights as seen by a layman. The most exciting find for me was the peripatus. This is an ancient life form and is like a caterpillar. This is the first time that Frank had seen one and it is certain to be a new species. They occur in the rainforest as well. Two were found, one in the end of Long Shot and the other in Two-Ten-Tunnel. The two locations are about 500 m apart. At the end of Long Shot Cave troglobitic singing crickets were found. They have only been reported elsewhere in the world from South-East Asia.

Another exciting discovery was the same blind plant-hopper as found in Bayliss and Nasty Caves over 30 km away. This is in contrast to Chillagoe where in adjacent towers the most and least cave adapted plant-hoppers occur.

A large eyeless spider of unknown family is found both in Bayliss (Undara) and Long Shot. This is probably the largest troglobitic spider in the world.

Also seen in the tunnels were a toad, possum, rat and a snake as well as the tracks and burrow of possibly an echidna. These would all add to the food supply of troglobites when they die.

More work has to be done in the system. An interesting juvenile cockroach specimen was collected from Collins No. 1. It is hoped that more collecting will take place there in the New Year.

Dave Collins of Spring Creek Station recently reported seeing more tunnels while helicopter mustering in the area. We are dependent on the graziers for help in finding new systems. Perhaps when satellite technology improves more discoveries may be made with the help of the mining companies in the area.

ACKNOWLEDGEMENTS

My special thanks to Gerry and Dave Collins for their generous help, especially the use of their aircraft and helicopter in finding tunnels. Members of the Chillagoe Caving Club Inc. did most of the field work, in particular Mick Godwin whose excellent field notes made this paper possible.

APPENDIX I.
LIST OF TUBES IN COLLINS SYSTEM.

NAME	LENGTH (m)
Collins No. 1	150
Collins No. 2	100
Daylight	50
Graveyard	50
Handful	80
Impatience	17
Longshot	370
Tourist Trap	100
Two-Ten-Tunnel	210
Total	1127

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LAVA TUBES

NOTES

BIOLOGY

CAVE-DWELLING PLANTHOPPERS OF AUSTRALIA (INSECTA: HOMOPTERA: FULGOROIDEA)

Hannelore Hoch and Manfred Asche.

ABSTRACT

Recent investigations in caves in Cape York Peninsula, Queensland, have revealed the existence of at least 11 previously unknown cavernicolous Fulgoroid species of the families Cixiidae and Meenoplidae. These species represent at least 7 separate evolutionary lines within the Fulgoroidea that have invaded caves. The species belong to the genera Solonaima Kirkaldy, Undarana Hoch & Howarth, and Oliarus Stal within the Cixiidae, and to Phaconeura Kirkaldy within the Meenoplidae. In the present paper a preliminary account of the known Australian cave Fulgoroids is given, the morphological alterations they have undergone during the process of cave-adaptation are briefly described, and notes on the geographic distribution and ecology of each species are given.

INTRODUCTION

Until recently terrestrial troglobites (obligate cavernicoles) seemed to be poorly represented in Australia compared to similarly large areas in temperate regions, e.g. the United States (Matthews and Kitching, 1976). Various authors (e.g. Moore, 1964; Hamilton-Smith, 1967) have tried to rationalize this apparent impoverishment by the ecological stability of tropical surface environments. Recent investigations in Karst and lava caves in tropical northern Queensland, however, have revealed a remarkably diverse cave-adapted fauna (Howarth, this issue).

In the collections from the caves were several Homoptera species of the Fulgoroid families Cixiidae (Hoch and Howarth, in press) and Meenoplidae. Epigean Fulgoroidea are distributed worldwide and comprise about 15,000 species. Some groups of Fulgoroidea are pre-adapted for a life underground - their nymphs live close to or within the soil where they suck sap from roots. Prior to the investigations in Queensland caves only one troglobitic Fulgoroid species was known from Australia: the meenoplid Phaconeura pluto Fennah (Fennah, 1973) from Quandong Cave, Nambung National Park, Western Australia. Outside Australia, cavernicolous Fulgoroidea are known to exist in New Zealand, New Caledonia, Hawaii, Mexico, Jamaica, Zimbabwe, Madagascar and the Canary Islands (see table 1 in Remane and Hoch, 1988: 405). As a result of the recent findings of cavernicolous planthoppers, which belong to at least 11 species, Queensland now has the highest concentration of cave-adapted Fulgoroidea in the world.

GEOLOGY AND CAVE LOCATIONS OF THE STUDY AREA IN QUEENSLAND

The caves studied are located in Cape York Peninsula, North Queensland, and have different geologic histories with surface rocks ranging in age from Precambrian granites to Recent basaltic lavas. The karst caves of Mt. Mulgrave and Chillagoe areas are within the same limestone formation deposited during late Silurian (416-434 m.y. ago) as coral reefs in shallow seas similar to the Great Barrier Reef. Since then the limestone has been subject to uplift and inundation, and erosion has left highly dissected cavernous limestone towers (Ford, 1978). In the area around Chillagoe these towers stand up to 100 m above the surrounding plain, in the Mt. Mulgrave area, about 100 km to the north, they may reach heights up to 200 m. The current cycle of uplift and cave formation started during Tertiary (Ford, 1978), about 30 - 35 million years ago, and fossil bearing sediments indicate that the caves have been colonizable at least that long. The current cave passages have existed for perhaps 5-10 million years (Pearson, 1982). The main caves are described in Ford (1978) and Robinson (1982). The lava tubes south of Chillagoe are of a much younger age than the limestone caves of Chillagoe and Mt. Mulgrave. Bayliss, Nasty and Pinwill's Caves are in the Undara lava flow which is 190,000 years old. The Undara lava flow covers portions of older lava flows of the McBride Formation (Atkinson, Griffin and Stephenson, 1975). Collins and Long Shot Caves are in an undated lava flow 30 km SE of Bayliss. The two flows, however, are connected by other basaltic flows. The caves studied provide a variety of ecological conditions: due to the more vertical development within limestone and also to the more advanced state of erosion the caves at Chillagoe and Mt. Mulgrave areas are often characterized by numerous entrances which allow airflow and desiccation within vast passages of the caves. In contrast, the lava tubes at Undara form more closed passages with stagnant air, high relative humidity and increased carbon dioxide concentration (Howarth and Stone, in prep.).

So far, Fulgoroid species have been found in 2 karst towers in the Mt. Mulgrave area, in 11 towers in the Chillagoe area and in 6 lava tubes near Mt. Surprise south of Chillagoe (see table 1).

RESULTS

CIXIIDAE

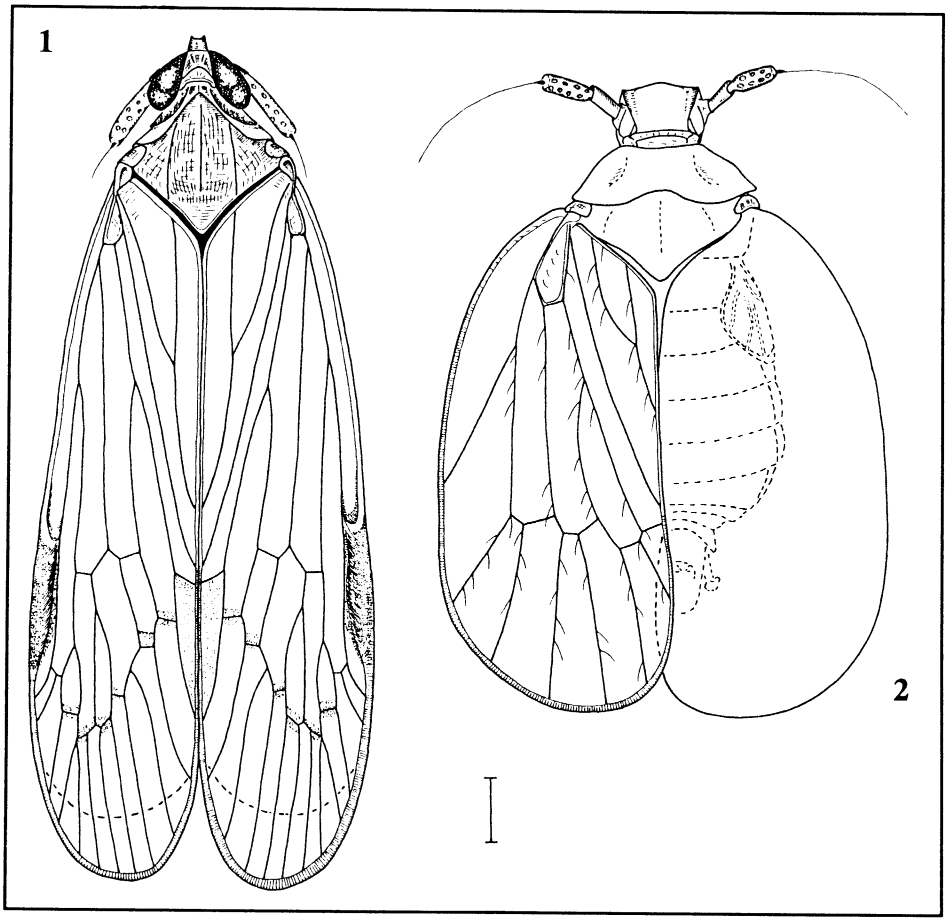
The Cixiidae found in Queensland caves belong to 3 genera: Solonaima Kirkaldy (6 species), Undarana Hoch and Howarth (in press) (2 species) and Oliarus Stal (1 species). Solonaima and Undarana are endemic in Australia, while Oliarus species have a worldwide distribution. The species of each genus are clearly distinct in characters of the male genitalia. The 3 genera are also represented in the epigean fauna of Australia: Solonaima with 7 species in Queensland (Kirkaldy, 1906; Distant, 1907; Hoch, in press), Undarana with 4 species in Queensland (Hoch and Howarth, in press), and Oliarus with 16 species in Queensland, New South Wales, Western Australia (Kirkaldy, 1906, 1907; Distant, 1907; Jacobi, 1928; Muir, 1931).

2. **S. pholetor** and **S. stonei** still have well developed eyes, but are weakly flighted.

3. **S. irvini** and **S. halos** are pigmentless and display only remnants of compound eyes and strongly reduced wings.

4. **S. baylissa** is completely blind as well as flight- and pigmentless.

Besides these reductive characters (troglomorphies) that are usually found in correlation with cavae adaptation, additional specialized structures were found in obligate cavernicolous Solonaima species, e.g. the pilose



Figs. 1-2. Habitus of Solonaima Kirkaldy (Cixiidae) species. 1. S. solonaima Kirkaldy (epigean species); S. baylissa Hoch and Howarth (troglobitic species). Scale: 0.5mm

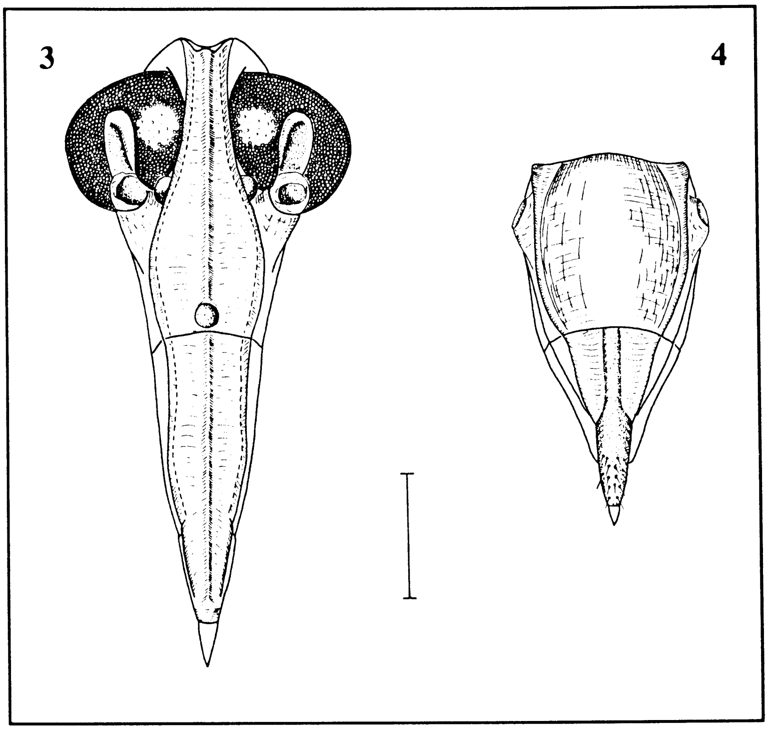
The 6 known cavernicolous Solonaima species (Hoch & Howarth, in press) display varying degrees of cave adaptation (Hoch and Howarth, in press). Examination of the male genitalia revealed that they form 4 morphological groups which were interpreted to represent 4 separate evolutionary lines that have invaded caves (Hoch and Howarth, in press).

1. **S. sullivani**, the least cave adapted species, shows virtually no modifications from surface-dwelling Solanaima species: it has nearly fully developed compound eyes and is flighted.

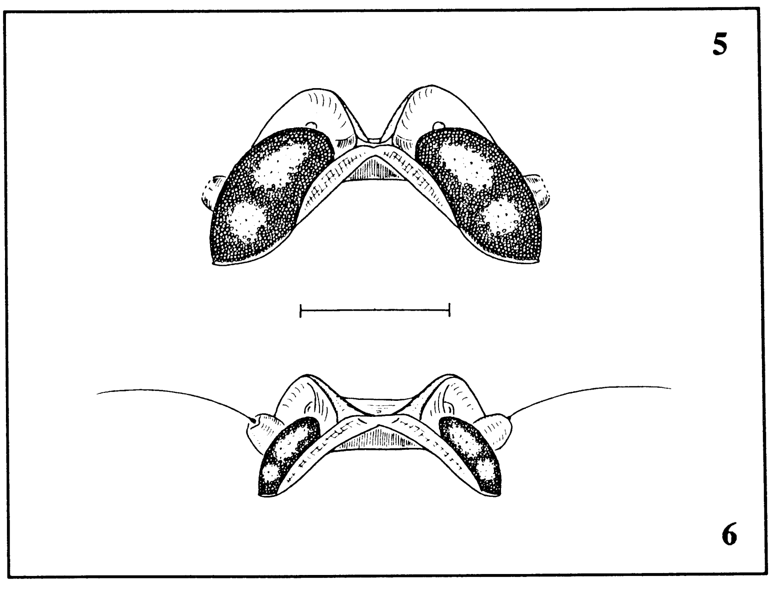
antennae and clypeus, the apical spinulation of the tarsal segments of the hind legs, a blue wax fringe of the wings as well as a more planate general body form (Hoch and Howarth, in press). Except for S. sullivani which appears to be closely related to the epigean S. solonaima Kirkaldy, none of the other invasions showed evidence of closer relationship either to each other, or to any of the epigean species.

Ecology and Distribution:

Solonaima nymphs and adults suck sap from tree roots of possibly Ficus spp. (Hoch and Howarth, in press) which are common on the towers as well as on the surface above the tubes. Unfortunately, the host trees have not been identified. The six cave-dwelling Solonaima species are found to occur allopatrically in different caves (Hoch and Howarth, in press). Amazingly, the degree of troglomorphy was observed to be correlated with the particular cave environment rather than with the age of the caves (Hoch and Howarth, in press): S. sullivani, the least cave adapted species occurs in two vertical caves which are subject to desiccation by cool air flow from outside within a single tower at Mt. Mulgrave. The two weakly cave-adapted and presumably facultative (troglophile) cave species, S. pholetor and S. stonei, are - although poor flyers - presumably still capable of some epigean dispersal: each species is found in two separate towers near Chillagoe. The two nearly blind and flightless Solonaima species, S. halos and S. irvini, each occurring in a single tower near Chillagoe, seem to be restricted to deeper passages with stagnant air, and are thus regarded intermediate obligate cave species. S. baylissa which is morphologically highly modified (completely blind, strongly reduced wings) is found only in the deep cave zone passages with stagnant air, saturated atmosphere and high carbon dioxide concentrations in 3 lava tubes at Undara. Since no morphological differences between S. baylissa populations from Bayliss and Nasty Caves in the Undara lava flow and Long Shot Cave, which is at least 30 km away, could be found, it is assumed that gene-flow between these populations is maintained by subterranean dispersal (Hoch and Howarth, in press). This indicates that the geographic range (and also its population size) of this troglobitic species is much larger than that of the less cave-adapted Solonaima species (Hoch and Howarth, in press). Within this genus the morphological differences between surface- and cave-dwelling species are less strongly pronounced than in Solonaima (Hoch & Howarth, in press). Within the two known cave-dwelling species of this genus the degree of troglomorphy is less advanced in U. rosella which in several characters is intermediate between epigean species and U. collina, e.g. in comparison to epigean species, the compound eyes are reduced but the ommatidia-bearing area is still comparatively larger than in U. collina. Accordingly, U. rosella is sometimes attracted by bright head lamps, while U. collina does not show any reaction to light. Other characters undergoing gradual changes between epigean Undarana species and U. collina are the ability to maintain sustained flight, pigmentation, proportions and carination of the vertex as well as reduction in number of the lateral hind tibial spines. Although proportions of tegmina and wings do not differ significantly from those of epigean Undarana species, U. rosella is a weak flyer and capable of only short sustained flights, while U. collina is nearly flightless, being able to hop and flutter only a few metres.



Figs. 3-4. Solonaima species: head, ventral aspect. 3. S. pallescens (Distant) (epigean species); 4. S. baylissa (troglobitic species). Scale: 0.5mm.



Figs. 5-6. Undarana species: head, dorsal aspect. 5. U. towomba Hoch & Howarth (epigean species); 6. U. collina Hoch & Howarth (troglobitic species). Scale: 0.5mm.

According to the morphological similarity in structures of the male genitalia of U. rosella and U. collina it seems likely that these two species are the result of a single invasion into the caves and that speciation has occurred subsequently rather than two separate cave invasions (Hoch and Howarth, in press). The cavernicolous Undarana species do not appear to be closely related to any of the four known epigean species.

Ecology and Distribution:

Cavernicolous Undarana species have so far been found only in 2 lava tubes in the Undara region. Also in Undarana species, the degree of trogolomorphy is correlated with their physical environment: U. rosella, the less cave-adapted species, inhabits the transition zone of Bayliss Cave, while U. collina seems to be restricted to deeper passages within Collins Caves. Although permanently dark, the transition zone is subject to influences from the surface environment (desiccation, changes in temperature and relative humidity), whereas deep cave zone passages are characterized by stable conditions (saturated atmosphere, constant temperature, stagnant air) (Howarth, 1982). From their degree of cave-adaptation, different flight ability and different reaction to light we regard U. rosella as troglophilic, and U. collina as troglobitic (Hoch and Howarth, in press).

In contrast to Solonaima baylissa which obviously manages to maintain gene-flow between populations from Bayliss and Long Shot Cave (which is in the same flow as Collins Caves) the Undarana populations from Bayliss and Collins Caves differ significantly in external and genital morphology which was interpreted by Hoch and Howarth (in press) to be an indication for interrupted gene-flow and the existence of two separate biological entities. This may be due to the less advanced degree of cave-adaptation which may not allow subterranean dispersal along voids and cracks over long distances (Hoch and Howarth, in press).

Both cave-dwelling Undarana species have been observed feeding on roots; possible hosts are Myrtaceae (Melaleuca spp. and Eucalyptus spp.) which are common in the surface vegetation (Hoch and Howarth, in press).

<u>Oliarus Stal</u>

In lava tubes at Undara, several adult specimens of an (apparently undescribed) Oliarus species with normally developed compound eyes, wings and pigment were found.

Ecology and distribution:

In Bayliss Cave, adult specimens were found in the entrance zone, in Pinwill's Cave adults and one nymph also in transition zone and deep cave zone passages.

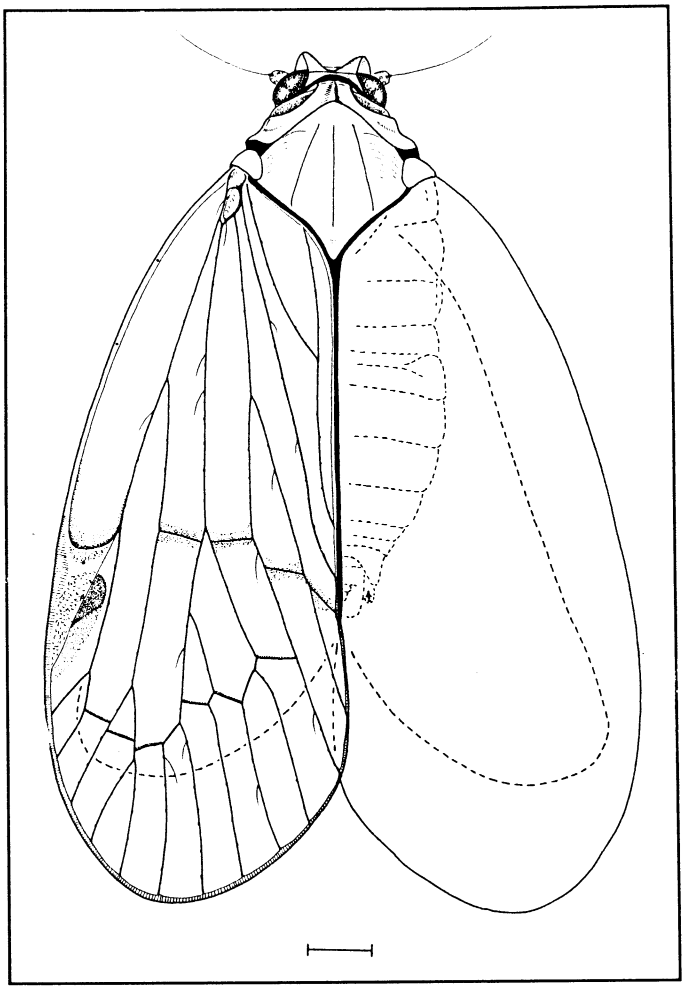


Fig. 7. Habitus of Undarana rosella Hoch and Howarth (Cixiidae) (troglophilic species). Scale: 0.5mm.

These specimens represent accidentals, trogloxenes, or belong to troglophilic but not yet morphologically modified populations of a surface-dwelling species.

<u>Meenoplidae</u>

The cavernicolous Meenoplidae so far known from Australia belong to the genus Phaconeura Kirkaldy which is represented in the epigean fauna of Australia with 6 species (Fennah, 1963; Kirkaldy, 1906; Woodward, 1957).

Cave-dwelling Phaconeura species are so far known from Western Australia (Phaconeura pluto) and Queensland. In Queensland, cavernicolous Meenoplidae have been found in 6 caves, and belong to at least two species. Taxonomic descriptions of these previously undescribed species are in preparation and will be published in a taxonomic journal.

1. **Phaconeura spec. 1** shows troglomorphies such as the reduction of eyes, wings and pigment.

2. **Phaconeura spec. 2** morphologically is intermediate between surface-dwelling Phaconeura species and P.

spec.1: the compound eyes are present, although smaller than in epigean species, the adults are able to maintain a sustained flight, and the bodily pigment is not as significantly reduced as in P. spec. 1.

Amazingly, the male genital structures of the two cavernicolous Phaconeura species which in one cave near Chillagoe were even found to occur syntopically are very similar. We do not yet know whether these two species represent a single cave invasion, or two separate invasions by the same or closely related epigean ancestors. Within Phaconeura, the two cavernicolous species from Queensland belong to the P. smithi Woodward group, although no closer relationship to a particular epigean species could so far be assessed.

Phaconeura pluto of Western Australia although belonging to the same genus clearly represents a separate evolutionary line that has invaded caves.

Ecology and distribution:

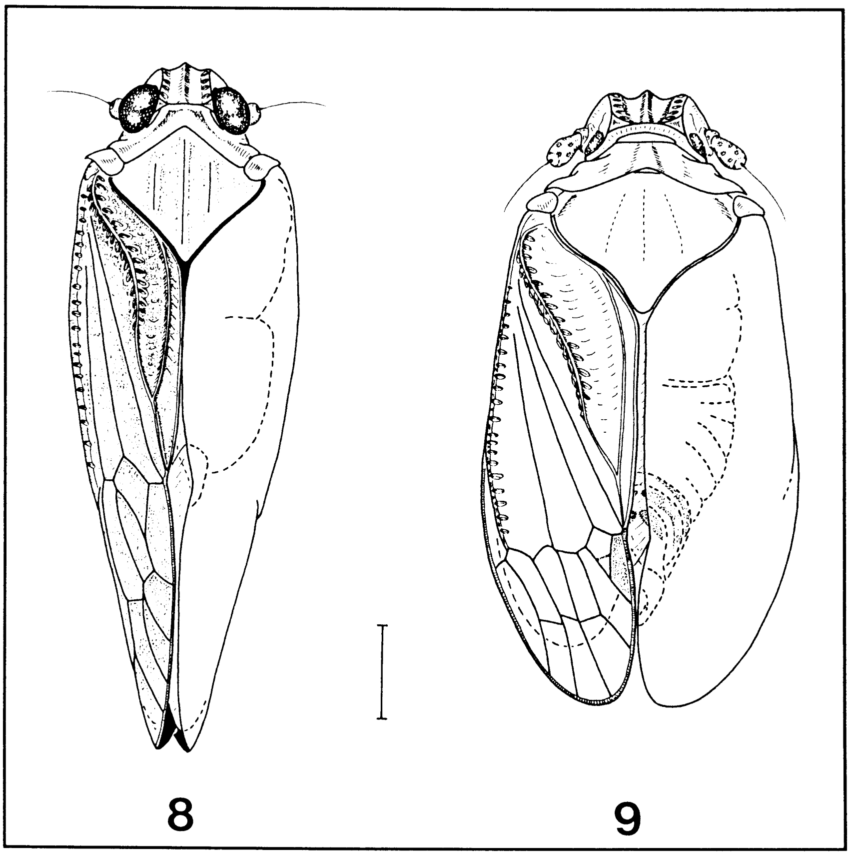
Phaconeura sp. 1 has so far been found in the transition and deep cave zones of caves within 3 different towers in the Chillagoe area. According to its degree of troglomorphy Phaconeura sp. 1 is not likely to be able to survive and disperse outside the cave environment and is thus regarded troglobitic. Since no morphological differences were observed between populations of different but neighbouring towers, we assume that geneflow is maintained by subterranean dispersal through voids in the cavernous rock. It cannot yet be decided, however, whether the specimens from one tower in the Mt. Mulgrave area, which is about 100 km away, belong to the same biological entity. The population from Mt. Mulgrave is so far represented in the collections only by females and nymphs, which do not allow a doubtless assessment to any particular species.

Phaconeura spec. 2 has been collected in the twilight and transition zones of caves within 3 different towers. Two of these populations (from Ryan's Creek and Queenslander Towers) are represented by males. Since no morphological differences either in external or genital structures could be found we assume that gene-flow is maintained between these populations and thus regard them conspecific. From Carpentaria Tower only a single female is known, occurring syntopically with P. spec. 1, virtually feeding side by side on the same root. According to its external morphology, size and coloration we assume it to be conspecific with the populations from Ryan's Creek and Queenslander Towers. Its degree of troglomorphy indicates that this species is able to survive outside caves and we thus regard it as a troglophile.

The two cavernicolous Phaconeura species most likely feed on roots of the same or similar host plants as the cave-dwelling Cixiidae. Nymphs are possibly attended by ants, which would help explain their dispersal ability. The adults are much more closely associated with their host roots than are the cixiids.

P. pluto, the cavernicolous Meenoplid described from Quandong Cave, Nambung National Park, Western Australia, displays a degree of troglomorphy (complete reduction of compound eyes and pigment, strongly reduced wings) that suggests it to be an obligate cave species, although no ecological information concerning its habitat is available to the authors. It is still unclear whether the nymphs of Cadda Cave (already mentioned in Fennah 1973) are conspecific with the population from Quandong Cave.

We examined an adult Phaconeura male from Tick Cave, also Nambung National Park (ex coll. CSIRO, Canberra), which in its degree of troglomorphy and genital characters resembles P. pluto; however, its conspecifity with P. pluto can only be confirmed after re-examination of the holotype.



Figs. 8-9. Habitus of Phaconeura species (Meenoplidae). 8. P. spec. (epigean species); 9. P. spec. 1 (troglobitic species). Scale: 0.5mm

DISCUSSION

The recent findings of cave-dwelling planthoppers in Queensland caves pose several research questions:

Are there more evolutionary lines of Fulgoroidea which have invaded caves in Australia?

As already mentioned previously, Queensland now has the highest concentration of cave-adapted Fulgoroidea in the world. So far, comparatively few karst towers and lava tubes have been investigated biologically, and research has concentrated in the areas around Chillagoe, Mt. Mulgrave, and Undara. The karst band, in which the towers at Chillagoe and Mt. Mulgrave are found, continues to the north for over 150 km, providing over 300 isolated exposed towers. Recent studies (Hoch and Howarth, in press) indicate that most of them might house additional species of cave-adapted Fulgoroidea, many of which are likely to be highly modified obligate cave species.

But not only in Queensland caves are more species of cave-adapted Fulgoroidea to be expected: the Australian Karst Index (1985) lists an immense number of caves, especially in the Northern Territory that by containing tree-roots as the essential food resource within deep cave zone passages are theoretically suited to support cave-adapted Fulgoroidea.

What factors have led to the convergent evolution of cave-adapted species of Fulgoroidea in tropical North Queensland?

There are two major hypotheses to explain the evolution and distribution of cave-dwelling animals. The isolation-hypothesis, as formulated by Barr (1968) and Poulson and White (1969), assumes that climatic changes, such as during glaciation, cause extinction or extirpation of surface populations. By this, troglophilic populations are trapped within caves and subsequently acquire cave-adaptations. The alternative model as suggested by Howarth (1988) explains the evolution of troglobites by parapatric speciation from surface species. According to this hypothesis, cave invasions are the result of adaptive shifts which enable the organisms that are accidentals in caves to exploit new food resources. In this model extinction or extirpation of surface populations are not prerequisites for cave-adaptation, and close surface relatives may still be extant (Howarth, 1988).

We cannot at present decide which of these models applies to each case of cave-dwelling Fulgoroidea of Australia. Although there is evidence of climatic change in Australia during Miocene - according to palaeoclimatic data rain forest vegetation retreated due to an onset of increased aridity in association with the ice expansion in the Antarctic (Kemp, 1981) - the cave-adapted Fulgoroid species might as well be the result of adaptive shifts since in some cases close epigean relatives exist in the same area. Evidence supporting either hypothesis might be gained by relating genetic distance estimates within the different taxa to evolutionary time (e.g. Nei, 1972, 1975).

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TABLE 1. DISTRIBUTION OF AUSTRALIAN CAVE FULGOROIDEA.

Cave locations	Cixiidae Solonaima	Undarana	Oliarus	Meenoplidae Phaconeura
QUEENSLAND:				
Mitchell-Palmer Karst				
West Mordor Tower:				
Crystal Cascades C.	+ (a)	-	-	-
Here-it-is C.	+	-	-	-
Capricorn Tower:				
Swiss Cheese C.	n	-	-	* (?l)
Chillagoe Karst				
Markham Tower:				
Swiftlet Scallops C.	* (e)	-	-	-
Hercules C.	* (e)	-	-	* (l)
Ryan Imperial Tower:				
Marachoo C.	n	-	-	* (l)
Carpenteria Tower:				
Carpentaria C.	n	-	-	*(l), + (?m)
Queenslander Tower:				
Queenslander C.	* (d)	-	-	+ (m)
Haunted Tower:				
Spooked C.	+ (c)	-	-	-
Spring Tower:				
Spring C.	+ (c)	-	-	-
Arena C.	+ (c)	-	-	-
The Throne Room C.	+ (c)	-	-	-
Gordale Scar Pot	n	-	-	-
Suicide Tower:				
Christmas Pot	n	-	-	-
Ryan's Creek Tower:				
Ryan's Creek C.	n	-	-	+ (m)
Donna Tower:				
Donna C.	+ (b)	-	-	-
Trezkinn C.	+ (b)	-	-	-
Royal Arch Tower:				
Royal Arch C.	+ (b)	-	-	-
Walkunder Tower:				
Clam C.	n	-	-	-
Rhino C.	n	-	-	-
Octopus Hollow	n	-	-	-

*: troglobite;
+: troglophile;
o: trogloxene;
n: nymphs (not identifiable to species level);
a: Solonaima sullivani;
b: S. pholetor;
c: S. stonei;
d: S. halos;
e: S. irvini;
f: S. baylissa;
g: Undarna rosella;
h: U. collina;
i: Oliarus spec.;
k: Phaconeura pluto;
l: P. spec. 1;
m: P. spec. 2.

TABLE 1. DISTRIBUTION OF AUSTRALIAN CAVE FULGOROIDEA (CONTINUED).

Cave locations	Cixiidae Solonaima	Undarana	Oliarus	Meenoplidae Phaconeura
QUEENSLAND (Continued):				
McBride Lava Tubes				
Bayliss C.	* (f)	+ (g)	? o,+ (i)	-
Nasty C.	* (f)	-	-	-
Pinwill's C.	-	-	? o,+ (i)	-
Long Shot C.	* (f)	-	-	-
Two-Ten-Tunnel	-	* (h)	-	-
Collins No. 2 C.	-	* (h)	-	-
WESTERN AUSTRALIA:				
Nambung Nat. Park:				
Quondong C.	-	-	-	* (k)
Cadda C.	-	-	-	n
Tick C.	-	-	-	* (?k)

*: troglobite;
+: troglophile;
o: trogloxene;
n: nymphs (not identifiable to species level);
a: Solonaima sullivani;
b: S. pholetor;
c: S. stonei;
d: S. halos;
e: S. irvini;
f: S. baylissa;
g: Undarna rosella;
h: U. collina;
i: Oliarus spec.;
k: Phaconeura pluto;
l: P. spec. 1;
m: P. spec. 2.

ENVIRONMENTAL ECOLOGY OF NORTH QUEENSLAND CAVES: or WHY THERE ARE SO MANY TROGLOBITES IN AUSTRALIA.

Francis G. Howarth.

ABSTRACT

Forty-three species of troglobites (obligate cave-dwellers) are listed from the tropical caves of north Queensland, Australia. All display morphological adaptations to caves, i.e reduced eyes, wings, and bodily color, compared to their surface relatives. They live deep in caves and interconnected systems of medium-sized voids, where the air is stale, saturated with water vapor, and often with a high concentration of carbon dioxide and where the substrate is damp, although many species are found in, or make forays into, more exposed cave passages, where the air is fresher but still saturated with water vapor. Cave habitats are zonal, and five zones are described based on the physical parameters that correspond to ecological communities. These are the entrance, twilight, transition, deep cave, and stagnant air zones. A community composed almost entirely of terrestrial troglobites is found in the stagnant air zone. Twenty-four of these troglobites live in Bayliss Cave, making this 190,000 year old lava tube one of the world's most significant biological caves. The existence of these troglobites and the potential for many new troglobitic species as the numerous caves of northern Australia are surveyed should lay to rest long-held assumptions and confirm that terrestrial troglobites are well represented in Australian caves, as well as in tropical caves in general.

INTRODUCTION

Conventional wisdom has long assumed that obligate cave-dwelling animals, i.e. troglobites, were poorly represented in continental Australian caves, and Moore (1964), Hamilton-Smith (1967) and Barr (1973) have published salient arguments explaining the apparent paucity of troglobites here. Their reasoning stressed the aridity of the continent, which was thought to have caused the extinction of a supposed earlier fauna, and the absence of preadapted moist litter species, which could colonize the caves. For completely different reasons, obligate cave animals were thought to be virtually non-existent in tropical caves, which are numerous in Australia. Vandel (1965), Barr (1968, 1973), Mitchell (1969), and Sbordoni (1982) explained the absence of terrestrial troglobites in tropical caves as resulting from the absence of climatic vicissitudes during the Pleistocene, which they felt were necessary to extirpate the epigean populations of evolving troglobites. However, the discoveries in the Galapagos (Leleup, 1968), Hawaii, and elsewhere (reviewed in Howarth, 1983b), have revolutionized our thinking on the evolution of troglobites and the biology of tropical caves.

On the basis of work in Hawaii, several hypotheses were put forward to explain the apparent disjunct distribution of troglobites in the world's karst regions. The more important are the tropical winter effect (Howarth, 1980; 1983a), a bioclimatic model (Howarth, 1980), a redefinition of the subterranean biome (Howarth, 1983b), and physiological ecology of troglobites (Howarth, 1980; Ahearn and Howarth, 1982).

Briefly, troglobites are behaviorally and physiologically specialized and appear to have evolved to exploit resources within the medium-sized voids (mesocaverns) and to colonize cave-sized passages (macrocaverns) only where the environment to which they are adapted is found or approximated. Since tropical caves are warm, limestone solution and evaporation rates are high, and in the tropics night-time temperature often falls below mean average surface temperature, creating nocturnal drying winds almost daily (the tropical winter effect). Therefore, the bioclimatic model predicts that it is more difficult to find troglobites in cave-sized passages in the tropics than in the temperate regions. In 1980 I wrote, "In fact, the bioclimatic model predicts that many more troglobites will be discovered as more tropical caves are surveyed and also predicts that they will be found only in cave passages that have a stable saturated or nearly saturated atmosphere" (Howarth, 1980).

In 1984, Brother Nicholas Sullivan presented me with an opportunity to come to Australia to study the tower karst around Chillagoe. The Chillagoe karst with the neighboring lava tube area at Undara has proved to be an ideal location in which to test the theories developed in the insular caves of Hawaii. Cave adaptation in insular Pacific caves was considered a special case and not representative of the tropics, or temperate caves in general (Culver 1982; Holsinger, 1988; Holsinger and Culver, 1988).

These studies on environmental ecology and cave animal distribution are still in progress, particularly as the expeditions to Chillagoe have all been fielded in the cool winter season when the tropical winter effect would theoretically be most severe. Thus we may have a parochial view of the cave climatic regime and ecology, having seen only part of one season.

This report is also preliminary because of the huge wealth of specimens and data collected. It will take years of uninterrupted study to sort through this material, obtain reports from the systematics collaborators, and decipher the story. It cannot be stressed too strongly that a study of this type is only as good as the systematics research upon which it is based. However, the story that is unfolding expands our view of the environmental ecology of caves, the evolution of cave faunas, and the numbers of troglobites in Australia.

The Chillagoe caves provide an ideal locale for conducting evolutionary and ecological studies of importance. They lie in an extremely complex area geologically with old, relatively isolated limestone pinnacles (tower karst) separated by both igneous intrusions and alluvial deposits. The climate is tropical with a monsoonal rainfall regime. Each tower has several entrances leading to numerous caves. Each cave can be quite different morphologically, environmentally, and faunistically. Within each tower, a suite of different cave types often occurs, while suites of similar cave types can be found in neighboring towers. In other words, each tower or group of nearby towers can be viewed as an island, its fauna having developed in isolation but under similar gross (i.e., long term) geological, biological, and climatic regimes with those of neighboring towers. This happenstance presents a unique opportunity for significant comparative research on environmental ecology. For one can conduct detailed ecological studies in each of several analog caves with very similar features but which are isolated from each other. One can also study animal distribution and resource exploitation in the suite of caves in one tower and then find analog caves in other towers which differ in one or only the few biotic or abiotic factors being examined. This comes as close to having an experimental control as is possible in ecological studies.

Adding further to this potential for comparative evolutionary studies is the existence of the significant caves in the McBride Formation lavas only 100 km southwest of the limestone. These lava caves have had a very different geological history, being much younger but possibly more interconnected than the limestone caves. Many of the same taxonomic groups have invaded each of these insular cave regions. In some cases perhaps the same ancestral species may have colonized several different caves and evolved independently in adapting to the caves. Some of our results are reported here. See also Hoch (this issue) and Stone (this issue).

METHODS

Biosurveys

Field work was done in conjunction with the 1984, 1985, and 1986 Chillagoe Caves Expeditions. Over 50 separate caves were visited in 15 towers in the Chillagoe-Mungana area, another two caves in two towers in the Rookwood area, 8 caves in 4 towers in the Mt. Mulgrave sector of Mitchell-Palmer area, and 10 lava tubes in two separate lava flows south of Mt. Garnet. We attempted to visit as many separate caves as possible and as many different types of caves as possible, but concentrated on larger caves and those known to contain moisture, guano, roots, or other abundant food resources, as these were found to support the most diverse fauna.

The caves were searched for animals, paying special attention to arthropods. Methods used were visually searching, placing baits (especially tubers, meats, cheese, and grains), and, to a lesser extent, setting pitfall traps. Promising caves were visited repeatedly. Voucher specimens of the arthropod species and some other invertebrate groups were collected. Additional specimens, which had been collected on previous expeditions or by members of the Chillagoe Caving Club, have been incorporated in the results where possible. The voucher specimens are deposited at the Queensland Museum in Brisbane, the B.P. Bishop Museum in Honolulu, and when appropriate at the home institution of the collaborating systematists.

Environmental ecology

The distribution of each of the different species of invertebrates was noted within the caves and correlated with cave and passage shape, relative humidity, temperature, moisture, food resources, and in selected caves also with carbon dioxide concentration. Temperature and relative humidity were measured with a battery-powered portable Bendix aspirating psychrometer. In Tea Tree, Bayliss, Nasty, Barker's, and Long Shot Caves, the concentrations of CO_2, O_2, NH_3, and CO were measured with a Draeger Multi Gas Detector.

CAVE ECOLOGY

Geologic history

The geology of the study area is complex, and ages of surface rocks range from Precambrian granites to Recent basaltic lavas. The 416-434 million year old Silurian limestone in the Chillagoe Formation outcrops as a band of over 300 isolated, cavernous marble towers, extending 150 km from Chillagoe north to the Palmer River (Best, 1983). The current main dry caves formed by phreatic solution during the last 5-10 million years (Ford, 1978; Pearson, 1982; Jennings, 1982), but there are remnant older passages and solution breccias near the tops of many towers, indicating that there may have been caves continually available for colonization since the area was uplifted and the limestone exposed in the mid-Tertiary about 25 million years ago. Near Chillagoe, the limestone towers stand nearly 100 m higher than the surrounding plain, which is between 350-400 m above sea level. The tower karst of Mitchell-Palmer 100 km to the north has experienced different rates of uplift and erosion, which have produced larger and higher towers (up to 200 m) often with a wide apron of limestone talus at their bases. Since the caves generally open only above the talus slope, they are often more open and more vertical than those at Chillagoe.

The lava tubes south of Chillagoe are strikingly different. The 190,000 year old Undara lava flow is less than 5% of the age of the Chillagoe caves. The pahoehoe lava flow, however, covers portions of older flows within the McBride Formation (Atkinson, Griffin, and Stephenson, 1976) and therefore, the cave fauna could have migrated through the numerous cracks and voids in young basalt and colonized caves in each flow in succession. Some McBride Formation lava flows may date from the Pliocene, more than 2.5 million years ago (Best, 1983). The troglobitic species could be, and probably are, older than the age of their caves.

Physical environment

Caves are strongly zonal environments. There are 3 obvious zones: entrance, twilight, and dark, based on degree of light penetration and its associated environment. From a biological perspective, the dark zone can be subdivided, based on the degree of climatic disturbance, into three distinct subzones: 1) transition, 2) deep, and 3) stagnant air zones. The transition zone, as the name implies, is a passage that is in total darkness but where the climatic events on the surface are still operative. The deep zone is beyond the transition zone. The substrate remains moist, the atmosphere remains saturated with water vapor, and the cave climate remains stable for extended periods. Air exchange with the surface keeps the air fresh. The stagnant air zone is beyond the deep zone, where air exchange with the surface is too slow, allowing the build-up of gasses, especially carbon dioxide, from organic decomposition.

Whether these zones occur in a given cave, and the location of the dynamic boundaries between them are determined by -

(1) the size, shape, attitude, and location of the entrances in relation to the surface environment and the size and shape of the cave passages,

(2) the availability of water, and

(3) the climatic regime on the surface.

Since water vapor is considerably lighter than air it will tend to diffuse out of deep open caves. Carbon dioxide on the other hand is much denser than air and will accumulate only in deeper passages. Thus the two gasses rarely reach high levels together in cave-size passages. However, U-, n, or N-shaped passages into dead-end rooms can trap both gasses, and it is here that troglobites are often found in abundance.

The main caves within the study area are described in Ford (1978) and Robinson (1982a), Atkinson et al., (1976), and in issues of Tower Karst. Cave types range from open aerated caves; e.g. the transition zones between large entrances in the main passages of Royal Arch, Carpentaria, and Spring Caves, to stagnant foul-air cave passages like Bayliss, Nasty, and Long Shot Caves. Most caves are complex with both open, aerated passages near the entrances and deep, remote passages, which approach stagnant conditions at least temporarily, e.g., Donna, Royal Arch, Arena, and Rhino Caves. In Chillagoe area caves there are 3 passage configurations that act in consort to trap air masses and lead to stagnant air conditions (stagnant air zone) and an environment suitable for troglobites.

a.) Deep caves reaching water or moisture near the water table;

b.) Small crawl way entrance to dark room, i.e. large cave volume to entrance size ratio; and

c.) a U-, n-, or N-shaped passage separating an inner passage from all entrances.

a]. Caves that are deep enough to reach water or moist soil layers; Spooked Cave and the main chamber in Donna Cave are the simplest examples. Many of the larger caves in the tower karst near Chillagoe have similarly deep, moist passages but also have a mixture of the other configurations. Marachoo has a crawl way entrance, U- and n-shaped inner passages, and water in its lowest level. Surprise Packet has an offset n-shaped crawl to the pit leading to the lowest moist level. If the pit was not so offset, the mud at the bottom would dry out much more quickly.

b]. Small crawl way entrance into large dead-end passage. Nasty Cave at Undara is the simplest example. Bayliss Cave at Undara and well-known Marachoo, Carpentaria, and Rhino Caves at Chillagoe combine the crawl way entrance with the next configuration.

c]. A U-, n-, or N-shaped crawl way or constricted passage leading into a dead-end upper level. This configuration is an excellent one for defining passages where troglobites can be found. The Snake-pit area of Carpentaria Cave is so different in environment and fauna from the rest of the cave that visitors are surprised. Hercules Cave contains one of the most diverse troglobitic faunas in the Chillagoe Karst, and the rich passage is an upper level beyond a particularly complex N-shaped passage. Arena Cave has a U-shaped entrance crawl which leads into a moist room with a high dead-end upper level. It is a much smaller cave than Spring Cave in the same tower, but the constricted and convoluted entrance allows the cave to support greater populations of troglobites than Spring Cave.

The long downwardly sloping lava tubes in the Undara and Collins systems are particularly well suited to trap both carbon dioxide and water vapor. The lava is old enough for a surficial soil layer to have formed which seals the cave from leakage except through entrances and larger cracks, The mud floor holds both moisture and organic debris for gas build up. In both Long Shot and Bayliss Caves constrictions at the entrance and within the cave help trap both moisture and carbon dioxide. Nasty Cave has a nearly sealed entrance, which when disturbed can lead to air overturn and exchange.

Temperature

Cave temperatures are generally near MAST (mean annual surface temperature) ca. 26° C (Robinson, 1982b); however, passage shape can significantly dictate the equilibrium temperature within a cave. Passages below entrances often act as cold traps and are cooler than MAST. These passages are also subject to the winter effect and are often dry, e.g. Spring (T = 19° C), Haunted (T = 21° C), and Donna Caves (T = 20-21.5° C). Passages above entrances or dead-end upsloping passages within the cave act as heat traps and remain warmer than MAST, e.g., Tea Tree Cave (T = 30° C) or at least warmer than the lower parts of the caves e.g. the Snake Pit room (T = 26° C) compared to 20° C in the Grand Canyon room of Carpentaria Cave. Many Chillagoe caves have several entrances at different elevations and the passages between have variable temperatures because of the chimney effect between the entrances, e.g. the main room in Donna Cave varied between 21.5° C and 20° C between 3 and 12 June 1985, during a period of cool nights and a strong winter effect.

Several caves near Chillagoe contain permanent pools of water, which were surprisingly warm in May to July during our visits, ranging from 27° C in Marachoo Cave to 29.5° C in Tea Tree Cave. Although a geothermal source of the heat is possible, it seems more probable that the water temperature results from the stored heat of the summer rains entering the caves. Mean temperature during the wet summer months approaches 30° C (Robinson, 1982b). In Centenary Cave, two small pools probably isolated from groundwater connection had a temperature of 19° C and 20.5° C respectively on 1 July 1984.

Biodiversity

About 5000 specimens of cavernicolous arthropods have been collected from the caves in the study area. These represent hundreds of species, many of them new to science. Over 40 species of troglobites are so far recognized in the material (Appendix I). Only one of these troglobites was known and named before the current survey. Three quarters of the troglobites live in two lava tube systems within the McBride Formation, and over one half (24) species are found in Bayliss Cave, underscoring the significance of this cave.

Bayliss Cave, with a total known fauna of at least 52 resident species, also supports the most diverse assemblage of arthropods of any cave in the area, either limestone or lava. However, as discussed below the Bayliss Cave fauna is segregated into distinct communities based on the physical environment.

Food resources

The major food energy in North Queensland cave ecosystems is supplied by -

(1) guano from trogloxenes, especially bats and swiftlets,

(2) abundant leaf litter and organic debris falling or washing into the doline entrances and cracks,

(3) abundant tree roots, and

(4) accidentals i.e. those animals that blunder into caves but can not survive there.

Accidental animals, both vertebrate and invertebrate visitors, which die or become easy prey in the cave, supply abundant food for troglobites. Several trogloxenous ant and termite species penetrate deeply into cave habitats in search of water and may be a large resource for cave animals, but evidence of significant use is weak. The defensive and navigational abilities of these social insects may be sufficient to prevent significant exploitation.

The most abundant tree roots probably belong to Ficus and Brachychiton, but the roots have not been authoritatively identified. In the tropics on karst and young lava flows, water washes off the barren rocky surfaces into cracks and sinkholes and sinks rapidly to the water table. Vadose water held in a surficial soil layer, as typically occurs in temperate regions, rarely occurs on tropical karst or new lava flows. Vegetation growing on these porous rocky substrates must cope with this stressful rapid percolation of water. One of the common specializations shown by trees able to grow on these terrains is deeply penetrating roots. Their roots must extend to the water table often 30 m or more below ground. These deeply penetrating roots provide energy resources for troglobitic animals, which accounts for the better development of troglobitic root feeders in tropical caves than in temperate caves.

The food resources in these caves are relatively abundant compared to those recorded for temperate regions, but the availability of each is highly seasonal. The monsoonal rainfall climate washes most of the leaf litter and other organic matter into the caves during the three wetter summer months; bats and birds use the caves seasonally, dumping fresh guano in the caves over a short period of time, which then ages before additional guano is deposited; and flushes of the trees in response to rainfall and warm weather bring more food to the roots. All of these would pulse populations of cavernicoles and synchronize their life cycles. Possibly these caves are as seasonally variable as many temperate caves, but the seasonality is driven by a completely different climatic and biologic regime.

Communities

Species exploiting the same food resource often form communities which interact and support separate food webs within the cave. Generalists and predators may interact with several food webs. As in other zonal habitats, these communities can sometimes be better defined by the physical parameters dictating animal distribution than by the food resources present. Distinct Chillagoe cave communities include the entrance and twilight zone communities, the aquatic community, the terrestrial tree root community, the transition zone bat and swiftlet guano communities, and the stagnant air zone community. There is some overlap as some generalists may exploit more than one resource or zone. Troglobites occur mainly in the deep and stagnant air zones, and it is these zones and their fauna that are the focus of this paper.

The aquatic cave communities in Chillagoe and Undara are so far inhabited by only one macroscopic invertebrate group, the amphipods. These are scavengers in every permanent pool of water in the study area. Why there appear to be no predators or other species in this habitat remains an enigma.

The tree root community contains not only plant feeding species but also a number of predators and scavengers which prefer to forage on or near roots. Many species are host specific, that is occurring on only one type of root, e.g. the meenoplid and cixiid planthoppers, or are found on roots only in certain zones within the caves, e.g. the cixiid planthoppers and the moths. Among the latter, the noctuids (undetermined species of Schrankia) all prefer wetter roots in the deep and stagnant air zones, while the pyralid (Bocchoris acamesalis, det. G. B. Monteith, Queensland Mus.) prefers drier sites in the transition zone. Several ant species, including Paratrechina longicornis and Paratrechina sp. 1 (det. R. Taylor, CSIRO, Canberra) use roots for navigation to gain access into the cave both for water and for food when available.

Several guano communities overlap within the caves depending on zone and type of guano, and its age. Some of the guano food webs appear to develop differently on the same food resource in different caves. Is this succession as the resource ages or history of animal colonization within the cave? For example, in Taylor Cave at Undara, and Collins Cave No. 1, the bat guano seethes with mites, which are preyed upon by pseudoscorpions, Protochelifer cavernarum Beier (det. M.S. Harvey, Mus. of Victoria). Numerous small beetles and fly maggots also live in or on the guano. In contrast, in nearby Pinwill Cave, large cockroaches, Paratemnopteryx sp., and isopods dominate the guano surface. How did these two different distinct communities develop? Most of these guano species are considered guanobites or troglophiles, although many of them show some troglomorphies.

The cave environment and the distribution of troglobites

The distribution of most cavernicoles within caves and their degree of cave adaptation are more clearly correlated with the physical environment within the cave than with either food resources or cave geology. As already described, troglobites are found in passages with stagnant air, which is saturated with water vapor, although many species do make forays into the transition zone for food or by accident. For example, the meenoplid planthoppers in the Grand Canyon passage of Carpentaria Cave maintain water balance by sucking sap from their host roots.

The relationship between environment and distribution of cave troglobites is nowhere more dramatic than in Bayliss Cave at Undara. During our surveys in May and June of 1985 and 1986, a community made up almost entirely of troglobites occurred in the inner parts of the cave. Most of the 21 troglophilic species occurred only in the outer transition and deep zones within the cave, while 3/4 of the 24 troglomorphic species were found only in the stagnant air zone, where the carbon dioxide concentration ranged from 0.6% to 6% (200 times ambient) (Howarth and Stone, in prep.). With 24 troglobitic species, Bayliss Cave supports one of the most diverse specialized faunas known in the world. The long term stable inner atmosphere in Bayliss Cave approaches equilibrium with the gas concentrations within the surrounding mesocaverns. The discovery of a community of troglobites in a foul air cave supports the hypothesis that troglobites are specialized to exploit the resources within the medium-sized voids in cavernous rock, where gas mixtures, especially CO_2 and H_2O, are limiting for most surface species.

With the able assistance of Douglas Irvin, I was able to repeat the studies in Bayliss Cave in 1986, confirming the 1985 results and to study two additional foul air lava tubes, Nasty and Long Shot Caves. Although neither cave is as large or as diverse as Bayliss Cave, the results corroborate those from Bayliss. Long Shot Cave is in the Collins Lava Tube System on Spring Creek Station about 30 km southeast of Bayliss. It has a crawl way entrance down slope to a small room in twilight. The cave extends over 360 m as a 3-5 m wide tunnel dissected by short crawl ways over or through breakdown piles. The constrictions trap both water vapor and CO_2. On 27 May, 1986, the carbon dioxide ranged from 0.1% at the base of the entrance slope (Site 1) to about 2.75% near the end. Relative humidity ranged from about 90% at Site 1 to saturated beyond the first constriction, where the first troglobites were found. Temperatures ranged from 20.2° C at Site 1 to 25.2° C near the end. The arthropod community in the final room was composed mostly of troglobites. Eight of the 13 troglomorphic species appear to be the same as those that occur in Bayliss Cave (Appendix I), but the systematic research is preliminary.

Nearby Two-Ten-Cave trends upslope from the entrance and does not trap CO_2, but the inner rooms were saturated or nearly so (RH = 98-100%) On 26 May 1986, the temperature ranged from 20.1° C in twilight at the base of the entrance slope to 21.8° C in the final room, 200 m from the entrance. The inner fauna consisted mostly of troglophiles, but a few troglobites similar to those in Long Shot were found. However, the cixiid species in Two-Ten-Cave belongs to a different genus and shows fewer troglomorphies than the cixiid found in Long Shot Cave (Hoch and Asche, this volume).

Nasty Cave is a 100 m long segment of the Undara system down slope of Bayliss Cave. The entrance is nearly sealed and must be enlarged to enter. On 29 May, 1986, the first troglobites were found only 50 m from the entrance (where RH = 98%; T = 25.5° C, O_2 = 14.8%, and CO_2 = 3.5%). Less food was available than in Bayliss Cave, and the number of species and populations were less. The final room was in the stagnant air zone and contained a community of troglobites (RH = 100%, T = 26.7° C, 0_2 = 13.7%, and CO_2 = 5.1%).

In spite of the apparent or implied stability of the environments of these zones, the boundaries between them and indeed the environmental conditions themselves can be dynamic. For example, on 30 May, the day after the entrance had been reopened and following an exceptionally cool night of the 29th, the air in Nasty Cave had changed. The readings in the final room had changed to RH = 100%, T = 26.5° C, CO_2 = 3.25%, and most of the troglobites had disappeared. Two common species on the 29th, a Nocticola cockroach and a polydesmid millepede, could not be found, and the populations of the other 9 troglobites were greatly reduced. Most of the troglobites appeared to have retreated into cracks during the unfavorable conditions of the previous night and were beginning to recolonize the cave as the environment improved.

Many troglobites are capable of making short forays into less than ideal environments to gather food or to disperse. This explains the effectiveness of baits and the apparent rarity of cave species, which is often related to the serendipity of being at the right place at the right time to find an animal that is normally wandering deep within the mesocaverns.

CONCLUSIONS

Why are there so many troglobites in Australia? There are potentially as many or more troglobites in Australia than on other continents because (1) there are so many caves, especially in the tropics and subtropics; (2) the cave areas are more or less isolated from one another, allowing the faunas to evolve and diverge independently; (3) food energy entering the caves is diverse and abundant; (4) the arthropod fauna of Australia is large and diverse, providing many preadapted colonists for the invasion of caves; and (5) a sampling of a few caves on the northeastern corner of the continent found a troglobitic fauna more diverse than most of the world's better studied cave areas.

Future surveys will certainly turn up additional new troglobites, both in the areas that we studied and in other limestone and lava regions. Most biological surveys in north Queensland have been done in the dry season. Surveys during the wet season, when the major drama in the cave ecosystem probably occurs, should be more productive.

We sampled just 2 lava flows in the northern corner of the McBride Formation and found about 30 new highly troglomorphic species. Many other caves and additional cave-adapted species can be expected further south in the McBride Formation. There are four other areas of Cainzoic basaltic provinces in north Queensland (Atkinson, et al., 1976), and each can be expected to harbor additional unique troglobites.

Over 300 limestone towers are known in a band from Chillagoe north to the Mitchell-Palmer area. About 7% of these have been sampled to date. Many of the more than 280 unsurveyed towers contain caves suitable for troglobites, and a large percentage of these troglobites could be new species. Additional karst areas occur at Camooweal, the Kimberleys, and at scattered localities elsewhere in northern Australia.

It is ironic that lava tubes were once thought to be exceptional environments for the evolution of troglobites (Barr, 1968), for lava tubes are now found to support far greater numbers of troglobites than neighboring limestone caves. The observation is real. Young basalt typically has far greater systems of mesocaverns than does most limestone, and so is a better habitat for troglobites.

One has to actually enter a cave and look for troglobites before proclaiming on theoretical grounds that none could exist. The results of the environmental ecology studies reported herein can be used to predict what types of caves and cave passages will most likely yield troglobites. The developing theory portrays troglobites as specialized to exploit resources within medium-sized cracks and crevices in subterranean rock and to colonize or stumble into cave-sized passages only where the physical environment is close enough to their favorite one. Thus the passages where troglobites would be expected will be dark, damp, saturated with water vapor, draft-free, and stable in temperature. Troglobites appear to be tolerant of the relatively high concentrations of carbon dioxide that exclude many troglophiles from deeper passages. This fact makes sense for an animal inhabiting a complex maze, where CO_2 concentrations fluctuate rapidly. The longer the air mass and other parameters of the physical environment in cave-sized passages are stable, measured in days, the more likely troglobites will be present. The presence of appropriate food resources and hiding places, such as roots and rock piles will improve the habitat for troglobites. Their environment is an inhospitable one for most organisms.

Contrary to earlier views that mainland Australia was devoid of troglomorphic troglobites, the preliminary data reported herein indicate that Australia will be found to support one of the most diverse troglobitic faunas of any of the continents.

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APPENDIX I

Annotated list of troglobites (obligate cave-dwelling species) known from the Chillagoe and McBride Formation caves, north Queensland.

Onychophora: - peripatus: A new, possibly troglobitic species of these unusual living fossils, which share features with both the earthworms and arthropods, was found in the deep zone of 210 Cave and stagnant air zone of Long Shot Cave.

Crustacea: Amphipoda; (det. by A. Friend and B. Knott, Univ. W. Australia, Nedlands). Blind, white, aquatic amphipods occur almost wherever permanent water is found in caves (Bayliss, Road, Tea Tree, Marrachoo, Christmas Pot, and Centenary Caves). The distribution of the different species may provide clues to ground water flow.

ISOPODA: Family Armadillidae - the pill bugs (det. by Miss A. Green, Tasmanian Mus., Hobart). Two presumed troglobites occur in Chillagoe caves: Armadillo (Troglarmadillo) cavernae Wahrberg (1922), and an undescribed species.

Superfamily Oniscoidea - Two white, vestigial-eyed species, still undetermined, live in Bayliss Cave, and other Undara lava tubes.

ARACHNIDA: SCHIZOMIDA --schizomids: (Det. J. Reddell, Texas Mem. Mus.) Family Schizomidae: Cave populations are known from Barker's, Marrachoo, and Tea Tree Caves but are doubtfully troglobitic.

pseudoscorpionida -- pseudoscorpions: (det. by M.S. Harvey, Mus. of Victoria, Melbourne).

Family Chthoniidae: A large Tyrannochthonius species with small eyes, possibly troglobitic, lives in washed in leaf litter in Royal Arch Cave in the transition zone.

PHALANGIDA -- daddy long legs: (undetermined). Pale, small-eyed specimens, possibly troglobitic, have been collected deep in Hercules and Long Shot Caves.

ARANEAE --spiders: (det. by V. E. Davies, Queensland Mus., and M. Gray, Australian Mus., Sydney.)

Family Pholcidae: Spermophora sp. nov. B (Gray, 1973): This long-legged pale spider with 6 vestigial eyes builds sloppy webs on roots, walls and across drip holes in the stagnant air zone in lava tubes in Undara and Collin's lava systems.

Family Linyphiidae (?): An eyeless sheet web builder lives in the stagnant air zone of Bayliss Cave. Other possible troglobites, presumably in this family, have been collected in Chillagoe caves. Several troglophilic species also occur, including a conspicuous sheet-web building species on old guano in Clam and Ryan Creek Caves.

Family Zodariidae: A remarkable large, dark colored species with vestigial eyes is found in Bayliss and Nasty Caves.

Family Nesticidae (?): Two species of small cob-web spiders live in Bayliss Cave, a troglophile in the transition zone and a blind troglobite in the stagnant air zone.

Family Oonopidae (?): Tiny eyeless hunting spiders, representing an unknown number of species, have been collected in several caves, including Bayliss, Ryan Creek, Arena, Gordale Scar Pot, Pioneer, Tea Tree, and Donna Caves.

Unknown Family: A large, pale, completely eyeless hunting spider with uncertain affinities lives in the stagnant air zone of Bayliss and Long Shot Caves.

DIPLOPODA -- millipedes (undetermined):

CAMBALIDA: A large white, eyeless cambaliform milleped lives in the stagnant air zone of Undara and Collin's Lava Tubes.

POLYDESMIDA: Two species, probably troglobitic, live in the stagnant air zone of Bayliss Cave.

POLYXENIDA: A blind, white species living in the stagnant air zones in Bayliss and Nasty Caves at Undara is a doubtful troglobite. However, it was among the most sensitive to the changing conditions in Nasty Cave.

CHILOPODA: SCUTIGEROMORPHA: -- long-legged cellar centipedes ("100 mph bugs"): A large (> 4 cm body length), pale, small-eyed, slow-moving species lives in the stagnant air zone of Bayliss, Nasty, and sometimes Barker's Caves at Undara. It is one of the largest terrestrial troglobites in the world.

COLLEMBOLA - springtails (det. by P. Greenslade, CSIRO, Canberra). Blind, white springtails are common in Bayliss Cave and other caves. Most are soil forms or troglophiles; however, it seems likely that some are troglobitic.

INSECTA: DIPLURA: bristle tails: (undetermined). A possible troglobite is common in the stagnant air zone of Bayliss Cave.

THYSANURA: silverfish: (undetermined). Two blind, white species live in the stagnant air zone of Bayliss Cave. One appears to be associated with ants (Paratrechina); the other may be troglobitic.

DICTYOPTERA - cockroaches, {det. by L.M. Roth (1988), MCZ, Harvard, and F.D. Stone, (This issue)}.

Family Blattellidae: Paratemnopteryx sp. This large, eyeless cockroach is still known only from females and nymphs from the stagnant air zone of Bayliss and Nasty Caves.

Family Nocticolidae: Nocticola australiensis Roth: This small, pale, tiny-eyed cockroach is known from the moist areas (deep zone) of Donna Cave and other Chillagoe caves, with each tower having a distinctive race. Two other Nocticola are known: one from Long Shot Cave, and one from Bayliss and Nasty Caves (See Stone, this issue).

HEMIPTERA: -- true bugs: (det. by G.B. Monteith, Queensland Mus., Brisbane, M. Malipatil, Northern Territory Mus., Darwin, and the late W.C. Gagne, Bishop Mus., Honolulu.)

Family Enicocephalidae: A single blind white nymph is known from Arena Cave and is possibly troglobitic.

Family Reduviidae: assassin bugs,Two troglobitic species live in the high CO_2 areas of Bayliss Cave. The larger (> 1 cm long), a Pirates sp., has small pink eyes and tiny wings and stalks prey on the wet, muddy floor. Each leg has a thickened tip covered with water repellent hairs ("mud shoes"!). The smaller species (0.5 cm long) belongs to Micropolytoxus and is pale straw white in color with vestigal eyes and wings.

Subfamily Emesinae: -- The thread-legged bugs: A blind flightless species lives in the high CO_2 stagnant air zone of Long Shot Cave. An apparently closely related troglophile lives in the deep zone of nearby 210 Cave.

HOMOPTERA: Superfamily Fulgoroidea -- planthoppers, (det. H. Hoch, Marburg, Germany).

Family Meenoplidae: One troglobite from Carpentaria and Marrachoo Caves (See Hoch & Asche, this issue).

Family Cixiidae: Four troglobites are known from the Chillagoe area: one each from Hercules Cave, Queenslander Cave, and Two-Ten-Cave and one from Bayliss, Nasty, and Long Shot Caves. (See Hoch & Asche, this issue).

COLEOPTERA: Family Pselaphidae: A blind species is known only from the stagnant air zone of Bayliss Cave and is presumed troglobitic. Another blind species lives in Trezkinn Cave.

Family Staphylinidae: A small blind species lives in the stagnant air zone of Bayliss Cave, it may be a deep soil species or a troglobite.

Family Curculionidae: Subfamily Rhytirhininae: -- weevils (det. by E.C. Zimmerman, CSIRO, Canberra). Two remarkable blind cave weevils are known from the Undara Lava tubes, one from the deep zone of Taylor Cave and one from the stagnant air zone of Bayliss Cave.

THE COMMON SHEATH-TAIL BAT: A TROPICAL BAT WITH ADAPTATIONS FOR A TEMPERATE LIFE-STYLE

Simon Jolly.

ABSTRACT

It has been suggested that bats originated in the tropics and have since radiated into the temperate regions. A study of the tropical common sheath-tail bat at the southern end of its range has given some insight into the adaptive changes necessary for the invasion of colder latitudes. The sheath-tail bat does not hibernate but conserves energy over winter by lowering its body temperature in response to a decreased body weight or a reduced ambient temperature. Energy is stored in the form of fat, and large deposits are accumulated in autumn each year. Cold winters impose restraints on reproduction and in females this is highly synchronized to place pregnancy, lactation and growth of the young at an optimum time in the summer months. Because of reduced body temperatures, males are unable to produce sperm in winter and must lay down a store of sperm in the warmer months for use the following spring. Juvenile survival is jeopardized as they have little time to build up fat reserves before being faced with their first winter.

INTRODUCTION

About 20% of all known species of mammals are bats. They are found on many oceanic islands and range from the equator to 55°S in Chile (Koopman, 1967) and 65°N in Iceland (Koopman and Gudmundsson, 1966). The diversity of bat fauna is far richer in the tropics and it has been suggested that bats originated in the tropics and have since radiated into the temperate regions (Hand, 1984).

The further a bat ventures from the equator however, the more difficult life becomes. Clearly bats must adapt to cold winter temperatures, but of greater consequence is the risk of starvation. Most bats are insectivores, and in temperate regions insects virtually disappear in winter. Insectivorous birds cope by either migrating to warmer climes or by using beak specializations to remove dormant insects from rotten wood or from under bark. Clearly the second option is not open to bats. Some bats do migrate, but most bats living in the temperate regions rely on a third option, hibernation. If bats did radiate into the temperate latitudes from the tropics then what adaptations have enabled them to pass through the transition from a purely tropical animal to a hibernating temperate animal?

To gain some insight into the adaptive changes necessary for the invasion of colder regions I have been studying the tropical bat, *Taphozous georgianus*, (the common sheath-tail bat) at the southern end of its range in central Queensland. This bat is an insectivore averaging 30 g in weight found roosting in caves across the northern half of Australia. On the eastern side of the continent it is found as far south as Rockhampton.

METHODS

Field studies were carried out over a four year period from January 1985. The majority of bats were tagged and released and over 2,000 captures and recaptures were recorded. Some bats were maintained in captivity for the long term study of body temperature. This was remotely monitored with a radio-transmitting thermometer glued to the back of each animal. Several male bats were sacrificed for a detailed study of their reproductive physiology.

Figure 1. Body temperature in relation to ambient temperature at a body weight of 25 g (± se).

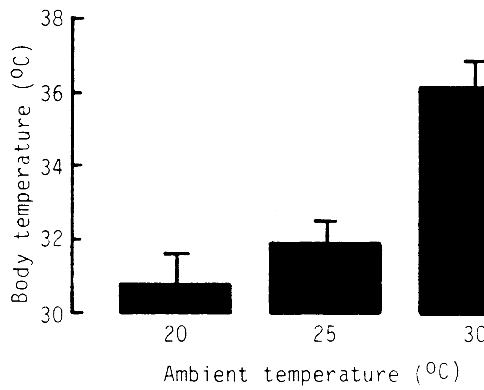
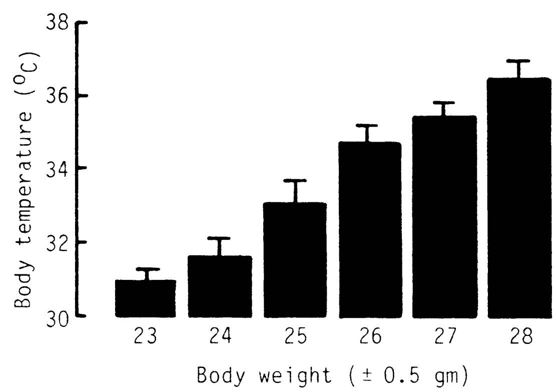


Figure 2. Body temperature in relation to body weight at an ambient temperature of 25°C (± se).



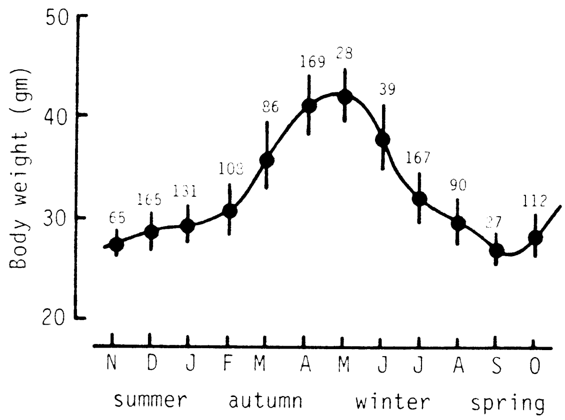


Figure 3. Seasonal change in the body weight of adult bats (± sd)

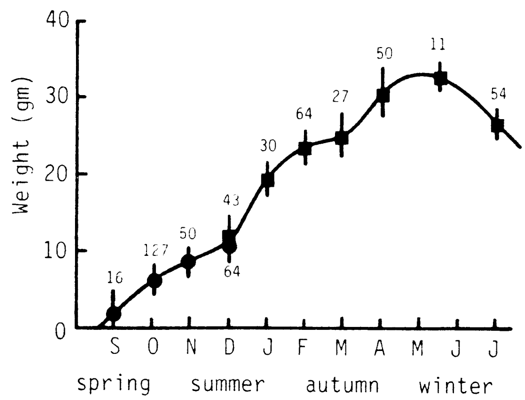


Figure 4. Weight of pregnancies (●) (mean difference between male and female weights) and body weight of juveniles (■) (± sd)

RESULTS AND DISCUSSION

The sheath-tail bat does not hibernate over winter but does lower its body temperature in response to certain conditions. Body temperatures as low as 25°C were recorded and torpor (a depressed body temperature) could be induced in these bats when body weight declined (Figure 1) or ambient temperatures were reduced (Figure 2).

When environmental temperatures are reduced, the maintenance of a high body temperature is energetically expensive. Such an expense can be ill afforded by a bat in winter when food resources are scarce. The ability to lower body temperatures is a valuable adaptation and it is evident that the sheath-tail bat switches into this energy saving mode whenever challenged with reduced environmental temperatures or a declining body weight as a result of food shortage. Some physiologist have suggested that this failure to rigidly maintain a high body temperature is a primitive characteristic, but I can not agree with this view and see the ability to lower body temperature as an advanced feature which has been a crucial adaptation for the invasion of the temperate zones by tropical bats.

Conserving energy is fine, but it is of no value if you don't have the energy to conserve in the first place. It became apparent from the field studies that bats were laying down large fat stores for use over winter. Figure 3 shows the annual body-weight changes in a population of sheath-tail bats. The mean weight of adult bats increases in summer and autumn to a peak of 42 gm in April. Fat reserves are used over winter and the body weight of bats declines by an average of 40% to reach 25 gm in September. Without these fat reserves the sheath-tail bat would not make it through the winter.

Personal survival is one thing, but what really counts is survival of the species. Bats must reproduce, but a number of reproductive constraints are placed on the sheath-tail bat by the difficult winter months. Pregnancy and lactation are energetically expensive for female bats and the rapid growth of young bats also requires a high plane of nutrition. As a consequence, reproduction in females is highly synchronized to place pregnancy, lactation and growth of the young at an optimum time in relation to the summer flush of insects (Figure 4). Mating occurs in September and the females give birth in December. The young bats grow rapidly, reaching adult dimensions within a few months and a peak in body weight by May.

So the females have got their act together, but their reproductive timing makes it difficult for the males. Under normal circumstances, for males to impregnate females in the spring they would be required to produce sperm during winter. Spermatogenesis is not energetically demanding, but the difficulty faced by the male sheath-tail bat is the excessive lowering of testicular temperatures as a result of low body temperatures during the winter. Although the testes of most mammals are maintained at temperatures below the body temperature, enzyme systems within the testes have narrow temperature ranges in which they work most efficiently and the action of the dartos and cremaster muscles to draw the testes of scrotal mammals closer to the body in cold weather is well known. Males have no problem producing sperm in the warmer months, but when winter comes the males lower their body temperature to conserve energy and as a consequence sperm production in the testes collapses. By the time spring rolls around and the females are demanding service, the testes of the males are completely empty. So what the males have to do is lay down a store of sperm in the cauda epididymidis during the warmer months and keep this in readiness through the winter for use the following spring.

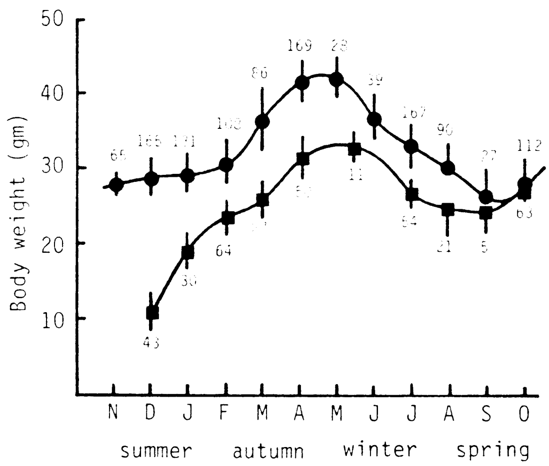


Figure 5. Seasonal changes in the body weight of adults (●) and the body weight of juveniles (■) (± sd).

So in summary, a complex interplay of physiological adaptations is enabling the sheath-tail bat to survive and reproduce at the southern frontier of its range and penetrate further into the temperate latitudes. The 3 key mechanisms involved are :-

1. The reduction of body temperature to conserve energy.

2. The deposition of fat as an energy reserve.

3. The storage of sperm to permit an asynchrony of male and female cycles and allow each to be optimally timed in relation to environmental conditions.

So why hasn't the sheath-tail bat got any further south than Rockhampton? Obviously they're not doing the job well enough yet and if they want to get any further south they are going to have to hibernate completely. Perhaps the biggest problem faced by the species is the survival of the juveniles who have little time to build up fat reserves before being faced with their first winter. While adult bats attain an average weight of 42 gm in autumn, juvenile bats reach an average of only 33 gm before entering their first winter (Figure 5) and they must conserve energy very efficiently if they are to survive to see a second summer.

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THE COCKROACHES OF NORTH QUEENSLAND CAVES AND THE EVOLUTION OF TROPICAL TROGLOBITES

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ABSTRACT

Although cockroaches are common and widespread inhabitants of Australian caves, only ten species (one troglobitic) were listed prior to the current biological surveys of North Queensland caves. At least six new cave species in two groups were collected by the Explorers Club Expeditions to Chillagoe and Mt. Garnet regions: two troglophilic/guanobitic species and a related troglobitic species of Paratemnopteryx (Blattellidae), and three troglobitic species of Nocticola (Nocticolidae). Roth (1988) described Nocticola australiensis, from Donna and Trezkinn Caves, Chillagoe and an epigean species, N. babindaensis from Babinda rainforest.

The cockroach species of North Queensland caves are all endemic, and they show close correlation between degree of troglomorphy and the environmental conditions of the five cave zones described by Howarth (this issue). Paratemnopteryx sp. A and B are slightly troglomorphic and are concentrated in twilight and transition zones; Nocticola australiensis shows moderate troglomorphy, and is found in the saturated deep cave zone; N. sp. A is moderately (?) troglomorphic but occurs in the stagnant air zone of Long Shot Cave; the highly troglomorphic Paratemnopteryx and Nocticola relatives are both found in the stagnant air zone of Bayliss Cave. Finally, non-troglomorphic and moderately troglomorphic Nocticola occur in moist epigean rainforest habitats.

INTRODUCTION

Cockroaches (Dictyoptera: Blattaria) are common, widespread inhabitants of Australian caves, and can therefore make important contributions to our understanding of cave ecology and the evolution of cave adapted species.

Richards (1967) listed 10 species of cockroaches from Australian caves, while recognizing that large areas of the country had not been surveyed for cave fauna. Only one troglobitic cockroach was known at that time, the highly troglomorphic Trogloblattella nullarborensis from caves in the Nullarbor (Mackerras, 1967).

Since 1982, the Explorers Club expeditions to the caves of North Queensland, led by Brother Nicholas Sullivan and supported by the Chillagoe Caving Club, have discovered at least six new species of Australian cave cockroaches. Two groups are represented in these collections (as determined by L. Roth):

1. The genus Paratemnopteryx (family Blattellidae), with two troglophilic/guanobitic species and a third related troglobitic species (so far known only from female and immature specimens).

2. The genus Nocticola (family Nocticolidae) with 3 species, all troglobitic; this is the first record of this family in Australian caves. One of the species collected from Donna and Trezkinn caves during the Chillagoe expeditions has recently been described by Roth (1988) as Nocticola australiensis.

It is remarkable, and important for ecological studies, that none of the common cosmopolitan cockroach species, ubiquitous in caves of other tropical regions, have been found so far in the caves of North Queensland. Hamilton-Smith also did not report any alien cockroaches in his 1967 list of Australian cave fauna.

Howarth (this issue) presents a model describing five environmental zones of caves in relation to adaptations of cave species; the **entrance, twilight, transition, deep cave,** and **stagnant** air zones (also see Howarth, 1980; 1983; 1988). In this paper, I will describe the distribution of cave cockroaches of the Chillagoe and Mt. Garnet regions and compare their degree of troglomorphy to their relative occurrence in the five cave zones.

PARATEMNOPTERYX

Distribution: This genus and related genera (Gislenia, Shawella are widespread in caves throughout Australia (Richards, 1967; Hamilton-Smith, 1967). The North Queensland species are medium sized cockroaches (about 8 to 20 mm long). They are abundant as troglophiles and guanobites in twilight and transition zones of caves where food and moisture are available. They are also found in the deep cave and stagnant air zones, but the populations drop rapidly as one moves further into these zones. Roth (Pers. comm.) is currently preparing a paper describing these species, so I will refer to them as P. species A and P. species B.

P. sp. A adults, smaller with either long or short tegmin, were collected from Nasty Cave (Undara lava flow), Tea Tree Cave, Kiwi Cave (Dumpy Tower), and Christmas Pot (Suicide Tower). Immatures, probably of this species, were found in Hercules Cave and Surprise Packet (Markham Tower), Parasol Cave (Katie Breen Tower) and Smeagol's Lair and Here It Is Cave (Mitchell-Palmer).

P. sp. B adults, larger with short tegmin, were collected from Bayliss, Barkers and Pinwell Caves (Undara

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lava flow), Clam, Spatial and Rhino Caverns (Walkunder Towers), Royal Arch Cave (Royal Arch Tower), Donna and Trezkinn Caves (Donna Tower), and Spring Cave (Spring Tower). Immature specimens were found in additional caves from the same and adjacent towers.

The **third** species, probably in the same or a related genus, is highly troglomorphic, and has been found only in the stagnant air zones of Bayliss and Nasty Caves in the Undara lava flow. It is often glimpsed in cracks (mesocaverns) in the cave walls, and only ventures into large passages when saturation humidity and high carbon dioxide levels are present.

So far, we have never collected both P. sp. A and P. sp. B from the same cave, from caves in the same tower, or even from caves in adjacent limestone towers. In the Chillagoe area, P. sp. A is found in caves east and/or north of the Chillagoe-Mungana road, while P. sp. B is found in caves west and/or south of the road. If it weren't for the Nasty cave population of P. sp. A we might interpret the distribution pattern as showing range boundaries of two allopatric species. However, this apparent pattern could be an artifact of our limited sample of the numerous caves of the region, and of our seasonally restricted field work.

P. sp. A is most often found in hot, humid caves (Tea Tree, Kiwi, Christmas Pot, Hercules, Nasty), often in areas with abundant bat or swiftlet guano. P. sp. B often occurs in the transition zone of large, relatively better ventilated, and less humid cave passages (Royal Arch, Donna, Spring, Clam, Spatial, Pinwill, Barkers and initial section of Bayliss) but it can also be found (with declining frequency) in the saturated deep cave zone of Bayliss and other caves.

Therefore microhabitat preference, possibly with competitive exclusion, could explain the distribution patterns. Further detailed field work is essential in testing such hypotheses, or in rejecting them for alternative hypotheses.

Morphology: Roth is publishing detailed descriptions of these species, so my remarks will be brief. Both species show slight troglomorphy, with considerable variation among individuals both within and between caves. P. sp. A shows variation in wing size (both macropterous and brachypterous forms occur), but lacks pulvilli. Reduction or loss of pulvilli and increased dependence on tarsal claws are adaptations for walking on cave surfaces (Christiansen, 1965; Roth and Willis, 1952). P. sp. B are all brachypterous, but show much variation in pulvilli reduction in populations both within and between caves (Roth, pers. comm.).

The variability among individuals within caves could be due to adaptations to heterogeneous microhabitats at various distances from entrances and on different substrates or food sources, or they might be due to gene flow between epigean and cave populations. Variability between caves could be due to a combination of the above factors plus restricted gene flow over longer distances. Continued field research will be necessary to enable us to sort out these complex patterns of variation.

NOCTICOLIDAE

Cave adapted cockroaches from tropical caves were first collected by Simon in the Philippines nearly 100 years ago. The Philippine cave cockroaches were described in the new genus Nocticola and later they were placed in their own family, Nocticolidae (Bolivar, 1892; Princis, 1966). From rare collections this family was found to be widespread throughout the old world tropics, with cave and surface species found in Africa, India, Southeast Asia, China, and Okinawa (Asahina, 1974; Bolivar, 1892, 1897; Chopard, 1921, 1924, 1932, 1945, 1950, 1966; Gravely, 1910, 1921; Karny, 1924; Roth, 1988; Shelford, 1910; Silvestri, 1946, 1947).

Biological surveys of the caves of Thailand by me (supported in 1986 by the Explorers Club) and of Thailand and Indonesia, by L. Deharveng and colleagues through the Association Pyreneenne de Speleologie, (1986) indicate that Nocticolidae are abundant in suitably humid habitats. In regions that have been intensively surveyed, a range of species occur from non-troglomorphic epigean species to highly troglomorphic species from deep cave and stagnant air zones.

NOCTICOLA: EPIGEAN SPECIES

On the Chillagoe expeditions we were able to find female and immature specimens from a rotting log in Running Creek, Mitchell-Palmer. Roth (1988) includes 2 surface species:

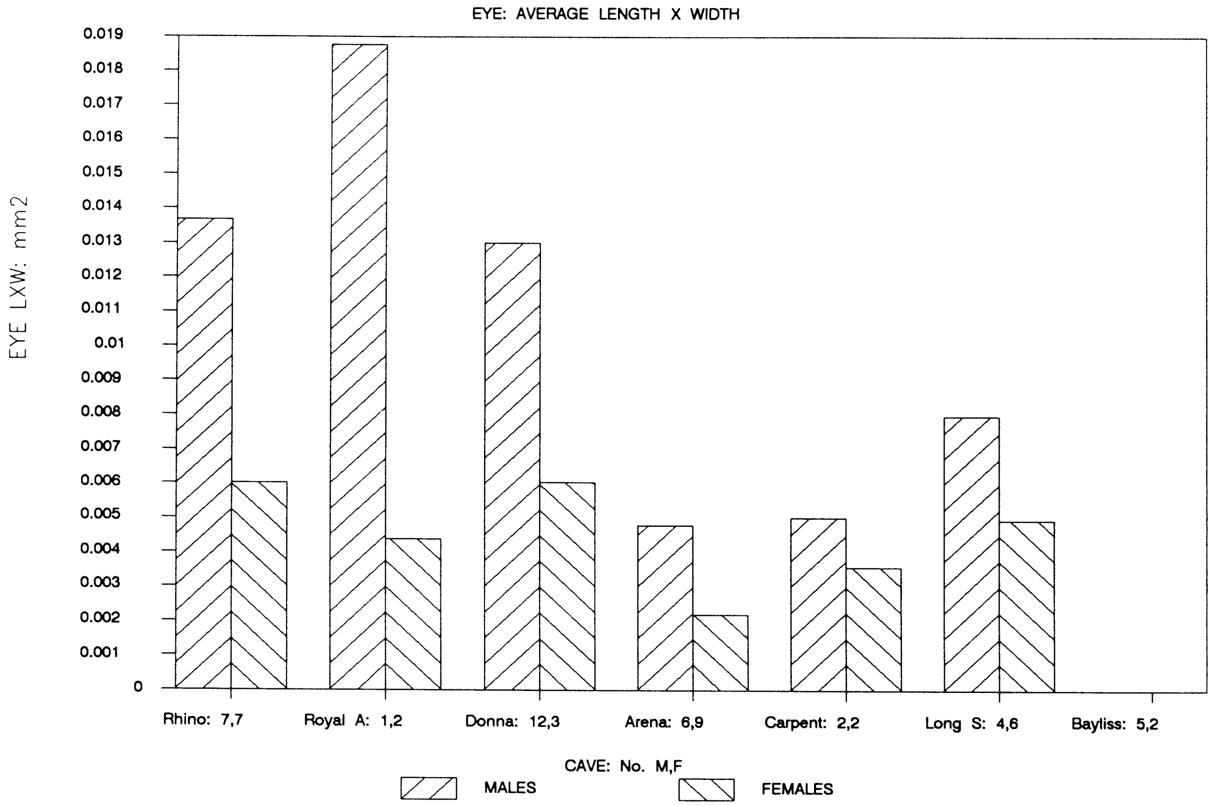
N. babindaensis, collected in a light trap in the rain forest at Babinda, Queensland has fully developed eyes, tegmina and wings. Though in color and lacking ocelli, it can be classified as non-troglomorphic.

The second species **(unnamed)** found under rotting logs at Crater National Park, has reduced eyes and tegmina, and no wings, but a large tergal gland present on the male. This species apparently has moderately troglomorphic characteristics, leading us to question to what extent the mesocavernous habitat extends to holes in the rainforest substrate (holes left by dead roots, holes under or in rotting logs, and termite or other animal burrows).

CAVE NOCTICOLA: DISTRIBUTION AND MORPHOLOGY

N. australiensis adults were collected from Rhino and Pioneer Caves (Walkunder Towers), Royal Arch Cave (Royal Arch Tower), Donna and Trezkinn

GRAPH 1



Caves (Donna Tower), Arena and Spring Caves and The Throne Room (Spring Tower), Kiwi Cave (Dumpy Tower), Carpentaria Cave (Carpentaria Tower) and Hercules Cave (Markham Tower). Immature specimens only were found in Spatial Cavern (Walkunder Towers), Marachoo Cave (Ryan Imperial Tower), Gordale Scar Pot (Spring Tower) and Project 31 Cave (Moffat Tower).

N. australiensis are found in the humid deep cave zones (or in moist microhabitats of transition zones) of caves in the Chillagoe region. They are all moderately troglomorphic, with body color pale yellow, eyes much reduced or absent (smaller in females than males), ocelli absent, tegmin in males reduced, wings in males reduced to scales fused to mesothorax (tegmin and wings absent in females), and 3rd, 4th and 5th tergites modified to glands in males. Individuals show a consistent gradation of forms from relatively less troglomorphic in the south (Walkunder Towers) to more troglomorphic in the north (Carpentaria Tower) (Table 1, Graphs 1, 2).

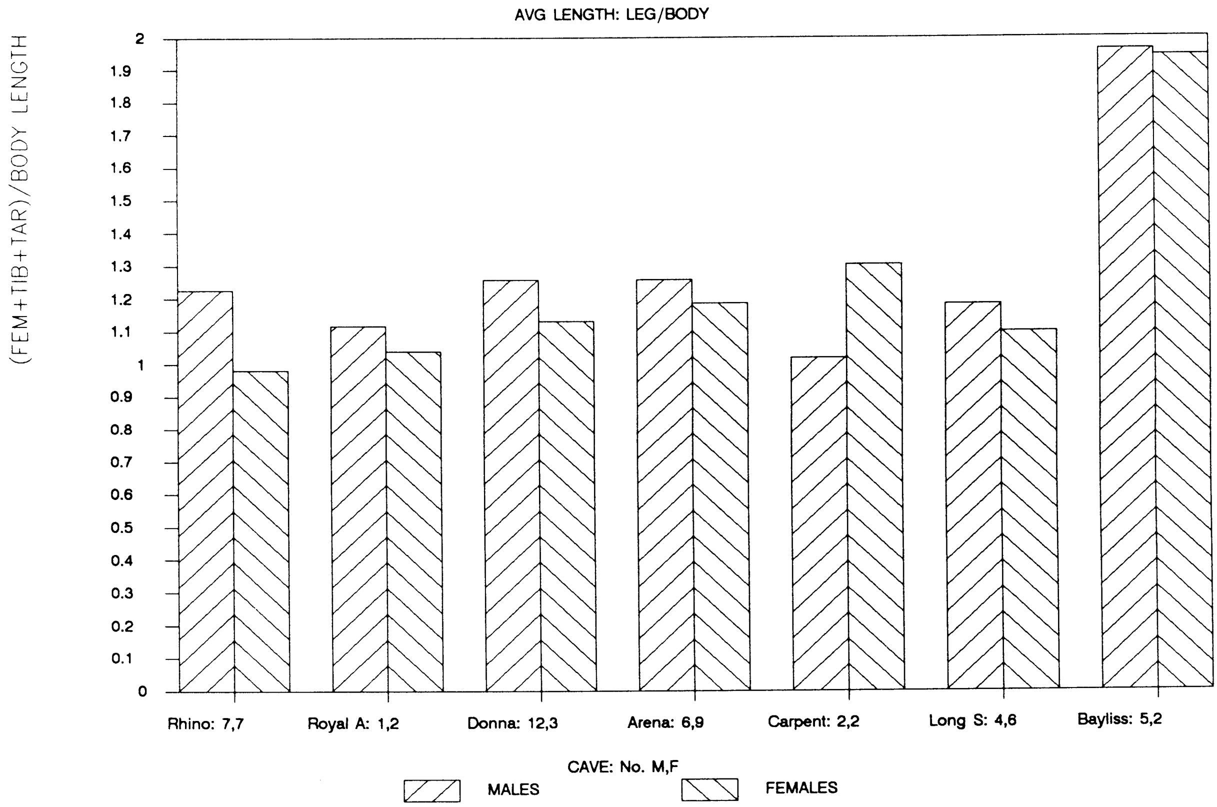
The darkest individuals are from Rhino and Royal Arch Caves, paler from Donna and Arena, and palest from Carpentaria. The eyes of Arena and Carpentaria specimens are much smaller than those from Rhino, Royal Arch and Donna specimens. Body size is also smallest in Carpentaria individuals. Tergal glands also vary consistently among males from different towers. With additional material from Royal Arch and Carpentaria Caves, it will be possible to decide whether geographic races or separate species occur in the separate limestone towers of the Chillagoe region.

The reasons for the regular pattern of variation of N. australiensis are no easier to determine than the reasons for the more complex variation of Paratemnopteryx. Is it possible that deep cave environments are less prevalent in the southerly towers than the northerly ones? Detailed microclimatic data from the caves might provide the answer.

I am currently working on descriptions of two additional species of Nocticola from lava tubes. N. Sp. A from Long Shot Cave is moderately troglomorphic, with leg/body ratio and eye size similar to N. australiensis (Table 1, Graphs 1,2). However, it has the most modified tergal gland of any of the Australian cave Nocticola.

N. sp. B, from Bayliss and Nasty Caves, Undara, is one of the most highly troglomorphic species yet discovered. It is a pale, translucent white color, with eyes, tegmin and wings lacking. It has the smallest body size but the longest legs and cerci of any of the Australian cave Nocticola, and a leg/body ratio nearly twice that of the other species (Table 1, Graphs 1,2). Unlike individuals of N. australiensis, which run rapidly if disturbed, N. sp. B moves slowly. It occurs only in the stagnant air zone of the Bayliss and Nasty caves, and it (along with the highly troglomorphic Paratemnopteryx which occurs in

GRAPH 2



the same locations) provides excellent evidence for the correlation between extreme troglomorphy and the stagnant air zone of these caves.

DISCUSSION

Answers to questions about the ecology and evolution of tropical troglobites can only be gained by careful field studies of relatively undisturbed tropical cave ecosystems, such as those of North Queensland. Although troglobitic species of the Nocticolidae have been known from tropical caves for nearly 100 years, the limited number of specimens from scattered locations mislead cave biologists to believe that true troglobites did not occur in tropical caves (Vandel, 1965)! Now that we know that troglobites are widespread and common in the tropics and probably in Australia where ever the deep cave and stagnant air zones of caves allow us entry into the mesocavernous conditions, it is no longer necessary to invoke special theories of climate change as a cause of presence or absence of troglobites (Barr, 1968; Culver, 1982; Hamilton-Smith, 1967; Holsinger, 1988; Howarth, 1980, 1983, 1988; Moore, 1964; Richards, 1967).

The ability to do long-term, detailed, field work, made possible by the Chillagoe Expeditions, has allowed us to begin to work out the relationships between degrees of cave adaptation and the environmental zones of caves. The cockroaches described in this paper, the planthoppers described by Hoch and Asche (this issue), and other groups yet to be studied in detail (Howarth, this issue) often show a remarkable degree of correlation between levels of troglomorphy and the cave zone where they occur (Howarth and Stone, in prep.). Much additional field and laboratory research remains to be done to test these relationships: will they stand up to more detailed field work, or will new patterns and relationships emerge? Finally, what are the processes at work in tropical caves that commonly produce the adaptive shifts from epigean to troglomorphic species? Only continued field work can lead us to the answers to these questions, or suggest new avenues for investigation.

ACKNOWLEDGEMENTS

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TABLE 1:

MORPHOLOGICAL COMPARISON OF NOCTICOLA FROM CAVES OF NORTH QUEENSLAND: AVERAGE VALUES FOR SAMPLE SIZES SHOWN

	1	2	3	4	5	6	7	8	9	10
CAVE	SEX	NO.	BODY LGTH mm	LEG: FEM+ TIB+ TAR mm	RATIO LEG/ BODY	RATIO FEM: L/W	CERCI LGTH mm	EYE LXW mm^2	TEGM LGTH mm	PRONOT LXW mm^2
Rhino	M	7	4.43	5.43	1.23	5.30	1.53	.014	2.18	2.01
Royal A.	M	1	4.65	5.20	1.12	5.00	1.45	.019	2.05	2.10
Donna	M	12	4.19	5.27	1.26	5.27	1.36	.013	2.14	1.95
Arena	M	6	4.28	5.38	1.26	5.61	1.29	.005	2.10	2.03
Carpent.	M	2	4.10	4.18	1.02	4.82	1.00	.005	1.73	1.36
Long S.	M	4	3.88	4.59	1.18	5.52	1.13	.008	2.20	1.64
Bayliss	M	5	3.55	6.95	1.96	9.57	1.67	abs	abs	1.13
Rhino	F	7	5.65	5.54	0.98	4.73	1.46	.006	abs	2.66
Royal A.	F	2	5.10	5.30	1.04	4.24	1.40	.004	abs	2.63
Donna	F	3	4.98	5.63	1.13	5.61	1.30	.006	abs	2.29
Arena	F	9	5.03	5.95	1.18	5.44	1.33	.002	abs	2.54
Carpent.	F	2	4.01	5.23	1.30	4.90	1.15	.004	abs	2.08
Long S.	F	6	4.30	4.72	1.10	5.29	1.11	.005	abs	1.89
Bayliss	F	2	3.85	7.48	1.94	8.17	1.75	abs	abs	1.41

2. Number of individuals measured.
3. Front edge of pronotum to tip of abdomen.
4. Leg length: femur + tibia + tarsus.
5. Ratio of leg length (No. 4) to body length (No. 3).
6. Ratio of femur length to femur width.
7. Cerci length along axis, not including hairs on tip.
8. Maximum length times maximum width of pigmented area of eye.
9. Maximum tegmin length.
10. Maximum length times maximum width of pronotum.

Donna Cave specimens are N. australienses. Nocticola from Rhino Cavern, Royal Arch Cave, Arena Cave and Carpentaria Cave are also from the Chillagoe region, and are either geographic races or closely related species of N. australiensis. The Long Shot and Bayliss specimens are two separate species from lava tubes. One female from Spring Cave and one from The Throne Room are included with the Arena Cave females (all from Spring Tower).

CHILLLAGOE CAVES FAUNAL CHALLENGES

Brother Nicholas Sullivan.

ABSTRACT

A review is made of early biologic studies at Chillagoe. The precise meaning of Chillagoe as a site of study is indicated. The danger of high carbon dioxide levels in certain Undara lava caves is evaluated. Current studies are briefly described and summarized. The peculiar environment milieu of Chillagoe is an ideal site for studies of evolution of cave life and cavernicolous adaptation. Finally, a research facility is proposed as essential for continuing significant research.

EARLY STUDIES

The first humans to become aware of the fauna of Chillagoe Caves could have been members of the aboriginal Ojanken and Wakamen tribes since their territorial boundaries are believed to have existed east of Chillagoe. It is not improbable they would have entered the larger caves seeking reptiles, fruit bats, wallaroos, *(Macropus robostus)* Wallabies *(Petrogale sp.)* and other smaller mammals peculiar to their diet. In the Walkunder Arch Cave, where occupation has been dated at older than 18,000 B.P. wallaby bones and a portion of a Diprotodon molar have been found at the lowest level. The probability of these organisms coming from some of the caves in Walkunder Tower is remote, but demonstrates the proximity of living sites to caves. The Children's Python *Liasis childreni,* a common reptilian inhabitant of the Chillagoe Caves is believed to have been a common component of aboriginal diets.

Hence we can, in a sense, indicate that the fauna of Chillagoe Caves have been objects of interest since the Pleistocene times. Early histories are a bit imprecise, but modern humans were aware of the Chillagoe Caves by 1881, and copper was being mined on a commercial basis by 1890. As is well known, several thousand humans resided in the Chillagoe-Mungana metropolitan area by 1908. Given the mining background of many of these inhabitants and the difficulty of transportation, it is probable that caves close to town were frequently visited and the more astute visitors would have noted some of the prominent species. By 1920 six species of bats had at least been recorded as occurring at Chillagoe. *Miniopterus schreibersii*, the common bent-wing bat; *Miniopterus australs*, little bent-wing bat; *Eptesicus pumilus,* little brown bat; *Rhinolophus megaphyllus*, Eastern horse-shoe bat; *Taphozous georgianus,* sheath tailed bat; and *Hipposideros diadema*, large diadem horseshoe bat. Also, the Northern Grey Swiftlet, *Aerodramus spodiopygius chillagoensis* would have been noted since caves in the Tower of London represent only one of the few known roosting sites.

Both the macro- and micro invertebrate fauna remained unnoted scientifically until recently, notwithstanding all the visitation of the caves. The Sydney Speleological Society visited the Chillagoe area in January, 1966 and August, 1967 and published a list of fauna collected, mainly by means of light trapping (Anon, 1969). A troglobitic Blattellid and a troglobitic Staphylinoid were reported.

CHILLAGOE-GEOGRAPHIC DEFINITION

Before detailing more recent studies it is necessary to specify what is precisely meant by the term "Chillagoe". In a sense it has become almost a generic term for caves in a large geographic area of the Cape York Peninsula, North Queensland, Australia. The remoteness of the area to all but those intimately acquainted with its geologic diversity has resulted in the term "Chillagoe" being applied rather loosely to three discrete geographic areas. I find that those investigating this area tend to overlook this discreteness which results in confusion to others less intimately familiar with the distinctive geomorphology of Chillagoe.

Originally, **Chillagoe karst** was applied to a series of pinnacled towers which project up to 80 m above the surrounding plain in a belt of limestone 5 km wide and 50 km long extending from South of Chillagoe to North of the Walsh River. This belt is some 200 km West of Cairns. The limestone, Silurian in age, has undergone extensive uplift and erosion in the late Cenozoic resulting in dozens of these highly dissected towers looming up above ground level concentrated around Chillagoe, Mungana and Rookwood, (Ford, 1978). A rather simplistic explanation is that the heavy summer precipitation results in sharp, narrow grooves, Rillenkarren, developing along these sometimes massive towers. Investigators of this karst terrain are acutely aware of the sharp edged grooves in the limestone that can readily lacerate skin, clothes and even heavy boots. Occasionally flat shallow pans, kamenitzas, occur on level plots of the karst. Deep, vertical flutes scour many of the cliff faces. Finally, grikes, which are larger and deeper indentations, are to be found in many towers. These grikes may give access to some of the caves to be found in the towers.

Some caves, usually smaller and lacking significant vertical relief, are to be found in low lying extensions of the Chillagoe karst outside the zone of tower karst. Several of these, for example, Tea Tree Cave, have significant paleontological deposits.

Approximately 120 km NW of the belt of Chillagoe karst is the **Mitchell-Palmer karst** on Mt. Mulgrave and Palmerville Stations. This limestone is virtually inaccessible during the rainy season and not overwhelmingly inaccessible even in good weather. For all practical purposes there is only one poorly maintained track passing near the Mitchell-Palmer limestone. Here caves are found in towers up to 200 m high. The towers tend to be more massive than those closer to Chillagoe. Being more isolated they hold a greater potential for biologic diversity. There have been only three serious faunal collecting trips to the Mt. Mulgrave sector of Mitchell-Palmer area and none for more than a few days. Although frequently included as "Chillagoe" caves in references, there is some uncertainty as to whether they developed contemporaneously with caves at Chillagoe. (Pearson, 1982).

Some 130 km South of Chillagoe are a series of **lava tubes** formed in the **Undara** lava flow. This is an extensive flow, over 160 km in length, much younger geologically than the Chillagoe karst. It has been dated as late Pleistocene with an approximate age of 190,000 years. (Atkinson, Griffin and Stephenson, 1976). Three caves, Bayliss, Pinwill's and Nasty have been studied on three of the previous expeditions (Sullivan 1984). Much to the surprise of all concerned, one of these caves, Bayliss, has yielded 51 species of terrestrial arthropods of which forty three are troglobites (Howarth 1987). Howarth and Stone will be reporting on this biota during this conference. Two constrictions in Bayliss trap the cave atmosphere into three zones. The inner zone has a downward sloping floor that acts as a trap for CO_2. It is assumed that the CO_2 is biogenically generated.

HAZARD OF HIGH CO_2 CONCENTRATIONS

An unanticipated hazard to studies of the cave fauna in the Undara lava is this abnormally high concentration of CO_2. This phenomenon is also referred to as foul air, and the terms have come to be used interchangeably in the literature. (James, Pavey and Rogers, 1975). Foul air can also denote the presence of NH_3 in caves rich in bat guano and H_2S from decaying organisms. Australian cavers have known of high concentrations of CO_2 in Grill Cave at Bungonia as early as 1931, which eventually caused the closure of this cave (Nurse, 1972). James (1977) reported specifically on the presence of higher than normal CO_2 concentrations in Bungonia. In 1984 we used a Draeger Multigas Detector to test for a number of gases in Bayliss Caves and obtained readings approaching 5% CO_2 concentrations. The accuracy of this technique depends on the tubes used. Normally, a 0.1% CO_2 concentration is tolerable. But at a 3% concentration in the inspired air, there is an increase in the rate and depth of respiration. One subjected to such a concentration suffers a measurably diminished capacity for physical work and exhibits befuddlement. At 4% CO_2 concentration the rate of ventilation triples; nausea, sweating and a throbbing headache can occur. If one can survive a 5% CO_2 concentration there is an "off effect" in which respiratory problems persist even after leaving the cave. Obviously, rescuing an individual in a high CO_2 environment is a danger to the rescuers themselves.

It is not clear if the high CO_2 concentration is constant or seasonal. There may be seasonal variations in the amount present depending on air movements and on rainfall, so that measurements need to be taken on an annual basis (Wigley and Brown, 1976). High CO_2 concentrations have been reported from Gaden-Coral Cave, a part of the Wellington Cave complex (Armstrong and Osbourne, 1981). In passing, it should be noted that the concentrations of 12%-13.5% CO_2 reported from Molong and Wellington Caves (Frazer,1958) are not endogenous to the cave. Probably this was an exogenous source, possibly due to flooding through porous sediment.

SUBTERRANEAN ENVIRONMENTAL IMPLICATIONS

Thus, in the Chillagoe area there are several widely diverse subterranean environments worthy of study. The Australian Karst Index contains listings of over 500 caves in the Chillagoe area (Matthews, 1985). Many members of the Chillagoe Caving Club believe this is but a small percentage of the total number. To say that there is a great potential for caves in and around Chillagoe ranks as a classic understatement. The remoteness of the Chillagoe area has resulted in little human disturbance of the cave environment. The limestone towers vary in distance from 0.5 km to 3 km from each other. Thus, no caves in one tower connect with those in another, although caves in any given tower may extend to the water table in the phreatic zone. For terrestrial organisms each system of caves within a tower constitutes a geographically isolated area; hence the populations of cave organisms are also isolated. This presents an ideal opportunity to study the rate of evolution of cave life manifested by different but related species and the mechanisms of adaptation to a cavernicolous environment. In addition, each cave may be different geomorphologically, environmentally and biotically. Within each tower can be found a suite of differing cave types with similar suites of cave types to be found in other towers.

In effect, each tower or assemblage of towers can be viewed as an island with their faunas having developed in isolation giving the opportunity for significant comparative research on evolutionary and ecological processes. (Barr, 1968; Howarth, 1980). It is possible to conduct detailed ecological studies in an analog cave of similar features which is isolated from the first cave. It is also possible to study animal distribution and exploitation in the suite of caves in one tower; then study analog caves in other towers which differ in one or but a few of the biotic or abiotic factors being examined. This approaches as ideal a situation as is possible in ecological studies for having an experimental control. The large number of caves with fig tree roots reaching down into deep cave zone passages establishes a whole new source of energy input and needs continuing study.

Several preliminary lists of material collected at Chillagoe have already been published. (Matts, 1987; Hoch and Howarth, in press). This symposium will feature reports from Stone, Howarth, Hoch and Asche which will complement earlier investigations. We are, in a way, suffering from an embarrassment of riches. The backlog of undescribed organisms increases annually, notwithstanding the efforts of numerous invertebrate taxonomists to reduce this backlog. And it seems that each year a dozen or more new caves are located, none of which have been investigated for their biologic potential. Just recently a 500 metre extension of Bayliss Cave has been discovered by the Chillagoe Caving Club. The ever widening wave of investigations into the Mitchell-Palmer and Undara areas reinforce the richness of faunal diversity indicated by the term Chillagoe.

FUTURE PLANS

What next? Before our logistical lines of support get totally out of hand, it is essential to establish a research center in Chillagoe to store and maintain the equipment critical for on going biological investigations. Also, laboratories in which organisms can be studied in a sedate environment are urgently needed. Microscopic analysis; photographic studies; storage of comparison species; taxonomic and morphologic reference works should all ideally be available to be utilized on site. If one measures the great distances many investigators at Chillagoe must traverse before having a suitable arena for study, then our expeditions have an extremely low efficiency rating. We desperately need a modern, well equipped, functional laboratory where the rapidly escalating collections of specimens can be evaluated and stored for future reference. With transportation to Chillagoe improving, investigators can more readily visit Chillagoe and its caves. The incipient publications referred to today will focus even more attention to the distinctive and impressive fauna of Chillagoe. Fifty years ago Chillagoe was a center of great mining import. It is pleasurable to contemplate that today Chillagoe is now evolving into a center of biological research.

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WHAT SWIFTLETS DO IN THE CAVES AT CHILLAGOE AND SOME IDEAS ON HOW CAVERS CAN SHARE THOSE CAVES WITHOUT INTERFERENCE

Michael K. Tarbuton.

ABSTRACT

The breeding of the White-rumped Swiftlet ***Aerodramus spodiopygius chillagoensis*** *was studied during both a good and a poor season at Chillagoe, Queensland, Australia. Most of the nests were in totally dark sections of caves where colonies contained from 1 to 264 nests. The clutch of one was incubated for an average of 26.6 days during the better season when 64% of eggs hatched successfully. If the clutch or young brood was lost, it was usually replaced within 14 days. Fledgling success for this season was 69% giving a breeding success of 44% or, 0.9 young fledged from the two broods of a breeding pair. In the poor season incubation took 28.7 days, hatching success was 60%, fledging success was 50% and the nestling period had increased from 46.1 days to 51.0 days. Most chick mortality resulted from chicks falling from their nests. While the fledging rate for the single-egg clutch of chillagoensis is well below that of the two-egg clutch of Fijian swiftlets the unique practice of laying a second single-egg clutch for the first chick to incubate, increases the breeding rate in good seasons to almost that of the Fijian subspecies. There is no sexual dimorphism and both sexes share in incubation and feeding nestlings. Chillagoe chicks were fed an average of 5.2 times a day. Even though chillagoensis increases immediate energy demands by synchronizing moult and breeding, the length of time to complete the moult of primaries is as short as any swift studied so far and is shorter than some that moult independent of breeding.*

An effort is made to make cavers aware of which activities may prejudice the breeding efforts of swiftlets and which may be continued without putting the birds or their young at risk.

INTRODUCTION

The white rumped Swiftlet that inhabits the Chillagoe district of inland peninsular Queensland *(Aerodramus spodiopygius chillagoensis)*, has only recently been separated from *A. s. terraereginae* which inhabits coastal Queensland (Pecotich 1982).

In this paper these two subspecies will be referred to as *chillagoensis* and *terraereginae*. Some comparisons are made with the subspecies *(A. s. assimilis)* that occurs in Fiji and it will be referred to as the Fijian subspecies. The subspecies *chillagoensis* breeds in the caves that have formed in the tower-like outcrops of limestone at Chillagoe and Mitchell-Palmer districts. The vine thickets of the limestone outcrops and the intervening savanna woodlands sustain the aerial insects that form the swiftlet's diet. Descriptions of this vegetation (Godwin 1983) show that while most species in the area are typical savanna, some species on the limestone outcrops are rainforest remnants. Some of the bird species are also more likely to be met with in rainforest and it is more characteristic to find the White-rumped Swiftlet over rain forest than such dry country.

Currently 25 of the 400 caves south of the Walsh River that have been recorded and tagged, contain Swiftlet colonies. Swiftlets use these caves for roosting each night of the year and for breeding each wet season (October - March). This paper summarizes the breeding biology, feeding behaviour, and flight of the Swiftlet that occupies the caves at Chillagoe. It also makes some suggestions as to how cavers can reduce or eliminate the possible decrease in breeding success caused by their presence in a cave used by White-rumped Swiftlets for roosting and breeding.

METHODS

Data were obtained in the main from colonies in Gordale Scar Pot (CH187) and Guano Pot (CH146). These were visited six days a week from 28th November 1985 to 27th January 1986 and from 2nd December 1986 to 23rd January 1987. Most other sites were visited only once.

Two all day chick watches were made in Gordale Scar Pot, to determine the number of times a day each chick was fed. The first one was made from 0600 to 1300 hours on 18th December 1985 and 1300 to 1800 hours on 19th December 1985 and the second was from 0615 to 1715 hours on 22nd December 1986.

The first season at Chillagoe was a normal wet season in which chicks grew more quickly and fledged in higher numbers than in the following season. The second breeding season was markedly dry and for the first time in my study of this species in Fiji and Queensland, I found nestlings that had starved to death. Because of this the 1985/86 season is referred to as the good season and the 1986/87 as the poor season.

Individual chicks were identified with daubs of fast-drying model paint placed on their head, shoulder or rump. Once the chicks were old enough they had an individually numbered band from the Australian Bird and Bat Banding Scheme, Canberra, Australia, placed on one leg. Wing growth, which Lack and Lack (1951) demonstrated to vary with the quantity of food provided was determined by measuring from carpal joint to the tip of the longest primary when the wing was held flat on a ruler. Weights were measured on 5, 10 and 50 g Pesola spring balances.

By experimental manipulation some parents were given a second chick to see if the parents could raise one more than they normally did. If parents had been able to raise an extra chick then the manipulative doubling up of broods would have been a quick way of increasing any endangered population. The measures that were taken daily on all chicks were averaged and when reported in the text are given with the standard error of the mean in the form (mean $\pm$ S.E.).

The only other detailed breeding study published on this species is that on the Fijian subspecies *assimilis* (Tarburton 1986b). As comparisons with *assimilis* are frequent this reference is not given each time. In both studies, nest volume was determined as an approximation, called the volume index. This is derived by multiplying the average length, breadth and depth measurements together. In determining colony size where nests were empty or their contents could not be observed, only those nests having some fresh, glistening saliva were counted. Generally this method rejected only a few whole nests.

RESULTS AND DISCUSSION

Breeding Distribution

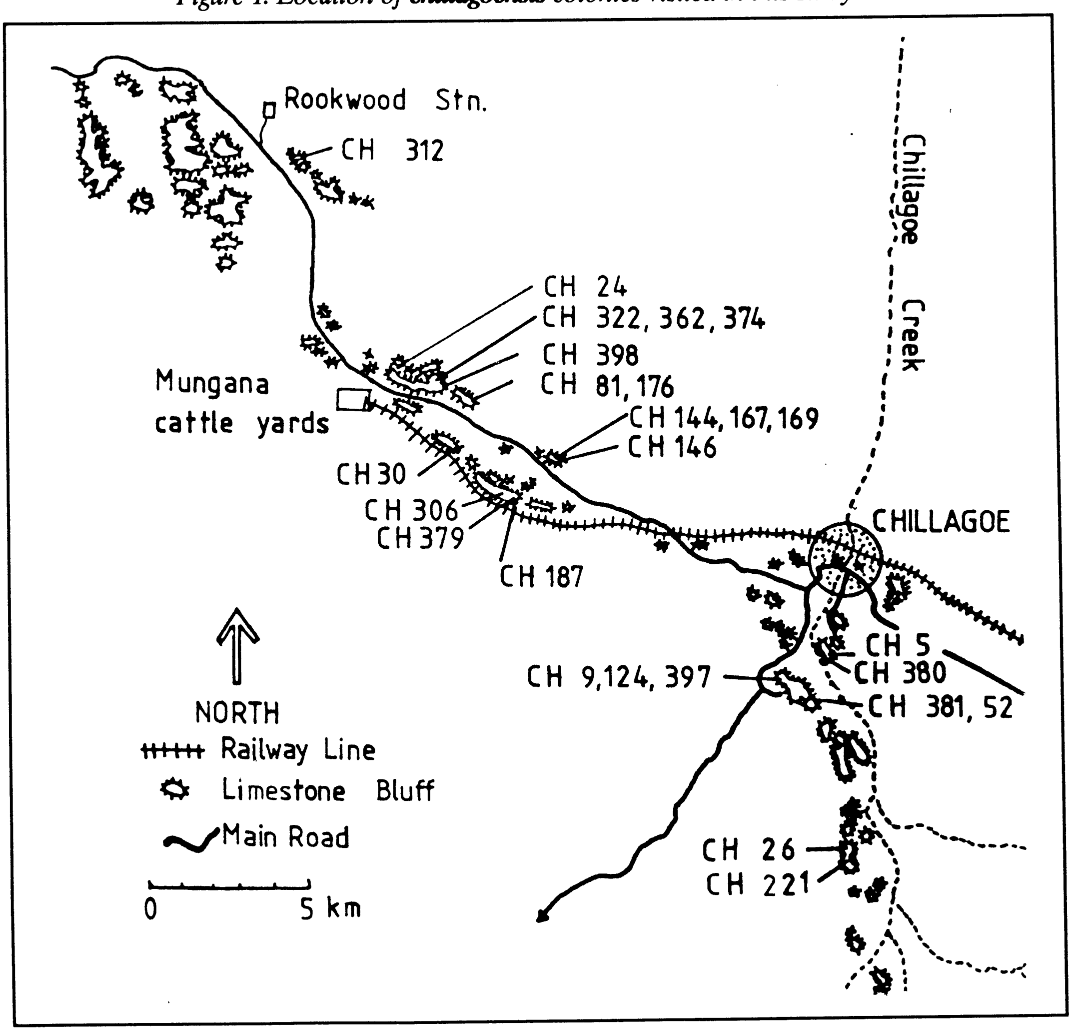
The White-rumped Swiftlet is restricted to areas having caves and sufficient aerial insects for food. The feeding range is restricted to the savanna surrounding the Chillagoe and Mitchell -Palmer limestone outcrops in which it breeds and it has not been recorded foraging more than 30 km from known breeding areas. The approximate location of the nesting sites visited in this study are shown in Figure 1.

The Nests

The nests of *chillagoensis* have similar construction to those in Fiji except that they are all composed of dried grass whereas those in Fiji are more often composed of filmy ferns and mosses or fibres from the crown of coconut trees. The most common grass species used are Kangaroo Grass *Themeda australis* and Black Spear Grass *Heteropogon contortus*.

The internal dimensions of 36 nests averaged 51.5 $\pm$ 0.9 mm across, 44.9 $\pm$ 0.8 mm front to back, and 12.5 $\pm$ 0.7 mm in depth. The average volume index of the Chillagoe nests (23 cm^3) is smaller than that of Fijian nests (52

*Figure 1. Location of **chillagoensis** colonies visited in this study*



cm^3). This is to be expected as Fijian nests hold two young at a time, whereas Chillagoe nests hold only one young.

In both subspecies, parents may also sit on the nests at night. Up to five adults and fledged chicks (not disturbed by our presence) were seen on a single nest in Keef's Cavern. This means that the smaller size of the nests at Chillagoe does not reduce the number of fledged birds that they can support in a good season. However in the poor season some nests that were never seen to have more than three birds on them, had so little saliva in them that they fell apart.

The Nest and Colony Size

All colonies were in totally dark sites, though in a few, twilight could be seen from unoccupied parts of the nesting chamber. Colonies at Chillagoe are on smooth concave walls 2 - 20 m above the cave floor. However, small protrusions such as solution furrows or fault cracks in the limestone are often favoured within the colony. Thus rows of nests appear in the general random scatter, with those alongside closer than those above and below.

The average distance between nests at Chillagoe was greater than that between Fijian nests. This may result from *chillagoensis* having more caves in which to nest, though the situation is not clear for even in Fijian colonies where many nests were joined, there appeared to be large areas of suitable though unused cave wall and ceiling. The average distances between Chillagoe nests were 7.9 cm at Gordale Scar Pot (n = 20), 17.4 cm at Guano Pot (n = 36), 29 cm at Crack Pot (n = 41), 29.4 cm at Keef's Cavern (n = 11), an estimated 10 - 40 cm at Squeeze Pot (n = 50) and an estimated 3 - 4 cm at Mudlark Cave (n = 31). The greatest distance between nests were found in Flow Cavern, where nests were 10 cm to 5 m apart (n = 8). A new site with just one nest was established in Swiss Cottage Chamber of Royal Arch Cave (CH9) during October 1986. This site is about 90 m from the other site in this complex cave system.

The population size of *chillagoensis* colonies visited is given in Table 1. With the average colony size of *chillagoensis* being 77 nests, it is clear that this subspecies breeds in much smaller colonies than the Fijian subspecies which has an average colony size of 1,762 nests. However, it must also be noted that colonies of *chillagoensis* are much closer to one another than those in Fiji. This means that the population density per hectare for the two subspecies might not be as different as the difference in colony size might at first indicate.

While colonies of *terraereginae* are also small compared to those in Fiji they they tend to be in twilight situations (Smythe, Pecotich and Roberts 1980, Crouther 1983) where predation may be greater.

The Breeding Season

Working from the oldest chick (which had a 51 mm wing) found in Gordale Scar Pot and at Guano Pot at Chillagoe on November 1985, it is estimated that the first egg for that season was laid about 6th October. The oldest chick found on December 1986 (wing span 57 mm) gives an estimated laying date of 4th October for the first egg that season. In both seasons the first few eggs were followed two weeks later by a heavy bout of laying. Initial egg laying in *chillagoensis* precedes the marked increase in rainfall that usually occurs during November or December. In 1985 there had been no rain recorded at the Post Office for 28 days prior to laying of the first egg for the season and there had only been small showers prior to the peak laying period. In 1986 there had been rain just 5 days prior to the laying of the first egg but only two good rain days before the middle of January, when most of the laying was over. So if rain stimulates laying in *chillagoensis* only small local showers, which may not fall on the Chillagoe township, are needed even though more persistent rain (Tarburton 1987a) is essential to raising chicks. This early laying in anticipation of the heavy rain suggests that the time provided by the average breeding season is limiting and that the birds may have other adaptations that reduce the time required to hatch their eggs and raise their chicks.

In that Alan Cummins and Les Pearson report having seen numerous eggs in Squeeze Pot in early May, it is possible that when heavy rains are later than usual the birds relay in a season that extends later than normal.

The Eggs

As in all swifts but one, the eggs are white and without gloss. The average dimensions of 118 *chillagoensis* eggs (from Gordale Scar Pot and Guano Pot) were 19.81 $\pm$ 0.06 by 13.04 $\pm$ 0.04 mm ($\bar{x} \pm$ S.E.). The fresh egg of the Chillagoe Swiftlet weighs 1.83 $\pm$ 0.01 g. The average weight of eggs declined to 1.66 $\pm$ 0.03 g the day before hatching. The average fresh weight of the Chillagoe eggs represents 19.7% of the average adult weight. This is slightly more than the 18.7% for the Fijian eggs but is not extreme for swiftlets, which lay proportionally larger eggs than swifts (Tarburton 1986b).

Incubation

The incubation period was found to average 26.6 $\pm$ 0.23 days (n = 27) and to range between 25 and 29 days.

Egg Loss and Replacement

The average time for the replacement of all lost clutches and broods less than ten days old, was 10.4 $\pm$ 0.4 days (range 6 - 18 days, n = 41). When *chillagoensis* lost chicks older than 20 days the nest either already contained the second egg or the second egg appeared in less

TABLE 1
THE SIZE OF BREEDING SWIFTLET COLONIES AT CHILLAGOE

CCC No.	Cave Name	Number of currently used nests. Previous	85/86	86/87
CH005	Tower of London Cave:			
	Site A	-	0	1
	Site B	80*	0	0
	Site C	-	-	23
CH009	Royal Arch Cave			
	Swiftlet Cavern	122#	15	26
	Swiss Cottage	0	0	1
CH024	Keef's Cavern	P~	109	-
CH026	Clam Cavern	23#	11	11
CH030	Stop Press Cave	P~	-	4
CH046	Snakey Cavern	46*	-	0
CH052	Swiftlet Cave	P~	-	129
CH081	New Southlander Cave	P~	22	14
CH124	Flow Cavern	13#	-	8
CH133	But Good Cave	P~	-	0
CH138	Chinese Cavern	P~	-	0
CH144	Christmas Pot (a)	P~	29	-
	(b)	P~	44	-
CH146	Guano Pot	P~	81	88
CH167	Crack Pot	P~	194	188
CH169	Squeeze Pot	P~	135	-
CH176	Capricorn Cave	47#	0	-
CH187	Gordale Scar Pot	500?#	169	160
CH221	September Cave	P~	-	118
CH227	Pope John Paul I Cave	P~	-	0
CH306	Mudlark Cave	P~	31	28
CH312	Project 31 Cave	60+~	-	253
CH322	Swiftlet Scallops Cave	-	-	8
	Entrance CH374	P~	-	49
	Hercules Cave CH362	P~	-	23
CH379	Tarby's Swiftlet Pot	-	180	179
CH380	Golgotha Cave (a)	-	48	-
	(b)	-	69	-
CH381	Swiftrimelt Cave	-	25	29
CH382	Otobeaswiftlet Cave	-	P	P
CH397	Shirl's Triple Twirl Cave	-	-	21
CH398	Swiftlet Swallet Cave	-	-	264

Note:

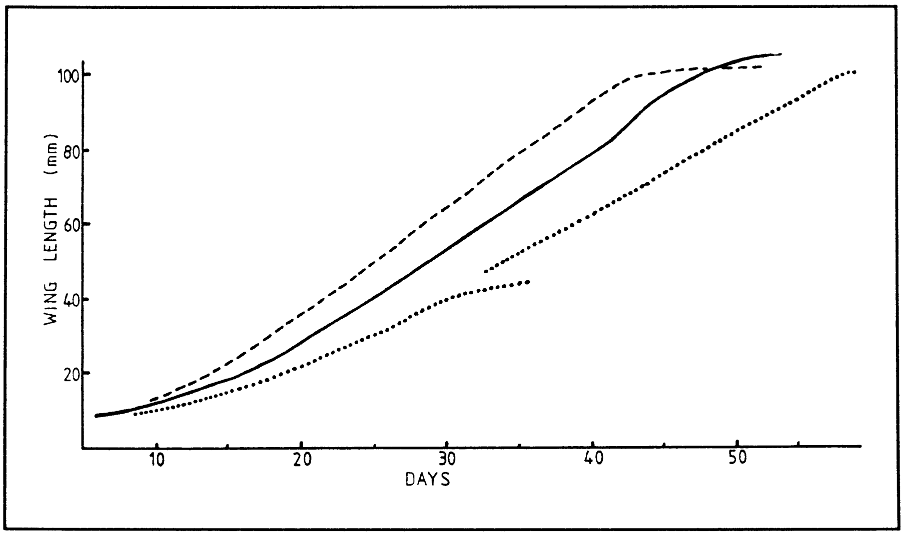
CCC	Chillagoe Caving Club Inc.
CH###	ASF registered cave number issued by CCC.
*	Indicates that marks left on walls by previous nests were counted, these may not have all been occupied in any year.
+	Indicates possibly more nests on shelf not fully visible.
?	Indicates my doubt that this number of nests were recently found in this cave.
#	Refers to Smythe et al.
~	Data from Chillagoe Caving Club Inc. records.
P	Indicates swiftlets reported present but no count.
-	Indicates no record.

Figure 2. Mean daily increase in wing length of chicks at Chillagoe

Average daily measurements have been smoothed by eye to show the following growth curves:-

Broods of one in the good season represented by a discontinuous line and in the poor season by the continuous line.

Chicks from broods of two represented by the first dotted line and survivors from the broods of two by the second dotted line.



than six days, probably because the second egg, which is laid approximately 50 days after the first, was already developing in the ovary.

Of 58 eggs produced by *chillagoensis* in 1985/86, 69% (40) were successfully hatched. In the dry season of 1986/87 60% (40) of 67 eggs were hatched. The average hatching success for both years was 64% (n = 125). Of those that failed to hatch, 78% disappeared. Another 11% were infertile and 11% broke. That some of the eggs that disappeared were infertile, cracked or addled is possible for Lack and Lack (1952) found Common Swifts usually ejected cracked eggs and sometimes ejected infertile eggs. Good eggs may be accidentally ejected due to sudden disturbance at the nest.

Nestling Development

After chicks hatched their egg shells rapidly fragmented with the pieces remaining in the nest for one to three days. Daily average wing lengths of chicks are shown in Figure 2. The data clearly shows that in the good season single chicks grew significantly faster and fledged earlier than those hatching in the poor season. The average time taken for the first flight feathers to break out of their sheaths is 18.7 $\pm$ 0.4 days (range = 16 - 24 days, n = 24), when the wing measurement is between 25 and 36 mm (29.3 $\pm$ 0.06 mm). The growth of chicks from the manipulated broods of two was significantly slower than those in single broods. This disparity increased after 30 days and always ended in the death of one chick. The remaining chick then grew normally though it never caught up the time lost while sharing food with another nestling and it fledged up to 12 days later than normal. Adult wing size in both years and from both brood sizes was reached only after fledging.

The average weight of newly hatched *chillagoensis* chicks was 1.31 $\pm$ 0.01 g, (range = 1.09 to 1.6 g, n = 52). The daily average weight increases for the chicks show similar trends to those from wing measurements and are shown in figure 3. Adult weight is not reached until the 21st day. Chick begging calls are described in Tarburton (1987b).

The Nestling Period

The average age at fledging in the good season was 46.1 $\pm$ 0.08 days (n = 8) and in the poor season was 51 $\pm$ 1.3 days (n = 5). This difference is significant ($P < 0.01$; $\underline{t}$ =

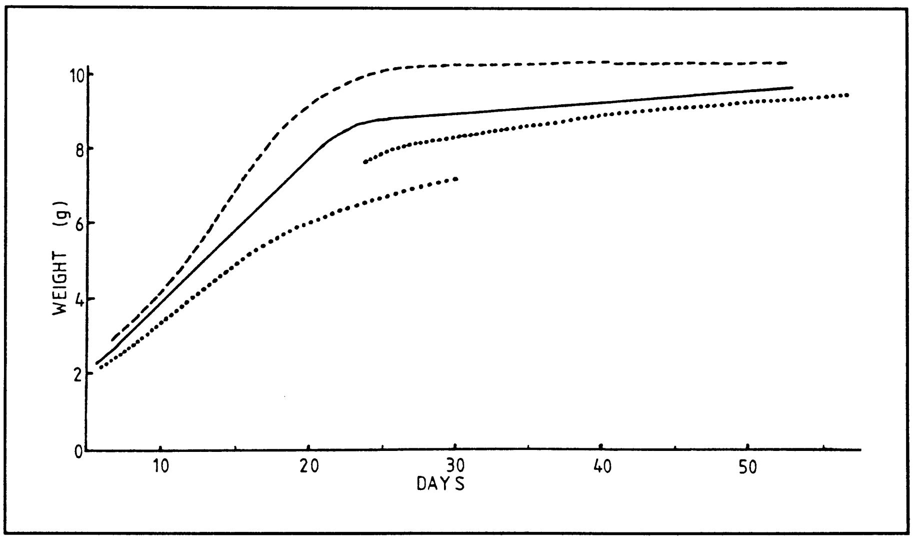


Figure 3. Mean daily increase in chick weight at Chillagoe.

Average daily weights for single-brood chicks in the good season are represented by the discontinuous line and for the poor season by the continuous line. Chicks from broods of two are represented by the first dotted line and survivors from broods of two by the second dotted line

3.15, df = 11) and so it is clear that *chillagoensis* is struggling to raise a single chick in dryer years. The nestling period is similar to those of other Apodidae having similar incubation periods.

The average wing length at the time of fledging was 101.6 mm which is 95% of adult wing length. The minimum wing length at fledging (range = 91.3 - 108 mm), was 85% of adult wing length.

Fledging Success

Chillagoe birds raise a second brood of one whereas Fijian birds raise only one brood of two. This means the Chillagoe birds raise an average of 0.9 chicks per season which is very close to the average of 1.1 chicks that Fijian birds raise per season. However in poor seasons such as the 1986/87 season, when fledging success in *chillagoensis* was only 50% (n = 18) and hatching success rate was reduced from 69% to 60%, the breeding success achieved was only 30% a brood and therefore only 0.6 chicks per season.

Chick Mortality

The major cause of chick deaths was from falling out of the nest. Because of the chicks' resistance to starvation, many of the chicks picked up from the ground and placed back in the nests recovered. It is presumed that Childrens Pythons *Liasis childreni* and Brown Tree Snakes *Boiga irregularis* were responsible for the disappearance of some of those that fell from the nest as these were seen near the nest sites. Rats may also prey on fallen chicks for John Barton of QNPWS has reported seeing rats in several caves. There was no evidence of predation upon chicks in the nests, almost all of which were in totally dark sectors of the caves. It appears that snakes cannot reach most nests, which are placed high on smooth concave surfaces. This view is supported by Vince Kinnear (pers. comm.), who has watched Childrens Pythons fall off the smooth wall as they have tried to reach the nests. Subsequently, I observed a Childrens Python on the wall adjacent to the nests in Mudlark Cave, but as all the nests still contained their egg or chick, it was evident that the python had not been able to cross the smooth overhanging wall that surrounds the colony. I have also seen a 1.5 m Brown Tree Snake fall from the smooth wall above the nesting colony in New Southlander Cave. Evidence that the tree snake could only cross the smooth wall where it did not overhang was that there were only two empty nests and these were the only ones on vertical rather than overhanging wall.

Adult Mortality at the Nesting Caves

Although snakes cannot reach most swiftlet nests adult birds are not free from predation by snakes. I have watched Childrens Pythons position themselves on the wall adjacent to narrow sections of cave passage through which swiftlets must fly to reach their nests. Numerous elongated scats containing swiftlet flight feathers in the vicinity of such pythons in Golgotha Cave, Project 31 Cave, September Cave and in the tube connecting Christmas Pot and Squeeze Pot, indicated that the python's ambush method was successful.

There are also other predators at Chillagoe. The entrance to Swiftlet Cavern is a low crawl from a daylight chamber of Royal Arch Cave and the ground was littered with swiftlet feathers. John Barton and Lionel Leafe (cave guides with QNPWS) had seen cats in the vicinity and were convinced they were preying on the swiftlets. A pile of flight feathers but no scats generally indicates cat predation. That the subsequent laying of baits for the cats was successful is indicated by the reduction of swiftlet feathers at the cave entrance and the increase in the size of the breeding colony the following season (1986/87). Similarly fresh feather piles were observed at Clam Cavern, Swiftrimelt Cave, Hercules Cave and Project 31 Cave. A pile of decaying feathers was seen in the entrance to September Cave indicating that cats had discontinued killing swiftlets at that site.

On 25th January 1986 I was watching about 50 swiftlets feeding very close to some rocky pinnacles, above Otobeaswiftlet Cave, which I had discovered just that day. There had been an exchange of birds through the cave entrance when a Brown Goshawk *Accipiter fasciatus* landed in a nearby tree. The birds responded suddenly and in unison by rapidly dispersing in all directions. About five to ten minutes later the swiftlets began to reassemble overhead at an altitude of about 130 m from where they made a call (a high pitched "shree") I had not heard before.

In a separate incident a Brown Goshawk left a tree near the swiftlet entrance to Guano Pot on 20th January 1986 to make an unsuccessful stoop at a swiftlet that was flying steeply and slowly out of the cave entrance. The next day another Brown Goshawk sat outside the entrance to Tarby's Swiftlet Pot. All three observations of Brown Goshawks near entrances to Swiftlet breeding caves were at the time when most first-brood chicks were taking their first flights. The young Swiftlets are much slower than adults when leaving cave entrances and it is likely that Goshawks are able to take young birds in this situation. On 4th January 1987 I saw a Brown Goshawk scatter the swiftlets over Gordale Scar Pot and Tarby's Swiftlet Pot when it caught an individual out of the flock. Four days later an unidentified falcon circling approximately 80 m above the same two caves caused abnormal behaviour (mainly erratic flying) in the swiftlets and so it is possible that falcons as well as goshawks take swiftlets.

That swiftlets enter and exit at high speed, is further evidence of the swiftlets' vulnerability to predators at this point. By timing *chillagoensis* over a measured eight metres at the entrance to Tarby's Swiftlet Pot, the average speed was determined to be 37 km/hr. the maximum speed recorded was 111 km/hr which is similar to that (106 km/hr) recorded for Fijian swiftlets entering Waterfall Cave in Fiji (Tarburton 1986a).

Nest Sanitation and Ectoparasites

From the first day, nesting White-rumped Swiftlets defecate over the low front rim of their nest, thus leaving the nest free of faecal contamination. Thus although a variety of insects inhabit the swiftlet nests at Chillagoe none was abundant except towards the end of January when a tiny feather louse covered some chicks.

Louse flies (Hippoboscidae, *Myophthiria spp.*) appear to be the exceptions and are numerous on chicks and adults at Chillagoe. By collecting and recording the number of Louse-flies found on the chicks or in their nests, the data in Table 2 were accumulated. These data indicate that this ectoparasite is least common on 1 - 10 day-old chicks with a peak density on 21 - 30 day-old chicks.

Feeding of Young

From observations on nestlings for one full day in both the good season (18 and 19th December 1985, n = 20) and the poor season (22nd December 1986, n = 9) feeding rates of 5.2 $\pm$ 0.28 ($\bar{x} \pm$ S.E.) per day for the good season and 2.9 $\pm$ 0.5 for the poor season were determined. Fijian birds left their caves by 0430 hours and most did not return to roost until after dark, whereas those at Chillagoe shortened their foraging by about an hour at each end of the day. However, there are two factors which prevent *chillagoensis* from raising two chicks simultaneously. The first is that the density of available prey is much below the density of that available in Fiji (Tarburton 1987a). The second is that the irregularity of extreme wet and dry periods throughout the breeding season at Chillagoe means that the abundance of prey is very low at times and species such as termites are not flying each day for they only fly a day or two after each period of rain ends.

Raising a Second Brood - a New Method

Whereas it is common for perching birds (passerines) to produce two or more clutches per breeding season it is not common for swifts to do so (Lack 1956). That *chillagoensis* produces a second clutch makes it an unusual apodid. That it utilizes heat from the first nestling to incubate the second clutch (Tarburton and Minot 1987) means it is the first bird to be recorded using such a strategy. Such behaviour was not aberrant as 85% (n = 140) of nestlings near to the age of fledging (having wings longer than 70 mm) were incubating an egg.

When incubating nestlings were removed from the nest and then returned, they resumed an incubating posture over the egg that was typical of that of their parents. They settled over the egg rather than making any effort to move the egg aside or flick it out of the nest. thus, the presence of an egg in the nest was sufficient stimulus to release incubation behaviour in the nestling.

The strategy of utilizing the warmth of the first chick to hatch the second egg not only allows both parents the freedom to feed all day but it also reduces (by three weeks) the time required to raise two chicks consecutively. The first benefit would help overcome food shortages during dry spells, while the second would help raise the two chicks within the short time that rain and insect prey are available in sufficient quantities to raise a chick.

Moult in the Breeding Season

The synchrony of breeding and moulting in this species is discussed more fully in Tarburton (1986a) where possible benefits of this uncommon combination are suggested. Data in Table 3 show that moult of the primaries begins for most Chillagoe birds in late November or early December. Moult follows immediately upon egg laying and because of the difficulty of sexing individuals it is not certain whether one sex starts before the other.

If the rate of moult in the primaries of Chillagoe birds continues as it does during December and January (Table 3), then moult of the primaries takes about 120 days to complete.

Adult Morphology

The average wing length of 300 adult *chillagoensis* was 107.1 $\pm$ 0.1 mm (range = 101 - 103). This was signifi-

TABLE 2
NUMBERS OF LOUSE-FLIES ON CHICKS AT 10 DAY AGE INTERVALS.

Period (days)	0-10	11-20	21-30	31-40	41-50
x/nest at Chillagoe	1.0	1.5	5.9	4.0	3.1
n	46.0	38.0	26.0	20.0	10.0
SE	0.21	0.23	0.78	0.74	0.78

TABLE 3
PROGRESS OF MOULT IN THE PRIMARY FLIGHT FEATHERS

	29 Nov -8 Dec	9-18 Dec	19-28 Dec	29 Dec -7 Jan	8-17 Jan	18-27 Jan
No examined	108	97	87	106	50	55
No not in moult	23	9	1	0	0	0
No in moult:-						
P1	58	17	2	3	-	-
P2	20	29	30	10	2	-
P3	6	14	27	36	10	2
P4	1	18	14	33	20	10
P5	-	7	13	13	16	31
P6	-	2	3	1	2	10
P7	-	-	-	-	-	2
P8	-	-	-	-	-	-
P9	-	-	-	-	-	-
P10	-	-	-	-	-	-

Note: Pn = the number of the most recently moulted (smallest or missing) flight feather.

cantly ($t = 14.4$ $\underline{P} < 0.001$, df = 400) smaller than the wing of Fijian birds. That my average measurement is also significantly ($t = 12.8$, $\underline{P} < 0.001$, df = 350) larger than that taken by Pecotich (1982) on the same population is perhaps explained by the use of different methods of measurement. The average weight of 300 adult chillagoensis was 9.3 ± 0.04 g (range = 7.9 - 12.1 g). This is significantly ($t = 15.4$, $\underline{P} < 0.001$, df = 400) heavier than Fijian birds and significantly ($t = 10.0$, $\underline{P} < 0.001$, df = 350) lighter than the average weight given by Pecotich (1982) for the same population some years previously.

As *chillagoensis* weighs more than the Fijian subspecies and yet has a shorter wing, suggests that selection pressures have been operating on *chillagoensis* to reduce wing length, and/or on *assimilis* to increase wing length. The latter is more likely for, the Fijian birds forage further and longer each day than *chillagoensis*. It also appears likely that heavier weight has been selected for in *chillagoensis* as it is to its advantage to have a good body store of energy when food can be in short supply at any time of the year due to the erratic savanna rainfall and the long dry winters.

Feeding Method and Analysis of Prey

The White-rumped Swiftlet breed during the wet season, when insects are generally accepted as being more abundant. However the density of potential prey (caught in a sweep net in areas where swiftlets were found feeding) is shown to be significantly lower than that taken during the breeding season in Fiji. Swiftlets spend the whole day feeding and only land inside the caves when they have returned to their nest. At Chillagoe they normally fed above the tree tops though where grassed areas had been watered in the dry season the repeated circling flight of birds feeding low over these lawns was very noticeable.

Planthoppers (homoptera), flies (diptera), social insects (hymenoptera) and termites (isoptera), were the most numerous prey in 44 food boluses. These samples were taken from parent White-rumped Swiftlets while delivering them to their chicks inside six Chillagoe caves. Numerically the main food items were planthoppers (47%) and flies (24%).

The number of insects in each food bolus ranged from 7 to 587 ($\bar{x} = 149$). The average weight of a bolus was 0.33 g (range 0.11 - 0.62 g). The average length of all prey was 3.6 mm, which is larger than the average length of available prey (2.2 mm). The number of prey "species" ranged from 2 to 83 ($\bar{x} = 40$) per bolus. Altogether, 303 invertebrate "species" were recorded in food boluses. Most were insect species but spiders were fairly common.

Flight Behaviour

One of the best ways to understand something of the swiftlets ability in flight is to compare a number of its flight abilities during feeding flight with those of the Welcome Swallow *Hirundo neoxena* a common bird over much of the rest of Australia. As gliding uses less energy than flapping a comparison of these activities is a good place to start. The average length of time in each glide for the Swallow (1.5 s) and the Swiftlet (1.2 s) was not significantly different ($t = 1.94$, $\underline{P} < 0.05$ df = 63). However, since the time spent flapping by Swallows (17.6 s) was considerably longer than that spent flapping by Swiftlets (1.8 s), it is clear that the Swiftlet glides more than the Swallow when feeding. Two other factors also show that the Swiftlet conserves energy better than does the Swallow. Firstly, feeding Swallows have a significantly faster wing-beat rate (0.57 s) than the feeding swiftlet (0.47 s) ($t = 3.8$, $\underline{P} < 0.001$, df = 34). Secondly

Swallows rest from flying by perching for an average of 3.0 minutes after an average flight time of 2.45 minutes compared with the Swiftlet, which does not perch at all throughout the day in the non-breeding season. Even in the breeding season parents take only one to three rests (lasting one to 20 minutes) at their nests.

During travel flight, differences between these species were even greater. The Swiftlet beats 4.7 times a second and the Swallow 5.8 times a second. The Swiftlet glides for much longer (10.4 s) than the Swallow (1.0 s), but beats for much shorter periods (4.4 s) than the Swallow (39.8 s). A Swiftlet that started flapping overhead rarely flew out of sight in the same flapping sequence, whereas Swallows in travel flight usually did so.

Visual differences in the flight of the two species were obvious. Swiftlets fed from 10 cm to 130 m above the ground. This is considerably higher than the altitudes at which the Swallows fed (from nearly zero over water to 30 m).

A second difference is that when gliding the Swallows held their wings slightly closed and close to the body, whereas Swiftlets held their wings well away from the body resulting in the characteristic sickle-shaped curve.

A third difference is the amplitude of the wing beat. The Welcome Swallow almost always use large amplitude strokes, whereas the Swiftlet only uses such strokes in tight manoeuvres and slow flight, especially in caves.

A fourth difference occurs when feeding flight is in a straight line: Swallows exhibit a regular undulation but the Swiftlet does not. Rather, Swiftlets change altitude irregularly, sometimes pulling up to a halt to catch prey and then diving down again to gain air speed. The tail is often fully spread in this activity and it is considerably larger than that of the Swallows' forked tail and must aid in performing the manoeuvre.

Fifthly, deviation to the side is infrequent and gradual in Swallows, but not in the Swiftlet. A gliding Swiftlet may quickly drop one wing to swerve sideways; or if the insect prey is further to the side the bird may rapidly twist the body and tail to bring the momentarily gaping mouth in line with the prey.

A further difference is that only Swiftlets fly in total darkness. Audible clicks are used to guide their way in the dark.

Although the Swiftlet conserves energy by gliding more and having a slower wing-beat, it also reaches higher speeds and altitudes and spends more time in flight each day than the Swallow.

CAVING ACTIVITIES AND THEIR POSSIBLE EFFECT ON BREEDING SUCCESS

If speleological activities in caves containing breeding colonies of White-rumped Swiftlets were only carried out in daylight hours between May and September, persons engaged in these activities would rarely even see a Swiftlet in the caves. Under these circumstances cavers would be most unlikely to affect the Swiftlet population numbers at all. This is because the birds are not breeding and rarely use the caves for diurnal roosting during these months. Using the caves at the same time as the birds may not necessarily be as harmful to the swiftlets as some have thought. However, the likelihood of harm to the reproductive effort of breeding birds is proportional to the knowledge and care taken by the cavers concerned.

Where colonies need to be closely approached during the breeding season (October to March) the rapid departure of the birds from their nests that causes some eggs to be kicked out of the nests can be prevented. **A quiet and slow approach where light is either kept off the nests or brought onto them slowly** will give the incubating birds time to move off their egg before departing. This will reduce or even prevent egg loss.

Handling chicks or eggs does not prevent parents caring for them. This means cavers can pick up freshly fallen eggs and chicks and replace them. If you saw them fall and can identify and reach the nest from which they came they are best returned. If you cannot identify the nest from which they came you can increase their chance of survival by placing them in an empty but glistening nest. These are the nests that have recently been receiving maintenance and to which parents will return at the latest by nightfall. Both eggs and chicks can endure hours without incubation and yet show no ill effect.

Not all eggs on the guano under a colony will be viable as some may be infertile, cracked or dead. Shining a light into the egg will show its condition and whether it is worthwhile replacing in a nest. If an egg appears sound and there are no empty nests above it then one of the large chicks (distinguishable from adults by having light edges to the flight feathers and wing tips that do not extend beyond their tail) may have kicked it out. Replacing it under a large chick that is without an egg will increase its chance of hatching.

Catching adults should not be attempted unless you have a good reason and a written permit from QNPWS (Brisbane). Catching adults at the nests or keeping them off their nests for too long may cause them to desert their breeding effort. To prevent desertion only the minimum period required should be spent in the vicinity of the nests. Attempting to catch adults on their way to the nests will often cause them to regurgitate the food they are carrying for their chick and so causes depletion of the chick's food supply. If this happens too often or at critical times such disturbance could be fatal to the chick.

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BIOLOGY

NOTES

AUSTRALIAN ARCHAEOLOGY AND THE STUDY OF ROCK ART IN THE CHILLAGOE AND MITCHELL-PALMER LIMESTONE BELTS OF NORTH QUEENSLAND.

Bruno David

ABSTRACT

Some of the archaeological work on Aboriginal prehistory is reviewed and comparisons made of Aboriginal rock art in the Chillagoe and Mitchell-Palmer areas with rock art in other areas of North Queensland. The idea of rock art fashions being transmitted by trade and social contacts between groups is discussed.

INTRODUCTION

Following many years of amateur and semi-professional archaeological work, it was only during the early 1960's that the first professional archaeological investigations were undertaken in Australia. It had become customary until then to see Australian Aboriginal prehistory as the product of a sequence of relatively independent migrations, and of ideas (characterized archaeologically by distinct forms of stone tools) which diffused from one or more centres of cultural innovation within Australia.

Mulvaney's archaeological work at Kenniff Cave (Central Queensland Highlands) during the 1960's established three major aspects of Aboriginal prehistory, each of which has now become a major tenet in the history of Aboriginal culture. Firstly it was thence established that the direct ancestors of modern Aborigines settled wider Australia (Papua New Guinea, Australia and Tasmania) sometime during the Pleistocene (the period of the ice ages, from about 2 million to 10,000 years ago). Secondly, Mulvaney found that the earliest episode of Aboriginal occupation in Australia was characterized by stone tools qualitatively different from those of later times (the Holocene, from 10,000 years ago to present). And thirdly (and this, to me, is the most important), Mulvaney argued that the change from the earlier to the later stone tool sequence was a gradual one, involving the adoption (or invention) of new tool types, but at the same time also involving the partial retention and gradual abandonment of the older types. I say that this was a major new idea in Australian prehistory because for the first time Aboriginal prehistory was not seen as the sum of distinct Aboriginal cultures replacing each other sequentially, but as Aboriginal culture(s) developing internally through time. Mulvaney saw Aboriginal society as a dynamic cultural system, changing through time, and characterized by its own, particular historical development. This, then, was the setting for the archaeological innovations of the 1970's.

Some archaeologists believe that perhaps the most important revolution in the history of Australian archaeology has taken place only during the last 15 years. I say this in full awareness of the invaluable pioneering work of Australia's first generation of professional archaeologists (including Mulvaney's), professionals who established not only the Pleistocene antiquity of Australia's initial settlement, but who also placed Australian archaeology firmly in the realms of international prehistory. Yet it was not until the early to mid 1970's that Australian archaeologists began questioning the very foundations upon which their discipline was built: archaeology was to become more than the study of stone tools and buried bones (and in this way the discipline reverted, in some ways, to the archaeology of the first half of the 20th century, although the methods had changed), giving way to the study of peoples who made the societies in which they lived. In the spirit of Mulvaney's contributions, social systems were no more seen as frozen in time, but it was the people that made them that were finally seen as the active creators, recreators, and transformers of the very societies in which they lived. Let me illustrate this point by reference to one of the most important debates currently under way in Australian archaeological circles. It is this debate that has led me to undertaking an analysis of the rock art of the Chillagoe and Mitchell-Palmer limestone zones.

In the mid-1970's a number of archaeologists noticed that Aboriginal prehistory was far more complex than previously imagined. Led by the work of Dr. H. Lourandos (now of the University of Qld), the idea began to be developed that sometime in the latter period of Aboriginal prehistory, Australian Aboriginal societies witnessed dramatic changes in many arenas of life. These changes affected stone tool technologies, hunting and gathering strategies, and many believe also socio-political systems and trading networks. More specifically, after noting that in South West Victoria it was not until the last 2,000 years that extensive water management networks were developed by the local Aborigines, Lourandos suggested that this latest period of Aboriginal prehistory was one of intensification, whereby local populations developed extremely complex systems of social relations which enabled them not only to care for the maintenance of the water management networks he studied (such networks diverted natural water systems over long distances to facilitate the trapping of eels, which migrated annually along creeks and rivers), but at the same time resulted in an intensification of social interaction during this time. These findings have become extremely important (although archaeologists disagree, or rather are still debating, the precise nature of changes in the Aboriginal prehistory of different regions) because it places Australian Aboriginal society on the same footing as other types of societies: the intensification question had previously been applied almost entirely to agricultural, pastoral and industrial societies, whilst hunter-gather societies were usually thought of as relatively static (when change was considered amongst hunter-gatherers it was usually in terms of a "static" type of change, not one coined in terms of intensification).

It is the intensification debate which led me to an interest in rock art in general, and to a study of the rock art of the Chillagoe and Mitchell-Palmer regions more specifically. As briefly stated above, one of the key points to come out of the intensification question is that the nature of Aboriginal social relations are believed to have changed during the later stages of Aboriginal prehistory. These changes may have involved changes in trading networks, in inter-group ('tribal') relations, and perhaps even changes in the structure of Aboriginal familial (kinship) systems. To test these ideas, however, we need to study aspects of human behaviour which are sensitive to changes in these spheres of life. Creative activities which involve fashion are one such sphere, and the formation of rock art is an excellent example of such an activity. The logic of this is briefly summarized below.

When people paint, they are restricted, both consciously and unconsciously, by complex social conventions, the nature of which differs in every culture. Some of these restrictions take the form of explicit taboos, but of greater importance to us is the fact that the way pictures are created depends on the methods and styles of depiction practiced by the culture(s) from which the artist has been influenced. These influences change with time (through history), and affect the stylistic conventions associated with artistic behaviour. These are the "fashions" which come and go in every human society.

So fashions are not static. They are passed on from group to group, and the way these fashions travel through time depends on the way people relate between each other. Here two friendly groups may influence each other in such a way that fashions are passed on between them, perhaps slightly modifying them in the process. In another case, the nature of social relations may inhibit the interchange of ideas, and hence artistic conventions (or fashions) are not shared, resulting in the creation and development of distinct artistic styles.

Archaeologically, one of the best ways to study fashions is by an analysis of pictures, and more pictures survive in caves and rock shelters than on any other surface (e.g. sand, bark, human bodies, items of material culture, trees, etc.). Since a comparison of the rock art from different regions can tell us how different cultural groups related between each other, an incorporation of the time factor (i.e. seeing how these relations changed over time) can tell us a great deal about the dynamics of social groups in the past; it offers us a window into the past in the sense that we can, by studying rock art, find out how cultures have developed through time, and how these changes are related to changes in other, neighbouring or distant cultures. This is largely why I have turned to rock art in my studies of past Aboriginal societies (cultures) in Australia.

The rock art of North Queensland has been studied, both in amateur and professional circles, for many years. The art of the Laura region has received particular attention, first by Percy Trezise (since the 1960's), and later by professional archaeologists Dr. Andree Rosenfeld of the Australian National University (Canberra) and Dr. Josephine Flood (Australian Heritage Commission, Canberra) who has recently studied the art of the Koolburra Plateau region, to the immediate NW of Laura. More recently, I have been involved in a detailed study of the art of the Chillagoe and Mitchell-Palmer limestone zones, and this work aims at a fine grained comparison of these various bodies of art with the cave art from more distant regions (e.g. Lawn Hills, Mt. Isa, South Australian, etc.), in order to find out more about the way people from different cultural groups interacted with each other in the past. I now turn to a presentation of the results obtained so far.

RESULTS OF STUDY

The Chillagoe and Mitchell-Palmer limestone belts are geologically parts of the same formation, formed under shallow sea conditions around 400 million years ago. At that time reef conditions prevailed to the east of what is now known as the Palmerville fault, which, following continued uplifting, resulted in the formation of massif fossiliferous limestone karsts, many of which became riddled with caves and rock shelters of various sizes. It is in the entrances to these caves that Aborigines have left so many traces of their prolonged presence, an occupation which undoubtedly spanned the entire length of Aboriginal prehistory on this continent (45,000 years ago to present, although to date the oldest direct evidence for Aboriginal presence in North Queensland dates to 19,000 years ago).

Archaeological investigations in the Mitchell-Palmer region has merely begun. With respect to the rock art, some very interesting patterns are already emerging. By far the predominant motifs from the region are naturalistic pictures of animals (e.g. catfish, dogs, sawfish, flying foxes, emus, turtles, and perhaps echidnas) and humans. These depictions are painted in a style that is reminiscent of the Laura and Koolburra paintings, and indeed are believed to be a sub-set of paintings from these regions. The Mitchell-Palmer animal paintings are often undertaken in profile, and this is especially so of the larger animals such as dogs and large birds. Other animals, such as bats, are painted front-on, whilst turtles are depicted in plan view. In each case, the picture captures that animal's most characteristic features, whilst simplifying the complexity of its separate anatomical parts. For example, the profile view of emus highlights the elongated neck and legs, and pays particular attention to the beak and trident feet. The body itself, however, is generalized, so that the bodies of most of the animals depicted are extremely similar, and could not be differentiated in themselves.

It is interesting to note the very great similarity between these paintings and those from the Laura and Koolburra Plateau region to the immediate north and northwest. Whilst variations do exist (for example the large human/spirit figures from Laura, and the echidna dreaming figures from the Koolburra, do not appear to occur here), stylistically each of these three regions appear to have followed a very similar tradition. It is also important to note that a very similar pattern emerges linguistically: although the languages spoken in these three regions show some variation, they are extremely similar both in terms of semantics and syntax. The pattern, then, is one whereby, north of the Mitchell River, Aboriginal peoples developed relatively homogeneous artistic fashions, coupled with similarly homogeneous linguistic identities.

On the other side of the Mitchell River (to the south-southeast), are a series of extremely rugged mountains (parts of which are known as the Featherbed Ranges) as well as the Walsh River, which holds water throughout the year in its upper and middle reaches. It is to the immediate south of the Walsh that we find the Chillagoe limestone belt.

Here the rock art is entirely different to that of its northern neighbours, in spite of the short distance between the two (70 km). Around Chillagoe, decorated caves and rock shelters are painted with long, linear designs, usually painted in a single colour (mostly red, white, or black, but with some yellow, orange and brown). These paintings are not naturalistic, and do not remind the casual observer of any obvious features of the land. Typical motifs are circles, star-shapes, long, relatively straight lines, grid-patterns (often undertaken in charcoal) and various amorphous linear shapes. Undoubtedly these pictures had meanings to the artists who painted them and to the peoples whose culture they were from, but these meanings are largely lost to us now. The important thing archaeologically, however, is the fact that they are so different from the paintings from the regions to the immediate north. Could they have been painted by peoples from a culture with little to no contact with the peoples north of the Mitchell River? Do these two different artistic traditions (fashions) reflect the relative isolation of two distinct Aboriginal groups, one which had affinities with peoples to the north, the other with peoples to the southwest? I say southwest because of another interesting observation: the art of the Chillagoe region shows very great similarities with the art of the Mt. Isa region to the southwest, and even to regions as far away as the Olary Province (South Australia), 1700 km away. It is likely that these patterns reflect the nature of prehistoric Aboriginal socio-economic relations; the peoples from the Chillagoe region probably had extended trading links with peoples to the southwest, so that ideas, and with them stylistic conventions, travelled in that direction, creating a "chain of connections" progressively further and further away from Chillagoe itself. On the other hand, it may have been the presence of rugged mountain ranges, major rivers, and rain forests which isolated peoples of the Chillagoe region with peoples to the immediate north (the Laura, Koolburra and Mitchell-Palmer peoples) and to the immediate east (the rainforest peoples, which also had a very distinct artistic tradition).

FUTURE STUDIES

But many questions remain. For example, how did these patterns of contact change through time? Was there ever a time when people interacted in a totally different way in this region? Heavily patinated, and believed to be much older than the paintings, are numerous engravings in the Chillagoe area, testimony to more ancient artistic traditions. An investigation of these may well reveal important differences (or similarities) in the way Aboriginal society was structured in the more distant past. It is to investigate these questions that my own work is geared, and future research in both the Chillagoe and Mitchell-Palmer regions and beyond may well prove to offer invaluable answers to such questions, questions which archaeologists have as yet had little opportunity to ask because most archaeological materials are relatively insensitive to preserving the types of information which can enlighten us on these issues.

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SOLUTION AND PRECIPITATION OF LIMESTONE IN THE CHILLAGOE KARST AND OPPORTUNITIES FOR DATING LANDSCAPE DEVELOPMENT.

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ABSTRACT

Solution of limestone in the Chillagoe area proceeds rapidly at the rock surface but concentrations of calcium carbonate reach levels of only 50 ppm or so. In the soil and near-surface environments, much additional material is dissolved, such that concentrations in bore water and in springs reach 300-400 ppm dissolved carbonates. Spring waters in the area undergo rapid degassing of carbon dioxide upon reaching the surface and consequently set down secondary carbonates (travertine and tufa) along stream channels. Rates of carbonate accumulation observed at present suggest that existing accumulations of stream travertines may be no older than Holocene. However, there are widespread relict travertines in the Chillagoe area, often located as terraces and benches set above present stream levels, which relate to much earlier periods of limestone solution and spring precipitation.

A number of these relict deposits have been sampled by diamond drilling and their ages will be determined through the use of Uranium-Thorium radioisotope dating. The chronology of travertine accumulation should equate approximately to that of upland (tower, pediment, etc.) solution and hence provide us with a partial view of the timing of landscape evolution in the karst.

INTRODUCTION

The karst landscapes of tropical Australia pose a series of interesting questions about landform evolution which are deserving of scientific study. The landscape features developed in these areas must also be documented and understood because of the increasing resource pressure arising from the development of Northern Australia, and the growth of visitor numbers. These pressures result in conflicts between development and the protection of natural features.

Among the geomorphic issues which warrant attention are the nature of the landscapes themselves (notably the tower-and-pediment assemblage), the weathering processes and geochemistry, and the age and evolution of the towers, pediments, caves, springs, and other karst features. There are also issues related to archaeology, hydrology, and the management of biota.

Several field visits have been made to the Chillagoe area in order to continue the investigation of issues such as these. This work follows on from earlier studies in the area such as those of Wilson (1974), Lundberg (1976), Jennings (1982), and many others. The present paper addresses in particular the nature of solution and precipitation of carbonates in the Chillagoe area and the use which may be made of the products of these chemical processes in dating aspects of landscape evolution there.

SOLUTION OF LIMESTONE IN THE CHILLAGOE KARST

Analyses of water chemistry within a study area around Chillagoe have been made during three field seasons, in the summers of 1980/81, 1983/84, and 1987/88. The particular goals of the water sampling program were to examine the nature of solute loads and solute uptake in a seasonally arid karst area, both at the surface, and within the groundwater system, and to examine the relationships between weathering processes and the lithological characteristics of the several limestone and marble varieties represented in the area (see Dunkerley 1983). A second objective was to document the processes involved in the deposition of secondary carbonates at springs and along drainage lines. These studies were seen as a necessary precursor to attempts to understand past weathering processes, and to study the timing of landscape development in this solutional environment.

The collection of water samples has involved several procedures. Firstly, water collected in natural rock solution pans, or dripping from overhanging rock outcrops, was collected manually; secondly, artificial catchments were constructed on rock outcrops to direct run-off water into sampling bottles. These collecting sites were set up to enable sampling of water which had freshly fallen onto rock outcrops, and travelled no more than a metre or two in contact with the rock surface; residence times on the rock surface were measured in seconds. To facilitate collections of this kind, artificial barriers of silastic compound were set up across the slope of the outcrop, directing all intercepted down slope flow into a length of polyethylene tubing set in to the lowest point on the barrier, and hence into a collecting bottle placed lower down. The mouths of bottles were protected against rain entry by a covering plastic envelope (apparatus described by Dunkerley 1984). Thirdly, samples have been collected from springs and streams, as well as artificial water bores, in the karst.

After collection, all water samples were promptly returned to a field laboratory where pH and conductivity were determined. Over the following day, selected additional chemical analyses were performed by standard titration techniques. Subsequent analyses of saturation levels were made using the WATSPEC computer program (Wigley, 1977).

TABLE 1.
AVERAGE WATER CHEMISTRY PARAMETERS FOR THREE LITHOLOGIES
(surface run-off water lumped with solution pan samples)

Site	pH	Cond.	Total	Ca	Mg	pCO_2	SIc	SId
Coarse marbles	7.82	81.9	34.1	32.7	1.6	3.36	-0.82	-2.42
Fine marbles	8.06	87.6	41.3	39.9	2.4	3.52	-0.38	-1.28
Fossiliferous limestones	8.04	100.9	41.9	40.6	1.8	3.42	-0.27	-1.52

[SIc and SId are the mineral saturation index for calcite and dolomite, respectively; pCO_2 is -log(PCO2) where PCO_2 is expressed in atmospheres.]

The results of this work will not be presented here in full. However, a summary of the most general results from three rock types is included in Table 1.

Table 1 summarizes the results obtained when all the collected data from particular rock types are lumped. These data include those derived from installed run-off collectors, as well as from water collected from solution pans after rain.

It can be seen from this table that the fine-textured fossiliferous limestones (e.g. in Royal Arch bluff) are the fastest to move into solution. This is indicated by the highest mean total and calcium hardness values (reflected in the highest mean electrical conductivity), and the nearest approach to saturation in the collected waters. Least rapid to pass into solution are the coarse-textured marbles such as those of Dome Rock: the mean total and calcium hardness of samples from this site is about 18% less than at Royal Arch, and the samples displayed greater mean undersaturation. The marbles of intermediate texture (e.g., Racecourse Tower; Donna Bluff) are also intermediate in terms of rate of entry into solution. The three lithologies are very similar in terms of the computed equilibrium concentration of carbon dioxide required in the associated gas phase, at a mean value of 3.43, very close to the expected atmospheric value of 3.47. The distribution of measured pCO_2 values is shown in Figure 1.

These results clearly imply that solutional weathering and the development of minor solutional features at the outcrop level proceeds most rapidly on the fine-textured rocks and least rapidly on the coarse marbles. However, they say nothing in detail about the way in which solution rates and solution processes vary across the complicated surface of a typical fluted bluff outcrop, or about the rate at which solute uptake varies through time during the period in which water is in contact with the rock surface, nor about relative solution rates among tower and pediment areas. However, they clearly indicate the kinds of dissolved limestone quantities collected by fresh water as it interacts with the limestones- in all cases less than 50 mg/litre average total hardness (expressed as $CaCO_3$ equivalent). Much additional material must be taken into solution in the weathered zone at the soil-bedrock interface, where the water is enriched with carbon dioxide from the soil atmosphere. This is shown by the chemistry of springs, discussed in the next section.

CHEMISTRY OF SPRINGS, STREAMS, AND GROUNDWATER

There are many small springs in the Chillagoe karst which apparently flow perennially, generally associated with the deposition of secondary carbonates encrusting the channel. Six springs have been studied, and several of these sites have been sampled both at the resurgence itself and at intervals down the spring- fed channel in order to look at rates of deposition of secondary carbonates. Information on the processes involved in the present-day deposition of secondary carbonates is necessary for a proper understanding of the origin of fossil or relict tufa or travertine deposits in the Chillagoe area. The work on

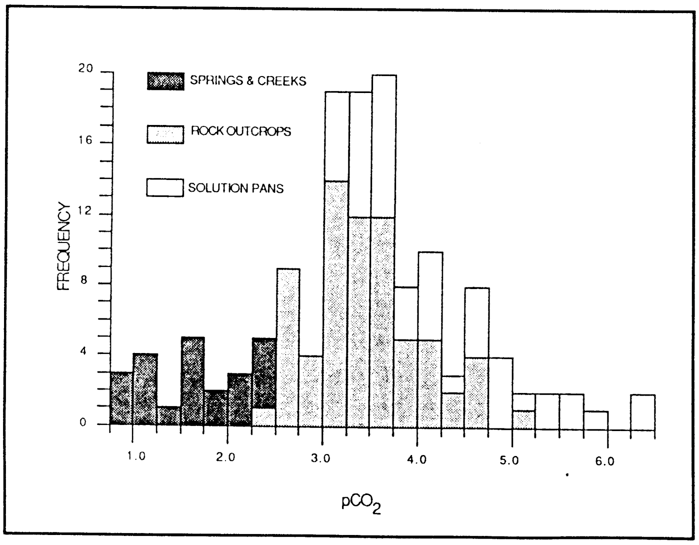

Figure 1: Distribution of calculated pCO_2 values, using all data.

depositional processes has been undertaken for its own value, but also as a precursor to dating and interpretation of the secondary deposits.

The deposition of secondary carbonates involves at least three distinct sets of processes. First, there are chemical effects which arise as spring waters rise to the ground surface after having percolated downward through the soil and zone of weathered bedrock into pore spaces within the underlying limestone. Such waters are normally enriched in dissolved carbon dioxide as a result of passage through the soil, and cooler than surface waters. Hence, on reaching the surface they are warmed (as well as agitated) and tend to lose CO_2 to the atmosphere in the process of degassing. This forces the solution into supersaturation, and once a sufficient level of supersaturation is reached, the deposition of carbonates begins. Previous work (Jacobsen and Usdowski 1975; Dunkerley 1981, 1987) has indicated that precipitation generally occurs where SIc is greater than 1 (i.e., with concentrations of more than 10 times saturation levels). Only slight accumulation occurs at lower levels of supersaturation.

Secondly, there is the role of evaporation. In the dry season especially, evaporative loss of water from spring-fed streams is large, and this is enhanced if they are impounded to form a cascade of large pools by natural tufa barriers. This evaporative loss again forces the solution into progressive supersaturation, and causes secondary carbonate deposition. This process has been documented in the Chillagoe area by Dunkerley (1984).

The third group of processes, not yet investigated at Chillagoe, involves a more direct role of aquatic biota. In particular, the growth of mosses and algae in the water may contribute substantially to the chemical changes required to initiate deposition. This has been investigated at other sites (e.g., see Pentecost and Lord 1988). Comparing water chemistry between day and night has been employed by some workers as a means of revealing the role of photosynthesis by plants in affecting the water chemistry (e.g., see Jacobsen and Usdowski, 1975; Usdowski et al. 1979).

Much deposition at Chillagoe is believed to result from processes in the first group, following emergence of water at the ground surface. The change in environment involved here may be considered in terms of the characteristics of water samples collected from deep bores and from springs before alteration in the chemical properties. Samples of deep ground water were obtained from water bores at the Chillagoe marble quarries and at the Red Dome gold mine. The sample at the Red Dome site was pumped from a depth of 165 m below the terrain, and presumably reflects concentrations in the deep circulation water below the karst area. Samples were obtained from 5 springs in the Chillagoe-Mungana-Rookwood area, all of which displayed deposits of secondary carbonates (travertine and tufa) along the stream channel below the spring.

Results from the sampling of deep groundwater and spring water are tabulated (see Table 2). The results indicate a mean total hardness of 284 ppm as $CaCO_3$, with a maximum of 388 ppm at the Red Dome bore.

The composition of the waters was about 80% calcium carbonate and 20% magnesium carbonate, in terms of hardness. Mean pH was 6.9, with mean SIc of 0.104, indicating close approach to saturation. SId in contrast displayed a mean value of -0.54, indicating slight undersaturation with respect to dolomite. Mean theoretical equilibrium carbon dioxide level in the spring and bore waters was 1.22, corresponding to about 6% CO_2; the value correlated well with pH of the sample (r = 0.94).

Mean total hardness is about 7 times that of surface run-off waters, which displayed a value of less than 40 ppm as $CaCO_3$ (Table 1). Surface run-off waters were also considerably more undersaturated than the deep waters, especially with respect to magnesium carbonate. It is not possible to comment on the temperature difference of the waters in situ as the samples were always collected at the surface after warming had undoubtedly already occurred during upward passage through the rock.

However, it is clear that waters with a mean PCO_2 of 1.22 would undergo rapid degassing upon reaching the surface where the free air value is about 3.4. There is clearly a large groundwater store (since the springs in the district are perennial) and so we may make the assumption that the groundwater residence time has probably always been sufficiently long for water to reach calcite saturation. In times of moister climate in the Chillagoe district, with consequent more vigorous and sustained plant growth and soil microbial activity, it would be reasonable to assume that even greater concentrations would have been reached in the groundwater, and therefore for more extensive tufa deposition to have taken place at the surface. The possibility of greater surface run-off from adjacent impermeable rocks needs to be recalled, however: in causing dilution of the karst waters, such allogenic water would have acted to reduce the tendency for tufa deposition. Active dissolution of some of the tufa by run-off water might also have been active at spring sites, which in the Chillagoe district tend to be located at geological contacts, which are exploited by rising groundwater as conduit sites.

Rates of carbonate precipitation have already been described for Ryans Creek at Mungana (Dunkerley 1987). This spring has total hardness in the range 280-300 ppm, a pH of close to 7, and SIc of about 0.05. In the form of a major sequence of tufa barriers, it precipitates carbonates over a distance of 1-2 km below the spring; the deposited material is almost entirely calcium carbonate, so that the magnesium hardness actually rises downstream.

TABLE 2.

WATER CHEMISTRY - SPRINGS AND BORES
(mean values)

Samples included	pH	Cond.	Total	Ca	Mg	pCO_2	SIc	SId
All data	6.86	711	284	257	31	1.22	0.10	-0.54
Bores	6.97	709	289	253	36	1.39	0.16	-0.23
Springs	6.82	738	294	269	29	1.13	0.10	-0.64

The loss of calcium carbonate amounts to about 130 ppm, or about 50%, over the first kilometre. At an estimated average flow rate of 5 l/minute, this amounts to about 1 kg per day, or about 1 m^3 of tufa in about 6-7 years. Thus a deposit 2 km long, over a depositional surface 50 m wide, and built up to a depth of 1 m, could form in about 16000 years. This can be taken as no more than at best an order-of- magnitude rate estimate, and in times of altered climate, the accumulation rate would almost certainly have been different for reasons already mentioned. However, it indicates that tufa barriers of the dimensions of those found on Ryans Creek need be no older than perhaps Holocene, and that these may indeed only have begun forming as the climate of this area became drier (because of reduced allogenic surface water input).

Similar studies have been made at a spring in the Rookwood area, which rises with a total hardness of about 300 ppm, a pCO_2 of 0.98, and calcite saturation. This spring has set down a series of tufa barriers and water sampling indicated a decline in hardness to about 95 ppm after 350 m of surface flow, which appears to be the downstream limit of significant tufa deposition at this site at present.

RELICT TUFA AND TRAVERTINE DEPOSITS OF CHILLAGOE AREA

Field inspection at many sites within the karst revealed substantial accumulations of travertines lying well above present-day stream beds. The volume of secondary carbonates involved in these deposits is considerably greater than that associated with active deposition on streams at present. These deposits had earlier been mentioned, but not described in detail, by De Keyser and Wolff (1964) who employed the older term calsinter (see definitions at end of paper). Some of these materials were apparently quarried earlier this century. The deposits are generally undergoing breakdown and erosion at present. The travertines were located in relation to the geologic structure, by inspecting sites at geologic boundaries, close also to large expanses of limestone. Generally the tufa and travertine deposits begin at about the line of geologic contact and extend downstream, often siting on the Devonian granites, or in some cases, on marbles resulting from the granitic intrusions (see Jennings 1982 for a sketch). One such deposit is located on Chillagoe creek; there are excellent exposures at the rail bridge crossing. The level surface on which the rail line sits is the surface of the relict travertines. Inspection of the banks of Chillagoe creek indicates the presence of an internal stratigraphy of travertines of varying character; these were mapped and sampled. The materials are generally cream to buff in colour, have a bulk density of about 2.36 g/cm^3, and are composed of secondary calcite intermixed with detrital grains of whole rock (limestone fragments) and quartz grains presumably derived from weathering of the granites adjacent to the limestones. Older travertines low in the site stratigraphic column appear to have lower porosity than the recent deposits forming active tufa barriers.

Sampling was done by collecting drill cores having a diameter of 100 mm. Drilling was performed with a portable motorized diamond drill with pumped water for cooling and removal of rock particles. Cores were extracted from many travertines in the area. It is proposed that these materials be dated by isotope techniques.

The considerable accumulations of tufa clearly must relate to periods of substantial dissolution of the limestone source areas (the towers, caves, and shallow vadose zones). Therefore, the chronology of tufa accumulation should equate essentially with the chronology of tower formation. Probably only the most prominent travertines have at present been located, and these are probably relatively recent in terms of the history of tower development. Older fragments may well be found in sites at higher levels in the terrain, where they have been protected from subsequent erosion, although there may have been almost complete removal of these materials by subsequent solution. The other source of dateable secondary carbonates is, of course, the caves themselves; however, the volume of material available is generally much smaller and the detrimental effect of sampling much greater in the cave environment, so that work on these materials should only proceed with due care and when other avenues have been exhausted.

The dating techniques which might be employed for age determination on the tufas and travertines include

- radiocarbon isotope dating
- Uranium-Thorium isotope dating
- Electron spin resonance (ESR) radiation-dose dating
- thermoluminescence (TL) radiation-dose dating (on detrital mineral grains from igneous rocks).

The Uranium-Thorium dating technique has been widely applied to age determination for secondary carbonate materials (travertines, soil carbonates, etc.: see for example Ku et al. 1979; Schwarcz, 1980, Goff and Shevenell 1987). It is hoped to date samples from the Chillagoe deposits with this technique, the aim being to establish a chronology of tufa accumulation, and hence, indirectly, a chronology of solutional activity in the landscape as a whole.

The secondary carbonates also provide a potential record of past environments in the Chillagoe area, which it is hoped to exploit in a later stage of the research. In particular, the stable isotopes of carbon and oxygen undergo fractionation during deposition, recording a temperature effect in so doing; this can be interpreted if the geochemistry of deposition is understood (e.g., see Turi 1986). Pollen and spores are incorporated into the carbonates as they are laid down, and these preserve a record of the vegetation communities of the time. These fossil materials can be extracted and identified readily (e.g. Weinstein-Evron 1987).

Details of the locations of the travertines samples and of any dates available by that time will be presented at the Conference.

DEFINITIONS

Definitions of the terms tufa, travertine, and calc-sinter are provided below. These are taken from the American Geological Institute Glossary of Geology (Bates and Jackson 1980). It should be noted that in present usage only surface deposits would be referred to as travertines; secondary carbonates set down in caves would be referred to as speleothems.

SINTER A chemical sedimentary rock deposited as a hard incrustation on rocks or on the ground by precipitation from hot or cold mineral waters or springs, lakes, or streams; specif. siliceous sinter and calcareous sinter (travertine). (Glossary p.584).

TUFA A chemical sedimentary rock composed of calcium carbonate, formed by evaporation as a thin, surficial, soft, spongy, cellular or porous, semifriable incrustation around the mouth of a hot or cold calcareous spring or seep, or along a stream carrying calcium carbonate in solution, and exceptionally as a thick, bulbous, concretionary or compact deposit in a lake or along its shore. It may also be precipitated by algae or bacteria. The hard, dense variety is travertine. (Glossary p.669).

TRAVERTINE A dense, finely crystalline massive or concretionary limestone, of white, tan, or cream colour, often having a fibrous or concentric structure and splintery fracture, formed by rapid chemical precipitation of calcium carbonate from solution in surface and ground waters, as by agitation of stream water or by evaporation around the mouth or in the conduit of a spring, esp. a hot spring. It also occurs in limestone caves, where it forms stalactites, stalagmites, and other deposits. Synonyms: calcareous sinter; calc-sinter. (Glossary p.663).

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WHERE'S THE HISTO? HISTOPLASMOSIS IN CHILLAGOE CAVES AREA, NORTH QUEENSLAND, AUSTRALIA

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ABSTRACT

Ideal climatic and ecological conditions in many caves in the Chillagoe area suggest the existence of Histoplasma capsulatum. A study in progress proposes to identify those caves that may be reservoirs for the organism, subsequently presenting a potential health risk for cave visitors. Soil samples collected from caves containing bat and bird (swiftlet) populations are being processed by the Division of Mycotic Diseases, at the Center for Disease Control, Atlanta, Georgia. Preliminary results from 15 caves have been negative, though a more precise technique will be utilised in further collections. Histoplasmin (intradermal) skin testing of cavers intends to identify the possibility of cave exploration as one source of Histoplasma capsulatum exposure.

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CAVING, COMPUTERS AND COMMON SENSE

Gordon L. Greaves

ABSTRACT.

The Personal Computer became a usable tool for scientists and researchers in all fields some time ago. Although the prediction of "a computer in every home" still has a long way to go, a computer in every office is becoming a reality. Certain aspects of personal computing are tailor made for the caving field.

INTRODUCTION.

Using a Personal Computer is no longer a habit restricted to the fortunate few. Computers have dropped in price and gained in power in quantum leaps. In the early days (and bear in mind that we are discussing a life span of fifteen years!), there was very little that a personal computer could do. It was, in reality, not much more than a diabolically expensive calculator that took up far too much room to be practical. That situation did not change until the advent of the first of the spreadsheet programs, VisiCalc. At last the computer could do some useful work. From this simple beginning, the explosion took place. Todays equivalent, Microsoft Excel, is usurping some of the work that required major installations in earlier days.

One major factor is required in any aspect of computing - the operators imagination. To sit down with a standard word processor, spreadsheet or even an accounting package with no imagination means that you will only reap about thirty to fifty percent of the benefits that program is capable of bringing you.

DESKTOP PUBLISHING.

Desktop Publishing, or DTP, is the art of utilising everyday computer equipment to create work that would normally be done by a professional printer using typesetters and gluepots. With DTP, this can all be done in one operation under *your* control, and allows you try various layouts at minimal expense. There are various traps to avoid in DTP, some of which have been dealt with in our other paper, but we did not cover fonts and graphics in any detail.

A page of varying type styles (or "fonts" as they are termed in DTP) tends to detract from the actual content of the document itself. Some examples of fonts are virtually unreadable when used en masse - a short notation in a different font can attract the reader and be acceptable, whereas a large block of text in the same font is not. An example is the Helvetica font. Helvetica is ideal as a headline. It is stark and stands out. As "body text", however, Helvetica can be confusing. The generally accepted font for body text is Times Roman, or a variety thereof. The major difference between these two fonts is that Helvetica is a "sans serif" font, while Times Roman is a "serif" style. A serif is a small cross-line at the top and bottom of a character which tends to lead the human eye from one letter to the next. The curves are also carefully designed to be pleasing to the eye. It is interesting to note that most of the typefaces in general use today are several hundred years old.

Another area that deserves discussion is "justification" of text. It is generally considered that a "ragged" right margin is an informal style, while "flush" right margins indicate a formal passage. You will note that this entire publication is fully justified (flush left and right margins). While this can occasionally mean slightly larger spaces between some words, using a "proportional" font will tend to alleviate this. A proportional font is one that takes up the required amount of space for a given letter, while a non-proportional font takes the same amount of text space for every letter, regardless of that letter's width.. Table 1 should help to clarify the distinction. Table 2 shows some of the fonts generally available.

TABLE 1.
PROPORTIONAL AND NON PROPORTIONAL FONTS.

abcdefghijklmnopqrstuvwxyz 1234567890 Times Roman 10 point proportional.

abcdefghijklmnopqrstuvwxyz 1234567890 Helvetica 10 point proportional.

`abcdefghijklmnopqrstuvwxyz 1234567890 Courier 10 point non-proportional.`

`abcdefghijklmnopqrstuvwxyz 1234567890 Lineprinter 8.5 point non-proportional.`

**TABLE 2.
FONT TYPES.**

Courier font, general use.

Times-Roman, body text.

Helvetica, headlines.

University Roman, old fashioned.

Broadway, headlines.

Cooper Black, headlines.

Coronet, invitations, tickets, etc.

Bauer Bodoni, decorative.

Another major factor in the presentation of documents is the use of graphics. A picture may be worth a thousand words, but it can also make the author wish that the picture had been left out altogether. There are certain rules that should be followed to attract interest in a publication, and a lot of these rules concern the placement and sizing of graphic images. Graphs that are nowhere near the text which describes them should be avoided at all cost, as the reader has to continually move their eyes away from the centre of interest, the text. Graphic images in the top left-hand corner tend to keep drawing the eye back up to the top of the page, whereas the same graphic placed in the bottom right-hand corner will tend to force the reader to continue through the page.

Graphics should be scanned at their final size - in other words, if the required final image is 10 cm by 10 cm, enlarge or reduce using the scanners software so that the image file generated is 10 cm by 10 cm. If you generate the image at a different size, re-scaling it in the publishing software will lead to distortions and an enormous loss of quality.

Careful use of background graphics (i.e. Graphic images faded into the background behind the text) can be a great attraction on a page, giving the reader the impression of friendliness. A plain page in a dry text can be almost impossible to read, as no doubt you have discovered. You must encourage the reader to read and assimilate the information you are trying to put across.

SPREADSHEETS.

From its humble beginnings, the spreadsheet has now advanced to the stage where they are amongst the most powerful programs available on a personal computer. The major programs, such as Excel, Multiplan and Lotus, feature a capability known as a "macro". A macro is simply a method of writing a sub-program, so that when a certain combination of keys is pressed, a predetermined action will occur that is not an original function. Most major programs now allow you to "record" a macro, rather than having to write it as a program. To record a macro, you turn on the recorder, then step through the proposed task yourself until such time as the task is completed. The recorder is then turned off, and the macro assigned a key which will initiate it. No programming skills are required. The macro is then ready for use whenever a new set of data is entered.

Given a datum line through the centre of a cave, it is a simple task, using Microsoft Excel as an example, to draw a cave map. At points one meter apart along the datum line, measure the distance from the datum line to one side of the cave wall. Then measure the other side in a similar fashion. Enter the figures into Excel, giving one side a positive value and the other side a negative value. The floor layout of the cave (or roof to floor, should you have those figures) can then be charted using a line graph. And you also have the figures available should you wish to calculate the floor area of the cave, or the area of any section. While in the chart section, text can be added anywhere on the page. As the only requirement for drawing this map is the entry of two rows of figures, the speed and accuracy benefits can be enormous.

Unfortunately, caves do not very often run in a straight line. This means that a new chart would have to be prepared for each section, then the sections joined together.

Printing on a laser printer will give a very professional quality to your map. Refer to Appendix I for an example of an imaginary cave map drawn using a combination of Excel and a Hewlett-Packard LaserJet Series II. This map was drawn solely to test out the theory, which was conceived during the writing of this article.

Spreadsheets can, of course, calculate all the variables involved in statistically reporting on cave and surface biology. Since spreadsheets have the capability of manipulating figures in any way, shape or form, most jobs that would previously have required many hours of hand calculation or the use of a large computer, this power is now available cheaply to all.

DATABASES.

A database program is simply a method of holding data. Up until the last twelve months or so, this data had to be in a rigidly structured form. Recently we have seen the advent of the "hyper" databases, such as HyperCard for the Macintosh and similar software for the IBM. These programs allow related data to be entered without any regard for format. As data is entered, keywords are marked and future retrieval on the subject matter involves simply telling the software what information you want. It then searches by keyword and retrieves all relevant data.

Structured databases, on the other hand, limit the amount of data that can be placed in any field on a screen form. They also limit the type of data that can be entered into a field. For example, a field may require numeric data, and will reject any alphabetic input, often with an indecipherable message. Once again, the power of the program is far greater than many realise. Many of the databases in use today are what is known as "relational"databases, describing the feature that allows them to have multiple files linked together in a programmable form. From these, which include such programs as dBase, Informix and filePro, a complete "stand-alone" program can be constructed - for example accounting packages. However, programming knowledge is definitely required.

Structured databases can also be of the single file, "flat file" type. These do not allow interlinked files, and all data must be entered into one large file. Some clever variations have appeared in this area in recent years, not the least of which is a program called "Q & A". This program has a feature called the "Intelligent Assistant", which can be trained to answer queries that bear no relationship to program requests. For example, given that each item was in a separate field, it would be possible to type in **"give me a list of all caves in Chillagoe that contain more than 50 swiflets and less than 100 bats and have a cave tag number higher than 200"**. The Intelligent Assistant would examine your request and return a confirmatory question, for example **"do you want me to list all caves where prefix = ch and swiflets > 50 and bats < 100 and tagnumber > 200?"**. A press of a key and the information is on your screen in something under three seconds! Q & A also has word processing facilities, and can enter the databases answer directly into your document. The main drawback is the amount of memory required, as all database and word processor documents are held in memory - 640K is a minimum.

HARDWARE (COMPUTERS).

This is probably the most argued about item in the personal computing field. There is, however, one standard, IBM/MS-Dos, and we are seeing the emergence of the Macintosh as a second standard. There are a great many systems that operate under the IBM standard, but only Apple computers can run Macintosh software. Beware of the cheaper machinery with a brand name of which you have never heard. While it is not necessarily bad equipment, it would be comforting to know that the equipment you buy today will still have a viable supplier two years from now. "Your Computer" put it best some time ago when they said "If we threw a party for every supplier who advertised in our first issue who is still in business, we would have to get some people from Rent-A-Crowd to help fill a very small room". This is a fair indication of the situation in the industry.

Another area that requires careful consideration is the type of equipment you require. These days some of the portable machines are more powerful than their desktop equivalents - and they can be run on batteries in the field, or from the cigarette lighter outlet in a vehicle. For example, referring back to the section on spreadsheets, it would be possible to take a portable computer into a cave and actually map it while you were there, checking the output given against what you can see around you. You would not need to print; an on-screen display would be sufficient.

HARDWARE (PRINTERS).

Printers range from quite cheap dot matrix printers to the high-output lasers and beyond. Two kinds of lasers are expected within the very near future at affordable prices - the colour laser and the high-resolution laser. High-resolution lasers will have output around 1200 dots per inch, and will be virtually indistinguishable from typeset documents. Colour lasers will almost certainly have the capability to produce any colour or shade at very high resolution. In fact, both are available now, but the pricing is prohibitive. Recently Hewlett-Packard released the IID, a duplexing laser printer - it can print both sides of a sheet of paper at 300 dots per inch at a rate of 7.4 pages pages per minute.

Some of the dot-matrix printers are also capable of printing in very high resolution, due to making multiple passes over each line of text or graphics. The more pins in the head, the better the output. Head types are either 9 pin or 24 pin, and one manufacturer has recently released a 32 pin printer.

HARDWARE (SCANNERS).

Scanners come in two major forms, the hand held and flat-bed type. While the flat-bed has been around for some time, the hand held scanner is a comparatively recent innovation. Both types have special software which must be loaded prior to use, and may generate images in a number of formats. Great care needs to be taken here - not all image types are acceptable to all publishing software. As a rule of thumb, if the scanner won't generate a "TIFF" file (Tag Image File Format) don't bother with it.

HARDWARE (DIGITISERS).

Digitisers come in many types. The simplest digitiser is the common joystick, which can be used with some graphics software to draw on-screen images. The most versatile digitiser is the mouse - preferred because of it's ability to work with a wide variety of software and it's insignificant price. With most mice (meese?), two buttons are more than sufficient. Some have one, others have three or more (there is one on the market with seven....), but the most common, the Microsoft Mouse, has two, and most software is written to utilise just two. Other digitiser types include the graphics tablet, which requires the use of a flat, generally A4 sized tabletop

Other digitiser types include the graphics tablet, which requires the use of a flat, generally A4 sized tabletop device equipped with either a cross hair or stylus type cursor, and capable of being used up to 10 cm away from the pad itself. This can be handy should you be trying to recreate a graphic from a bound publication.

CONCLUSION.

Rules are made to be broken, but the following should assist anyone contemplating entry into the Personal Computing field.

- If you cannot guarantee on-going support, don't buy it!
- If it's been around for a while and no-one else is using it, there has to be a good reason. It probably doesn't work...
- Don't be an orphan. Buying something simply because it looks good is not a recipe for continued enjoyment of computer hardware or software. Will it do the job?
- Buy major software and hardware from a brand name you know.
- Ensure that the dealership from whom you purchase knows what they are talking about. When they have finished talking, make them show you. If you cannot get a demonstration of what they are offering, run, don't walk, to the nearest exit!
- When taking delivery of equipment, ensure that the equipment is set up for you, if you don't have the knowledge to do so yourself and you are shown that the system does in fact work as advertised.

Until you consider yourself an expert in computing, stay away from anything new - the .01 version of anything has most of the "bugs" removed from the .00 version....

Computing can be anything from a labour saver to an art-form. You can enjoy your time with a Personal Computer, or it can be a nightmare. Every computer system should have at least one game on it somewhere - hours and hours of technical work staring at a screen can send your mind totally numb, or even mildly insane. Rest and Recreation is definitely advised (Flight Simulator is GREAT!).

The following and others used are registered trademarks or trade names and are copyright -

Aldus PageMaker
Apple Macintosh
Bauer Bodoni
dBase
filePro
Hewlett-Packard LaserJet and ScanJet
HyperCard
IBM Personal System/2
Informix
Intelligent Assistant
Lotus
Microsoft MS-Dos, Excel, Multiplan, Mouse and Word
Q & A
VisiCalc

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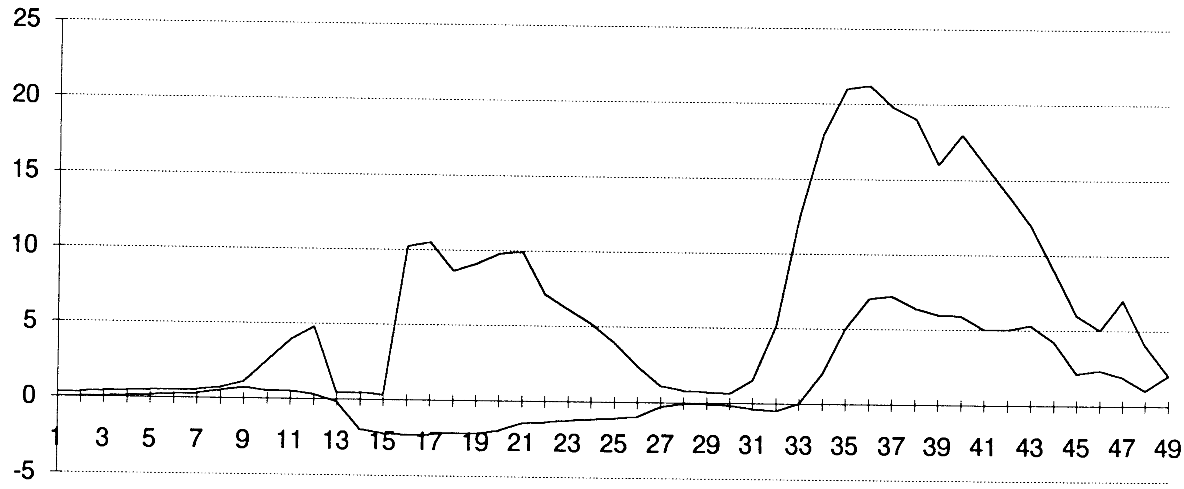
Scanned Photo - The IBM Personal System/2 Model 70 scanned on a Hewlett-Packard ScanJet.

APPENDIX I.

TYPICAL CAVE PROFILE PRODUCED BY "EXCEL".

Cave Profile - A series of points was entered, using positive for above the datum line, and negative for below. The data was then sent to the charting section and the resultant chart printed.



MISCELLANEOUS

DESKTOP PUBLISHING OF CAVING PUBLICATIONS.

Gordon Greaves and Les Pearson.

ABSTRACT.

Having recently prepared several extensive caving publications to the stage where they are ready for the printer or photo copier we thought that it could be useful to others to record our methods, computer equipment and software and some of the difficulties which have to be solved in the process.

As our publications were assembled on IBM computer desktop publishing equipment using text set by word processors some of our work may appear novel to people not yet computer literate.

INTRODUCTION

Personal computing covers many fields. It may include games, control of a business or company or just a way of keeping personal notes and records and for writing of letters.

One of the areas in which personal computers have made significant advances in the last two years, since the development of laser printers, is desktop publishing. These laser printers have a resolution of 300 dots per inch which, while far below the 2400 dots per inch resolution of most commercial printing equipment, is more than adequate for most publishing.

Using desk top publishing equipment an organisation can produce professional looking documents which have features that, surprisingly, would be very difficult for a commercial printer to achieve.

This volume of pre-prints for the conference has been produced using desk top publishing technology, giving, we feel, an acceptable standard of documentation at minimal expense. We have not by any means used all the capability of the equipment. Many of the capabilities were designed for advertising artwork layouts and are not entirely suitable for this style of publication.

Standardisation is all important. You will note that throughout this publication we have tried to use the same margins, type styles, paragraphs etc. Continual change of these tend to confuse the reader as too much time is spent in adjusting to differences.

PLANNING

"Though this be madness, yet there's method in 't"
William Shakespeare, Hamlet Act 2, Scene 2.

It is necessary to determine clearly what is required of the publication - in terms of content, format, time for printing, number of copies required, cost etc - at an early stage so that later decisions can be made correctly.

At this stage deadlines also need to be set for authors to produce their copy. Our experience in this area is that no one meets deadlines set and some are significantly worse than others. Leaders should look at their past record in this regard and perhaps set a better example for other members to follow in future.

EQUIPMENT AND SOFTWARE.

"For all a rhetorician's rules
Teach nothing but to name his tools"
Samuel Butler.

Text transfer - Text is usually prepared on the author's computer which is, in his eyes, the ultimate. This can provide some interesting problems as many computers are totally incompatible.

With IBM computers and the many IBM clones it is usually possible to transfer information on floppy disks. While there are several sizes of disks this presents no significant problem.

For transfer of disks from a number of other computers it is possible to use software such as Alien which allows for different methods of formatting of information recorded on the disks.

Experience with Apple computer disks shows that transfer is possible but only through a translation on Apple to provide a disk in ASCII format readable by IBM and its clones.

Wordstar 4000 word processing language was used as the standard for text preparation and for editing on an IBM clone computer (CCS). This was perhaps not the best choice as Wordstar 4000 justifies by adding spaces and does not have all the facilities of Microsoft Word which was used later in the process.

Final preparation was carried out using two software packages, Aldus PageMaker, which is a desk-top publishing package, and Microsoft Excel, a state-of-the-art spreadsheet/database/graphics program. Excel was chosen because of its ability to manipulate fonts and page layouts.

Hardware used in the final printing was an IBM Personal System/2 Model 70, a desktop system which uses a high speed Intel 80386 processor and a 120 megabyte hard disk drive. This was coupled to a Hewlett-Packard LaserJet Series II with 1.5 megabytes of memory.

Additional equipment was Bitstream downloadable fonts, a Microsoft Mouse and a lot of coffee.

PREPARATION OF TEXT

"Choice, word and measured phrase above the reach
Of ordinary men"

William Wordsworth.

Text Entry - Text supplied by authors comes in a variety of forms most of which can be input to the computer from a disk either directly, translated by Alien (or equivalent) or on a computer of the same type to an ASCII file which is readable by most computers.

Some text of course comes as hard copy and has to be laboriously retyped into the computer. We are planning a special award to authors who prepare their paper on a word processor and then send only hard copy, making sure we are kept busy.

It is anticipated that in future use will be made of telephone linkup of computers and the text sent over the line, saving that week wait while the courier loses or misdirects already late text.

Some text was sent by facsimile from Hawaii - how much better if we could have got it by computer hook-up!

Editing - It is necessary to standardize text as far as possible to reduce the time involved in the layout process.

This involves setting all text to the same size, justifying of text to the standards used, setting headings in standard positions with consistency in size and style of type.

Position proposed for photographs and diagrams needs to be determined to locate these adjacent to the text where they are referred to and suitably flagged with spaces in the text so that they are readily seen when laying out.

Tabulations present special difficulties and should be flagged in the text and the table moved to the end of the text or preferably to a separate file. Tabulations should be tabbed, not set with the space bar.

Some computers justify text by inserting spaces in the line. When this text is transferred to the page layout computer the spaces cause irregularities in spacing which look untidy. To avoid this problem the text was run through a search a number of times and double spaces replaced by single spaces. This procedure totally fouls up spacing of any tables left in the text but they are readily re-tabbed.

To avoid long times in assembly, files should be short, an article or a chapter is usually suitable. However we did one publication with a file of over 100 pages of text which was slow to load and tended to slow down the whole operation. Tables would be better as separate files suitably named as relating to the main file, for example KARST for main file and KARST1 and KARST2 for tables 1 and 2.

Actual text of labels for tables, figures and diagrams should be placed in the text next to the flagging for these items.

Checking - All text then needs to be run through a dictionary check as we do not believe that any author of note ever does this sort of mechanical check and few can spell or type without errors. No author for this publication, other than those of this article, appeared to have done a dictionary proof check of the text supplied.

The text must be carefully read and re-read by several people looking for inconsistencies, wrong words, errors of grammar and other possible errors. The more correct the text can be made at this stage the easier is the layout job. And with all of this checking you can be sure that the printer's devil has been about and made a few mistakes for everyone to note.

ILLUSTRATIONS.

"Look here, upon this picture, and on this"

William Shakespeare, Hamlet Act3 Scene 4

Photographs can be either screened by the photographic process, or scanned and converted to an almost equivalent screening through a computer scanner. The photographs supplied for this publication were already screened with two exceptions which were scanned.

Diagrams supplied for this publication were in general well prepared, but some reduction was unfortunately economically necessary. The graph in Dunkerley's paper was prepared by computer and was supplied to us in finished format. The two graphs in Stone's paper were supplied as Lotus 1-2-3 "PIC" format files, which were then readily loaded direct into PageMaker. The emblem for the Chillagoe Caving Club Inc which appears in the preceding paper was drawn on the computer using a drafting program, MicroGrafx Designer.

Most people are familiar with Letraset or equivalent methods of labelling on diagrams. It is necessary to allow for reduction in size and use large print on diagrams so that they remain readable.

Several diagrams proved to have borders not parallel and sides only "almost" at right angles..... these are better left to the computer to draw.

PAGE LAYOUTS

"It is not the weight which counts, but how it is distributed"

Article on fitness in the Australian Womens Weekly.

Page layouts were done with PageMaker software, the publication being laid out page by page in sections. Spaces were allowed for paste in of screened photographs and reduced copies of diagrams. As each page is laid up care is taken in appearance of layout, that paragraph breaks do not occur only part of a line from the end,and that references in the text are located where illustrations can be readily seen. Sometimes it is not possible to relate text and illustrations and some editing is done to show where the illustration is to be located.

Table of contents is prepared when all the content of the publication is laid up so that page numbering can be given.

Then title page, copyright and cover layouts are completed on PageMaker.

PageMaker has the ability to layout data files from scanning of photos so that photos can be put in the page layout rather than pasted in. Other illustrations can be drawn with computer software and can be similarly inserted in the page layout if desired.

CONCLUSIONS AND RECOMMENDATIONS

"Of making many books there is no end; and much study is a weariness of the flesh"

Ecclesiastes xii. 12.

Desk top publishing appears to be most suitable for preparation of most caving publications at club or association level. Developments are occurring at an amazing rate and economical colour publication would appear to be a not too distant possibility.

Recommendations to Authors - The following recommendations are made for preparation of text for publishing by this method:-

(a) Do not fully justify your text. Leave it left justified only and tell the publisher how you want it justified.

(b) Tables and labels for illustrations should be on separate files.

(c) Where possible use the same computer software as the publisher for word processing.

(d) Always supply a hard copy of your text in case the publisher has any problems.

(e) Graphic images should be on separate files or as pen and ink or photographic copies, preferably at a size suitable for use.

(f) Footnotes are a problem as in PageMaker they will not appear at the same page position, so mark with an asterisk or similar. Provide the publisher with a list of footnotes referring to flagging symbols, with a request to to show as footnotes and delete your flagging symbols.

(g) Use tabbing for layout tables as proportional fonts will not align unless tabbed. Not to do so makes your publisher less than friendly.

(h) For tables consider using a spreadsheet to create the file.

(i) If possible make yourself familiar with what software such as PageMaker will do as this can also lend new ideas to your future published work.

(j) Use your word processors dictionary, and then proofread your final text.

(k) Make sure you provide all illustrations required.

(l) **Finally, get your article in by the requested deadline.**

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BREATHING APPARATUS FOR USE IN FOUL AIR CAVES.

Douglas Irvin.

ABSTRACT.

Some of the lava tunnels of the McBride Volcanic Province, North Queensland contain a lot of carbon-dioxide and cave adapted life. This device was developed to allow the continued safe exploration and study of the tunnels. A safe level for CO_2 and O_2 is proposed. The prototype is described and some preliminary results are given. Some suggestions for further development are made.

INTRODUCTION.

The lava tunnels of interest vary in length between 100 m and 1400+m. They have gently sloping silt or rocky floors and mostly walk-in type entrances. The tunnels are usually damp and sometimes the floor can be slippery. Biological collecting mainly entails crawling around the floor for hours at a time. By normal caving standards it is very easy going. Measurement of the tunnel atmosphere with a Dreager Multigas Detector has shown CO_2 levels of up to 5.7%. As the CO_2 increases the O_2 seems to decrease at a greater rate. Checks for other gases e.g. oxides of nitrogen, carbon monoxide, hydrogen sulphide, methane and ammonia have shown nil or insignificant amounts. This kind of atmosphere is called a Type II (James 1977).

Work in the tunnels has taken place in foul air, luckily without incident. If a caver were to have a problem the extra exertion required by the rest of the party could put everyone at risk. On two occasions climbing a few metres into an upper gallery has produced a panic reaction causing the person to bolt for about 100 m and then rest. Lying down to rest was not a good idea. In fact in coal mines it is against regulations to lie down because of the possible pooling of poisonous gases. This year the most important cave Bayliss was extended by 500 m and contains even worse foul air. As we were all getting older and wanted to continue to do so something had to be done about the foul air problem.

PROPOSED SAFE LEVELS OF CO_2 & O_2.

This apparatus is **solely** for dealing with moderate CO_2 levels. If other poisonous gases e.g. oxides of nitrogen, carbon monoxide, hydrogen sulphide, methane, ammonia etc. are present then self-contained breathing apparatus must be used. We have to consider only two gases:-

- CO_2.

Armstrong and Osborne (1981) proposed a safe CO_2 level in tourist caves of 0.5%. This is in line with the standard set by the American Bureau of Shipping and U.K., U.S., U.S.S.R. and N.S.W. mine regulations. These are industrial standards for day in day out work. James, Pavey and Rogers (1975) proposed a safe level of up to 4% CO_2. I think that with this type of device available a much lower level is acceptable. In anaesthetics the recommended level varies between 0.1% and 1% so that is not much help.

A maximum level of 0.75% in the inhaled air is proposed with a caution range of 0.5-.75% if hard work is involved.

- O_2.

The atmosphere normally contains 21% O_2. The effect of reduced O_2 is called hypoxia. The NSW mine regulations have a lower limit of 19%. The chart on Coal Mine Gases claims that life is threatened below 16% O_2. This is too conservative. Hypoxia can be experienced by mountaineers and in aircraft. Mountaineers are not bound by regulation and are probably not using O_2 much below 6 000 m. The regulations require pilots in unpressurised aircraft to be on O_2 above 10 000 ft. (3 050 m). For passengers O_2 is required above 14 000ft. (4 268 m). (A.N.O. 20.4). I propose a safe level of O_2 equivalent to being at or below 4 000 m with a caution range equivalent of 3 000-4 000 m if heavy work is involved.

Being at 3 000 m and 4 000 m elevation is equivalent to breathing air with 14.2% and 11.9% O_2 at sea level.

The term Sea Level O_2 Equivalent (SLOE) is proposed. It is defined as the percentage of O_2 at sea level equivalent in effect to that being inhaled in the cave. The ambient O_2 level is adjusted for the effect of an absorber (if used) and the elevation above sea level of the cave passage.

For example, in a normal cave at 3000 m measurement of the cave atmosphere with a Draeger would still show 21% O_2. Because the pressure is reduced this is the same as breathing air with only 14.2% O_2 at sea level.

Use the following formula to find if the CO_2 and O_2 levels are within limits. (See appendix for derivation of formula).

C_c	=	Cave CO_2%.
C_i	=	Inhaled CO_2%.
C_a	=	Absorbed CO_2%.
E	=	Absorber Efficiency (%).
O_c	=	Cave O_2%.
O_i	=	Inhaled O_2%.
SLOE	=	Sea Level O_2 Equivalent.
A	=	Cave altitude in meters.

$$C_i = \frac{C_c \times E}{100}$$

Is $C_i < 0.75\%$?
If so, is C_i in the 0.5-.75% caution range?

$$C_a = C_c - C_i.$$

$$O_i = \frac{O_c \times (C_a + 100)}{100}$$

$$SLOE = \frac{O_i \times [1013 - (A \times 0.1093)]}{1013}$$

Is SLOE > 11.9%?
If so, is it in the 11.9-14.2% caution range?

DEVELOPMENT.

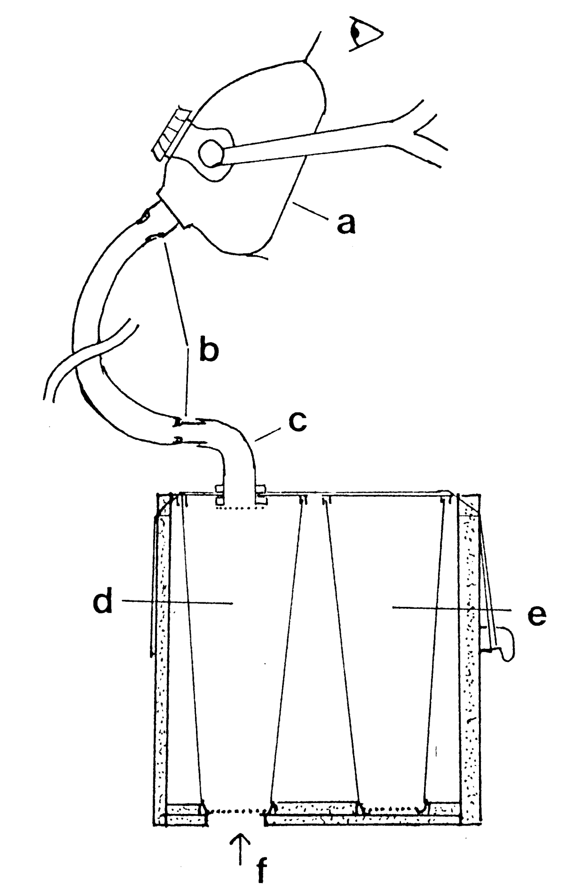
On asking the advice of the NSW Cave Rescue Group I was told "Don't go in". Notwithstanding their good advice there was a pressing need to continue the scientific study. There seem to be three ways of going about it:-

1. Self contained breathing apparatus.
2. A hookah system to feed air from outside.
3. A scrubber to absorb the CO_2.

The latter seemed to be the most practical and cost effective method. I approached Dr. Walter Stark for advice. He developed the ELECTROLUNG, a high-tech scuba system. It uses the product BARALYME to absorb CO_2. This chemical was developed for use in anaesthetics. It is manufactured by National Cylinder Gas of Chicago. It is not known if it is available in Australia. There are other chemicals available. BARALYME is a specially formulated, granulated barium/calcium hydroxide with a dye added (Dorsch 1984). As it is used up it changes color from pink to purple. The ELECTROLUNG is a closed system and BARALYME is used to absorb the 4% CO_2 in the exhaled breath.

CONSTRUCTION.

The canisters are plastic 750ml Decor brand with tight fitting lids. Woolworths sell them for $4.95. Their worst feature is that they come with 6 plastic cups and one ends up with cups to burn. A canister holds 550 g of BARALYME. A ply frame was made for two canisters held in by elastic. Two canisters are carried- one in use called "active" and the other "spare". Air can enter the active canister through the base. The spare canister is sealed. They can be swapped and in use in seconds. The frame



LEGEND.

a. CIG mask
b. Anline fittings
c. PVC fittings
d. Active canister
e. Spare canister
f. Air inlet.

Fig. 1. Mk.ll FAD (shown with empty canisters for clarity)

hangs low down below a backpack. The canister has a 50 mm hole in the bottom with fly screen mesh fixed in it. The top has a 28 mm hole with 28 mm I.D. PVC plumbing fittings fixed through it. A piece of lint serves as a filter as Baralyme gives off a stinging dust. Also in unusual attitudes a granule could go along the inlet hose and jam a valve or be inhaled. A length of Anline hose leads to a PVC T-piece. In this are some 25 mm scuba valves to control air flow. A scuba mouth-piece is used. A nose clip completes the outfit. (Figure 1.)

TRIAL.

In a hastily prepared trial the unit was able to support five cavers in fairly foul air. They were very happy to have it along and would not have been able to go into the Bayliss extension without it. The Firemans breathing apparatus they had taken in was just too bulky to use. As there was no Draeger available no readings of CO_2 levels were possible. The unit got hot and the incoming air was warm. This may be a good feature in cold caves but a drawback in the Tropics.

GENERAL CONSIDERATIONS.

In anaesthetics CO_2 absorbers are found to be 90-95% efficient. Let us assume that our unit is 90% efficient. Take the case of Nasty Cave at Undara in June 1986 where the following readings were made:-

	CO_2 %	O_2 %	CO_2+O_2 %	N_2* %
Station 1	3.6	14.8	18.4	81.6
Station 2	5.1	13.7	18.8	81.2

* N_2 not measured.

(Note that if CO_2 were replacing O_2 exactly the sum of their percentages would be about 21%). If we used our device at Station 2, 90% of the CO_2 would be absorbed leaving .51% to be inhaled. With some CO_2 absorbed the O_2 proportion would increase from 13.7% to about 14.3%. Adjusting for the 650 m elevation of the cave, the SLOE is 13.2% (or the same as being at 3530 m). In this case both the CO_2 and O_2 would be in the caution range and one shouldn't be doing heavy work.

PHYSIOLOGICAL CONSIDERATIONS.

The article by James, Pavey and Rogers (1975) gives a good explanation of respiration in foul air. The medical aspects of trekking/mountaineering are applicable to our problem i.e low O_2 sometimes combined with strenuous activity.

Cavers with heart/lung problems should not go where the SLOE level is in the "caution" range. They probably should seek medical advice before going into any foul air cave.

People who live at high altitudes are adapted to the low O_2 conditions. It has been found that trekkers and mountaineers can acclimatize as well. A daily cycle of high altitude during the day and lower altitude at night is an ideal acclimatization method. It is strongly recommended that trekkers go to altitude slowly. e.g. 5 days to reach 3350 m (Bezruchka 1981). We could be doing that in minutes. This could be a problem. It will probably inhibit acclimatization of anyone doing sustained caving.

Hypoxia's first effect is on vision. Below 18.25% O_2 (4 000 ft. or 1 220 m equivalent) vision starts to be impaired and eventually one gets tunnel vision. Cavers should take care in low light conditions as one's judgment of distance is impaired. Smokers will be more susceptible.

Mental ability is one of the first effects that can be checked. Cavers particularly doing vertical work need all their facilities. A prepared set of simple sums should be done by all the party and checked on leaving the cave. Checking them in the cave is not necessarily effective. Hypoxia is so insidious that gross errors can be accepted as perfectly normal.

In extreme hypoxia a person will sink into a blissful sleep and not wake up. Hypoxia can kill. Cavers should also watch out for Acute Mountain Sickness (AMS) some of whose symptoms range from nausea, dizziness, weakness, headaches to bubbily breathing, vomiting, staggering, confusion and coma. If anyone has any abnormal symptoms the whole party **must** immediately leave the cave. AMS too can kill. It is not related to age or fitness. Surprisingly the latest treatment for AMS is to administer CO_2.

FURTHER DEVELOPMENT.

It is hoped that other cavers will do more work with this type of absorber. From the collected data a proper design can be made and hopefully would be standardized across Australia.

An important feature is the "active" and "spare" canister system. This allows a quick change no matter where the caver is, on a rope, in a squeeze or on a stretcher. One does not want to be filling a canister from a packet in these cases. The units should be standardized in the party for added safety. Naturally all spent absorbent is taken from the cave.

I look forward to getting feedback from other cavers and by next Conference it should be properly refined. Other points to consider for development are:-

1. Cavers should be careful about foul air caves. It would be unwise to charge off with this device into foul air without knowing if it is safe. The cave atmosphere should be checked with a Draeger or similar instrument for O_2, CO_2 and poisonous gases. Trials also have to be made to measure the efficiency of the absorber over a range of CO_2 levels. The larger the canister the higher the efficiency.

2. BARALYME can absorb 270 litres of CO_2 per kg. In 5% CO_2 and with 90% efficiency 1kg should last a resting person about 16.6 hours.

3. The temperature in the canister and inhaled air has to be measured to see that it is acceptable.

4. In anaesthetics it is found that the air flow tends to go along the side of the canister leaving unused chemical in the middle (Dorsch, 1984). It could be worth while lining the canister with sandpaper to break up the laminar flow.

5. The product SODA-LIME is also used in anaesthetics. It is available from CIG under the brand name VIVALIME . It costs $29.00 for 4.5kg. SODA-LIME should not be wet as it very reactive to water. As well it is hygroscopic and in very humid conditions may lose its ability to absorb CO_2. SODA-LIME will absorb about 250 litres of CO_2 per 1kg. These chemicals have to handled with care as they are caustic.

6. SODA-LIME has the ability to "regenerate" (Dorsch 1984). Using the "active" and "spare" system, a canister may be able to be rested and reused. This would make it more economical on absorber chemical. The literature is vague on how long it should rest. Field tests will have to be made.

7. Canisters should always be completely filled. If not, in unusual attitudes a channel may form along one side by-passing the absorber.

8. A Metal canister could be used to suit more strenuous caving conditions.

9. The system could be made more water resistant to suit wetter conditions.

10. A transparent window in the canister would allow the color of the chemical to be monitored.

11. A face mask rather than a scuba mouthpiece is probably more practical. The Mk.ll model uses a CIG Respirator Mask (type 55456) which has valves built into it. The Anline fittings are a good tight fit into the mask. It is much more comfortable. In a rescue situation a mask would be easier to put on a patient. The fit around beard, glasses and chin strap has to be considered. Small leaks would not be critical.

12. The King Systems 8600B 08 (60") hose used in anaesthetics in hospitals is far more flexible than that used in the prototype. Your local hospital will probably donate some used hose if asked nicely.

13. The hose could be attached to the chin strap if coming around over the shoulder. This would stop the twisting action on the mask or mouthpiece. The hose could also go around the waist and come up the front.

14. Before taking a system underground it should be tested by going jogging with it. This may show up some deficiencies.

15. The thing has been called a Fad (Foul Air Device) until now. Is this a suitable name?

16. Graphs or tables will be developed to determine safety levels.

CONCLUSION.

This type of device should allow safer caving and more scientific work to be done. If the Greenhouse Effect goes exponential we might all be using one. There could even be designer devices.

ACKNOWLEDGEMENTS.

I would like to thank Dr.Walter Stark of Daintree and Dr. Phil King and his colleagues at the Cairns Base Hospital for their practical advice. Dr. Stark also donated 40lb of Baralyme. My thanks to members of the Chillagoe Caving Club Inc. who conducted the preliminary trial for me.

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APPENDIX

The composition of the atmosphere stays fairly constant as altitude increases. Therefore the availability of O_2 is proportional to the atmospheric pressure.

Derivation of the SLOE formula:-

Atmospheric pressure is 1013 hectopascals (hp).
Atmospheric pressure drops at 1hp per 30ft. altitude gain.
To convert metres to feet use, A x 3.28

$$\text{The drop in pressure at altitude A} = \frac{A \times 3.28}{30} = A \times 0.1093$$

$$\text{The pressure at altitude A} = 1013 - (A \times 0.1093)$$

$$\text{Proportionate drop in pressure} = \frac{1013 - (A \times 0.1093)}{1013}$$

To find the SLOE of being at altitude A the O_i has to be reduced by the proportional drop in pressure i.e.

$$\text{SLOE} = \frac{O_i \times [1013 - (A \times 0.1093)]}{1013}$$

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MISCELLANEOUS

RESULTS OF CHEMICAL ANALYSIS AND NOTCH WEIR GAUGING OF THE RAIL BRIDGE SPRING IN CHILLAGOE CREEK, NORTH QUEENSLAND, AUSTRALIA.

Les Pearson.

ABSTRACT

Over a period of six years from mid 1982 water samples have been taken on an irregular basis for chemical analysis, and notch weir gauge levels recorded at a spring in Chillagoe Creek close to the Railway Bridge.

Chemical analysis of samples has been performed by Anne Woolley, Cairns City Council Chemist, and values recorded. The levels of the various elements appear to be relatively stable and not greatly affected by the flow rates of the spring.

INTRODUCTION

In May 1982 I spent a week with Dr Joe Jennings accompanying him on his only trip to the Mitchell-Palmer area and taking water samples at every possible water source along the way. In discussion with Joe he suggested that it would be worthwhile to take samples from a spring at intervals over a long period to set a base line of data for use of scientists researching solution of limestone.

This has been done at a resurgence spring at the Chillagoe Rail Bridge on Chillagoe Creek. Here water issues up out of the last main limestone band crossing Chillagoe Creek and would appear to be draining the valley up towards Dome Rock and possibly across towards the town dump. This spring is a significant one and appears to normally contribute about half of the flow in the creek at the Rail Bridge. There are times however when the creek carries flood flows or when the creek dries up above the spring which alter this approximate balance of flows. The spring is limited in its maximum discharge by the head loss in the conduits through the limestone so that when the Chillagoe Creek is flooding the reservoir in the limestone supplying the conduit is being recharged.

Samples of the spring water has been collected from the pool in the area where the flow from the spring can be felt. This is the nearest practical source of water from the spring which issues through a crack several feet under the water surface. Care was taken to rinse the collection bottle in the spring water and cap under water surface to minimize entrapped air. Water temperature just below the water surface was also recorded on most occasions.

Flow measurements were taken with a simple notch weir to a specification obtained from the Queensland Water Resources Commission at Mareeba. Flow is measured as millimetres of water above the bottom of the notch and flow in litres per second is derived from tables from supplied by the Queensland Water Resources Department. These tables are derived from the formula as set out below.

Where Q = discharge in litres per hour
H = water depth in notch (upstream side of notch)

$$Q = 0.17556\, H^{2.48}$$

(The notch weir needs to be set well into the ground and care taken to avoid leaks around it. Also the downstream side needs to drop away so that the bottom of the notch on the downstream side is not flooded.)

All water tests made by Ann Wooley of Cairns City Council were as set out in Standard Methods for Examining Water and Waste Water, APHA 14th Edition. With several samples water showed abnormal sulphate levels and the water containers were considered to be probably responsible. The containers had previously been used for photographic chemicals and perhaps still had sufficient residues to affect results of sulphate content which is normally in the 5 to 10 ppm range.

RESULTS AND CONCLUSIONS

The results of all tests are tabulated in Table I.

From the results obtained I believe it can be said that there is a consistency in the results from chemical analysis of the water from the spring over a range of flows which vary from 2.51 to 10.24 litres per second.

Water temperature above the efflux was also consistently around 29 degrees Celcius regardless of the air or ground surface temperature.

TABLE I - DETAILS OF WATER SAMPLES FROM RAIL BRIDGE SPRING, CHILLAGOE.

DATE	TEMP C	pH	ALKALINITY mg/l CaCO3	HARDNESS mg/l CaCO3	CONDUCTIVITY uSiemens/cm	CALCIUM mg/l	MAGNESIUM mg/l	SODIUM mg/l	POTASSIUM mg/l
11-07-1982	28.0	7.10	299	296	590	111	4.60	6.50	1.10
12-08-1982	28.5	7.00	295	293	590	111	3.80	6.90	1.00
03-10-1982	29.0	7.00	298	300	-	112	5.00	6.40	1.10
23-10-1982	29.5	6.90	294	299	-	113	3.80	7.00	1.10
31-12-1982	-	7.30	297	307	575	115	4.70	7.10	1.10
13-01-1983	26.0	7.00	297	294	590	110	4.80	8.40	1.00
18-03-1983	-	6.80	287	295	610	110	5.00	6.50	1.03
02-05-1983	-	7.00	290	299	590	110	6.00	6.50	1.03
15-05-1983	-	6.90	298	303	600	115	3.60	6.50	1.09
12-06-1983	-	7.20	307	316	560	112	8.80	6.80	1.00
16-07-1983	-	7.20	311	301	560	113	4.50	9.30	1.40
25-09-1983 #	-	7.20	249	338	550	126	5.70	7.00	1.24
19-10-1983	-	7.20	298	200	520	113	4.30	8.00	1.00
13-11-1983	-	7.10	292	298	560	113	3.80	7.00	1.00
01-01-1984 #	31.0	7.10	271	315	570	120	3.80	11.80	1.40
31-03-1984 #	28.0	6.90	270	315	590	120	3.60	10.50	1.10
04-06-1984 *	29.0	7.40	181	178	390	65	3.90	9.00	1.50
28-07-1984	29.0	7.10	302	316	570	120	3.90	8.00	1.20
23-09-1984	29.0	7.10	308	328	590	125	3.80	8.00	1.20
01-01-1985	31.0	7.00	280	314	550	120	3.40	8.00	1.50
06-05-1985	-	6.80	310	290	590	110	3.70	8.00	1.20
09-06-1985	29.0	6.80	311	290	590	110	3.70	7.00	1.30
15-09-1985	29.0	7.10	291	328	550	120	3.90	7.00	1.20
26-10-1985	30.0	7.30	295	304	550	115	4.10	7.00	1.30
05-01-1986	29.5	7.30	210	227	-	86	3.00	7.00	1.20
15-01-1986	30.0	7.20	255	249	-	93	4.00	7.50	1.30
05-05-1986	30.0	7.10	315	328	-	125	3.90	10.00	1.20
27-06-1986	29.0	7.10	305	289	-	110	3.50	8.00	1.20
29-06-1986	29.0	7.10	305	289	570	110	3.50	8.00	1.00
20-07-1986	29.0	7.10	305	302	-	115	3.50	7.00	1.30
31-08-1986	29.0	6.70	294	265	-	100	3.80	8.00	1.30
16-11-1986	29.5	7.10	300	273	-	103	3.90	8.00	1.30
14-03-1987	29.5	7.50	302	320	550	122	3.70	7.00	1.40
28-03-1987	30.0	7.50	306	327	550	125	3.60	7.00	1.30
02-05-1987	29.5	7.10	316	310	550	118	3.60	8.00	1.40
17-07-1987	29.0	7.50	310	316	570	120	3.90	7.00	1.20
07-09-1987	29.0	7.40	295	316	570	120	3.90	7.00	1.30
26-09-1987	29.5	7.30	300	316	566	120	3.90	7.00	1.20
10-10-1987	29.0	7.20	295	303	560	115	3.80	7.50	1.30
24-10-1987	29.0	7.00	300	315	560	120	3.80	7.50	1.30
03-12-1987	-	7.10	291	301	-	115	3.40	7.20	1.10
04-01-1988	31.0	7.30	291	302	550	115	3.60	7.00	1.10
04-04-1988	29.5	7.60	270	276	515	105	3.40	7.00	1.10
14-04-1988	-	7.10	300	303	570	115	3.90	7.00	1.10
14-06-1988	-	7.10	291	301	570	115	3.00	7.00	1.00
28-08-1988 *	29.0	7.00	215	215	410	80	3.70	6.00	1.20

Notes : * Sample showed signs of precipitation before analysis.
Abnormal sulphate - suspect containers previously used for photographic chemicals.

MISCELLANEOUS

TABLE I (CONT) - DETAILS OF WATER SAMPLES FROM RAIL BRIDGE SPRING, CHILLAGOE.

SILICON mg/l	CARBONATE mg/l	CHLORIDE mg/l	SULPHATE mg/l	IRON mg/l	MANGANESE mg/l	COPPER mg/l	ZINC mg/l	FLUORINE mg/l	FLOW l/s
-	365	8.9	16.00	0.01	0.01	0.01	0.05	-	-
27.00	360	8.9	6.60	-	-	-	-	-	-
29.00	364	9.2	6.50	-	-	-	-	-	3.91
30.00	359	9.2	6.00	-	-	-	-	-	3.81
30.00	363	9.6	7.10	-	-	-	-	-	4.23
28.00	361	7.4	6.70	0.01	0.01	-	-	0.12	6.30
28.00	350	9.6	-	-	-	-	-	-	-
16.00	361	9.9	8.00	-	-	-	-	-	-
26.00	364	12.1	7.20	-	-	-	-	-	-
26.00	375	10.3	7.20	-	-	-	-	-	-
25.00	379	10.0	8.00	-	-	-	-	-	-
25.00	304	8.9	78.00	-	-	-	-	-	3.9
25.00	364	12.4	6.60	-	-	-	-	-	3.90
25.00	356	10.6	5.40	-	-	-	-	-	3.90
32.00	331	11.7	51.00	-	-	-	-	0.17	5.7
32.00	329	9.2	55.00	-	-	-	-	0.18	5.4
36.00	221	8.5	6.50	-	-	-	-	0.11	6.3
33.00	368	7.0	6.50	-	-	-	-	0.11	4.50
33.00	376	8.5	7.00	-	-	-	-	-	5.00
32.00	342	12.0	7.00	-	-	-	-	-	5.00
31.00	378	6.0	10.00	-	-	-	-	0.20	10.24
31.00	379	6.0	9.00	-	-	-	-	0.28	4.44
31.00	355	6.0	7.00	-	-	-	-	0.23	4.81
30.00	360	6.0	8.00	-	-	-	-	0.29	2.71
29.00	256	8.0	7.00	-	-	-	-	0.20	8.52
25.00	311	8.0	6.00	-	-	-	-	0.20	6.70
29.00	384	10.0	8.00	-	-	-	-	0.20	8.52
30.00	372	7.0	7.00	-	-	-	-	0.16	7.43
30.00	372	7.0	7.00	-	-	-	-	-	7.43
29.00	372	7.0	7.00	-	-	-	-	-	8.99
29.00	358	8.0	6.50	-	-	-	-	-	9.70
33.00	366	8.0	7.00	-	-	-	-	-	4.12
22.00	369	12.00	7.00	<0.10	<0.10	-	-	<0.10	4.44
30.00	373	12.00	7.00	<0.10	<0.10	-	-	<0.10	5.50
32.00	386	8.00	7.00	0.07	<0.10	-	-	0.22	3.71
32.00	378	9.00	7.00	-	-	-	-	0.24	3.91
32.00	360	9.00	7.00	-	-	-	-	<0.10	3.18
32.00	366	11.00	8.00	-	-	-	-	<0.10	2.88
34.00	360	10.00	7.00	-	-	-	-	0.20	3.05
36.00	366	10.00	7.20	-	-	-	-	0.27	2.48
32.00	355	8.20	6.40	-	-	-	-	<0.10	2.51
29.00	355	9.20	7.20	-	-	-	-	0.07	3.23
29.00	329	7.00	8.00	-	-	-	-	0.28	6.15
32.00	366	7.00	7.00	-	-	-	-	0.18	2.84
32.00	355	8.00	7.00	-	-	-	-	<0.10	2.51
28.00	262	7.00	9.00	-	-	-	-	0.20	1.76

My belief is that the water from the spring is controlled and limited in flow by the friction in the conduits in the limestone and is in contact with the limestone over a sufficient length that relatively stability is reached in temperature and in minerals dissolved from the limestone and surrounding groundwater.

The results are so consistent that I believe there is no advantage in continuing collecting this data any longer.

ACKNOWLEDGEMENTS

I would like to acknowledge the assistance of the Queensland Water Resources Commission, Mareeba for providing details of a suitable water gauging weir, John Barton of Queensland National Parks and Wildlife Service for providing a more permanent weir, Anne Woolley of Cairns City Council who performed the chemical analysis of water samples over the full period. Also I acknowledge the assistance of various members of Chillagoe Caving Club who obtained water samples for me on occasions when requested and even on some occasions when not asked.

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RESCUE AT CHILLAGOE.

Chris Parr.

ABSTRACT

This paper deals with the support services available to a rescue being carried out in North Queensland. I am not discussing the physical aspects of hauling stretchers about a cave as this has been done in many other publications. Rescues usually have to be carried out with the equipment and personnel of the trip.

INTRODUCTION

Chillagoe is a remote caving area by most standards, but by Queensland standards Chillagoe is close, with many Northern Australian caving areas being many times the distance. The best way to prevent a rescue is not to have an accident. If and when an accident occurs self rescue is the only practical solution. If an accident victim can be moved to a comfortable location his or her survival is enhanced. Medical help can be provided by the Royal Flying Doctor Service of Australia (R.F.D.S.).

CAVE CLIMATE

Choosing an underground camp site for an injured person could be the difference between survival and not surviving. The temperature in Chillagoe caves varies between 22 and 28 degrees. Exposure to cold (hyperthermia) is a remote possibility. Water is not generally present in Chillagoe caves and re-supply from an external source would have to be considered if a prolonged underground stay is necessary. Dry dirt floors provide the best insulation and it would be desirable to find one as night temperatures underground are lower than body temperature. Tropical thunder storms can drench a tower in ten minutes making floor areas subject to rainwater inflow very wet.

Varying surface temperatures on the limestone causes air flows in the caves to alter. This may also have an effect on the relative comfort of a camp site. The need to prevent loss of body heat is not critical as it is in temperate climates and insulation provided by overalls is usually adequate. Wet areas are subject to evaporative cooling.

SELF RESCUE

When a fall occurs and the injuries sustained are not immobilizing the following procedure is suggested:

1) If possible move the victim to an area and climate most suitable for survival.

2) This move should be made in the shortest possible time after the accident before shock and pain become apparent, this may only be 10 to 20 minutes.

3) Elementary first aid should be applied to deal with simple broken bones, sprains etc.

In remote areas leaving a person down the bottom of a pitch, in a crawl or any other inhospitable area should be avoided. A full rescue party with stretchers may take more than a day to organize. The success of moving the victim in the first twenty minutes may be critical to their survival.

MEDICAL HELP

Rendering of immediate first aid to injuries like severe bleeding, depressed rib cage and severe fractures is critical to the survival of the victim. After this initial treatment the seeking of medical help becomes a priority. At Chillagoe the first step is to go the local hospital matron (Linda Pearce) who will then contact a doctor. The hospital matron will then liaise and administer treatment and drugs.

A similar service is provided by Elders Resources from the Red Dome gold mine but the amount and variety of drugs held is limited.

A number of years ago the Chillagoe Caving Club Inc. purchased a medical kit and a portable high frequency radio. The medical kit has a number of prescribed drugs which the poisons regulations to the Health Act allows the Club's authorized officer (Alan Cummins) to control these drugs. The Health Act Regulations state:

D2.15. The Director-General may authorize in writing the obtaining, possession, sale, supply or use of a dangerous or a restricted drug by a person under the conditions set out in such authority.

'Person'- Includes a company, partnership, and any body or associated persons.

G1.01. (a) A person authorized by or under Regulation D2 of these Regulations to buy or obtain a dangerous drug or a restricted drug shall do so upon a written order in accordance with the provisions of this part.

G1.02. A written order under this part shall-
(a) be legibly written in ink;
(b) bear on the face thereof
(i) the date when written
(ii) the name and address of the person, hospital, university, institution, college, establishment, department, base, or service requiring the supply; and
(iii) the quantity and description of the dangerous drug or the restricted drug to be supplied; and
(c) be signed as prescribed by sub-regulation G1.03.

G1.03.
(f) For sale or supply of a dangerous drug or a restricted drug to the person in charge of a base or outpost established in the State by the Royal Flying Doctor Service of Australia, such written order shall be signed by a medical practitioner employed by the Royal Flying Doctor Service of Australia with his usual signature.

To actually use these drugs radio contact with a doctor of the R.F.D.S. has to be established. The portable radio has an output power of 25 watts and has to be set up according to instructions to gain maximum benefit. This radio is equipped with the standard emergency calling system which is activated by depressing the red button on the front of the radio for 30 seconds or longer. This emits a 500 hertz tone which activates a paging system at the Cairns base. An R.F.D.S. radio operator is wakened as well as a doctor. Communication is then made with the outpost station (you) and the doctor determines if a medical evacuation is required. If an evacuation is required a pilot and nursing sister are called and air transport organized. When the situation warrants the R.F.D.S. will charter any specialized aircraft.

TOURIST CAVES

When tours are being conducted for a fee it becomes the responsibility of the guides to rescue an injured person. In the case of serious illness advice should be obtained from the Chillagoe hospital or the safety officer at Red Dome mine. Both these have oxygen breathing equipment.

CONCLUSION

Medical aid is available if an injured person can be placed in a position to receive it. It was not intended to cover the physical hauling of people around inside a cave but to cover the support services. The constructing of emergency airstrips is adequately covered in the booklet in the medical kit.

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WORKSHOPS

INTRODUCTORY WORKSHOP ON COMPUTER SIMULATION TECHNIQUES FOR STUDYING NATURAL SYSTEMS.
Preliminary Notes

Paul Wilson.

THE PURPOSE OF SIMULATION

There are many reasons why it is inconvenient or impossible to study natural systems in the field. In the case of karst, as for many other dynamic systems, the time scales are too long and changes are unobservable. In order to test hypotheses, processes can be greatly sped up by simulation using dynamic models. In the field of engineering, models are very frequently used when it is too costly or dangerous to experiment with the actual hardware.

A TAXONOMY OF MODELS AND SYSTEMS

Models can be classified in four ways, as follows (Shannon, 1975, p.7).

a. Static or dynamic models.
b. Deterministic or stochastic models.
c. Continuous or discrete models.
d. Iconic, analogue or symbolic models.

The first three ways, a, b, c, of classifying models can also be applied to systems. This gives eight possible types of system to be modeled. The final classification applies to models only.

Any one of the eight types of system may not necessarily be simulated by the same type of model. For instance, the distinction between static and dynamic systems depends on whether any of the independent variables in the system is time. Often, however one of the variables in a static system can be transformed into time for the purpose of, say, plotting curves on a chart recorder or oscilloscope. A real-time model can be made analogous to a static system.

Deterministic systems are ones where all the variables have particular values, governed by the state of the system. If one or more variables are governed by a probability distribution the system is stochastic. Stochastic systems are often run as deterministic models, by replacing a probabilistic variable by its mean value.

Continuous systems have variables which are continuously differentiable, whereas discrete systems are governed by events. When continuous systems are simulated on digital computers continuous variables have to be represented by series of numbers. Digital computer models are sampled data models which are discrete, whereas analogue computer models are themselves continuous. Sadly, analogue computers are now unfashionable, even though they run very much faster than comparable digital ones.

Shannon recognizes a continuous spectrum of model types. One end of the spectrum represents models which are very similar to the real system, and are dubbed ISOMORPHIC. Models which differ from the real system are called HOMOMORPHIC. The other end of the spectrum represents totally abstract or conceptual mathematical models. Most workers in the field are content to divide the spectrum into three groups:

Iconic models - those which are created in the same or a similar medium to the original, such as architects' models or working scale models.

Analogue models - those which are mathematically comparable models created in an essentially quite different medium from the original. In a way, computer software models usually fit into this category.

Symbolic models - which are mathematical models in the form of concepts and equations.

EXAMPLES OF SOME NATURAL SYSTEMS

Most natural systems are dynamic, continuous and stochastic, and this certainly applies to geomorphology. The karst model that I have been working on fits into this category. The system is dynamic since all the variables change with time. The system is continuous since none of the variables change instantaneously. It might be thought that the start of rain is an event, thus making the system discrete, but the smallest value of rainfall rate can always be smaller, so it is continuous. There is often an element of chance, or more correctly, probability, about many of the variables, for example the incidence of joints and bedding planes in the rock, and so the system is stochastic.

Traditional geomorphology has often taken systems to be discrete, which, in my view has been a mistake. For example "the plateau was uplifted, and then the rivers carved gorges....". In fact the uplifting is usually slow and the action of the rivers continues all the while.

Ecological systems or evolutionary systems can be modeled as discrete, if the birth of an individual is used as an event - which it is, since there cannot normally be half a birth, or part of an individual.

PREPARING A MODEL

Often the system simulation is part of learning about the system. The researcher starts with a fragmentary knowledge. An early model based on that knowledge will usually reveal information, or at least, raise some questions which may prompt a line of experiment.

A model consists of three parts:

a. An operation section or process. This part has a whole variety of names depending on the academic discipline or the techniques. With some discrete systems it is called a transition matrix. The process IS the system, or at least, the system behaviour. It is an information modifier, taking input information and generating output information.

b. The input information. This can often be the initial state of the system, but may incorporate other information. It very often incorporates feedback, or information derived from the output of the process.

c. The output information. This is often the new state of the system, or may embody other derived information.

It is important, when creating a model, not only to classify the model and the variables correctly, particularly if they are of mixed type, but to identify the input information, the process and the output information.

With stochastic systems a very useful technique is the Monte Carlo technique. Where an input signal (a trigger, or driving function) is made to be random. The random signal is fed into the process for a length of time to see if the output stabilizes.

I am using the Monte Carlo method to simulate random rainfall, rock jointing, and other variables to see if my ideas about how tower karst develops will generate a stable tower shape. The resulting shape is checked against some typical samples such as Mount Etna at Rockhampton or the Royal Arch at Chillagoe.

A WORD ABOUT PROGRAMMING LANGUAGES

Choice of programming language can get quite emotional as most people have their favourites. This a personal view only. FORTRAN is a traditional medium, since it has very powerful mathematical routines, although I have never used it. BASIC is often used, but I believe that its value is extremely limited, because of slowness and lack of structure. Many people are using C now but it is not really designed for simulation. MODULA 2 is probably the best option, but I use PASCAL, and Borland TurboPASCAL is undoubtedly the best package for PC's. There are also many proprietary software simulation packages on the market.

REFERENCE

SHANNON, R. E. (1975). **Systems Simulation: The Art and Science.** Prentice-Hall.

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WORKSHOPS

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