AUSTRALIAN SPELEOLOGICAL FEDERATION INCORPORATED

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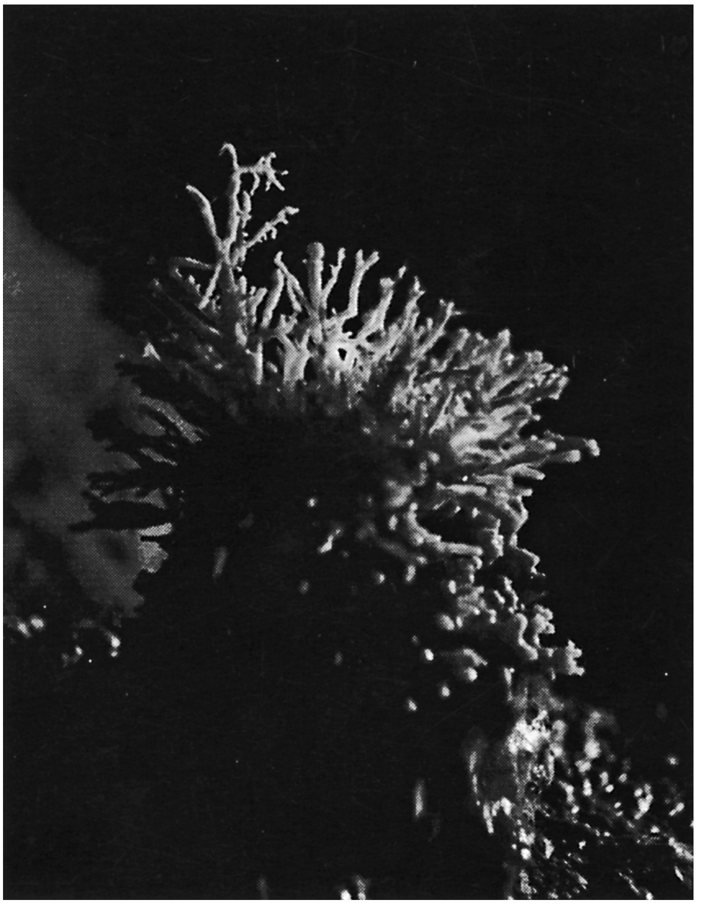

Quorn, Flinders Ranges
South Australia

29th March - 3rd April
1997

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THE ART OF COMPUTERISED CAVE MAPPING

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For the last five years all my cave maps have been prepared and printed entirely with a computer and exist completely as computer CADD files which I can modify and print from as required. But getting a map to that stage involves several steps and initially spending a significant amount of money. Here I will describe the process involved in producing a cave map via a computer (See Figure 1 for a summary of the steps).

First survey your cave

This involves a team of 2-4 people, who use tape, compass and clinometer (and other optional devices) to survey a base line through the cave and to locate points that assist the sketcher in drawing a picture of the cave. The survey is the mechanical part and necessary to maintain accuracy of the sketch and the overall map. However, the important job is the sketching (to scale) of the wall outlines, floor and roof detail, cross-sections etc. This requires a certain artistic flair, supported by rough measurements.

The techniques and art of the physical survey could fill a book (and have done so) and I will not go into that here. Short books on the subject have been published by both the NSS and the BCRA. If your club library does not have one perhaps you should talk to your librarian.

Computerising the survey data.

There is now a good range of cheap or even free software available for converting cave survey data to co-ordinates. These allow you to type in your survey data (station names, length, bearing etc.) and then convert that to a set of grid co-ordinates which can be accurately plotted (no more playing around with ruler and protractor). The better ones will also make automatic adjustments for magnetic declination and instrument corrections, and will adjust loops for misclosures. They will then display the final survey plan as a line map on the screen. This allows you to check for gross errors (such as a back bearing entered as a forward bearing). They may also let you display side views (profiles). They will finally print the survey lines in both plan and profile views for you at whatever scale you want, along with station names, a scale bar, and other extras you might ask for.

Generating grid co-ordinates.

Data entry: First enter details of survey team, date, and instrument corrections. Then type in the survey data using the data entry part of the program. You will typically enter station names (from & to), length, bearing (fore or back), vertical angle, floor and roof height and wall distances, and possibly comments describing what object you used as a station. Print this out and check it carefully against the original. Fix any typing errors. You also enter the grid co-ordinates and elevation of any known stations (typically the tag at the entrance), or you can let it use 0,0,0 as a default.

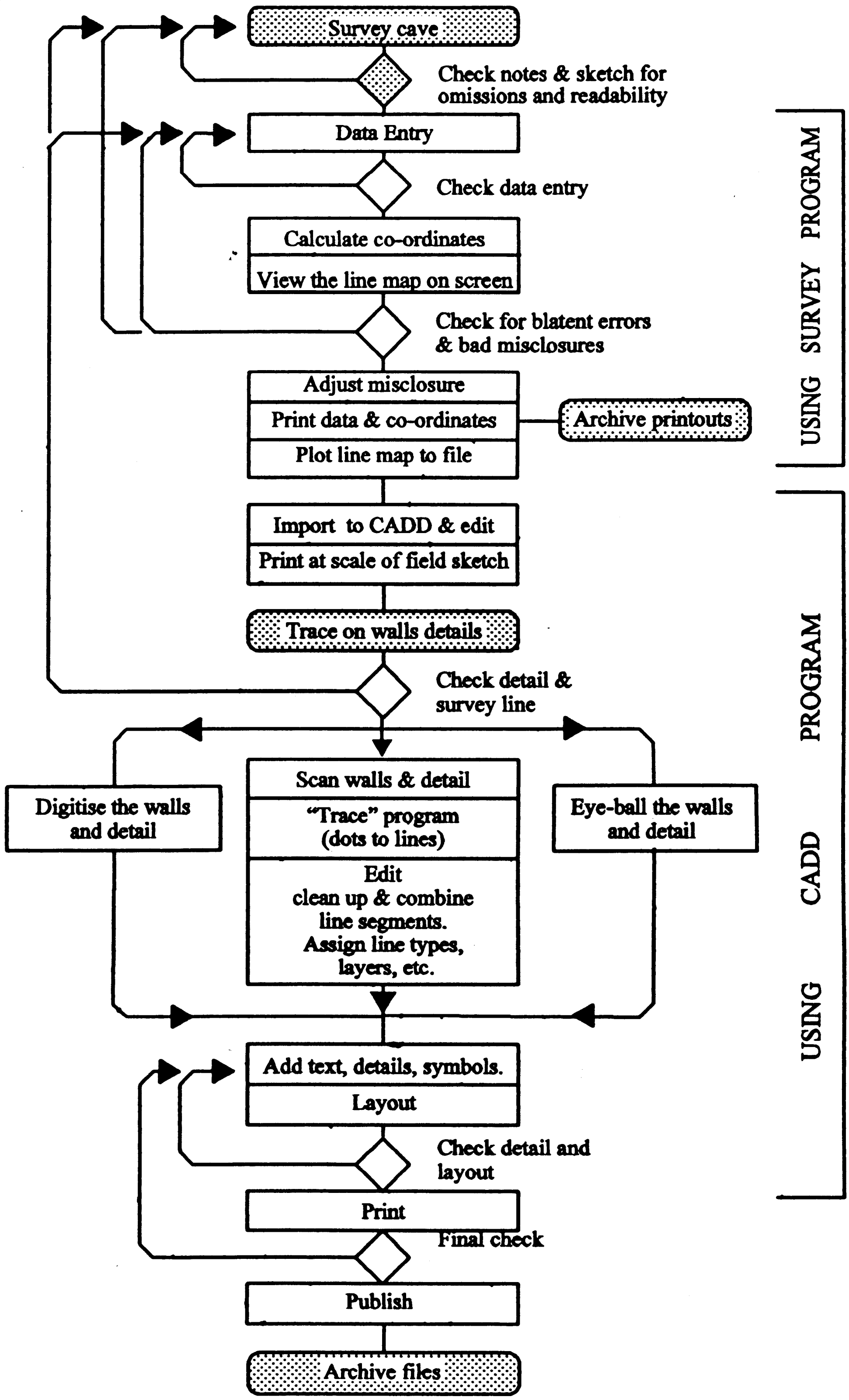

Figure 1: Steps in making a map.
Shaded boxes are non-computer activities. Diamonds are check points.

Reducing the data to co-ordinates: The program should do this automatically and will give you a list of x,y,z co-ordinates for each survey station (i.e. eastings, northings and elevation). It may also pick up discrepancies between fore and back sights, misclosures, and "hanging" chains that do not connect to the main survey (perhaps you miss-typed a station name?). It will probably also give you a total length of survey line - which is an approximation to the "length" of your cave - and the extent of the cave, including its vertical range.

Adjusting misclosures: The program will offer to do automatic closure corrections, but don't do that yet. First, inspect the results (see below) then come back to this step. You may be able to fix some of the errors and re-calculate the co-ordinates to eliminate the problem. Adjusting for misclosure simply spreads the error over adjoining stations so it is less obvious, and it is then easier to fit the base line to your field sketches. But the error is still there, and the adjustment may well be moving accurately located stations to less accurate positions. Automatic closure adjustment does not "fix" the error, it merely hides it. But if you main objective is just a picture of the cave this is probably OK.

Viewing and plotting the survey lines.

The program should let you view the survey on the screen as a line map (or print off a copy). Check it against your field sketches. Look also for major misclosures in loops where a chain of survey legs joins back onto itself, or into the main survey at another point. Minor discrepancies can be adjusted for by the software, but if there are major errors check first that the data has been entered correctly. You may have to go back to the cave and resurvey that part.

What constitutes a "major error" depends on your own level of pride, and also on the intended use of the map. Most cave maps are just done to give people an idea what the cave looks like, or to help in underground navigation - in which case a few metres error isn't going to bother anyone. But if the intention is to dig an access tunnel into the back of a tourist cave, or to make a connection between two nearby caves, or to blow up parliament, then better accuracy is needed. As a rule of thumb, if the error is less than 1% of the loop length, then you can go ahead and adjust it out of sight.

Most of the better programs will let you rotate the view and look at it from the side as well as above. Rotating it as you watch is fun, and gives you a good feel for the 3-dimensional shape of the thing.

You will probably cycle through the calculate-view-correct-adjust steps several times until everything looks OK.

Adding details to the map with CADD

The cave survey program should let you plot the stations and survey lines as both plan and side views, along with title blocks and scale bar etc. But you only get the skeleton formed by the survey line - adding the walls and other detail is another matter. Most cavers go to manual drafting methods here, drawing in the detail by hand and adding hand lettering or Letraset etc. But using a CADD[1] program makes life a lot easier - albeit a bit more expensive.

[1] CADD = Computer Aided Design and Drafting.

In CADD any mistakes can be removed at the press of an *Undo* button. You can quickly add and move north arrows, scale bars, text etc around to get the most pleasing layout. You can change the shape of a wall by grabbing a control point and dragging it about on the screen. Newly surveyed passages can be merged in (from separate files, or directly - as shown below). If you are doing an area map you can suck in the wall lines from a series of pre-existing cave files and position them according to their 'real-world' co-ordinates (assumes that in the co-ordinate calculation and align stage you used actual AMG grid-references - but even if not, you can still pick the cave outlines up and drop them at the approximate location.). Figure 2 in my paper on the Mt Eccles caves in the *Vulcon Proceedings* started that way - each of those little cave silhouettes was originally a separate full scale cave map.

The key to efficient CADD work is to organise your data into "*layers*"; the electronic equivalent of multiple sheets of tracing paper - you can 'hide' or 'display' layers at will or do global changes to them such as changing the thickness of all lines in your 'Walls' layer. Put the grid and traverse lines on separate layers & hide them - you can redisplay them again if you need them for reference. Have a 'TEMP' layer for construction lines and text messages to yourself (such as a reminder list of which layers should be hidden before plotting !) If you think you might be plotting two versions at different scales you might want two text layers, with different sized lettering - display whichever one is relevant before plotting. If there is a special cave passage that you do not want the great unwashed public to find out about you can put it on a separate layer and only plot it on versions for your washed (?) mates. This is also useful if you want to add a location diagram for club records but not for publication - one of my Vulcon map files had a hidden layer that showed the relation between a known cave and one I wasn't talking about ! It is printed in the version held by VSA.

Only one layer is active at any time, and anything you draw goes on that. Any editing actions (e.g. erasures) will only effect the current layer - unless you switch on an "*All Layer Edit*" mode.

A typical set of layers which I use in my cave maps is given here. The colour is used to help see what is what on the screen (they all plot as black), a * indicates a layer which is usually hidden when printing the map.

TEMP * (construction lines, messages, & misc. things)
Grid * (normally only in the early stages)
Survey lines * [Dark Red] (as imported from the Cave Survey program)
Walls [Magenta]
Sections
Detail [Grey]
Text [White, note, I use a Black background]
Fill & hatches (these are easier to manipulate if on a separate layer)
Construction lines for flood-fills & hatches *
Surface details (sometimes you might want to see these, sometimes not)
Water [Blue]

An alternative to CADD programs are "Draw" or "Paint" programs (referred to here collectively as DRAW). These are cheaper, but less satisfactory. The problem is that they are oriented to free-hand sketching or the production of text and diagram displays such as sales charts and brochures. They are good for artistic layouts, but fall down when it comes to precise location of points (essential for a cave survey) and sophisticated editing of objects. In a DRAW program you locate an object (say a survey line) by moving the mouse pointer and clicking (approximately) where you want it on the screen. In CADD you can, instead, type in the actual co-ordinates in real-world units or an angle[2] and distance from the previous point. In CADD you can also *"snap"* a new point accurately to an existing point or object (essential if you want a closed cave outline that you will later fill in for a silhouette effect). DRAW programs are better for fancy text effects, such as bending a line of text to follow a curved wall line. The fill patterns in DRAW programs look better, but suffer from the fact that they are predefined dot patterns and cannot be enlarged or rotated to suit the scale of the drawing. The cheaper DRAW packages do everything as a "bit-map", i.e. in dot patterns rather than lines with the ends defined as co-ordinates. This means they cannot be easily scaled to larger size without getting nasty jaggy effects.

But the best part of CADD is the editing and management of objects. You have a sophisticated array of tools for selecting sets of objects (in DRAW building a selection group is more tedious). CADD lets you iteratively add and subtract objects from the selected group, and also set filters so the selection process will only effect (e.g.) all straight-line objects that are coloured red and in the "WALL" layer. Having done that you could then remove from the selection any that have a specific line type and then do something with the remainder.

Transfering the survey line map from the survey program to CADD.

Tell your survey program to plot the line diagram using a HPGL format (i.e. tell it you have a pen plotter - they all use HPGL), but plot **to a File**, not to paper. If the survey program can export in other CADD readable formats (such as DXF) you should go that way and jump straight to the next step. My survey program (SMAPS) only knows HPGL, which is why I am describing that way in detail.

Before plotting the file - set the program's plot options so that as well as the survey lines and stations it plots a grid of crosses at (say) 10m intervals - you will use these for control later on. If it has an option to plot different parts of the map, or different cave levels, in different colours this is useful, but do **not** use dot or dashed line types if it offers them as an option. Each dot and dash will go across as a separate line object, which makes for a big file and complicates things when you get inside CADD. Select a plot 'scale' that approximates the intended final scale or larger - the larger the better from accuracy point of view[3]. Select a "paper size" big enough to hold the whole plot in one go. (A0 is pretty safe !) This is just to ensure that the program does not split the plot over several "pages", which confuses things later on !!!

You may also want to plot one or more horizontal views to other files to assist in construction of projected elevations.

Importing the survey line file to CADD.

How you import the plot file depends on your CADD program. My CADD program, Generic Cadd, has a separate program that reads a HPGL format file and converts it to CADD file format. I think most (decent) CADD programs can suck in HPGL; they all can read DXF format (if they can't, don't

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[2] Angles in CADD are confusing to cavers. They use the mathematical convention of measuring anti-clockwise from east - we are used to bearings that go clockwise from North !
The conversion is: **Angle = (90 - Bearing)**.

[3] HPGL has a theoretical plot accuracy of 1/1000 inch, so plotting at 1:1000 means all locations are rounded to the nearest inch.

buy them). If you imported via HPGL use the grid crosses as a guide to re-scale the drawing so that 1m = 1m (i.e. a "Real World" scale of 1:1). Tidy this up in CADD - removing any unwanted lines and text that the survey program insisted on including. If your survey program plots different parts of the map in different pen colours you might want to use those colours as a basis to select and shift the objects to different CADD "layers".

Adding the wall detail.

From CADD, print the survey lines & grid crosses (on paper this time) at whatever scale your field sketches are drawn at. This requires a plotter, or an appropriate printer driver for your CADD program - Windows based CADD will just use the windows drivers, but sometimes you can get better results from third party drivers. Depending on the size of the cave and scale of your sketches you may have to plot several sheets. Having an A3 size (or better) printer or plotter is a distinct advantage here[4].

We now go old-fashioned. You put your field sketches under the plotted sheet (on a light table, or taped against a window, or plot onto tracing paper if your printer can handle that). Manually trace off the wall outlines and any other detail that needs to be accurately located. This is just an interim version, it does not have to be tidy (unless you intend using a scanner - in which case your fingerprints will also get scanned). Trace any cross-sections also. Note, this works best if you used a ruler and protractor in the cave to assist in accurate sketching. This step is essentially the same as what you would do in the old non-computer method.

Getting the wall detail into the CADD program.

You have to make a decision here as to how much money you want to spend and what hardware is most useful to you. The alternatives are using a digitiser, a scanner, or just eyeballing it. Digitisers and scanners are expensive, but they are only one (albeit essential) step in the process. If you have access to one at work you may be able to use it at work or borrow it for the weekend. Perhaps your club could consider buying one.

(a) Digitising it: Go out and buy a Digitiser Tablet. But first make sure that your CADD program can USE a digitiser (and THAT model of digitiser). Some cheap CADD programs (and most DRAW programs) only use Mice; others claim to know about digitisers but only use them as an expensive mouse substitute. If you are running Windows you will need a WINTAB driver - with luck it will come with the tablet when you buy it (ask first).

What you are looking for is the ability to "*align*" the drawing on the tablet so that as you move the tablet pointer the program converts the position of the pointer to the real-world co-ordinates of your CADD file.

Put your outline map on the digitiser tablet and tape or weigh it down so it cannot move. "Align" it to the CADD drawing using reference points of known co-ordinates (the grid crosses, or survey points at diagonally opposite corners of the drawing). Your CADD manual will tell you how this is done.

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[4] I do not recommend the small desk-top pen plotters; they are very slow, and the standard felt-tip pens produce lines that are too thick for detailed work. If you want colour plots get one of the new colour bubble-jets (Canon has one that can print on A3).

If you are converting someone's pre-existing map to CADD this is where you start. Align it using the scale bar as reference, and also digitise the north arrow as well as everything else and use those as a guide to rotate the drawing to north inside CADD.

Select an appropriate layer, line type, colour and line width and start digitising (tracing) the lines on your drawing into the CADD file. For cave walls you will use a '*curve*' line rather than a series of straight lines[5]. This involves starting at the end of each wall segment and working along it clicking the puck[6] button on the line whenever there is a bit of a bend. Some programs allow you to hold a button down and just move the cross-hairs along the line; the program puts in control points wherever it thinks they are needed - usually a lot more than you really need and so it makes for larger files.

(b) Scanning it: Can't afford a digitiser? Buy a scanner ($500+ for an A4 flat-bed) or use a scanner service at an office services shop (about $5? for each A4 sheet, plus extra if you need it converted to a special format). As with a digitiser, make sure that your software knows how to talk to the hardware or can import the resulting file formats from someone else's scanner.

This is a bit cheaper (if you do not cost your time) but less satisfactory. The output from a scanner is a bit-map, or raster data (lots of little dots). You have to run this through a "trace" program - which you have to buy[7], or perhaps the office shop will have one and charge you to use it. It makes decisions as to what groups of dots represent lines and generates a vector file of line segments which can then be imported into CADD (via DXF or HPGL in the same way as you imported the survey line map). You then have to tidy up the scanned version within CADD.

I have only done this once (in 1990), and then went and bought a digitiser !!!

The problem is that you have to spend a lot of time tidying up. The 'trace' program will often split what should be a single straight line into a series of shorter line segments, and you will have to convert all those lines to whatever layer, line-thickness etc you want to use in CADD. Curved walls will end up as oodles of very short lines. You cannot move or edit a cave boundary line easily if it is a lot of separate segments (whereas if you digitise it using a '*curve*' line type you can pick up or change the whole curve in one go). It might prove easiest to redraw a new line over the top of the scanned version (on another layer) but that is essentially what you are doing with a digitiser. You will then need to re-scale and rotate the drawing to face north - using control points of known co-ordinates as a guide.

Mind you, the time spent in editing the scanned file, might not be too much more than that in digitising a very complex map from a tracing. And you can do other useful things with scanners (scanning photos, text recognition etc), but not much else with a digitiser (except use it as an expensive mouse).

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[5] I prefer '*spline curves*' to '*bezier curves*' as they are easier to edit.

[6] A ***puck*** is the tablet equivalent of a mouse - it has cross-hairs and buttons. Some tablets use a pointed pencil shaped thing instead.

[7] ***Corel Draw*** comes with a *trace* program built into it.

Note, I am a bit out of date here. Scanner software may have improved in recent years, so talk to someone who uses scanners a lot and has been importing the data into CADD. If the "trace" programs now link the line segments into a curve or other compound object that can be manipulated as a single unit that would help a lot.

(c) Eyeballing it: Can't afford a scanner? Use your mouse as a cheap-skate alternative. When plotting the base-line map, include a fairly close pattern of grid crosses. When tracing the wall detail onto the plot, pencil in the grid also (join the crosses).

Now you sit in front of the CADD (or DRAW) screen with the mouse, and eyeball in the walls and other detail using the grid and survey lines as a visual guide. It is slow and not very accurate but it is cheaper than the alternatives, and if your field sketches are pretty ratty anyway the loss of accuracy may not matter. Mind you, if your field sketches are ratty your eyeballing will probably also be ratty! It helps if you have a good graphics bio-computer mounted behind your eyes, but there was a lot of variation on that production line and they don't sell upgrades. Accuracy will improve a bit with practice but, as with sketching, the skill is largely innate.

Now use CADD to add text, symbols and other details.

Now add text, pre-defined symbols for stalactites etc, fancy North arrow, your club logo, ans so on. You need to decide fairly early what scale the final drawing will be plotted at, as that determines what size letters and symbols you use[8]. Do a test print with just a few symbols and text lines to see what it looks like. An alternative is to re-scale the whole drawing to the final scale - a 2mm letter is then drawn as 2mm. With a DRAW program you may have to do that. The disadvantage of that is possible future confusion when you come to merge two adjoining caves (at different plot scales) or adding new passages. I prefer to do everything at "real world" scale.

This stage can be a bit tedious if you have a lot of floor detail (such as rubble piles) that needs hand drawing with the mouse, but it is great for the text side of things - my hand lettering has always been abysmal and Letraset takes ages. You will only get up to speed after a fair bit of experience in the CADD package you use. If you make a mistake just press the Undo key. No worries about spilled ink !

Cycle through a series of test plots and editing stages.

Up till this stage it has probably taken longer than drawing the map freehand would have (assuming you can do neat hand-lettering). But from here on CADD comes into its own. Any mistakes can be removed at the press of a button. You can take pre-defined symbols from a library and place them with a single mouse click. You can play about with the layout - moving things about to get the best look. And if there is a major new discovery in the cave that runs off the edge of the map sheet, you can add it in with minimum effort instead of re-doing the whole drawing from scratch. Soon we will be able to buy digitised versions of the topographic maps, and import surface contours and other info into the cave map.

[8] If plotting at 1:500, a 2mm letter will need to be 1000 mm high in "real world" scale !

Finishing up.

Print the final map. Spot a last-minute spelling mistake, fix it, and plot again! Send it off to the publishers or whoever is going to use it. Archive your survey data & sketches with your club records. Photo copy the original sketches & field data (complete with mud-stains). Also give them a printout of the entered data from the computer (which is more readable but may have data entry errors !!).

Archive the data and CADD files and store in a safe place. Some day soon you will be e-mailing the CADD files and the survey data to your club records keeper.

Some books on cave surveying

Brian Ellis: Surveying Caves. *British Cave Research Association.* (Out of print?)

Brian Ellis: An introduction to Cave Surveying. *British Cave Research Association.*

George Dasher: On Station. *National Speleological Society.* (USA).

?? The Art of Cave Mapping. *National Speleological Society.* (USA)

(I have not seen the USA ones yet, but have them on order)

See also the **ASF Cave Survey and Map Standards** document, which is on pages 18-1 to 18-20 of the *Australian Karst Index*.

CAVE GATING

An integral part of a cave management plan

Heather Jefferies

Speleological Research Group of Western Australia

1. INTRODUCTION

The question of whether or not to gate a cave has historically proven to be a contentious issue, and one which concerns both cave users and cave managers.

1.1 Visitation pressures on most well-known caves have increased over recent years, and this trend is expected to increase as the public's attention is focused upon caving through cave education programmes set up by various land managers (such as the Caveworks "Ecomuseum" at Margaret River, W.A.).

1.2 "Adventure Caving" by both commercial and non-commercial groups is an activity which has also seen a great increase in the last 10 years. This also focuses public awareness upon caving experiences outside of the range of guided trips presently offered by Land Managers.

1.3 Cave gating must be seen as only one part of an integrated cave management plan. Gating may be undertaken for a variety of reasons. Prior to the formulation of any cave management plan involving the gating of a specific cave, equal consideration must be given to both sides of the cave gating argument.

2. WHY GATE CAVES?

2.1 Principally, cave entrances are gated to limit the intentional and the unintentional damage which inevitably occurs when there are no limitations on visitation of a site. "Intentional" damage considers acts of both vandalism and indifference. "Unintentional" damage considers the damage that occurs by accident, and by those uninformed about cave environments and requirements. Accidental damage is an inherent quality of even the most cautious and experienced of caving groups.

Damage within a cave may occur to:

i) formations
ii) specific fauna and their associated ecosystems, and to
iii) the cave environment itself.

The unique nature of caves presents special problems with respect to any potential or actual damage which may occur:

i) Formations sometimes take many thousands of years to form; damage may therefore be irreparable, at least on human time scales.
ii) Fauna and their ecosystems survive within caves at a tenuous level; even trivial damage may upset the fine balance, disrupting ecosystems and endangering fauna.

iii) The cave environment is the sum interaction of a number of different factors (including air and water flow, humidity, temperature, etc). Even the most innocent disruption to one aspect of the cave environment (such as the gating of a cave interfering with cave airflow, or the excessive tramping of a mud floor) may potentially result in a devastating and widespread effect upon the whole cave environment.

2.2 The gating of a cave (or cave section) may be a logical step in the management of a specific cave. Accordingly, gating of a cave (or section of a cave) may be appropriate if the cave:

i) possesses significant decoration or features, which are vulnerable to damage from open visitation.
ii) possesses fauna deemed significant, and which are vulnerable to damage from open visitation.
iii) environment is assessed as fragile, and vulnerable to damage from open visitation.

In these cases, the gating of a cave or section may be appropriate, and should be considered if other cave management procedures would not, or have not been successful in preventing such damage.

Caves may be deemed capable of supporting limited visitation. Implementation of concurrent alternative cave management processes (for example, track-marking, interpretive sign posting etc.) can facilitate minimisation of the impact of limited visitation. In these situations, the gating of a cave may present a sound means by which visitation numbers can be limited. Gating will facilitate cave use in "a manner and quantity consistent with the preservation of the resource". (1) Regular assessment of the impact of such visitation should then be implemented (see sections 4.6, 5.4), the results of which may enable alteration of visitation numbers accordingly.

These following reasons for gating caves are secondary arguments:

2.3 Caves, by their nature, present a potentially dangerous environment. The very nature of the features within a cave present risks to cave users. Mazes, vertical pitches, water, loose rocks, and CO2 present potential hazards. It then follows that cave gating (as one aspect of an integrated management plan) may then be advisable in order to decrease the risks presented to inexperienced cave users.

Cave gating, and the regulation of visitation through, for example, the permit system already in place in the Leeuwin-Naturaliste National Park, is one method by which to ensure that groups entering a cave possess the specific skills required for each individual cave (for example, possession of vertical roping skills, an appropriate degree of caving experience, etc). In this manner, gating allows regulation of the "**quality**" of the cave user.

2.4 Gating of caves which may present a potential risk to cave users, and the regulation of access to these caves ,may be seen as a form of risk-minimisation or risk-prevention by the land managers. As such, they may in some part decrease their liability should a caving accident occur.

2.5 The gating of caves, and the regulation of access, would allow archaeological/scientific research to be conducted relatively uninterrupted, and without intentional or unintentional interference.

2.6 Cave gating facilitates and enhances the effectiveness of a "user-pays" access system which is capable of generating funds. All funds from the Permit System currently in place within the Leeuwin-Naturaliste National Park are utilised specifically for cave restoration and management.

3. WHY NOT GATE CAVES?

3.1 Cave gating may be unnecessary. Gating will not significantly decrease the risk to cave or cave user if:

i) the cave does not possess valuable or vulnerable decorations/ fauna/ ecosystems/ environment.
ii) the cave does not currently receive significant visitation. (This may be a function of the location of a cave, how conspicuous the cave entrance is -including the degree of bush cover present, and the degree of public knowledge concerning the cave.)
iii) the cave does not possess a significant risk to cave users.

3.2 Effective gating of a cave may be too costly. Gating the entrances of many caves could be expensive exercises in logistics. The limited management funds available may be better used implementing other cave management strategies.

3.3 Gating the entrance to a cave may potentially restrict airflow within the cave system. This can result in a marked change in cave temperature pattern and in this manner alter the cave environment. Ecosystems may accordingly be altered.

3.4 The gating of a cave may be counter-productive. It may sufficiently provoke some individuals as to encourage them to vandalise or remove the gate. The cave may be liable to suffer as a result of these actions. In this form, gating may serve to <u>increase</u> visitation to a cave, and therefore in itself, gating presents a potential risk to a cave.

3.5 Gating may be considered to limit the rights of the individual to visitation of specific caves. (In actuality, as in the Leeuwin-Naturaliste National Park, this right is limited by Permit Systems already in place.)

3.6 A cave gate is by its nature an unnatural structure; thus gating can be seen as an intentional "vandalism" of a cave; an act which may potentially damage the cave entrance, as well as the fauna and flora resident there.

3.7 Cave gating will limit (unofficial?) group access to a cave. Commercial groups may consider that they may suffer financially as a result of this action.

3.8 Gating may potentially limit access to part-time cave occupants such as birds and bats.

4. CAVE GATING AS AN INTEGRATED PART OF A CAVE MANAGEMENT PLAN

Cave gating is certainly not the only, and often not the most appropriate form of management strategy which can be implemented to protect a cave and its environment. There are many alternative management options available which indeed may be more effective. Gating is viewed by some individuals as prohibitive, and as such, alternatives to gating may be considered more "user-friendly".

4.1 Appropriately based interpretive signs are essential in any cave management plan. Placement of these signs is just as important as their content. Placement inside a cave can serve to produce a "conspiratorial" attitude of caring for the cave. Inside placement also ensures information is supplied to caving parties at relevant points in the cave, and thus maximises the effectiveness of such signs. Conversely, interpretive signs outside a cave may be detrimental in that they:

i) draw unnecessary public attention to the cave
ii) may be inadequately read in the rush to "get in"
iii) may be forgotten in the course of the trip
iv) may provide a challenge to some individuals (the vandals)

As mentioned previously, alternative management strategies may be <u>more</u> effective than gating, as is the experience in Hollow Hill cave in New Zealand - in this cave, rather than gate the entrance, interpretive signs have been placed at a position a considerable distance into the cave, but at a position immediately prior to a section where mud poses a risk to formation. This sign alone has proven extremely effective in co-opting cave users to protect the valued decoration from the effects of the mud.

4.2 Appropriate track-marking, which is informative yet aesthetic can reduce or prevent visitation to sensitive areas, whilst not detracting from the cave experience.

4.3 Some form of regulation of access (numbers and quality of cave users) may be essential in a Cave Management Plan. This system of regulation can be on a small scale, for example, the controlling of a single cave, or on a large scale; for example, the Permit System of the Leeuwin-Naturaliste National Park.

4.4 Proximity relays at the entrance of a cave may be an effective and less costly alternative to gating. However, unless these relays are set to provide only a visual and/or sound deterrent to the undesired cave user, such a system would require the proximity of some form of supervision.

4.5 Gating of a cave cannot be seen as a management strategy in itself. Rather, it needs to be conducted as part of an integrated management plan. Furthermore, once gated, a cave inevitably requires that further management measures be implemented, for example, to direct traffic away from vulnerable areas. Gated caves still require some system in place to decide who, and how many people gain access to the cave.

Experience in other parts of the country suggests that gated caves are most effective when they are in close proximity to some form of supervision (for example, in the Jenolan Caves region). This serves as a deterrent to individuals to dismantle/remove/vandalise any gate (such as has occurred at Tantanoola Lake Cave, S.A., a rather isolated cave where vandals drove off with gate attached), and also allows a degree of supervision of the sites.

4.6 Once gated, the management plan for a cave must include regular Limits of Change surveys in order to assess the effectiveness of gating and other management plans. According to the results of such surveys, strategies may be altered, discontinued, or commenced as required. Visitation numbers may be altered in accordance with results.

It goes without saying that in order for a Limits of Change survey to be relevant, the appropriate cave inventory and survey must be conducted prior to gating, in order to provide baseline data.

5. CONSIDERATIONS PRIOR TO THE GATING OF A CAVE

Each cave must be considered on an individual basis; furthermore, the gating of a cave must be considered for its effects upon other caves within the region – for example, how the gating of a particular cave may effect visitation patterns of other nearby caves.

In any region considering an overall management plan which includes the gating of some caves, gating priorities must be set:

5.1 SETTING PRIORITIES

* Which caves are the most valuable, and which of these are most vulnerable to visitation? (Cave surveys and inventories will provide this data.)
* Which of these caves receive the highest rate of casual visitation? (Visitation surveys will provide this data.)
* Which caves are already somewhat protected by their location, or their inconspicuous nature?
* Which caves in the region provide the most significant risks to cave users.

5.2 CONSIDERING INDIVIDUAL CAVES

* Is it logistically possible to gate the cave?
* What are the management objectives for this cave, and will gating meet these objectives?
* Would other management strategies be more effective for this cave?
* If gated, what additional management strategies will need to be implemented?
* Will gating adversely affect the cave environment or ecosystems?
* Will installation cause significant damage to the cave in any way? (And will the benefits of a gate outweigh this damage?)

5.3 GENERAL CONSIDERATIONS

* Is there enough money to gate the cave(s) required?
* Are the gating priorities for the region clear?
* Has the management body (in this case, CMAC) approved the gating procedure?
* Who will construct and install the gate?
* Who will conduct maintenance once the gate is installed?

5.4 FOLLOW-UP

As mentioned previously, regular Limits of Change surveys will be required after a gate has been installed in order to assess the effectiveness of that specific intervention, as well as the other strategies implemented within a particular cave.

6. PROCEDURE FOR THE LOCKING OF A CAVE

i) Gather all available data on the cave, then if necessary:
ii) Conduct a cave inventory and survey, and a casual visitation survey
iii) Formulate clear management objectives for gating the cave
iv) Outline the expected gating impact upon the cave
v) Submit a written application (outlining i & ii) to the local cave management authority, (and/or interested parties such as Caving Clubs)

vi) Parties such as Caving Clubs may then make relevant proposals to the appropriate management authority
vii) The management authority recommendations are then submitted and acted upon.

ALTERNATIVE PROCEDURE

i) The management authority canvasses clubs for suggestions on gating priorities, or concerning the gating of a specific cave.
ii) These suggestions are brought back to management authority and the decision is made at this time.

RECOMMENDATIONS

1. Before considering the gating of a particular cave or the setting of gating priorities by the management authority, background data with which to work must be obtained. It is strongly recommended that the management authority consider obtaining the services of groups or individuals, paid or unpaid, to conduct the necessary surveys ie.:

   i) casual visitation survey
   ii) cave survey and inventory

   Without this data forming the basis of decision making, any action with respect to cave gating will be uneducated and amateurish, and may result in unintentionally causing <u>more</u> damage to a cave(s) within the region.

2. By the very act of gating a cave, it is suggested that to breach a gate is trespass of some form. It would also be an act of vandalism. Without the appropriate penalties for such actions, gating may be ineffective. Provision of some form of supervision for the gated caves of the region would potentially increase both the effectiveness of cave management strategies, and decrease the incidences of vandalism (both to gates and to caves themselves). Therefore, it is strongly recommended that prior to considering further gating in the region, the management authority initiates appropriate penalties for cave / gate vandalism, and also strongly considers appointing a full time ranger whose duties are dedicated specifically to caves.

3. An entrance impact study must be conducted before gating any cave, in order to assess the impact of the gating not only on the cave in question, but also <u>on all the other caves within the region</u>.

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POTENTIAL WEALTH AND GREAT OPTIMISM:

MINING BAT GUANO IN THE FLINDERS RANGES

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INTRODUCTION

This is the second in a projected series of papers dealing with the mining of bat guano in Australia. The first (in press) briefly reviewed the distribution of such mining in Australia and described the political and administrative battles over the guano at Naracoorte, South Australia. It was virtually entirely located in the 19th. century.

This paper turns to the less controversial, but nonetheless interesting, story of guano mining in the caves of the Flinders Ranges. Although there were probably various incidents of unrecorded mining over a long period, the period of greatest activity was in the 1920s and early 1930s.

The numbers identifying specific caves are from the Karst Index of the Australian Speleological Federation. Sites discussed or noted in this paper are listed in Tables 1 & 2 below.

Cave	Mining Tenure	Operator
Burr Well (F26)	Mineral Claims 11169 & 11376	??
Wooltana (F9)	?	Wooltana Fertilisers P/L
Mairs Cave (F3) Clara St. Dora Cave (F4) Lizard Cave (F27)	Mineral Claims 11512, 11513, 11594 (little mining)	Nitrogen Ltd.
Arcoota Creek Cave (F5) Fearby Cave (F43) Hardy Cave (F44)	Mineral Sections 1252, 1253, 1267, 1268	Nitrogen Ltd.
Mt. Sims (F7)	?	Nitrogen Ltd. ?
Blinman (F89)	?	Nitrogen Ltd.
Oraparinna (F8)	Mineral Claim 13975	?
Good Friday (F6)	Mineral Claim 13645	?
Walpunda Creek Blowhole (F53)	?	?
Bucket Cave (F56)	?	?

Table 1 : The Mined and Partly Developed Caves of the Flinders Ranges.

Bunyeroo Gorge Cave (F13)	Used by small groups of bats ; no significant guano deposits
Wilcowie Cave (F14)	Some guano but no evidence of mining
Eyrie Cave (F15)	Some guano but no evidence of mining
Clarke Cave (F17)	Some guano but no evidence of mining
Orroroo Cave (F20)	Some guano but no evidence of mining
Brachina Cave (F49)	Used by small groups of bats ; no significant guano deposits
Oratan Rock Cave (F72)	Some guano but no evidence of mining

Table 2 : Other Bat Caves of the Flinders Ranges.

A PLACE OF MINERAL WEALTH

The Flinders Ranges has long been recognised as a place of quite remarkable geological and mineralogical interest. The Adnyamathanha people mined ochre from a number of sites, including immense operations at both Lyndhurst and Bookartoo. That from the latter site was widely considered the finest in Australia, partly because of its admixture of mica and the resulting sheen, and all Flinders Ranges ochre was traded widely across much of the continent (Flood 1990 : 185-186). The Aboriginal people were also aware of other minerals of interest, often because of their striking appearance, and led early prospectors to lodes of copper and radioactive ores.

They also demonstrated a good understanding of the geology ; one excellent example is the story of the Thumping Kangaroo (Tunbridge 1988 : 54-56) which shows that they understood a great deal about the integration of the karst system over some 300 km. of the length of the ranges - something not generally appreciated or understood today, even by cavers.

Then white man arrived, and commenced the long battle for wealth from the Flinders Ranges. The first of many disastrous attempts at copper mining commenced in 1846. By 1865, in spite of enormous efforts, over a hundred different leases for copper mining had proved unprofitable. Over the next 40 years, large-scale mining developed at Blinman, Yudnamutana, Beltana and associated localities but again, in spite of great investment and some fascinating innovations (including Australia's first road-train), none were profitable. Various other minerals were also extracted and mines came and went, many of them being very short-lived. Looking back, the only significant mining operations which have both survived over long periods and made a profit are those of coal at Leigh Creek, barytes at Oraparinna and talc at Mt. Fitton (Mincham 1983). Some very small operations, e.g., the gathering of Chiastolites, may also have made a modest profit for lone operators.

But in spite of constant failures, prospectors always believe the next one will be the lucky one. So at the end of World War I, the search resumed, and set the context for the discovery and exploitation of bat guano from the caves.

THE NORTHERN CAVES

Brown (1904) appears to have been the first to describe a guano cave in the Flinders Ranges region. He dealt briefly with a cave in the quartzite of Oratan Rock, and described it as containing a guano deposit which was remarkably rich in nitrogen and which also contained many bone fragments. It was a small deposit and does not appear to have been mined (McBriar et al., 1981).

The mining thus appears to have started in the North. An immense cave (F9) on Wooltana station proved to have considerable deposits of guano, and a company, Wooltana Fertilisers Pty. Ltd., was established to operate the mining, processing and sale of the guano. Those interested in bats have long known of Wood Jones (1925) report of the mummified specimens of the ghost bat, *Macroderma gigas,* which were found there. What is not so well known is that these were so numerous that they adversely affected the quality of the guano, and so had to be sieved from the guano and bagged separately (*Register*, 23 Jan 1920). Even four years later, when the mining was well advanced, Winton (1924) referred to 'numerous dried bodies'.

Some of the guano had been transformed into ammonium salts, at least principally sulphate and choride, although there were also the familiar dark brown material, some of which was apparently of relatively (?) recent origin. Winton also refers to the black pitch-like substance which is seen in many locations throughout the Flinders Ranges and is generally known today as 'dung bitumen' (or Amberat, particularly in the U.S.). This is more likely to be derived from rodent dung rather than that of other species. He argues, following advice from L.K. Ward, that the salts were probably produced through interaction with ground water rising up through the guano from below.

Winton's report is somewhat superficial and he was only able to estimate the extent of the deposit (some 900 tons) and recommend further investigation. Clearly he had inadequate time or equipment for a proper study to be carried out. His analysis showed considerable variation from one sample to another, but in the deeper material, an average content of 62.5% Tri-calcic Phosphate equivalent, 1.9% nitrogen and 3.9% potash. Much of the paper is taken up with general discussion of other guano deposits, and a lot of speculation.

The mining method was to bag the guano in the cave ; haul it to the surface using a timber slide and a small diesel motor, then allow gravity to take the bags down a further timber slide to the foot of the slope where they would be stored until taken by truck to Copley and railed to Port Augusta. It was planned that a processing plant would be established there.

In spite of the high costs of this operation, the company continued for many years, apparently profitably, but eventually turning to other sources of phosphate. The miners, at least a number of whom were Adnyamathanha, camped on site. The last survivor appears to have been Rufus Wilton (Tunbridge, 1989 : 73).

The other site in the North, Burr Well Cave (F26), which is a cluster of small caves and fissures, was also worked from at least 1920. This was a small deposit, and Winton (1920) reported an analysis which shows relatively poor quality material with a great deal of insoluble material. It is likely that work on the deposit did not continue for long. However, a retired mission worker told the author that the Adnyamathanha at Nepabunna (established c. 1930) took guano from a nearly cave - almost certainly Burr Well, unless another exists in the area - for their own gardens. The caves and associated fissures contain deposits of bone breccia which may be worthy of investigation. Some empty bags and mining gear remain on site.

POTENTIAL WEALTH

Under this heading, the *Advertiser* (21 March 1922 and later articles) enthusiastically announced the development of further mining ventures at Buckalowie and Arcoota Creeks in the Southern Flinders. Their 'special representative' reported that :

> *. . . a great proportion of the most expensive manures needed had to be shipped thousands of miles and extra costs borne by the farmer.*
> *Now in a flash the whole situation has changed. A lonely prospector, who, for the past 40 years, has been chasing the golden fleece, and meeting with no success, was working a guano cave hundreds of miles from civilisation. One day there came to him a man from another district and told him of better caves. The prospector packed up his things and went to look for himself. He was so satisfied with what he saw that he dismantled his workings and had them brought here to Buckalowie . . . It only need a little while for him to be convinced that he had stumbled on a discovery that was not merely a matter of district or state importance, but was something that would bring about a reorganization of the whole artificial manure market.*

Of course, this sounds very like the opening of any one of the many unsuccessful mining ventures of the previous 70 years ! Regrettably, we know nothing more of the prospector - not even which previous site he had worked, although it may have been at Burr Well. A later press report (*Advertiser*, 21 June, 1922) names one Captain F.W. Montague as 'discoverer of the Carrieton guano caves' and then reports his later discovery of the Blinman Caves (see below). However, it is not clear whether he is the lonely prospector, the man who drew that prospector's attention to Buckalowie, or even another.

The 'special representative' reported immense cave systems - an excellent example of journalistic licence. He describes both Clara St. Dora (F4) and Mairs (F5) Caves, but gives them a majesty and scale which is just not true (*Advertiser*, 22 March 1922). Crossing a smallish pond is described as 'swimming across the Styx' with sufficient drama to warrant those words. All dimensions are at least doubled and often increased far more.

A company, called Nitrogen Ltd. was established to work these caves, with A.R.G. Fearby as managing director and J.W. Hardy of nearby Pamatta Station as one of the directors. Later references to the company also list Alan Sinclair as chairman of directors and a Mr. Giles as site manager (*Advertiser*, 5 August 1922). Two others, probably directors, who held mineral sections at Arcoota were A. Clarke and G. Anesbury.

The correspondent also referred to the presence of Frederic Wood Jones, who was searching for other mammalian fossils, and he was apparently successful in locating *Thylacoleo,* Tasmanian Tiger, Ghost Bats, and Stick-nest Rats. *Antechinus flavipes* is also listed, but this record does not appear at all in the zoological literature, so must be treated as questionable. However, significant deposits of bone material remain, both above and below layers of flowstone on the floor.

The other caves, Clara St. Dora and four at Arcoota Creek (*Advertiser*, 24th. March, 1922), are described simply as being extensive ramifying systems filled, sometimes to the roof, with guano. One of those at Arcoota (F5) again had considerable deposits of bone material. The accounts conclude :

, , , the discovery of the enormous deposits in the two series of caves will mean a big asset to the state and the solving of the problem of manuring for the more or less intense cultivation areas throughout the Commonwealth (*Advertiser*, 13 May 1922).

Winton (1922) again provides a somewhat superficial report on the caves, but probably judged correctly that they did not deserve the attention which might have been suggested by the press stories. He clearly did not 'swim the Styx', and his only samples from Mairs Cave consisted mainly of bones from the entry area. He points out that only the surficial part of each deposit had a significant level of nitrogen, as leaching by both inflow and groundwater had removed this from the lower levels. He states 'there is undoubtedly a huge quantity of guano to be obtained here', and later, 'Without, therefore, being able to make an actual estimate, it is certain that there is a considerable amount of guano to be had.'

Certainly, considerable work was done. A platform, obviously to accommodate winding gear, was constructed at the entrance to Mairs Cave, but there is no evidence that any guano was removed, and indeed, no evidence that there was ever any significant deposits in the cave. Some material near the entrance was taken, but appears to have consisted largely of bone fragments. Adits were driven into Clara St. Dora and Arcoota No. 1 and several shafts, both natural and excavated, were shored with timber to provide for access or extraction. Shored shafts or drives also exist at Lizard Cave (Buckalowie), Fearby Cave and Hardy Cave (Arcoota Creek).

The *Advertiser* (5 August 1922) reported that a conveyor belt and other facilities were being developed at Clara St. Dora, capable of conveying 18 tons per hour ! Similarly, a rail system was being installed at Arcoota to carry small trucks laden with guano to the entrance from which they would be conveyed by gravity to storage below. Although considerable guano was removed from both these caves, it does not appear to have been adequate to utilise these arrangements for very long. An adit was constructed to facilitate extraction from a further cave at Mt. Sims (F7), which does not appear to have been documented in any way until visited by cavers in the 1950s. Both empty bags and sieves obviously used for preliminary processing of the guano can still be seen here.

Nitrogen Ltd. also developed another cave (F89) near Blinman (*Advertiser,* 21 June 1922), but other than the initial press announcement, no details are available. Finally, a brief report appeared (Segnit, 1933b) on Good Friday Cave (F6), also in the southern area near Arcoota. A shaft had been sunk into the cave, and it was clearly planned that guano would be taken out , but the evidence is that little or none has been removed. There was clearly some investigation of other caves, especially the Walpunda Creek Blowhole. This has a high enough level of carbon dioxide to prevent entry without special equipment, but has a wooden ladder, and evidence that a windlass has been used. Similarly Bucket Cave has a mining bucket on site and evidence of some mining.

The last site is the cave (F8) at Oraparinna (Segnit 1933a). Segnit makes reference to 8 tons of guano being removed prior to the opening of the operation which commenced in 1932 and he inspected in 1933, but gives not details. The holders of the 1932 lease are also not identified, but up to the time of Segnit's visit, they had taken some 131 tons which had been sent on to Wooltana Fertilisers Ltd. for processing. Two shafts had been sunk, only one of which appeared to be of use in extracting the guano. The guano was bagged on site, dragged to the foot of the shaft and hauled to the surface with a windlass, then trucked to Pt. Augusta.

Segnit's analyses indicated that other the top twelve inches of the deposit, the material was so leached by water that it was of little value. He estimated that no more than 160 tons of useful material was available.

The map included in Segnit's report shows that the cave comprises a grid of joint-controlled passages on two levels. Many passages and features are named, many after streets and other features of the City of Adelaide. The upper level was called the Pompa Cave and one can only assume this is a mis-spelling of Pumpa. Eddie Pumpa had built, and lived at, the Aroona out station of Oraparinna. Amongst other things, he became well-known as the man who first introduced Han Heysen to the Flinders Ranges and who assisted him on his visits to the Ranges (Mincham, 1983 : 178).

A small number of other caves (see Table 2), like that at Oratan Rock, had limited deposits of guano, but were never developed or mined. It is almost certain others remain to be discovered.

AND WHAT OF THE BATS ?

Bones and desiccated remains of *Macroderma gigas* have been recovered from Wooltana, Arcoota, Buckalowie and Mt. Sims Caves. Wood Jones had collected, or was familiar with, specimens from the first three of these. He assumed that it was M. gigas which was responsible for the immense accumulations of guano. He also referred to his finding that '. . . intestinal content of cave mummies . . . consists entirely of masses of the hairs of small insectivorous bats' (1925 : 444) and thus established the myth of the Ghost bat as a bat-eating bat.
It is extremely unlikely that *M. gigas* was solely responsible for the guano and almost certain that it shared the caves with the 'small insectivorous bats.' However, there appear to no sub-fossil remains which would allow identification of the species concerned.

At least two species are possible candidates. *Vespadelus finlaysoni* has a significant population in Wooltana Cave to this day and *Chalinolobus morio* has been reported from abandoned mines in the region. Various observers have reported seeing a few 'small bats' in virtually all of the Flinders Ranges caves but these have not been identified and could be either species.

CONCLUSIONS

It is not clear when mining ceased but as already noted, the amounts extracted were relatively limited, and much of the deposits remain in place. On one hand, guano mining suffered all the problems which had dogged the pursuit of copper : the need for labour-intensive techniques, the difficult terrain and the long distances from mine to market. This was compounded by the leaching and hence low quality of much of the material - probably a worse problem than Winton had realised with his relatively superficial work.

It seems likely that, other than at Wooltana, the guano-mining operations were so small that the capital cost of sulphuric acid processing was not invested ; further, Winton had suggested (wrongly) that this was probably un-necessary. In any case, the guano miners had to compete with the much more abundant and cheaper phosphates from the Pacific Islands The Federal Government subsidy schemes introduced in the early 1930s to lower the cost of super-phosphate would have dealt the final blow. So, despite the early optimism, the guano industry added one more economic failure to the history of the Ranges.

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ARE YOU EXPOSING YOURSELF TO HISTOPLASMOSIS ?

Garry K. Smith

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Around the world, hundreds of thousands of people each year are affected by a fungal infection called Histoplasmosis. In many areas of South America, Asia, Europe, Africa and East Central United States, the disease has been found in the droppings of domestic birds, such as fowls as well as starlings and other birds which often nest around houses. To humans this microscopic fungus is potentially fatal if the infection is not treated.

At this stage you are probably saying to yourself, "what has this to do with caving".?

Evidence exists that the fungus Histoplasma capulatum grows in guano, (bat droppings) and that it may be spread by bats flying from one roost cave to another. The fungus can survive in the intestinal contents of bats as well as transmitted to other locations by wind. To date the fungus has been detected in some caves inhabited by the Bent Wing Bat (Miniopterus schreibersii blepotis) however there is no conclusive evidence that it is confined to guano of this bat species.

Other names for this disease include:- "Histo", "cave disease", "cave fever", "Darling's disease", "Ohio Valley disease, "Tingo Maria fever", "reticuloendotheliosis" and "reticuloendothelial cytomycosis".

Habitat of the Fungus.

Histoplasma capulatum is an organism which grows in soil containing a high nitrogen content, generally associated with guano of birds and bats.

The fungus reproduces by releasing spore of 2 to 5 micron in size, to the air. Ideal conditions for this to occur is in caves with high humidity (ie 67% to 87% or more), temperatures of around 20 to 29 degrees C and the presence of dry guano. Many overseas reports have recorded high concentrations of the fungus in guano around poultry sheds. In "open" environments the occurrence of the fungus is generally restricted to between latitudes 45 degrees N and 45 degrees S. Outside of this tropical zone, concentrations of the fungus is restricted to appropriate environmental conditions which can occur in "closed" environments such as caves. This is due to the stable conditions which exist inside caves, where as the surrounding countryside may be too dry or cold for sustained proliferation.

Effect on the Human Body

Histoplasmosis is a fungal infection which can affect the whole body and is caused by inhalation of an aerosol of soil, dust or guano which contains fungal spore. When the airborne spore is breathed in by cavers it may infect the lungs. The degree of infection in humans varies widely, depending on the individual's immune status and degree of exposure to the fungal spores.

In most cases the spore are introduced in such a quantity as to produce a mild form of the disease and thus builds up the bodies immunity to the fungus. This form of infection is referred to as Asymptomatic and the infected person experiences no noticeable symptoms.

When a person is subjected to high exposure, some spore reach the alveoli and begin to germinate. Conversion to an invasive yeast phase takes place, and multiplication occurs by binary fission.

The second form of infection is Acute Pulmonary Histoplasmosis. Symptoms may occur two to three weeks after infection and include a general feeling of being unwell as if suffering a mild influenza with a raised temperature, malaise or tiredness and pleuritic chest pain. In most cases the person with a mild infection quickly recovers with no treatment.

The more severe third form of infection is called Chronic Pulmonary Histoplasmosis. The condition of persons with high exposure and/or low immunity to the fungus, may quickly deteriorate to include fever, night sweating, headaches, shortness of breath, lack of energy, muscular aching, weight loss, dry coughing and severe pain around the lungs. If untreated, the lungs continue to be slowly destroyed and death can occur months or years later from bacterial pneumonia or heart failure.

The most severe form of infection is called Acute Disseminated Histoplasmosis and the yeasts are spread throughout the body via the blood stream.

Overseas statistics show that in a small percentage of cases the disease may disseminate and infect the lymph glands, liver, spleen and other vital organs, resulting in fever and weight loss. Chronic respiratory infections resemble chronic pulmonary tuberculosis. The disease progresses over a period of months to years, possibly with periods of remission. This form is more common in males over 40 and often results in death. Symptoms at the chronic stage may vary, depending on the organs involved. Unexplained fever, anaemia, heart inflammation, meningitis, pneumonia and mucosal ulceration of the mouth, bowel or stomach may be seen. The infection is not transmitted from person to person and there is no immunization presently available.

It may be of interest that Histoplasmosis is not only confined to humans, as other animals such as dogs, cats, rats and foxes are also susceptible to infection.

Occurrences in Australia.

Prior to 1972 in Australia, the disease had only been identified on several occasions. In none of these cases was the infectious environment conclusively linked with bats. However between 1972 and 1976 a large percentage of cavers who visited Church Cave (WJ-31) at Wee Jasper contracted histoplasmosis.

This sparked a spare time study by Applied Science lecturers and students at the Riverina College of Advanced Education, Wagga Wagga to isolate the source of the fungus. On many occasions the researchers wearing respirators designed for poisonous pesticide sprays entered the cave to collect samples of cave air and guano from the deep layered deposits. Despite wearing respirators, three out of the eight researchers contracted lung infections. The investigation continued, however it wasn't until 1983 that the fungus was grown in laboratory cultures from samples of guano, soil, respirator filters and phlegm taken from the last of the histoplasmosis sufferers.

In November 1993 a group of 12 cavers undertook exploration of the Glenrock Caves located 120 Km north-east of Muswellbrook. Sixteen days after entering the caves, one of the cavers was admitted to the John Hunter Hospital (Newcastle, N.S.W) and diagnosed as suffering from histoplasmosis. Conclusive diagnosis is pending final fungal culture results, however this appears to be just a formality. The exact origin of the infection has not been positively identified, however there is a strong possibility that the fungal spore originated in the Glenrock cave called "Bats and Bandicoots" (GR-43). This cave contained large quantities of bat guano and has a cave climate suitable for the fungus' propagation. During exploration the cave temperature was uncomfortably hot and the guano was noticed to be dry and powdery.

There were six cavers who entered GR43 in November 93. Only one came down with the infection. The person involved suffered a lot of pain and discomfort from the infection, which appears to have permanently damaged a large section of his lungs. He spent 12 days in hospital and has incurred large medical bills, endured considerable inconvenience during medical tests and lost lots of work time.

This makes Histoplasmosis an infection not to be dismissed lightly with the old saying "it can't happen to me".

Hills Speleological Club Ltd. have published a comprehensive guide to the Caves of Glenrock. Between 1983 and 1987 they collected data and mapped the 108 caves in the area. This involved hundreds, possibly thousands of man-hours underground. I believe there were no reported cases of histoplasmosis even though the cave in question has been mapped and explored on several occasions.

Since these are not the only breeding caves for the Bent Wing Bats and no concrete evidence exists that they are the only species of bat to carry the disease, there is still the possibility for further outbreaks to occur in the future. Fortunately to date the occurrence of this disease in Australia is rare considering the numbers of people who enter caves containing bats each year. *Rippon (1974)* states, "Not all guano appears to serve equally well as a substrate", which might explain why the fungus to date, has not been isolated in guano of other Australian bats.

Diagnosis

There are several methods to diagnose the disease.

1. Involves laboratory examination of body tissue or fluids, often sputum or scrapings of lesions.

2. Histopathologic examination of several tissues such as bone marrow, liver, spleen and lung, stained with special fungal stain.

3. Tissue culture isolation of the fungus from sputum, blood, bone marrow, biopsy tissue, lesion scrapings or other body tissue and fluids.

4. Serologic tests may be used.

5. Histoplasmosis skin test is primarily an epidemiologic tool to define endemic areas. Its diagnostic value is limited as it does not distinguish between past and present infection, and non-specific reactions can result in false positives. (In 1972 around 100 speleologists were tested and approximately 30% returned a positive result).

6. Although not a conclusive diagnostic tool, a chest X-ray of severe cases will show many abnormal shadows in the lungs.

Previous severe infections may be noted on a chest X-ray film as small, scattered, radio-dense nodules in the lungs, mediastinal lymph nodes, and spleen.

Treatment

Most cases recover without any specific treatment. However even mild symptoms should be treated seriously as chronic infections may develop and result in damage to internal organs or in extreme cases death.

Benign localised lung infections should be treated, if necessary with bedrest and symptomatic care. In severe cases of histoplasmosis, the antibiotic of choice is intravenously administered Amphotericin B.

It should be noted that HIV positive sufferers have little chance of overcoming this fungal infection if contracted.

Conclusion.

If you have already visited a cave which contains dry dusty bat Guano, you have probably exposed yourself to the fungal spore. The more dust stirred up increases the chance of greater exposure and infection. Severity of infection may vary, depending on the degree of exposure and your state of immunity. Bear in mind that the disease may recur in later life once infected. Cavers should not become paranoid about Histoplasmosis, but moreover they should be aware of the possibility of infection and able to recognize the signs to assist in early diagnosis. Caves with wet or damp guano have greatly diminished chance of causing infection. If you must enter a cave with high humidity and dry guano, a good fitting fine dust mask may reduce (but not eliminate) the chances of infection, provided special care is taken to remove and dispose of contaminated clothes and wash hair before removing mask. If you suffer any Histoplasmosis symptoms after visiting a bat cave, see your doctor without delay. Make special reference to the possibility of Histoplasmosis and that it has common symptoms to tuberculosis (TB). Prompt action could save your life. The best prevention is to avoiding known sites of exposure.

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Radon and Its Decay Products in Caves

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Abstract:
Most radioactive substances are solids that possess physical properties and decay half-lives that prevent them from being considered a natural radiation hazard. Radon, however, is a gas with a half-life just large enough for it to be able to diffuse out of the ground in which it is formed and migrate in open air from its origination point with changes in air flow. Whilst being solids, the decay products of radon are highly reactive and possess half-lives in the order of minutes. Consequently, the decay of these compounds, with the associated production of high energy α-particles, presents a possible health risk. Investigations into radon and its progeny in Australian caves are showing the presence within the caves of high levels of these substances. Described here are the factors that have been shown in studies worldwide to affect these levels over time within cave systems.

Introduction

Radon and its short-lived decay products are a major issue in human exposure to natural sources of radiation, especially with regard to enclosed spaces such as mines, buildings and caves. This has certainly become the case over the last few decades as research has linked elevated levels of radon to the increased numbers of fatal cancers experienced by miners in some mines (Lorenz 1944; Jackson *et al.* 1987; Prime and O'Hara 1991); the levels of radon in some abandoned mines have been measured as high as 240 million Bq m^{-3}. Unlike mines, the study of radon levels in caves has been limited. Nevertheless, it has been found that in many of the caves commonly used by the general public, such as the Carlsbad Caverns (Wilkening and Watkins 1976) in New Mexico, USA, and in wild caves, such as the Giants Hole (Bown 1992) in Derbyshire, UK, there are high levels of radon and radon decay products, the highest at present being 160,000 Bq m^{-3} in the latter wild cave.

Investigation into the levels of radon in Australian caves was initiated almost by accident in 1991 (James 1996 pers. comm.). Test studies were required on the use and suitability of track etch detectors in measuring radon levels in buildings, and these tests were performed in the caves below the Nullarbor Plains. The results of these tests, and of subsequent studies at other Australian cave systems, showed the existence of high levels of radon in these systems (Lyons 1992, Solomon *et al.* 1992).

The reasons for studying radon and its decay products in caves can be summarised as:

(i) determining whether there are health concerns with regard to the concentrations of radon and radon decay products for tourists and, more significantly, guides and maintenance workers;
(ii) determining possible sources for any noticeably raised levels of radon;
(iii) determining the distribution and flow of radon within the cave; and
(iv) suggesting methods of reducing exposure to any levels of radon or radon decay products deemed to be dangerous to health in ways that do not harm the sensitive cave environments.

Background

The only naturally occurring heavy radioactive isotopes are uranium-235 (^{235}U), uranium-238 (^{238}U) and thorium (^{232}Th). These primordial constituents of all rocks and soils possess extremely long half-lives, the time elapsed since their creation being insufficient to facilitate the decay of these isotopes into other more stable compounds. The decay paths of these three elements is long and complex, proceeding through various shorter lived radioactive atoms until the formation of the stable non-radioactive lead isotopes (Figure 1). Because of their chemical reactivity, these intermediates tend to stay within the material in which they were formed. However, in each decay process, an isotope of the noble gas, radon, is formed. Essentially inert in cave environments, radon can diffuse slowly through solid matter into the air (Hopke 1987), where it becomes a significant contributor to the background levels of natural radiation. Indeed, over 50 % of the background radiation is from radon decay.

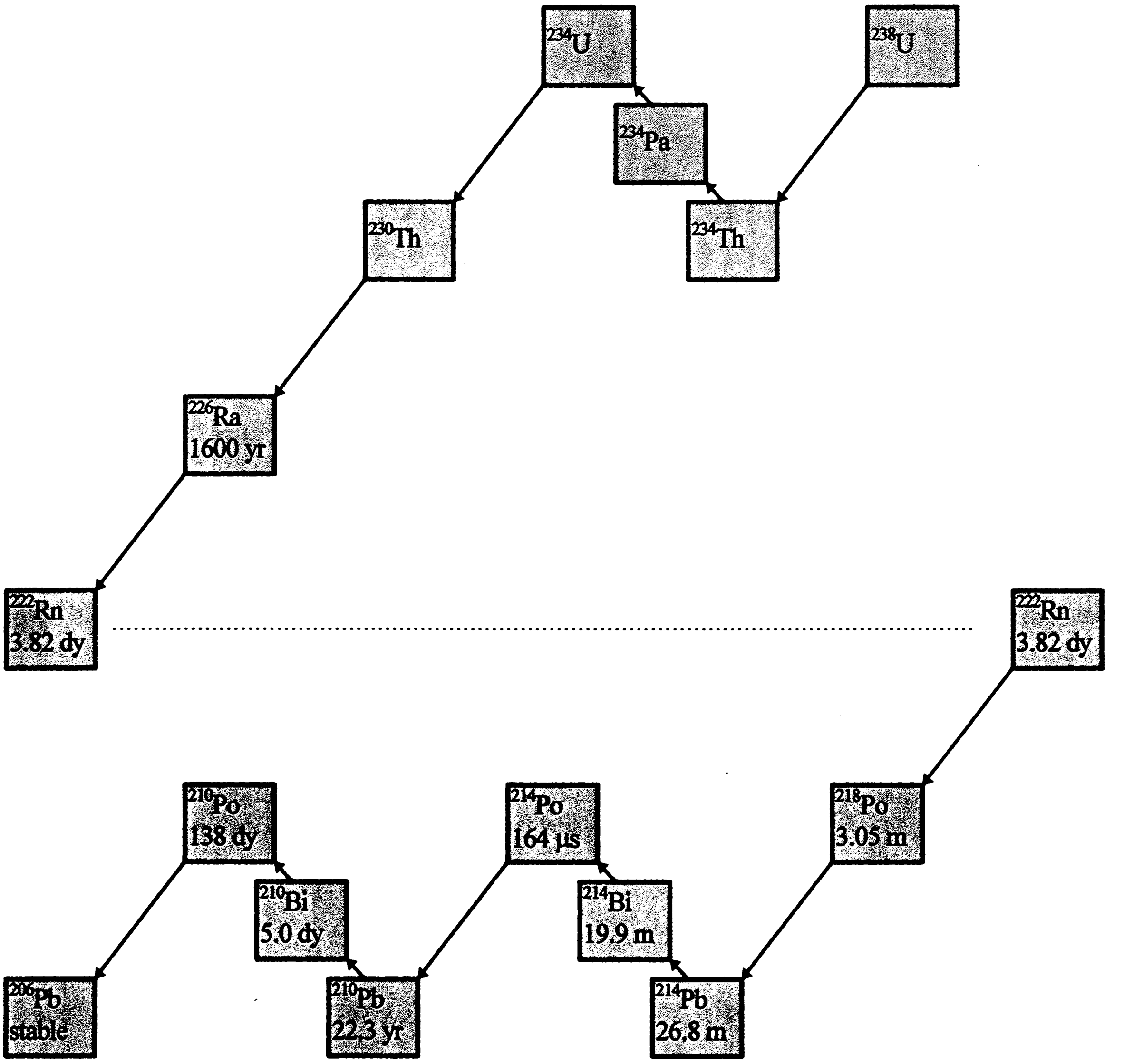

Figure 1. Decay chain and half-lives for the radon isotope, ^{222}Rn, and its decay products.
long downward arrow = a-decay short upward arrow = b-decay

Radon

The normal background level of radon in outdoor air is about 7 Bq m^{-3} ‡. Radon levels for enclosed spaces such as caves will generally be significantly higher than outdoor levels, because the dispersion of the gas by airflow changes is more restricted and thus less effective. Furthermore, the average air pressure differential experienced by caves often results in a pooling of gases within these spaces. Common radon levels found in caves range from 200 Bq m^{-3} to several thousand Bq m^{-3} averaged over a year For instance, levels at Wombeyan caves average 240 Bq m^{-3} annually whilst those at Jenolan (northside) caves are around 1500 Bq m^{-3} (Figure 2).

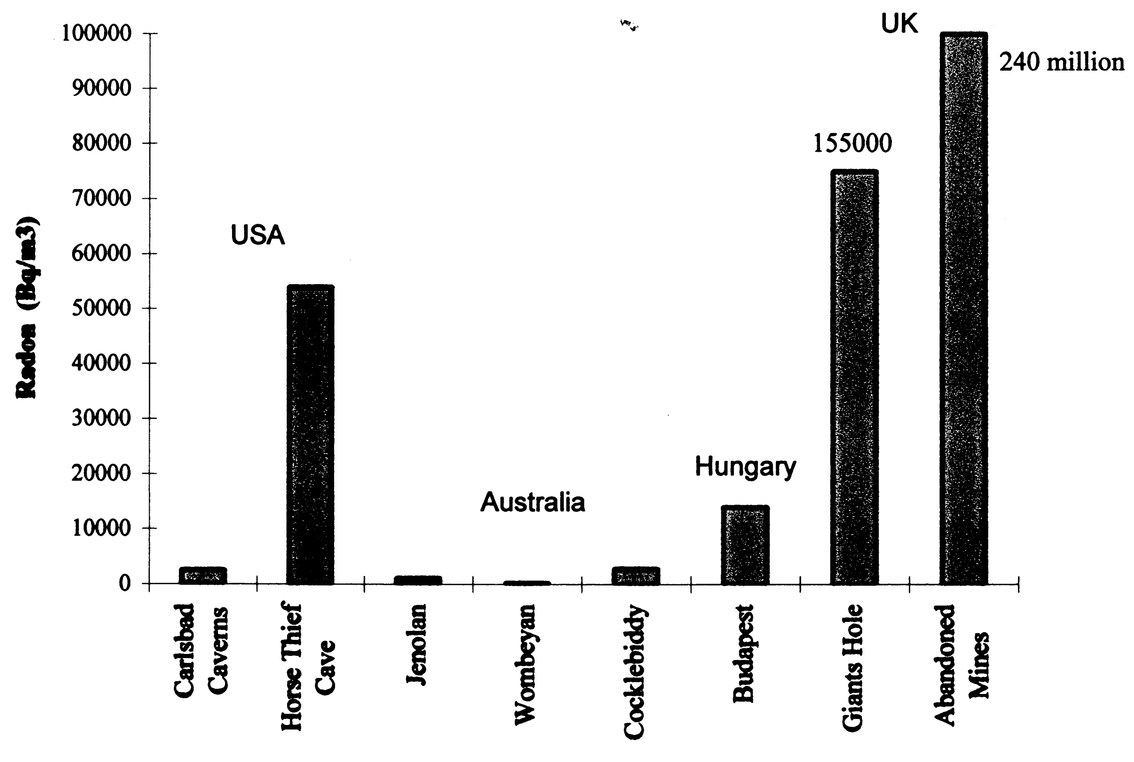

Figure 2. Radon levels in caves and mines.

The study of radon levels in caves began in the 1970's and, since 1974, radon levels have been monitored and analysed in both wild caves and show caves around the world. For example, radon levels have been measured in caves in Derbyshire, UK (Gunn *et al.* 1991a,b), New Mexico, USA (Wilkening and Watkins 1976), Australia (Solomon *et al.* 1996) and Budapest, Hungary (Géczy 1993). These measurements have shown radon to vary both seasonally and diurnally, with maximum levels observed in summer and during daylight hours, and minimum levels in winter and at night for most cave systems.

‡ The becquerel (Bq) is the SI unit for the measurement of radioactive decay, and is equal to one decay per second.

Radon Decay Products

The decay products (progeny) of radon are polonium-218 and -214 (^{218}Po, ^{214}Po), lead-214 (^{214}Pb) and bismuth-214 (^{214}Bi). Lead-210 (^{210}Pb), with a half-life of 22 years, is considered to be stable and, therefore, the end point for the progeny decay sub-chain (Figure 1). The chemistry of the radon progeny is of some importance. While both lead and bismuth are relatively unreactive, polonium isotopes are both reactive and extremely toxic. Consequently, high levels of these could be harmful in and of themselves, without the added danger of their being radioactive. In practice, the concentration of polonium present at any one time within a cave is extremely small, and so the radiation hazard predominates.

All of the radon decay products are solids, and so can "plate out" of the air onto other surfaces, such as those provided by the walls of caves, dust particles, moisture droplets and condensation nuclei. Condensation nuclei are small particles formed by photochemical or combustion processes in the outside atmosphere that have been transported into the cave atmosphere through air exchange. Because of the small size and high relative abundance of, and thus the large surface area provided by, condensation nuclei, radon decay products are more likely to attach to these particles rather than dust or water droplets. Therefore, the radon decay products are a mixture of "attached" and "unattached" particles.

As condensation nuclei are airborne, and dust and moisture can be, both the attached and unattached radon progeny have the capability of being inhaled into the lungs where, depending on the size of the particles, they become trapped anywhere along the respiratory tract from the nose to the lung tissue itself. Due to their more extreme reactivity, the unattached fraction pose a greater danger to health than the attached decay products. Moreover, the unattached fraction deposit in the respiratory tract with 100 % efficiency (Robkin 1987). Just like the decay of radon, the decay of the two Po isotopes produces a-particles which, when the nuclides are trapped in the lungs, can damage the sensitive lung tissues.

For a chain of radioactive isotopes where the parent is relatively long-lived, the amount of each chain member will adjust until the sources and losses of each are in balance. When the only source is an original amount of the parent and the only losses are decay processes, the equilibrium reached is one where the activities of the parent and its decay products are equal. That is, they are said to be in secular equilibrium. For the radon decay chain, in the absence of external influences, it takes approximately 4 hours for this state to be achieved (Robkin 1987). Processes, such as plate-out onto walls or those that cause changes in airflow, which operate within this time frame and which alter the abundance of the particles by introducing or removing them, can lead to departure from this "ideal" state.

The earliest research of radon decay products in caves was undertaken during the late 1970's in the Carlsbad Caverns, New Mexico, USA (Ahlstrand 1980). These studies showed that there existed temporal variations in the levels of radon decay products and that these levels were probably related to seasonal, diurnal and pressure related phenomena. A subsequent study of the decay product levels within Giants Hole, Derbyshire, UK (Middleton *et al.* 1991), found that changes in the radon decay product levels were primarily the result of changes in the direction of airflow within the cave and that this in turn was related on a seasonal and diurnal scale to temporal variations in the temperature gradient between the cave and external air.

Factors Affecting the Levels of Radon and Radon Decay Products Within Caves

Radon and radon decay product levels in cave atmospheres are dependent upon the whereabouts of the parent (radium) source, the diffusion rate of radon through and emanation from the ground, and the rate of introduction and removal of radon in air and water (Prime and O'Hara 1991; Lyons 1992; Nazaroff 1992; Blaauboer and Smetsers 1996) (Figure 3). The rate of diffusion varies with depth and geology. As the surface is approached, the diffusion rate will increase, as release of radon into larger air cavities like caves becomes important. The geology and physical processes such as weathering help determine the 'porosity' of the earth, and thus to some extent the moisture content and permeability of the soils. Consequently, levels of radon in caves is controlled by the radium concentration in the cave structure, the physical structure of the cave itself which affects the diffusion rate, and by atmospheric pressure changes.

Water can also be an important source of radon in caves, depending on the rock over (or through) which it has flowed (Prime *et al.* 1991) before entering the cave. Water flowing over or through rock of high uranium or radium concentration often has high radon levels. Despite the low solubility of radon in water, the high concentrations of radon found in most soils readily forces some radon into groundwater and circulating subsurface waters. Water flow is thus a significant transport path for radon dispersion, allowing radon to migrate along caverns and fractures as far as the transporting waters allow (Nazaroff 1992; Hakl *et al.* 1993a), leading to possible increases in radon levels at sites removed from the point of origin of the radon.

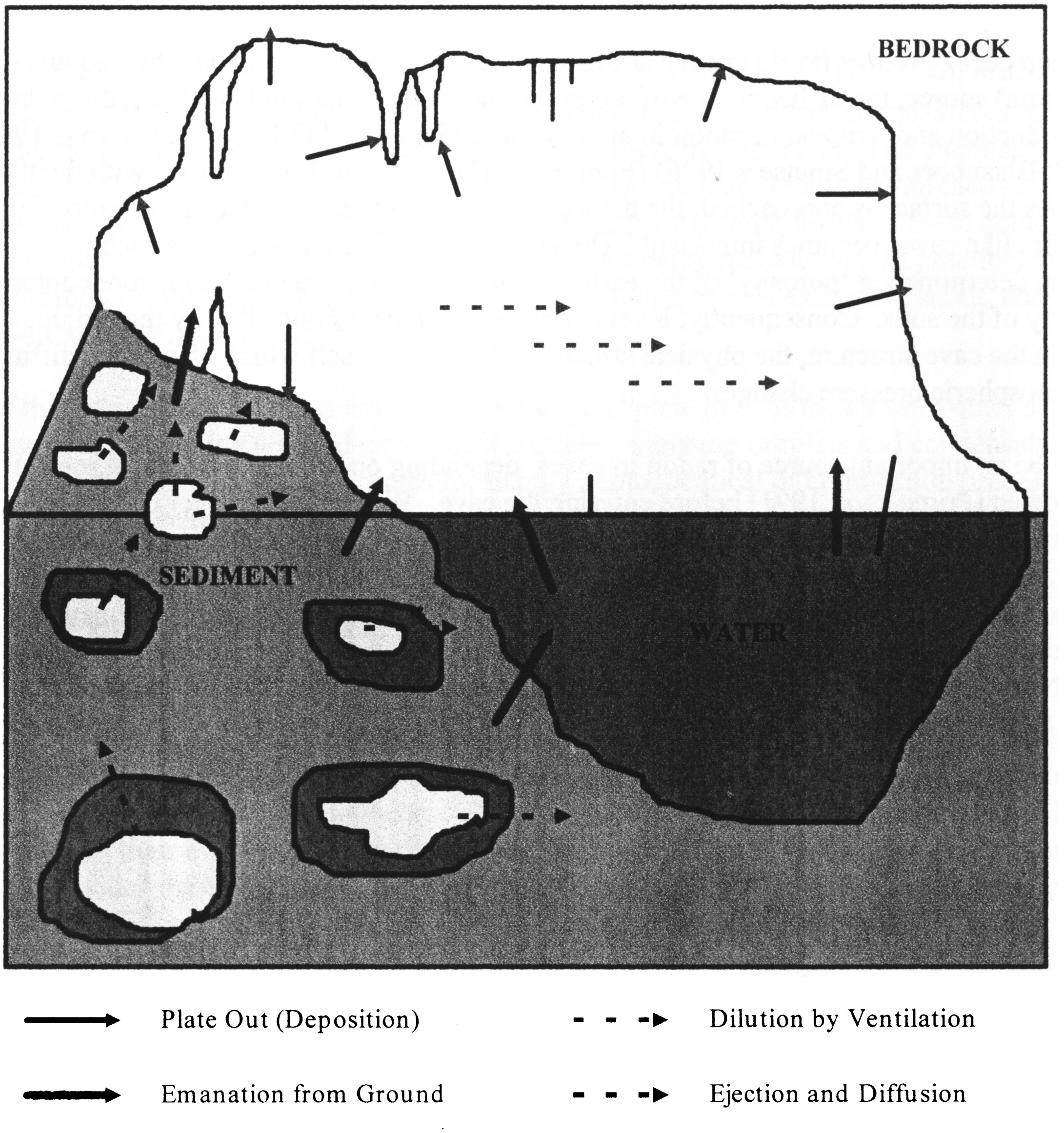

Figure 3. Factors affecting radon concentrations in air.

Exchange rates between cave and external air can be complicated, and are dependent upon temperature differences between the cave and outside and the cave configuration (entrance above or below the limestone voids, mazes, complex passages, chimneys etc.). For example, outside caves, a temperature inversion can occur some metres above the ground at night, resulting in an increased radon concentration at ground level. During the day, the air heats more uniformly and so mixes more thoroughly. This effect is enhanced seasonally, as the summer heat is more intense leading to warmer soils, and the winter nights are less stable leading to greater mixing and less likelihood of an inversion. Wind direction can also be important to cave airflow as can be the presence of active streamlets. Indeed, any factor likely to change airflow patterns within a cave is also likely to alter the levels of radon and its decay products.

Middleton *et al.* (1991) and Prime and O'Hara (1991) confirmed that the direction of airflow is one of the dominant factors affecting both the spatial and temporal distribution of radon decay products within caves. On both a seasonal and diurnal scale, airflow direction is determined by the temperature gradient that exists between the cave and external air; some of the temporal variations have been related to changes in atmospheric pressure. On the other hand, good correlations have been found between the variation in radon levels in the caves and outside temperatures (Géczy 1993) and changes in air pressure within the caves themselves.

Exposure to Radon-222 and Its Decay Products

Knowledge of the health effects of radon and its decay products is derived mainly from studies of cancers in underground miners, all of which have unambiguously shown that prolonged exposure to high concentrations of these substances leads to a high number of fatal lung cancers (Behounek 1970; Eisenbud 1987; Jackson *et al.* 1987). However, extrapolation of these results to situations where humans are exposed to much lower radon levels, for example, in caves, has severe limitations despite being of prime interest with respect to general public health.

Radon decays to ^{218}Po, emitting an a-particle in the process. Polonium-218 is a chemically active solid material that can bind to lung tissues, which has a half-life of about 3 minutes. It too decays by also emitting an a-particle, to ^{214}Pb. The properties of a-particles are such that they are only a health hazard if the emitter is in contact with living tissue. The relatively large, positively charged a-particles rapidly lose their energy to surrounding atoms. This means that they do not penetrate the skin and are stopped by a few centimetres of air. However, if the a-emitter is in the body (*e.g.* on the lung tissue), all of the energy is released to a much more sensitive tissue.

Being a gas, ^{222}Rn can be inhaled, although it is generally exhaled again. Radon is also somewhat soluble in blood and body fat (Eisenbud 1987). However, should radon decay within the body, it will not only emit an a-particle but deposit radon progeny as well, whereupon a further two a-particles will also be emitted within the body. Radon decay products produced outside the lungs can also be inhaled. Indeed, the amount of radon progeny deposited as a result of radon decay in the lungs is negligible compared to the amounts of radon decay products that are inhaled. These solids can be attached to condensation nuclei and other airborne particles or unattached, thus altering the overall size of the particle. Only a small fraction of those radon decay products breathed in will be exhaled again, with the particles possibly becoming trapped some distance along the respiratory tract in correlation to the size of the particle. The unattached radon decay products, which are smaller than the attached decay products, are more dangerous because they can travel further into the lungs before either being exhaled again or becoming trapped.

The chances of the energy released by a-particles breaking chemical bonds within organic molecules or causing ionisation or forming reactive free radicals are relatively high. All of these changes have the potential to disrupt the normal metabolism and produce changes which may either be easily reversed or affect cell replication, cause cell death, or in a limited number of cases, induce cancerous or abnormal growth. As those a-particles released by the radon decay products are more energetic than those emitted during radon decay, the progeny are once more revealed as being of greater concern to public health.

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CAVES, CARBON DIOXIDE and YOU

Garry K. Smith.

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Carbon Dioxide (CO_2) often occurs in high concentration at the bottom of deep caves. It is a colourless, odourless and non-combustible gas which is over one and a half times denser (heavier) than air.

EFFECT OF CO_2 ON THE HUMAN BODY.

Although carbon dioxide is not a poisonous gas, it can be dangerous and even life threatening by causing suffocation.

CO_2 is the body's regulator of the breathing function. It is normally present in the air at a concentration of 0.03% or 300 parts per million (ppm) by volume. Any increase above this level will cause accelerated breathing and heart rate. A concentration of 10% can cause respiratory paralysis and death. In industry the maximum safe working level recommended for an 8 hour working day is 0.5% (5000ppm by volume). (CIG Gases Catalogue, Dec 1991).

Are you placing yourself at risk by going caving?

Before answering this question we should study certain aspects of the CO_2 cycle dealt with in the following text.

HOW CO_2 GETS INTO CAVES.

Carbon Dioxide exchange is the dominant mechanism for carbonate deposition in most caves. In well ventilated caves the level is about 10 times higher than that of the outside atmosphere, and approximately 25 to 250 times lower than the CO_2 content of the ground water before reaching the cave. This is because plant roots and soil microbes give out carbon dioxide as part of their life processes, adding it to the air in the soil through which the rain water passes. When the ground water enters the cave, it looses carbon dioxide to the cave air until equilibrium is reached.

It is a popular belief that if the level of CO_2 increases in a cave, it conversely displaces an equivalent quantity of air, ie. oxygen (O_2) and nitrogen. In many caves this may be true however there are caves where the nitrogen level stays constant while the oxygen level decreases and CO_2 increases.

At Bungonia Caves (NSW), CO_2 levels of up to 6% have been linked to micro-organisms (i.e. fungi and bacteria) which depend on the nutrition present in organic material leached down from the soil or washed into the caves by floods. These organisms produce CO_2 as a by-product of their digestion process. This mechanism was observed to correlate with the reduction in O_2 accompanied by the increase in CO_2 concentrations. (Crawshaw and Moleman 1970)

At Bungonia it is generally agreed that foul air accumulation by loss of CO_2 from saturated ground water was not the major source, but a contributing factor. High levels in some caves can be attributed to micro-organisms and/or large bat colonies.

In 1958 members of S.U.S.S. confirmed that readings of up to 13.5% CO_2 at Wellington and Molong Caves were at the expense of oxygen. ie. the sum of CO_2 and O_2 was constant and the percentage of inert gases was reasonably constant. They also concluded that this was due to organic decomposition. ("Bungonia Caves" 1972, article E. Halbert).

Although caves naturally breath due to changes in surface temperature and changes in atmospheric pressure, CO_2 is heavier than nitrogen and oxygen, so it tends to congregate at the bottom of deep caves which do not have through ventilation to a lower entrance.

WHAT PERCENTAGE OF AIR DO WE USE ?

To get a complete insight into what actually occurs when a caver is exposed to a cave atmosphere, which contains higher than normal levels of CO_2, we should examine the mechanism by which our own body expels this unwanted by-product of metabolism.

The human body under average conditions inhales air which contains approximately 21% O_2 and 0.03% CO_2. The air breathed out of the lungs contains approximately 15% O_2 and 5.6% CO_2.

A person at rest inhales and exhales approximately 6 litres of air per. minute but in times of stress, this may increase to more than 100 litres per minute.

The lungs do not expel all of the air with each breath. The volume of air that moves in and out of the lungs during each breath is known as the tidal volume. The maximum possible tidal volume is equal to the vital capacity. The vital capacity is the amount of air that the lungs can hold after trying to force out as much air as possible and then taking the deepest possible breath. The amount of air left in the lungs after trying to breath out as hard as possible is the residual volume. It is impossible to empty the lungs of all air in this manner.

For an average adult, approximately 500 milli litres (ml) of air is drawn into the lungs with each breath during normal breathing. But of this 500 ml of tidal volume, only 350 ml is fresh air as the first 150 ml is 'dead' air already in the nose, trachea and bronchi. The 350 ml of fresh air represents only approximately 6% of the lungs maximum total capacity which is about 6000 ml (6 litres).

HOW THE HUMAN BODY GETS RID OF CO_2.

Normally a person is unaware of the complex mechanisms of breathing which are regulated and controlled by the respiratory center of the brain and the nervous system.

The carbon dioxide level in the blood is an important stimulus to respiration. Nerve receptors in the aorta near the heart and in the carotid artery that goes to the brain, monitor changes in the CO_2 in the body. If the amount of CO_2 in the blood increases, both the rate and depth of breathing increases. Changes in O_2 levels are also monitored, but the receptors are not as sensitive to changes in O_2 as to CO_2.

The exchange of the two gases (CO_2 and O_2) takes place in the lungs by diffusion across the walls of the air sacs (alveoli). O_2 from inspired air diffuses across the lining of the air sacs and enters the circulation, while CO_2 moves in the opposite direction. Then the gases are transported between cells and the lung by the blood circulation.

The principle by which diffusion occurs dictates that a gas in high concentration will move to an area of relatively low concentration, until an equilibrium is reached. This enables CO_2 in the body at a higher concentration to diffuse to the inhaled air.

HOW THE BODY REACTS TO HIGH CO_2 LEVELS.

As each persons body has a slightly different reaction and tolerance to stressful situations the following symptoms are general, however nobody is immune to the dangers of CO_2. It should be noted here that in many cases involving foul cave air, it is not the lack of O_2 which is the danger but moreover the critical factor is the high level of CO_2.

Exposure to levels of CO_2 in excess of 0.5% will cause a cavers breathing and pulse rate to increase. Other symptoms may begin to occur in areas containing 1% and greater. These include feeling hot and clammy, lack of attention to details, fatigue, anxiety, clumsiness and loss of energy which is commonly first noticed as a weakness of the knees (jelly legs) may occur.

Long term exposure to levels of between 0.5 and 1% as may be experienced by personnel on a submarine, is likely to increase calcium deposition in body tissues such as the kidney.

Exposure at 1.5% will result in a noticeable increase of breathing and pulse rate. Several hours at this level may cause severe headaches.

Accumulation of carbon dioxide in the body after prolonged breathing of air containing around 2% or greater will disturb body function by causing the tissue fluids to become too acidic. This will result in

loss of energy and feeling run-down even after leaving the cave. It may take the person up to several days in a good environment for the body metabolism to return to normal.
Other symptoms may occur such as severe headaches, dizziness and possible vision disturbance such as speckled stars.
However if the concentration in the cave atmosphere reaches 5% the bodies ability to get rid of its own CO_2 waste, is severely impaired. Shortness of breath and severe headaches are most common. The CCH Australia Ltd. Laboratory Safety Manual indicates that exposure to a concentration of 5% for a period in excess of 30 minutes will cause irreversible effects to health.
If the cave atmosphere reaches 6% and the caver remains in this environment for any length of time the levels of waste CO_2 in the body would reach an extremely dangerous level and could lead to suffocation.
Exposure to 10% CO_2 concentration for a few minutes will result in unconsciousness and suffocation without warning. Extremely high concentrations of 25 to 30 percent will cause coma and convulsions within one minute of exposure.

SIMPLE METHODS OF TESTING FOR CO_2.

A naked flame is a simple method of testing for a low level of O_2 which would indicate an elevated concentration of CO_2 in the cave atmosphere.
The naked flame tests uses any one of the following fuels:- matches, cigarette lighter, candle or carbide lamp. If any one of these items will not light or remain alight, then it is time to get out of the cave. Tests reveal that below approximately 15% concentration by volume of O_2 a flame will not continue to burn. *For more information on this subject, refer to "Naked Flame Tests for CO_2 in Limestone Caves & The Effect of CO_2 and O_2 on Humans", (Smith, G.K., 1997) printed in this conference proceedings.*

WHAT TO DO WHEN ENCOUNTERING CO_2.

A test should be made as soon as foul air is suspected and if a match will not strike or burns only briefly, all members of the party should immediately exit the cave in an orderly manner without panicking. Inexperienced cavers in the group should be especially watched and guided to the entrance.
When undertaking vertical pitches in caves suspected of foul air the first person down should make thorough checks for CO_2. Besides carrying ascenders, a safety belay is a wise option in the event that the first person down may be overcome when suddenly descending into an area of high concentration.
A safety belay should be mandatory with all pitches where a ladder is more than just a hand-hold.
Cavers should only enter areas of foul air during special circumstances, such as search and rescue operations, exploration and scientific work. Under these circumstances special precautions should be taken to ensure the safety of the group. For more information regarding safety precautions refer to ASF Cave Guidelines.

CONCLUSION.

By now you're probably bewildered as to whether the carbon dioxide in caves is harmful to you. The best advice is if you have any of the common side affects of CO_2, carry out a simple match test. If this indicates a high level notify the party leader and the group should vacate the cave.
Carbon dioxide when treated with respect is no worse than the other dangers in caves such as infections of cuts and abrasions, histoplasmosis, hypothermia, equipment failure, becoming wedged in a tight squeeze, trapped or drowning by rising flood waters, sustaining injury from a loose rock dislodged overhead, and loosing your footing or grip on small climbs.
Despite the seemingly endless list of possible dangers, caving is still safer than driving a motor vehicle, which most of us take for granted.

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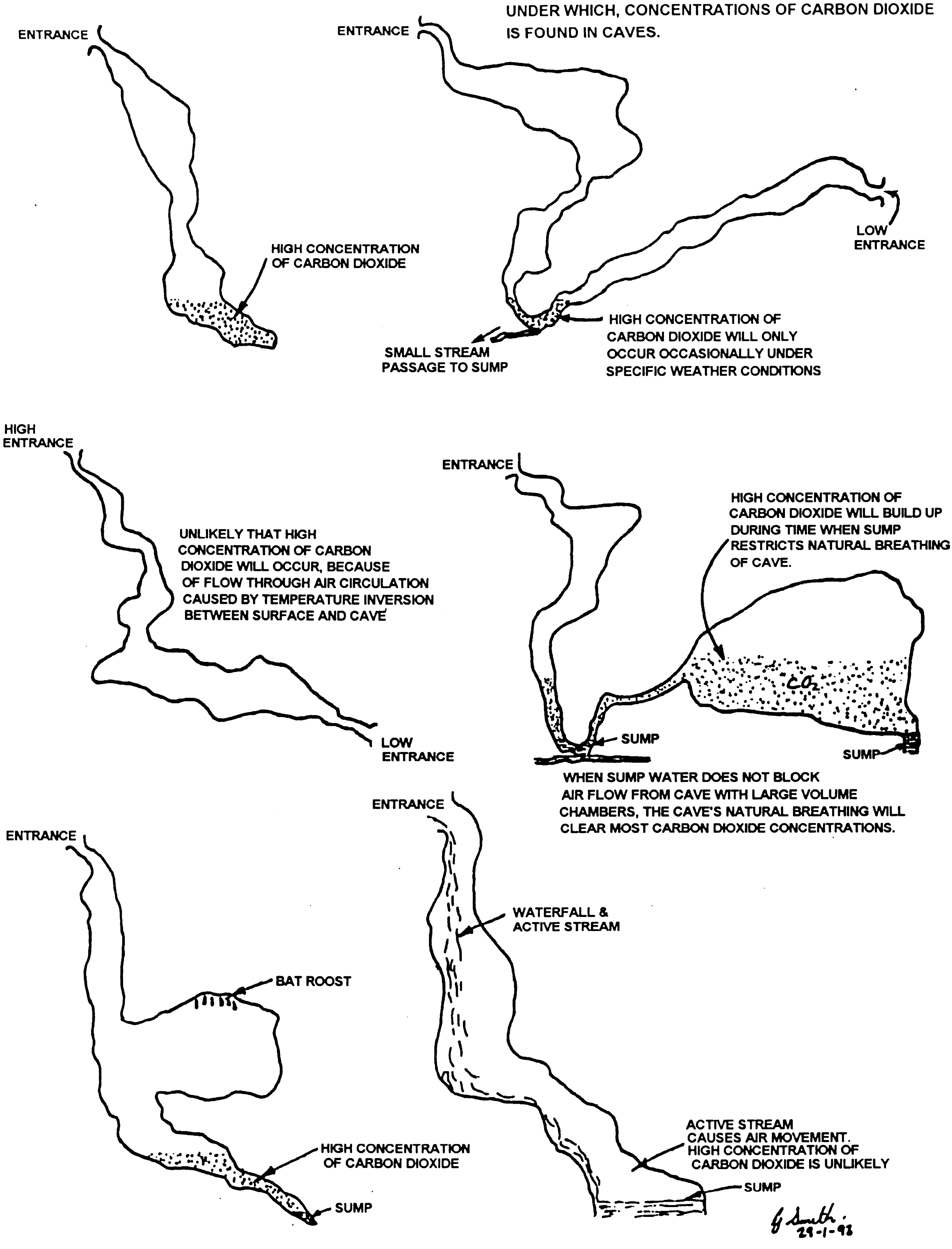
CARBON DIOXIDE IN CAVES

CAVE SECTIONS SHOWING THE MOST LIKELY CONDITIONS UNDER WHICH, CONCENTRATIONS OF CARBON DIOXIDE IS FOUND IN CAVES.



Naked Flame Tests for CO_2 in Limestone Caves & The Effect of CO_2 and O_2 on Humans.

Garry K. Smith.

Cavers are quiet aware that if they are breathing heavily, have a headache or feel tired and lethargic, there may be a high concentration of carbon dioxide (CO_2) in the cave atmosphere which they are breathing. For those without sophisticated instruments, a simple "Naked Flame Test" is often done to verify their suspicion. This "Rule of Thumb" method of measuring the approximate percentage of CO_2 in caves has been used for many years. This raises a number of questions which this paper will attempt to answer. They include:-

- How accurate is the naked flame tests for measuring CO_2 concentrations?
- Are we measuring CO_2 concentrations or low oxygen (O_2) concentration in the cave when a naked flame is extinguished?
- Should we be looking at low oxygen concentrations as the life threatening component of the cave atmosphere instead of elevated CO_2 concentrations?
- Can we add butane fuelled cigarette lighters (eg. common disposable gas type) to the list below?

The simple naked flame methods of testing for CO_2 uses the following indications. *(Australian Caver, 1990).*

1% CO_2 a lighted match will go out.
4% CO_2 a lighted candle will go out.
6% CO_2 a carbide lamp will go out.

To answer the question of, "how accurate is the test", one must first look at the concentrations of CO_2 in caves and the concentrations of O_2 which are required to support combustion of various materials. To find out what is the most life threatening situation (low O_2 or high CO_2), one must look at cave air compositions that the human body can tolerate.

How does CO_2 get into caves and form pockets of high concentration?

As discussed in more detail in the article "Caves, Carbon Dioxide & you", *(Smith, 1993),* CO_2 enters caves by two main methods.

1. In this scenario, CO_2 is absorbed by the ground water as it passes through surface soil containing high concentrations of the gas, due to the decay of vegetation. This water percolates through the rock strata and enters the cave system, usually taking part in the calcite deposition cycle. In this instance the addition of extra CO_2 to the cave atmosphere displaces approximately equal quantities of O_2 and nitrogen (N_2). See *Table 2.*
   Halbert (1982), relates this "Foul Air Type 1" cave atmosphere to the introduction of CO_2 into the cave atmosphere and all other components are diluted - the source of the CO_2 is immaterial. An atmosphere resulting from purely a type 1 process occurs quite slowly and it requires five percent CO_2 to reduce the O_2 level by one percent.
2. In the second scenario the CO_2 is a by-product of organic and micro-organism metabolism or respiration by fauna such as bats or humans. In this instance the oxygen concentration is reduced in proportion to the increase in CO_2. The N_2 concentration stays constant. See *Table 3.*
   Halbert, (1982) "Foul Air Type 2" describes in great detail the relationship between consumption of O_2, and production of CO_2 in the metabolic process of living organisms. Essentially the volume ratio of CO_2 produced to O_2 consumed, called the "respiratory quotient" (RQ) is not constant and can vary between 0.7 and 1, depending on organic matter involved. ie. carbohydrates, fats or protein. If fats were utilised solely in the metabolic process the RQ = 0.7, and would result in a consumption of O_2 with a relatively smaller amount of CO_2 volume being produced in return.

3. The other factor which one has to consider is that in deep caves where air movement is minimal, CO_2 will build up in the lower part of the cave. So, even though the CO_2 may have entered the cave by one of the two above mentioned methods, a very still cave atmosphere may allow CO_2 to sink to the deepest part of the cave and displace O_2 and N_2. Thus building up the concentration of CO_2 to a higher concentration, at the lowest point in the cave. See *Table 4.*
*This **should not be confused** with Halbert's (1982) "Foul Air Type 3", cave atmosphere which has resulted from introduction of methane and nitrogen production and the non-respiratory uptake of O_2 as well as CO_2 stripping by water. Also falling into Halbert's third type is an atmosphere which has resulted from a combination of scenarios 1&2 with addition of another mechanism ("Foul Air Type 3"), which alters the gas concentrations.*
The CO_2 / O_2 relationship in caves has been discussed in more detail by *(Halbert. 1982) and (Osborne, 1981)*

Elements required for Combustion

Before combustion can occur, three conditions must be satisfied.

1. There must be a fuel or substance which can be burnt.
2. The fuel must be heated to its *ignition temperature.* That is the lowest temperature at which combustion can begin and continue.
3. There must be enough oxygen to sustain combustion, either in the surrounding air or present in the fuel.

Statistics of Gases.

Specific Gravities at 25°C grams per litre at 1 atmosphere pressure.	**Molecular weight**	**% in normal atmosphere**
CO_2 = 1.931	CO_2 = 43.99	0.03%
O_2 = 1.404	O_2 = 31.98	21%
N_2 = 1.229	N_2 = 28.01	78%
		0.97% (rare gases)

Therefore we can calculate that at a given temperature, a volume of CO_2 is 1.57 times as heavy as N_2 (43.99/28.01 molecular weight ratio) and that CO_2 is 1.38 times as heavy as O_2 (43.99/31.98 molecular weight ratio).

Calculating the Gas Concentrations in a Cave Atmosphere.

In dry air the total pressure (of a mixture of gases) is equal to the sum of their partial pressures. In simplified terms, the atmospheric or barometric pressure of dry air is equal to pNitrogen (pN_2) + pOxygen (pO_2) + pRare Gases (pRG) + pCarbon Dioxide (pCO_2).
However since a great majority of cave atmospheres contain high humidity, the water vapour component should be included in the equation.
Barometric Pressure = $pN_2 + pO_2 + pRG + pCO_2 + pH_2O$.

Halbert (1982) uses the Cave Air Index (CAI) to characterise gas mixtures found in caves on a dry atmosphere basis. The water vapour component in the calculation, slightly changes the concentrations of CO_2 and O_2, but does not affect the arguments derived from the data. Essentially the water vapour constitutes about 0.5% by volume of a saturated cave atmosphere at 20°C and conversely in a dry atmosphere it would be 0%. *(Halbert, 1982).* For simplicity cave atmospheres may be considered to consist of O_2, CO_2, and a Residue Fraction (RF) made up of rare gases, N_2 and water vapour (H_2O).

Table 1. *Cave air scenario and* correlation with *Halbert's* "Foul Air Type" & Cave Air Index.

Scenario	Foul Air Type *(after Halbert, 1982)*	Cave Air Index
1	1	between 4 & 5
1+2	1+2 combination	between 1 &4
2 and 3	2	between 0.75 & 1
--	3 or 2+3 combination	between 0 & 0.75

Cave Air Index =

$$\frac{CO_2 \text{ Concentration}}{21 - O_2 \text{ Concentration}}$$

The theoretical "Foul Air Type 3", where CAI = 0, is rarely know to exist in caves. In general cave atmospheres with CAI of < 0.75 are regarded as falling into the Foul Air Type 3. *Halbert (1982)* gives the example of "Foul Air Type 3" atmospheres containing 1% CO_2, 17% O_2, and 82% RF and another with 4.5% CO_2, 10.5% O_2, and 85% RF. He points out that a low absolute O_2 concentration does not need to be present. However in practice "Foul Air Type 3" atmospheres likely to be encountered in caves will have low O_2. Also this type of foul air may have deceptively low CO_2.

Some readings at Bungonia suggest a "Foul Air Type 3". They include atmospheres in Grill Cave with a composition of 1.4% CO_2, 12.0% O_2, 86.6% RF which gives a CAI of 0.16 and readings in Odyssey Cave of 2.8% CO_2, 14.5% O_2, 80.3% RF which gives a CAI of 0.43. *(Halbert, 1982)*

Table 2, Theoretical gas concentrations in cave atmosphere. Using scenario 1 with CAI = 4.

Total CO_2 concentration in Cave atmosphere	Total O_2 concentration in cave atmosphere	Total RF concentration in cave atmosphere
1%	**20.75%**	78.25%
2%	**20.50%**	77.50%
3%	**20.25%**	76.75%
4%	**20.00%**	76.00%
5%	**19.75%**	75.25%
6%	**19.50%**	74.50%
10%	**18.50%**	71.50%
24%	**15.00%**	61.00%

Table 3, Theoretical levels of gases in cave atmosphere, Using scenario 2. with CAI = 1.

Total CO_2 concentration in Cave atmosphere	Total O_2 concentration in cave atmosphere	Total RF concentration in cave atmosphere
1%	**20.00%**	79.00%
2%	**19.00%**	79.00%
3%	**18.00%**	79.00%
4%	**17.00%**	79.00%
5%	**16.00%**	79.00%
6%	**15.00%**	79.00%
10%	**11.00%**	79.00%
13%	**8.00%**	79.00%

Table 4, Theoretical concentrations of gases in a cave atmosphere, using figures in the second scenario plus the effect of CO_2 sinking (concentrating) to the lowest point in the cave and displacing approximately equal quantities of O_2 and N_2. This would represent the theoretical worst case CO_2 to O_2 volume percentage (possibly life threatening), which could be expected at the bottom of limestone caves. Using scenario 3. with CAI = 1.34

Total CO_2 concentration in Cave atmosphere	Total O_2 concentration in cave atmosphere	Total RF concentration in cave atmosphere
1%	**20.25%**	78.75%
2%	**19.51%**	78.49%
3%	**18.76%**	78.24%
4%	**18.01%**	77.99%
5%	**17.27%**	77.73%
6%	**16.52%**	77.48%
7%	**15.78%**	77.22%
8%	**15.03%**	76.97%
9%	**14.28%**	76.72%
10%	**13.54%**	76.46%
15%	**9.81%**	75.19%

Levels of O_2 and CO_2 required to extinguish a flame.

In fire fighting terms, the main extinguishing mechanism of CO_2 is its ability to dilute the O_2 concentration in the atmosphere to a level that will not support combustion. If we take the extremes, and add a non toxic gas such as nitrogen, argon, neon or helium, to an atmosphere at about 17% concentration by volume, it will displace O_2 to a life threatening level. *(Safe Handling of Compressed Gases, 1992).* Bear in mind that in fire fighting terms the aim is to dilute O_2 to a concentration which will not support combustion.

From *Table 5*, it can be seen that the addition of CO_2, to dilute the O_2 concentration, will result in a CO_2 rich atmosphere which will not support human life. For this purpose much higher concentrations of CO_2 are present, than would be found in caves.

Nitrogen can also be used to dilute the O_2 concentration, however since N_2 is less dense than CO_2, extinguishing the flame would require almost twice the volume of N_2 to achieve the same result.

Table 5, Minimum volume ratios of CO_2 or N_2 to air which is required to prevent burning of various vapours at 25°C.

Vapour	Carbon Dioxide CO_2/air	The resulting atmosphere from addition of CO_2 would consist of				extra N_2/air	The resulting atmosphere from addition of N_2 would consist of			
		%O_2	**%N_2**	**%CO_2**	**Rare Gases**		**%O_2**	**%N_2**	**%CO_2**	**Rare Gases**
Carbon disulfide	1.59	**8.11%**	30.12%	61.40%	0.37%	3.0	**5.2%**	94.5%	0.0075%	0.243%
Hydrogen	1.54	**8.27%**	30.71%	60.64%	0.38%	3.1	**5.1%**	97%	0.00732%	0.237%
Ethylene	0.68	**12.50%**	46.43%	40.49%	0.58%	1.00	**10.5%**	89%	0.015%	0.485%
Ethyl eithe	0.51	**13.91%**	51.66%	33.79%	0.64%	0.97	**10.66%**	88.83%	0.015%	0.492%
Ethanol	0.48	**14.19%**	52.7%	32.45%	0.66%	0.86	**11.3%**	88.17%	0.016%	0.522%
Propane	0.41	**14.89%**	55.32%	29.1%	0.69%	0.78	**11.8%**	87.64%	0.0169%	0.545%
Acetone	0.41	**14.90%**	55.32%	29.1%	0.69%	0.75	**12.0%**	87.43%	0.017%	0.554%
n-Hexane	0.40	**15.0%**	55.71%	28.6%	0.69%	0.72	**12.2%**	87.21%	0.0174%	0.564%
Benzene	0.40	**15.0%**	55.71%	28.6%	0.69%	0.82	**11.54%**	87.91%	0.0165%	0.533%
Methane	0.33	**15.79%**	58.65%	24.83%	0.73%	0.63	**12.9%**	86.5%	0.0184%	0.595%

Table 5. (After Friedman. R.,1989). Data calculated from tabulations by Kuchta (1985.)

To calculate the final volume percentages of each gas from the (volume ratio) of CO_2 added to air. The following formulae are used.

$R+V=Y$

Where R = *Volume of CO_2 needed to give CO_2/ air volume ratio. (from table No.4)*
V = *Volume of air which CO_2 added to (=1)*
Y = *Total volume of gases when CO_2 and air is mixed.*

To find the percentage of gases in the new atmosphere (which will not support combustion of various vapours because the O_2 has been diluted). Using the known percentage of gases in air. ie. $O_2 = 21\%$, $N_2 = 78\%$, $CO_2 = 0.03\%$ and Rare gases = 0.97% It must be noted that R value must be added to air CO_2 of 0.03%

Gas % (fire retarding atmosphere) = % of gas (in normal air) ÷ Y

Example.
*To calculate the O_2 % in an atmosphere which **will not** support combustion of Propane vapour, CO_2 ratio is 0.41 from chart above.*
Therefore $Y = 0.41+1$
$Y = 1.41$
Gas % = 21 ÷ 1.41 = 14.89% oxygen in the new atmosphere.
(The same calculations can be made for gas concentrations if Nitrogen is added to an atmosphere.)

Looking at the fuel components of the "Naked Flame Test"

Matches.

There are two main types of matches, "Strike-anywhere" and "Safety". This paper will only deal with "Safety" matches as they are the only type readily available in Australia. In general, "Safety" matches can only be lit by striking them across a special surface on the side of their box or packet. The head is made of a mixture containing potassium chlorate, sulphur and other components, which will ignite at a temperature of approximately 182°C. The coating on the box is made of amorphous phosphorus and sand.

Wooden "Safety" matches are generally made of poplar wood, which is dried to reduce moisture content to below 7%, then the "splint" is treated with an anti-afterglow solution (*retardant*) which prevents embers from forming after a flame is blown out. The second stage in production is dipping approximately 10 mm of the tip end into paraffin. This provides a base to carry the flame from the head to the wood. Then the tip (sometimes called a bulb) is added. Some match manufacturers add a final chemical coating that protects the match from moisture in the air.

When a match is scraped across the box striking surface, it begins a chemical reaction between the potassium chlorate and amorphous phosphorus which in turn ignites the sulphur component of the head. The heat generated in the head vaporises the paraffin coating on the splint and the flame is drawn down from the head. Moisture is driven out of the timber, the retardant is burnt off, allowing the wood volatiles to vaporise and ignite. The head will fizz and not burst into full flame when there is a lack of O_2 in the atmosphere, since it is burning due to the O_2 in the potassium chlorate contained in the head.

Book matches are a type of "Safety" match made of heavy paper (called *paperboard*) and the row or rows (called *combs*) of matches are bound into a paperboard cover. The paperboard is also treated with an anti-afterglow solution and paraffin as with wooden matches. *(The World Book Encyclopedia, 1992).*

Candles

A candle burning in an area without draft will produce a steady flame. The flame's heat vaporises just enough candle wax to keep the flame burning at the same height. This is influenced by the length and type of wick and the type of wax. The wick serves as a place for the flame to form. When lit by another heat source, the heat from the burning wick melts the wax at its base and the liquid is drawn up the wick to the flame by capillary action. The heat in the flame vaporises the molten wax which then burns. Most candles today consist of beeswax or paraffin. The latter being the most common.

Paraffin is a wax obtained from petroleum and is a mixture of hydrocarbons which melt between 32 to 66°C and vaporises at between 150 and 300°C.

Cigarette Lighter (Butane type).

Butane is a colourless, flammable gas which can be readily kept in a liquid state while under pressure at ordinary temperatures. Once the pressure in the lighter reservoir drops below 265 kPa at 25°C, the liquid butane begins to vaporise until the pressure increases to an equilibrium point and further vaporisation ceases. When the lighter is operated, gas from the reservoir is liberated through a fine jet and a hot spark from the flint easily ignites the gas. Ignition temperature of butane can vary between 482 and 538°C, however the hot flint spark is sufficient to begin combustion of the gas. At atmospheric pressure the normal vaporisation point of butane is -0.5°C.

Laboratory Combustion Tests

To verify the O_2 concentrations required to support combustion of matches, candles and cigarette lighters, a series of tests were conducted in a controlled atmosphere chamber. A large inflatable glove chamber made of clear plastic was filled with normal atmospheric air. The "Glove Bag^{TM}" Model X-37-27, was pre-loaded with all the components required for the experiment, then sealed from the outside atmosphere. A stand was used to hold a burning candle and another stand held a mini video camera (ELMO 120 with 15mm lens). The chamber full of normal air, was then purged with argon to reduce the O_2 concentration. The O_2 concentration (as % by volume) was measured using a Teledyne Portable Oxygen Analyzer, (Model 320). A small bleed line, vented excess hot air and fumes from the chamber as the argon gas reduced the O_2 concentration. At each 0.5 % drop in O_2 concentration, four separate matches ("Kangaroo" brand) were lit and a video recording made of their burning. The lowest O_2 concentration reached in the chamber was 7.5%.

When the match tests were complete, the chamber was slowly re-filled with fresh air and a butane cigarette lighter was struck at each 0.5% rise in oxygen concentration. The level at which the butane would remain alight was noted. Then the O_2 concentration was reduced to verify the exact percentage which would extinguish the flame. Both ignition and extinguishing of the flame occurred between 14.25% and 14.5% O_2.

The atmosphere in the chamber was then returned to normal atmosphere air and a candle lit. Argon was slowly purged into the enclosed atmosphere until the candle went out. This occurred at an O_2 concentration of 15%.

The results of the tests are summarised in *Table 6.*

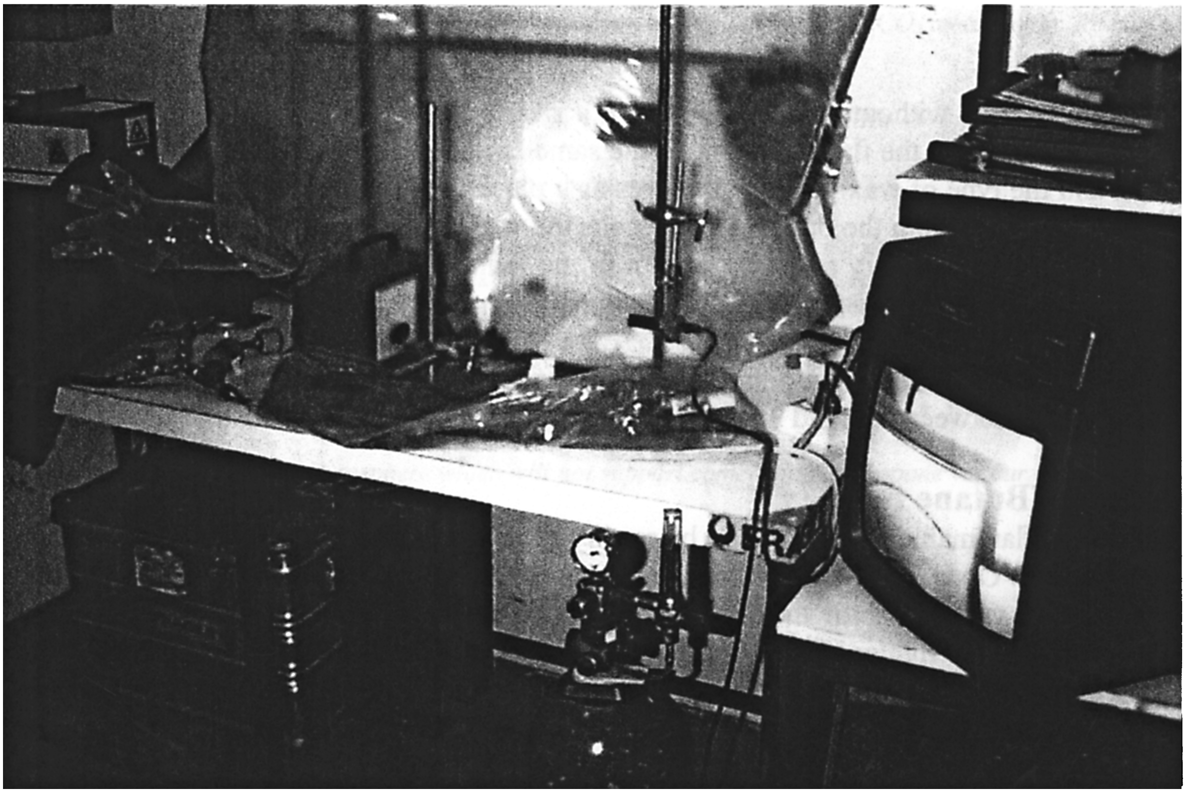


Figure 1. Testing setup using a Teledyne Portable Oxygen Analyzer, and large inflatable glove chamber to measure oxygen concentrations which would extinguish various fuels. ie matches, candles and butane cigarette lighter.

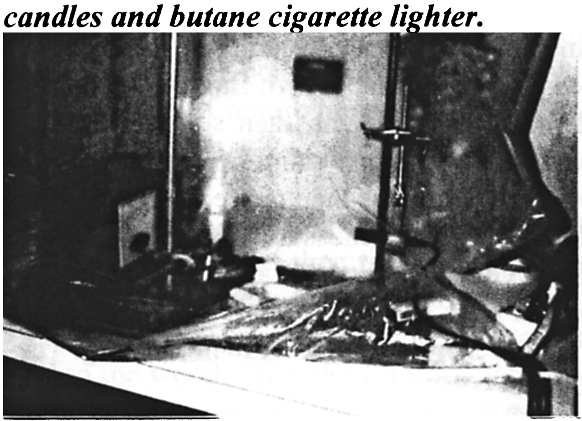


Figure 2. Closeup of experiment. Note, mini video camera - centre right.

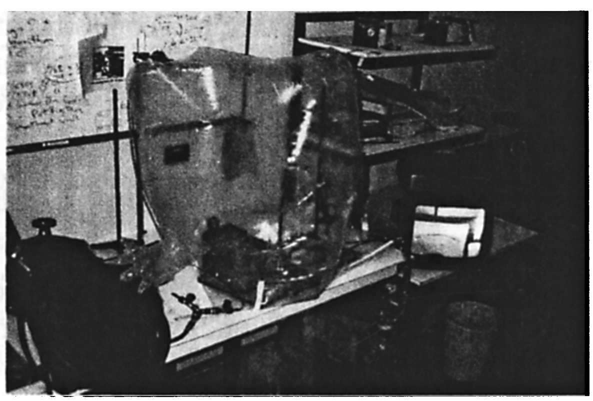


Figure 3. Overall view of experimental setup. Video recorder and argon gas bottle on right

Results of the Test.

On the whole the match tests were very consistent, with about half a percent variation in the O_2 concentration required for the ignition of paraffin on different matches from the same box observed. The test with "Kangaroo" brand matches (made in Sweden) did not show any sign of fizzing slowly like a sparkler as I have seen in the cave environment. One can only assume that the matches used in a cave on those occasions had absorbed some moisture which retarded combustion of the match head or that different brands behave differently because of variations in retardant or head composition. The candles and butane lighters were extremely sensitive to changes in O_2 concentrations at their critical combustion points.

Table 6. Gives condition of flame in relation to percentage of oxygen in the controlled atmosphere.

Match	Candle	Butane lighter
21% - 18% easily burns all of match .	>19% normal flame.	
17.5% Burns head and flame transfers down paraffin to wooden splint on most occasions	17% - 16.5% burns with elongated flame.	
17% - 16.5% ignited head and on nearly every occasion, burns down onto paraffin coating then extinguishes.	16.5% - 16% flame begins to shrink, but candle remains alight.	
16% - 15.5% ignited head just ignites paraffin coating on splint (some matches only)	16% burns slowly with small flame	
15% - head burns briefly with whispery flame & goes out.	< 15.0%, A burning paraffin candle is extinguished.	> 15% O_2, A Butane Cigarette Lighter can easily be lit and will stay alight.
		14.5% - weak blue flame with orange top, just stays alight
		<14.25% - Flame will extinguish
14% match head burns very briefly & goes out.		14% - 13% Large flashes of flame but will not stay alight.
<13% head flares & extinguishes immediately (less than 0.5 seconds)		12.5% sparks with partial ignition, small fireballs
		<10% - no ignition, only hot sparks from flint.

Should we be looking at O_2 deficiencies as life threatening while underground?

If we consider an atmosphere consisting of just N_2 and O_2, where the O_2 is at a lower concentration than the normal atmosphere, the human body would be affected in the following manner. *(Laboratory Safety Manual, 1992)*

- O_2 reduced from 21 to 14% by volume. First perceptible signs with increased rate and volume of breathing, accelerated pulse rate and diminished ability to maintain attention.
- O_2 concentration between 14 to 10% by volume. Consciousness continues, but judgment becomes faulty. Rapid fatigue following exertion. Emotions effected, in particularly ill temper is easily aroused.
- O_2 reduced from 10 to 6% by volume. Can cause nausea and vomiting. Loss of ability to perform any vigorous movement or even move at all. Often the victim may not be aware that anything is wrong until collapsing and being unable to walk or crawl. Even if resuscitation is possible, there may be permanent brain damage.
- O_2 reduced below 6% by volume. Gasping breath. Convulsive movements may occur. Breathing stops, but heart may continue beating for a few minutes - ultimately death.

The above data indicates that very little difficulty is caused by short-term exposure to O_2 / N_2 mixtures down to about 10% O_2. From *Tables 5 & 6,* it can be seen that the percentage of O_2 which will just not support combustion is approximately 15%. This is well above the concentration which will support human life. In *Tables 2, 3 & 4,* the theoretical cave atmospheres contain sufficient O_2 concentration to support life, however the CO_2 concentrations is sufficiently high to be dangerous to cavers, see *Table 8*.

The Le Chatelier's principal.

This states that *"any system in equilibrium shifts the equilibrium, when subjected to any constraint, in the direction which tends to nullify the effect of the constraint"*.
If the example of a Butane (cigarette lighter) flame is used.

Butane + Oxygen $\longrightarrow$ Carbon Dioxide + Water

$$2C_4H_{10} + 13O_2 \longrightarrow 8CO_2 + 10H_2O$$

Simply this means that if the CO_2 concentration is raised and /or the O_2 concentration is reduced, then the reaction will slow down and eventually stop. The CO_2 concentration will have a much lesser effect than the O_2 concentration. The experimental data and that of *Kuchta (1985)*, indicate that a 1% increase in CO_2 concentration will raise the O_2 concentration required to support combustion of a given substance by less than 0.05% O_2.

In the majority of cave atmospheres it is the low concentration of O_2 which stops this reaction, not the high concentration of CO_2.

Properties of Carbon Dioxide (CO_2).

Even though CO_2 is 1.57 times heavier than nitrogen and 1.38 times heavier than O_2, it will have a tendency to disperse in an isolated volume of air, due to molecular diffusion. In other words a mixture of gasses will not separate into layers of various density gases if they are left for a long time in a still chamber. On the other hand various gasses purged separately into a closed container will become uniformly mixed over a period of time. A possible explanation of the high concentration of CO_2 in deep caves (with a relatively still atmosphere), is that CO_2 is being produced metabolically or entering the cave via ground water at a greater rate than the gas can diffuse into the cave atmosphere, thus settling at the bottom of the cave because it is a dense gas.

Carbon dioxide is "regarded as a `hot gas' due to its low thermal conductivity, heat is not conducted away as rapidly as in normal air, so a person standing in it feels warm about his lower limbs". *(Strang, 1990)*

How fire fighting research is aiding cavers.

A paper by *(Fields, 1992)* studies the use of a new fire extinguishing gas mixture, designed to be used in enclosed spaces. While the actual percentages are not given in the paper, the gas called "Inergen" appears to consist chiefly of argon (Ar) with some CO2 added. The function of the gas mixture is to reduce the ambient oxygen concentration to less than 15%. The study then goes into great detail about the affect on human life when the O_2 concentrations are reduced to between 15.0% and 12.4%, while the CO_2 concentration is increased to between 3.1% and 4.3%. The research found that the addition of CO_2 was beneficial as it induced an immediate and sustained stimulus to increase breathing rates of persons caught in areas flooded with this gas mixture. It was the increase in CO_2 and to a much lesser extent the decreased O_2 which stimulated the respiratory response. For fire fighting "Inergen", would be injected into an enclosed space at between 0.4 and 0.7 cubic metres for every cubic metre of room volume. At 40% dilution there would be 3.1% CO_2 and 15.0% O_2, while at 70% dilution there would be 4.3% CO_2 and 12.4% O_2. The paper concludes that the elderly or people with heart diseases (eg. coronary artery disease) but not heart failure would be at some risk of clinically significant hypoxia when breathing 70% Inergen mixture at sea level, but not when breathing a 40% mixture. The use of Inergen was considered at altitudes with barometric pressure down to 650mm Hg, (Sea level atmospheric pressure $\approx$ 760mm Hg). There was an overall increase in risk, however not significant enough to warrant a change in the mixture. At sea level an average healthy person would be at low risk of suffering any affects other than reducing their capacity for physical exertion, to less than half the maximum they could normally sustain while breathing fresh air.

An increase in CO_2 would cause increased breathing rates and could impose serious limitations on the degree of physical exertion achievable by a person with lung disease, cardiovascular disease, anaemia or carbon monoxide poisoning.

One thing lacking in this paper is any real mention of time scales of exposure to this concentration of CO_2 and O_2.

Table 7. The % volume, composition of the two Inergen / air mixtures.

	40% Inergen in air	70% Inergen in air
Resulting volume % of gases in atmosphere which will extinguish fire	N_2 = 70.0 %	N_2 = 66.5%
	Ar = 11.4%	Ar = 16.4%
	CO_2 = 3.1%	CO_2 = 4.3%
	O_2 = 15.0%	O_2 = 12.4%
	Trace gases = 0.5%	Trace gases = 0.4%

After Field., 1992,

Interesting phenomena with cigarette lighter in O_2 deficient air.

A cigarette lighter when lit in an atmosphere which will support combustion of butane will burn with the flame extending directly from the jet. When this lit cigarette lighter is slowly lowered into an atmosphere that will not support combustion (lower O_2, higher CO_2 concentration), an interesting phenomena occurs. The flame will magically stay burning where the atmosphere will support combustion, just above the interface between the high and low CO_2 concentration, while the lighter is several centimetres below the interface.

In the CO_2 Pit of Gaden Cave (WE-2), a demonstration by Mike Lake showed that the flame extended to about 100 mm above the lighter as it was gradually lowered into the higher concentration in the Pit. At one stage a 25mm high flame flickered some 75 mm away from the lighter. Because of the low concentration of O_2 (proportional to high concentration of CO_2) there was no flame for the first 75mm out from the lighter jet.

This phenomena can not occur with the other solid fuels, such as matches and candles, as the heat from the flame is required to vaporise the volatiles which then burn.

A cigarette lighter which does not have adjustment for the flame can also be used to some degree to check for low O_2 concentrations. A subtle change in the flame height occurs as the O_2 concentration decreases. A longer flame indicating that the O_2 concentration is decreasing. This test is probably more desirable than the matches or candle method as unpleasant odours are not produced. However this method is not recommended for the novice as it requires some experience for reliable interpretation.

Why should we be aware of CO_2 concentrations?

Gases which create a hazard simply by displacing oxygen are called simple asphyxiants. However it is not the lack of oxygen in a cave which causes the physical symptoms or in extreme cases death, rather it is the increased concentration of CO_2. For example a person can survive several hours in an atmosphere with 3% CO_2 and 12% O_2. On the other hand an atmosphere of 8% CO_2 and 18% O_2 **could** result in suffocation and death within a few minutes. The exact percentage and timing will depend on the individuals physiological makeup and tolerance, however several minutes exposure to a concentration of >10 CO_2 will certainly result in death. For instance exposure to 25% CO_2 or greater, will result in death within one minute, even if there is 20 % O_2 in the atmosphere.

The *"Laboratory Safety Manual (1992)",* quotes 0.5% CO_2 as the `Threshold Limit Value Time Waited Average' (TLVTWA). This is the concentration to which a person may be exposed, 8 hours a day, 5 days a week, without harm. The manual also quotes 5% $CO_2$ and above as being `Immediately Dangerous To Life and Health' (IDLH). This is the concentration that will cause irreversible physiological effects after 30 minutes exposure.

Effect of CO_2 on the Human Body.

Exposure to just 1 to 2% CO_2, for some hours will result in acidosis, even if there is no lack of oxygen. This acid-based disturbance will occur in the human body when the increase in partial pressure of CO_2 (pCO_2) is greater than 44mm Hg.* Acidemia will result and secondary mechanisms are initiated by the body that attempt to prevent drastic changes in pH and tend to return the pH toward normal. "Intracellular buffering, via red cell haemoglobin, phosphate, and protein, exchange intracellular sodium and potassium for the excess extracellular hydrogen ion. In addition, hypercapnia leads to an increase in renal hydrogen ion secretion and net acid excretion, as well as an increase in bicarbonate reclamation. Although this response begins early, the maximum effect takes several days." *(Clinical Management of Poisoning & Drug Overdose).*

Table 8. Generally accepted physiological effects of CO_2 at various concentrations. *(Strang, 1990)*

Concentration	Comments
0.03%	Nothing happens as this is the normal carbon dioxide concentration in air.
0.5%	Lung ventilation increases by 5 percent.
2.0%	Lung ventilation increases by 50 percent, headache after several hours exposure.
3.0%	Lung ventilation increases by 100 percent, panting after exertion, headaches.
5 - 10%	Violent panting and fatigue to the point of exhaustion merely from respiration & severe headache. Prolonged exposure could result in unconsciousness and death.
10 - 15%	Intolerable panting, severe headaches and rapid exhaustion. Exposure for a few minutes will result in unconsciousness and suffocation without warning.
25% to 30%	Extremely high concentrations will cause coma and convulsions within one minute of exposure.

Treatment for exposure to CO_2

For persons exposed to high concentrations of CO_2, remove to a well ventilated atmosphere, keep the person warm and avoid exertion. In severe cases administer oxygen if available but be aware that vomiting and nausea often follows. Persons who have been exposed for short periods, generally recover without serious after effects.

Conclusion

If a paraffin candle which is alight and is then moved to an atmosphere in a cave which will not support combustion, the flame will be extinguished. From *Table 5*, it can be seen that a controlled atmosphere with about 15% O_2, will not support combustion of a number of organic compounds. The laboratory test results in *Table 6*, confirm that 15% O_2 extinguishes a paraffin candle when argon is used as the diluting gas. In *Table 7*, a fire fighting company recommends the use of a gas mixture which when released into confined areas will dilute the O_2 to 12.4% and increase the CO_2 to 4.3%. This is sufficient to extinguish general fires and sustain human life without long term adverse effects. In both cases, reducing the O_2 concentrations from normal atmospheric 21% O_2 to below 15%, appears to be sufficient to extinguish a flame. From *Table 3*, it can seen that a cave atmosphere with a concentration of 6% CO_2 could theoretically result in a 15% O_2 concentration where organic metabolism has been the major contributor to gas concentrations. This O_2 concentration is the same as that which the match head and butane cigarette lighter extinguished.

It would appear conclusive that the flame test is measuring primarily the O_2 concentration and that the CO_2 concentration has a much lesser influence. The accepted CO_2 concentration from "Naked Flame Test", adopted as the ASF Cave Safety Guidelines, 27th Jan. 1990 (Australian Caver 1990) are essentially meaningless other than to indicate an atmosphere which could be hazardous or life threatening .

The rule of thumb "Naked Flame Tests" using different fuels appears to be a very accurate indicator of the O_2 concentrations in a cave. The O_2 concentration being an indication in most cases, of the elevated CO_2 concentration. In general a high CO_2 concentration is the most life threatening situation encountered underground while a life threatening low O_2 concentration, is encountered to a much lesser extent. Therefore a flame test is not an accurate measure of the CO_2 concentration in a cave, but merely an indicator that there is an elevated concentration.

In the worst case limestone cave atmosphere scenario *(Table 2)*, O_2 at 15% correlates with 24% CO_2. This concentration of CO_2 is particularly life threatening despite the O_2 concentration being within human survival range. However in practice, cave atmospheres of this type, tend to be made up of a combination of scenario 1 & 2 and would have a Cave Air Index of between 1 and 3. This still results in an extremely dangerous CO_2 concentration at the critical flame extinguishing concentration of 15% O_2.

Without sophisticated measuring instruments, one can only speculate about the exact concentration of CO_2 in a cave, so if any one of these flame indicators will not burn, it is time to get out.

If sophisticated measuring equipment is not available, the best advice is to carry out a "Naked Flame Test" when you or a member of your group experiences the first signs of labored breathing, headaches, clumsiness, loss of energy or any of the other signs associated with elevated concentrations of CO_2. Ideally cavers should become aware of the subtle changes to a cigarette lighter flame associated with O_2 concentrations down to 13%. This will reduce the amount of unpleasant fumes emitted from matches burnt by people experimenting in the confines of a cave. The best advice is, "If in doubt, get out", in an orderly manner.

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Redeveloping A Show Cave

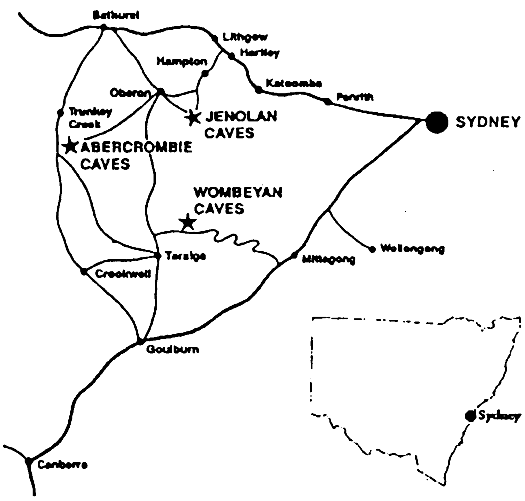
RimPoolArea - Junction Cave

JUNCTION CAVE

by Terry Matts, Junction Cave, Wombeyan Caves , NSW
Administered by the Jenolan Caves Reserve Trust

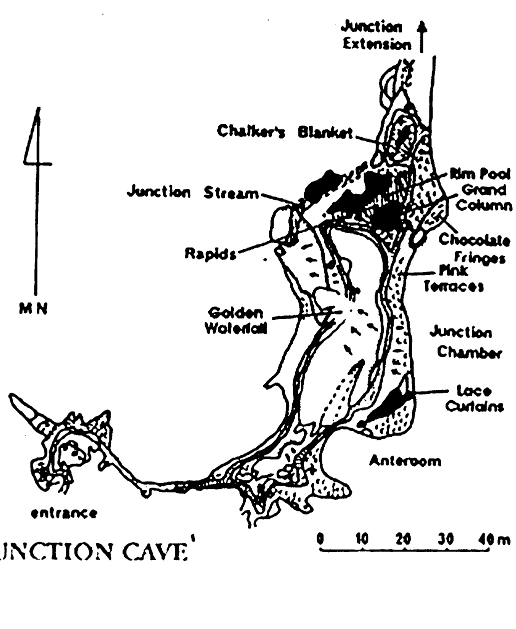
Introduction

Junction Cave is found within the Wombeyan Caves Reserve, north of Goulburn in the Southern Highlands of NSW.



The cave was discovered in 1897 and opened to the public nine years later. The early opening to visitors meant a lack of knowledge about the cave - with no formally made paths. Visitors could walk, stand or climb on any parts of the cave, dirtying much of the formations either by hand or foot.

A stream in the cave drains the Wombeyan Valley, a surface area of about thirty-six square kilometres, and also picks up seepage. The cave is the final path of that stream before the water finds its way out to Mares Forest Creek.



JUNCTION CAVE'

The water course, moving through a restriction at the bottom of Junction Chamber, 1m by 400 mm, creates an impedimence causing the system to fill with water, flooding sections of the developed cave. This slow moving and slow draining water, standing for many hours, allows silt and sediment to settle from the water on to the formations. Any flowstone, with water flowing over it as the water recedes, is self-cleaning.

The cave was first lit in 1928, by two diesel power plants in the valley, which produced 415 volts reduced to 110 volts, 55 volts each side. All electrical work complied with the Department of Mining regulations. There was only sufficient power produced to light the pathways. Features still had to be lit with magnesium. Lead sheathed cables were used with knife blade switches. In 1958 power was brought in from the state grid supplying more power and allowing more lights. Cables were replaced with building wire, which has a plastic outer sheath (known as T. P. S. by electricians). Cables were spliced together, soldered, then coated with pitch and covered with PVC tape to seal out the moisture. Features were lit using copper bowls, chrome plated and polished, with 100w globes mounted in them . Wiring was fixed to the walls by drilling a small hole and cementing in a short length of copper wire, which supported the cables. Lights were mounted on steel posts and fixed to the cave wall in the same manner. These installations were clearly visible to the visitor.

The aim of relighting was to conceal as much of the infrastructure as possible, hiding lights, circuit breakers and wiring.

Power

The power enters the cave via a main, going through earth leakage circuit breakers at three points, powering the lights through the C Bus system which controls the lights for five interpreted areas.

All circuit breakers are in moisture resistant boxes, and the use of glands on the wiring, keeps out any condensation or seepage.

To aid with cave aesthetics, cables were placed in as many side passages or under the pathway where possible .

Three differenct voltages were used.

The move from 110 volts to 240 volts provides access to a greater range of electrical accessories such as earth leakage circuit breakers to protect people in the cave, a lightning arrestor to protect the cave electrics. Dicroic globes are available to illuminate the cave with a white light. These items are available over the counter, at any electrical wholesaler.

Transformers are utilised to reduce the voltage to 12 and 24 volts.

One of the advantages of this, is the ability of caves staff to connect or repair defective lights safely without the need for a electrician.

In addition, smaller fittings and globes can be used, which are easier to conceal in fluted shawls and other difficult areas. Reduced diameter wire can also be utilised, which may be colour matched , by using white, grey and black wire, to the cave environment.

A small 12 volt light, with a narrow beam was required to light Chalkers Blanket. The light was mounted on a ledge to the side, some distance away and directed between the Blanket and a shawl-stalactite behind Chalker's Blanket.

As the cave is at the end of the overhead cables, emergency lights have been fitted for safety in the event of a power outage.

The C Bus by Clipsal

(I hear you say, "What is C Bus?")

Clipsal Data Bus Line

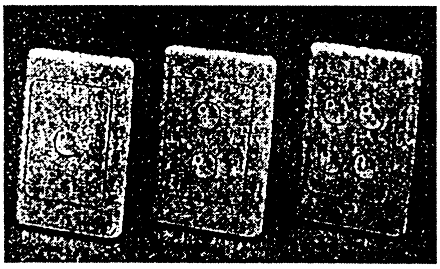
It 's a micro processor, controlled wiring system that uses unshielded telephone cable as its communication medium, which can control lighting, air conditioning, fire detector systems, access control systems, security and other applications in buildings, as well as, in our case, caves.

Each device communicates on the Bus and has its own in-built-micro-processor.

Information comes from Input Units, such as touch pads, remote control units, light level and passive infra-red sensors. Messages are sent via the Bus to the appropriate Output Units such as relays and dimmers. Messages control the loads connected to the Output Units.

We Chose the C Bus system as it has more potential and less control cabling than others. It enhances the visitors' experience as they are less distracted by obvious wiring. One can be face to face answering questions, then use the remote control, switching lights on as desired.

Each guide carries a remote control. This enables staff to control lights without moving to touch pads (key input modules). Touch pads are not needed in the cave, but in the event a remote is lost or becomes inoperable, a guide can continue the tour by using these touch pads.



The C Bus can be connected to any other C Bus items, being easily programmed with a laptop, to dim or switch the lighting system. A main switch at the entrance kills all lights that may have been left on, once a tour is completed.

See abstract 1 & 2.

Lighting

We decided on a new light from Sylvania. Halogen lights are reputed to last longer and fit a standard 120w Outdoor Liteflood from Phillips. Globes that were used, come in 25° flood, 10° spot, 50w, 10° spot and 25° flood 75w. Having a Dicroic reflector gives very good white light without the low voltage problems. Other lights used were 300w and 500w flood lights.

The halogen gives good light for features, while the flood lights are best suited to larger areas.

Thorn's Multibeam Dynaspot transformer light combination12v 50w is only used once in the cave. This lights Chalkers Blanket but suffers problems with moisture.

The 24 volt lights were put to use in confined areas - small fittings, globes and a reduced circumference wire, are ideal for places where the installation is right in the visitors line of sight and needs to be hidden behind small shawls and other delicate places.

Flood light fittings, also known as Flexifloods have been used, mounted on different junction boxes, fitted with glands to give a water resistant seal. Fitting heat resistant tube to the front of the lights stopped any cross glare when looking over or at the lights. To do this agricultural drainage pipe was used, as we were unable to locate any suitable fittings. We had to reduce the diameter ; hold it with cable ties and then force it over the globe. Lights have been positioned so the light will bounce off the walls and features to light the paths.

Repairs and New Pathways

Very little pathway had to be repaired as most of the floors are formed in naturally occurring sediments.

Some new paths and steps were added for safety and some risers were reformed due to wear. Much of the path work was done to stop dirt on the paths finding its way on to any formations. Work in the Rim Pool area included removal of the path in the main Rim Pool and replacing it with a bridge. Aluminium products were used for ease of construction. It was prefabricated in Taralga, manhandled into the cave and assembled on site.

Cleaning

From 1910 little attention was paid to visitor traffic, consequently, there were areas that were covered in mud. The cleaning task here, was a little different to that at Jenolan Caves. The formations at Jenolan become covered with lint from clothing, dust, and mud splashed from visitors shoes.

As this was Junction's first clean, the main problem was the cleaning of areas that had suffered from visitors walking randomly over the cave.

After the electrical work had been completed, cleaning of the Pink Terraces side of the Grand Column was tried first. This area would have been a high traffic area in the candle-lit days, as this was the route to the Wishing Pool area.

Water was pumped up six metres from the stream to a Gernie High Pressure Water Cleaner using a turbo head, then the nozzle, after the turbo head failed.

Starting high and washing down, we were surprised how easily the hand marks and most of the foot marks were cleaned. The dirt on the flowstone and in the rimpools was found to be sediment from flood waters that had been compacted into the rimpools by the traffic of many feet. This was removed fairly easily with the high pressure cleaner.

Moving into the Rim Pool area (formally known as the Wishing Pool), it was necessary to commence a little higher. The Rim Pool is six metres above the stream, lending this area to being syphoned. The sediment and gravel from the small gaps in the crystal came out with the dirty water. Some upper areas are covered with bat guano , natural to the cave, which we didn't want to disturb. An area of flowstone around this side of the Grand Column was guano stained and broke away in very small pieces when it was cleaned, so cleaning was stopped.

The pathway through the Rim Pool, once removed, left dirt and small stones. Once this was removed and a general clean done, it was apparent that the Rim Pools had been lined with cement. Possibly, it filled with mud in a flood and it was easier to cover it than clean out the mud? Maybe it was to get the coins out easily? Or so it held water longer after rain? No one on the staff at this time has any idea why.

This was the biggest job. A decision had to be made whether to remove the cement or leave it. After a little chiselling (I see you cringe) and much standing and looking, it had to go. By chiselling carefully the cement would come off the pool floor with little or no damage, as a thin layer of mud was under the cement. This helped to protect the pool crystal. The half metre or so that I did, proved it would take a long time. I encouraged (conned) two good friends into having a week off work and spending four "fun-filled" days in the main pool, chiselling small areas, rinsing and syphoning the mud and fine sediment. A 15mm diameter hose with a fitting in the pickup end to stop the hose getting blocked with gravel was utilised. All the cement has not yet been removed. It may be continued later but at this stage it is used as part of the interpretation of the area.

When all the cleaning around the Rim Pool area was completed, the Pool was filled with water, and then siphoned out three times to rinse it. After the rinsing a skull and many bones were found in the crystal under the removed pathway. Completely undamaged it may have been protected by the old path.

While this was taking place, cleaning continued on the main wall of the pool and the area under Chalkers Blanket. This was heavily used by early visitors, to gain a view of the Blanket. Where this flow meets the floor there was an additional area of path, which was found to cover two rim pools; one of these was cracked. Once emptied of rock and dirt, one of the pool walls broke away and is now in need of repair. Bones of a small animal were found under this cleaned area of path. Some other rim pools nearby had been levelled to make the path, which were also cleaned. The path was topped with cement and suspended over the cleaned pools.

Towards the Junction Extension, the area to the left was mainly covered with sediment from floods. This was difficult to clean as the area above it is moon milk. When hit with pressurised water it cleans off the mud splashing the moonmilk and leaving spots. We found that standing well back and letting the mist off the pressure water clean the moonmilk, would remove the spots . Strict attention to the procedure and much patience was required to ensure the moonmilk was not damaged.

Under some of the mud was coral . On some of this, in the crystal were found bat bones, including a skull. The path was dirt. This and a small area under Chalkers Blanket were cemented with a slope to keep the water on the path, and pipes were placed under the pathway to allow water to continue over the flowstone. Raised edges were added to the original steps, to help keep this area clean.

The Pink Terraces were next. They are located beside the Grand Column steps, extending to the Junction Chamber. About ten metres long and six metres high, only the lower metre or two were cleaned; again, hand and foot marks were removed.

The flowstone and rimpools at the Junction Chamber end, had been well trogged and in fact, had the appearance of a dirt floor. After cleaning, the results were extremely rewarding, with formations returned to near original condition. Additional handrail had to be added to protect this new piece. The edges of the pools are broken and much of this washed away when cleaned. Unfortunately, these pieces were too small to repair.

Putting a thin cement floor from Junction Chamber to the Grand Column steps along the base of the Pink Terraces will stop mud splashing on the wall and flowstone, keeping the path clean into and around the Rim Pool area.

Cleaning the lower Lace Curtains was mainly completed to remove the foot marks and debris left by people fitting lights to the shawls of the curtains in 1960. Lower down, handmarks were removed. The floor below the Lace Curtains is covered in small rimpools. These were full of compressed mud and formed the pathway.

A pathway was added to stop dirt walked in on visitors shoes, from getting into the rimpools. The path was formed over rubble so the water can run under it. If the rubble clogs with crystal, the water can run though polypipe also placed under the path in many places. These rimpools have had three trial spots cleaned. This area will clean very well when time allows. Drainage on the ladder to keep the water on the path will keep this whole area clean.

In the Ante Room, the pump wouldn't lift enough water to the pressure cleaner, which at this point, was sixteen metres above the stream. A trickle of water from the pump hose filled twenty-litre drums which were carried up fifteen steps to the platform, the highest chamber in the cave.

The Ante Room was well walked. After removing rock fragments larger than 20mm in size, the rest had to be washed off. Vacuuming couldn't remove the dirt, as it was well compacted. Pressured water was the only way to remove it and some two hundred drums of water were moved around, supplying the pressure cleaner.

Cleaning started, where dirt and rubble stopped and flowstone began. A path went up into the rubble leading to another section, which is now closed. Cleaning of the Ante Room took some time. So much dirt came out of the flowstone, cleaning was stopped every metre to remove it.

This chamber now has visible flowstone over all the floor area. The paths in and out of the Ante Room as well as walls on either side, were cleaned. An area of stalactites after the ladder out of the Ante Room was washed. Most of these stalactites had been broken and could contain mud. No matter how many times they were washed brown water would run off.

Fences

There was very little fencing, other than at steps and high areas, which were for the protection of visitors. Most of these were either too high or too low. No protection for flowstone on the floor, next to paths was provided. Consequently these areas would still be walked on, if not by visitors then by staff.

The addition of fences around much of the paths, was to stop visitors walking on formations. Replacement of almost all the old fencing was mainly due to rust. The majority of the netting was in good repair but the fittings had rusted. The bottom of the netting wasn't secured well with the netting left touching the pathway, causing it to rust.

Strainers were replaced or added and the netting re-tied. This tidied up the fencing and saved replacement of the wire netting.

Problems We Have Encountered

Possible Environmental Impacts.

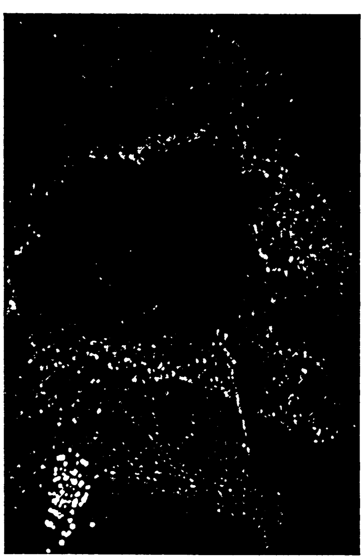
The new cable is coated with agents, possibly to assist in manufacture. This coating seems to form a mould when in the cave, making the wire go black. This stands in contrast to the environment, a possible solution may involve washing the cable before use in the cave.

Carrying all the material in, may import life from the outside. Around some of the lights can be found dark spiders in webs usually found outside.

Low voltage lights are not sealed. Corrosion on the pins of the globes may be from the damp air, causing electrolysis.

What are the effects of aluminium on the cave? This should be monitored to prevent any permanent damage to the cave.

Interestingly, the water in the stream has a very high calcite content. This is detrimental to water cleaners, wearing out the turbo nozzle in ten minutes and also lowering the pressure produced by the cleaner. The intake hose quickly became encrusted with calcite, this resulted in the turbo head twice being replaced by Gernie at no cost.



Stopping the cross glare. We used agricultural drainage pipe for a temporary fix. We are still looking for something to do the job.

Some Redevelopment at the Jenolan Caves Reserve

The Diamond Cave, part of the Imperial Cave at Jenolan Caves, is also being redeveloped. This branch has fences at differing heights, enclosing the path. It was also originally lit with 110 volt lights. Both lights and wire were clearly visible.

This section was totally stripped. Only the original path remained. This allowed the frame enclosing the path to be replaced at a standard height, removing a Health and Safety problem. 240 volt globes and fittings, as used in Junction Cave at Wombeyan, switched again with C Bus and infrared remote controls were installed. Wires were run and lights fitted to the frame which was replaced to hold the netting. Plastic fish netting is being trialled, in an attempt to decrease the amount of galvanised wire netting.

If successful, this will reduce the quantity of galvanised products in the caves, which is "*claimed*" to create environmental problems.

The dirt areas beside the pathways have been cemented to assist with future water cleaning programmes.

When all this work was completed, the Diamond Cave was cleaned, prior to being reopened to the public.

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	Nigel Scanlan
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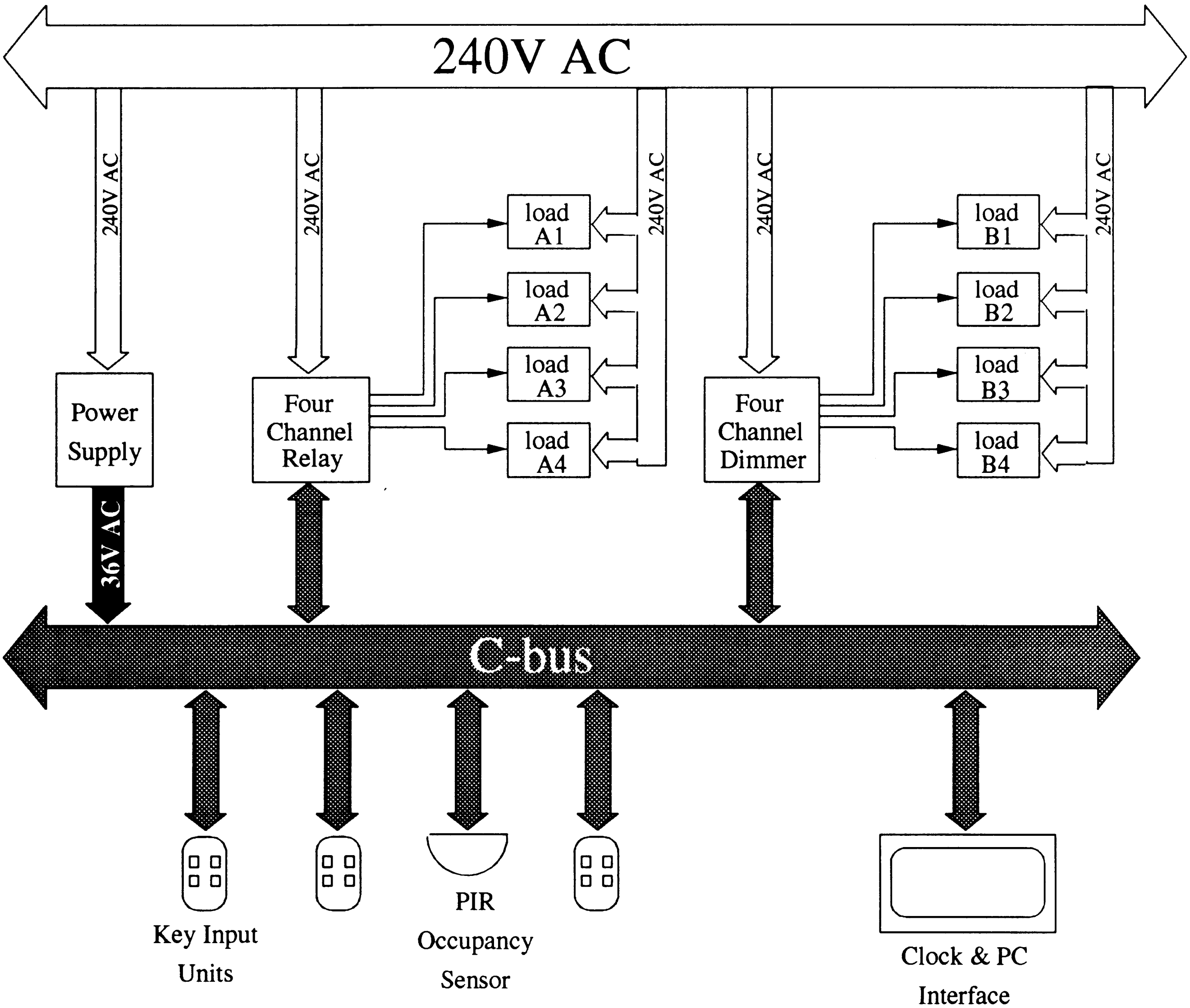
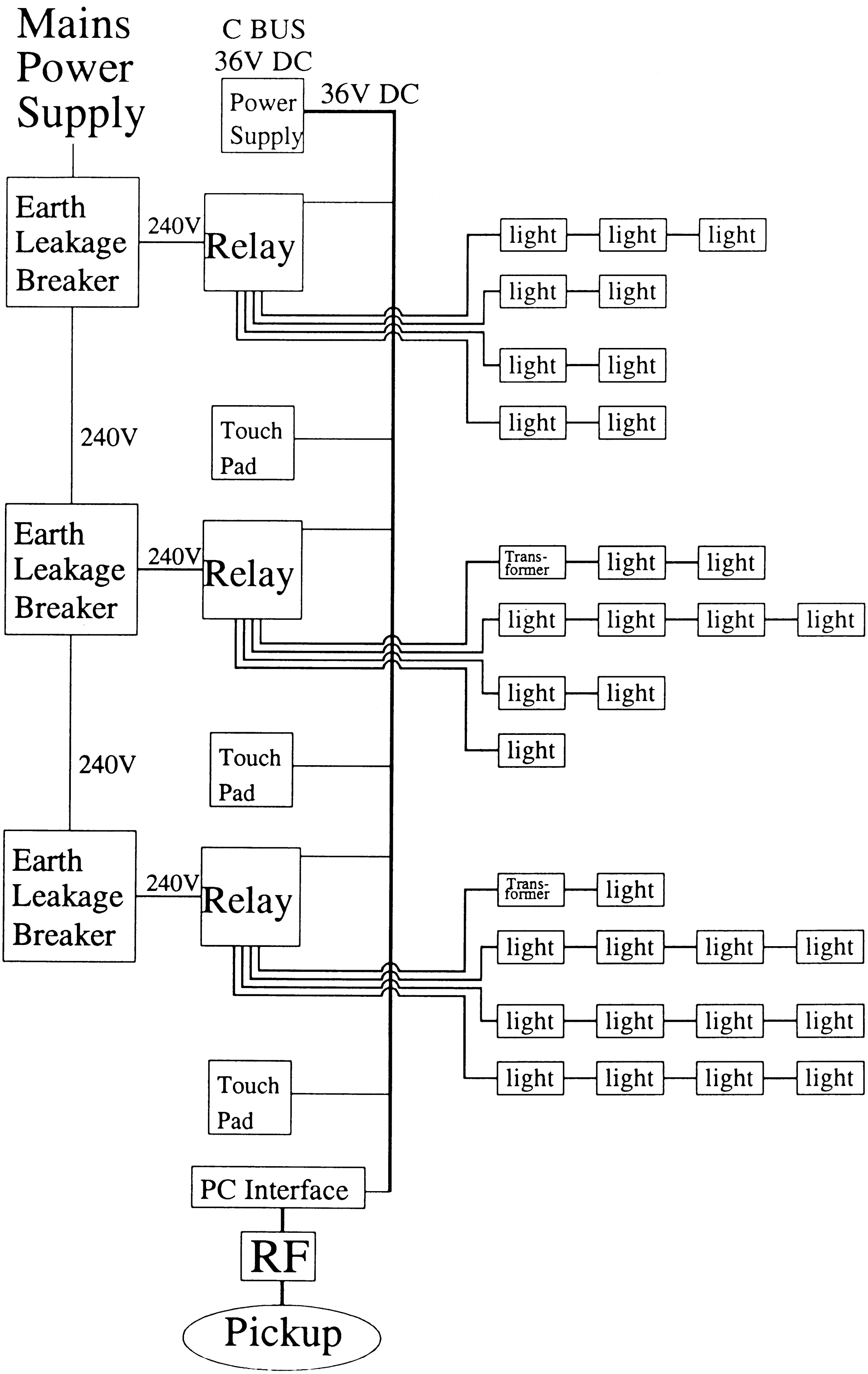
Abstract 1



Schematic Representation of the Components of the C-Bus System


Mains Power Supply
C BUS 36V DC
Power Supply
36V DC
Earth Leakage Breaker
240V
Relay
light
Touch Pad
Trans-former
PC Interface
RF
Pickup

RESULT OF NULLARBOR DOLINE SEARCH

Max G. Meth

Introduction

The Nullarbor caving region is a large area of nearly horizontally bedded limestone that lies on the south coast of Australia. The majority lies in Western Australia with about a quarter of the total in South Australia.

In 1961 most of the Nullarbor plain was photographed from the air with the South Australian side not being photographed until March 1963. Photos were made available with a scale of about 1:85,000 roughly equivalent to the current 1:100,000 topographic map series.

In September 1963, J. N. Jennings and David C. Lowry (Lowry 1968) after discussing the photos, separately to examine them. Initially Jennings concentrated on the SA portion of the plain and Lowry on the WA portion. But Jennings went on to examine the entire Nullarbor area. The aim was to determine what dolines could be detected.

At this time Koonalda Cave (5N4) was the longest of the seven deep caves of the Nullarbor that were known to cavers. Only 34 karst features had been numbered on the Nullarbor. Three of the known deep caves were not yet in the records system. The seven known deep caves being, from west to east, Cocklebiddy 6N48, Murra-el-eleven 6N47, Firestick 6N70, Abrakurrie 6N3, Weebubbie 6N2, Warbla 5N1, and Koonalda Cave 5N4. All these caves led off from large collapse dolines, and the hope was that by finding more dolines, other caves would be found.

Lowry (Lowry 1964) had the first success in November 1963 when he used locations that he had derived from his examination of the photos, to locate three dolines near Madura. Two of these, Kestrel No 1 and Kestrel No 2, were deep caves and the third a 20m deep doline with an overhang cave. At this point the strike rate for new deep caves was two out of three.

In December 1963 Ted Anderson was given maps by Jennings (Jennings 1964) that showed the location of nearly all the collapse dolines from Koonalda to Cocklebiddy. This led in January 1964 to Anderson (Anderson 1964) finding eight large dolines N35 to N39 and N43 to N45. Though N36 had not been identified off air photos, it had been found in looking for N35.

Of the seven new dolines visited only two were deep caves, but these both contained lakes, namely Mullamullang Cave 6N37 and Winbirra Cave 6N45. This trip was therefore among the more successful of all Nullarbor trips. In addition, in January 1964, Anderson numbered the caves he had found, as well as N40 to N42. And this presumption by Anderson to number the caves caused some consternation and even a little resistance by the CEGSA people who supposedly had that job.
At this point four deep caves had been found in nine dolines.

J. N. Jennings and D. C. Lowry Doline Lists

On 17 December 1963 Jennings supplied CEGSA and WASG with lists of dolines he had so far identified on the air photos. The lists detailed:

- 74 dolines in WA
- 25 dolines in SA

for a total of 99 dolines.
Jennings supplied David Lowry with the list of 74 WA dolines.

Though in March 1964 Jennings (Jennings 1964) said "So far I have listed 105 dolines from the air photographs". A further six dolines evidently having been identified. Jennings final list had 111 dolines, 75 in WA and 36 in SA

In May 1967 Lowry (Lowry 1967) listed 89 dolines in WA. Working for the WA Geological Survey, Lowry was not concerned with South Australia. This gave a total number of dolines identified by Jennings and Lowry of 90 WA and 36 SA.

Lowry stated that "the list of (89 dolines) is basically that of Mr J. N. Jennings, with some minor additions". But these were not detailed:

- There were 16 additions: N49 N93 N46 N138 N50 N137 N127 N139 N55 N143 N89 N90 N51 N86 N87 and N88.
- And one deletion: X678 (Forrest airport quarry).

In March 1964 Jennings (Jennings 1964) predicted that of the 105 dolines so far listed he did not expect more than 35 deep caves in total. Even this figure proved overly optimistic. By the end of the earnest searching in 1967 the total number of deep caves stood at nineteen. An increase of only twelve from the original seven. And two of the new deep caves had not even been on the doline list, namely Arubiddy Cave 6N81 and Dingo Donga Cave 6N160. No new deep cave had been found in SA, despite 36 of the new dolines being there.

Initial attempt to summarise the position

Alan Hill, as Nullarbor records officer for CEGSA, compiled data sheets for each new karst feature. However the allocation of new karst numbers proceeded very slowly, but hastened eventually by the publication of MULLAMULLANG CAVE EXPEDITIONS 1966 which listed features up to N80.

In September 1967, Alan Hill (Hill 1967) presented a "Checklist of caves and related features". By then, most of the dolines had been visited and N numbers allocated. This list features up to N154. A reference system indicated if a feature had been discovered using Jennings' air photos or Lowry's doline list. But there was no attempt to summarise what had been found.

On a second checklist, Hill listed 26 dolines with photo coordinates and no N numbers, because they had not yet been investigated. These included 24 from WA and two from SA. Three of these have since been numbered, Handprint Cave 5N210, Wave Cave 5N215 and False Hope Doline 6N713, leaving 23 (NX389 to 394 and NX396 to 412).

Inexplicably, Hill had failed to list seven further dolines from SA that had not been investigated (NX413 to NX419). I say inexplicably because Jennings' final list, undated, gave details of 25 dolines. This list was titled, "Unnamed, steep-sided, enclosed depressions or sinkholes, which may or may not have caves leading from them. Not explored to my knowledge or in speleological society records. Landmarks in Plain." An impressive title, if nothing else.

The first seven dolines on the list are numbered as N104 111 103 107 109 108 and 110. The next seven were simply ignored, and in 1995, I numbered them as NX413 to NX419. The others on the list are N124 125 148 179 178 210 215 144 146 145 and 173.

This last (6N713) was the first of the unvisited Jennings dolines to be located in over 25 years. It was located in 1993 by Plane Caving after Max Hall (pers com) suggested they fly over the area. I had given Max the AMG having noticed that a yardage map reference was actually given in CotN. And it was named False Hope Doline, when it failed to contain any cave.

The situation in 1967 regarding the doline search was, to a large extent very unsatisfactory:

- A large number (about 90) dolines had been visited and placed in the records system with an N number.
- There were 26 dolines listed in CotN for which the only location information was a photo coordinate
- 7 dolines had been omitted entirely.

This is the situation that has persisted up to the present date.

Current attempt to summarise the position.

I have for some years felt that a report of the final result of the 'doline search' should be written.

- Specifically, the search begun by the listing of dolines visible by Jennings and Lowry on air photos in 1963.

In 1997 the events have not quite finished, because 30 dolines have not yet been examined on the ground. At least there is no trip report in records for any of these dolines.

It is very interesting to note that a few cavers have advised me that all the Jennings dolines have been visited, but this is certainly not reflected in the records system. It is possible that some of the 30 dolines have been visited, and that trip reports either were not written or not placed in records. My feeling is that most of the 30 dolines have not been visited by cavers.

One difficulty that would stop potential explorers from locating these dolines is a lack of location information. A photo reference is NOT a useful tool to locate a doline. The requirement is a map coordinate. All the dolines still not located can be printed on a map, and an itinerary to visit each one can then be planned. Of course, having the relevant air photos on such a trip will aid in the location of each doline.

There was a major difficulty: How to derive map coordinates for the 30 unvisited dolines. Lowry (Lowry 1967) offered a solution, "The system for obtaining the photo coordinates is difficult to describe briefly, interested readers can obtain details from Mr J. N. Jennings or myself". Oh good.

But Lowry was working overseas and did not have access to his papers that were in storage. And Jennings had died in 1984.

With help, notably from Ken Bowland (Bowland 1995) of VSA, I did decipher the photo coordinate system. Lowry had been correct, the system was difficult to describe and worse, it was difficult and confusing to operate.

It was a great pity that Jennings or Lowry, once having located a doline, did not then record its map location. But it was not until 1965 that the series of 1:250,000 maps that has coordinates first became available.

I have now computed map coordinates for all the remaining dolines. I was amazed to see that some of these dolines lay close (within 10km) to areas that are regularly visited by cavers. A split of map sheets with dolines remaining to be visited is:

250,000 map	100,000 map		
EUCLA	Eucla	1	X389
EUCLA	Monaghan	1	X391
EUCLA	Sexton	1	X390
LOONGANA	Turner	2	X392, X393
CULVER	Caiguna	1	X394
CULVER	Culver	1	X396
BALLADONIA	Mardabilla	6	X397, X400 to X403, X405
BALLADONIA	Gambanca	9	X398, X399, X406 to X412
MALCOLM	Mount Dean	1	X404
NULLARBOR	Nullarbor	7	X413 to X419

On the Jennings/Lowry lists there are a total of 138 karst features. But twelve of these are blowholes and small dolines, not visible on the air photos. These twelve features were listed by Jennings as help for persons trying to locate the other dolines. They are N5 6 11 12 13 14 15 19 20 21 23 97.

This leaves 126 Dolines on the lists. The split of these is:

1	Forrest airport quarry (not a doline)
30	not yet investigated
3	investigated by Lowry in 1963 N40 41 42)
47	WA dolines on Jennings' original list
18	SA dolines on Jennings' original list
12	On Jennings' additional list
15	On Lowry's list

The last five items constitute 95 dolines that have been examined and placed in the records system.

Conclusion

Of the 95 dolines listed by Jennings and Lowry that have so far been documented:

- 14 were already known to cavers prior to 1963, namely: N1 2 3 4 7 8 9 16 17 18 22 47 48 and 70.
- 25 have no cave namely: N65 69 71 76 77 78 80 89 92 93 95 107 108 124 129 130 134 135 141 143 144 146 148 179 and 713
- 16 have tiny caves or overhangs up to 10m in length, namely: N35 43 54 66 67 86 87 88 90 125 128 137 138 140 142 and 178
- 40 have caves longer than 10m, namely: N37 38 39 40 41 42 44 45 46 49 50 51 53 55 56 57 58 59 62 64 72 74 79 82 83 85 91 96 98 103 104 109 110 111 127 139 145 147 210 and 215

Of the 40 new caves found:

- 20 have caves deeper than 20m, namely: N37* 40* 41 42* 44 45* 46 49* 50* 53* 55* 56* 58 59 64 74 79 83* 147 and with ten of these marked * deeper than 50m.
- 6 contained lakes: N37 45 46 49 53 and 56.
- 20 had caves longer than 50m: N37* 39 40 42 45 46 49* 50 53 55 56* 58 59 62 64 72 83* 103 and 210 with four of these marked * longer than 500m.

New caves continue to be discovered.

There are 30 dolines identified by Jennings that remain unvisited. Listed here are their locations and Jennings' description (if any was given):

	easting	northing	100,000 map	description
6 NX 389	490000	6508000	Eucla	Very degraded, cave unlikely.
6 NX 390	443000	6516000	Sexton	Shallow, shallow cave only possible
6 NX 391	467000	6515000	Monaghan	Very degraded, but large, no cave likely
6 NX 392	745000	6593000	Turner	Small irregular shallow doline
6 NX 393	746000	6592000	Turner	none given
6 NX 394	743000	6410000	Caiguna	none given
6 NX 396	663000	6378000	Culver	Slightly degraded, unlikely for cave
6 NX 397	591100	6351100	Mardarbilla	Degraded, unlikely for cave
6 NX 398	596400	6352800	Gambanca	Degraded, cave unlikely
6 NX 399	596800	6354400	Gambanca	Degraded, unlikely for cave
6 NX 400	584600	6348400	Mardarbilla	Degraded, cave unlikely
6 NX 401	584000	6356500	Mardarbilla	Degraded, cave unlikely
6 NX 402	587000	6353400	Mardarbilla	Degraded, cave unlikely
6 NX 403	589400	6354400	Mardarbilla	Degraded, cave unlikely
6 NX 404	575300	6340700	Mount Dean	Small, but promising
6 NX 405	555800	6349000	Mardarbilla	May be exposure of basement of depression
6 NX 406	622500	6366800	Gambanca	Gentle degraded doline, no cave likely
6 NX 407	622100	6365800	Gambanca	Gentle degraded doline, no cave likely
6 NX 408	619700	6365600	Gambanca	Gentle degraded doline, no cave likely
6 NX 409	617800	6362000	Gambanca	Promising fresh doline
6 NX 410	617300	6363900	Gambanca	Elongated degraded doline
6 NX 411	617800	6358500	Gambanca	Small but fresh doline
6 NX 412	607200	6355900	Gambanca	Degraded doline
5 NX 413	669100	6540700	Nullarbor	none given
5 NX 414	653400	6539900	Nullarbor	none given
5 NX 415	667800	6539300	Nullarbor	none given
5 NX 416	677100	6534500	Nullarbor	none given
5 NX 417	677100	6535600	Nullarbor	none given
5 NX 418	677200	6534200	Nullarbor	none given
5 NX 419	677600	6533600	Nullarbor	none given

A summary of all known Nullarbor caves reveals:
16 caves longer than 500m: N1 2 4 37 47 48 49 56 83 132 193 206 360 707 1411 1426
23 caves deeper than 50m: N1 2 3 4 36 37 40 42 45 47 48 49 50 53 55 56 70 81 83 160 206 707 734

The longest cave on the Nullarbor, Old Homestead Cave, 6N83, approaches 30km. There are still twelve fewer deep caves than the 35 predicted by Jennings in 1964.

Exploration and documentation of the Nullarbor karst continues to provide many challenges.

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CONSERVATION OF CAVE FAUNA IN AUSTRALIA

Stefan Eberhard and Elery Hamilton-Smith

Abstract of paper published in *Journal of the Australian Cave & Karst Management Association* No. 23, June 1996, pp 4-14, and presented to the 21st Conference Australian Speleological Federation Inc.

Australia contains a great variety of karst landscapes and environments which are distributed across a broad range of climate types. Whilst much of the karst biota remains poorly known and described, there are subterranean communities of exceptional diversity and significance to zoogeographical and evolutionary studies. Unfortunately, some communities have become extinct, and a great many more have declined or become seriously degraded as a result of human activities. Karst biota continues to be threatened by deforestation, agriculture, quarrying, and cave visitors. Conservation strategies which have been appliad include protection of sensitive habitats within individual caves, and public awareness campaigns. The current trend towards improved conservation and management of karst ecosystems depends upon a systemic approach to karst environments and processes, aided by further research and monitoring in combination with legislative protection of subterranean communities or taxa, and the fostering of public awareness.

Eberhard, S. & Hamilton-Smith, E. (1996) Conservation of cave fauna in Australia in *Journal of the Australian Cave & Karst Management Association* No. 23, June 1996, pp 4-14

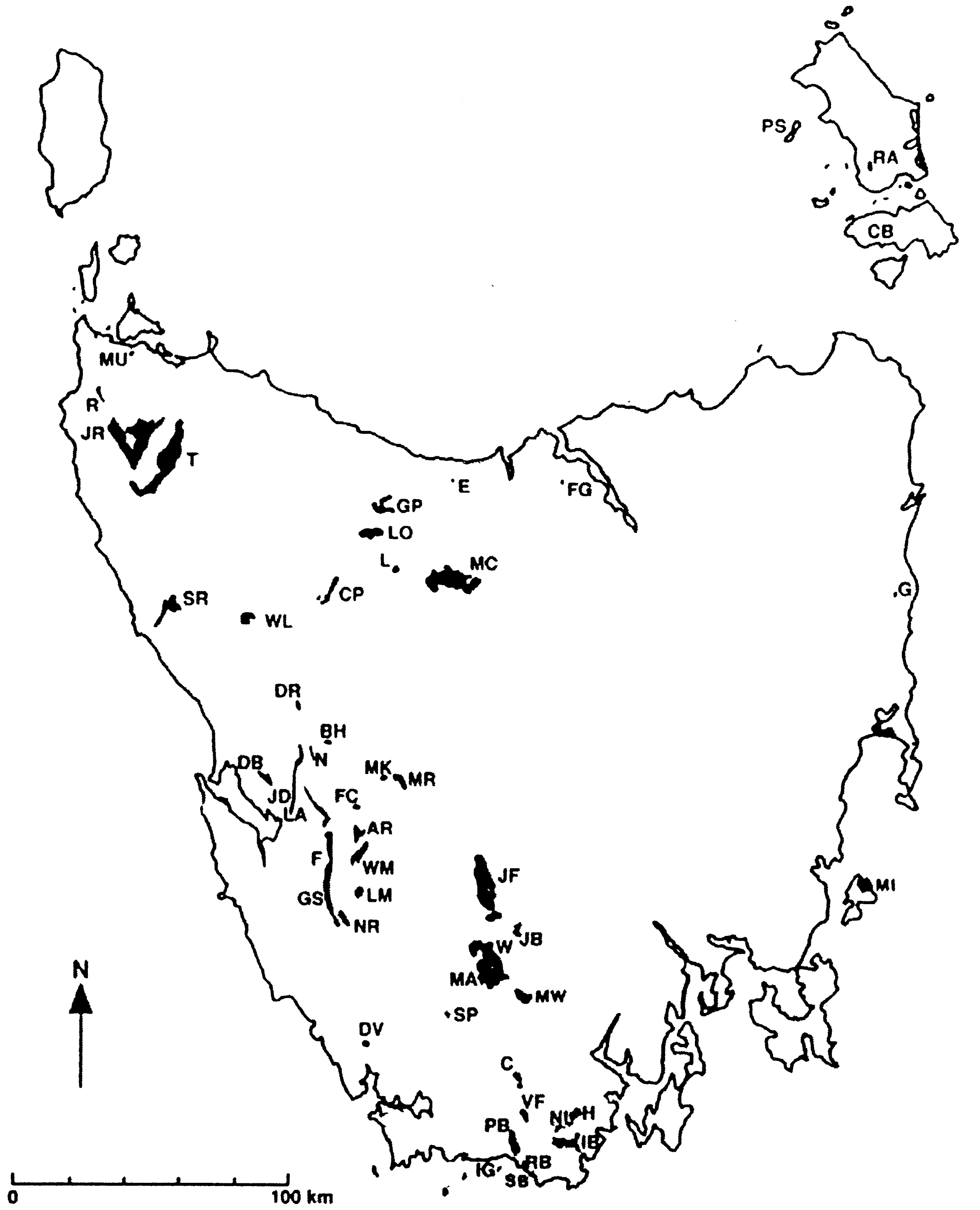

Figure1: Map of Tasmania showing locations of 50 carbonate rock karst areas in forested regions; these karst areas include all the caves with recorded occurrence records for invertebrate species (see Clarke 1997a; 1997b).

IMPACTS ON CAVE FAUNA AND RECOMMENDED PROTECTION MEASURES IN FORESTED KARST AREAS OF TASMANIA

Arthur Clarke

Introduction

The following paper represents a brief summary of some of the major aspects of a recent report relating to the cave fauna of forested karst areas in Tasmania (Clarke 1997). A brief synopsis is given of some of the major impacts of forestry activity on karst surfaces and karst catchments and the impacts to caves from cave visitors, together with some of the consequential effects on cave fauna from both surface (forestry) and underground (caving) activities. This paper includes some of the recommendations from Clarke (1997) for protection of cavernicolous invertebrates in the significantly karstified areas of Tasmania: areas with recorded karst bio-space.

Impacts of forestry activity on karstand cave fauna

Forest practices commonly include roadmaking and snigging tracks; quarrying of stone for road emplacement, fill for low-lying areas or as road gravels; timber harvesting, clearing, windrowing and burning plus the development and maintenance of plantations. Most of these forestry practices will lead to significant impacts on cavernicolous faunas, particularly direct effects on aquatic invertebrates and indirect effects on terrestrial species either in karst areas underneath forest activity or karst downstream from catchments that are being worked. The cave fauna of karst biospace will be directly impacted by surfaces disturbances in karst, particularly groundbreaking activity the destruction of surface litter or mulch by forest practices including fire (Holland 1994).

Soil mantles on carbonate rock are generally thin, clayey residual soils (Gillieson 1996; Jennings 1985; Kiernan 1988;1990) with even thinner mantles where limestone purity is higher (Lewis 1996).The soils over carbonate rock in karst areas have been likened to being on a sieve, because surface waters that drain into the immediate underlying epikarst (see below) can carry soil particles and grits directly into the karst hydrologic system (Lewis 1996). Solutional karst processes may also be impeded by blockages in solution-widened cracks or fissures in the bedrock due to mobilisation of clays and grits from disturbed soil profiles. In instances where karstslopes have been reduced to bare rock surfaces due to soil loss from logging and burning, trees are not likely to grow again until the litter and moss base has become re-established, a process which could take several centuries to occur and in steeper bare rock areas previously covered by transported soils and glacial tills, the forest may not return until "….the next glaciers have deposited a new layer of till...." (Harding & Ford 1993).

Ground breaking activity in karst catchments usually leads to an increase of sediment influx into streams and forest removal or changed vegetation regimes in the catchment which lead to altered stream flow conditions. Flooding in stream caves often occurs as a result of the increased water yield following forest removal.

Aquatic cavernicoles in hypogean (underground) habitats of karst areas will be threatened by the same impacts that affect aquatic species in epigean (surface) habitats. The effects on cave faunas will be more markedbecause of the limited mobility of some species to avoid impacts (e.g. the minute hydrobiid gastropods) or the narrow habitat range due to restricted hydrological system limits imposed by the individual subterranean karst, together with the naturally low nutrient input levels.

Terrestrial cavernicoles in hypogean habitats of karst areas will be directly and indirectly impacted by effects on aquatic species and alterations to stream hydrology which promote sediment deposition, affect moisture input levels or interfere with natural air current movements. Terrestrial cave faunas will also be directly impacted by disturbances to the epigean karst surface which will modify bio-space humidities due to reduced percolation flow or introduce toxic pollutants (including sedimentation) and similarly modify other natural meteorological conditions related to air volumes and air flow.

A number of caves and karst areas in Tasmania have been degraded byland surface disturbance in upstream catchments. Turbid floodwaters have been observed emerging from cave effluxes in the Gunns Plains karst in northern Tasmania and in the Weld River karst of southern Tasmania. Both these karsts are situated downstream from logging operations in forested catchments. Some of the stream caves in the Gunns Plains karst area contain very few aquatic species and during a recent visit in late December 1996, the writer noted that the terrestrial species component of cave communities in these sites at Gunns Plains appear to be mainly limited to epigean accidental species and trogloxenes. Similar impacts have been reported in sections of the Mole Creek karst as a result of poor management in forested areas, particularly on private landholdings (Kiernan 1984; 1989). In the Ida Bay karst of southern Tasmania, limestone quarrying has impacted on two cave systems which have related hydrological drainage during periods of high recharge: Exit Cave and Bradley-Chesterman Cave(Clarke 1989b; 1991b; Houshold 1995;Kiernan 1993).

Protection measures for cave fauna in Tasmania

The following recommendations (and their sub-sections) generally fall into one of seven categories: cave invertebrate species protection, habitat protection (including caves, karst surface environments, adjoining landsand catchments), recommended amendments to the Forest Practices Code (FPC) of Tasmania (Forestry Commission 1993), changes in land tenure in some forested karst areas (including recommendations for reservation of some karst areas in Crown land and landcare programmes on private land), habitat restoration and enhanced breeding programmes, mechanisms to increase public awareness of the uniqueness and fragility of cave ecosystems and recommendations for further research and study to assist in broadening the knowledge base of cavernicolous faunas in Tasmania and in particular to promote the conservation and management of cave fauna.

Eberhard and Hamilton-Smith (1995) suggest that cave invertebrate species may be protected by consideration for listing as endangered ecological communities under the auspices of the Commonwealth's *Endangered Species Protection Act* 1992 or by legislative protection of cave species by adding additional cave invertebrates to the list of rare and threatened species (following IUCN Red Data Book Codes applied at a State Level) under the *Threatened Species Protection Act*, 1995 (Eberhard and Spate 1995). In Tasmania, further cave invertebrates should be included in the "Threatened Fauna Manual for Production Forests in Tasmania" (Jackson and Taylor 1995).Collection of described cave species should be discouraged by promoting the publication of cave fauna collection records and new species descriptions in speleological journals or elsewhere in the public domain (Clarke 1997).

Habitat protection of caves with known fauna: (a) A register of all known caves with cave fauna should be prepared to assist in planning purposes forest-based activity or other permitted activities in forested karst areas. (b) Specific within-cave micro-habitats and exclusion zones should be defined to protect fauna in some caves of forested karst areas, perhaps by gating or limiting access. All such protective measures should be undertaken in consultation with biospeleologists or relevant local speleological organisations.

Habitat protection of karst areas: No forestry activity (roading, quarrying, plantation development or logging) or other surface disturbance (especially ground breaking activity) should be permitted in forests which contain the significantly karstified areas, e.g.those karst areas in Tasmania defined by Kiernan (1995) as "Category A" karsts, known or believed to contain a significant karst bio-space.Influencing the activity of land managers in private forest lands remain a particular problem. Pollutants such as petroleum products (oils and lubricants), herbicides (or pesticides) and fertilisers should be absolutely avoided on the surface of karst area in Tasmanian forests. The use of fire is not an acceptable management tool in (forested) karst areas. All fires,whether as cool fires or hot fires during regeneration burns, ground fuel reduction burns or perimeter hazard burns will affect cavernicolous invertebrates which are reliant on natural karst proccess and input of natural organic material from surface systems.

Habitat protection of karst catchments: Roading in karst catchments of Crown lands and private lands should follow strict guidelines, such as those in the Tasmanian FPC (Forestry Commission 1993) and be constructed in such a manner that avoids sediment input to streamways. Where possible roads in karst catchments should follow ridgelines; if not on ridgelines, roads should run parallel to and at least 100 metres distant from major watercourses and incorporate sufficiently sized drainage channels and sediment traps or settling pits to prevent sediment-laden waters reaching watercourses. If sediment overload is likely to be a problem, filtering mechanisms (such as tea-treebrush or pea-straw bales) should be deployed. Karst catchments should only be partially logged in any given season and logging coupe sizes should be minimal to minimise runoff and altered flow regimes in streams draining into karst areas which are known or likely to contain cave fauna communities.

A detailed submission has been presented to the Regional Forest Agreement process in Tasmania by Clarke (1997) which includes a substantial number of recommended amendments to the Forest Practices Code (FPC), particularly in relation to management of karst catchments. These include the revision of the FPC to prevent further forestry activity in karsts known or likely to contain cave faunas, recognition of dolines and sinkholes as potential water catchment sources (for subterranean drainage) and their inclusion in the FPC as catchment draining watercourses. (Following the completion of logging operations which involve deafforestation, many intermittent surface watercourses or otherwise dry channels become active watercourses during rainfall periods and similarly, some dolines become sinkholes and some sinkholes become significant swallets.) Other recommended amendments to theTasmanian FPC include changing management and work practices in karst catchments, such as widening the forestry activity and logging buffers in riparian zones of karst catchment streams, altering logging methods to suit the slope angle, surface geology and vegetation type and restricting use of fertilisers or herbicides etc. in plantation forests. Specific recommendations are also made in relation to plantation forests including preferred planting of native species and avoidance of fast-growing introduced or exotic species with higher evapo-transpiration rates, such as *Pinus radiata* or *Eucalyptus nitens*, both of which effectively alter surface ecology and stream flow levels (Clarke 1997).

Protection of cave fauna by changes in land tenure, including reservation of karst areas by reservation of Crown land to protect karst bio-space and its cave communities.Applicable Tasmanian karst areas with high conservation significance include the "High Sensitivity Zones" in the Junee-Florentine karst of southern Tasmania (Eberhard, 1994; 1996) which could be protected by an extension of the Mt. Field National Parkboundary; cave fauna communities in the Mount Cripps karst area in central-northwestern Tasmania (Clarke 1997); cave fauna communities in the Mole Creek karst area of northern Tasmania, outside the present Mole Creek Karst National Park (Kiernan 1984; 1989); fauna in the caves of karst outliers beyond the Hastings Caves State Reserve (Clarke 1997) and cave fauna communities in the unprotected North Lune karst of southern Tasmania (Clarke 1990).

Conservation management of cave communities in private forest presents a more difficullt proposition, but can be achieved to some extent by the adoption of regional planning schemes, Landcare programmes and conservation covenants (Dyring 1995). Some of these proposals may be practical to assist in the conservation of cave communities occurring in forested karst areas in Permian limestone karst of the Gray and Mount Elephant areas on the east coast of Tasmania (which includes some areas in State Forest). Cave fauna communities in Ordovician limestone karsts at Gunns Plains and Loongana in northwestern Tasmania should be recognised and protected as far as possible. Most of these areas are either in privately owned agricultural or forestry land (including additional areas at Mole Creek) or under threat due to unfortunate forest practices that are occurring in their catchments. Smaller areas which support threatened cave species, are often in pseudokarst sites located on private land. Some of these sites are only known by one or two species, sometimes equally rare and threatened as karst area species and the pseudokarst species should be recognised and protected as far as possible. Public awareness and education is probably the only means of protecting these sites, including advice to the landowner.

Preparing detailed studies of the habitats of rare and threatened species as an adjunct to cave management plans including a detailed study of the currently vulnerable or endangered species, such as the blind cave beetle *Goedetrechus mendumae* to ascertain population numbers, habitat requirements and true conservation status as part of the Exit Cave Management Plan. Additional specific studies of other rare and threatened species, including a study to search for recorded species not sighted since 1910 (Clarke 1997) or similar studies of specific cave communities to determine appropriate management of caves orkarst areas in other parts of Tasmania, particularly in the forested karstareas

Other recommendations for protection of cave fauna include: (a) rehabilitation or restoration of cave or karstcatchments; (b) habitat restoration in caves and micro-habitat protection as an aid to enhanced breeding; (c) increasing public awareness and promoting more education on the uniqueness and fragility of cave ecosystems (see below).

Rehabilitation and habitatrestoration or enhanced breeding programmes

Gillieson (1996) suggests that the rehabilitation and restoration of caves is best achieved by remedial activites related to the karst surface.Fundamental to the process is the restoration of the normal hydrological system. Amongst the other key elements recommended by Gillieson are control of any active erosion, ensuring there is a stable vegetation cover and getting the soil biology working, then establishing a monitoring programme above ground and below in the cave itself (Gillieson 1996).

Cave communities, species diversity and population densities have been impacted in both Exit Cave and Bradley-Chesterman Cave as a result of flocculent clays mobilised from the disturbed *terra rossa* surface soils and exposure of palaeokarst deposits (Clarke 1989a; 1989b;1991a; 1991b; Eberhard 1990a; 1992a; 1992b; 1993; Gillieson 1996; Houshold 1992;Houshold & Spate 1990). The severity of impact is more marked in Bradley-Chesterman Cave where other accidental contaminants including petroleum products have entered the stream system. Following closure of the limestone quarry, a restorative programme has been underway to rehabilitate the quarry site and ensure that all drainage points only permit the input or recharge of flocculant free waters into the karst aquifer (Clarke 1991b; Gillieson 1996; Houshold 1995). This has been achieved by using a numberof natural organic filtering devices including fibrous bark of the Brown-topped Stringybark (*Eucalyptus obliqua)*, *Leptospermum* and *Melaleuca* tea-tree brush with seed capsules plus hay bales or pea-straw. There has been a marked improvement in the water quality of Eastern Passage of Exit Cave and some improvement in Bradley-Chesterman Cave (Eberhard 1995), though the depth of silt still remains a problem and may take hundredsof years to be flushed out. However, during recent inspections in 1995 and 1996, it was noted that epigean (surface) species are beginning to re-colonise Bradley-Chesterman Cave (Clarke, inpress 1997) and their presence may assist the return of surviving cavefauna species forced to migrate into karst biospace beyond the cave space during original impact from quarry runoff.

Another example of cave fauna protection by restoration of cave and karst catchments is demonstrated by the sustainable landcare management initiatives adopted by the Waitomo Catchment Trust Board to protect Waitomo Glowworm Cave and other stream caves of the Waitomo Catchment in New Zealand (Martin 1996). In 1992, the Waikato Regional Council embarked on a comprehensive conservation policy designed to protect the soil and water resources in the Waitomo River catchment. This included protection schemes for existing native forest, gradual retirement or afforestation of steep slopes, particularly where erosion was already apparent, establishment of temporary sediment dams, pole planting on active eroding slopes to prevent further downward slide of sedimentand retirement of riparian stream margins with establishment of suitably wide buffer zones where no ground-breaking surface disturbance occurs (Martin 1996).

Rehabilitation methods such as those described in previous paragraphs maybe able to be applied to other forested areas to prevent runoff from unmade roads or snigging tracks entering catchment streams that drain into karst areas or caves. Similarly, these techniques or similar methods could be used to assist all forest land managers including private landowners ensure that exposed or disturbed sediment is not washed into dolines. Forest land managers should be encouraged to strictly follow the Forest Practices Codein relation to karst catchments and re-vegetate exposed land surfaces toensure that future forestry or other forest-based activites do not permit sediment influx into streams that drain into karst.

Habitat restorationin caves

Habitat restoration in caves is described by Gillieson (1996) as requiring a long time scale to achievesatisfactory results. Habitat restoration is already occurring in somecaves in forested areas of Tasmania where "no-go" areas have been defined by taping off areas in so-called "substrate protection zones" e.g. in caves of the Mole Creek karst: Kubla Khan (MC-001), Little Trimmer (MC-039) (Eberhard & Hamilton-Smith in press 1997) and in My Cave (MC-141). This course of habitat restoration is only useful if all the cave visitors have good intentions and don't overstep the line to get their good photo shots! Management plans for caves can assist the process, but once again unless the cave fauna are locked in (or the cave visitors are locked out), the process is reliant on voluntary compliance by the cave visitors (Hamilton-Smith &Eberhard, in press 1997) being prepared to do the right thing. Habitat restoration is also being conducted at Exit Cave in southern Tasmania, following closure and rehabilitation of Benders (limestone) Quarry which was generating sediment input and probably dilute concentrations of sulphuric acid into cave waters (Houshold1995).

The impact on cave fauna by cave visitors

Cave visitors can impact on the biological attributes of caves in various ways: by both deliberate or accidental means. In late December1996, the writer found a deliberately baited "fishingline" in Gunns Plains Tourist Cave; a piece of hay-bale twine tied around a piece of meat had been placed in the cave stream where the large Tasmanian freshwater crayfish: *Astacopsis gouldi* was known to frequent. Cave visitors have also been known to light fires in caves for warmth, apart from the more inadvertant acts of littering with food scraps, lollie wrappers and leaving behind clothing lint, plus the more deliberate discard of plastic wrappers or food containers, used torch batteries, spent carbide or human wastes.

Cave visitors need to be more informed about the environment they are passing through and be aware that the habitat niches for terrestrial or aquatic species in caves are numerous and variable, as well as often being fragile and easily destroyed. It is highly probable that many cave invertebrates have perished as a result of cavers inadvertantly walking on a species or compacting the loose and friable sediment in which the species once lived (Gillieson 1996). Faunal habitats may include the substrate that cavers walk over with boots, the muddy-floored passages they crawl through on their hands and knees, the cavewalls they brush against with overalls or the streamways they wade through with gumboots. Even the small impact of a boot-sized imprint on a moist sandy slope or gravelly streambank could be impacting on a habitat that supports a small range of species, possibly impacting on part of a food chain within the wider cave ecosystem. Repetition of foot traffic in certain areas, such as over-use of soft sediment banks or clay-banks as pathways, can lead to collapse of these features or development of erosion gullies, both of which potentially affect cave species habitats. Cave visitors may be requested to walk in cave streams to avoid these unconsolidated or fragile sediment banks and potential erosion gullies; but in fact the stream beds may be equally or more important as habitat niches for aquatic species such as hydrobid gastropods, anaspidean syncarids, crangonyctoid amphipods or even the aquatic larvae of adult insects.

Some cave communities in forested karst areas of Tasmania maybe under threat due to visitor access by cavers which has been inadvertantly assisted by virtue of the roading emplaced by Forestry Tasmania or its predecessor. Hence, it may be appropriate that some means for dialogue be established between the Tasmanian Forest Practices Unit and the Tasmanian Parks and Wildlife Service with the speleological fraternity to discuss the possible installation of road barriers or gates on cave entrances to limit access to sensitive sites. Similarly, further management plans may need to be addressed by Forestry Tasmania for caves in State Forest or other forested areas.

Micro-habitatprotection as an aid to enhanced breeding

Many of the macroinvertebrates in caves, especially the troglobites, are likely to be "low-breeding species" easily affected by environmental change (P. Greenslade, pers. comm.). Disturbances to karst surface environments such as mechanical ground-breaking activity, vegetation modification and other ecological interference above caves can lead to a drying out of the normally humid bio-space, which may unnaturally stress or desiccate cave invertebrates. Similarly, surface activity in the karst catchment can affect both the water quality of streams and stream ecology which are fundamental to cave ecosystems, particularly to aquatic populations. In caves where typically low-breeding cave invertebrates are only known from small populations or where species numbers are less abundant than would be expected, these individual species may be already vulnerable and at further risk of becoming endangered, possibly to the point of extinction, hence some micro-habitat protection maybe required as an aid to species survival.

Breeding enhancement is unlikely to be successful unless the micro-habitats of threatened species are accurately defined and the source of threat is nullified or curtailed altogether. Ideally, these particular micro-habitats within caves should be closed off to access by cave users, unless artificial breeding colonies or underground laboratories are established, such as those in France. In Slovenia, over-collecting of the rare aquatic vertebrate: the salamander *Proteus* (the first troglobite ever described) lead to it becoming an endangered species; its continued existence is now only guaranteed because of protection in artificial breeding colonies outside of Slovenia (Humphries1993). Underground (cave) laboratories have the ability to ensure species survival because they can environmentally enhance the habitat niche of any rare and threatened species and monitor that immediate environment without the impacts of regular cave visitors to an unprotected site.

In Tasmanian caves, micro-habitat protection is virtually the only means to promote survival of threatened species, providing a more stable environment to enhance breeding and hopefully maintain or increase population numbers. In order to define these particular micro-habitats or the broader habitat range of any endangered species, cave biologists (and possibly cave managers) should carefully study the known or likely habitats for these species and select appropriate within-cave protection zones or "no-go" areas to exclude visitors from this section of the cave. It should be possible to determine or define these protection sites during the course of cave management plans. In addition to creating zones of "in-cave" isolation or closure of known species micro-habitats with appropriate signage or physical barriers, the best additional assistance is an assurance that the karst surface and catchments will remain undisturbed.

Public awareness and education on the uniqueness and fragility of cave ecosystems

Means to assist in conservation and protection of cave ecosystems and their fauna include: increasing the awareness of other karst land users; inclusion of appropriate cave ecology coursework in school or tertiary curricula, or where ever biology is taught; preparation of media articles in newspapers or television, publication of articles in speleological magazines (including records of cave fauna collections) and signage or information leaflets at popularly visited cave entrances.

Cave visitors themselves need to be educated, to be more aware oftheir subterranean environment and its ecosystem, and encouraged to adopt a cavers' equivalent of the bushwalkers' Minimal Impact Bushwalking code: look around you, tread lightly and take nothing but photographs! The majority of speleologists that visit Tasmanian caves would belong to affiliated or member clubs of the national caving body: the Australian Speleological Federation (ASF). This national body already has its own established *Code Of Ethics* in relation to cave use and most ASF clubs should have access to copies of these for distribution to new members. However, caving is becoming increasingly popular as an outdoor adventure sport or recreational activity for young people, but unfortunately, many are not involved with caving clubs and do not necessarily know about the ASF cavers' *Code of Ethics* or other conservation requirements for caves, cave fauna and cave ecosystems.

It has been recently suggested that repeated cave visits may have a greater biological impact than the physical effects of sediment compaction anderosion (Gillieson 1996). Although the Tasmanian Parks and Wildlife Service and Forestry Tasmania are introducing cave management plans for frequently visited caves, these plans are often more directed at conserving physical features such as speleothems or sediment deposits, rather than the biological attributes of a cave. Therefore, all Government departments and speleological organisations, or other cave management structures, need to include provision for conservation of cave fauna in their management plans as well as being involved in public awareness and education campaigns aimed at the persons who visit caves. If cavers are careful to avoid known or likely faunal habitats and are otherwise mindful of their caving activity in this subterranean environment, e.g.remaining on established or marked passage routes in caves, the impacts to cave fauna will be less severe.

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KARST BIO-SPACE

Arthur Clarke

The following paper on "karst bio-space" is based on a concept introduced in a recently commissioned report on the cave fauna in Tasmania (Clarke 1997). The report was commissioned as one of a series of reports for the biodiversity component of the environment and heritage assessment for the Tasmanian and Commonwealth governments comprehensive regional assessment (CRA) process for Tasmanian forests. (The CRA process in itself is a preliminary stage in the negotiation of a Regional Forest Agreement (RFA) for Tasmania.) In this cave fauna report, Clarke (1997) describes a number of management recommendations for the conservation and protection of cavernicolous invertebrates in forested karst (and pseudokarst) areas of Tasmania including a range of prescriptive protection measures for karst catchments, karst surfaces and caves: the humanly enterable component of the karst bio-space.

Karst bio-space: an introduction

Karst bio-space can be defined as the sum-total of the actual or potential habitats and micro-habitats of all living species in karst. The karst bio-space is composed of the interconnected network of cracks, joints, pipes, vertical channels, tubes, voids, horizontal conduits and cavities (including caves), that have formed as a result of the long-term effect of all solutional processes in carbonate rock and subsequent geomorphic events. At any given time, depending on conditions of recharge (water input) and discharge (drainage), this honeycombed network of spaces or spongework may be air-filled, water-filled or alternating in between.

This network of air or water filled spaces can be inhabited throughout by invertebrate (and vertebrate) fauna and along with the minute spaces in the interstices of cave sediments and detritus can all be collectively termed as the karst bio-space. This paper focuses on the aquatic and terrestrial invertebrate species that inhabit the karst bio-space. Aquatic and terrestrial species have the potential to move freely and migrate throughout the bio-space following moisture and nutrient inputs.

The actual or potentially water-filled parts of the karst bio-space are commonly referred to as components of the karst aquifer or karst hydrological system. These include the layers of karstified rock in the unsaturated epikarstic region, the recharge or discharge waters of cave streams and the permanently flooded or saturated phreatic zone (Ford and Williams 1989; Jennings 1985). Carbonate rocks such as limestone are deposited in layers or beds; some layers may be more soluble and more permeable to water than others, causing selective solutional development of cavities or permitting bodies of water to be "perched" one above another. This has important implications for cavernicolous fauna particularly during periods of recharge, permitting greater mobility of aquatic species through the bio-space, and also "trapping" terrestrial species that may be forced into the unsaturated cavities of the epikarst region till recharge waters subside. During periods of significant recharge, drainage waters from swallets or surface seepage can feed separate hydrological systems and emerge at different effluxes or springs (Ingle-Smith 1974) providing an explanation for the fact that the same aquatic species may be present in adjoining hydrological systems within one karst area.

The predominantly air-filled cavities in the karst bio-space range in size from minuscule cracks and fissures to the fist-sized or smaller voids, sometimes described as microcaverns or microcaves (Howarth & Stone 1990; Holland 1994) and to the larger caves and passages that can be entered by humans. Biologists cannot effectively study the faunal component of microcaverns etc. and can only examine those caves that are accessible. It has been estimated that for most karst areas of the world, only 10% of all caves have surface openings or connections enabling underground exploration and biological study (Curl 1958). The record of collections of invertebrate fauna from caves only represents a small proportion of the fauna in the total biospace of any given karst area with potentially many more species to be found, particularly in the small spaces of the epikarstic or groundwater (phreatic) zones which are not accessible.

The visible karst bio-space of caves includes all the visually more obvious micro-habitats for terrestrial species such as the exposed surfaces or small pores and cracks in cave walls, cave ceiling and other rock surfaces. However, even in large caves, there are many other less obvious habitats for invertebrate fauna. The minuscule interstitial spaces between dirt particles, sand grains, gravels, small stones or organic material deposited by floodwaters on cave floor substrate are all potentially habitat niches, along with the larger voids between rock fragments or the boulders in a rock fall chamber. Similarly the water-filled interstitia of bedload sands or gravels or streamside deposits maybe habitat niches for aquatic fauna, e.g. the tiny bathynellacean syncarid from saturated streamside sands in Western Grand Fissure of Exit Cave in the Ida Bay karst of southern Tasmania (Clarke 1997). Undersides of loose cobbles in a streambed may be the habitat for aquatic larvae or the feeding site of crangonyctoid amphipods and anaspidean syncarids, while the sides of more firmly wedged or "cemented" cobbles in a streamway or the silty organic substrate of the streambed could be occupied by small aquatic snails such as the minute 1-2mm long hydrobiid gastropods.

The formation of karst bio-space

Karst bio-space is initially formed by solution processes, plus the subsequent geomorphic acts of corrasion, erosion, deposition of sediment and collapse of weakened rock strata that in total are described as the process of karstification. Solution processes are basically either chemical or biochemical whereby slightly acidic percolation waters and throughflow waters dissolve the carbonate mineral component (typically calcium or magnesium carbonate) of rock types such as limestone and dolomite, as the waters pass through the rock strata. The acidic component in solution waters has three origins: firstly, carbonic acid derived from hydration of atmospheric carbon dioxide (CO_2), plus the CO_2 produced by biological process in soils (Ford & Williams 1989; Gillieson 1996; Jennings 1985), secondly, the humic and fulvic acids produced by rotting vegetation in soil and leaf litter (Ford & Williams 1989) and thirdly, the sulphuric acid derived from the weathering of pyritic limestones, interbedded shales and mineralised palaeokarst (Clarke 1993; 1995; Houshold 1995; James 1991; Jennings 1985; Osborne 1995).

In the classic model for karstification of carbonate rocks such as limestones, rainwater is lightly charged with atmospheric carbon dioxide forming a weak solution of carbonic acid. The concentration of carbonic acid is considerably enhanced as water subsequently seeps through soils absorbing additional CO_2 derived from the respiration of invertebrates, bacteria and the decay of soil organic matter, derived from the forest or other vegetation cover. Due to the important role played by decaying leaf litter and soil humus content in promoting solution, it is imperative that soils overlying limestone are not disturbed (Clarke 1997; Harding and Ford 1993; Lewis 1996).

Water enters the limestone through minuscule (often microscopic) pores, cracks, joints and bedding planes or into larger crevices such as fissures, solution-widened joints, other zones of rock "weakness" and swallets in what is referred to as the epikarstic region (under soil layers) in the unsaturated vadose zone (Ford & Williams 1988). This latter region is sometimes referred to as the endokarstic, unsaturated, vadose zone (Gillieson 1996). In this zone of free draining percolation or seepage water, a continuing process of solution slowly widens or expands drainage paths over a long period of time. Solution also occurs in the saturated phreatic zone (flooded zone) below the water table and a tubular network of water-filled conduits (Jennings 1985) provides further habitats for aquatic faunas. Drainage waters exit the limestone via predominantly horizontal floodwater channels or conduits and further enlargement of both vertical and horizontal passages occurs through the erosive processes of abrasion and corrasion as gravels or other clastic materials are fluvially transported through the karst system. Some of this transported sediment is deposited in stream channels; the streambank gravels or cobbles and water-filled interstitial spaces provide a further habitat niche in the karst bio-space for aquatic species.

Caves and cave fauna with reference to invertebrate species in Tasmanian karsts

Caves represent the major component of the known karst bio-space and include a range of cave fauna species in many habitats. The cave fauna, particularly invertebrate species, are commonly referred to as cavernicoles; these can be simply defined as any animal living in a cave (Eberhard, *et al.* 1991). Described as cavernicolous species, these cover a wide range of invertebrate taxa with varying degrees of dependence on the subterranean habitat, ranging from those obligate species totally dependent on caves to opportunistic or accidental species that follow streamways into caves, or are washed in/ fall in, or simply carried in by air currents. The invertebrates which enter caves as parasites in the fur or skin of vertebrates or attached to other invertebrates, e.g. mites and ticks, can also be classified as accidental species. Animals that can only live in caves and nowhere else are sometimes referred to as obligates, because they are "cave-limited", totally dependent on the cave habitat and therefore obliged to live in that subterranean environment. Obligate species are usually confined to the dark zone of caves, formerly known as the troglic zone (Richards 1962) and sometimes described as the deep cave zone (Eberhard *et al.* 1991; Eberhard 1992) - often located in the inner or deeper parts of a cave, away from external influences, and normally considered to be a very stable, but humid environment with naturally low nutrient input. In this stable environment, there is a reduced seasonal definition of reproductive events, which are usually more related to micro-climate conditions within a particular habitat (Doran 1991). Many of the obligate cavernicoles are cryptic (or secretive) by nature, or by virtue of their preferred micro-habitat (as narrow wall crevices or the interstitial spaces in soil and streamside deposits) or due to their very small size (often <5mm) and may elude even the best of cave-biologist sleuths!

Individual species population numbers in caves are variable. Generally speaking, when obligate species become confined to one cave or a number of inter-connected caves of one contiguous karst or common hydrological system, population numbers are likely to be small (Culver 1986), particularly in the case of terrestrial species. Some cave species are only described from one or two specimens, sometimes only one gender. It is often difficult to locate mature males and/or mature specimens of either gender due to a range of factors including seasonality, moisture levels and food supply and species may be absent altogether or only represented by immature specimens and females, unless both gender are observed during a mating period.

Some aquatic species may have relatively large populations with a wide geographic dispersal range due to enhanced mobility in aquatic mediums. However, some aquatic species with abundant populations have low dispersal power as exemplified by the minute hydrobiid gastropods: aquatic snails which are known to often only live in small bodies of water (Eberhard 1992a). Hydrobiids have been recorded from single caves or cave systems in Tasmania (Ponder 1992), and in cave systems of the Ida Bay and Precipitous Bluff karsts, there are several populations of different species living sympatrically in the same cave stream (Clarke 1990c; 1997; Eberhard 1992b; 1995). In caves where the dominant hydrological regime is seepage or percolation water, rather than throughflow water, aquatic species appear to be less abundant, e.g. the small population of troglobitic (obligate) heterid isopods in A.F. (IB-110) at Ida Bay (Clarke 1989a; 1990c).

The mobility of cavernicolous invertebrates in the karst bio-space

The mobility of aquatic species is obviously governed by the extent of each localised hydrological regime, which is largely governed by the extent of permeable layers of the limestone. Carbonate rock outcrops often extend each side of a topographic ridgeline or surface divide and hence surface runoff or seepage waters may flow in different directions, not necessarily downslope. The concept of a surface watershed where drainage extends downslope in opposite directions is not applicable in karst areas; water may breach these surface divides draining "backwards" to emerge on the opposite side or surface ridges. Examples of surface divide breaches in forested karst areas of Tasmania include those in Cracroft (Clarke 1987a; Goede 1977), at Ida Bay in southern Tasmania (Clarke 1990c; Goede 1969), in the Junee-Florentine karsts (R. Eberhard 1994; 1996; Hume 1991) and at Mole Creek in northern Tasmania (Jennings & Sweeting 1959; Kiernan 1990). It appears likely that a similar breach in a surface divide occurs in the Hastings karst of southern Tasmania (Clarke 1997). Following rainfall events in the catchment of the Hastings karst, flood waters have been observed in Newdegate Cave (H-X7), and it is believed that these may be derived from the slopes of Adamsons Peak, an area northwest of the known karst area. High turbidity has also been recently reported in the floodwaters in Newdegate Cave and the flocculent clay may be emanating from logged lower slopes of Adamsons Peak or the recently logged upper reaches of Creekton Rivulet in the neighbouring valley north of the Hastings karst (Clarke 1997).

Terrestrial obligates are often less mobile and may only be known from very small populations in only one cave system (Holsinger 1963). Some of the pseudoscorpion species from caves in the Appalachian mountains of USA are known from less than ten individuals (Culver 1986; Holsinger 1988). In Tasmania, the blind carabid beetle *Goedetrechus mendumae* is only known from a small cavernous section of the karst bio-space in the Ida Bay karst system. When first discovered by cave biologists in the northwestern extremity of Exit Cave during early March 1969, *G. mendumae* was only known from two female specimens found in one small passage section; subsequent collections in late March and May (1969) from the same area yielded two males and two more females. In December 1974, a visiting beetle expert from Japan collected another 6-7 specimens from an adjoining passage and since then the beetle has not been reported (Clarke 1987b; 1991a), although the writer collected a single specimen in late March 1989 from Thun Junction (IB-020), a vertical cave system which connects directly into Exit Cave in the vicinity of the earlier collection sites. [Although currently listed as vulnerable species (Eberhard 1993), based on present knowledge *Goedetrechus mendumae* should be considered as an endangered species.]

Cave communities

Invertebrate communities in the karst bio-space (including both terrestrial & aquatic species) are composed of the sum total of all species found in caves, i.e. the troglobites/stygobites, troglophiles/stygophiles, trogloxenes/stygoxenes, accidentals (and parasites) which are all "bound" together by inter-related food chains. Many of those terrestrial species which fall into the categories of trogloxenic or accidental cavernicoles, are species which have an aquatic larval or nymphal stage in the cave streams or other permanent water bodies. Clarke (1997) records many of the accidental species commonly found in Tasmanian stream caves: e.g. Plecoptera (stone flies), Trichoptera (caddis flies), Ephemeroptera (mayflies), Odonata (dragonflies), Dipteran chironomids (midges), tipulids (crane flies), trichocerids (winter crane flies), culicids (mosquitoes), sciarids (fungus flies), and phorids (hunchback flies).

Each cave community has a restricted and disjunct distribution pattern that is not repeated and the community structure often varies between different cave systems of a single karst region (Eberhard *et* *al.* 1991; Eberhard 1992c; Clarke 1997). The species diversity (richness) of cave communities includes the total range of species in all cave zones and all micro-habitats. Some cave communities include diverse assemblages with many obligate cave species, whereas some cave communities are predominantly composed of accidental species, mainly terrestrial species (see Table 1). Accidental species and trogloxenes are fundamental to survival of higher order cavernicoles, contributing to the nutrient input of cave ecosystems (see below) and enhancing the diversity and abundance of obligate species. Examples of species diversity or species richness and the variable numbers of aquatic and terrestrial species within cave communities of Tasmanian caves are given in Table 1 (following page).

Cave ecosystems and food sources

Fundamental to the cave ecosystem and its constituent biota is the maintenance of stream flows, water volumes and moisture levels (particularly in the dark zone), together with the input of natural organic food sources. The importance of water balance and stress to cave invertebrates due to water loss has been well documented in numerous scientific studies (Culver 1982; Hüppop 1985; Humphreys & Collis 1990; Doran 1991).

Table 1: A list of 27 selected caves from karst areas in Tasmania, which have the most cave fauna records showing the respective numbers of aquatic and terrestrial species based on data in Clarke (1989c; 1990b) and RFA Cave Fauna database (Clarke 1997).

Cave number	Cave name	Occurrence records	Aquatic Species	Terrestrial spp.
BH-008	Main Drain	38	4	25
BH-203	Thylacine Lair	110	7	81
CP-006	APPM Cave	11	0	11
CP-037	Philrod Cave	28	5	17
E-201	Sherrills Cave	47	0	32
F-034	Kutikina Cave	76	6	43
FG-201	Flowery Gully Cave	62	1	45
G-X3	Rum Pot	26	2	17
GP-001	Gunns Plains Cave	77	9	42
H-214	King George V Cave	124	5	30
IB-010	Mystery Creek Cave	104	5	45
IB-014	Exit Cave	154	10	50
IB-110	Arthurs Folly	64	14	24
JF-004	Khazad Dum	51	6	33
JF-006	Cashion Creek Cave	72	0	25
JF-036	Growling Swallet	49	4	23
L-004	Mostyn Hardy Cave	87	13	45
MC-001	Kubla Khan	63	5	54
MC-032	Baldocks Cave	46	1	17
MC-052	Scotts Cave	47	3	19
NL-003	Spider Den	71	1	45
PB-001	Damper Cave	73	7	32
PB-004	Cueva Blanca	43	5	23
PB-006	Bauhaus	67	3	32
R-202	Glue Passage Cave	31	3	20
VF-X2	Salisbury River Cave	33	3	22
WE-X1	Campers Cavern	30	0	25

Organic matter from epigean sources provides the basic food resource for most cave ecosystems; exceptions could include those caves where cavernicolous species rely partly or entirely on the faecal deposits of vertebrate mammals, including bat guano in mainland Australian caves (Howarth and Stone 1990), or rely on the growth of plants such as fungi in low light regions or dark zones (Eberhard 1988). Organic matter, which may consist of tree roots, fragments of living green plants, detritus, faecal matter, animal remains (including vertebrate carcasses), other invertebrate organisms including eggs and larvae (Holsinger 1988). Most the organic matter from epigean (surface) sources is transported underground by streams, swallets, percolation seepage waters, air currents or gravity fall. Due to more or less constant temperatures and the reduced seasonality effect, some aquatic species have prolonged larval stages or larvae present all year round providing a more constant food supply for other higher order organisms. Trichopteran philoptamid larvae have been observed in parts of Exit Cave almost all year round, in a dark zone region almost two kilometres from the nearest known horizontal entrance (Clarke 1997).

Because of its isolation from external influences and relative distance from epigean environmental conditions, the dark zone of the cave where most obligates live, receives comparatively little nutrient input, apart from the limited dregs of food sources carried in by streams or air currents. The total darkness prevents any photosynthetic activity and there are virtually no "primary producers", except for chemosynthetic autotrophic micro-organisms which synthesise organic materials (Daoxian 1989; Holsinger 1988); these probably have relatively little input into the energetics of cave ecosystems (Holsinger 1988). A low nutrient input in the dark zone is the main reason why cave ecosystems and their cave communities are considered unique entities with either rich or significant faunal assemblages in what may be considered as a "closed ecosystem" (Sullivan 1971). In this part of the cave, everything is recycled, so live specimens, dead remains or waste products (including faecal pellets) of one organism become the food source of another organism in the immediate food chain component of the larger food web.

For example, during a recent visit to Exit Cave, in southern Tasmania, in November 1996, four aquatic obligates (all believed to be troglobitic stygobites) were observed in close proximity to each other within a short (metre long) stream section of Western Passage: anaspidean syncarids, crangonyctoid amphipods, paludicolan flatworms and tiny 1mm long hydrobiid gastropods. This section of feeder passage to the main cave lies in the dark zone approximately two kilometres from the nearest horizontal entrances: Exit Cave efflux (IB-014) or Valley Entrance (IB-120) and well over one kilometre downstream from the nearest vertical entrance: Halfway Hole (IB-136). Microscopic examination of live specimens of the hydrobiid molluscs collected in natural cave waters in November 1996, indicated that these small snails yielded a massive amount of minute elongate cigar-shaped/oval-shaped faecal pellets (approximately one-tenth of a millimetre long) which appeared to be being consumed by other micro-organisms, possibly bacteria, and in the cave environment these pellets would probably be a major food source for the other aquatic troglobites (Clarke 1997).

Many caves (or karst areas) contain significant populations of invertebrate species which comprise complex and diverse cave communities composed of aquatic and/or terrestrial species (Eberhard 1992c). Invertebrate species in Tasmanian cave communities live in a predominantly (and naturally) low level nutrient environment dependent on natural organic input from the surface systems and nutrient recycling within the respective cave ecosystem. Most cave ecosystems are very fragile and easily susceptible to disturbance from both surface impacts or "within" cave visitor impacts (Clarke 1989b; 1997). Fundamental to the viability of these cave communities is the stability of a moisture regime: either a constant supply of "clean" unpolluted stream waters with natural nutrient input and/or percolation (seepage) waters which maintain natural cave air humidity in a stable environment with low evapotranspiration rates.

The biological importance and conservation significance of cave faunas in karst bio-space

The cave communities include many obligate (cave restricted) species which have specialised troglomorphic adaptations enabling species to live in total darkness in the stable low nutrient environments. Separated from their surface ancestors, many of these cavernicolous invertebrates in karst areas include phylogenetic or distributionally isolated relicts which have evolved in subterranean environments over a considerable period of time, possibly dating back to a geomorphic era in the subterranean biospace before the development of the caves they now live in (Holsinger 1988; Richards and Ollier 1976). Due to separation of karst areas or contiguous cave (drainage) systems within a karst area, genetic isolation has occurred and speciation of cavernicolous faunas indicates high levels of endemicity. Most of these obligate species can be considered as rare and threatened species (Clarke 1997) with actual categorisation to a conservation status dependent on individual species population dynamics, level of habitat protection and otherwise known or potential habitat threats or disturbances to the karst bio-space.

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KARST BIO-SPACE - a GLOSSARY of TERMS

Abbreviations and conventions

Syn. = synonym (word with same meaning);
Cf. = confer (compare) with the following term which is not identical but related to it;
A word in brackets on the left-hand side (in upper case) is commonly used in conjunction with the following or preceding word without altering the meaning;
A word underlined is defined elsewhere in this list.

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ACCIDENTAL: (n.) An animal accidentally living in a cave, usually either fallen or washed in, but can include those carried in: i.e., parasites on mammals, other vertebrates or invertebrates. Used for both aquatic and terrestrial species.

ADAPTATION: An inherited structural, functional or behavioural characteristic of an organism which improves its chances for survival and reproduction in a particular microhabitat or environment. (See also troglomorphic adaptations.)

ANTENNAE: Pair of "feelers" on heads of crustaceans, insects and other invertebrates that function as sensory organs.

AQUATIC: Pertaining to organisms that live in water.

AQUIFER: A body of rock capable of allowing subterranean water to be stored, transmitted or issue yield as discharge and also capable of absorbing recharge.

ARAGONITE: A less common crystalline form of calcium carbonate belonging to the orthorhombic crystal class, dimorphous with calcite, but denser than calcite.

BACTERIA: Unicellular microscopic plant organisms, sometimes aggregated in filaments, which can manufacture their own food without sunlight; probably important in caves as decomposers and perhaps as chemosynthetic autotrophs.

BIOGEOGRAPHY: The study of the geographical distribution of animals and plants over the globe. Cf. zoogeography and phytogeography

BIO-SPACE: The separated or interconnected network of "spaces" as air or water-filled cracks, pipes, vertical channels, tubes, voids or microcaverns, horizontal conduits and larger cavities including caves that are inhabited by invertebrates, including in the interstitial medium and saturated zone.

BIOSPELEOLOGY: The scientific study of plant or animal organisms living in caves; usually applied to studies of cavernicoles.

BIOTA: Sum total of all plants and animals.

BIOTIC: Pertaining to biota.

CALCITE: The commonest calcium carbonate ($CaCO_3$) mineral and the main constituent of limestone, with different crystal forms in the hexagonal-rhombohedral crystal subsystem; dimorphous with aragonite.

CATCHMENT: The area drained by various sized watercourses including dolines.

CAVE: A natural subterranean cavity (or series of cavities) large enough to be humanly enterable, commonly formed by solution of carbonate rock in karst, but may also be formed by wind, fluvial erosion or collapse (see "Pseudokarst"). It may be an air-filled or water-filled cavity. Syn. cavern.

CAVE COMMUNITY: All the cavernicolous animals (and plants) that live together in cave habitats, "bound" together by food chains and other inter-related processes.

CAVE ECOLOGY: The study of the interaction and relationships between cave organisms and their environment, e.g. energy input from surface, climatic influences, etc. (See also cave ecosystem and cave community.)

CAVE ECOSYSTEM: The ecological system formed by the interaction of the biotic community with its abiotic environment; in biospleleological terms: the coacting organisms of the cave community with their subterranean bio-space environment.

CAVERNICOLE: An (invertebrate) animal which normally lives in caves; includes accidentals, trogloxenes, troglophiles and troglobites and their aquatic equivalents: stygoxenes, stygophiles, and stygobites.

i.e. corrosion and abrasion
CRYPTIC: (adj.) Term used to describe cavernicoles which may be difficult to locate, due to being very small (often <5mm) or secretive by nature or virtue of their preferred habitat, e.g. in narrow wall crevices or the interstitial spaces in soil and streamside deposits.
CONDUIT: An underground stream course completely filled with water and under hydrostatic pressure or a circular or elliptical passage inferred to have been such a stream course.

CONTIGUOUS KARST: The interconnected air-filled or water-filled solutional or hydrological network of space/s in any area of karstified carbonate rock.

CORRASION: The wearing away of bedrock or loose sediment by mechanical action of moving agents, especially water.
DARK ZONE: The insulated (inner) stable part of a cave shielded from external factors where conditions remain relatively constant all year round including a relatively constant temperature that approximates the annual surface mean and high humidity (often near saturation point) with a very low rate of evaporation and in Tasmanian caves, this zone is also characterised by low nutrient input. Syn. "troglic" zone; "deep cave" zone.

DECOMPOSERS: Living things, chiefly bacteria and fungi, that live by extracting energy from tissues of dead animals and plants.

DETRITUS: Aggregate of fragments from organic structures, as detached or broken-down tissues; small pieces of dead and decomposing plants and animals.

DISCHARGE: The outflow drainage of aquifer waters.

DISJUNCT (VICARIANT) DISTRIBUTION PATTERN: Relates to the separate occurrences of corresponding species in separate karst areas; these species are related to a (now extinct) once widespread surface-dwelling common ancestor. Cf: Distributional Relict, Phylogenetic.

DISTRIBUTIONAL RELICT: Relates to a species surviving in an area isolated from the main or original distribution area usually as a result of intervention of broad scale environmental events such as glaciation or continental drift, e.g. Gondwanan relict or Pangean relict species.

DOLINE: A closed depression, often basin-shaped or roughly conical, funnel-shaped depressions, usually formed in the karst land surface of carbonate rock area, as a result of solution or collapse of underlying carbonate rock strata. Dolines have a simple but variable form, e.g. cylindrical, conical, bowl or dish-shaped, and may vary in size dimensions from a few metres to many hundreds of metres wide. Dolines also include sinkholes, which are sites of sinking water that drain underground in karst.

DOLOMITE: (1) A mineral consisting of the double carbonate of magnesium and calcium, $CaMg(CO3)2$.
(2) A carbonate rock made chiefly of dolomite mineral.

EFFLUX: Place of outflow for karst waters from aquifer; often applied to place where cave stream emerges. Cf: resurgence, spring.

ENDEMIC(ITY): Pertaining to genera or species that are native to a particular area; often only found in one particular cave, hydrological system or karst area.

ENDOGEAN: Pertaining to the faunal domain (usually for terrestrial species) in the region immediately beneath the surface, i.e. within the soil or under plant litter. Cf: epigean; hypogean.

ENDOKARSTIC: Subterranean region in karst, below near-surface epikarstic zone, includes the "upper" unsaturated, vadose zone with free draining seepage water and streamway floodwaters plus the "lower" saturated, phreatic zone within static water table or slow flow flooded zone.

ENTRANCE ZONE: The interface between surface and subterranean (underground) environments leading internally into the twilight zone.

EPIGEAN: Pertaining to the biological domain at the surface or above it, including streams.

EPIKARSTIC: Pertaining to the upper/ outer layer of karstified carbonate rock in the unsaturated zone, immediatlely below the soil layer.

EROSION: The wearing away of bedrock or sediment by mechanical and chemical actions of all moving agents such as rivers, wind and glaciers at the surface or in caves.

EVAPOTRANSPIRATION: A process by which water is lost from a catchment or karst surface which includes evaporation of water from wet surfaces as well as transpiration of water from trees and plants.

FISSURE: An open crack in rock or soil.

FLOCCULANT: Syn. suspended sediment.

FLUVIAL: Pertaining to processes of flowing water. Cf. lotic.

FOOD CHAIN: A series of plants or animals linked together by their food relationships or a specific nutrient and energy pathway. (See also food web.)

FOOD WEB: An interlocking system of separate food chains in any (cave) community.

GUANO: Large accumulations of dung, often partly mineralized, including rock fragments, animal skeletal material and products of reactions between excretions and rock. In caves, derived from bats and to a lesser extent from birds.

HABITAT: The immediate surroundings (in the specific bio-space) of plants or animals (cavernicoles), with everything necessary for life of the organism that normally lives there.

HYPOGEAN: Pertaining to the subterranean domain below the endogean, including the dark zone of caves.

HYPORHEOS: Pertaining to water flowing over streambeds in lotic environments.

INTERSTITIAL MEDIUM: Air or water-filled spaces between grains of sand, fine gravel or detritus.

INVERTEBRATES: Animals without backbones. Includes the annelids (worms), molluscs (snails) and arthropods found in caves. (See also macroinvertebrates).

KARST: Terrain with special landforms and drainage characteristics due to greater solubility of certain rocks (notably carbonate rocks such as limestone, dolomite or magnesite) in natural waters. Derived from the geographical name "krs" from part of the karst terrain in Slovenia.

KARSTIFICATION: A periodic or cyclic process, where phases of active solutional development of karst are followed by infilling of karst conduits and voids, depending on global climatic regimes.

LARVA(E): The active immature, but self-sustaining and independent stage of invertebrate species, prior to assuming the characteristic features of an adult form.

LIMESTONE: A sedimentary rock consisting mainly of calcium carbonate, (CaC03), derived from the accumulated deposition (and fossilisation) of the calcareous remains of marine or freshwater organisms.

LOTIC: Pertaining to the aquatic environment of running water.

MACROINVERTEBRATES: Larger invertebrates that are visible to the naked eye.

MAGNESITE: Usually considered as a mineral, but in geomorphic terms as a form of magnesium carbonate rock (cf: dolomite) with varying amounts of magnesium, calcite or iron and may be susceptable to karst solution processes, e.g. the magnesite karst at Savage River in northwestern Tasmania.

MICROCAVERNS: Predominantly air-filled cavities ranging in size from "fist" sized voids or smaller, usually referring to those bio-space voids in the epikarstic region of the unsaturated zone and can be considered to include all cavities that are not large enough to be defined as caves. Syn. microcaves.

MICROCLIMATE: The climate (i.e. temperature, humidity, air movements, etc.) of a restricted area or space, e.g. of a cave or on a lesser scale of the space beneath stones in a cave. (See microhabitat).

MICROHABITAT: The individual faunal habitat or niche within a larger (cave) environment; maybe used to encompass broad regions such as the dark zone or smaller defined habitat niches,where environmental conditions differ from those in a surrounding area, e.g. under logs, in wall crevices or in the interstitial medium.

NETWORK: A complex pattern of repeatedly connecting passages in a cave.

NICHE: An organism's place in the cave ecosystem: where it lives, what it consumes, what consumes it and how it interacts with all biotic and abiotic factors.

NYMPH: Pertaining to a juvenile form, particularly related to juvenile insects without wings or with incomplete wings.

OBLIGATE: Pertaining to a species which is unable to live outside the cave environment, often found in the dark zone and may display troglomorphic adaptations.

ORGANIC: Of biological origin. Syn. biogenic.

PALAEOKARST: "Fossil" karst: cave or karst features remnant from a previous phase or period of karstification, characterised by the presence of ancient (buried) deposits, as lithified cave fills or (bone) breccias.

PARASITE: An organism which at some stage in its life history derives its food from the tissues of another organism; in cave ecosystems, the Acarina (ticks and mites) are commonly found as parasites on other invertebrates or vertebrates.

PERCOLATION WATER: Water moving mainly downwards through pores, cracks and tight fissures in the unsaturated epikarstic zone and vadose zone; may also relate to water draining underground from a swallet or streamsink.

PHREATIC ZONE: Zone usually below the water table where voids or tubes in the rock are completely saturated with water. Syn. saturated zone.

PHYLOGENETIC: Pertaining to an ancient lineage with a long history of development for the species. Viz. race history.

POPULATION: Individuals of a species in a given locality which potentially form a single interbreeding group separated by physical barriers from other such populations (e.g. populations of the same species in two quite separate caves).

PSEUDOKARST: Terrain with landforms (including caves) which resemble those of karst but are not the product of karst solution processes.

PUPA(E): The inactive stage in the life history of certain insects during which the larva undergoes a gradual reorganisation of its tissues in the process of metamorphosis to becoming an adult.

RECHARGE: The process involving the input or intake (absorption) of water into the zone/s of saturation in karst aquifers; also relates to the quantity of water added to the saturation zone.

RESURGENCE: A spring where a stream, which has a course higher up on the surface, reappears lower down at the surface.

SATURATED ZONE: The zone below the water table, composed of the shallow phreatic zone, deep phreatic (or bathyphreatic) zone and stagnant phreatic zone. Syn. phreatic zone.

SEEPAGE WATER: Syn. percolation water.

SINKHOLE: A word of American origin used to describe sites of sinking water in a carbonate rock (karst) area; often formed in a doline. Sinkholes also include swallets.

SOLUTION: In karst study, the change of bedrock from the solid state to the liquid state by combination with water. In physical solution the ions of the rock go directly into solution without transformation. In chemical solution acids take part, especially the weak carbonic acid formed by hydration of carbon dioxide (CO2).

SPECIES: A group of (invertebrate) animals that have a high degree of similarity and are actually or potentially interbreeding populations reproductively isolated from other such groups by their biology, not simply by physical barriers. Cf. speciation.

SPRING: A natural flow of water from rock or soil onto the land surface or into a body of surface water. Syn. rising.

STREAMSINK: A point at which a surface stream disappears underground; may be empty into a collapse feature, cave feature such as shaft or be the gradual downward percolation through streambed gravels or boulders. Cf. swallet.

STYGOBIONT: A term originally coined to describe the aquatic obligates in subterranean groundwaters and cave streams (i.e., the stygofauna), particularly relevant to species with troglomorphies that are restricted to groundwater habitats, i.e., the aquatic troglobites and phreatobia (phreatobites). The term is now expanded to cover the aquatic equivalents of terrestrial cavernicoles in karstic groundwaters: stygobites, stygophiles and stygoxenes and also covers aquatic species in alluvial groundwaters.

STYGOBITE: An obligate aquatic species of hypogean waters with troglomorphic adaptations, an aquatic equivalent of a (terrestrial) troglobite. Cf. stygobiont. In the expanded definition, stygobites also include the obligatory hypogean forms present in alluvial groundwaters, sometimes found very close to the surface and the phreatobites: stygobites which are restricted to the deep groundwater substrata of alluvial aquifers.

STYGOFAUNA: Ecologically descriptive term covering (aquatic) groundwater fauna.

STYGOPHILE: A facultative stygobiont, usually lacking troglomorphies, and considered as the aquatic equivalent of a (terrestrial) troglophile. In the expanded definition relating to porous aquifers, stygophiles are divided into three categories: occasional hyporheos, essentially the larvae of aquatic insects (which require an aerial epigean stage to complete their life cycle); amphibites, whose life cycle requires the use of both surface and groundwater systems; and permanent hyporheos - the diverse assemblage of species present in all life stages in the groundwater or benthic habitats.

STYGOXENE: An habitual stygobiont (aquatic species) which spends only part of its life cycle in cave waters and returns periodically to the epigean domain for food.

SUBTERRANEAN: Pertaining to underground environments (in karst).

SUSPENDED SEDIMENT: Small particles of insoluble organic or inorganic matter suspended in the water column. Syn. flocculant, suspended solid.

SWALLET: Usually related to karst, may be considered as a form of sinkhole, but could refer to a streamsink; (often associated with a cave entrance) and is one of the major entry points for recharge waters that drain underground in carbonate rock areas such as limestone. Swallets may empty directly into open or choked cave features such as shafts or avens, or simply be a zone of gradual downward percolation from the base of a streambed.

TERRESTRIAL: Pertaining to animals living on "land" surfaces in epigean, endogean or hypogean environments.

TRANSITION ZONE: Region between the twilight zone and dark zone where no there is no visible light, but some external factors from the entrance environment may still be apparent, e.g. seasonally fluctuating air temperatures.

TROGLOBITE: An (obligate) cavernicole unable to live outside the cave environment; usually defines an obligate species with troglomorphic adaptations. The term is usually restricted to terrestrial species, but sometimes aquatic obligates maybe referred to as aquatic troglobites.

TROGLOMORPHIC ADAPTATIONS: Adaptations to the cave environment, particularly for species living in the dark zone e.g. lengthening of appendages including antennae, loss of pigment; modification of eyes; modified olfactory sensory organs (for "sniffing" out prey and mates etc.); extra sensory structures e.g. elongated legs used as feelers and sometimes modified chelicerae (the grasping organs used to hold prey foods etc. and reduced metabolic rate are all considered adaptations to the dark zone of caves.

TROGLOXENE: A terrestrial cavernicole which spends only part of its life cycle in caves and returns periodically to the epigean domain for food.

TURBIDITY: Relates to the muddiness, cloudiness or "milkiness" of water and usually reflects the amount of suspended sediment in the water.

TWILIGHT ZONE: The outer part of a cave in which daylight penetrates and gradually diminishes to zero light, where transition zone takes over.

UNSATURATED (VADOSE) ZONE: The component of the karst hydrographic zone including endogean region in soil and the subterranean subcutaneous epikarst and free draining percolation water where voids in the rock are partly filled with air and through which water descends under gravity.

GEOLOGY AND CAVES OF THE FLINDERS RANGES

by

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I. INTRODUCTION

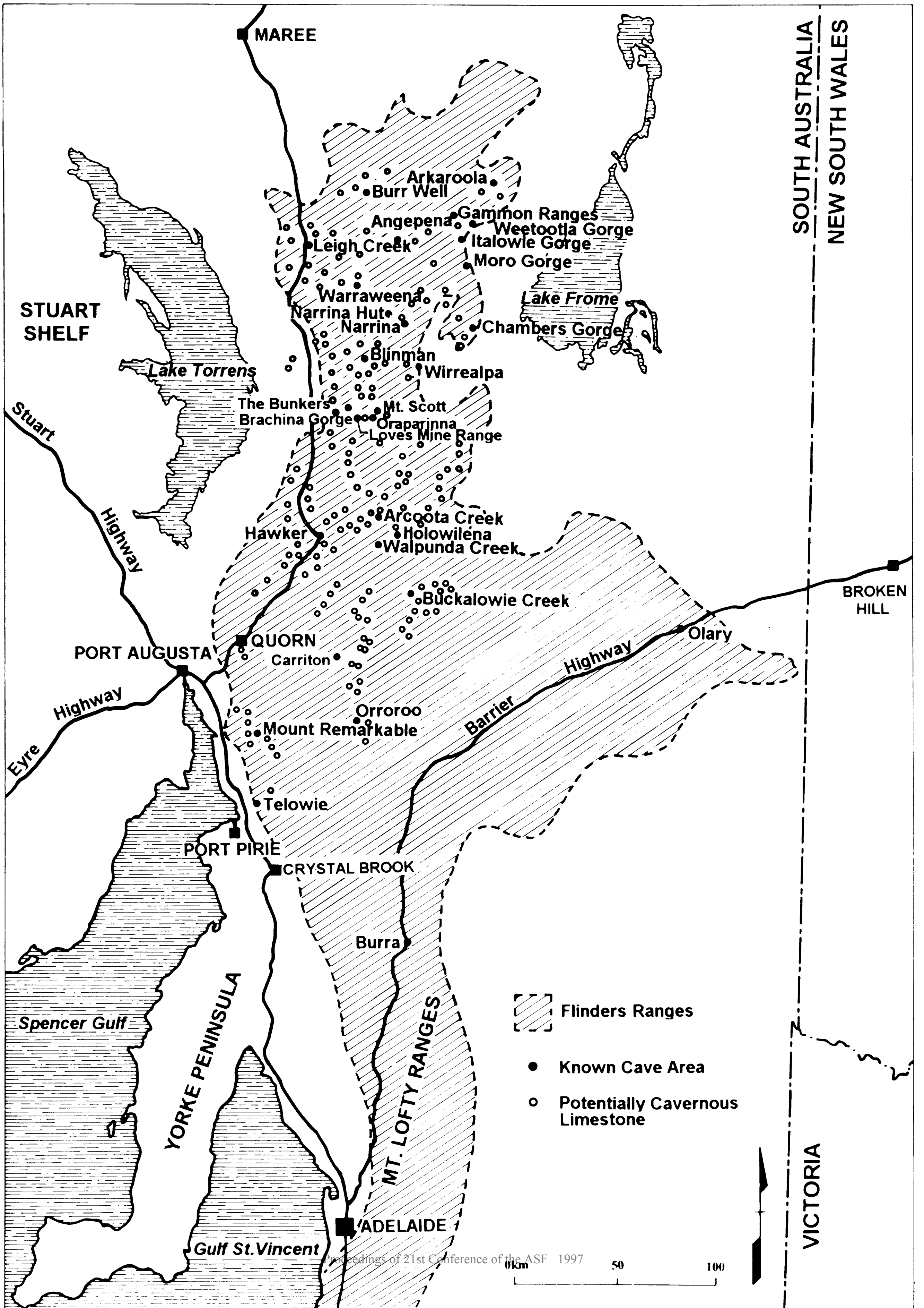
The Flinders Ranges are a spectacular place in which to go caving. The geology of the Flinders Ranges is the main scenic attraction of the area, and allures many people to the region. Imposing mountain ranges, upturned layers of rock and hidden gorges provide a strong aesthetic appeal to visitors. Quartzite, sandstone and siltstone tends to dominate the landscape, but there are also some areas of limestone. The focus of this paper is the limestone outcrops throughout the Flinders Ranges, and the caves within that limestone are described.

The Flinders Ranges constitute the northern component of the geological feature known as the Adelaide Geosyncline. The mountains of the northern part of the Flinders Ranges known as the Gammon Ranges, the Flinders Ranges themselves, the Mount Lofty Ranges, the Fleurieu Peninsula, and the underlying geology on Kangaroo Island are all part of the Adelaide Geosyncline. In fact, the same rocks which constitute the Flinders Ranges also outcrop in the Officer and Amadeus Basins in central Australia, the Barrier Ranges in New South Wales, and the Ross Orogen region in Antarctica (Preiss 1987).

The Flinders Ranges are generally regarded to be those mountain ranges north of Crystal Brook and Burra in South Australia (Figure 1), and include the Gammon Ranges. The Australian Speleological Federation have classified all caves north of the roads linking Port Pirie, Crystal Brook and Burra to belong to the 'Flinders Ranges' cave region, and are allocated 5Fx numbers (Matthews 1985).

The majority of the Flinders Ranges are above 200 metres elevation, with some parts in the vicinity of Wilpena Pound and the Gammon Ranges rising to over 1000 metres. The distribution of native vegetation is closely related to climate and landform. Low open woodlands of native pine (*Callitris columellaris*) and black oak (*Casuarina cristata*) often occur in the ridge areas, mallee species dominate the lowland country, native grasses tend to grow on the rounded ridges, river red gums (*Eucalyptus camaldulensis*) line all the major water courses, and saltbush (*Artiplex* spp.) and bluebush (*Marieana* spp.) occupy the plains and alluvial fans (Gell & Bickford 1996). The variety and distribution of vegetation against the backdrop of colourful mountain ranges adds to the scenic appeal of the Flinders Ranges, especially when seasonal rains result in spectacular wildflower displays including the Sturt's desert pea (*Swainsona formosa*).

FIGURE 1 Known and potentially cavernous areas in the Flinders Ranges. Source: Author's research based on records held by the Cave Exploration Group of South Australia.



Mean annual precipitation for the Flinders Ranges varies from over 500 mm in the Mount Remarkable area in the south to less than 200 mm on the northern slopes (Schewerdtfeger & Curran 1996). Most rainfall falls during the winter months, and there is a strong east-west gradient, with those areas to the east subject to the rainshadow effect. Surface water in the Flinders Ranges is scarce, and is usually restricted to a few deep water holes along the main river valleys. These water holes are replenished only after infrequent and intense storm events, such as the one which occurred in February 1997, when major road and valley features were realigned. The paucity of readily available water in the Flinders Ranges severely restricts the movement of visitors away from base camp areas, which are usually located along the creek lines.

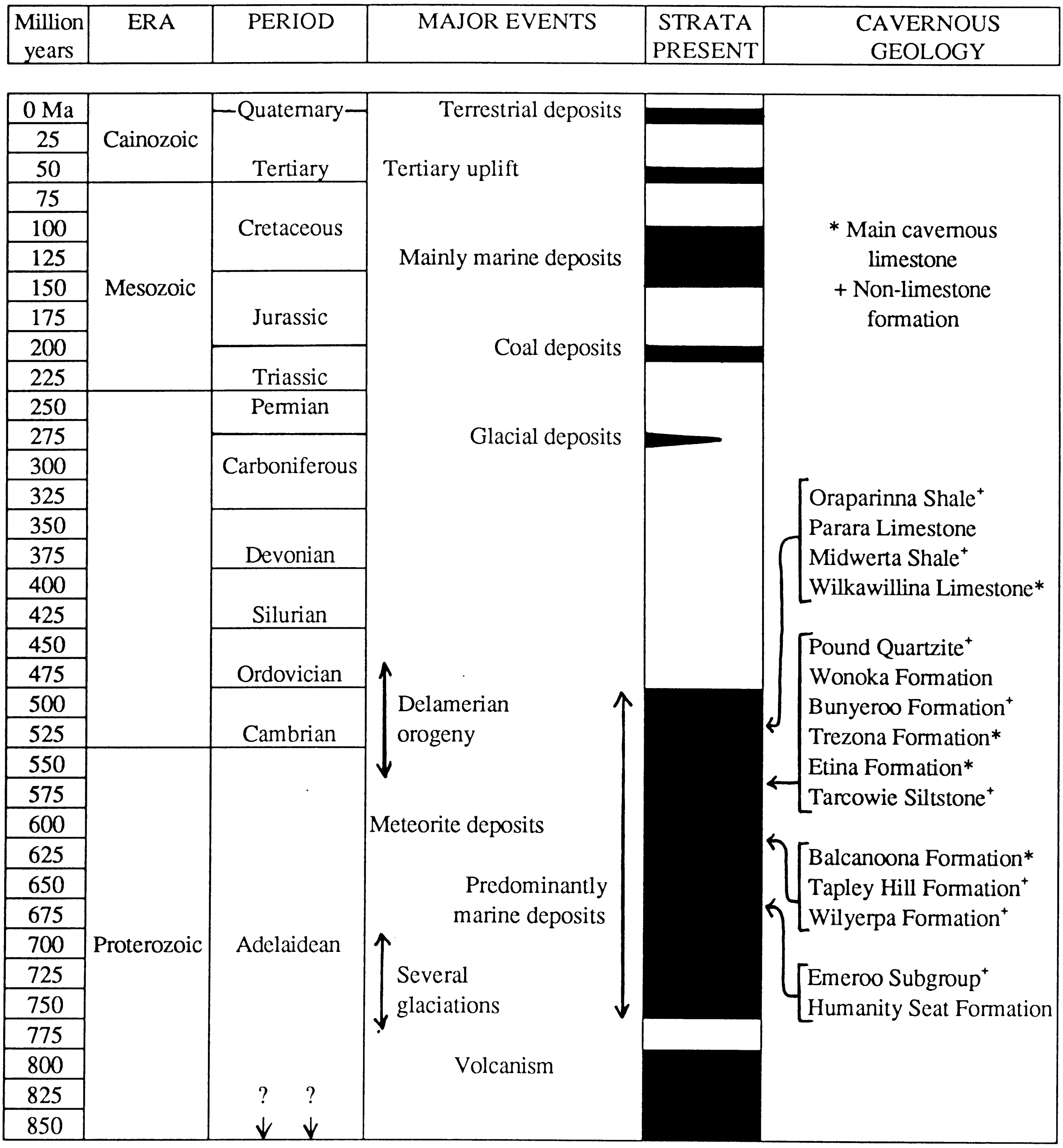
Contemporary land uses range from grazing and arable land in southern areas where rainfall exceeds 300 mm, to sheep grazing on leasehold land in the northern sector. There are several National Parks in the Flinders Ranges, the most notable of which are the Gammon Ranges National Park, Flinders Ranges National Park (encompassing Wilpena Pound) and the Mount Remarkable National Park (Bonython 1996). There is also a large segment of the north-central Flinders Ranges around Nepabunna and Mount Serle which belongs to the Adnyamathanha Aboriginal people (Jones & McEntee 1996). Thus, access to caves in the Flinders Ranges is not automatic, and permission with the relevant land owner or lease holder should always be sought before entering each karst area.

II. GEOLOGICAL HISTORY OF THE FLINDERS RANGES

The rocks which underlie the Flinders Ranges and Adelaide Geosyncline are considered to be a basement of the earth's crust comprised of metamorphic and granitic rocks. These do not outcrop anywhere, but are known from extensive drilling operations conducted in the area, and are also inferred from the composition of the numerous diapirs in the region (Preiss 1987). Associated ancient crustal rocks occur west of the Flinders Ranges in the Gawler Craton, and to the east in the Curnamona Craton. The formation of the present day Flinders Ranges commenced when the earth's crust in this area thinned due to extension at the western and eastern perimeters. This resulted in faulting, so that the basement became a series of linear, fault-controlled downthrown areas, or a rift zone (Lemon 1996). Selby (1990) considered this to occur during the Proterozoic Era.

Being a low point in the landscape, the area was then suitable for the deposition of sedimentary material which began to infill the rift zone. Initial deposition took the form of alluvial fans, fluvial deposits, and lacustrine sediments, and was accompanied by the extrusion of volcanics in the Arkaroola area. This deposition phase resulted in subsidence of the area until the rift dropped to below sea level. Once this happened, the sea flooded in and resulted in the deposition of marine deposits, which forms the vast bulk of the sedimentary sequence seen in the Flinders Ranges today. Most deposition occurred during 'Adelaidean' Period (Figure 2), which can be divided into the Willouran, Torrensian, Sturtian, Marinoan and Ediacaran Epochs. Preiss (1987) has identified 45 major time periods within the Adelaidean Period, and more than 165 distinct sedimentary units. Preiss (1987) should be consulted for details of these periods and units. Suffice to say here that the maximum thickness of sedimentary layers is fifteen kilometres, and that the sediments are composed of a variety of muds, silts, sands, quartzite, conglomerates and dolomite, and that stromatolites commonly accompany the dolomite formations.

FIGURE 2 GEOLOGICAL TIME LINE SHOWING MAJOR GEOLOGICAL EVENTS AND CAVERNOUS STRATA IN THE FLINDERS RANGES. Source: time line adapted from Lemon (1996) and supplemented from data held by the Cave Exploration Group of South Australia



Even though the majority of the sediments which now constitute the Flinders Ranges are of marine origin, there are a few notable exceptions. There is evidence of glacial activity in the Arkaroola and Holowilena areas, where distinctive glacial deposits known as tillite have been found. In fact, at the glacial maximum during Appila time (Preiss 1987), the entire depression was covered with an extensive ice sheet, and the surrounding peaks in the Gawler and Curnamona Craton areas were permanently covered with snow. Also, there exists a continuous layer of volcanic rock debris throughout much of the Flinders Ranges which is considered to be of meteoritic origin (Gostin *et al.* 1986). Williams (1986) demonstrated that these deposits originated from a meteorite impact at a site known as 'Lake Acraman' north of Gawler Ranges hundreds of kilometres to the west of the Flinders Ranges.

Once the sedimentary units were deposited, a period of folding and faulting followed. Preiss (1987) recorded that this occurred principally during the late Cambrian era, during an event known as the Delamerian Orogeny (Figure 2). This event was preceded by extensive diapir intrusions, where multiple domes or anticlinal folds of underlying soft and plastic rocks were squeezed upwards, rupturing the overlying rocks, and often producing breccia. The Delamerian Orogeny then operated in two phases. The early phase produced linear north-south folds in the southern and central Flinders region, and was responsible for the essentially linear mountain ranges between the Fleurieu Peninsula in the south and the area east of Port Pirie. The second phase of the Delamerian Orogeny affected mainly the northern Flinders area, and resulted in strong east-west folds in that area and relatively tight northeast-tending folds in the eastern central zone of the Flinders Ranges. Fault line activity in places such as the Northwest Fault, west of Leigh Creek, occurred during this phase.

Since the deposition of the main sedimentary deposits, other geological events have occurred, including a minor glacial event, the formation of coal deposits in four small circular basins in the Leigh Creek area, deposition of marine sediments in the northern part of the Flinders Ranges associated with the inland Cretaceous sea, and uplift of the mountain ranges during the Tertiary period.

The uplift which occurred during the Tertiary period resulted in the present relief of the Flinders Ranges. Initially, the uplift occurred gradually, and resulted in sedimentation of lacustrine and fluvial material around the margins of the ranges. The major phase of uplift of both the Flinders and Mount Lofty Ranges took place towards the end of the Tertiary and beginning of the Quaternary period. Associated with the uplift, the top layers of the sedimentary sequence were eroded, exposing the 165 geological units identified by Preiss (1987), and resulting in the present elevation of the ranges and their current rugged character (Lemon 1996). The geological units can be seen in cross-section along many roads in the Flinders Ranges. For example, twelve main geological units are exposed along the Brachina Gorge Road ranging from the older Enorama Shale in the east to the younger Wirrealpa Limestone to the west (Selby 1990).

A feature of the geology of the Flinders Ranges today is that outcrops of specific rock types are scattered and discontinuous. Most rock strata are dipping quite steeply, which is a function of the high frequency of folds and faults in the area. Rock outcrops frequently occur in couplets and there is often a mirror image of the same sequence on either side of anticlinal ridge or synclinal depression. For example, the Pound Quartzite, which is resistant to erosion and thus often constitutes the high points in the landscape, forms the perimeter of the wall of Wilpena Pound and the main ridgeline of the Elder, Chase and Druid Ranges (Selby 1990).

Much of the material that was eroded from the Flinders Ranges during the Tertiary Uplift has since been reworked and deposited beneath the plains to the west, north and east, or as alluvial fans along the boundaries of the Ranges. Today, the dominant process throughout the Flinders Ranges is erosion, with sedimentation restricted to the flanking areas.

Thus, the distinguishing features of the Adelaide Geosyncline are threefold. Firstly, the rocks are sedimentary in nature. There are the usual assortment of sandstones, limestones, mudstones and quartzite, but there are also scattered layers of glacial deposits and ash from an asteroid impact. The majority of the sediments are of marine origin. Secondly, the rocks are very old. The vast majority of the rocks of the Flinders Ranges are considered to date from the Pre-Cambrian (or Adelaidean) era, with some rocks being of Cambrian age (Preiss 1987). This implies that considerable time has been available for cave development in the Flinders Ranges. Thirdly, the Flinders Ranges have been subject to extensive folding and faulting. Much of the top layers of rocks have been sheared off over time resulting in massive amounts of erosion of the uplifted material and associated deposition in the adjacent lowland plains.

III. THE LOCATION AND USE OF CAVES IN THE FLINDERS RANGES

There are 115 known caves scattered throughout Flinders Ranges (Kraehenbuehl *et al.* 1997). The best known caves are as follows: 5F3 Mairs Cave and 5F4 Clara St Dora Cave in the Buckalowie Creek area; 5F15 Eyrie Cave in the Bunkers Range; 5F1 Mt Remarkable Blowhole at Mount Remarkable; 5F11 Woodendinna Cave on Narrina Station; 5F8 Oraparinna Cave, 5F29 Thunderdrum Cave and 5F33 Yellow Foot Rock Wallaby Cave in the Oraparinna area; 5F5 Arcoota Creek Cave, 5F6 Good Friday Cave and 5F7 Mt Simms Cave in the Walpunda Creek and Holowilena region; and 5F9 Wooltana Cave on Wooltana Station. In fact, caves are found at all the locations shown in Figure 1.

To the casual observer, there is no apparent pattern to the distribution of caves in the Flinders Ranges. Indeed, caves occur in a variety of locations (Figure 1) and many different rock types (Table 1). The scattered nature of cave locations is due to the geological history of the region outlined above, where the same geological unit may outcrop at multiple sites. As with other rock types, the distribution of limestone in the Flinders Ranges is scattered and discontinuous. Hence, the Flinders Ranges are not a typical karst region of more or less continuous limestone, but limestone outcrops occur in elongated strips or semi-circular bands. However, there are four main limestone units in which the majority of the caves of the Flinders Ranges are found, and these are detailed in the following section.

As with other geological units, couplets of outcropping limestone often occurs. For example, in the Buckalowie Creek area north-east of Orroroo, there are two parallel bands of limestone running north-east to south-west. Two caves in the northern outcrop, 5F3 Mairs Cave and 5F4 Clara St Dora Cave, have been known for many years, and there are three other smaller caves in the same outcrop: 5F27 Lizard Cave, 5F28 Chimney Cleft Cave, and 5F35 False Wall Cave (Kraehenbuehl *et al.* 1997). The southern outcrop of limestone has the same potential to be cavernous, although its remoteness from access tracks has so far precluded investigation of that area for caves.

However, only about 70 percent of the known caves in the Flinders Ranges are found in limestone. Other caves are found in quartzite, sandstone, shale or siltstone (Table 1). For example, 5F99 Yourambulla Cave, which is famous for its Aboriginal art work, is found in Pound Quartzite. Most caves in non-limestone are small, being little more than large rock shelters, and some do not have zones of permanent darkness.

Past Aboriginal interactions with caves in the Flinders Ranges were significant. The Adnyamathanha, Walypi, Ngadjuri and Nukunu languages were spoken by the original inhabitants of the Flinders Ranges, although the Adnyamathanha tradition dominates the area today (Jones & McEntee 1996). Karst areas such as Chambers Gorge and Moro Gorge feature extensively in Adnyamathanha mythology (Tunbridge 1988), on account of the presence of permanent water holes in the vicinity of caves. Some caves such as 5F84 Wild Dog Cave and 5F99 Yourambulla Cave show evidence of Aboriginal art work (Kraehenbuehl *et al.* 1997), and it is likely that many caves and shelters were known and visited for the purposes of hunting euros and wallabies which lived there. Other caves in the Flinders Ranges were taboo. For example, 'Yamuti', the name of a large mammal-like being, was said to have originated from 5F9 Wooltana Cave, and indeed Tunbridge (1988) claimed that the entrance to that cave lends itself to the idea that it was made and inhabited by a prehistoric creature.

Many of the more popular and well-known caves in the Flinders Ranges were mined for bat guano by Europeans early this century. Before the advent of superphosphate, bat guano provided a valuable fertiliser for the generally nutrient-poor soils in Australia. This land use activity had a deleterious effect on the bat populations of the Flinders Ranges, but did ensure vehicular access to the site of some caves, and easy access into other caves via adits. Caves thus affected included 5F9 Wooltana Cave (Winton 1920a), 5F26 Burr Well Cave (Winton 1920b), 5F3 Mairs Cave, 5F4 Clara St Dora Cave (Winton 1922), 5F8 Oraparinna Cave (Segnit 1933a) and 5F6 Good Friday Cave (Segnit 1933b).

IV. THE FOUR MAIN LIMESTONE FORMATIONS IN THE FLINDERS RANGES

The four main formations in which caves are found in the Flinders Ranges are the Balcanoona Formation, Etina Formation, Trezona Formation, and the Wilkawillina Limestone. About 70% of the known caves in the Flinders Ranges occur in one or other of these formations, and details of each are described below based on the work of Preiss (1987).

The Balcanoona Formation

This is the oldest of the limestones in the Flinders Ranges, being deposited early in the Proterozoic era. This formation is equivalent to the Brighton Limestone of the Mount Lofty Ranges, and comprises material of a sandy limestone with flat shale pebbles and fragments of stromatolites. It is up to 75 metres thick and is overlain by a dark grey massive limestone that is usually 60 metres in thickness. Stromatolites are domical or columnar structures produced by cyanobacteria which trap, bind and precipitate sediment such as calcium carbonate. There are about 240 square kilometres of outcrops of the Balcanoona Formation, mainly in the eastern and northern parts of the Flinders Ranges.

TABLE 1 LOCATION OF CAVERNOUS ROCK STRATA AND CAVES IN THE FLINDERS RANGES. Source: strata information adapted from Preiss (1987) and cave location information based on records held by the Cave Exploration Group of South Australia

ERA (PERIOD)	EPOCH	FORMATION CONTAINING CAVES		LOCATION OF OUTCROPS	SPECIFIC SITES WHERE CAVES ARE FOUND IN EACH FORMATION
Palaeozoic (Cambrian)	Lower	Oraparinna Shale	Cho	Northern Flinders Ranges	Angepena
		Parara Limestone	Chr	Central & northern Flinders Ranges	Narrina, Wirrealpa
		Midwerta Shale	Chd	South-central Flinders Ranges	Narrina Hut
		Wilkawillina Formation	Chw	Central & northern Flinders Ranges	Angepena, Brachina Gorge, Moro Gorge, Narrina, Oraparinna, Wirrealpa
Proterozoic (Adelaidean)	Marinoan	Pound Quartzite	Pwp	Central and northern Flinders Ranges	Gammon Ranges, Hawker, Italowie Gorge, Narrina
		Wonoka Formation	Pww	Throughout the entire Flinders Ranges	Leigh Creek, Wirrealpa
		Bunyeroo Formation	Pwb	Throughout the entire Flinders Ranges	Narrina Hut
		Trezona Formation	Phz	Central & northern Flinders Ranges	Arcoota Creek, Buckalowie Creek, Chambers Gorge, Oraparinna, The Bunkers, Trezona, Walpunda Creek, Warraweena
		Etina Formation	Phe	Central & northern Flinders Ranges	Arcoota Creek, Blinman, Buckalowie Creek, Holowilena, Mt Scott, Oraparinna, Orroroo, The Bunkers, Walpunda Creek
		Tarcowie Siltstone	Pu	Southern Flinders Ranges	Carrieton
	Sturtian	Balcanoona Formation	Pfb	Extreme western & north-eastern parts of the Flinders Ranges	Arkaroola, Burr Well, Chambers Gorge, Mt Remarkable, North Flinders, Warraweena, Weetootla Gorge
		Tapley Hill Formation	Pft	Throughout the entire Flinders Ranges	Walpunda Creek
		Wilyerpa Formation	Puw	Central & northern Flinders Ranges	Loves Mine Range
	Torrensian	Emeroo Subgroup	Po	Throughout the entire Flinders Ranges	Telowie
		Humanity Seat Formation	Por	North-eastern Flinders Ranges	Arkaroola, Italowie Gorge

Caves in this formation have been found in the Mount Remarkable, Chambers Gorge, Burr Well and Arkaroola areas (Figure 1). It is probable that both 5F1 Mt Remarkable Blowhole and 5F9 Wooltana Cave are found in this formation, and both have near vertical entrance pitches of 40 or 50 metres (Kraehenbuehl *et al.* 1997). Other caves found in this formation do not show any vertical control. Most caves in the Balcanoona Formation are small - generally having less than 50 metres of main passage, which is a reflection of the limited thickness of the limestone laid down at the time of deposition. Very little speleothem development is evident in these caves.

The Etina Formation

Occurring mainly around the central Flinders Ranges region, the Etina Formation consists of grey oolitic and sandy limestone with interbedded green dolomitic siltstone and shale. The oolitic component comprises spherical or ellipsoidal ooid grainstones of quartz and feldspar cemented by calcite. This is the most common limestone formation in the Flinders Ranges, and outcrops in about 760 square kilometres and is up to 700 metres in thickness.

Due to the extent and thickness of the Etina Formation, many significant caves have been found in this limestone deposit. In fact, 30% of all known caves in the Flinders Ranges have developed in the Etina Formation. Caves have been found at Orroroo, Buckalowie Creek, Wulpunda Creek, Arcoota Creek, Holowilena, Oraparinna, The Bunkers, Blinman and Mt Scott (Figure 1). The most well known caves in this formation are 5F3 Mairs Cave and 5F4 Clara St Dora Cave at Buckalowie Creek, 5F5 Arcoota Cave at Arcoota Creek, 5F6 Good Friday Cave and 5F7 Mt Sims Cave at Holowilena, 5F8 Oraparinna Cave at Oraparinna, and 5F15 Eyrie Cave in The Bunkers Range.

The largest caves in the Flinders Ranges are all found in the Etina Formation, and most display a strong structural control. Flinders Ranges caves are generally not noted for speleothem development, but most caves in the Etina Formation are well decorated. Both Mairs and Clara St Dora Caves have examples of unusual calcite formations (Kraehenbuehl *et al.* 1997). Some speleothems in these caves are active, but the majority are not. The relic speleothems tend to be very large.

The Trezona Formation

The Trezona Range north of Wilpena Pound is named for the alternating limestone and shale beds of the Trezona Formation where a series of terraces have formed. Located mainly in the central Flinders Ranges, this formation is comprised of pale red and grey fine-grained limestones alternating with greenish grey laminated shale and siltstone. The content of the limestone is up to 92% carbonate, and the shale is up to 32% calcite. There is about 250 square kilometres of outcropping Trezona Formation in the Flinders Ranges, and the depth of the formation may reach 240 metres.

Caves in the Trezona Formation have been found at Arcoota Creek, Oraparinna, the Trezona Range, and the Walpunda Creek areas (Figure 1). Thunderdrum Cave (5F29) and Yellow Foot Rock Wallaby Cave (5F33) in the Trezona Range near Oraparinna are two well-known caves in this formation. Some caves developed in the Trezona Formation have multiple passages that are parallel to each other and linked by smaller squeezes perpendicular to the dominant passages (Kraehenbuehl *et al.* 1997). Cave passages tend to be horizontal or slightly dipping, following the orientation of laminations. Many caves in the Trezona Formation have developed at creek level, and very few display speleothem development.

Wilkawillina Limestone

This is the youngest of the limestones in the Flinders Ranges, being of Early Cambrian age. This limestone is oolitic, stromatolitic, often dolomitised, and contains fossil archaeocyathans. Over 500 square kilometres of outcropping Wilkawillina Limestone has been mapped, and most of that is located in the central-western and north-eastern Flinders Ranges. Caves in the Wilkawillina Limestone have been found in the Brachina Gorge, Oraparinna, Wirrealpa, Angepena and Moro Gorge areas (Figure 1). Bunyeroo Cave (5F13) at Oraparinna and Anticline Cave (5F24) at Wirrealpa are two notable caves in this unit. Some caves in Wilkawillina Limestone have developed reasonably-sized chambers and some also display speleothem development (Kraehenbuehl *et al.* 1997).

V. CHARACTERISTICS OF LIMESTONE CAVES IN THE FLINDERS RANGES

Due to the non-uniformity of the rock type and the scattered nature of the limestone outcrops, no unifying hydrological or geomorphological process can be invoked to account for the caves of the Flinders Ranges. It is probable that some caves have formed under current climatic conditions, and that others are relic of past eras. This section is intended to highlight some of the major processes which have contributed to the development of the cave systems in the Flinders Ranges, so as to stimulate further work in the area.

Structural control shown in caves

The most obvious factor contributing to cave development in the Flinders Ranges is that of the structure of the rocks themselves. Due to the tectonic activity associated with both the Delamerian Orogeny and the Tertiary uplift, the dip of the sedimentary rocks ranges anywhere from 0° to 90°, with most around 30° to 40°, as at Brachina Gorge (Selby 1990).

Caves in both the Etina and Trezona Formations display structural control, with the most pronounced effect being seen in the larger caves in the Etina Formation. For example, 5F3 Mairs Cave has developed along the contact between the Etina Formation and an adjacent shale member. First-time observers of a map of Mairs Cave (Kraehenbuehl *et al.* 1997) often conclude there is something wrong with the plan, as the north-western boundary of most of the cave is a straight line. However, the map is accurate, as the cave features a near-vertical wall for about 100 metres in length, which reaches a height of at least ten metres in some parts. It is likely that the Buckalowie Creek was responsible for the formation of this cave, as it gradually lowered the land surface over time. Standing water is still occasionally observed in Mairs Cave, as the cave extends ten metres below the current creek level. A three-metre deep pool formed at the bottom of the entrance shaft following the 1974 rains.

Both 5F8 Oraparinna Cave and 5F17 Arcoota Creek Cave are maze systems where the joints and slightly-dipping bedding planes have been enlarged by the action of water on limestone to produce hundreds of metres of cave passage (Kraehenbuehl *et al.* 1997). Gillieson (1996) writes that maze caves often form where flat-lying well-bedded limestones are invaded by floodwaters, and Segnit (1933a) reported that at least three distinct phases of water erosion are evident in Oraparinna Cave. These three phases are represented by the three distinct levels found there: during the first phase the channels were formed in a direct plane with the north-westerly dip of the beds; during the second phase, which was the period of greatest cave formation, the channels were eroded in a general north-south and east-west direction; and channel development was similar during the third phase (Segnit

1933a). The third phase operates at the present time, and evidence of water having moved through the third (lowest) level of the cave was seen following the flood events of February 1997.

Not only do bedding planes play a role in the development of the Flinders Ranges caves, but some of the larger caves occur where fault lines are present. This can be seen for the two caves at Buckalowie Creek (5F3 Mairs Cave and 5F4 Clara St Dora Cave), 5F11 Woodendinna Cave on Narrina Station, and several caves in the Mt Scott area (Kraehenbuehl *et al.* 1997).

Surface hydrological influences

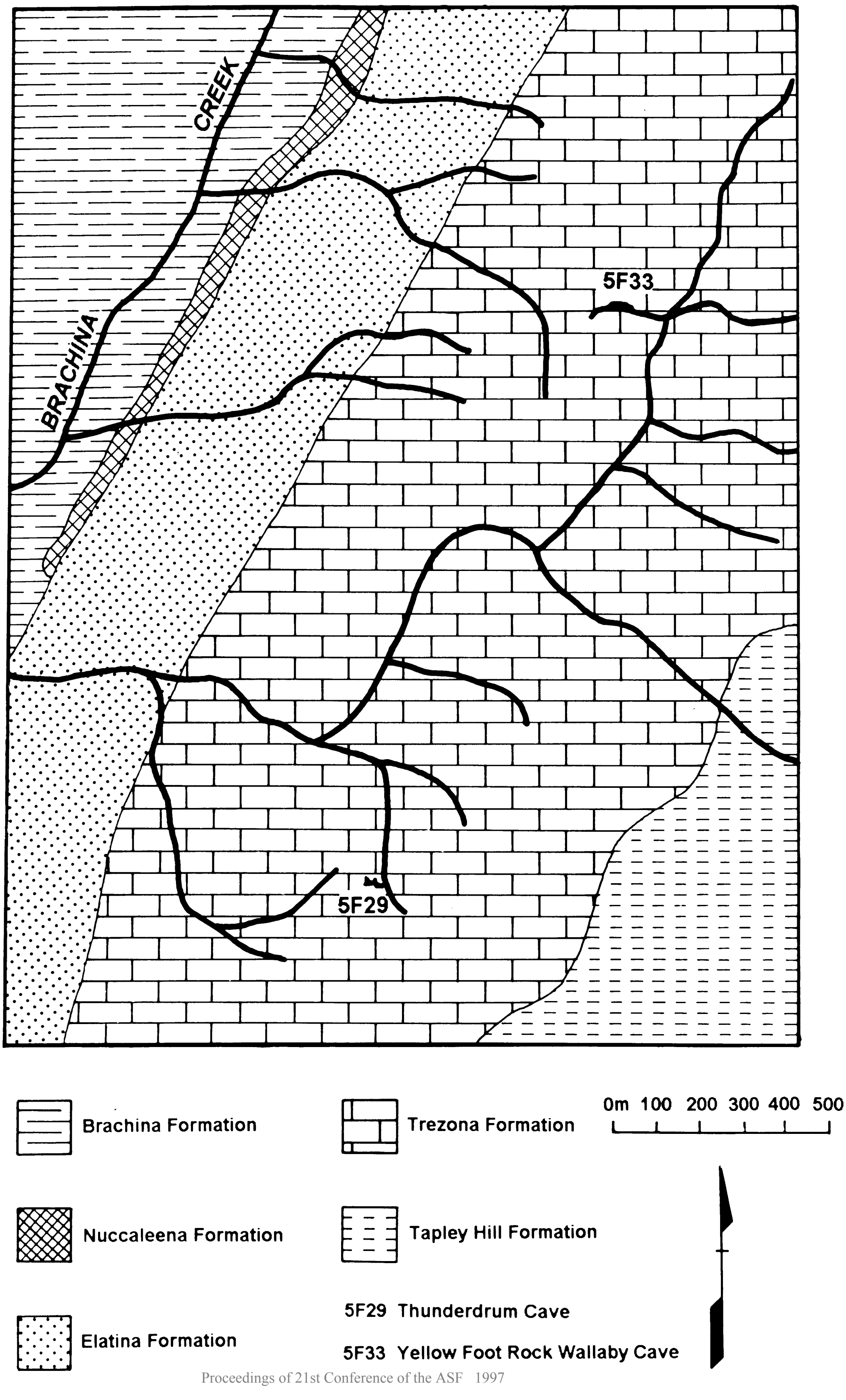
As one moves northwards through the Flinders Ranges, the amount of rainfall received diminishes. Parts of the southern Flinders Ranges receive 500 mm per annum, whereas the far northern slopes average about 200 mm per annum (Schewerdtfeger & Curran 1996). Local variation in incident rainfall does occur, with western peak areas receiving more annual rainfall than the eastern rainshadow areas.

The monthly distribution of rainfall throughout the Flinders Ranges is variable. Generally reliable rainfall occurs in the south between May and September as a result of cold fronts embedded in westerly air streams moving across the southern part of the continent. Alternatively, rain-bearing cloud banks from the tropical north may move into the Flinders Ranges at any time of the year, and often result in afternoon or evening thunderstorms and associated flash flooding (Schewerdtfeger & Curran 1996). Such an event occurred between 6 and 10 February 1997, when a tropical depression moved through the area resulting in a two-hour downpour every afternoon for five days. The most severe thunderstorm occurred on 7 February 1997, when 52.4 mm and 72 mm of rain fell in two hours at Blinman and Wilpena Pound respectively. This event was determined by the Bureau of Meteorology to have been a 1 in 100 year rainfall event (Burrows, pers. comm.).

The sporadic rainfall of the Flinders Ranges results in even greater sporadic runoff events. Surface drainage from the Ranges flows either west to Spencer Gulf or Lake Torrens, north to Lake Eyre, or east to Lake Frome. The influence of present rainfall and runoff regimes on cave development is seen in the Oraparinna area, where two caves have developed in the Trezona Formation. Both 5F29 Thunderdrum Cave and 5F33 Yellow Foot Rock Wallaby Cave are located at creek level and act as stream swallows (Figure 3). The surface catchment area for these two caves are small - 3.9 ha and 1.5 ha for Thunderdrum Cave and 5F33 Yellow Foot Rock Wallaby Cave respectively. Yet the orientation of Thunderdrum Cave is perpendicular to the surface stream, and Yellow Foot Rock Wallaby Cave runs parallel to the surface gully but slopes away from the land surface. Both caves appear to be reorienting runoff in a more direct line to the local base level of Brachina Creek.

The recent heavy rains have interacted with the caves in a number of ways. In the case of Thunderdrum Cave, the silt and boulder floor which was present throughout most of the cave until January 1997 was washed clean during the February 1997 storm event and the main passage was extended beyond that mapped in Kraehenbuehl *et al.* (1997). In all probability, subsequent smaller rainfall events will replenish the supply of sediment to the floor of the cave. At Chambers Gorge, even more dramatic changes occurred, when 5F115 Waterfall Cave, which was located at creek level, completely disappeared! Obviously, current hydrological conditions play an important role in some caves in the Flinders Ranges.

FIGURE 3 Geological setting of 5F29 Thunderdrum Cave and 5F33 Yellow Foot Rock Wallaby Cave in the Oraparinna area of the Flinders Ranges. Source: adapted from published topographic and geological maps and supplemented by data collected by the Cave Exploration Group of South Australia.



Groundwater influences

The Flinders Ranges are not noted for having abundant groundwater supplies. This is because the fractured rock nature of the geology of the Adelaide Geosyncline precludes the storage of large volumes of water. Where groundwater is present, salinity levels are commonly around 3000 mg/l (Shepherd 1983). It seems that the groundwaters in the fractured rock aquifers rarely interact with the caves of the Flinders Ranges.

However, scattered throughout the Flinders Ranges are several sedimentary groundwater basins. There are three groundwater basins of agricultural and pastoral significance in the Flinders Ranges: the Pirie Torrens Basin on the extreme western edge of the Flinders Ranges, and the small Willochra and Walloway Basins east of Port Augusta (Shepherd 1983). Also, there is another unnamed groundwater basin in the Narrina area (Figure 1) which is highly significant in explaining the presence of 5F11 Woodendinna (Narrina Lake) Cave.

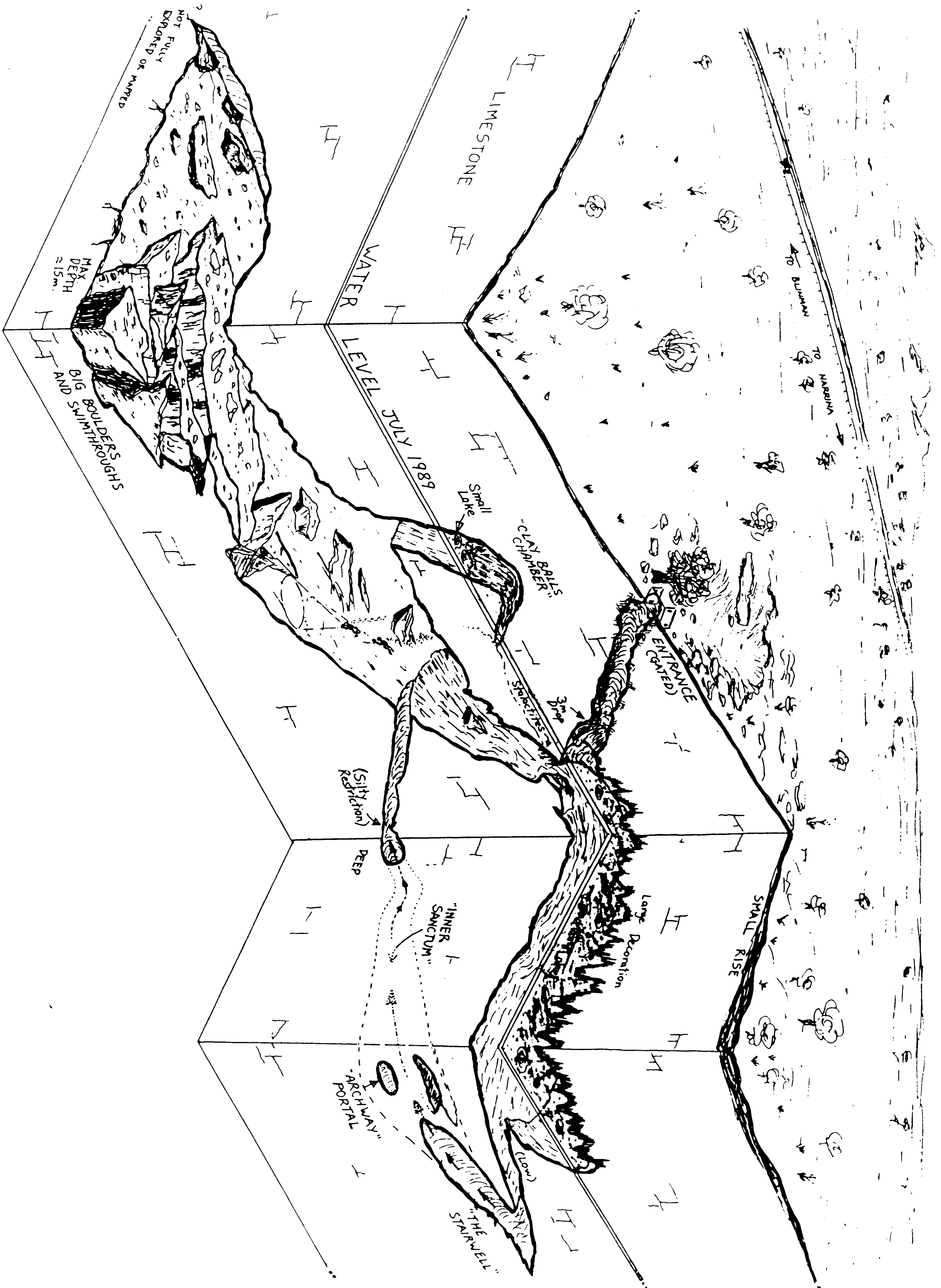
Woodendinna Cave is located in Wilkawillina Limestone in the north-central region of the Flinders Ranges. It is the only cave in the Flinders Ranges with permanent standing water, and provides a unique cave diving opportunity in a region usually devoid of permanent surface and groundwater. The watertable is located about ten metres below the surrounding land surface and the water-filled section of the cave extends to a depth of about fifteen metres (Figure 4). No other caves in either the Wilkawillina Limestone or other formations are permanently water-filled, and indeed Woodendinna Cave only exists because of the relationship between the limestone and the underlying Pound Quartzite. The Narrina area forms a pound similar to that of Wilpena Pound, where the Wilkawillina Limestone is underlain by the impervious Pound Quartzite in a saucer-shaped depression. This has resulted in a groundwater catchment area of approximately 700 square kilometres and the development of a perched aquifer. Woodendinna Cave has formed in the middle of the pound within this perched aquifer at a point where a faultline crosses the pound.

The water in Woodendinna Cave is of meteoric origin, as evidenced by both the water and salinity levels in the cave. The cave was first surveyed in 1970 when the water level was such that swimming access to features such as the 'Clayballs extension' of the cave was possible. When cave divers re-entered Woodendinna Cave in the early 1980s to explore and map the subterranean section, however, the 1970 map proved to be confusing and inadequate (Horne pers. comm.). It was subsequently found that heavy rainfall during 1974 had resulted in a rise in the water table of at least five metres (Kraehenbuehl *et al.* 1997). Both extended droughts periods and floods during the subsequent years have also caused fluctuations of the lake level in Woodendinna Cave, and it is thought that there is a time delay of about six months after heavy rains before the lake level responds by rising. In May 1990, salinity values of the water in the lake ranged from 1160 mg/l at the surface to 1300 mg/l at fourteen metres depth (Horne, pers. comm.). These factors seem to indicate periodic replenishment of fresh water to the lake in Woodendinna Cave after incident rainfall has percolated through the porous limestone aquifer.

Caves formed in a bygone era

One of the features of the geological history of the Flinders Ranges is that the sedimentary sequences are very old. This implies that considerable time has been available for cave development and, indeed, there is evidence that some caves could not have formed under present climatic conditions.

FIGURE 4 Three-dimensional perspective view of 5F11 Woodendinna (Narrina Lake) Cave. Sketch not to exact scale.
Source: Peter Horne of the Cave Exploration Group of South Australia.



There are many caves in the Flinders Ranges which are located just below the summit of mountain ranges. Within that subgroup of caves, there are a few caves of particular note which contain large and relic speleothems. Both 5F13 Bunyeroo Cave and 5F15 Eyrie Cave are two such examples. Eyrie Cave is noted for its decorations - it has expansive stalactities, stalagmites, columns and flowstone. In fact, one particular column is more than two metres in diameter and about four metres in height (Kraehenbuehl *et al.* 1997). Most of the speleothems in Eyrie Cave are inactive, apart from a few dripping straws deep in the cave. What makes these large and mostly relic features so remarkable is that Eyrie Cave is located 70 metres above the present creekbed, with only about eight metres of rock above it.

The size of the calcite formations in caverns such as Eyrie Cave implies two things. Firstly, at the time the speleothems were formed, there had to have been much more rock above the cave through which vadose water could percolate and dissolve the limestone before it reached the cave where degassing and deposition of calcite occurred. Eight metres of overlying limestone is not sufficient for the production of such massive columns. Secondly, a much wetter climate would also be needed to account for the size of the speleothems, as the current rainfall regime has only produced straws. These factors suggest that some of the caves in the Flinders Ranges were formed in a previously wetter climate prior to extensive erosion of the landscape. These caves were obviously formed in a bygone era, and the association of the caves with the Tertiary uplift has yet to be determined.

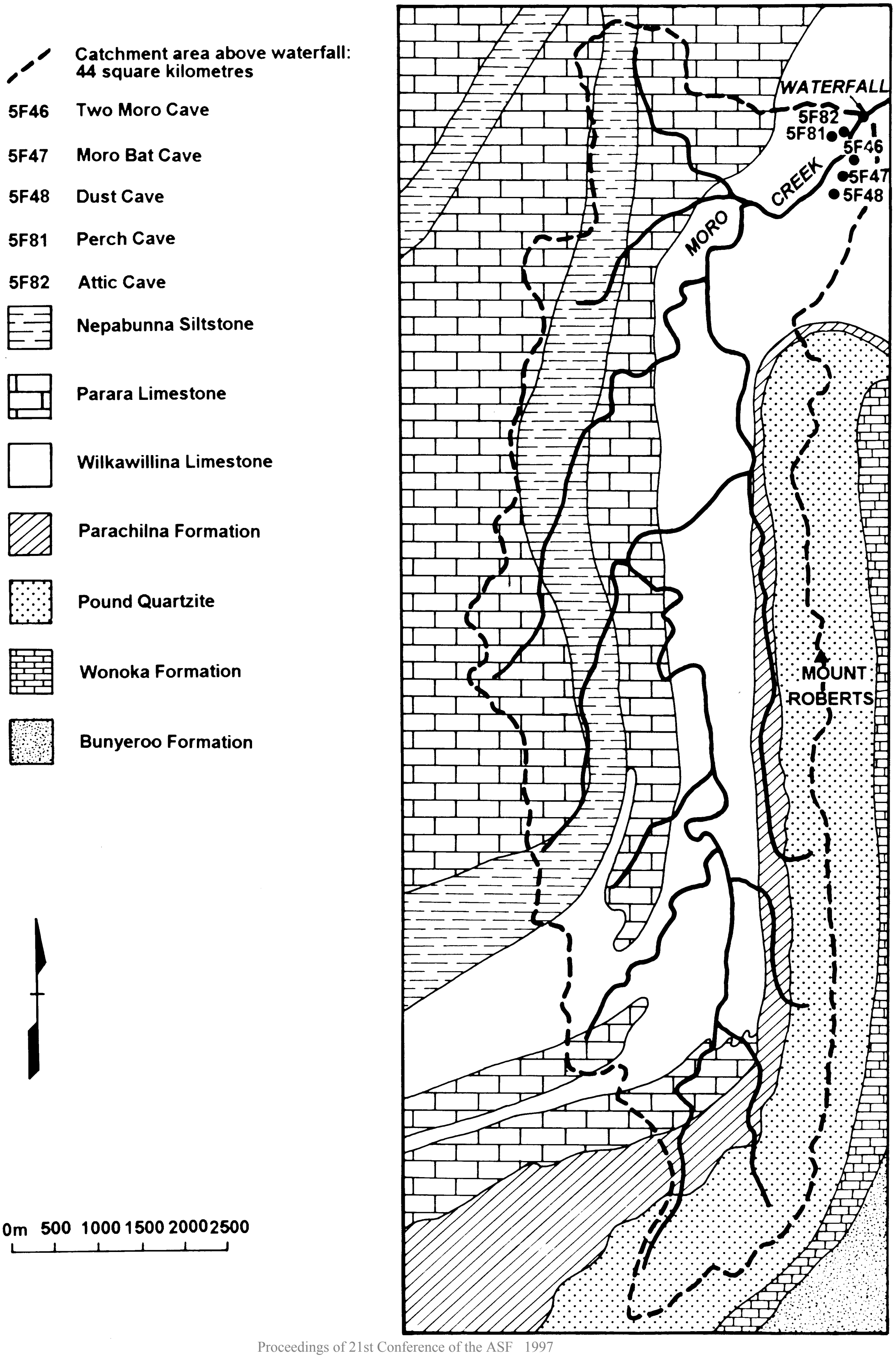
Caves that are a relic of previously bigger systems

In tandem with the idea that some caves in the Flinders Ranges were formed in a bygone era is certain evidence that other caves are relic of previously bigger systems. The basis of such an assertion is the presence of large tufa deposits in several places in the Flinders Ranges. Jennings (1985) claims that the most important factor producing these secondary carbonate deposits is the diffusion of carbon dioxide to the atmosphere after water emerges from caves or soil with a higher partial pressure than that of open air. However, tufa deposits in the Flinders Ranges have been found to be unassociated with current rivers and caves.

At the foot of Mt Caernarvon in the Loves Mine Range is a feature known locally as 'The Skull'. This is a twenty metre high tufa deposit which is so named because of the cavities that resemble a hairline, eyes, nose, mouth and ears in perfect symmetry. In fact, the deposit is so large that it contains two small caves. Both 5F65 Black Cave and 5F66 Out Flow Cave (which forms the mouth of the skull) have speleothems including stalactites, stalagmites, shawls, flowstone and cave coral (Kraehenbuehl *et al.* 1997). However, when the area upstream of the tufa deposit was explored for the mother cave, nothing was found. If the large tufa curtain has resulted from the deposition of calcite-rich waters at mouth of cave, there is no evidence of that cave today. It is likely that the cave through which water flowed and deposited tufa at its exit has since disappeared.

Another large tufa deposit can be found in the Moro Creek area. At this site, the tufa curtain is marked on the relevant topographic map as a waterfall, as it is immediately upstream of a large permanent water hole. Unlike The Skull, however, the Moro Creek tufa curtain is located in Wilkawillina Limestone and there are five known caves immediately upstream (Figure 5). Only one of these five caves - 5F46 Two Moro Cave - is located adjacent to the tufa waterfall, and the other four are all small and found in the cliffs on either side of Moro Creek (Kraehenbuehl *et al.* 1997). All caves appear to be oriented perpendicular to the present creek line. Could it be that these caves are the arms of a much larger system which has collapsed to form the present Moro Gorge and tufa curtain?

FIGURE 5 Geology of the catchment of the Moro Creek above the tufa waterfall in relation to the location of known caves. Source: adapted from published topographic and geological maps and supplemented by data collected by the Cave Exploration Group of South Australia.

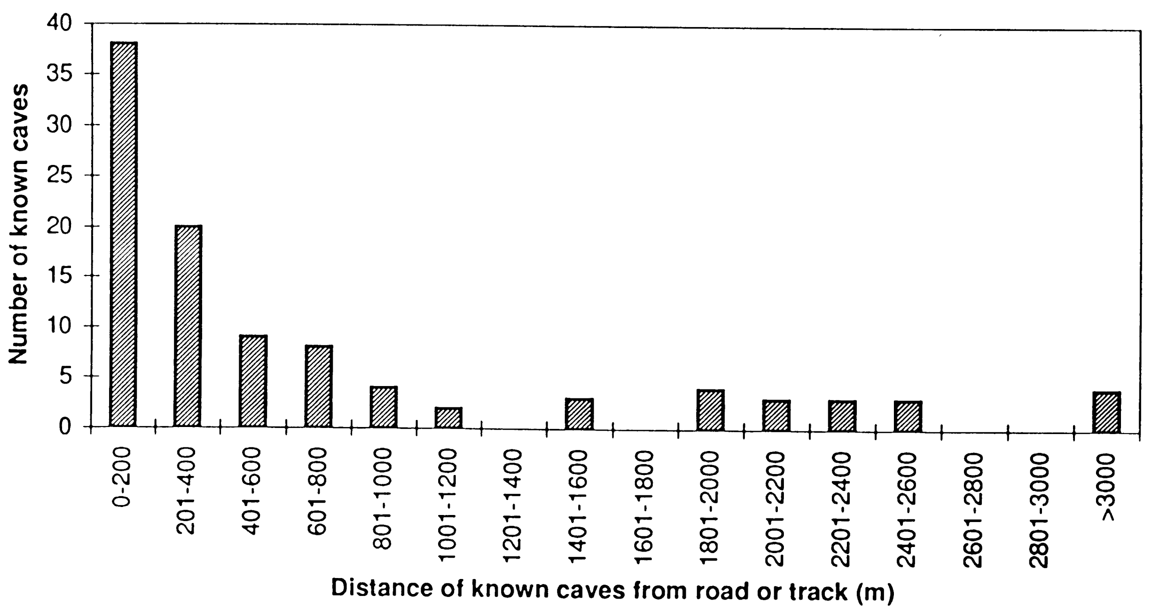


VI. CONCLUSION

There is no commonality of explanation for the caves of the Flinders Ranges. Some show a strong structural control, others are influenced by present surface and subsurface hydrological conditions, and yet others appear to be relic features of either a bygone era or a bigger system. It is possible that some caves and karst features in the Flinders Ranges may provide significant evidence of palaeo environments not available elsewhere in the landscape. These apparent relic systems deserve much more geomorphological attention than has been possible here.

And yet, for all the surmising that can result from presently known caves in the Flinders Ranges, there is still a lot of exploration to be done. Despite the fact that there is about 2000 square kilometres of outcropping limestone in the Flinders Ranges, only about five percent of that total area has been systematically explored for caves! Why? To date, the Flinders Ranges have not been regarded as a karst province of any significance, and so have not been targeted for cave exploration activities. Added to this is the difficulty of access to the bands of limestone. Due to the rugged nature of the landscape, most limestone areas have to be explored on foot (or horse? or camel?). The semi-arid and arid nature of the Flinders Ranges has meant that penetration of the region has been minimal. Most visitors are restricted to the main roads and gorges, and cave exploration across limestone outcrops are limited by both access restrictions and availability of water. These twin factors have resulted in the fact that, to date, most caves in the Flinders Ranges are found within 400 metres of either a road, track or gorge (Figure 6).

FIGURE 6 The relationship between known caves and access routes. Source: compiled by author based on records held by the Cave Exploration Group of South Australia.



The selection of the Flinders Ranges as a venue for the twenty-first conference of the Australian Speleological Federation signifies that the area is worthy of consideration as a karst region. May there be much more exploration of the area in the future! The areas of greatest potential for new cave finds are outcrops of Balcanoona, Etina, Trezona and Wilkawillina Formations in the areas shown in Figure 1. If (or when) more caves are found in the Flinders Ranges, it would be appreciated if accurate location information (preferably a GPS reading) and description details (preferably using the forms found in the 'Australian Karst Index' (Matthews 1985)) are reported to the official South Australian repository of such information. The appropriate person is:

The Records Officer
Cave Exploration Group of South Australia
PO Box 144
Rundle Mall
Adelaide
South Australia 5000

VII. ACKNOWLEDGMENTS

Thanks to Stan Flavel, Ray Gibbons, George MacLucas, Kevin Mott, Kerry Ninnes, Graham Pilkington and Eddie Rubbesa from the Cave Exploration Group of South Australia for organising the records of the Flinders Ranges caves from the multiple notes and bits of paper collected over the years. Most of the caves in the Flinders Ranges are known through the untiring efforts of Stan Flavel who revisited the well-known caves and found many other caves during the 1980s. Stan endured my many questions, emails and discussions relating to this paper. Assistance in the production of the maps for this paper was provided by Craig McVeigh and Sue Murray of the Department of Geography at the University of Adelaide.

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MAPPING WORKSHOP

Ken Grimes

About 20 people joined the group, which was convened by Ken Grimes.

The main event was a presentation made by Don Glasco, comprising a slide show and discussion of the surveying and map production for an extensive maze cave system in the Northern Territory. The size of the cave and time limitations due to its remote location meant that field sketches were done at 1:1000 and this limited the amount of detail that could be shown. Rather than sketch numerous cross-sections they developed a classification comprising six typical cross-sectional forms found in the cave, and noted the closest match at each survey station. All stations were permanently marked with flagging tape. Access to Arc/Info GIS software and a large format ink-jet plotter had allowed Don to produce a regional 1:10,000 scale A0 map of the system, other outlying caves and surrounding contextual information such as hydrology and exposed karst. For in-cave navigation a multi-page "street directory" book of 1:1000 A3 maps was produced.

We also looked briefly at the proposed UIS cave map symbols, and compared them to the existing ASF symbol set. This proposal is up for comments, and will be finalised at the UIS conference in August.

The use of SUUNTO KB series compasses was discussed, with a warning about possible "lazy eye" problems that many people can have using the "two-eye" sighting method. A SUUNTO with built-in battery light was on display. I was uncertain about how water-proof this would be, but a Tasmanian user indicated that he had had no problems in wet Tassie caves. Comments on the Tritium lighted SUUNTOs suggested that this light source was a bit weak, but the intensity of the glow could be enhanced by holding it in front of ones helmet light immediately before use. Someone mentioned having seen SUUNTO compasses selling for about $250 - which is excessive. The standard model (KB-14) can be bought for half that price from Prospectors supplies in Sydney (their 1996 price list).

Search and Rescue Workshop
Convened by Clare Buswell.

Although attendance to this session was small it managed to have representation from all states except Tasmania, Queensland and the Northern Territory. The group outlined the procedures for cave rescues for the State in which they cave.

NSW has a cave rescue squad, which is accredited and has representation on the State Training Advisory Panel. This panel sets policy on all rescue operations, Eg., road accident etc, for the state. Currently if an accident in a cave occurs and a rescue is needed the local SES are the first to attend. They then give hourly up dates to the cave rescue squad and if the situation warrants then the Squad is called in. In cave communications for the cave rescue squad is via the Michie Phone. Ask what do NSW caving clubs do when they cave interstate (particularly the Nullarbor), do they take any rescue gear, stretchers etc, the answer seemed to by one of no.

Victoria has a cave rescue group, which has good relations with the police, SES, and Ambulance personnel. There are set call out procedures and the Victoria Disaster Plan is followed. In cave communications is via the 'Bat Line' communication system.

South Australia has no organised cave rescue group. The local police are in charge of any cave rescue and must be called in first. However all clubs spend some time each year practising first aid, and search and rescue techniques. The un written policy in the caving fraternity is one of : as we cave in remote areas, Flinders ranges, Nullarbor we are generally on our own as any form of rescue is many hours away. Therefore first aid and patient in cave care are of up most importance."

Western Australia has no organised rescue group. There is a degree of friction between cavers, police SES and ambulance in the South East of the State mainly over the locations of all caves in the area. The ambulance service is the first to be called out in the Leeuwin Naturaliste Ridge if an accident occurs. This area is visited by approximately 100,000 persons per year. West Australian cavers, like their South Australian counterparts, take the view that they are on their own on the Nullarbor and other remote areas.

The discussion then turned to the role of the ASF and more pointedly its Safety Commission. The group suggested that the Commission could act as a clearing house for information on such things as in cave communication systems, rescue gear, set national cave rescue standards which are accredited with ORCA and other rescue organisations and are applicable to cave guides and commercial operators. It was also felt that a newsletter from the Commission to clubs would be very useful in coordinating training standards. It was also felt that the Commission should be highly involved in the training of cave guides and commercial operators now making in roads into adventure caving.

The session concluded with some discussion on the role of commercial operators who undertake abseiling and caving and lack accreditation and training. The problems of the Occupational Health and Safety Laws that operate tending to emphasise equipment maintenance rather then training and risk analysis was also raised.

A REMARKABLE VISION
Looking Back at the Australian Speleological Federation

Elery Hamilton-Smith

Beginnings

Inevitably, this paper has to tread the narrow line between the proper recounting of a story in which I have played some part, and self-indulgent nostalgia. But to simply tell the story might just be a dry-as-dust account of arguments over constitutional questions and the proper role of the organisation. Nostalgia deals with the real stuff of organisational life and so I trust I will be excused for any self-indulgence or bias in my version of the story.

I guess it all started with a trip to Yarrangobilly by Brian O'Brien and Fred Stewart of the Sydney Speleological Society in December 1953. Their trip report, in somewhat laconic style, says, 'We explored in the Western Deep Creek Cave for about half an hour, and intended to be in the Eastern Cave for a similar time, but here an untoward incident occurred which forced us to postpone the remainder of the trip.

This is not the place to detail that incident, but in short, as they were leaving the cave, Fred went back to camp, but Brian stayed behind to just have a look at another section of the cave, became lost, and ran out of light. On realising he was missing, Fred notified Bruce Head, then manager of the caves and the police were called. After a cursory look in the cave, they decided that Brian must have become lost in the bush on his way back to camp and thereafter focussed their efforts on a bush search. Fred then called other members of the Sydney University Speleological Society, who all rushed to Yarrangobilly to join in the search. An item on the ABC news alerted others, and over sixty cavers gathered to join in the long search. After 74 hours, Brian was found, in surprisingly good shape, by a group from Canberra and walked out of the cave with them.

Apart from Brian's survival, one of the most interesting long-term outcomes was that this incident brought to light the fact that there were in fact a number of informal groups going caving. In turn, this led to discussions about cooperation, particularly recognising the need for some sort of coordinated approach to safety and rescue. So, sometime in 1954, a letter, signed by both Brian as President of the Sydney University Speleological Society and Ben Nurse as president of the Sydney Speleological Society was sent off to caving groups in Cooma, Canberra, Hobart, Mt Isa, Orange and Adelaide.

The letter was received in Adelaide, and was duly discussed by the committee of the Cave Exploration Group of South Australia. The late Alan Hill, who was secretary of the Group had a new-found and passionate patriotism to South Australia rivalled only by his similarly passionate patriotism to his home town - Sydney. I recall very clearly his response: "We can't leave it to those bastards from Sydney; they think Sydney should run everything; tell them we'll convene a first conference!". So, in due course, an invitation was mailed off - and to our amazement it was accepted, virtually by return mail.

Planning got under way, with an initial proposal to hold the first conference in Koonalda Cave. Reason prevailed, and so it was decided that the conference would be held in or near Adelaide, with a field trip to the Nullarbor.

The Inaugural Conference

Looking back now, I am amazed that the first conference and field trips really happened more or less as planned. It was a truly mammoth undertaking, as it involved a conference with attendance from every state and several international wanderers; a Nullarbor expedition of 62 people and a Kelly Hill Expedition of some 20 people. All of this took place in a world where all cavers were poor and few owned a car; hitch-hiking to caving areas was common; those cars that were owned went on grossly overcrowded journeys and often broke down; after all, some of them were over 30 years old.

I well recall hitching all around Australia to 'sell' the conference and the Nullarbor Expedition. Because of the formidable logistics of a Nullarbor expedition in those days, we had to plan well ahead, and by the beginning of April 1956 we had 62 people committed to and signed up for the expedition; there were changes as the months went on, but on the 28th December when the trucks rolled out at 4.00 am., there were 62 on board! I also recall falling asleep as we drive out the gate of the conference centre and not waking until we reached Kyancutta that night.

The Conference was held at the Parnanga National Fitness Council camp and although it was a bit hard to keep track of attendance, with both full-time attendees and day visitors, the total was probably some 130 people. The formal business of the conference was simply a very protracted discussion of what the Federation should be and what it should do. The possibility of a national society was considered and rejected in favour of a federal structure. A draft constitution was shaped by the meeting, the first office-bearers were elected (President, Secretary, Treasurer and Librarian), and a second conference was set down to be held in Hobart. Issues of safety standards, search and rescue organisation, and setting standards for maps and reports were all canvassed, although at that time, the only action on these matters was to establish a safety code committee.

But in spite of the usual wrangling about constitutional niceties, the first conference was certainly distinguished by a sense of fun, unity and fellowship.

The Nullarbor expedition provided a particularly memorable event. Three groups of 19 people each were established, each group being basically self-contained and travelling on a Ford F500 Truck with petrol, water, food, caving gear and people. Each of the 19 people had pre-arranged responsibilities for various aspects of the program. Then five others, responsible for various aspects of overall expedition management, travelled in a VW Kombi. It probably seems bizarre, but we had established that the only two bits of the Nullarbor that were surveyed to anything resembling a reasonable level of accuracy were the railway line and the coast. All else, including the state border, could not be accurately located. So the VW team included a professional surveyor who did two star fixes per night throughout the expedition and thus set up the ground control for the first topographic maps of the Nullarbor.

A range of other bits of pioneering research were done, all caves visited were mapped, and numbering of the Nullarbor caves commenced. In retrospect, the most remarkable achievement was the discovery by Alexander Gailus of the Koonalda Cave workshop, and by Adrian Hunt of the Aboriginal art within the same cave. These two discoveries both constituted a massive revolution in Australian archaeology and the foundation of the scientific study of Australian rock art, now recognised as the oldest dated rock art in the world. Joe Jennings also wrote the first of his many papers on the geomorphology of the Nullarbor.

But there were lots of other accomplishments. Joe had recognised that the expedition members were drawn from four different time zones - and so, of course, we had to have four New Year's Eve parties! Despite the impact of that night, Joe organised a survey training program the following day, as we had discovered that we had too few people with good experience in cave mapping. It is some tribute to the capacity of cavers to bluff that Paul Rose actually got a surveying job with the Snowy Mountains authority on the strength of that training.

We had told people at the conference that on the Nullarbor one only had to walk far enough in a straight line to discover a new cave - Tom Draper immediately put it to the test and discovered Tom's Cave in under 30 minutes. Then there were Jim and Ozzie from Orange. Jim went for a walk one morning and when Ozzie awoke, he set out to find Jim; in due course Jim returned, and then went to find Ozzie; Ozzie returned and went to find Jim, and so on for the day.

On return to Adelaide and the arranged expedition depot, Ben Nurse phoned up each of the major distributors of washing machines and arranged for them to deliver a machine for demonstration purposes. Not surprisingly, they all failed the test and no purchases resulted - but a lot of caving gear got washed. The expedition had also proved a wonderful opportunity for beard-growing. Joe Jennings was so successful that he was able to get away with returning to the National University and attending, unrecognised, a reception for new staff members.

But the Federation was under way, with considerable enthusiasm.

Growing Up

At Easter 1957, the newly elected executive met at Yarrangobilly to commence planning for effectively carrying out their assigned role. Here we saw both one of the early results of the Federation and the beginning of the some of the divisions which have haunted the Federation over many years. Many of those who had attended the conference had been impressed by the cave numbering system which had been developed by Alan Hill and had determined that it would be executed more widely. So by Easter, the Sydney Speleological Society had been formally authorised by the Kosciusko State Park Trust to commence numbering of caves at Yarrangobilly. However, The Sydney University Speleos were adamantly opposed to cave numbering - and a dramatic confrontation developed during the course of the weekend.

By this time, the foundation membership was defined as including :

- Canberra Speleological Society
- Cave Exploration Group (South Australia)
- Cooranbong Speleological Association
- Cooma Cave Club
- Hunter Valley Caving Club
- Jenolan Speleological Society
- Mt. Isa Speleological Society
- Newcastle Technical and University College Speleological Society
- Orange Speleological Society
- Sydney Speleological Society
- Sydney University Speleological Society
- Tasmanian Caverneering Club
- Victorian Cave Exploration Society
- West Australian Caving Group

A number of these groups had been formally constituted out of pre-existing informal groups, at least partly as a result of the establishment of the Federation.

The second conference was also a remarkably memorable one. It also focussed its proceedings very much upon constitutional wrangling - but again with great good humour and some remarkable expedition caving. Professor Carey spoke on his war-time experience at Mt. Etna, training commandos to fight in the caves of the Pacific region. The great Des Lyons also made his particular mark on the occasion. Noel Fraser as minute secretary was being particularly punctilious about ensuring that all resolutions were clearly worded and properly recorded, and at one stage, David Taylor was having difficulty getting his wording right; Des (a lawyer) assisted him in phrasing his intentions but David's gratitude was shattered by the next step, when Des said, 'Mr. Chairman, now that my honourable friend's intention is properly clarified, I intend to argue against it". He did, and ensured its defeat.

Des also commemorated the occasion with a wonderful series of poems in the next issue of the TCC Bulletin all of which have stayed in the minds of many of those present (or even absent);. But more seriously, he had, as a one-man safety committee, drafted the Federation's first safety code and that made a great impact on caving practice. Until that time, we had such monstrosities as the people who refused to purchase safety helmets, and instead bought cheap aluminium kitchen basins from Woolworths and lined them with thin sponge rubber.

By now cave numbering was widely accepted and used virtually right across the country. Various other initiatives were under way ; the newsletter was formally established; and committees established on survey standards, Yarrangobilly, bat research, speleological terminology, code of ethics, and NSW coordination.

The third conference was held in Canberra; the constitution only occupied a small part of the agenda, but wrangles over the number of societies in New South Wales wasted a lot of time in this and the next few meetings. However, there was considerable progress : a revised safety code, a standard glossary of speleological terms, and a code of ethics and courtesy were all adopted and some first moves were made towards advocating the conservation of caves. Given some of the problem in finding officers to take on the work of the Federation both prior to and following this meeting, it is indeed interesting that there was a high profile campaign for election of office-bearers and this in fact proved to boost the administration of the federation considerably.

Over the next few years :
· conservation emerged much more strongly and a first conservation code appeared
· the founders of Helictite endeavoured to get Helictite accepted as an ASF responsibility, but this was rejected
· the Federation became deeply involved in negotiations with the NSW Tourist Bureau over caving at Jenolan
· the idea of a centralised cave map archive was rejected
· the infamous Bill Penman cave-sitting record led one to of the many divisive arguments within the Federation
· another source of division was the concern of some members that far too much attention was being devoted to the 'political' problems of caving in New South Wales
· the potential use of track marking as a conservation strategy was first suggested
· the ASF Handbook idea - the first move towards a national karst index - was developed and the first edition published in 1968
· The Australian Bat Research Newsletter was established with the support of the CSIRO Wildlife Research Division and continued for many years before being replaced by the formation of a formal bat society with its own newsletter.
· The Edie Smith award was established to celebrate the work of one of the pioneer cavers
· Although the presentation of papers at conferences steadily increased over the years, it was not until 1968 that publication of proceedings commenced.

Into the Seventies

At the 1971 conference, a document which I had prepared on the future structure and organisation of the Federation (known as (Elery's Green Thing') was discussed at very considerable length. This document was a response to long standing problems about the administration of the Federation, which had until then been divided between the annual meeting which made more-or-less ad hoc decisions and too few officers who were then responsible for implementing them. The new arrangements delegated greater responsibility to a series of commissions, established clearly defined terms of reference, enabled the establishment of state liaison councils clearly defined. This in turn led to an administrative handbook which provided a sort of owner's manual for the Federation.

As in many spheres of Australian life, the 1970s saw a great boom of activity and productivity within the Federation. Much of this was on a continuing business-as-usual basis, but with a gradual improvement in the quality of what was being done, but there were some important new initiatives. Greg Middleton commenced the compilation and publication of Australian Speleo Abstracts. A grant from the Australian Heritage Commission enabled the production of an important policy document on conservation of the karst estate of Australia.

One action with extremely important and far-reaching outcomes was the convening of a first conference on Cave Tourism at Jenolan in 1973. This was well attended, attracting cave tourism managers from all states of Australia. It led to a continuing series of such conferences, the involvement of the Federation in a number of important management planning projects, including that at Naracoorte which laid the foundation for the recent World Heritage recognition, and ultimately to the establishment in 1987 of the Australasian Cave and Karst Management Association (ACKMA).

Even during this period of activity, the Federation continued to face the perpetual problems - lack of money, hence reliance upon volunteer workers for all of the Federation's activities, and the inevitable unpredictability of those volunteers, who in spite of the best intentions, often found themselves frustrated, usually by their work responsibilities getting in the way of caving. Particular angst was expressed about the Karst Index, which proved to be a mammoth project, but which finally appeared in hard copy in 1985. But looking back over the years of the Federation's existence, this and its many other accomplishments are indeed significant.

And More Recently

Many members will be aware of the more recent history and so I will only briefly deal with some of the key issues of the 1980s and 1990s. Organisationally, the Federation became incorporated in 1985, and given the breadth of the Federation's activities, this provided a long-overdue improvement in infrastructure arrangements. However, divisive arguments and dissatisfactions have continued to emerge; these sometimes represent genuine differences in ideology, but it really seems to me that they more often represent lack of organisational experience by Council members or lack of resources to enable the Federation to achieve what members expect.

But in spite of recurrent problems -

- The Newsletter finally assumed the Australian Caver format and has become a worthy publication .
- A Federation insurance scheme has become a reality
- Continuing its long commitment to conservation, the Federation has been particularly productive and taken a more effective approach to conservation issues

The Federation and some of its officers and members have played a key role in the development of the NORLD program and the Outdoor Recreation Council of Australia. While the Council operates within a wider national framework for training development which is extremely problematic, a great deal has been accomplished. It is interesting to note here that the NORLD conference demonstrated that no other outdoor activity has a body equivalent to the Federation, although canoeists have for some years had a national canoe education board and several are now looking at establishing some sort of national body.

Conclusion

Looking back, one can only marvel at the vision of those Sydney cavers who first proposed the establishment of the Federation back in 1954. It has accomplished a great deal in spite of formidable difficulties.

It currently seems to face a new set of problems. Increasingly, clubs or societies with their emphasis upon collective responsibility are being pushed aside by commercial operations and other managerial arrangements. At the same time, a great gaggle of social and economic pressures are impinging upon younger people. So, club and society members are both fewer and older. Yet the capacity of the Federation for advocacy and action in relation to all sorts of issues - safety, documentation, conservation and advocacy to name only four - is probably more necessary than ever.

A second problem of much longer standing is the decline in genuine exploration. Except in a few areas (eg Old Homestead, Thampanna, some other Nullarbor sites, the Kimberlys, Cape Range and the Gregory River) cavers keep returning to the same old caves, and adding little or nothing to our knowledge of those caves. Even the fact that this conference (and many of the more recent ASF conferences) do not include genuine exploratory expeditions as part of the program highlights this problem. As one local example, the documentation of many Flinders Ranges caves is remarkably inadequate and very little has been done beyond basic documentation. Further, my knowledge of the region leads me to believe that there are probably two or three hundred further caves to be identified and documented. A number of these which Alan Hill and I identified on a bushwalking trip many years ago certainly remain uninvestigated and a brief and all too rapid recent walk by Ernst Holland certainly identified a further number.

I believe it is vital that the current administrative malaise and decline in member confidence be addressed and resolved. And I hope that we will eventually see a wider revival of genuine exploration rather then the current pattern of repetitive tourist-type visits.

Speleo - Sports

For the

1997 Flinders Conference

21st Biennial Conference Australian Speleological Federation Inc.

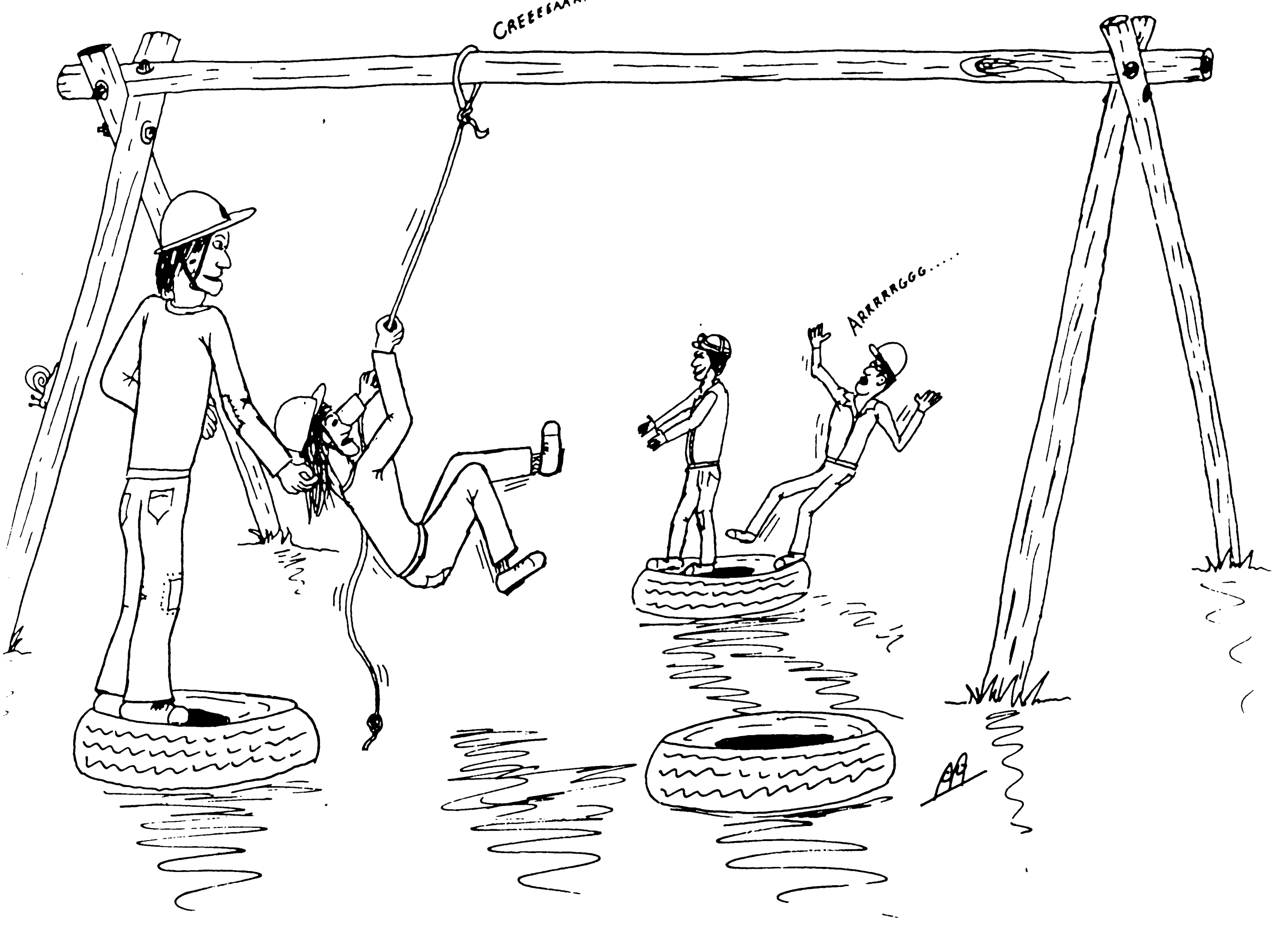
GENERAL INFORMATION

This is intended to be a fun event and should be treated as such, any attempts to take things too seriously will be dealt with harshly by the organisers.

Teams are to be made up of four participants, preferably of mixed gender, and an even spread of ages. Any groups showing exceptional speed, agility and a high level of fitness will suffer extreme point handicaps. While any teams entering into the spirit of things with their attire, attitude or offers of bribes to the organisers will be looked upon very favourably.

An organiser will be allocated to each team and will follow them throughout the course, any diversion from the path as set out in this booklet will be penalised. (unless it adds to the entertainment value) The judges are aware of most tricks and tactics used during these events to make life easier for the competitors but if you think you can get away with something, TRY IT. But be warned, if caught, YOU WILL PAY!!

Above all please do everything with safety in mind and have FUN.



To begin your grand trek
Here is the first thing you must do,
And real swingers you must be
To get all the way through.

All start on island one
Then singularly swing,
Across to island two
Till you have all made a ring.

And then and only then
May you all Make the move,
On the rope to island three
Then you're really on the move.

One more thing I must tell
Which will gladden your heart
Touch the ground on the way
and you all go back to the start.

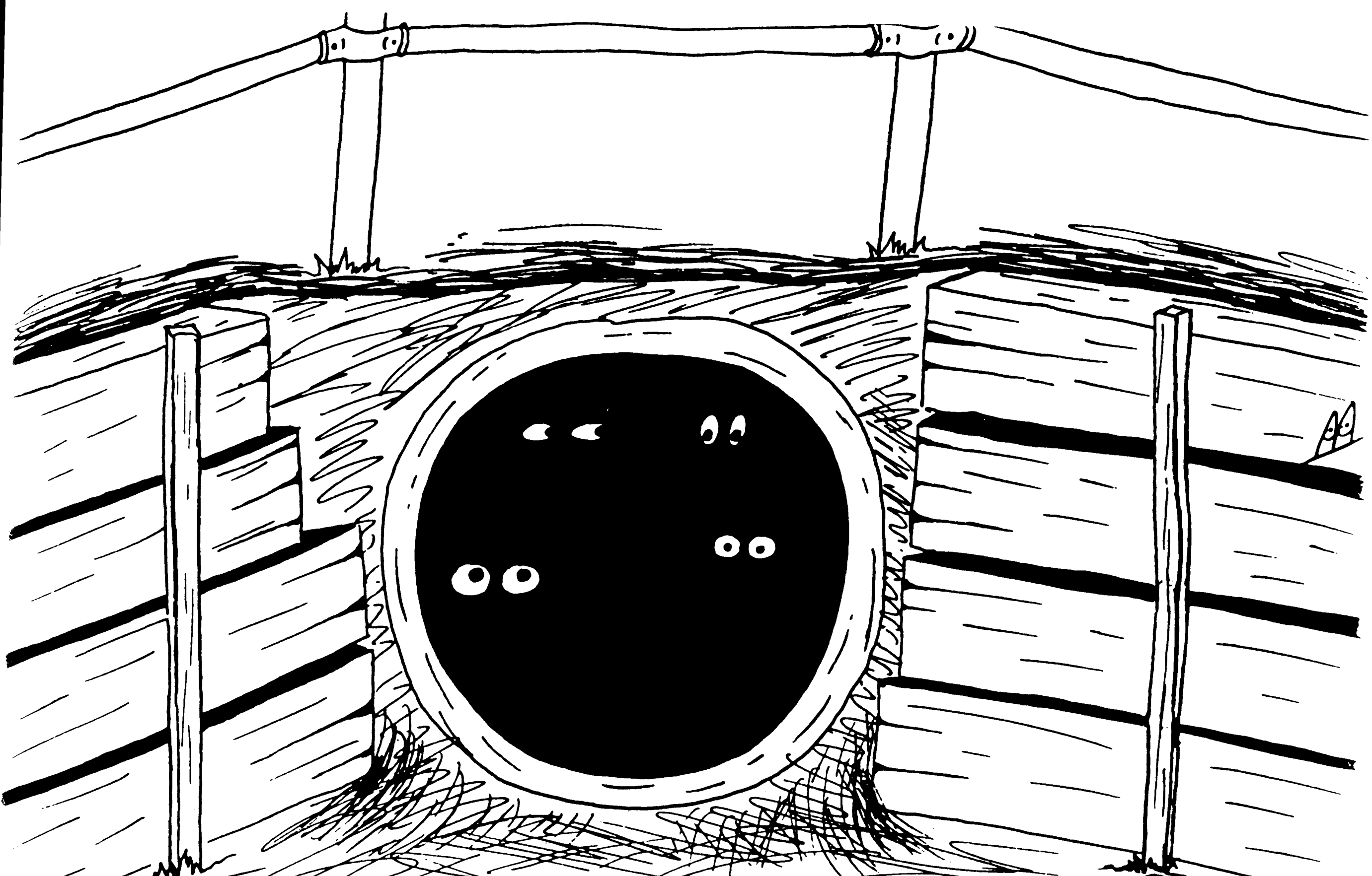
Now you have completed
The very first task.
We go on to the second
As the minutes tick past.

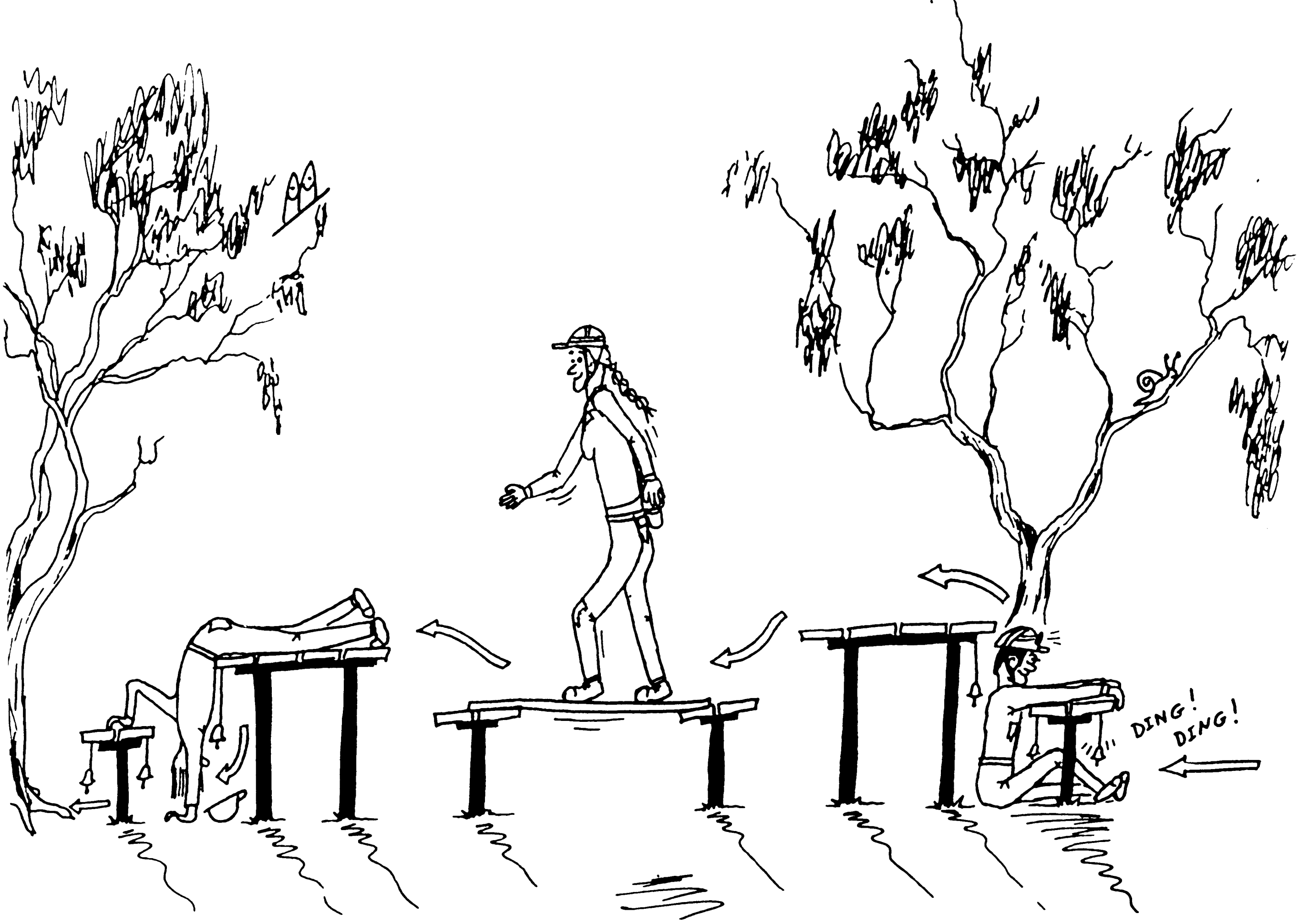
Find the start of the string
And follow it right through.
Of those in your group to do it
be at least two.

Yes I did say two,
But it could be in your favour
If all got through.
It just might be your saviour.

Because you all think you are cavers
Here's a bit of a test
You all must try it
Just give it your best.

From one end to the other
You may say traverse
Keep up above the lines
If your team wants to come first.





We all know how important
It is to take care
When crawling about
In those passages down there.

So move on through this one
Without touching a thing
That when brushed against
Goes ding-ding, ding-ding.

If you all get through this
And the bellictites haven't moved
You've proved to us all
As cavers, you're smooth.

Sometimes there's a need
When crawling about
To take a specimen
For study while out.

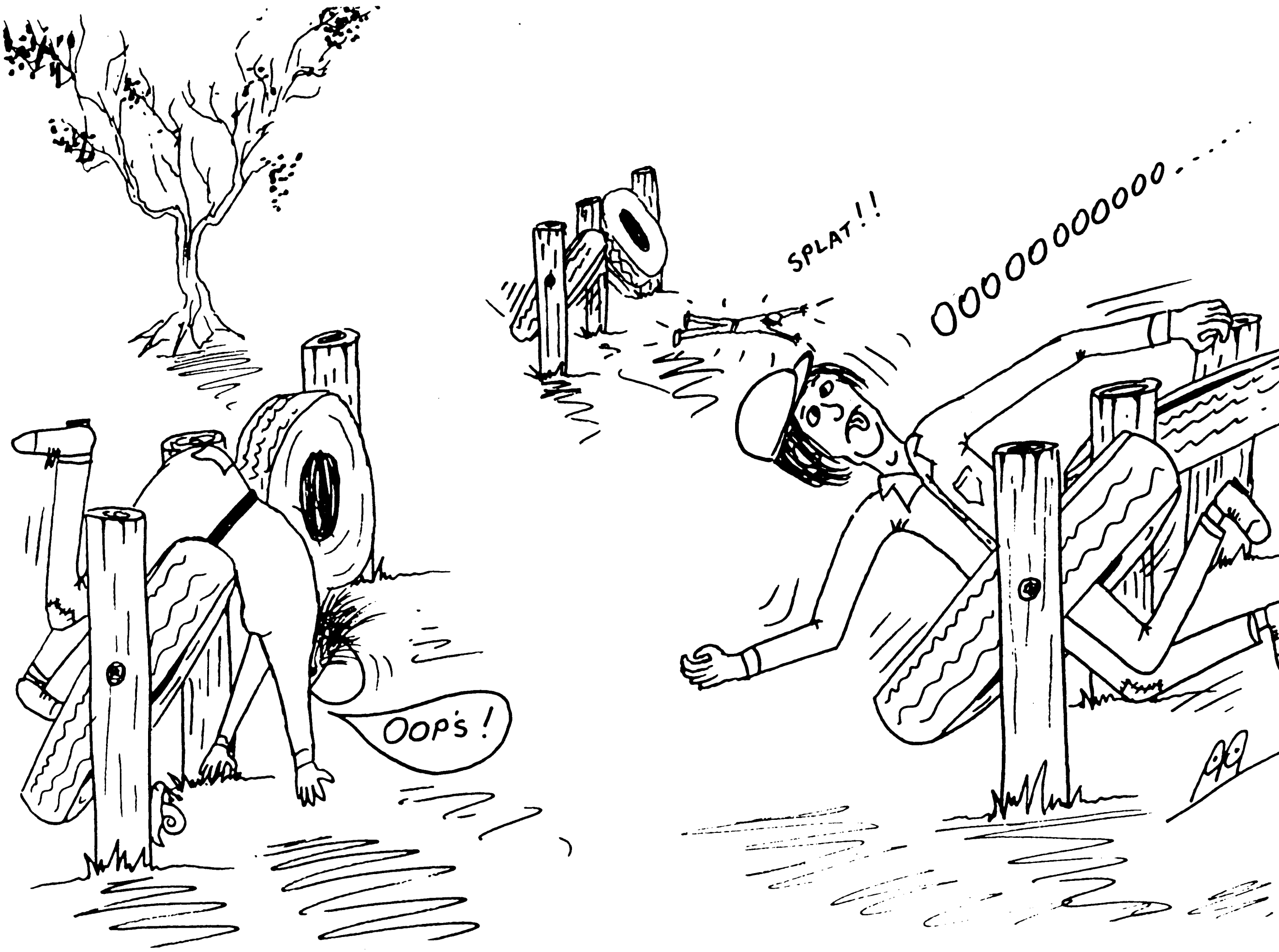
You have been given a jar
Now in it must go
Six large black ants
Which at the end you must show.

Treat these poor creatures with care
And let their health stay at best
For when you have finished
They will be returned to their nest.

Here's a nice test
That we think you will love
You all must get through
Not below but above.

There are four to choose from
So each take a pick
And all at the same moment
Climb over, that's the trick.

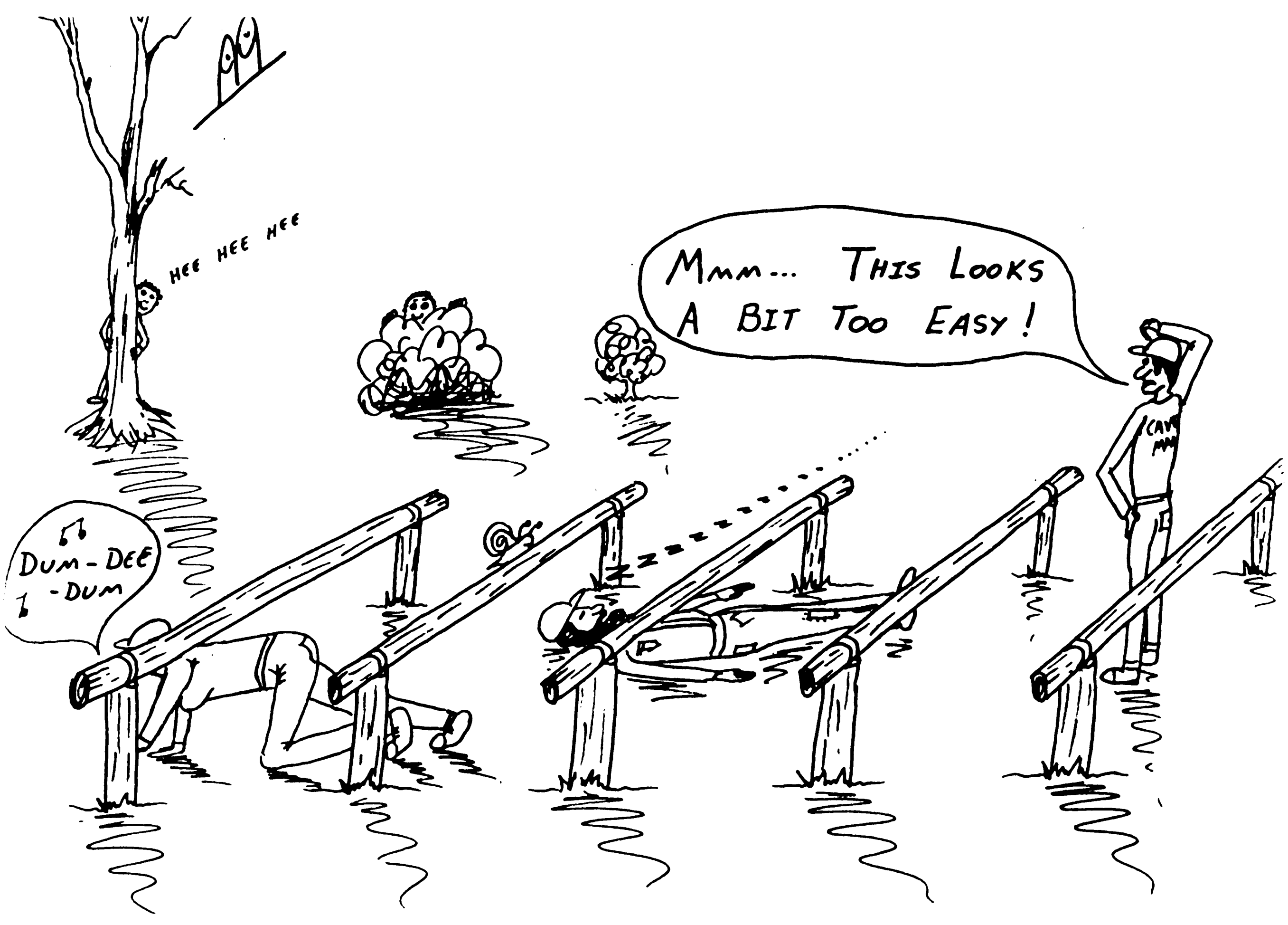
But its not quite that easy
For once you're all clear
You all must repeat
On the twin that is near.

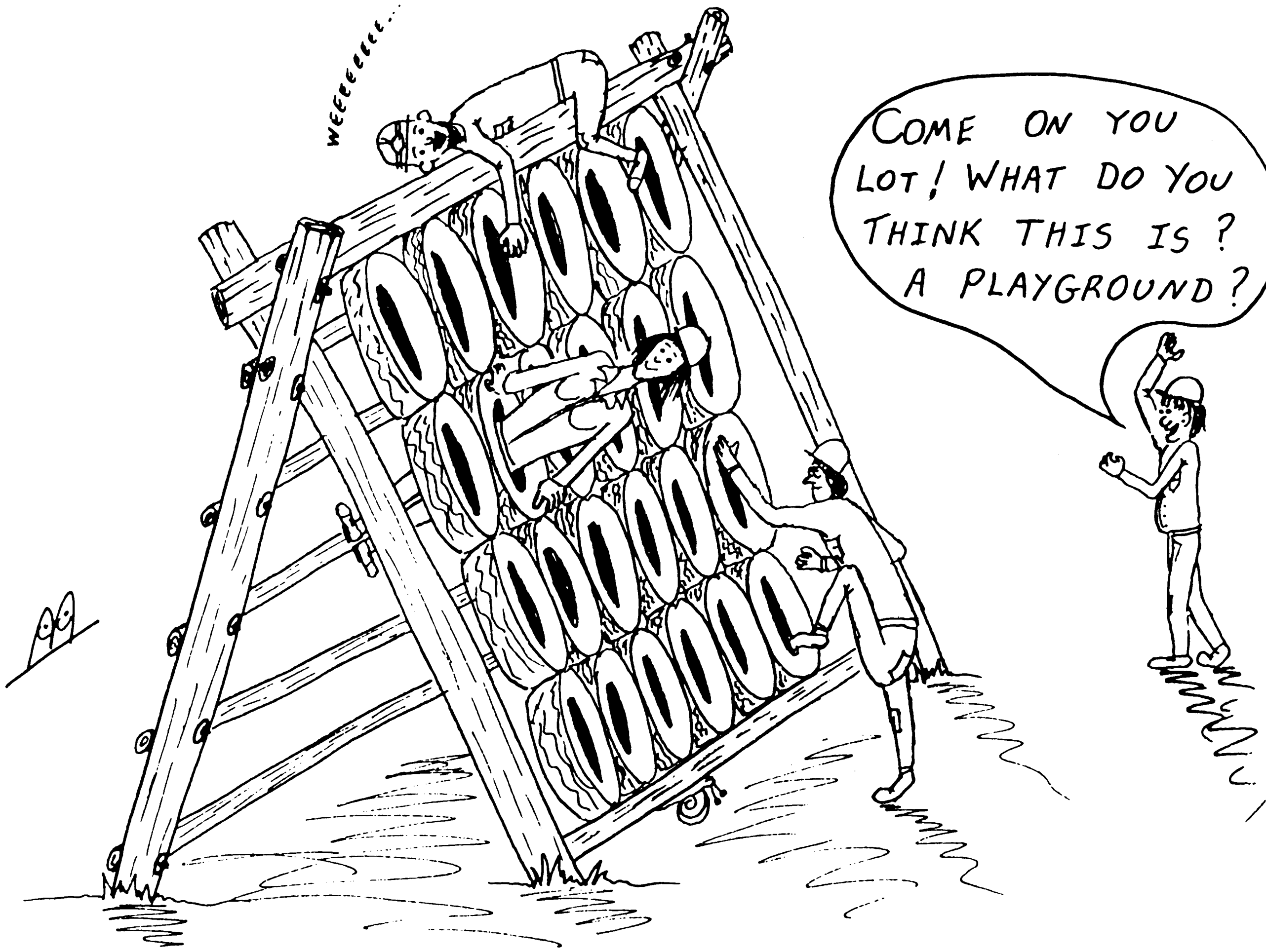


If you like to move along
In a horizontal way
This ones for you
And the whole group must play

On your back or on your belly
Either one will suffice
But do not touch the beams
Or you will pay a price.

It may be a bit tricky
To make your way along
But when you see what's to come
You'll think it's a song.



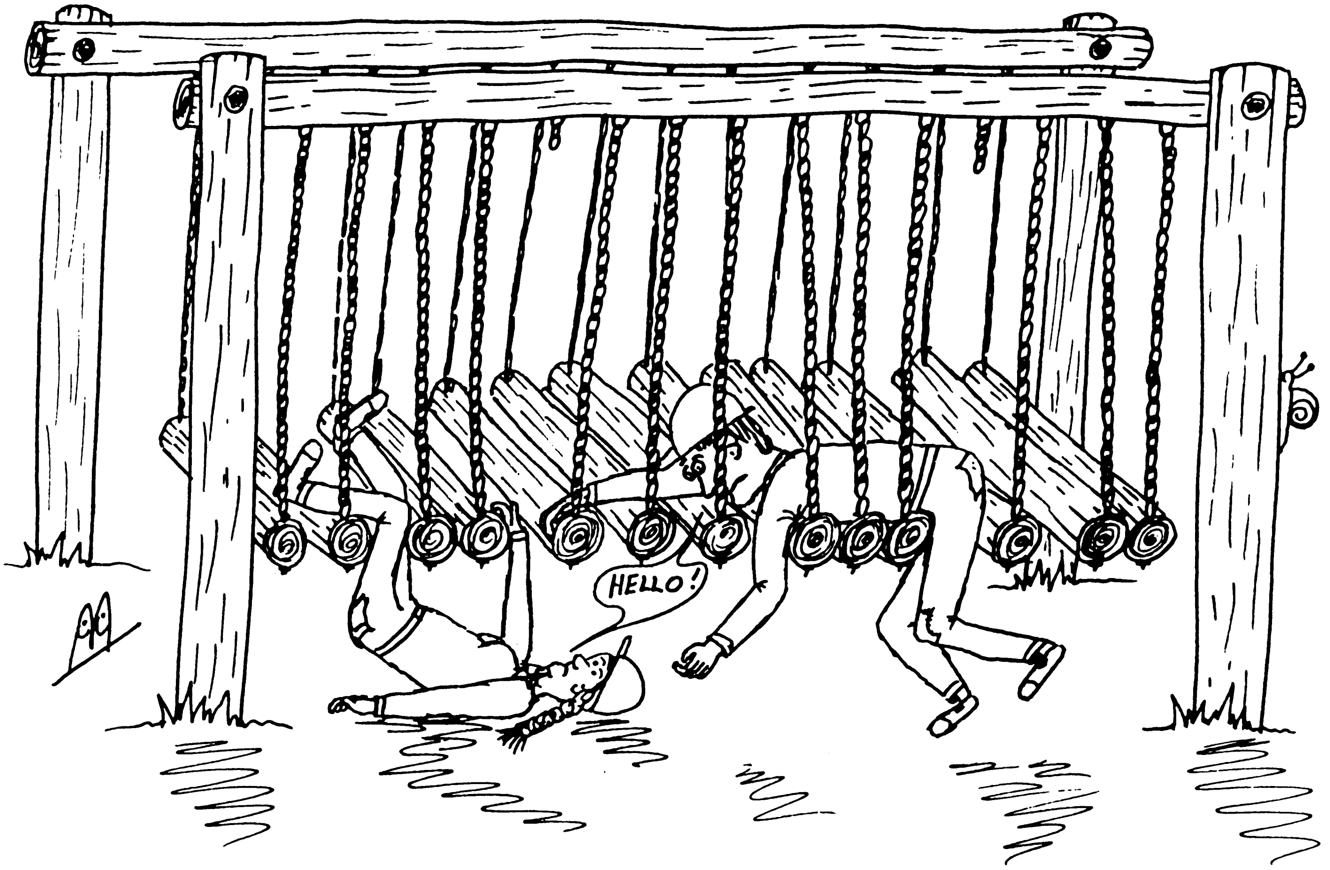


When you go caving
There's always a need
To take care of oneself
So this advice please take heed.

Use the tape that's been left
Make a harness from it
For one person to wear
While the rest of you sit.

You see only one needs to go
But they must do it right
Hook the carabineer on
And tie the prussic loop tight.

Once your all set
Then over you go
We hope you've done it right
Because the judges will know!



This one looks easy
But we think you will find
That it's not quitc that simplc
Although we know you won't mind.

It is another on which
The whole group must complete
To gain the most points
Try to keep it quite neat.

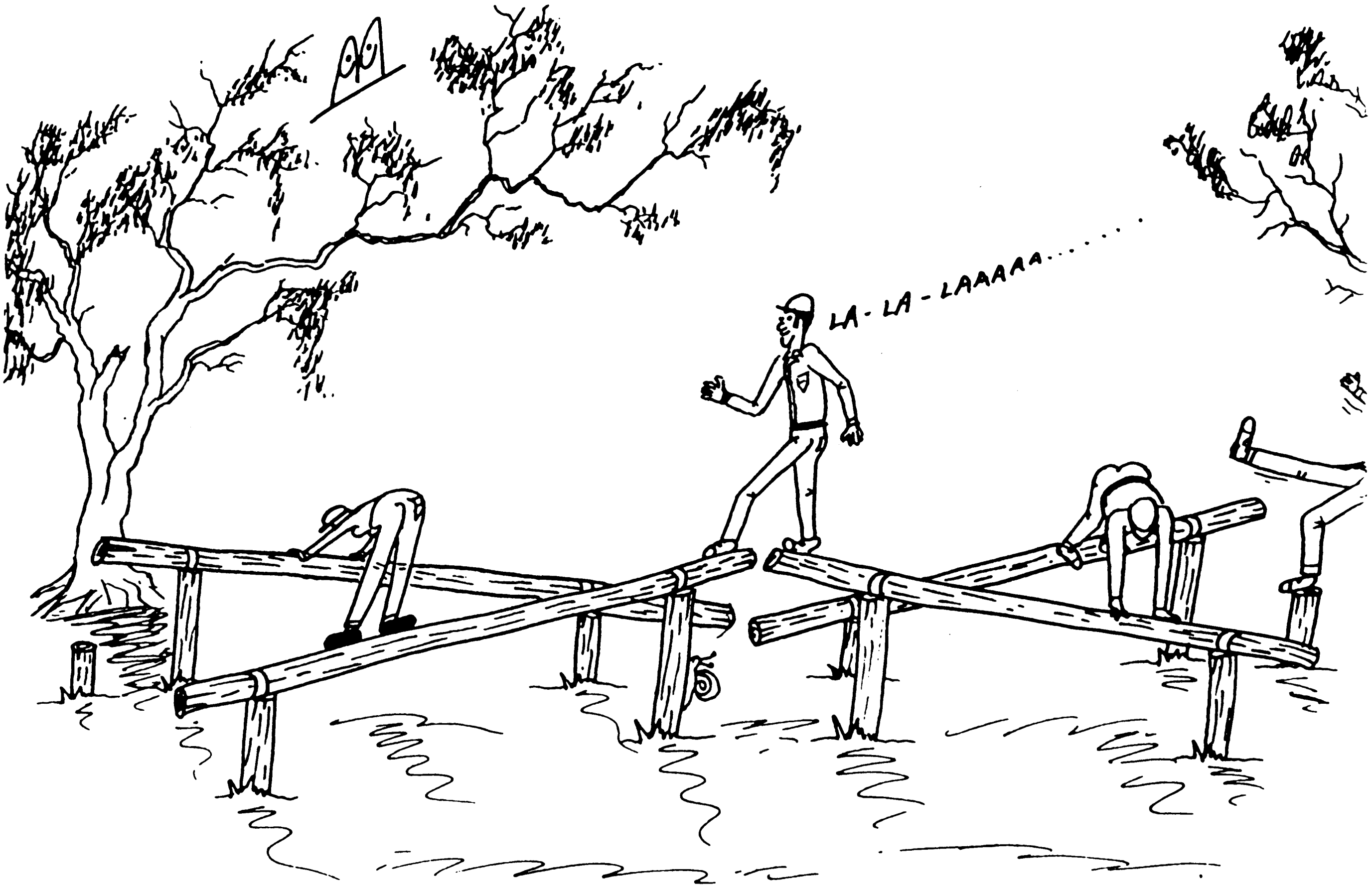
The rules are very simple
It must be done laying down
Any by-passes will be looked upon
With a very stern frown.

Here's another traverse
For at least two of you to do
But just as before
It's better if more do it too.

From the south to the north
Move along the rails
Keep your feet off the ground
Or else you may fail.

Once at the end
You must turn around
Use the stump that's implanted
But still don't touch that ground.

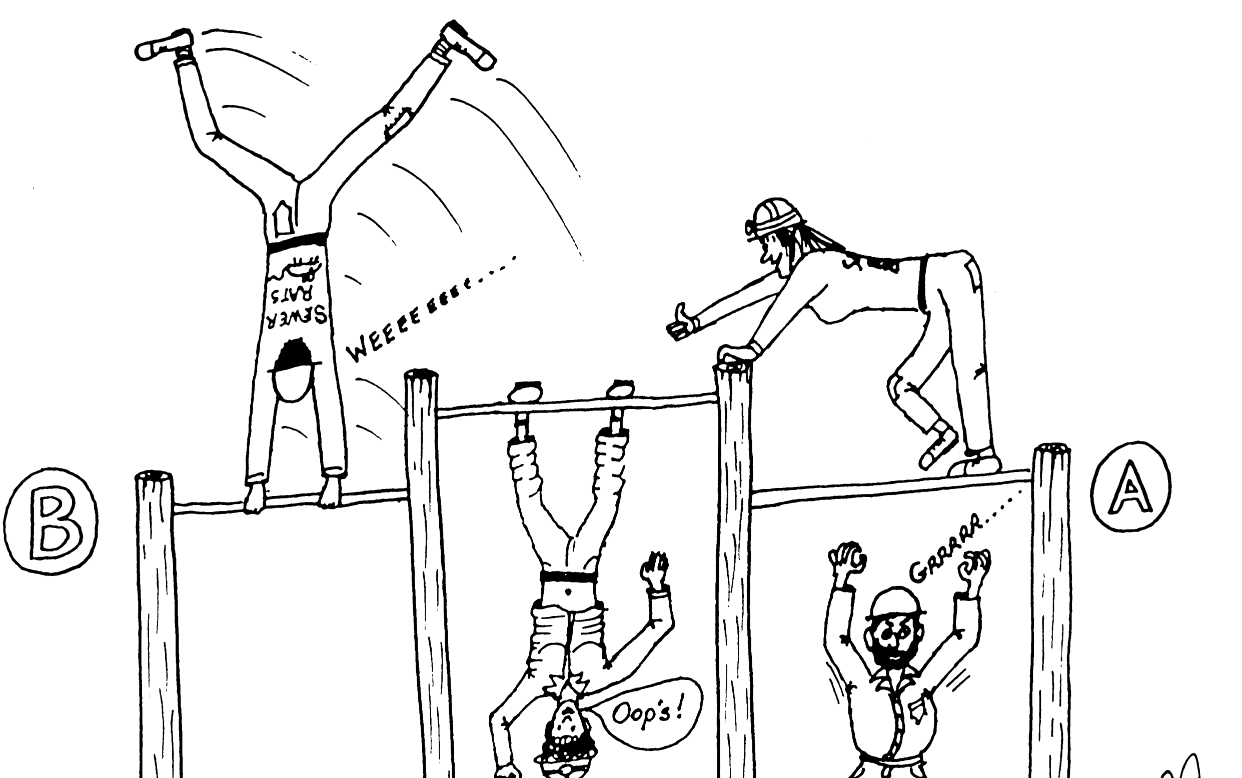
So now head back along
In a southerly direction
And it won't be long
Till you've finished this section.

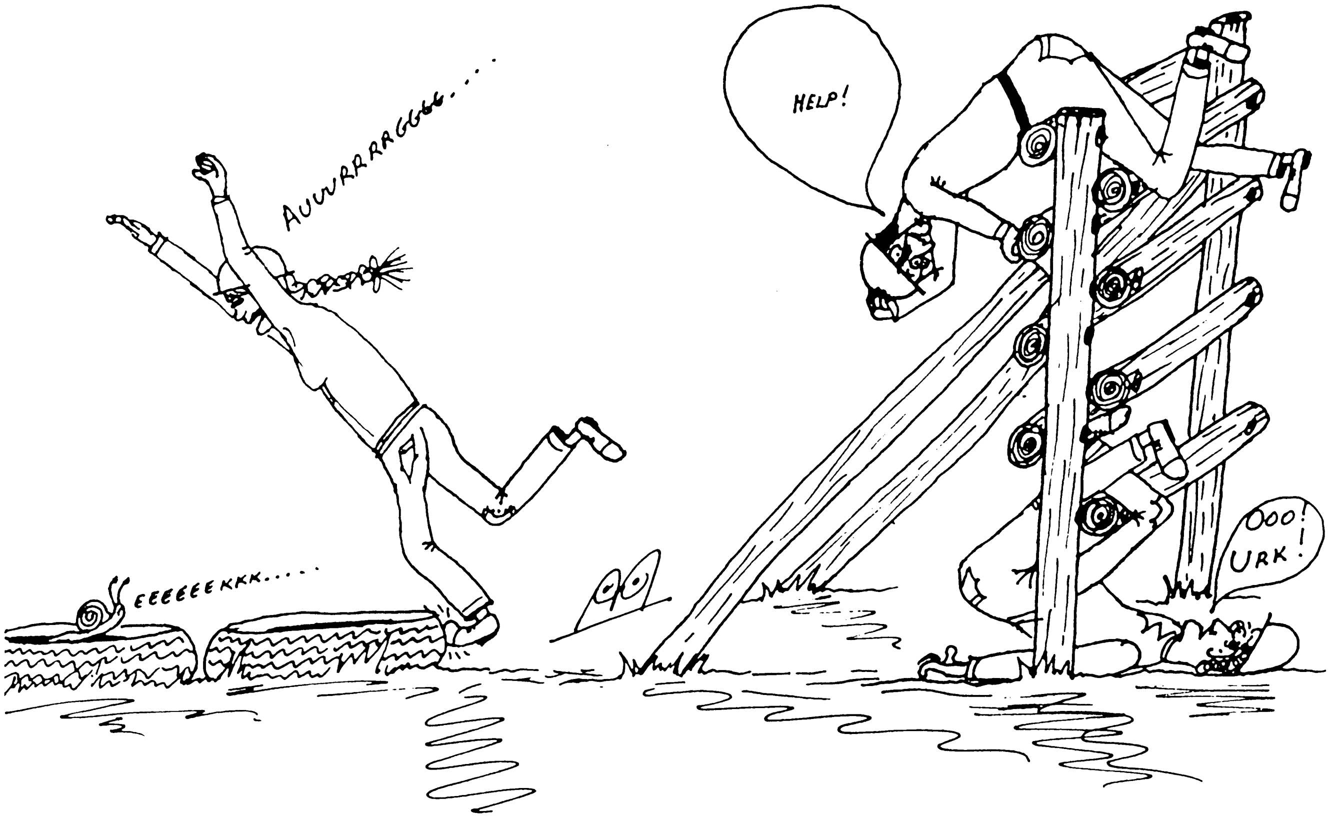


This onc is so casy
A gymnast you need not be
Of those of you to do it
Yes just one, and no three.

Just reach for the bar
Either end is OK
Then move on along
But off the earth you must stay.

Yes it is really that easy
And if you stop to plan
The one up above
May get a helping hand.

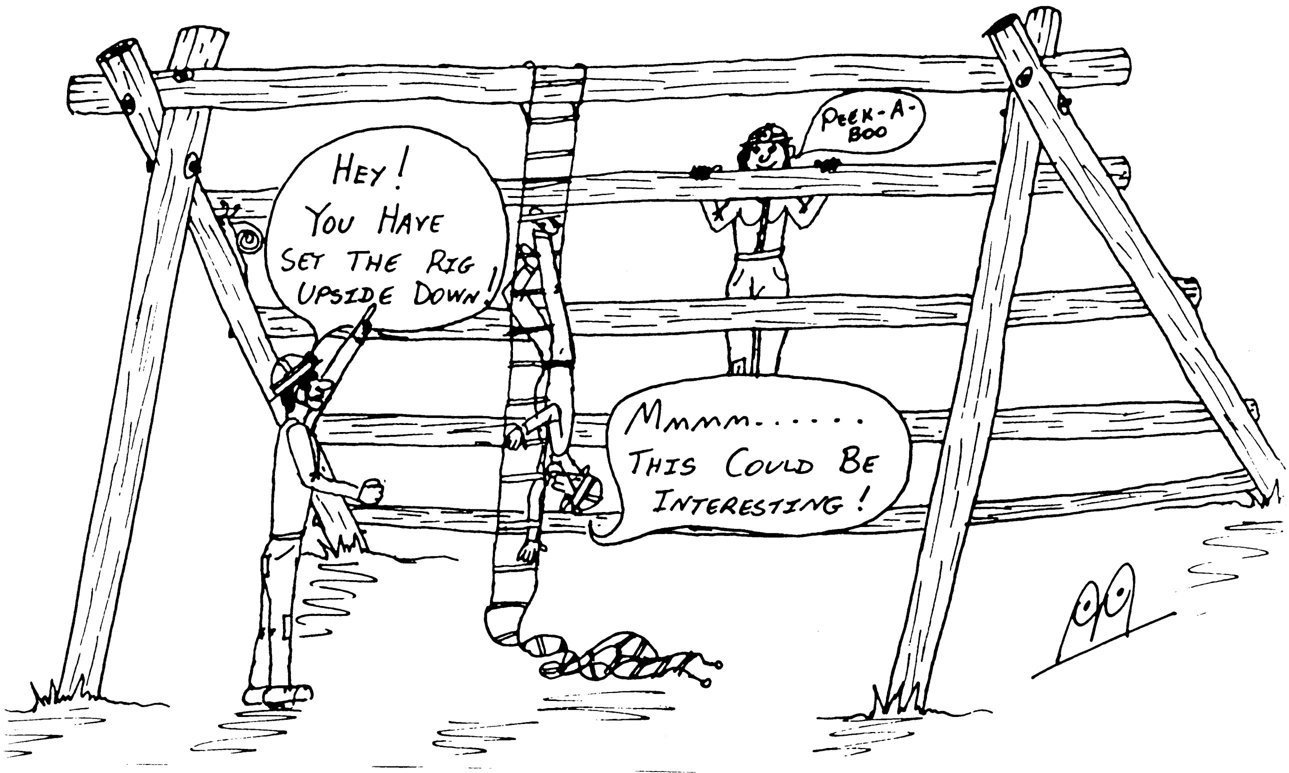




Here's one to make you feel
Like a big kid again
Because it's either that
Or you're going insane.

All go over the top
Then get down on the floor
Slip back underneath
Then over once more.

Once you have done that
Keep going ahead
Away across the tyres
But beware of the tread



Well here it is
The very last one
Get over this
and maybe you've won.

One put on a harness
Made from a tape
Tie a prussik loop on the rope
Hook on, then climb like an ape.

Up over the top
And to the other side
Get your safety gear off
Then ready another for the ride.

Yes back they must go
To where you came from
So another can try
Just don't get it wrong.

Once four have done this
And hopefully survived
GUESS WHAT, it means
That at last you've arrived.

Go back to the start
Not to do it once more
Just get your ants checked
And find out your score.

THE END

1997 FLINDERS CONFERENCE ATTENDEES

SURNAME	FIRST NAME	ADDRESS	CLUB
ADAMS	Jan	8 Sampson Rd, Mitchell Park SA 5043	MESA
ALVARO	Pam	PO Box 2135, Pt. Adelaide SA 5015	CEGSA
BINNIE	Ian	8 Berripa Close, East Ryde NSW	MUCG
BROWN	Cathy	113b Kambalda Crs, Fisher ACT 2611	
BUSWELL	Clare	52 Main Street, Henley Beach SA 5022	FUSSI, CEGSA
CASWELL	Heather	3/5 Iramoo St, Balwyn VIC 3103	
CHOI	Marie	75 Capella Drive, Hallett Cove SA 5158	CEGSA
CLARKE	Arthur	17 Darling Pde, Mt Stuart TAS 7000	Southern Tasmanian Caverneers
COCKS	Keven	10 Sloan Rd, Hawthorndene SA 5051	FUSSI
COOPER	Andrew	3/3 Lehn Rd, East Hills NSW 2213	
CROCKET	Jim	8 Greta Place, Oakhurst NSW 2761.	
DUNNE	Chris	PO Box 193, Westgate NSW 2048	
DYKES	Peter	Trickets Arch, Jaunter Rd, JAUNTER via Oberan NSW 2787, PO Box 428, Orange NSW 2787	
EBERHARD	Stefan	33 Godfrey St, Campbell ACT	
FERRARI	Brendan	PO Box 888, Kew VIC 3101	VSA
FUREY	Marie	28 Griffell Way, Duncraig. WA	SRGWA
GLASCO	Don	3/39 Wooten Cres, Gordon ACT 2905	
GRIMES	Ken	PO Box 362, Hamilton VIC 3300	VSA, CEGSA
HALL	Max	C/-Balladonia Hotel Motel, via Norseman WA 6443	SRGWA, CEGSA, WASG, Plane Caving
HOBBS	Derek	Cairnes Lane, Glenorie NSW 2157	MUCG, SUSS
HUBYCZ	Anne-Marie	55 Nicolle Drive, Morphettvale SA 5162	CEGSA
JACKSON	Athol	6 Hudson Ave, Rostrevor SA 5073	CEGSA
JEVONS	Alan	18 Exhibition Drive, Modbury North SA 5092	SCG, CEGSA
KERSHAW	Bob	15/56 Duke St, Woonona NSW 2517	
KRAEHENBUEHL	Peter & Janine	PO Box 273, Belair SA 5052	CEGSA, SCG
LATTA	Joanne	16 Stoddart St, Pt Augusta SA 5700	CEGSA
LAWRENCE	Ruth	Geography Department University of Adelaide SA 5005	VSA, CEGSA
LENSER	Michael	6c Crinigan Rd, Morwell VIC 3840	
MACHIN	Sharron & Andy	15 Sandery Ave, Seacombe Gdns SA 5047	Cavex
MACLUCAS	George & June	11 Gulfview Parade, Valley View SA	CEGSA
MACOUN	Angus	37 Chelmsford Ave, Lindfield NSW 2070	Rovers Speleological Society
MATTS	Don & Grace	176 William St, Bankstown NSW 2200	CCC, NSS, SSS, NSW Cave Rescue Squad
MATTS	Terry	Wombeyan Caves	CCC, NSS
MEREDITH	Ann-Marie	27 Beckenham St, Beckenham WA 6107	WASG

1997 FLINDERS CONFERENCE ATTENDEES

SURNAME	FIRST NAME	ADDRESS	CLUB
METH	Max	PO Box 622, Ceduna SA 5690	CEGSA
MURTON	Paul	10 Modler Rd, Morphett Vale SA 5162	Cavex
NAGLE	Harry	66 Dover St, Malvern SA 5061	Cavex
NETHERTON	Luke	18 Boorri St, Woomera SA 5720	Cavex
NINNES	Gordon	8 Sampson Rd, Mitchell Park SA 5043	CEGSA
PAYNE	Tim	2/29 Rose St, Prospect SA 5082	ASF Individual
PILKINGTON	Graham	66 Eyre Cres, Valley View SA 5093	CEGSA
POULTER	Norman	PO Box 120, Nedlands WA 6909	SRGWA
RILEY	Chris	5 Reserve St,	
ROBINSON	Dorothy & Lloyd	167 Mt Keira Rd, Mt Keira NSW 2500	
ROWSELL	Kath	12 Ormonde Court, Diamond Creek Vic 3089	
SCHULZ	Geoff & Val	319 Esplanade, Aldinga Beach SA 5173	Cavex
SEFTON	Mark	36 Norman St, St Marys SA 5042	CEGSA
SMITH	Garry & Michael	5 Fourth St, Seahampton NSW 2286	Newcastle & Hunter Valley SS
STEWART	Peter	47 Cunningham St, Northcote, VIC 3070	
SZABO	Tom	33 Pamela Drive, Para Hills SA 5096	CEGSA
WATSON	Tony	14 Glendale Crs, Berwick Vic 3806	VSA
WHITBY	Gary & Jenny	48 Park St, Charlestown NSW 2290	Newcastle & Hunter Valley SS
WOOLS-COBB	David	PO Box 20, Ulverstone TAS 7315	
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