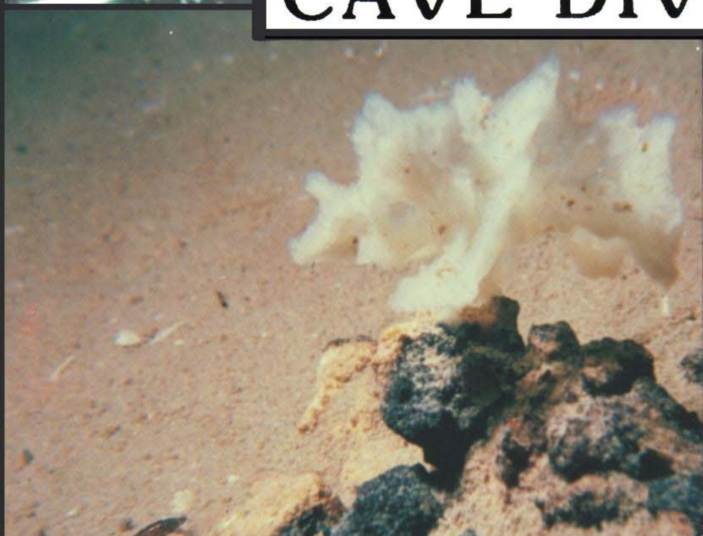
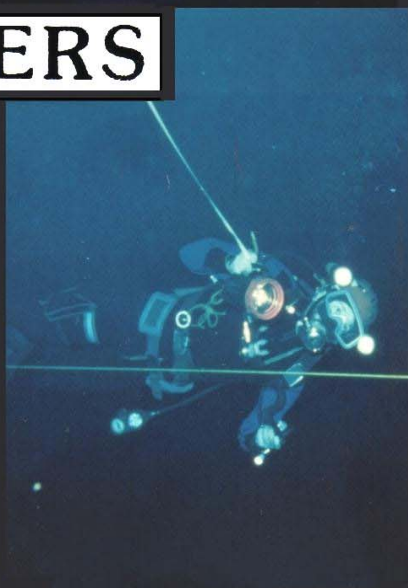



# RESEARCH HANDBOOK


for

# CAVE DIVERS

Peter Horne

# RESEARCH HANDBOOK for CAVE DIVERS

**An Introduction to the Realm and Techniques**

**of the Underwater Speleologist**

Peter Horne
Adelaide, South Australia
February, 1990

(Partially revised November 2004)



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**Other Photo Credits: Stan Bugg and Greg Bulling**
***Homocavernous siltoutus* and all other drawings by the author**

# FOREWORD

This book was originally produced to serve as an introductory guide to the vast world of the underwater speleologist for the benefit of those members of the cave diving community who would like to do more useful things with their time, skills and resources than simply paddling around in a waterfilled cave. It is not intended to be very comprehensive and like all such diving reference publications, the handbook should ideally be used in conjunction with specialized TRAINING so that readers can more fully understand how everything fits together as they gain experience.

Many of the techniques and ideas outlined in this publication were mainly learnt through simple trial and error over a period of more than 20 years as the author and his friends (particularly Mark Nielsen and Andrew Cox) initiated many of the first cave and "sinkhole" studies, and the major mapping and research projects, in Australia – in particular the original "Research Group" of the Cave Divers Association of Australia (set up in March 1983 by the author and Peter Stace, Robin Garrad, Jenny Hiscock, Peter Girdler and others) and the South Australian Underwater Speleological Society (1986-1998). Numerous other skills were also picked up during the author's private explorations and adventures throughout the 1980s.

While the majority of techniques covered in this book comply with currently-accepted scientific standards for speleological work (for example, the construction and setting of various fauna traps and the collecting of samples being classic examples of work which has been undertaken under the watchful eye of experienced scientists in these fields), the very nature of the "speleology beast" means that underwater researchers need to have a broad range of generalised knowledge about cave research so they can be innovative and good at improvising as required. The inherently hostile and extremely limiting, airless environment in which we work means that we cannot enjoy the relative luxuries of "dry" cave researchers such as unlimited amounts of breathing air, warmth, food, communication, visibility and time, and it is possible that a technique which may work well in one situation may be quite inappropriate for another. Therefore, some readers may know of other techniques that have not been covered in this book which may also be of considerable use in this exciting field of adventure, and they are welcome to contact the author if they would like to share this knowledge further!

Because cave diving imposes considerable additional burdens on divers who already have many important gear management, dive/air planning and decompression requirements and so on to consider as a normal part of their dives, divers who may wish to participate in a major underwater research or mapping project should ideally have a great deal of general scuba experience as well as a considerable amount of experience in the environment in which they wish to work. And, while you do not need to be a terrific number-crunching engineering graduate or diving instructor to usefully survey and draw up maps of waterfilled caves or collect important data or specimens, you should have at least some general caving and speleological awareness and be a careful and meticulous observer and recorder.

Poorly-recorded or erroneous data (e.g. poor distance/bearing estimates) are worse than no data at all, so if you possess basic reading and writing language skills and the ability to properly and safely carry out specific research-oriented tasks in waterfilled caves, you have every chance of advancing the cause of underwater speleology in a very real way!

It is the author's hope that, if nothing else, this handbook will help to make research-oriented cave divers more aware of the many unexpected traps and time-wasting pitfalls that can occur so that they can avoid them and go on to gain useful research knowledge and experience. And, when things just don't seem to be working, remember that in these early days of underwater speleology, NOBODY is an "expert" in every field!


## ACKNOWLEDGEMENTS

The author would like to thank the many people who helped in the production of this publication in various ways, whether directly or via past support (including the first edition of this handbook). Special thanks are extended to the following for their very much-appreciated, help, advice and support throughout the closing years of the 20th Century:

- ◊ Mr Paul Harvey (Senior Hydrologist, State Water Labs)
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- ◊ Dr Thomas Iliffe (International researcher and cave-diving explorer, Bermuda Biological Station for Research)
- ◊ Dr Jeff Bozanic (International researcher and cave-diving explorer)
- ◊ Messrs Graham Pilkington, Kevin Mott, Grant Gartrell and other caving friends and speleologists (Cave Exploration Group South Australia), and especially
- ◊ fellow cave divers Mark Nielsen, Andrew ("Grovel") Cox, Terry ("Batman") Reardon, Grant and Lynne Pearce, and Ken Smith.


Cheers and safe cave diving,

Peter Horne
Adelaide, South Australia
October 2004
(Minor update: May 2009)

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***Important Footnote, May 2009:*** *This publication was only ever intended to provide information about how to undertake mapping and research activities in caves, not how to ensure that landholders and other stakeholders are appropriately consulted. However the author would like to briefly mention here that it is strongly recommended that you formally approach the relevant landholders for their permission and consent before any program commences or any material is made publicly available. In the case of sites managed or accessed by the Cave Divers Association of Australia, the CDAA should also be contacted and advised of the planned project prior to commencement so that any "hidden" potential problems such as safety, insurance or liability aspects etc can be appropriately recognised and discussed. Survey lines should also not be left in sites without the permission of the landholder and other site users such as cave divers. Many thanks to Victorian cave diver Adam Hair for raising this important issue.*

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# INTRODUCTION

**Underwater speleology**, the study of waterfilled cave features by cave divers and members of the scientific community, is a very young field of investigation which is only just beginning to blossom in this country.  Back in the late 1970s, when the author and some of his fellow cave divers first became curious about the unusual life-forms and environmental conditions they observed whilst cave diving in the lower south east of South Australia, only a handful of sporadic "scientific" investigations had been attempted in the waterfilled caves and sinkholes which are to be found in the region. A few of these early efforts involved fossil-bone discoveries in a couple of caves and biological studies in some of the more photogenic or popular spring-fed ponds near the coast (particularly Ewens and Piccaninnie Ponds), but both the diving community and the general public seemed to have little interest in the shapes, history or contents of these other hidden features.

So, for many decades, the waterfilled caves and sinkholes were usually simply (but erroneously) considered to be little more than dangerous, mysterious caverns spawned by Mount Gambier's volcanic activity, when in fact their genesis as limestone "karst" features was much more ancient than the region's relatively recent tectonic events.

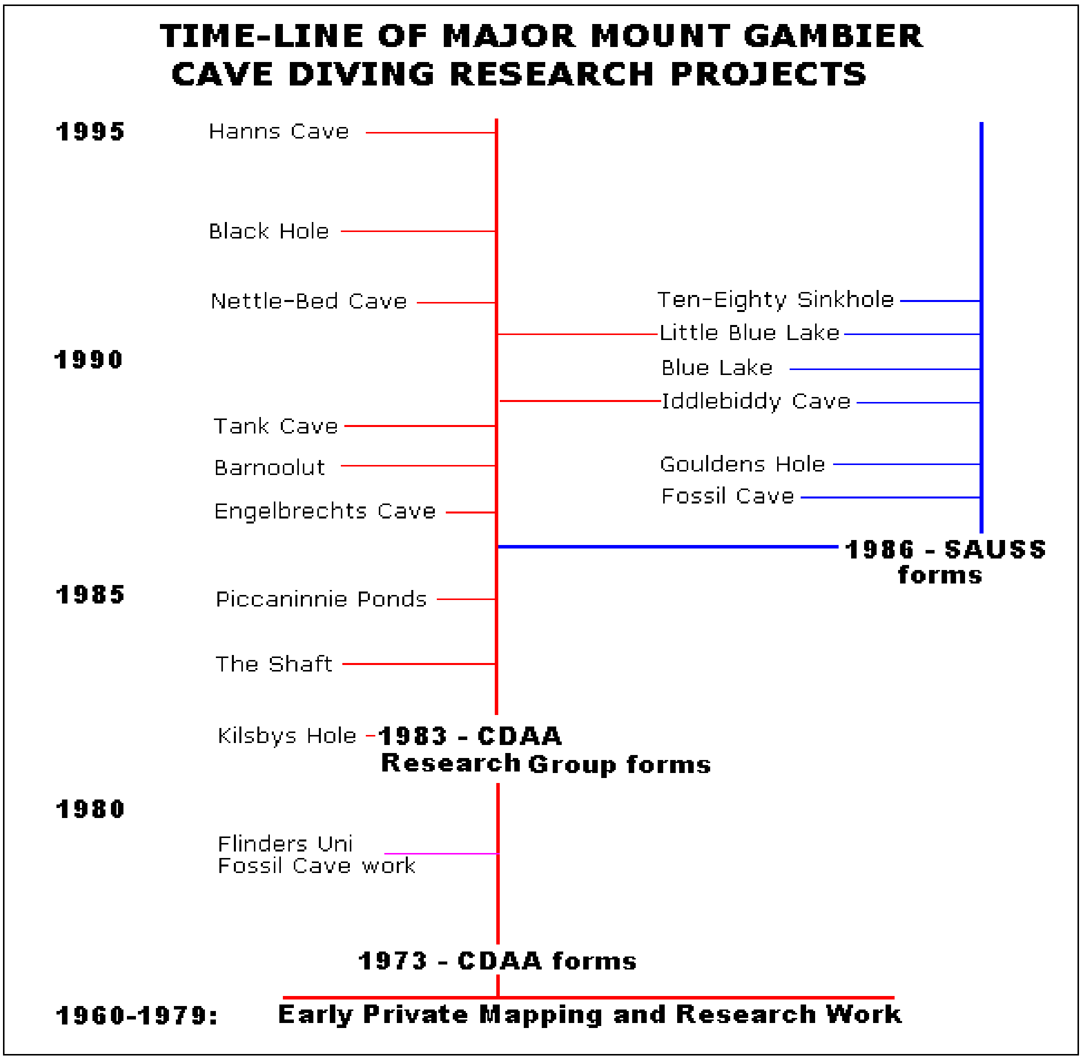
After learning that the sinkholes were actually cave features which had been "drowned" as water levels rose at the end of the last great ice age (around 10,000 years ago), and spurred on by rapidly-growing curiosity as well as the knowledge that very little detailed underwater surveying or other research work had been done prior to that time, the author and a few fellow underground enthusiasts started collecting specimens and data at every opportunity, within the limits of their knowledge and experience.

In view of the serious lack of earlier work it therefore wasn't long before some fascinating discoveries were made; previously undescribed species of sponges, hydroids, crustaceans and stromatolitic forms were discovered almost immediately (much to the delight and sometimes astonishment of scientific and professional consultants), and some basic water temperature and visibility studies of four major sinkholes by the author and his diving companions every three months during 1981-'82 (a continuation of similar work by the author in the local ocean waters during the early 1970s) revealed interesting anomalies which could not be readily explained.

The first basic maps of the more popular diving features were prepared privately by a few individuals using knotted guidelines and compasses during the late 1970s, and in 1979-'80 the author, along with a number of other underwater cave surveyors, assisted cave diving authors Peter Stace and Ian Lewis during the compilation of their groundbreaking book, "Cave Diving In Australia", by providing feedback from underwater observations and maps to ensure that the most accurate information available at that time was presented. These early maps were fine as representations went, but it took several years more before the main players in cave surveying formally pooled their resources to commence more detailed cave surveying tasks in the Lower South East of South Australia.

The impetus for this joining of forces was the sinkhole known as Kilsby's Hole (5L46), which had been closed to the public for some 14 years and which several different parties (including the author) had independently and unsuccessfully sought access for a variety of reasons.

Under Peter Stace's farsighted perceptiveness and leadership in drafting and surveying matters, the first "Research Group" of the Cave Divers Association of Australia was formed in March 1983, and the first mapping team comprising the author, Peter Stace, Robin Garrad, Jenny Hiscock, Ian Lewis, Phil Prust, Peter Girdler (who had originally dived the site in the late 1950s) and Martin Garrad successfully completed the most detailed map of an underwater sinkhole in Australia at that time. Robin and Jenny's academic backgrounds and associated report-writing skills played a major role in laying the foundation for today's standard practice of writing up projects in an entertaining and interesting manner (a very important aspect of any speleological investigation), and the Kilsby project also served as the baseline for the many research projects that were to follow in the following 15 years.




The growth of South Australian cave diving research

Early cave diving "research" work in South Australia was mainly restricted to underwater surveys which often used pioneering techniques or borrowed ideas from overseas divers, but other aspects such as palaeontology and biology were gradually introduced by divers with specific interests in such fields. In late 1986, because of long-term and ongoing political instability within the cave diving community and out of concern that research could be compromised, the author established an independent organization called the South Australian Underwater Speleological Society Inc. which was totally dedicated to the growth of underwater cave knowledge in Australia.

Through the work of SAUSS and the reorganised CDAA Research Group (now called the Mapping and Research Group), about half a dozen of Mount Gambier's larger waterfilled caves as well as several more remote features had been studied and mapped in considerable detail by the end of the 1980s, and numerous other projects were on the drawing board. The results of these groundbreaking efforts are self-evident and readily available for all to see, and it is hoped that, especially in view of the recent demise of SAUSS because of economic considerations, plans will eventually be drawn up to reform and protect the CDAA's research arm to ensure that the political weaknesses of yesteryear will not easily recur.

# Underwater Cave Research: Getting Started

So, you're interested in underwater cave research? From the outset, it is important to stress that if you think there's some sort of glamour in being an underwater groveller, think again! Much of this type of diving involves following very specific scheduled plans and undertaking mundane, repetitive activities which frequently play havoc with diving gear (worn out wetsuits and drysuits, flooded torches and cameras, damaged tank valves and regulators etc), and often the only reward awaiting your efforts is the sense of accomplishment (or relief!) experienced once a project has been completed.

While you DO need to be a competent and experienced cave diver who is capable of working both independently and as a team member, it is important to again stress that you do NOT need to be a qualified scientist or other specialist to participate in under-water research work in a very real way. The ability to understand and carry out relatively simple (although sometimes awkward) tasks, and being able to communicate effectively in the dark, hostile environment of a waterfilled cave, is far more important than proudly boasting of being a "doctor of such-and-such". That said, while most recreational cave divers can assist in all types of research projects, only divers with considerable cave diving experience should participate in the more demanding tasks of collecting data or specimens in confined or silt-prone areas, or at depths in excess of 30 metres, where aspects such as nitrogen narcosis and decompression considerations become extremely important. Cave diving researchers need to have the right equipment, experience, attitude and knowledge if they want to be able to collect useful information or specimens safely and in a coordinated manner.

No matter how confident you are or how competent you may believe yourself to be, you must always remember that you should never do anything or go anywhere underwater if you feel unhappy about doing so, or if there is any risk of your exit being seriously impeded in an emergency situation. Also, being 'experienced' means a lot more than simply logging a thousand ocean dives or a few dozen "deep dives" in such places as the relatively safe and serene Piccaninnie Ponds, or being 'good' at avoiding zero-visibility situations; research divers rarely operate under ideal conditions (usually they are almost completely unable to communicate with anyone else), and often the mere presence of a "buddy" in these situations can actually be an added hazard, so the 'buddy system' which is so widely advocated in general recreational diving circles and many professional businesses must be modified or even almost totally discarded under certain circumstances, as in independent (solo) "penetration" cave diving. For this reason, divers who always insist on diving with a "buddy" and rigidly abide by many of today's ultra-conservative sport-diving practices need to realize that they will be of very limited use in more demanding diving operations.

Naturally, research work frequently entails a lot of hard thinking and careful recording, and obviously very little useful scientific information will be collected if divers are unable to feel completely at ease in a deep, dark and silty underwater cave environment.  People who are at all anxious about water trickling into their mask, the rising silt or their buddy swimming more than 5 metres away are not ideally placed to recognize such dangerous and time-consuming things as slack fibreglass measuring tapes or erroneous depth and compass readings!  The author has also found that the ideal research team should be made up of cave divers with approximately the same interests and skill levels; nothing causes greater confusion than a mixed group of divers who do not understand or respect each others' special concerns or experience in a certain area.  Since experience is truly the best teacher, newer divers can also accompany more experienced researchers where possible so that they can better understand the data gathering process in its entirety.  This will also allow the lead diver to monitor their work and take corrective action as required.

In special situations where once-off or critical data must be collected properly, however – for instance in delicate or unassessed "new" sites – ALL members of the research team need to be well-versed in general speleological standards and ethics as well as having the skills, equipment and planning abilities that are required. Obviously such instances are NOT the best times for training new people or testing out items of gear such as new dry-suits or regulator configurations! It is also important for the more experienced members of the party to realize that other team members might not feel comfortable in what they may believe to be a "normal" situation.  For example, divers who have not yet acquired the confidence and knowledge that comes with zero-visibility experience might very well erroneously consider low-vis (or solo) diving, or diving beyond 40 metres, to be foolhardy and unacceptable under all situations, so due consideration must be given to such concerns if projects are to proceed smoothly.

Divers with little knowledge of, or experience with, mapping and research activities may think that such work is little different from run-of-the-mill cave diving activities, but mapping and research work is actually much more task-oriented and gear-intensive than the activities of happy-paddlers.  Carelessness or bravado on the part of a task-loaded cave diver can exact a rather heavy price!  In his book "Basic Underwater Cave Surveying", American cave diver John Burge Jnr devoted a whole chapter to diving safety, and he identified four major safety aspects in particular that need to be considered by cave divers when they are planning to do underwater cave mapping work.  These considerations are equally valid for virtually all forms of research work in waterfilled caves in this country:-

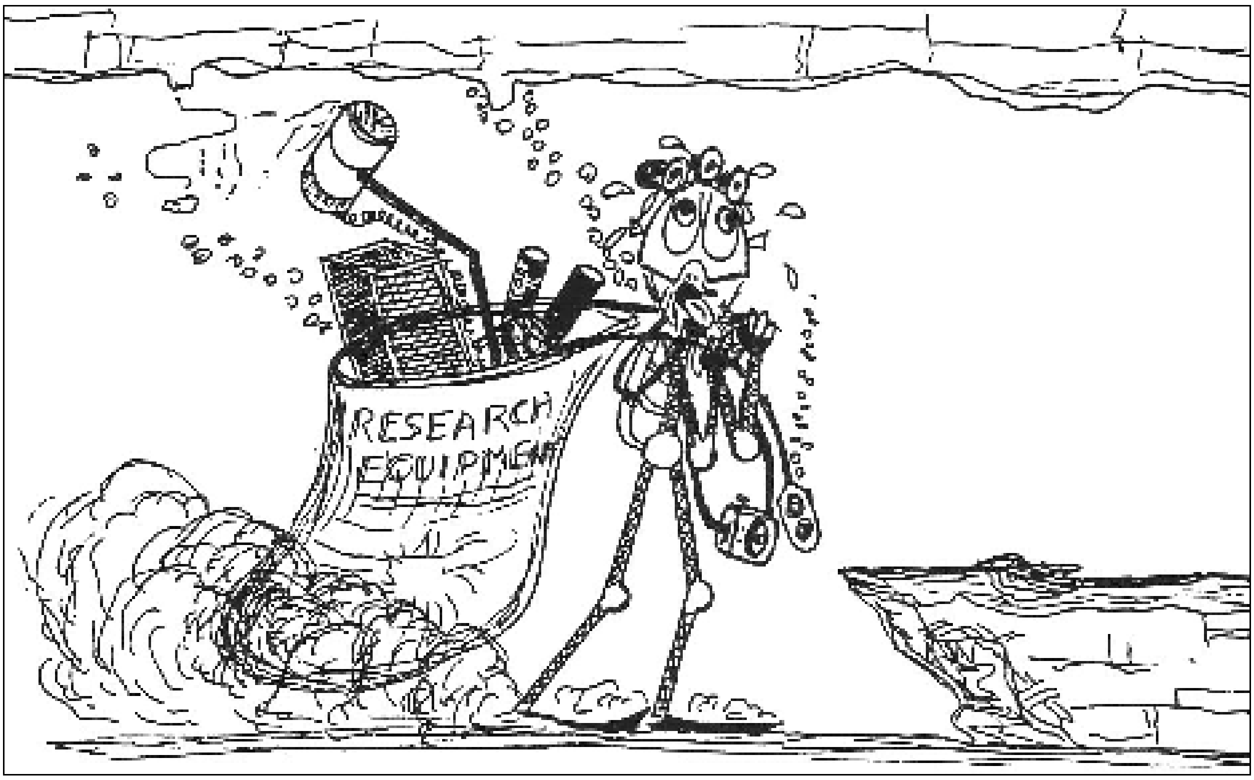
- The **"Dangly Dilemma":** the increase in risk by carrying or wearing additional danglies" such as survey slates, helmets, hammers, reels, tapes, bottles and thermometers etc;

- **Preoccupation and Task Loading:** losing track of essential safety considerations such as air supplies and decompression requirements, unless specific tasks are written down in a detailed dive plan and followed religiously;

- The need for **Proximity Planning:** avoiding problems of excessive separation between the diver/s and other members of the party, for example in sudden silting situations or through restrictions etc; and

- The **"Push Factor":** the drive for more data when one is rapidly approaching (or might already have exceeded) safe turnaround times or penetration distances, etc.

Once you have recognised and dealt with such concerns, and have formed or joined a well-organized "research" team, you can then concentrate on selecting a suitable project – one which is interesting, scientifically useful and realistic, and which will give you invaluable experience in learning how to plan, undertake and report upon such studies. Tips about how you might proceed from here on are covered in the next section.




A typical underwater speleologist!…

# Selecting & Planning a Research Project

Cave diving research activities are only limited by the amount of time, money and imagination you are prepared to put into them. Because so little scientific research has been undertaken in Mount Gambier's waterfilled cave environments to date, cave divers are in the unique position of being able to choose from a wide range of "new" research fields because **any** research project is better than none at all. Divers who are more interested in knowing the shapes and overall dimensions of waterfilled features can bring 'dry' cave mapping skills to bear to produce underwater surveys, and others with biological or environmental leanings can collect a terrific amount of "new" data and specimens of scientific value on virtually any dive. In fact, more research has probably been undertaken into the recently-discovered deep-sea hot water vent communities and the sunken wreck of "TITANIC" than our sinkholes and caves.

Most underwater research activities can be placed in one or more of the following general categories:-

- **SURVEYING** – the collecting of data regarding the location, directional trends and physical dimensions of underground voids and prominent areas or features within those voids to enable accurate descriptive representations (maps, 3D models etc) to be produced for scientific and other practical uses;

- **ENVIRONMENT/HYDROLOGY** – the study of the physical aspects (chemistry, identification and distribution of water-borne contaminants, visibility and thermal stratification etc) of the water contained in caves and atmospheric studies of related dry cave components;

- **BIOSPELEOLOGY** – the study of cave flora and fauna of all types (including such obscure life-forms as bacterial colonies and "stromatolite"-like structures) and ecological interrelationships;

- **GEOMORPHOLOGY** – physical aspects and structure (joint control, sedimentation, associated geology and hydraulics etc) of the caves and how they evolved to their present shapes and sizes; and

- **PALAEONTOLOGY & ARCHAEOLOGY** – the study of fossils and associated remains (including human artefacts) which are often uniquely preserved or otherwise represented in waterfilled caves.

**UNDERWATER PHOTOGRAPHY** is also increasingly becoming a very useful tool in many of the above disciplines, and nowadays, video is more and more often proving its worth as an invaluable recording medium, especially when divers want to obtain additional "fill-in" survey information or record important or unique features for posterity. A single photograph or video sequence can show much more detail about a feature's shape, size, colour, contents and texture than many pages of writing, and photos play a major role in presenting aesthetically pleasing books and reports to the non-diving public as well.

If your research team has had little or no previous experience with such activities as sample collecting or underwater cave mapping, you would be wise to at least seek some advice from others who have done such work. There are many little "tricks" in performing these seemingly-easy tasks underwater, and apart from being forced to reinvent the wheel, divers may innocently place themselves in hazardous situations when they don't need to do so. The commitment of team members to the project, their willingness to perform specific tasks and the amount of money they are all prepared to spend on trips and extra gear are some of the important aspects you need to sort out early in the project.

From our own experience, it is certainly preferable to start with a relatively simple study, for instance, collecting water samples, temperature and visibility data over a period of time, because this will allow you to gain important skills involving underwater dexterity, setting up suitable lighting systems (preferably helmet-mounted types which don't dazzle everyone but leave your hands free) and establishing a useful working liaison with interested scientists as well as other supportive cave divers; this style of research also generally provides immediate results and writing up your findings in a useful manner can in itself be a valuable learning exercise. If you do NOT sort out your gear immediately you will soon find out how awkward things become without getting into too much trouble! Alternatively, you might want to try your hand at more complicated, long-term projects such as actually surveying a waterfilled feature.

If you have very little knowledge about this fairly involved activity, it is strongly suggested that you consider steering clear of mapping anything more than the simplest features in the early stages because if such work is not done properly, faulty surveys will result. You might also consider assisting in taking basic tape measurements and the like as a member of a larger, more organised group – such involvement is a good way to gain experience – but the main planning and plotting of surveys, with all of their little quirks, angular corrections and so on should be left to others until you are properly set up for such projects. This field especially requires a lot of hands-on experience, and working with a group of dry-cave surveyors (e.g. by joining a caving club) is probably the best way to gain the knowledge and experience you need to map caves usefully.

All research activities require planning and assessment input from specialists in relevant fields if useful results are to be obtained. If you want to collect samples, you need to carefully think about exactly HOW you will physically collect, secure, preserve and transport them (and who will ultimately analyse them) BEFORE you start, since poorly-collected specimens or those with contaminants are of almost no scientific value. This therefore means that you will need to establish contact with suitable academic and scientific professionals who can advise you on such matters. Sample collecting should also only be undertaken if you have a definite goal (e.g., studying nitrates or heavy metal levels at different depths) and only as long as such samples will have no significant effect on the sites' environment or biology.

If you are interested in recording less-critical observations such as temperature and visibility changes at different depths, you might prefer to experiment with your own equipment and techniques so that you can improve your observational skills through trial-and-error. Whatever your field of interest, both you AND our caves can only benefit if you seek useful input from interested professionals at universities, museums and associated institutions as you get more involved in exploring the fascinating worlds of our mysterious underground/underwater world!

# Basic Underwater Cave Mapping

The author has found that without doubt, one of the most rewarding and interesting aspects of underwater speleology is the final production of a **CAVE MAP**. The work involved is at times challenging and complex, but the sense of achievement attained as a cave falls into place on paper or computer monitor for the very first time can be truly fantastic! A cave map, based on some sort of SURVEY, is still the best way to provide at a glance an accurate and easily-understood representation of the overall shape, dimensions and contents of a feature which otherwise could only be seen and appreciated by cave divers. Starting from a simple baseline "skeleton" of lines and measurements, cave divers can "flesh out" their survey sites to create very detailed maps which concisely represent their beloved waterfilled feature.

In addition to providing information of interest to other cave divers such as identifying awkward restrictions and showing penetration distances, maps are also of value to scientists and other non-divers, performing among other things such useful functions as providing information for calculating the volume and movement of underground water for agricultural, scientific, industrial or domestic purposes, identifying likely collapse points relative to important surface features such as highways (and toxic chemical blending plants!), highlighting the location of important artefacts or fossil remnants, providing information about the possibility (and probable direction and extent) of previously undiscovered passages, and educating the general public about these otherwise-hidden wonders of nature.

Surveying any cave, let alone one filled with water, is usually a very time-consuming and complicated procedure involving a lot of mathematical components, but a large amount of very good mapping work can still be done by average, non-academic cave divers (the author included!). To highlight this, consider that most underwater cave surveying work undertaken to date in South Australia (and indeed, the whole country) has been done voluntarily by cave divers who were armed with little more than sheer enthusiasm, basic fibreglass tapes, compasses and other mapping and drafting tools, and a rudimentary understanding of triangulation and mapping principles (as well as perhaps a bit of an artistic flair!). So don't be put off with the thought of dredging through logarithmic tables or doing complex number-crunching for countless drudging hours; your pencil and graph-paper drawings will be just as useful and impressive (perhaps even more so) than a super-computed CAD map which has baselines computed down to five decimal places but which might also severely lack important finer details.

Since there are no formal underwater cave surveying training courses in this country, the people who have been involved in such work to date have all learnt their own ways by trial and error, so a myriad of techniques and mapping styles have developed over the past three decades. And, just as in dry cave surveying, people have different opinions about what should be represented on a map and how such features should be represented. One may denote distances using the **ground surface** as the main reference point while another may prefer measured **water** (pressure) **depths**, for instance, or one diver might sketch actual boulder shapes while another will simply draw representative rectangles on their sketch to denote the presence of some kind of talus mound or rockpile.

The key is to ensure that anything outside of the accepted mapping conventions is shown in a **legend** which should always appear on the map, along with, of course, the magnetic and/or true North points, a Bar Scale, and survey information such as the date and survey team members' names, etc. Cave divers with a strong interest in mapping in particular are also strongly advised to get hold of a few publications on cave surveying so they can gain a better understanding of the many principles involved in this field. As was mentioned earlier, an ideal introductory text in relation to cave diving mapping work is John W. Burge Jnr's ***Basic Underwater Cave Surveying*** produced for the Cave Diving Section of the National Speleological Society Inc., USA.

In this field, experience is truly the best teacher, so prospective cave diving surveyors are advised to join a caving organisation or surveying party, practice mapping their living room and read up on the topic as much as possible before they jump in at the deep end with their tape reels and survey slates!

## GENERAL PRINCIPLES OF MAPPING

Anyone who can draw anything at all can draw a map of a cave. It can be a simple memory sketch with only general, approximate features drawn in or it can be more detailed and accurate, depending on the surveyors' goals, skills and equipment. The simplest maps can be made a little more accurate than mere guesswork if one can estimate directions and distances of significance; the sun's position at the cave entrance, the number of paces/fin strokes/metre-per-second swimming speed, or measured knots in their guidelines, for example. Even a couple of simple knots on the line at specific locations within the cave will provide important penetration distances from the entrance and relative to each other, and if the magnetic bearing of the line can also be recorded (even within 20 degrees if one hasn't the time, equipment or experience to use compasses more accurately), future cave surveyors will at least have a good idea of the dimensions and rough layout of the cave from which they may plan a far more complex and accurate underwater survey comprising detailed measurements from well-placed baselines and stations.

Most of the cave and sinkhole diving sites in the Mount Gambier region consist of relatively simple, open but deep caverns which formed as a result of major roof collapses into vast rooms, so the mapping can generally be undertaken by just swimming from place to place and taking notes and measurements. By comparison, detailed surveys of "dry" caves require more comprehensive knowledge and training in the different skills and equipment used in such instances (e.g. forestry compasses, levelling staffs, clinometers for vertical angle measurements and wall-scaling poles etc) because unlike divers, dry cavers have a rather hard time floating up to high points in the ceilings, and formal drafting skills involving the use of special boards and pens (and sticking rigidly to standard symbols and the like) are considered mandatory by many traditionalists. But again, remember that even basic paper-and-pen drawings can present a map of a cave in an attractive and useful manner.

To assist in classifying the degree of accuracy and detail of any cave survey, the dry caving community has devised a number of SURVEY GRADES and DETAIL GRADES which should always be written on any survey. Some of the earliest map grades were developed by the British Cave Research Association, and for many years these standards were used in many other countries including the United States and Australia.

The cave survey grades used by divers in the US generally relate back to the BCRA standards in one form or another, but here in Australia, where the Australian Speleological Federation has developed its own national standard, cave divers utilize the ASF standards as much as possible so there are some differences between the various grading schemes used in different countries.

## A Guide to Cave Map SURVEY Grades

**Grade 0** : **Unknown.** Might be very high or extremely low-grade map: very little or no other information available, so no way to know!

**Grade 1** : **Very rough memory sketch only,** not drawn on-site or to scale. May be either low or high in accuracy, depending on the size and type of feature and the memory, estimating ability and artistic skill of the visitor!

**Grade 2** : **Basic map based on some on-site notes** regarding major aspects. Distances and rough bearings/positions etc., **estimated** distances and positions only. No instruments used or available.

**Grade 3** : **On-site sketch with some key bearings measured to about 5°** by compass and fairly accurate distances (fibreglass tape, knotted line, belt or careful pacing etc) to key features: expected accuracy to about 10%.

**Grade 4+** : **Much more accurate representations ...** carefully checked compass bearings, detailed traverses and loop closures. Underwater, **Grade 6** using cross-checked distances and highly-accurate closures or RDF equipment etc is the general practical limit for deep, silty caves and caverns although if the need is there, one can survey right up to **ASF Grade 9** standard.

## A Guide to Cave Map DETAIL Grades

**Grade 1** : **Sketch from memory, not to scale.**

**Grade 2** : **Map compiled from rough notes, sketches and estimates *in situ,*** no major measurements.

**Grade 3** : **Maps compiled from measurements and drawings in the cave,** based on approximate measurements of significant details. Additional sketching of secondary features.

**Grade 4** : **Details of features based on measured points from survey,** involving all features of major speleological interest, and

**Grade 5** : **As for Grade 4,** with the addition of significant geomorphological features (e.g., types and dip angle of rock and bedding planes etc) and details of deposits.

It's also worth remembering that increasing the quality or grade of a cave map requires an almost exponential increase in the amount of measurements taken, as well as much higher accuracy requiring better equipment which eventually makes the highest level grades almost impossible to achieve in your standard underwater cave environment! This is the main reason why the vast majority of underwater cave maps fall somewhere around ASF Grades 3-5; it just isn't worth tripling one's underwater time to come up with a map that is perhaps 10% more accurate than the original 10-minute sketch!

## PLANNING A MAPPING PROJECT

Underwater cave surveying work, more so than "dry" cave surveying, requires a considerable amount of special planning as well as post-dive debriefings if work is to be undertaken safely and with the minimum of confusion. Knowledge of the site is the first important consideration, because if the general size and orientation of a cave is only roughly known, problems with general dive planning and inadequate provision of pre-marked line or numbers of measuring tapes and compasses etc. will be encountered before things even get going! Therefore, it is important for all team members to have orientation dives prior to commencing operations.

Having worked out **WHAT** you would like to survey, you then need to work out exactly **HOW** you intend to do it, to what sort of **GRADE** of accuracy and **WHO** will likely be involved. Aspects to consider include:-

- **TIME FRAME:** Is it just a "one-dive-quickie" or are you prepared to spend many days/months/years collecting the information?
- **ULTIMATE PRODUCT:** Do you intend to produce just a small, private map, or is it a huge science project and intended for publication? Do you need to consider collecting data in a special way to present the map in 3D (e.g. CAD computer-graphics) or as a physical model? Do you need to research historical and formal scientific publishing aspects? Who will ultimately benefit from this work?
- **SURVEY DETAIL:** How detailed do you intend the final map to be – will it be just a general representation or will the farmer need to know exactly where to drill that bore-hole? How skilled at mapping are the members of your dive party and what features (boulders, decoration, sediment types etc) will you need to locate? What "grade" will you be aiming to achieve, and what scale do you intend to use for the final map; i.e., do you want a highly-accurate, 1:100 (lcm = lm) scale Grade 6 monster, or can you get away with, say, 1:500 or smaller Grade 3 (remember that each step upwards in a map grade entails an astronomical increase in the time and effort required to record and plot the information). Will you need to take measurements at many different points, at set distances along a tape or line, or will you use several styles? Should you use a single-line traverse with additional supporting offsets and back-bearings in preference to a "closed" survey, or do you want to combine different surveying techniques?
- **PERSONNEL:** How many divers will you need or want to use? What practical experience has each person had and how much general knowledge do they have about mapping principles, calculations and drawing? Do they also have any previous involvement with, or knowledge of, other important aspects of underwater speleology and research? Can the planned team members all work well together with minimal supervision? Will they be able to truly COMMIT themselves to the work?

What is the maximum number of people you can manage at a time, considering the information that will be coming in, the access and diving conditions at the site and other similar considerations?  And what possible political issues may arise if certain people can join your team while others cannot?

- **RESOURCES & EQUIPMENT:** Will you need to borrow/buy/rent/steal more diving gear than usual to do the work? How many metres of line will you need and will it need to be pre-marked (if so, with what and how far apart)? How many measuring tapes and waterproof compasses will be needed? Will you need to modify gear to communicate better, write notes, carry samples and take accurate bearings in a dark, silty, waterfilled cave?  And so on…

As with dry cave surveying, divers map waterfilled sites by establishing a series of REFERENCE STATIONS (rocks, nails in appropriate places and wall features etc) which are then connected together by SURVEY LINES. The divers then measure the DEPTH at each station and the DISTANCES and BEARINGS between stations using the "DAD" (**D**epth, **A**zimuth, **D**istance) principle (refer to Burge 1987, page 43), and from specific reference stations such as boulders, markers and knots on their survey lines divers then take numerous additional measurements to the ceiling, floor and walls etc.  It might all sound pretty simple, but if you give a large group of experienced underwater surveyors the job of mapping even a relatively simple waterfilled cave, you will find that they will all use slightly different surveying and recording techniques with the result that their cave maps (while hopefully still being representative of the feature) will be very different to each other.

Where one diver may be content to run a single line through the centre of the cavern and make quick, fairly-accurate estimates to the walls and ceiling from that one line, another may choose to run the line around the circumference of the cavern from point to point, and a third may use a prominent boulder near the centre of the room from which to run perhaps half a dozen single lines at different compass bearings. It all basically comes down to the surveyor's goals, time, financial resources and overall cave mapping experience.

Divers also see different aspects of importance when they are surveying a waterfilled cave, and while some techniques might seem plodding and unnecessary to other observers, they often have benefits which are not readily apparent.  And, since no two caves are the same, surveyors need to be fairly flexible in their styles so that they don't find themselves becoming slaves to certain techniques; for instance, an easy radial survey running from a readily-visible central point in one cave might not be repeatable in a shallower, boulder-strewn cavern elsewhere, and likewise, the presence of unseen metallic debris (all too common in many of Mount Gambier's sinkholes) might cause so much disruption to compass bearings that divers will be forced to use underwater triangulation to locate features in some caves.

Because dry-caving techniques and standards do not always lend themselves to underwater applications, divers have developed their own unique techniques and symbols. While dry cavers plot underground features or stations in terms of the depth below GROUND level, cave divers tend to use WATER DEPTHS at stations within the feature because these figures are of more immediate relevance to our activity.  But because the level of the regional water table can vary seasonally by more than a metre, it is very important to establish a surface reference station from which all "depth" measurements can be converted into standard distances.

This is especially important if the water table is changing quite quickly, because a station at say 36 metres (pressure depth) one week might be at 34m the next; it really doesn't matter which system is used as long as it is clearly identified on the final drawing; however, ceiling height DISTANCES (i.e. the distance from the floor to the ceiling) rather than water DEPTHS should ALWAYS be used in horizontal systems where fluctuating water-table levels can seriously adversely affect a survey, or where the ceiling is less than a metre or so from the floor (i.e. less than a safe width for the passage of a "large" cave diver!).

**SURVEYING TECHNIQUES AND EQUIPMENT**

The cave divers' surveying rig basically comprises a good **COMPASS**, accurate **DEPTH GAUGES**, 30m or 50m fibreglass **MEASURING TAPES** or pre-knotted **SURVEY LINES** (the latter for long-term installation or over survey legs which are too large for the tapes) , **STATION MARKERS** (e.g. tags, pegs, star-droppers and hammers etc) and appropriate **RECORDING FACILITIES** (survey slate, notepad, spare pencils etc), as well as a range of support equipment such as tape sinkers and floats, sonar range-finders, water sampling bottles and thermometers and "normal" cave diving gear such as guideline reels and the like. All of these funny little items are very easily dropped or lost in the heat of action whilst surveying, and their presence requires additional gear-management skills as well as "anti-tangly" and buoyancy skills.

If you don't organise yourself properly, your survey dive could be a major waste of effort or perhaps even lead to a major problem; the author can assure the reader that it really isn't much fun to find oneself getting accidentally clipped onto another diver's tank valve at depth because of a single exposed "snap-lock" karabiner, or watching a whole hour of hard-won measurements on a survey slate (not to mention attached depth gauges and compasses etc) spiralling slowly into the depths just because the granny-knot on the nylon cord of your survey slate magically untied itself during your 3m decompression stop!

It is impossible to say that one particular item of equipment is the "most" important in underwater surveying, just as it is impossible to say that one particular piece of cave diving gear by itself is "the" most important. Many items need to be used in conjunction with each other to obtain the necessary information and the lack of one item can easily compromise the value of the other three or four. The use of a good compass to take the bearing of each line is important, but the information is pretty useless if you can't measure the depth or distance between each station (and ditto if you know the distance and depth, but have no bearings with which to work); and even if you have all of the gauges and lines, if you broke your only pencil, you will only be able to record what little information your memory will permit! So, as with all cave diving activities, one needs to seriously consider the need for redundancy with all of the important cave surveying gear, as well as the best type of unit to buy in the first place.

**COMPASSES**

Compasses play an important role in most surveys, but the majority can only be reasonably read to within 2-5 degrees underwater after much practice (depending on the type of compass and environmental conditions), so confirmation tape measurements between adjacent stations generally need to be made to minimize any errors.

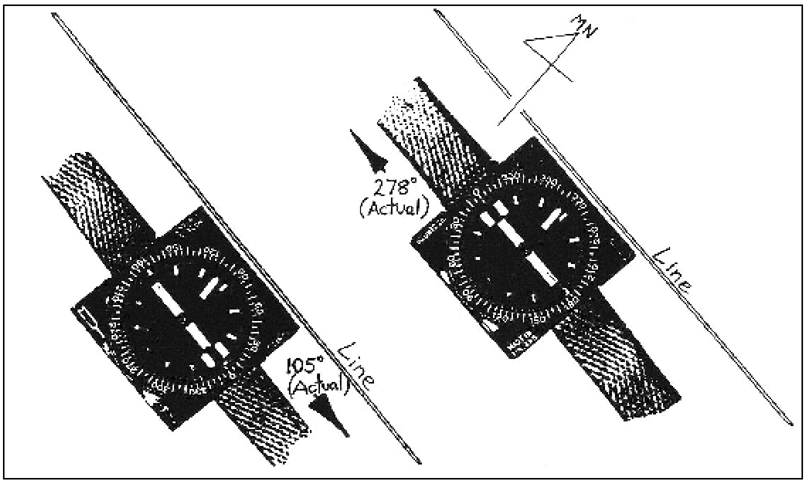
For instance, if you were to measure the four sides of a rectangle and took compass bearings along every line (and in both directions), and still found that the final leg of your drawing still did not come back to the starting point, you could reconfirm your compass readings or simply run a tape from each corner of the rectangle to the opposite corner and check the measurements. This will greatly assist in "closing" the survey and can also provide clues about where the compass errors may be occurring. (Since the late 1990s another useful tool has been utilized to locate underwater survey stations – an electromagnetic "pinger" is placed at the survey station by divers and the signal sent out by this device is located directly overhead by a surface surveyor using a magnetic loop-detection system to detect the "null point" in the signal. However this system has only recently come into play and is rarely available, and it is still generally not as accurate as a good fibreglass-tape measurement).

Compasses also need to be both accurately calibrated and used correctly if useful readings are to be made. While an acceptable level of accuracy can often be obtained using the "targeting"-style sighting compasses that are held up to eye level in line with the target feature and read from the side, underwater conditions are generally not favourable for this kind of procedure and so measurements need to be obtained by referring to the bearing of a **line** that connects one station to another. In some situations the targeting compasses can still be used here, but the author believes that far more accurate compass readings can be obtained if divers use a suitable type of compass which can be flush-mounted to a large flat survey slate which can then be carefully aligned with the reference line.

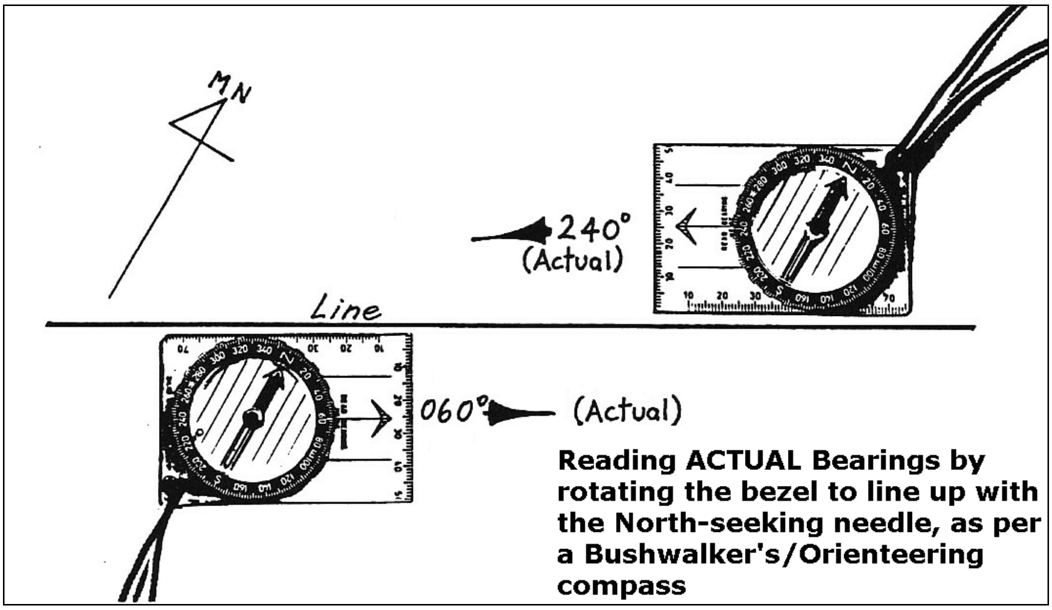
As attractive as many general divers' compasses may appear to the "colour-coordinated" set, many are unfortunately much better suited to indicating the direction back to a dive boat than for detailed cave surveying work. These units tend to be difficult to read to within a few degrees for a multitude of reasons but especially because of their design, where parallax errors are easily amplified. The ideal divers' surveying compass should be oil-filled and have a smooth, fast-reacting needle that points clearly to the bearing number around the bezel, and the needle must be steady and lie as close as possible to the numbers, especially if it is on a floating card which can wobble to any extent. It is difficult to know when you are hovering precisely over the top of an underwater compass at the best of times, but it is impossible to be sure when you are trying to hover a metre or more above a steeply-sloping and dimly-lit survey reference line in 30 or 40 metres of very cold water!

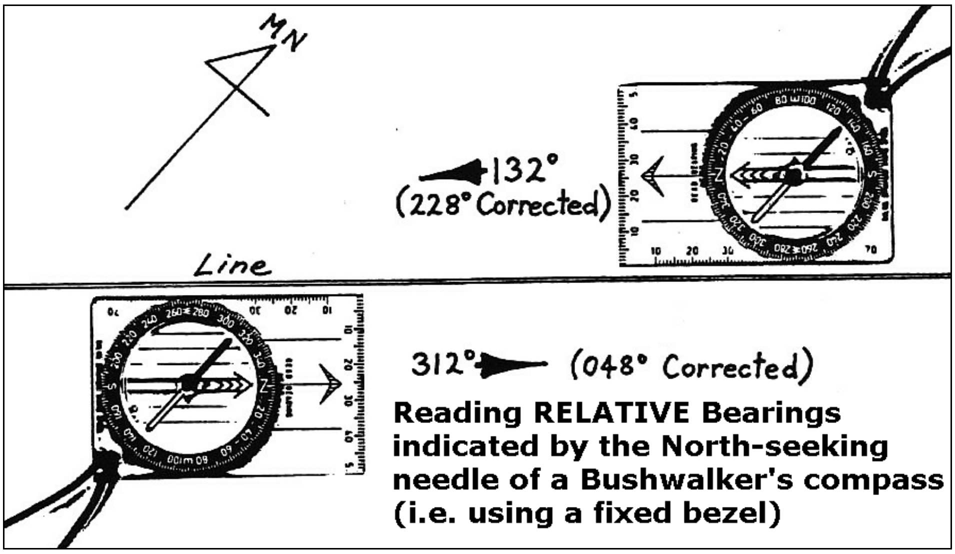
The author personally prefers two common types of compass for their relative cheapness, ease of use and very-acceptable accuracy: the standard WRIST-MOUNTED DIVERS COMPASS which has the ACTUAL BEARING written on the bezel around the outside rim (in 5 degree increments) so that the north-seeking needle will immediately show you the direction you are facing, and various styles of bushwalkers' ORIENTEERING COMPASSES which are perhaps more accurate (generally 2-degree increments) but which also require more care to use and read as their bezels need to be rotated to align the north point with the needle for each reading. The latter form of compass can also be used in a similar fashion to the divers' compasses without rotating the bezel if the surveying conditions force you into that position (e.g. lying in near zero-vis in a very narrow restriction, with just a couple of seconds in which to see anything at all!), but any such "relative" bearing reading need to be recorded carefully as such so that appropriate reciprocal calculations are made before the bearings are plotted on the map.

This procedure is obviously more complex and prone to errors, which is the last thing you want to worry about after getting the measurements in the first place.




**ACTUAL** bearings as indicated by the
North-seeking needle e.g. a standard diver's compass






**DEPTH GAUGES**

In the case of the simple rectangular survey of four stations mentioned in the earlier discussion about compasses, a quite accurate map of the feature can be easily plotted providing the stations at each corner of the rectangle are at the same depth – for instance, around someone's fence-line (which should be surveyed as well, if it surrounds a cave entrance). But what happens when the four corners of the rectangle are at significantly different depths, as is almost always the case in waterfilled caves? You cannot simply just draw up the measurements to scale as before because the SLOPE distances are different to the actual HORIZONTAL distances (i.e. as seen from directly above), and so you will need to convert each line measurement into a "corrected HORIZONTAL" distance which takes into account the slope angle of the line before being plotted on your master map. And this means that you will need to know the DEPTH of each station as accurately as possible.

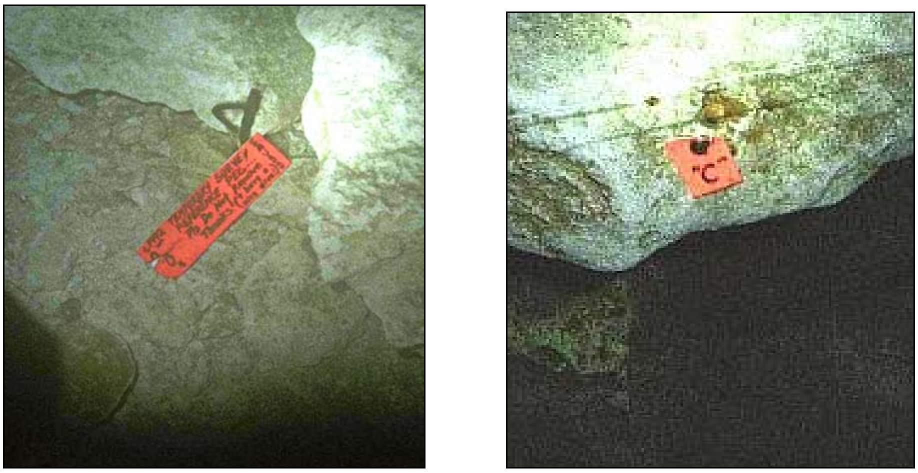
There are many depth gauges available these days, but due to the incredible improvements in technology in the past decade the ELECTRONIC, DIGITAL gauges are by far the most accurate and easy-to-read systems. Modern dive computers also have quite accurate depth gauges built into them as a function of their decompression calculations and many of these units have such terrific options that a diver can even record a lot of accurate depth readings at various stations simply by reviewing the dive profiles long after they have had their nice warm shower!

Also, because today's gauges tend to be far more accurate than was the case in the "good old days" (as well as the fact that depth variations of a few metres over quite long survey legs can tolerate relatively large generalisations anyway), the relatively minor variation in depth readings between fresh and salt water environments (just 0.3m for every 10m of depth) is hardly worth worrying about when one is aiming for a maximum error of somewhere around 2 or 3 metres!

However, one aspect worth remembering is that many gauges (particularly analogue units) can lose their calibration as a result of changes involving air temperature and pressure, altitude variations and travelling by air; it's therefore essential for surveyors to frequently recheck their gauges against some sort of standard or known gauge system such as a vertical fibreglass measuring tape. Such checks should be done whenever an opportunity to compare readings presents itself (e.g. while visiting a station), and while surveying errors of less than about half a metre for every 30m of depth can generally be ignored, some jobs may require much greater accuracy than this, especially in shallow sites or when during jobs such as fossil work that require very accurate locational information.

**SURVEY STATIONS**

Having set yourself up with the means by which to orient yourself (compass) and measure water depth (gauges), you will need to establish a series of reference STATIONS and BASELINES of some type which will serve as the foundation upon which you can begin to survey in other detail. Only when you have built up this framework from a series of accurately-located stations can you begin to usefully add important information such as floor distances, ceiling heights and wall distances etc at various places around the survey; the "fleshing out" of the "skeleton", as referred to at the beginning of this chapter. Selecting your survey reference stations will very much rely upon your past experience and plans for this particular mapping project, but whatever you decide to do you should always take care to avoid damaging the cave as much as possible.



Examples of survey station markers (from *The Pines*, placed in 1992 and still readable more than a decade later)

Some cavers and divers advocate using only naturally-occurring wall features etc as tie-off points for survey lines (to avoid the use of any sort of nails or pitons etc), but having seen how a seemingly-casual pull on a "handy wall projection" resulted in the collapse of a cubic metre of ceiling during one survey, the author generally prefers to set up his baselines away from such features, using boulders as tie-offs where possible as well as bigger star-droppers in deep sediment or nails and pitons (in discrete locations in boulders or around the walls of larger features) so that a diver’s careless fin-kick will not snag and pull on a line with disastrous consequences to the hapless feature connected to it!

Finally, you will need to mark your stations in some way so that you and others can easily identify them from a reasonable distance, say, every 10 metres. You might also need to set up some sort of short-term buoyed float to enable you to relocate a small station in a vast or deep chamber; a small glass bottle, sealed with air and carrying an identifying note, plus some marker flags etc attached to a 3m-long buoy line, has worked very well in some past projects as well as smaller plasticised (waterproof) survey markers which both identify the station and advise other divers of the purpose of the marker.

**SURVEY LINES**

With the survey stations selected, you will need to connect them together so that you can both survey each station into the map and establish the baselines from which to collect all of the other important data. Where the site permits the use of temporarily or permanently-installed reference lines, these should be used until you have collected enough data and are satisfied that they no longer need to remain in place. The ideal survey line for cave diving work is, in the author's opinion, a highly-visible, light-weight, strong and abrasion-resistant cord with minimal stretching qualities and a thickness of between around 5mm and 10mm.

The line should be roughly neutrally-buoyant, but if this isn't an option, it really doesn't matter too much whether the line is either positive or negatively buoyant as long as the various properties are kept in mind when the line is being used. Line that is slightly positively buoyant is easier to relocate and reconnect in many cave applications, a common problem where other divers also have access to the site. Also, in deep cavern surveys a floating line will follow the ceiling rather than the floor (which may be much deeper than you might be willing to go), whilst increasing the risk of entanglement along the ceiling. By comparison, sinking line is better for tying off on boulders and along the floor; the choice is yours and depends very much upon each survey's specific considerations.

Each survey line should be marked with distance flags or knots at convenient intervals (preferably about 3m, or 10 feet, apart) because you can get a very good image of a cave from such regular reference stations and can also easily estimate to at least half a metre's accuracy by simply spreading out your arms between adjacent knots. However, in much bigger or vastly deeper systems where detailed, time-consuming measurements are not a luxury you can afford, you might choose to use 5m increments which means that you can collect 6 sets of data along a 30m traverse where a survey using 3m increments would have required 10 sets, i.e. almost half the number of measurements and therefore nearly half the amount of dive-time to still get a very good idea about the structure of a large feature. It is also helpful to leave a small identifying marker (e.g. "wetnote" page) where different lines run from a single station to avoid confusion, and to place a much larger and easily-read marker page on a line at regular intervals when underwater video or other photographic recording systems are being used to fill in survey details.

In other countries where divers have much larger cave systems, survey lines are frequently used in place of measuring tapes and so the divers need to be as accurate as possible with respect to any knots or distance-markers they contain. However, in South Australia we generally have much more manageable systems and so we can both keep our survey legs short (no longer than 30-50m if possible) and physically check the distances between stations using a much more accurate fibreglass measuring tape.

It is also generally not critical to map the exact location of features beneath, above and to the side of a survey line to a high accuracy, so line knots can be up to half a metre "off" without creating any significant problems for the survey.  Anything REALLY important will still need to be properly surveyed-in by fibreglass tape, anyway.  You should also avoid installing excessively-long single-line traverses in ANY cave survey, whether dry or wet, because of the increase in error that the simplest misreading of an angle or compass will cause at the other end, not to mention the cumulative effects of line stretch.

If large knots are used on the line, you will also need to consider that if one should happen to become untied, the resulting slackness will seriously affect the distancing of other knots on the non-taut line and may even result in the line becoming disconnected from a tie-off. For this reason it is very important to INDEPENDENTLY tie the line to each survey station because a lot of time is wasted when a series of slack portions sees a single survey line popping off one station after another!

Once you have completed your measurements along the line, it should be removed except in situations where it can serve a useful purpose for other divers, e.g. leading the way directly to the sunken car in Little Blue Lake, or to House Rock in The Black Hole, because leaving unwanted lines in place constitutes a form of "underwater visual pollution" and may in time become a hazard to divers who will snag and loosen it. The removal of used line also ensures that it can be used again somewhere else.

**MEASURING TAPES**

Although easily-visible knotted lines are very fast survey tools, you will need to use a sturdy, non-stretching measuring tape if you want to ensure that your underwater distance measurements are as accurate as possible. The author has found that for most applications (excluding extremely muddy situations, or where a lot of underwater plant or algae growth can jam the reel), standard 30 or 50-metre fibreglass surveying tapes are ideal, and in freshwater applications (and with appropriate post-dive maintenance), such tapes are easy to handle and retain their smooth winding qualities for a very long time. They can also be stowed in a portable-pocket or goodie-bag easily, but their potential effect on magnetic compasses or other instruments need to be assessed and compensated for.

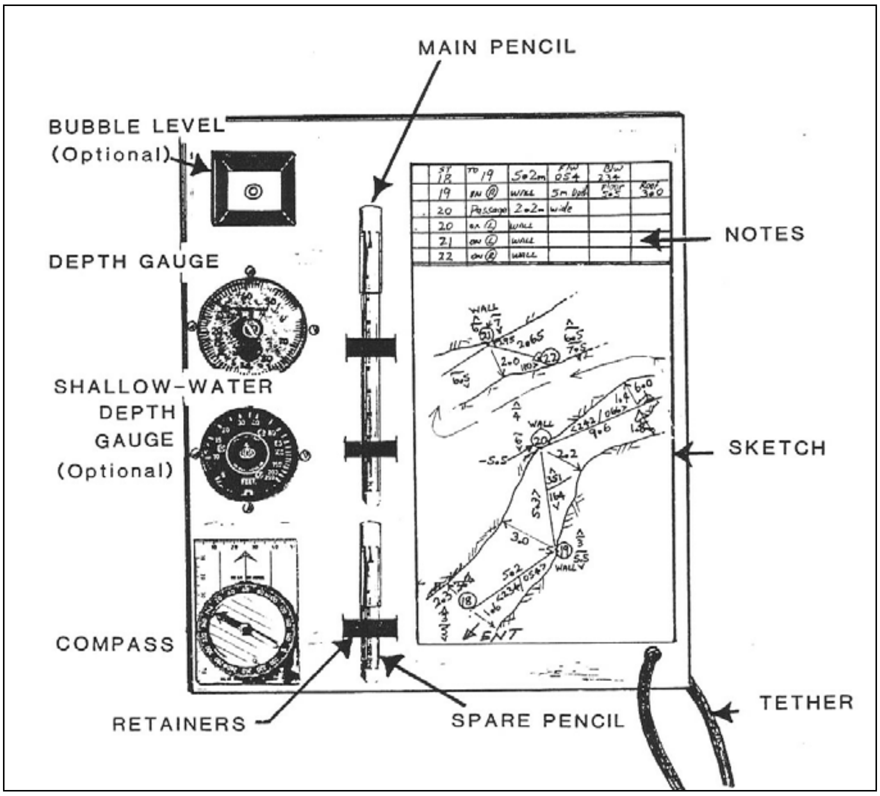
Most enclosed fibreglass measuring tapes are easy to pull out and wind in underwater if they run straight out of their reels, but they can be a pain if they get twisted on their way back "in" and may jam a reel which is being wound in vigorously by an overly-keen (or narked!) cave diver. Such problems are especially acute where gunk gets swept in with the tape, or if you have been pulling hard on the reel as though you were fishing, such as whilst swimming to another station and attempting to pull the tape in while it is straining against drag and "arcing" through the water.

Where such seizure occurs, one should NOT spend more than a few seconds trying to sort it out *in situ*; tapes are not good at handling localised stretching and may be damaged or even completely break.  In such cases just wind the exposed tape around your hand or the reel itself, tie it up securely so it won’t unravel and stow if for sorting later, back on the surface where you may need to dismantle the case.

In many instances, especially where one can readily see a featureless wall, ceiling or floor within a few metres of the reference line, hand-held sonar-ranging systems and the like are fast, efficient ways to record distancing information, but one needs to practice with these units to know their limitations and understand exactly WHAT they are range-finding TO (you might think it is the bottom, but it could be a single boulder off to one side of the centreline of the sonar beam, or a wall projection you can't easily see, for example). In the author's opinion there is still no substitute for actually swimming to the feature being measured; one can also pick up many other pieces of important information this way as well, such as sighting unusual fossils, geological features and perhaps even hidden (and unexplored!!) extensions to the cave.

**SURVEY RECORDING/SLATES**

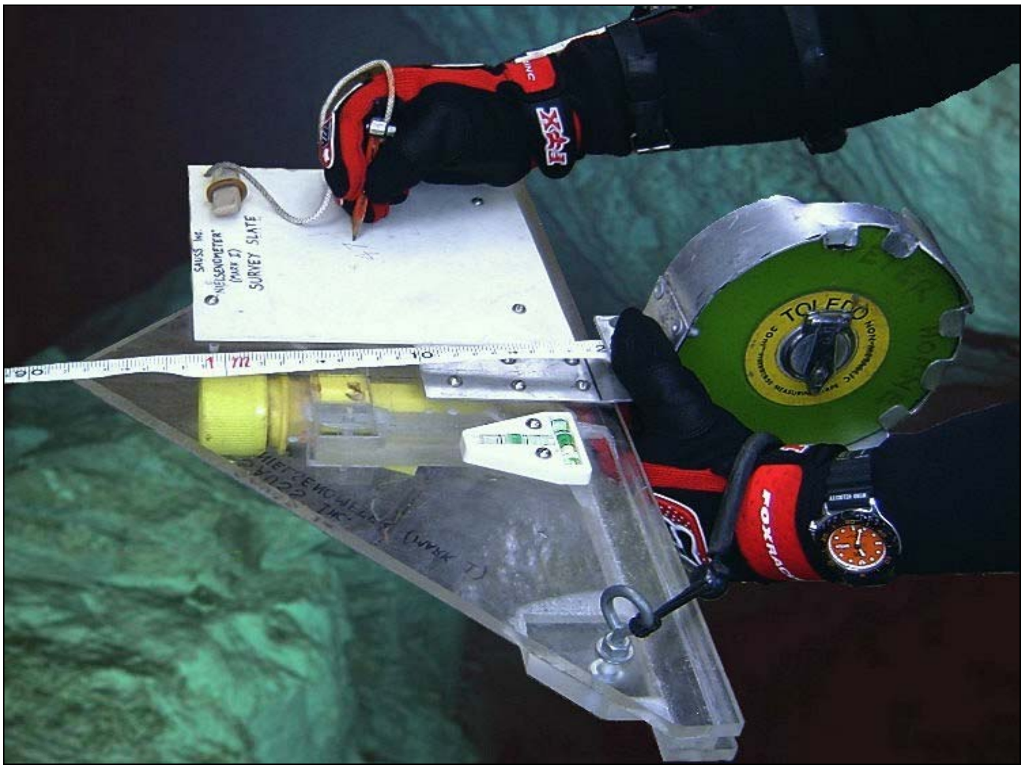
Naturally, you will need to record all of your measurements in some way, and until access to underwater computers or diver-to-diver voice communication becomes commonplace the good old underwater writing pad or divers "slate" will still play an essential role in this area. There are various forms of waterproof notebook available, but the author has found that the best form of note-paper is the type which can be torn out after each dive and kept separately with all of the other original notes. This may be a little more expensive but it prevents errors from occurring as a result of incorrect copying of survey data, a common problem if one uses non-disposable "hard" slates. Small notepads are easy to stow but they require two hands to use (not ideal when one is also trying to take compass and other readings in a dark environment), so it is advisable to set your note-pad up on a larger, hard base on which other useful instruments such as the compass may be mounted. This tool is known as a SURVEY SLATE and as long as it is not too big, it is a very useful addition to the surveyor's gear bag.




Example of a typical cave divers' recording ("survey") slate

The survey slate is also a very useful tool for taking accurate compass readings because when the compass is laid along the edge of the slate, you have in effect increased the size and stability of the lubber line and can more easily align the edge of the slate with any horizontally-laid reference line.  It's also helpful to carry a spare pencil (and notepad) in case you lose your main slate or pencil, and pencils should be of the renewable type such as the mechanical, propelling or rotating-nib models which do not require you to stop mid-survey and take out your knife to do some hurried (and potentially dangerous) underwater pencil-sharpening (which also pollutes the cave environment)!

Such survey slates can also be designed in a variety of formats which incorporate a whole host of functions such as additional bubble levels, depth gauges and thermometers, for example. One particularly useful all-in-one example was the "*Nielsenometer*" (see photo below) which the author rather frivolously named after its creator, fellow cave diving buddy Mark Nielsen.  This consisted of a large triangular slate with a special holder to accommodate a 30m fibreglass measuring tape as well as a horizontal, high-intensity narrow-beam torch for spotlighting the wall.  In use, the long edge of the slate was aligned with the survey line and balanced horizontally using inbuilt bubble-levels, so the torch-beam struck the wall at an angle of almost 90° from the survey line.  Once the spotlight hit the wall, the diver with the slate only needed to concentrate on keeping the light shining on the same spot while the second survey diver swam out from him with the tape – a technique which both improved the accuracy of the measurement and reduced the physical stress and buoyancy problems involved in trying to maintain a hovering position at considerable depth.   On the down side, the size of the Nielsenometer made it a formidable beast to handle underwater, but it still played a useful role in a number of research projects over the years!




The "Nielsenometer", a combined survey instrument for surveying large waterfilled features (photo courtesy Emi Okada)

## HELMET LIGHTS

Helmet-mounted lighting systems are a very valuable tool in underwater cave research and mapping applications. They only recently came into vogue in the wider Australian cave diving population after the mid-1980s, when some of us began to copy ideas from our European colleagues (and some visiting French cave divers) to make our underwater research and mapping work a lot easier by leaving our hands free to do other work and hold things other than bulky torches. However, bulky helmet-mounted lights can also be less than appropriate where one may encounter flowing water (in a current or whilst scootering, for example) or where you would like to actually see your favourite cave without the "blue glare-back" effect you always get in clear water from a bright torch mounted at near eye-level. Hand-held torches are also much easier to turn away from other divers so that anyone who looks your way will not have their night vision ruined by the equivalent of an oncoming freight train with its headlights on high beam!

## SURVEY TECHNIQUES – COLLECTING THE DATA

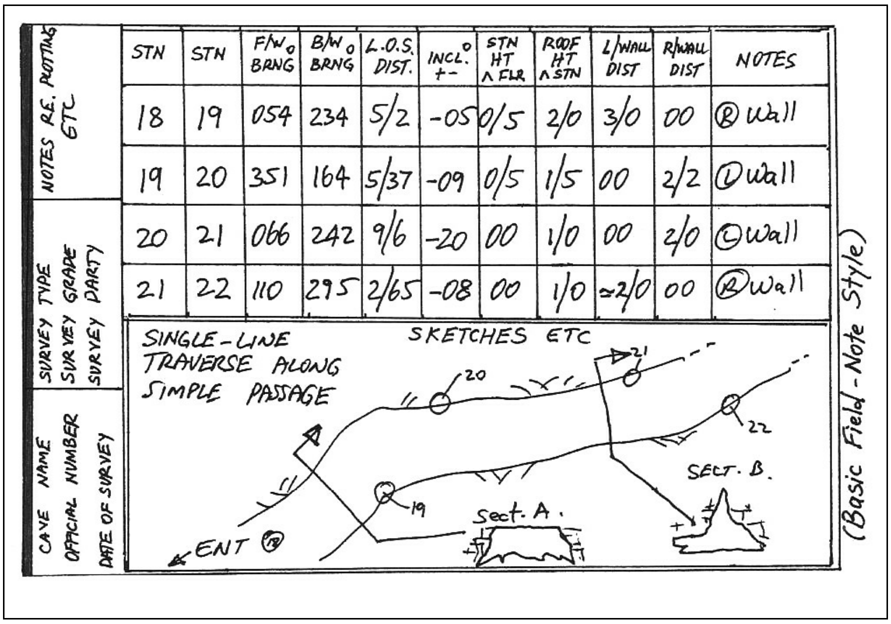
One of the greatest and most rewarding challenges of cave surveying is the choice of survey technique you finally decide to use. Some places can be very accurately mapped by using just one or two main reference lines throughout their lengths and working off this traverse to plot all of our data (either using proper offsets or just simple eye-balling estimates), but where one encounters much larger volumes such as in a sinkhole environment or where a cave passage enters a complex area or perhaps just a vast room, a single "central" reference line is of little or no real use and so we need to utilize a number of different line-placement techniques in such cases.

Recording survey information can also be a confusing and error-prone part of the survey project, because unlike in dry cave surveying, divers can’t easily ask their buddies to reconfirm measurements over a long distance or have the luxury of hours in which to carefully plot a draft map of the survey as they go along. Even the recording of numerical information in the right boxes is a major effort, especially at any depth where narcosis severely hampers one’s ability to concentrate or realise that an error has been made in the recording process; it is especially easy to "miss" a box and then just "automatically" record all of the later data in the wrong boxes beneath the mistake, particularly when it is common for divers to change the sequence in which they collect data (ceiling to floor, then moving across and doing floor before ceiling)!

The author therefore strongly recommends that divers DRAW A VERY BASIC SKETCH of their survey line on the slate and actually sketch all of the details as they are collected – for example, one can write "090/270" beside the line (to denote bearings taken in both directions) and draw "🡻5.7" next to a knot to denote the tape distance to the floor from a position on a survey line, instead of trying to work out which box you need to put the numbers in. Virtually every survey measurement can be reduced to simplified sketch-note characters like this and with practice, you will find it far easier and accurate than the more "refined" methods! The actual method of taking readings varies from dive team to dive team, and also from dive to dive depending on various factors such as the distances people must cover and the order in which features can most usefully be recorded; it might for example be most expedient for the survey diver to stay on a line while his buddy swims off to the wall directly out (at $90^{o}$) from the line.

To make floor and ceiling measurements from a station or knot on a line, it is often easy to tie a small fishing sinker to the tape and then just let it run out vertically to the floor before noting the distance and then quickly reeling it in before moving to the next station (otherwise you will again have to wait for the tape to finish its drag-arc to stabilize over the next floor-point).

Ceiling measurements are a little more tricky because we can't simply look up and see a specific spot on the ceiling if it is more than perhaps 5 metres or so away; upwelling masses of exhaust bubbles from open-circuit scuba systems also creates considerable turbulence which pushes a buoyed tape all over the place and may make it difficult or impossible to know when it has made first contact with the ceiling. For this reason a second diver should be positioned near the ceiling above the survey diver, watching slightly to one side of the rising bubbles to sight the rising buoy and guide it to the first ceiling contact point before holding it in place and waiting for the survey diver below to pull in the slack and take the measurement. The buoy is held loosely so the survey diver can then give it a tug and wind it back down, before moving on to the next station.



| STN | STN | F/W° BRNG | B/W° BRNG | L.O.S. DIST. | INCL.° +- | STN HT ^ FLR | ROOF HT ^ STN | L/WALL DIST | R/WALL DIST | NOTES |
|---|---|---|---|---|---|---|---|---|---|---|
| 18 | 19 | 054 | 234 | 5/2 | -05 | 0/5 | 2/0 | 3/0 | 00 | Ⓡ Wall |
| 19 | 20 | 351 | 164 | 5/37 | -09 | 0/5 | 1/5 | 00 | 2/2 | Ⓛ Wall |
| 20 | 21 | 066 | 242 | 9/6 | -20 | 00 | 1/0 | 00 | 2/0 | Ⓛ Wall |
| 21 | 22 | 110 | 295 | 2/65 | -08 | 00 | 1/0 | ≃2/0 | 00 | Ⓡ Wall |



Example of a typical dry-caving survey data sheet

## MAPPING TECHNIQUES AND CONSIDERATIONS

There are basically four major line-surveying techniques of use to underwater cave surveyors, namely:

- **SINGLE LINE TRAVERSE**

  Single-line traverses utilize just a single baseline from which all measurements and bearings are taken or read. It is the simplest and most time-efficient type of survey and ideal for getting a good first impression of the nature of a cave passage (and with care, often to better than 80-90% accurate anyway).
- **DUAL-BASELINE TECHNIQUE**

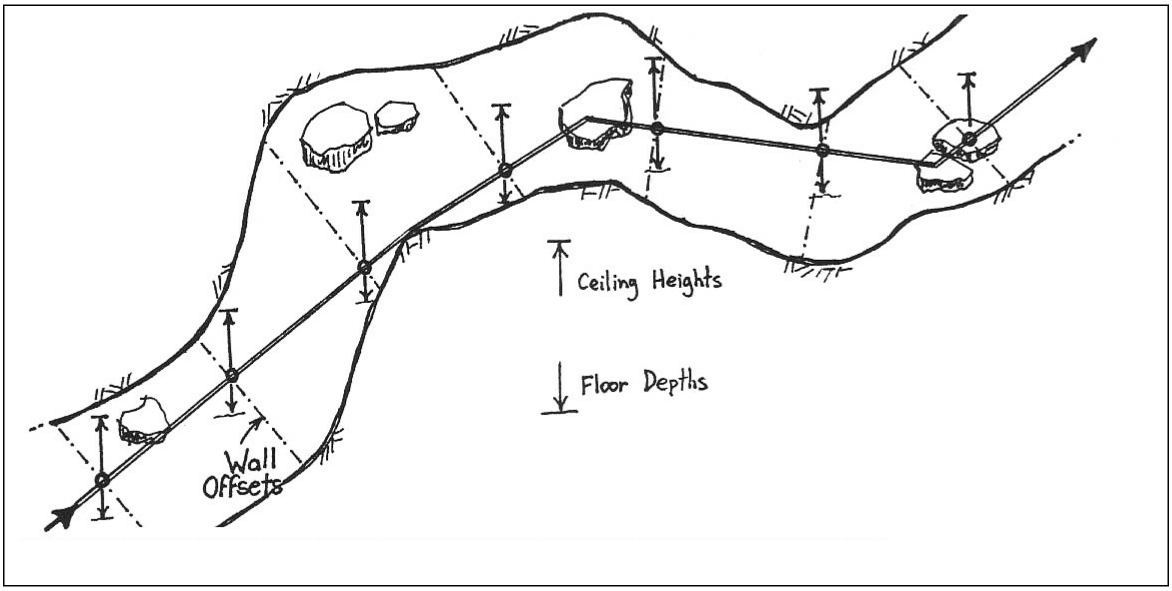
This technique uses a second survey line running roughly parallel to the first, and interconnected at various points to enable the much more accurate plotting of features between them: ideal for large horizontal passages.

- **RADIAL SURVEY TECHNIQUE**

  Effectively a cluster of "single line traverses" that are joined together at a single central radiant at a suitable reference station (e.g. a boulder in the middle of a large chamber).

- **CIRCUMLINE**

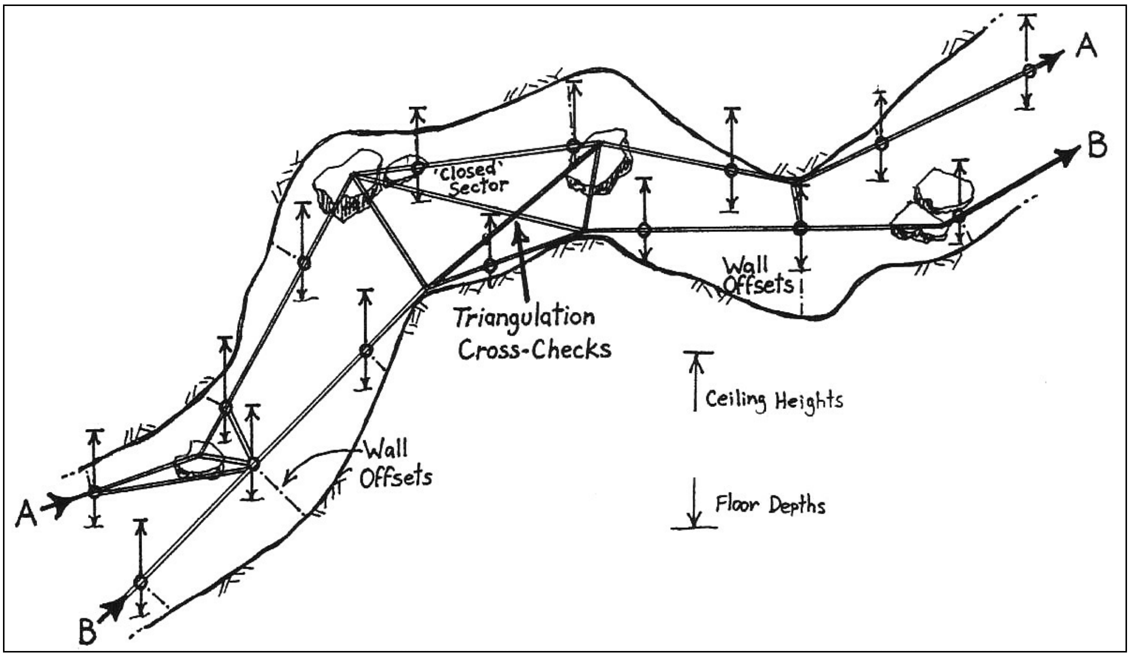
  A line running from point to point around the walls of a large cavern or wide passage and joining back to itself in a closed loop.



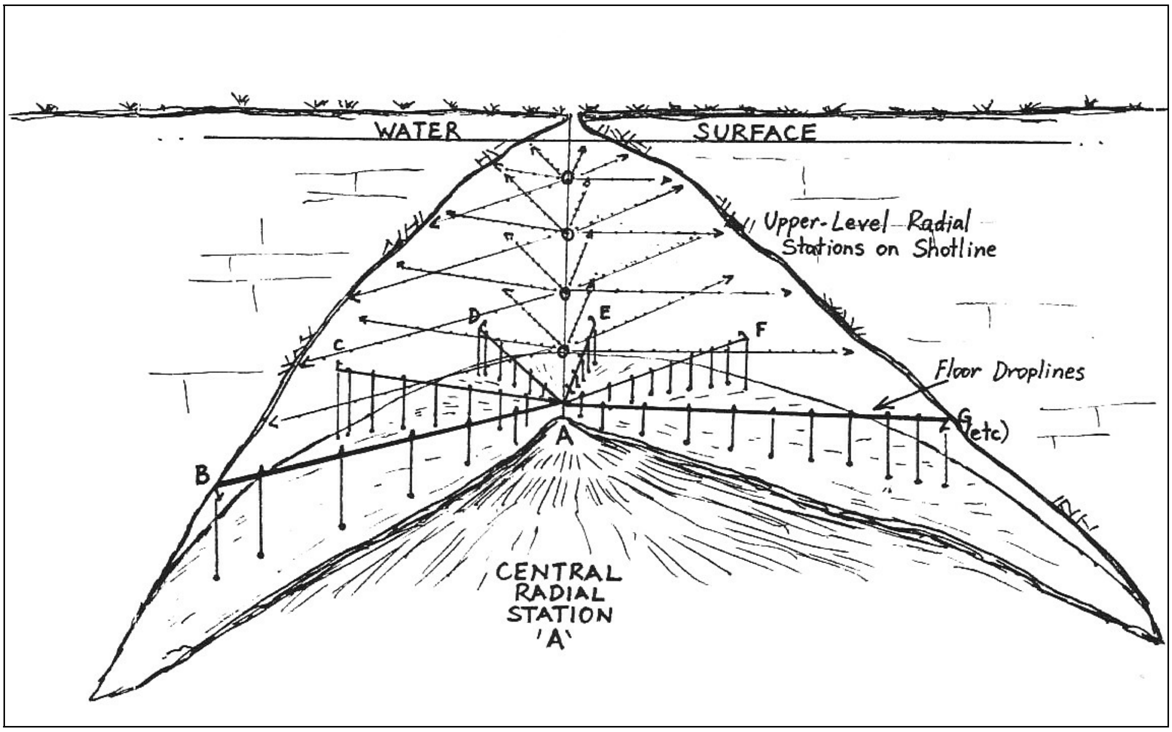

Basic **SINGLE-LINE SURVEY** technique

The ideal style for best results (if you have the patience) is by combining a series of radials, circumlines and triangulations with tapes or shorter lines to build up a very accurate network of sectors which "close" the survey properly. A very good way to start off the mapping of a large chamber is by running out a series of 4 main lines from a prominent boulder somewhere near the centre of the room to the distant walls at around 90° to each other (roughly north, east, south and west if possible), then running out another 4 lines roughly halfway between each of these (ie 45° apart), and finally interconnecting all of those radials with a single circumline run around the walls of the chamber, and measuring everything you can think of! Before you rush off into the darkness with fins flapping, though, you should also consider whether you will need to map the DRY component of a particular feature as well as the submerged regions.

In the case of our bigger sinkholes, the fence-line surrounding the entrance cenote makes for a very handy "reference line" of its own from which regular distancing can be undertaken around the perimeter to obtain a good picture of the shape of the edge of the hole. Then buoys in the main lake can be surveyed in via numerous compass checks until they are connected to part of the underwater grid or survey system.




More accurate (closed) **DUAL BASE-LINE** technique




A multi-level (open) **RADIAL SURVEY** from a single (central) reference station; the technique used in mapping "The Shaft" (5L158) by the CDAARG (1983)

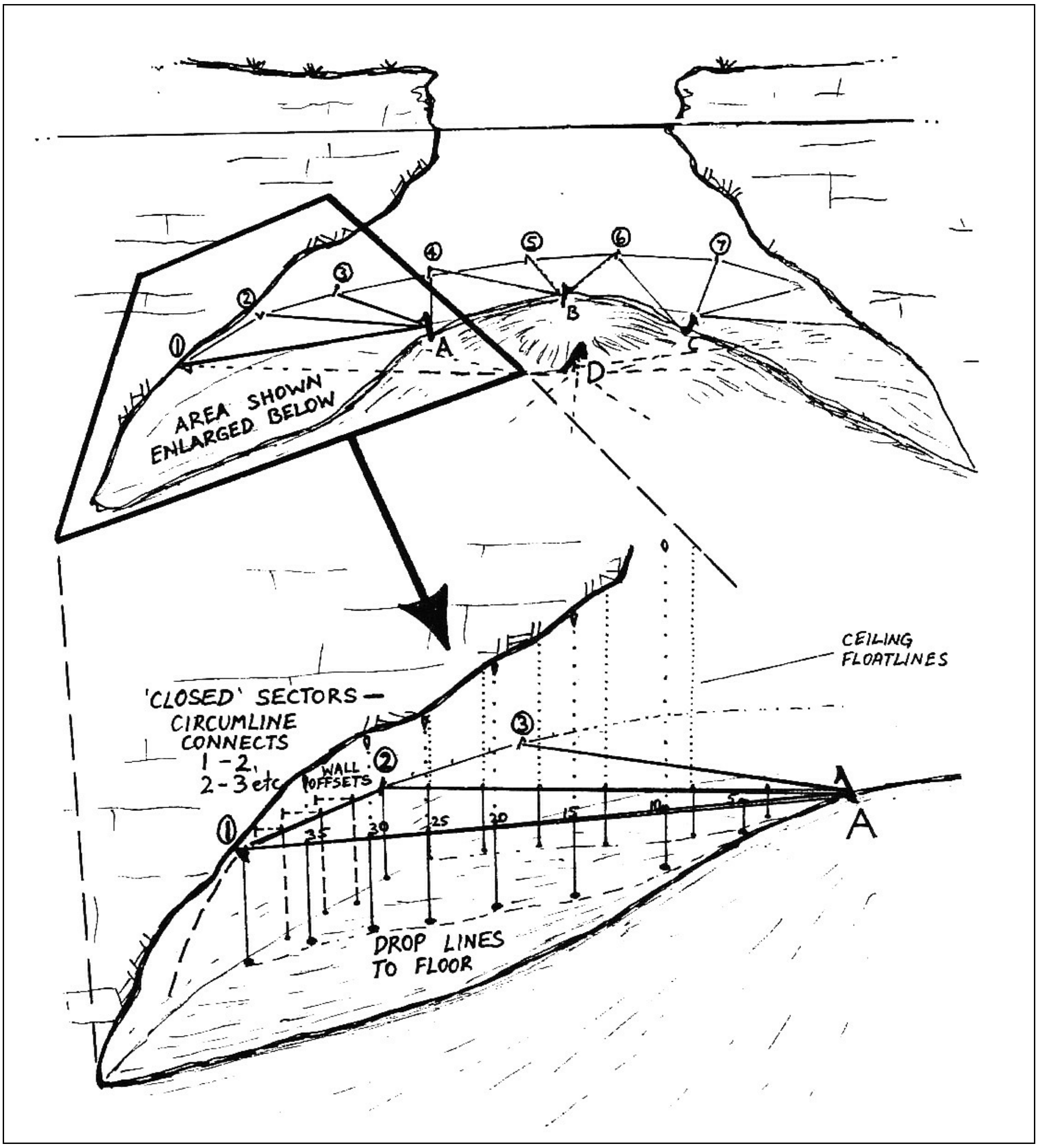
Beneath the surface, the most efficient method of laying and measuring the main reference line is for a party of two or three divers to move from rock to rock or to selected stations, placing and measuring knotted lines or fibreglass measuring tapes and taking simple FORWARD BEARINGS along the line (which should be left in place until everyone is sure that the best possible readings have been taken). However, even under the best of conditions and with years of experience under one's weightbelt, it is still very difficult to take accurate forward readings to better than about 3-5 degrees even if the compass can be read to finer increments, so every compass survey requires a number of verifying techniques and measurements to minimise errors which if left unchecked will accumulate and create a major error in the final map later; not a good idea if a farmer is relying on you to help him save money by locating the best place to punch down a bore, for example!!

To improve the accuracy of your survey, you will therefore need to find a way to check that your line is being plotted correctly, especially if additional legs of the survey are relying on earlier ones. The quickest way to get some idea of the basic accuracy of your initial forward line bearing is to turn around and read the BACKWARD bearing along the same line, and also get someone else to do the same. Then if you are unable to reconcile the two – the first bearing and the reverse – you know there is a problem that needs identifying and correcting. The need for accuracy increases the longer a survey leg is; short legs of just a few metres can have quite large bearing errors without seriously affecting the accuracy of the final map, but the error quickly increases if you are using very long survey legs.

The author has generally been quite happy with maps that are accurate to within 2 or even 3 metres when such surveying has involved the input of dozens of different volunteers with all sorts of background experience and different equipment working off perhaps a kilometre or more of reference lines at considerable depth! The good news is that once you have finally set up an accurately-known and plotted traverse (see information about survey "closures" below), you can in most instances then just rely on depth and distance measurements and further "loop closures" to build your map up by a form of simple triangulation. At least divers can simply "fly" from floor to ceiling and read gauges, where our dry caving counterparts need to worry about such things as scaling poles, hydrogen balloons and 'clino/vertical angle measurements!

Naturally, where dry caving surveyors can often use surface features, voice contact and radio direction-finding (RDF) systems to very accurately locate caverns etc on the surface, cave divers don't have such luxuries as time (or air!), voice communication and dry-survey cross-checks at their disposal, so we need to work out the accuracy of our underwater surveys by taking copious measurements and using cross-measurements or buoys etc to verify key compass bearings. The best way to do this is by adding other lines which are plotted relative to the single main line, and if you want to KNOW that your survey is anywhere near accurate, you definitely need to close it in some way. Offset measurements to the walls, ceiling and floor can be taken from stations along any survey base-line for extra detail, but if the survey is still "open" such data may have little value. The dual-baseline system is especially good for getting closure in wide passages, and in the case of mapping large chambers, a combination of techniques such as a closed-loop traverse (circumline) and the radius method can be very good for achieving a high level of accuracy. If you are surveying a passage system using the simple single baseline method, the first thing to do is to install your reference line correctly.

This line should be pre-marked with the required distances (knots or whatever) and connected to a surface reference station as well as being tied or pegged to various useful stations near the centre of the passage. In many instances it is also preferable to run the line from place to place along the floor or a suitable wall at around the same depth; you can also usually find more suitable natural tie-offs (or drop weights) along the bottom than on the ceiling or walls, thereby minimizing damage to the feature. Ceiling-runners can easily get snagged by a tank valve, but they are preferable to mid-water lines which run from side to side, causing cross-over entanglement problems for the dive team!



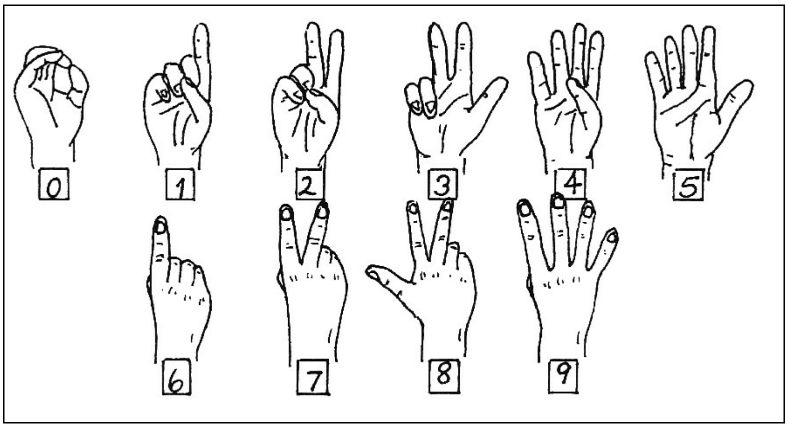

A (closed) **RADIAL SURVEY** involving numerous wall stations and diverging rays at the same level, and offsets from those rays ("Ten-Eighty Sinkhole" Project, SAUSS Inc.)

Floor, wall and ceiling offsets (i.e. lines run out at approximately 90 degrees from baseline stations) provide the information for "fleshing out" the "skeleton" that the baselines form in a cave survey. If the passage is fairly small with less than around 3 metres clearance in any direction, simply ascending or descending directly over or beneath relevant line markers will provide information of considerable accuracy. However, where the ceiling or floor distance is greater than this, or in cases where visibility is very poor or the bottom depths are considerable, divers should obtain distance readings using weighted or buoyed tapes as required. If the survey is being done over a fairly long period of time and in areas where the height of the regional water-table fluctuates by more than a metre seasonally (as it does in some areas of the lower South-East), you will also need to record relative water heights from a surface reference station every time you first arrive at the site, otherwise you will find more errors creeping into measurements of smaller (especially horizontal) areas in the cave.

A brief point also about underwater tape measurements here – DON’T run out a great length of tape and then haul it around with you as you swim in a circle! The amount of drag experienced is fairly phenomenal if it is used this way, and apart from getting snagged on unseen tree stumps, boulders and the like, you will stretch the tape thereby creating even more errors in your work. Likewise, use only small weights or buoys for vertical measurements if you want to minimize stretch factors; it is amazing how hard it can be to wind in a tape which has been too heavily weighted (small fishing sinkers are best), or overly-buoyed (again, a small fishing float has been found to be ideal).

Where distances need to be conveyed to other divers, it is useful to communicate by way of using hand signals. When the first edition of this book was prepared there was no such standardisation of diving hand signals (although this is rather strange in view of the fact that people with hearing disabilities had already been using sign language for words and numbers for a long time), so the author recommended the use of hand signals that were based on those appearing in the book "Basic Underwater Cave Surveying" by John Burge (USA) with just some minor variations such as the way of using the thumb and next 2 fingers to denote "3" and "8" instead of the three middle fingers because the formation of the latter is physically impossible for many people and it is also not as useful as the author’s preferred technique which leaves the last 2 fingers free to act as gripping or hooking points for that odd loose compass or measuring tape. It's also important to note that the Deaf numbering symbols are very different to the system which is currently being used by the cave diving community and some of their signals can erroneously be interpreted to mean something else ("7" for instance can mean "go over there" underwater).

Hand Signals commonly used by underwater cave surveyors (after Burge, 1987)



There are at least a few situations where cave divers can use their environment in a beneficial manner where their dry counterparts cannot. For example, we can simply glide over massive rockpiles to measure the depth at the ceiling where dry cavers would need to use rock-climbing equipment and hydrogen-filled balloons. It is still good to know of such techniques because you might need to become a "dry" cave surveyor if you should stumble across a large air chamber, as we found during the early explorations of Engelbrechts Cave in Mount Gambier. The important thing you will need to remember, though, is to ensure that you correct for slope angles in measured distances if one station is deeper than another; just because you ran out 37 metres of line doesn't mean that this is the horizontal distance from the surface station to the reference peg.

You will still need to find out its apparent horizontal (or 'PLAN') distance by either referring to a conversion graph, or using the formula H = Square Root of $S^2$-$D^2$, where the HORIZONTAL distance "H" is the SQUARE ROOT of the SURVEYED distance ("S") SQUARED minus the DIFFERENCE in DEPTH ("D") SQUARED, or, much more simply but less accurately, by drawing your plot to scale on graph paper (the author's favourite, being a non-mathematic type and a person who enjoys seeing the map coming together with every pencil-stroke!).

Underwater surveyors also need to remember to keep to their planned dives and record every aspect of their survey to ensure that aspects are not forgotten; there is no point in a second dive team trying to start surveying along a fixed line if that line has not been installed properly by the first team, or if people forget to count knots (or fail to realize one is missing!) along an overly-long baseline at depth. There are also different ways of collecting the data; some teams might prefer to draw wall details to scale *in situ* like most dry cave surveyors, while others wish to rely more on their memories, sketches and artistic skills, but again, practice is probably the best way for groups of divers to learn their preferred styles and lengthy discussions about the various styles are unfortunately beyond the scope of this publication.

When it comes to finally drawing up the map, you can again choose one of several styles, from the "technically correct" to the "mickey-mouse but useful and easy to follow" variety. The author personally found his eagerness for surveying rapidly fading away after spending hundreds of hours plodding through the use of 'correct' drafting gear to plot even a simple map with its North rose, magnetic deviation, bar scales, standard symbols and the like on a sheet of film, so nowadays he neatly plots the survey data onto a large sheet of graph paper (at its final scale and aligned to MAGNETIC north) in pencil before inking it in and then tracing the final product. This results in a map which is just as accurate as any other version and much less frustrating to produce, and you consequently can put a lot more effort into getting on with other similar projects. The wonder of modern microfilm techniques also eliminates the need to use translucent, brittle drafting film, which is awkward to handle and relatively difficult to correct.

And then, of course, there is the advent of the modern COMPUTER … but this aspect is beyond the scope of this little publication!…

# Environmental Studies

In dry-caving circles, studies involving the cave environments (air temperature and movement etc) are often as important as surveys and other studies. Because our medium is (usually) cold, clear fresh water, studies of cave divers' "environments" necessarily incorporates various hydrological aspects. To simplify discussion, and because it refers to one's immediate surroundings, the word "environment" is used here to describe the body of water in which we dive.

The scientific study of the environment of Mount Gambier's water-filled cave features has to date been minimal and fragmentary in nature. While a couple of fairly comprehensive recording projects have been undertaken by various individuals, the vast majority of related underwater research has involved once-off projects which resulted in new, "raw" data being catalogued for comparison with (possible) later studies. Before cave divers existed, research into the physical nature of the underwater environment was naturally restricted to what could be readily obtained from the surface. This meant that observations of the environment were limited to the vertically-accessible area beneath the interested parties; sampling containers and temperature probes which were designed for use from the surface were of absolutely no use once the floor of a cave sloped back under the walls. Nowadays, with careful planning and even more careful collecting techniques, divers can obtain invaluable data about the true cave environment beyond the daylight zone. Standard equipment can be used in some cases, but divers have also been forced to experiment with other techniques in their quest for collecting interesting comparative data.

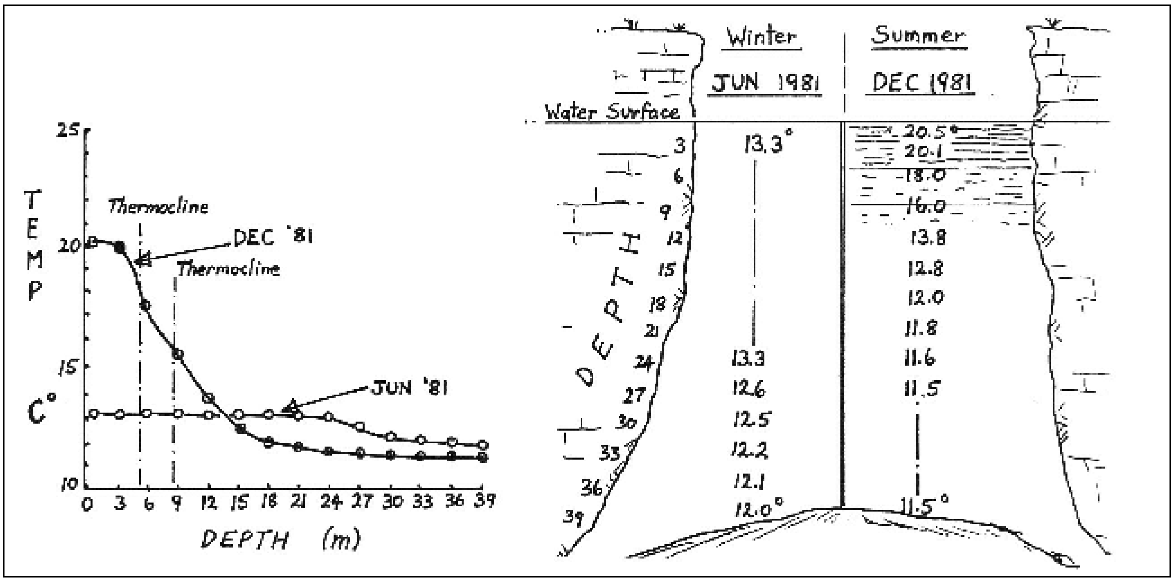
Underwater environmental research generally involves PHYSICAL studies (water temperature, visibility/turbidity, flow rates and movement of the water body and pollutants etc), CHEMICAL studies (salinity, acidity, dissolved oxygen levels, pesticides, nitrates, heavy metals and other contaminants etc), and BIOLOGICAL studies (distribution and quantity of zooplankton and phytoplankton, etc). From the cave divers' point of view, there are basically really only TWO aspects; IN-WATER observational recording and sampling work, and SURFACE research involving laboratory analyses which are beyond the scope of this publication. The following sections provide some insight into how you might best utilize your cave diving skills to observe, record and sample the underwater cave environment.

**TEMPERATURE STUDIES**

While the temperature of the water in many caves generally changes very little from place to place (especially in those caves which never receive direct sunlight), thermal stratification of the water in the larger, more open sinkholes is a significant phenomenon which can affect underwater visibility and divers' immersion times and decompression planning. The first attempts to study seasonal water temperature changes in the larger sinkholes (known to the author) occurred in the early 1980s, when the author and his friends undertook a series of data-gathering dives over a one-year period in four major features (namely, "One Tree", "The Black Hole", "Ten-Eighty" and "Ela Elap"). Descending slowly and taking care not to use our fins to disturb the water below us, the dive team used calibrated mercury thermometers (mounted on survey slates or held in protective metal sheaths) to measure the drop in temperature at regular intervals (every 3 metres) or whenever an obvious thermocline was encountered usually when the temperature variation was more than about one degree.

This project verified our suspicions that the sinkholes were indeed much warmer on the surface during the summer months than during winter (refer to the representative sketch and graph showing Ela Elap's stratigrafy), and it also highlighted the need for careful recording and cross-checking of data.

Dual thermometers were used for calibration purposes, and dramatically different readings were obtained during ASCENT, after divers' exhaust bubbles had lifted a lot of very cold water into the shallows, causing unwanted mixing and therefore scrambled recordings, showing how important it was for all readings (and other observations or sample-collecting, for that matter) to be taken ONLY during DESCENT.




Ela-Elap Sinkhole's Seasonal Temperature Fluctuations (P. Horne 1981-82 data)

There is no doubt in the author's mind that the proper use underwater of hand-held mercury thermometers results in very accurate and useful measurements of considerable importance. The abovementioned studies confirmed that, despite unremitting scepticism by at least one well-known speleologist about divers' claims that some sites are colder than "his" absolute minimum temperature of around 15 degrees C (in fact, as cold as 11 degrees in at least one site, Ela Elap), cave divers were able to repeatedly verify the accuracy of the above techniques using 'dissolved-oxygen meter' thermocouple probes and other temperature-measuring devices. So, until a more sensitive, waterproof and pressure-proof electronic device becomes cheaply available, mercury thermometers will continue to be important tools for underwater speleologists.

**POINTS FOR CONSIDERATION:**

- Purchase a large, easy-to-read mercury thermometer from a scientific supply shop and check its calibration BEFORE you take it to the cave.

- Make sure that it is mounted on a strong piece of plastic board or slate, or housed in a suitable metallic container (preferably one which does NOT affect compass readings) with the sensing bulb exposed. Also protect it as much as possible ... remember that mercury is particularly poisonous!

- Do not record the temperature of the surface water until the thermometer has stabilized - it might be hotter than the air temperature due to exposure to direct sunlight.

- Only take your readings during your DESCENT ... the passage of your body and the uplift of your exhaust bubbles will cause massive mixing effects in shallower regions, so you will only have ONE CHANCE to record temperature variations accurately!

- Descend SMOOTHLY in a face-down, horizontal position with your ARMS BELOW AND IN FRONT OF YOU so that you can observe and record temperature changes without disturbing the water body below you. Try to descend slowly and use your buoyancy control device regularly (NOT YOUR FINS OR HANDS!!) to control your descent speed (or to stop momentarily while recording observations).

- If you need to use your fins or hands for any reason, discard readings you may have recorded at the disturbed site and glide into undisturbed water HORIZONTALLY to take new readings.

- If you anticipate moving through areas of low visibility, make sure that you carry a suitable tether-line so that you can clip onto your buddy's main guideline (or a vertical shotline) if necessary. This will leave you with both hands free to write down readings while keeping you in touch with the line. You will also need to ensure that your buddy and other divers do not accidentally mix the water layers beneath you, and if YOU are the lead diver with the reel, keep the reel IN YOUR HAND and ALWAYS keep an eye on the line or tape – otherwise you might find yourself getting into all sorts of nasty entanglement predicaments!

- WRITE UP your results so that others can learn about your favourite sinkhole's weird and wonderful thermal stratification!

## VISIBILITY STUDIES

As every cave diver knows, the clarity of the underwater cave environment can fluctuate considerably during a dive. The contrast is remarkable; you might be enjoying optimum visibility where you can recognise individual divers swimming much more than 50m away when suddenly, as a result of a couple of careless fin-strokes, you may find yourself totally engulfed in impenetrable blackness as you are swallowed up by a silent, rapidly-expanding mass of billowing silt.

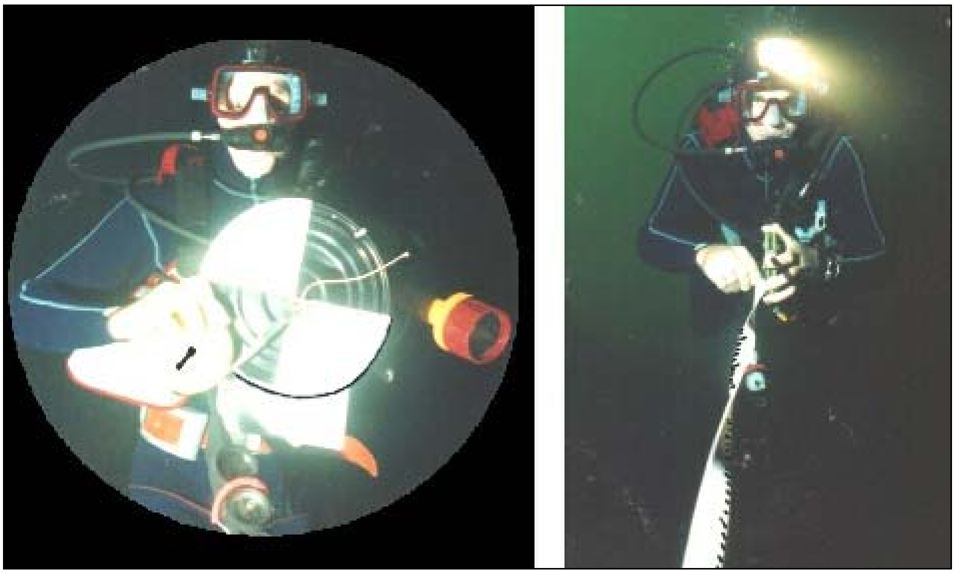
In the larger, more open sinkholes, the visibility of the water also changes periodically for reasons which as yet have not been clearly identified (although they are probably related to algae and plankton growth and chemical reactions in association with thermal stratification; see section above). During the warmer months, for example, the shallower regions of the more popular sinkholes in the Mount Gambier region take on a murky, yellowish-green hue, and often, millions of tiny planktonic life-forms and insect larvae can be seen swarming around, diffusing the light and lowering overall visibility. Since water clarity is obviously of importance to cave divers, and in view of its role in biospeleological and environmental spheres, studies of visibility changes in waterfilled caves may ultimately prove to be of enormous importance.

While no single standard can be used to define the overall 'visibility' of a water body (due to the highly-variable nature of individual particles from site to site and the way that they scatter or absorb light), scientists can use several different methods to obtain useful comparative data. To study samples in a laboratory environment, particles of different sizes can be filtered out of a known quantity of water and carefully analysed using microscopy or other methods, and light-measuring devices such as the "*nephelometer*" (not to be confused with the aforementioned "nielsenometer"!) can be used to obtain data about the general turbidity of a given water sample.

These devices work by measuring the amount of light which is reflected at 90 degrees to an incoming beam by suspended particles; the more reflected light, the dirtier the water (earlier versions of this technique include the *Jackson Tube Meter*, which was a clear glass cylinder through which a candle flame was viewed until it lost its sharpness). Researchers hoping to get some idea of the amount of scattering in calm bodies of open water can use a "*surface scatter nephelometer*", beaming light onto the surface at an angle of 45 degrees and measuring the amount of reflected light emerging at 90 degrees; yet another technique, used principally overseas, involves shining light through a sample and measuring how much comes out the other side of the container.

The most common device for obtaining relative readings 'in the field' is the "*Secchi disk*" (pronounced SECKEE), a flat plate about 25 centimetres in diameter which is usually marked up in high-contrast black-and-white quadrants (but sometimes all-white) that is usually lowered from the surface until it disappears from view. Since light has to travel both TO and FROM the Secchi disk before being viewed by the observer, it is influenced by such things as the colour of the water and its extinction coefficient, the type of particle in solution and/or suspension, and the angle of the sun and the amount of ambient light, so Secchi distances cannot be simply related to all other water bodies.

Because most of these laboratory-based systems obviously do not readily lend themselves to underwater applications, the author along with scientific adviser Paul Harvey developed the idea of utilizing Secchi disks UNDERWATER to establish a basic standard for measuring relative HORIZONTAL visibility distances during a planned detailed study of Mount Gambier's Blue Lake in 1985. Several Secchi disks were borrowed from the University of Adelaide's Zoology Department and assessed for their possible use in this application, and the author was delighted to find that with minimal training, almost any dive team could accurately record very useful distancing data at various depths over a range of visibility up to about 25 metres. The technique was subsequently modified and refined and it has now been used extensively in a number of other sinkhole projects, notably during the SAUSS Inc. Ten-Eighty Sinkhole and Blue Lake studies and the CDAA's Black Hole project.



Using a Secchi Disk to Record Visibility Differences

The underwater technique involves attaching the end of a 30-metre fibreglass measuring tape to the centre of a disk, and while a "disk-diver" holds the disk in an upright position, like a shield, the "reel diver" swims off at the same depth until the disk disappears, usually after the disk-diver's body has faded from view. The reel diver then takes up the slack in the tape and looks back along it as he reels in, recording the distance shown on the tape before heading down to the next level with the disk diver. Experience has shown that the maximum useful range of this technique is about 20 metres because the differences between the divers' depths tended to affect the accuracy of the readings beyond that distance. The technique is so simple that "Secchi-dives" can be performed easily by any competent diver who has standard cave diving buoyancy-control and equipment-handling skills.

Bearing in mind the need to avoid disturbing water layers below them, divers conducting Secchi-dives can obtain quite accurate results if they follow a couple of basic rules and recommendations:-

- Draw up your recording sheet before you get into the water so that you won't waste any time during the dive, and set up a vertical shotline if possible so that the diver holding the disk will have an accurate stationary reference line for each reading (preferably in 2 or 3-metre increments, but can be more or less if such is appropriate).

- Ensure that the "reel diver" is using an accurate depth gauge which has been checked against the shotline or his companion's gauges.

- Do a vertical disk reading from both above and at the surface BEFORE the dive, to obtain comparative readings.

- Take your first horizontal readings from half a metre below the surface with the sun both BEHIND and IN FRONT of you (and sideways as well, if time and interest allows!) if you are diving more than about two hours either side of midday, for comparison (you might want to do this at depth as well, but generally the ambient light is fairly evenly distributed by the time you descend 10 metres or so).

- Taking the readings: using careful buoyancy control (i.e. not your feet) and carefully monitoring your (accurate!) depth gauge, slowly descend to your reference level and clearly indicate "STOP" to each other when you arrive. After confirming that you are both at the same depth, the "disk diver" holds the disk upright (keeping his mind on the task at hand and NOT just "gawking around") while the "reel diver" swims away from him at the same depth, looking over his shoulder (or swimming backwards) until the disk disappears COMPLETELY from view. The "reel diver" then takes in the slack and peers along the tape as he slowly reels in until the barest outline of the disk (i.e., the pattern on its face) becomes visible. The "reel diver" then carefully moves back out of sight again and then slowly moves forward to confirm the earlier sighting, and it is at this point that the "reel diver" records the distance on his slate (and checks the depth again) before he heads back towards the "disk diver" until both divers can see each other clearly. You should then both signal "OK" and slowly descend to the next level, taking care not to drag the tape down too fast as friction will cause it to lag behind for a few seconds. Upon reaching the next reference level, confirm your depths again and repeat the above.

- Always ensure that you are close enough to communicate effectively during your descent while ensuring that unnecessary water-mixing and expenditure of swimming energy are minimized.

The results of various visibility observation projects has revealed important relationships between the plankton mass, water temperatures and dissolved-oxygen levels, thereby verifying the value of such underwater visibility-recording work. As has been mentioned previously, Secchi-dives have been utilized in only a few research projects to date (including four Blue Lake studies and an investigation of the sinkholes on "Barnoolut Estate"), so there is obviously a lot of visibility research work still waiting to be done.

**WATER SAMPLING STUDIES**

Water sampling is an important part of environmental research, as it is the water body which transports pollution or holds material in solution or suspension. Like other underwater research work, divers need to be aware of possible negative influences and considerable care needs to be taken during the collecting work. For this reason, watersamplers should consult with experienced specialists with hydrological or similar qualifications before grabbing an empty jam jar and filling it with mud!

Basically, water samples need to be collected in such a manner as to minimize unwanted contamination of the sample. Experience has shown that the following points need to be considered:-

- Ensure that you have obtained PROPERLY-STERILIZED CONTAINERS of the right size and material for the job, usually plastic laboratory bottles for most studies, but sometimes 1 or 2-litre glass bottles for special (e.g. pesticide) work. Because nitrate, chemical and bacterial levels change dramatically if the temperature of a water sample changes or if it is left in a bottle for a while, you will also need to ensure that you have suitable facilities for properly "fixing" and storing the samples.
- Fill all of your sample bottles with clean water just beneath the surface prior to commencing your descent; otherwise, apart from possibly being excessively buoyant and losing all of the bottles as soon as you open your catch-bag, you may find that you are unable to remove the lids on the softer bottles which have now been so crushed by the water pressure that they look like potato crisps! More seriously, if you are using a sealed GLASS container of some sort, there is a very HIGH risk of incurring blast injuries, or even simple lacerations, from the violent implosion of a sturdy sealed bottle, particularly if you are at depth or in a confined restriction. (The water is "pumped out" by inserting compressed air from the scuba cylinder at the sampling location – see below).
- Try to ensure that your sample bottles are CLEARLY marked pre-dive so that you can easily identify them in your catch-bag ... this is much easier than grabbing bottles arbitrarily, getting the samples and then being forced to record each sample on your slate before descending to the next sampling site.
- Always carry at least one SPARE bottle for unexpected, additional samples, or to replace sampling bottles which mysteriously disappear from time to time – and try to remember to look along the ceiling during your return swim. Underwater cave researchers, of all people, need to show that they are "conservation-minded"!
- As with the temperature studies, make sure that you always collect your samples from progressively deeper (or more distant) sites because divers' bodies will cause major mixing effects which will ruin shallower samples. If you miss a site, you might try getting similar samples from the 'other side' of the cave if it is large, but if you are hoping to get the "missed" sample during your ascent, FORGET IT! Remember that the large, swirling vortices of your exhaust air bubbles will lift cold, deeper water up into the shallows, so upper-level samples will be severely contaminated with lower-level water. Bad luck about that, but until we all get rebreathers!...
- Just before descending to or arriving at a sampling site, remove the appropriate bottle from your catch-bag, tip it upside-down and fill it with pure, dry air from your regulator (remembering that it is at such times that bottles tend to rocket to the surface if they are not held securely). Flush it once and fill it again, then hold it forward and below your body. As you approach the sampling site, turn it upright and pump the air out of it so that it quickly fills with 'local' water. Invert it again and refill it with air and water TWICE more. This is a standard sampling and bottle-cleansing procedure and it is an essential part of ensuring that you are getting a truly representative sample from each location.

Try to keep moving slowly forward as you do this; do NOT stop in one place while you are filling the bottle because disturbed debris or other material might waft around you and contaminate the sample, and in the case of bacteriological and other specialised sampling, even GREATER care needs to be taken because organisms or other influencing factors might find their ways into the container from your own body or equipment.

- As soon as you have refilled the bottle for the third and final time and ensured that there are NO AIR BUBBLES remaining in the bottle, replace the lid SECURELY and place it back in the catch-bag. Then grab another sampling bottle and move to the next sampling location, repeating the steps described above.

All samples should ideally be properly treated, logged and stored as soon as you have finished the dive. Do not let them sit in the sun and try to keep them cool (but not frozen). ALL water samples need to reach the laboratory quickly; some can take a few days, but others need to be received within mere hours, so you will need to find out just how much time you will have for each sampling program.

Because water analyses can also be very expensive, you will need to ensure that you know what you are looking for and have financial or other support to get the tests done. Parameters of interest or value to landowners and researchers include pH (acidity) and salinity (total dissolved solids or TDS) levels, potentially dangerous nitrates ($NO_3$) and metals. Studies involving pesticides, dioxins and the like are much more difficult (and therefore much more expensive) by comparison, and expert advice MUST be sought before such aspects are investigated!

# Other Aspects

Interested divers need to record EVERYTHING they observe if non-diving specialists are to gain any useful insight into "our" world. Because the colour and visibility of the water is critically affected by algal blooms, temperature variations and planktonic masses, we need to build up a much more comprehensive library of such observations if non-diving specialists hope to be able to work out interrelationships between these factors and other aspects like the oxygenation of the water and precipitation rates. Fascinating correlations between dissolved-oxygen levels, temperature and planktonic migrations have only recently been implied from the various Blue Lake studies, so who knows WHAT is waiting to be discovered during the next few years?

**BIOSPELEOLOGY**

THE word "biospeleology" was coined not too long ago to identify the scientific study of cave life-forms, and numerous studies have been done (mostly overseas) involving the unique flora and fauna which often inhabit air-filled caves. UNDERWATER biospeleological studies, however, have only recently "scratched the surface", so to speak, but already, many fascinating and scientifically-important discoveries have been made.

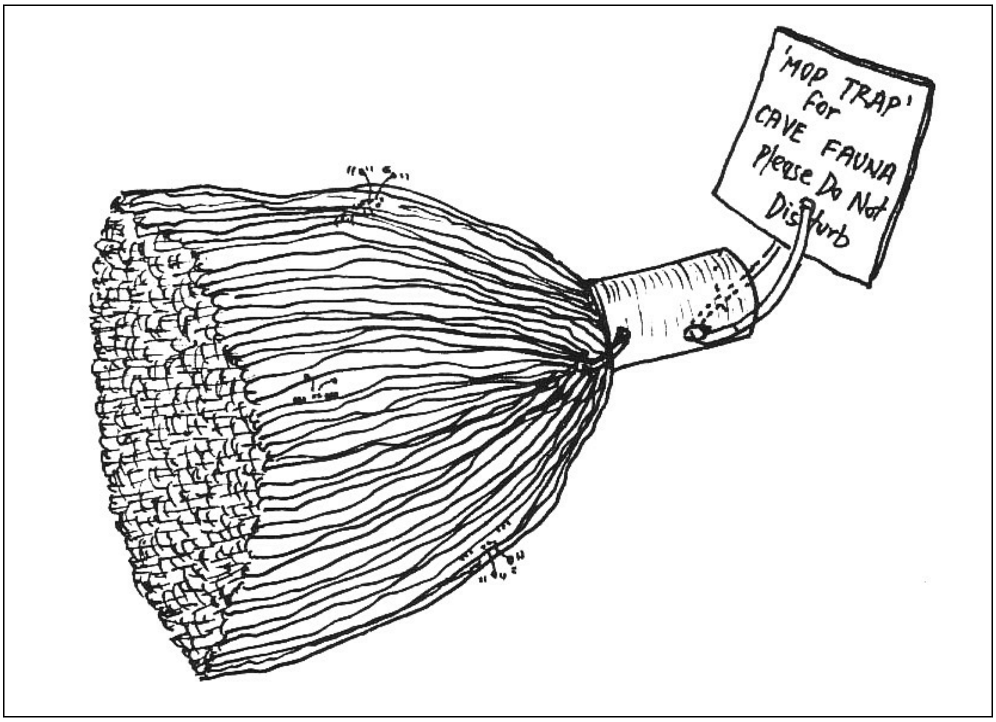
Before we can hope to understand the complex and unique ecological structure of various underwater cave environments, we must first set up a comprehensive database identifying the many plants and animals which are found there. As unbelievable as it might sound, very little recording of such cave flora and fauna has been done; attempts to trap and record the often hard-to-find creatures which often live in the silt or under boulders in waterfilled caves have necessarily been sporadic and far from thorough (as usual!), and the minimal involvement of biologically-qualified personnel has meant that this task has been largely left to keen but unqualified amateurs. The few interesting discoveries made to date involve creatures which even "laymen" could see were OBVIOUSLY unusual, and there is no doubt in the author's mind that there are still a lot of significant discoveries to be made right under our noses.

In view of this sparse collection of biological knowledge, cave divers can really help the scientific community if they take the trouble to carefully observe and record what they see, especially if creatures happen to be swimming about! Photographs are obviously very important tools here, but even a reasonable description would be enough to initiate further observation-dives if such were warranted. Initial collecting should be kept to an absolute minimum because cave species are usually extremely fragile and very limited in number, and you should ONLY collect representative specimens if you have a suitable means of preserving them (e.g., formalin, alcohol or freezer) AND if you know WHO can readily assess them. And of course, you must always consider where you are and whether you are even allowed to disturb a cave’s contents at all; certainly, even if you saw a solid gold crayfish in Piccaninnie Ponds Conservation Park, you would definitely not be permitted to touch it let alone catch and preserve it!!

Once the decision has been made to collect specimens, suitable equipment must be obtained if your efforts are to be rewarded, particularly if the specimens are very fragile (e.g., freshwater sponges etc). It is much better to set some sort of "trap" for mobile cave fauna because this does not require cave-disturbing techniques such as running around with containers or hand-nets (although these also have their place). Traps obviously need to collect specimens intact and unharmed, and because the vast majority of free-swimming fauna are extremely small, very fine mesh has to be used. The type and size of trap is strongly influenced by both the type of animal being sought and the nature of the cave; for instance, it would be undesirable to use large traps in small, silty caves which are unlikely to have large populations. There are many types of trap (especially if one considers home-made jobs!) but the author prefers to use "mop traps" and variations of yabbie-pot "inverted-cone traps" for most of his work these days.

"Mop traps" are exactly that: mop heads which can currently be purchased for several dollars at any hardware store. These fine cotton masses make ideal "eatery-homes" for smaller cave creatures (especially amphipods) which quickly locate and move into them if they are anchored on the bottom. After several months (but preferably no longer than a year because it will begin to disintegrate), the trap can be recovered intact (in a large plastic bag) and preserved in accordance with the research scientist's requirements. Most preserving is done using a solution of about 5-10% formalin or 75% alcohol, but some creatures (such as certain molluscs which need to be "relaxed" first) require more specialised preserving techniques. After being carefully transported to the research facility, the mop-head is then dissected strand by strand and scrutinized for its biological contents.

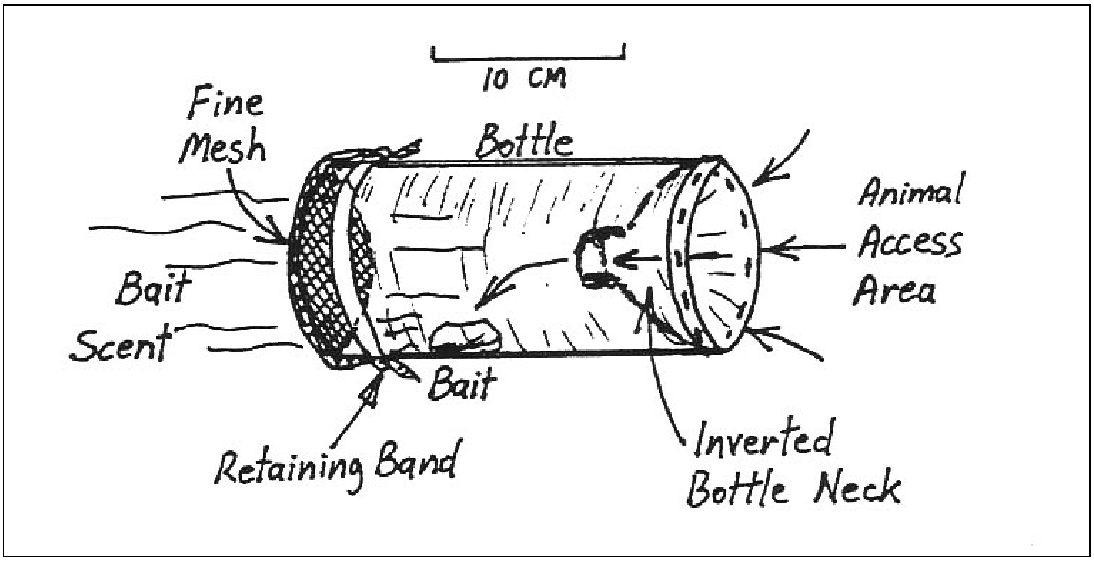
This simple form of trap has been successfully used in quite a few caves now, and many important specimens of blind amphipods and syncarids have been obtained (thanks to Wolfgang Zeidler, former Curator of Higher Marine Invertebrates at the South Australian Museum, who originally suggested the idea to the author in the 1980s).



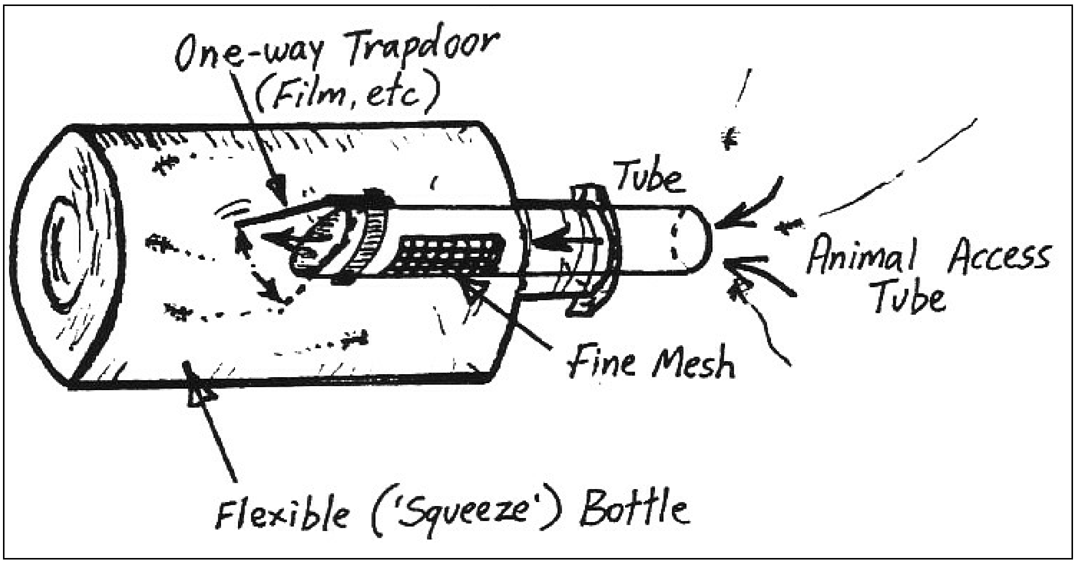

Sketch of a typical invertebrate "Mop Trap"

"Inverted-cone traps" have long been used to catch crayfish, shrimps and other crustaceans, but smaller 'cave-critter' versions have only recently been used by cave divers in Australia (thanks to the initiative of Dr Thomas Iliffe, who proved their usefulness when he brought some simple traps to Australia from Bermuda in 1988). These traps are simply plastic bottles which have had their bottoms cut out and their necks cut off and reversed, forming an inward-facing cone which readily admits creatures but which makes it difficult for them to escape. By covering the open bottom with a fine removable mesh, animals cannot escape although the scent of suitable bait (such as crushed land snails) will flow through and attract other creatures. Another style of hand-held collecting bottle called a "*Sket bottle*" (designed by Boris Sket and introduced to our cave diving community by noted American underwater speleologist, Dr Jeff Bozanic, during his visit of early 1990) will undoubtedly be used extensively in the next few years to collect more elusive individuals.

Free-swimming zooplankton (and phytoplankton) are best collected by using a long-handled, large-diameter plankton hand-net which has a small collecting bottle at the end of the collecting cone. These tiny critters can often move remarkably fast when they detect an approaching net, so care must be taken to seal the collecting bottle immediately after the "run" has been completed. Collecting stationary faunal and floral specimens in caves is generally a simple matter, provided that care is taken when they are 'picked' from the ceiling, walls or floor of the cave.



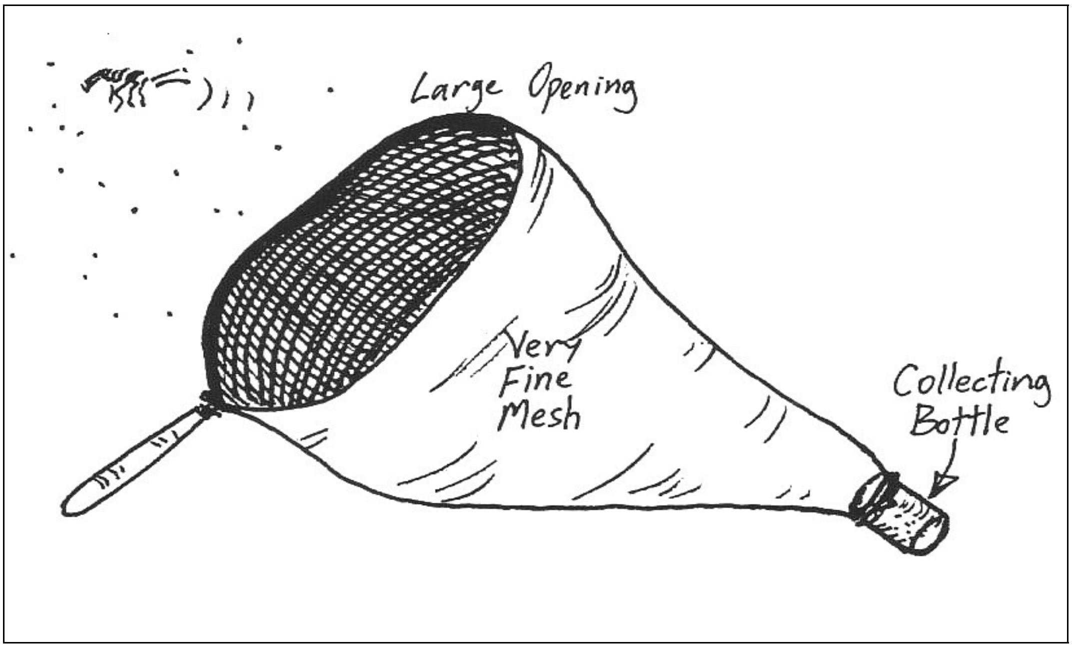

A Basic Inverted-Cone Mesh Trap




A Hand-Held Cave Fauna "Sket Bottle"

It is often easier to try to roll specimens into a large jar rather than scooping the jar over the specimen; the 'dead-space' created by the trapped water in the jar tends to push specimens away if fast motions are used, and it is often much better to move slowly and let fragile specimens simply drift down into the container. The water in the jar then tends to act as a built-in shock-absorber, and as long as the bottle is not unduly shaken or exposed to sharp vibrations (as often occurs when your car hits a small pothole while leaving a diving property), samples should remain quite intact for the journey home. Brittle aquatic plants and algae should also be stored in preserving liquid and water in this way because they tend to break up rapidly if they are removed from the collecting vessel. However, larger free-swimming fish and eels etc. are unfortunately a rather different matter!

If they are the type which don't generally take baits off a hook, you might have a fair bit of trouble collecting specimens. Hand-nets are almost certainly a waste of time, except in the case of slow-moving bottom-feeders or small, alcove-dwelling individuals which can be cornered easily.




A Hand-Held Plankton Net

The author has had marginal success with a large hollow cylinder with a syringe-like piston known as a "Slurp Gun" (which uses suction to trap specimens), but animals collected in this way are often damaged and usually don't survive for long. Large crustacea such as yabbies and crayfish can generally be easily caught by hand or with suitable nets – IF you remember to place the net BEHIND these creatures so that you can use your other hand to scare them into retreating backwards into it!

Even if you have no idea about what you might see in any given cave, it's always a good idea to be prepared and carry at least one small sampling bottle in your vest pocket or wherever. Remember that, as with the water sampling containers, you will need to fill such bottles with water and then seal them if you want to be able to open them under pressure and avoid nerve-wracking underwater implosions!

When more information about our caves' contents has been collected, we will then be able to study how underwater cave ecosystems actually work. The important thing for the moment however is to accumulate much more raw data and use this information to stress the unique intrinsic value of each waterfilled cave feature to those who are in a position to affect it in any way. If just ONE landowner can be swayed from filling in that "useless hole down the back" (and destroying yet another rare biological community), our efforts in this field will have been worth it!

## GEOMORPHOLOGY & RELATED STUDIES

The ways in which cave features form and the study of their sediments and breakdown processes can provide very important supportive research data for other speleological disciplines (for instance, working out how washed-in sediments have affected the distribution of ancient bone material and where prehistoric entrances existed prior to filling and re-cementing, etc). Potentially hazardous and unstable areas of caves can also be identified and the likelihood of undiscovered extensions to known features can sometimes be explored.

Although caves develop along lines of weakness (often along fissures or in soft limestone which is sandwiched between harder types of rock), the exact form varies significantly from feature to feature due to the combined effects of countless minor influences. Consequently, it is important for cavers and divers to be able to recognize significant morphological features if we hope to better understand exactly what influences and forces were (or are) involved in the creation of a particular cave.

Unlike many of the waterfilled caves overseas which contain fast-moving water (e.g. Florida, which has many caves in limestone of a similar nature and age to the Lower South East), Mount Gambier's waterfilled cave features generally exhibit vadose and collapse structures rather than hydrological scouring (i.e. erosion) or solution features. It is popularly believed that the large, open "sinkholes" of this high rainfall region originally formed in ancient times as massive DRY underground chambers which eventually broke through to the surface and later became "drowned" as the earth's water levels rose after the last Ice Age ended around 10,000 years ago. Evidence for this theory has been found in the form of cave decoration such as stalactites and shawls which exist underwater in several caves, but by the same token, there are also a number of karst features (especially vertical "joint-controlled" caves) which exhibit ceiling and wall "scallops" indicative of the past presence of fairly fast-moving water.

Today, we can still find active spring-fed "conduit" cave systems when we look at caves which are located near the present coastline (in effect at the lowest point in the regional water-table); Ewens and Piccaninnie Ponds are two classic examples of these. Of course, the basic questions still remain regarding their origins; is the water just flowing along pre-existing conduits, or creating them (or both)? Sedimentary studies will also hopefully play a major role in understanding cave formation.

Only a tiny amount of such work has been done to date, but it is hoped that such studies will help us to understand the depositional sequences in various caves. Coring is particularly important in underwater palaeontological applications because scientists need to understand exactly how they are related to each other in the stratum, and in relatively undisturbed caves, it might even be possible to work out exactly how different areas formed in relation to each other. As the reader will gather from the above discussion, this area of research requires a considerable amount of knowledge about limestone geology and hydrology if any serious work is to be done, but important aspects can at least be identified and recorded by cave divers who bother to note or photograph things such as different areas of colour or texture in a cave, the location and dimensions of major ceiling slabs (or floor breakdown) relative to domed ceilings and other obvious morphological features.

## PALAEONTOLOGICAL RESEARCH

THE study of fossils is known as palaeontology, and for more than 20 years now, Mount Gambier's waterfilled caves have been recognized as being important fossil sites. Many of the region's 500-plus known dry caves have long been known to contain invaluable deposits and historical remnants; cave paintings and artefacts have provided glimpses into mankind's past all around the world, and more recently, the value of drowned caves as protective graveyards has been recognised with the discovery of skeletons of extinct vertebrates in Tantanoola's Fossil Cave (5L81) and other South-Eastern sinkholes.

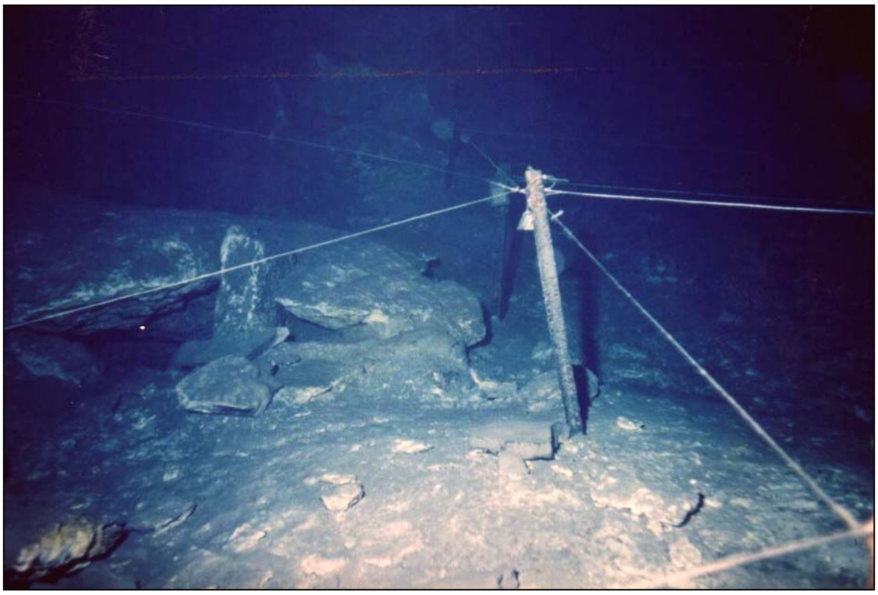
Early fossil recovery work was extremely poorly controlled. Divers often picked up obvious skulls and other bones without marking the sites, and poor documentation procedures meant that a lot of material actually went interstate (and maybe even overseas) with no follow-up information ever being left behind. In the late 1970s, the first serious attempts to undertake underwater palaeontological digging work in Fossil Cave was made by qualified cave divers who worked with Flinders University palaeontologist Dr Rod Wells, and again in the late 1980s, the South Australian Underwater Speleological Society continued with the project, removing thousands of well-preserved bones from several hundred individuals (again, mostly all extinct species). The anoxic, cold environment often found in the silt which covers the floors of most caves and sinkholes acts as a very good preserving medium, and bones many thousands of years old have been recovered almost completely intact, sometimes still with tissue such as brain matter. Often, underwater specimens are the only complete skeletons available to scientists, and provided that cave divers seek expert assistance before becoming involved in water-silting, cave-disturbing digging work, they can help palaeontologists in a major way.

Underwater bone-recovery work is quite unlike any other form of research work discussed above, and it is also quite different from most other types of typical search-and-recovery dives. While you need to be very experienced and well-equipped to handle TOTAL zero-visibility conditions (basically solo diving with back-up air supplies and safety lines), you also need to be able to manoeuvre around without getting snagged in hidden grid-lines or causing an underwater avalanche while deftly feeling through a mass of sludge with numb, ungloved fingers and still be able to find and store and safely transport anything you may find. Workers in the Fossil Cave studies, for instance, used home-made wire mesh bone baskets with side-lifting lids and slip-pin catches for easy use in zero-visibility conditions, and these were placed beside the divers as they carefully felt around and placed bones inside. These baskets served as very convenient transport containers and protected the material on its way to the surface party, and they were partitioned so that samples from two different sites could be carried if necessary.

Because of the loss of visibility and the need for divers to be able to accurately relocate digging sites again, it is always important to set up some sort of grid or reference station which can be used time and again in zero-visibility. Different caves require different techniques; the broad, open shape of Fossil Cave lent itself to a major underwater grid system comprising some 50 large "star-dropper" pegs and hundreds of metres of connecting line, but work in the deeper, more confined regions of large sinkholes might best be undertaken using strong, single horizontal reference lines which are anchored away from the low-visibility areas where narcosis problems become rife. Crossovers and tie-offs should be avoided at all costs in these situations.

The author holding a "Bone Basket" designed by Flinders University personnel and used during later Fossil Cave recovery operations

Before any digging commences, a photographic survey of the proposed site should be completed, preferably with high-resolution video (very much more affordable and of excellent quality in recent years) as well as colour photos, preferably slides for high-resolution reproduction, or good digital images. This will assist the non-diving scientists in their efforts to better understand the site and the type of material which may be present there. After working out the layout of the basic reference grid or stations and obtaining the required permission to do the work, the dive party can begin the task of recovering material, PROVIDED that a competent (preferably qualified) record-keeper is cataloguing everything as it is brought to the surface and knows how to properly wrap and protect the material.



Part of the extensive "star-dropper" survey grid system in "Fossil Cave"

Underwater palaeontological work at depths beyond about 30 metres or in very silty regions requires special planning, and extra safety-divers and other equipment (including mixed gas supplies) may prove handy in such cases; this is why some significant but highly unstable and silty bone-fields found in some sinkholes at depths in excess of 50 metres by the author and others remain untouched to this day.

As with geomorphological studies, silt sampling may also be required by palaeontologists and silt cores should be tried and proven in design and size. The author has successfully used 30 and 50-centimetre diameter sewer pipe (about 1 metre long, both with and without silt-retaining "teeth") and provided the tube is correctly capped, good cores can be obtained when the pipe is split in the laboratory. It is important to push the core tube down firmly, or use a hammer to knock it in without unduly twisting it, and in some applications, it is also wise to freeze the tube to minimize slumping and mixing of the sediments. Detailed discussions with the relevant personnel are again recommended before attempting to do such work if you want to minimize damage to the cave as well as saving dive-time!

It is the author's hope that this introductory handbook will fuel the simmering "research fires" in the hearts of the many cave divers who would like to know more about our fabulous "*Underland Wonderland*" (as noted biologist, Reg Lipson, once referred to Mount Gambier's waterfilled cave features). Very limited time and resources has regrettably meant that more detailed discussions cannot be entertained in this publication, but undoubtedly, more specialised information will become available as more divers "take the plunge" and become involved in research work!  Good luck and happy grovelling to those who are willing to give it a go!...

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